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UPPER OWENS RIVER BASIN

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INTRODUCTION

WATERSHED APPROACH

The natural unit for considering most water-related issues and problems is the watershed.

A watershed can be defined simply as the land contributing water to a stream or river above some particular point. Natural processes and human activities in a watershed influence the quantity and quality of water that flows to the point of interest. Despite the obvious connections between watersheds and the streams that flow from them, many water problems have been looked at and dealt with in an isolated manner. Many water problems have been treated within the narrow confines of political jurisdictions, property boundaries, technical specialties, or small geographic areas. Many water pollution problems, flood hazards, or water supply issues have been examined only within a short portion of the stream or within the stream channel itself. What happens upstream or upslope has been commonly ignored. The so-called watershed approach attempts to look at the broad picture of an entire watershed and how processes and activities within that watershed affect the water that arrives at the defining point. The watershed approach is a convenient means of considering water problems in a comprehensive manner.

This report describes how the 380-square mile watershed influences the quantity and quality of water that flows into the upper Owens River above the Crowley Lake dam. The study area has been called the Long Hydrologic Area (and Subarea) and is watershed #603.1 in the Calwater system of watershed delineation (http://www.ca.nrcs.usda.gov/features/calwater/ and http://cwp.resources.ca.gov).

CALIFORNIA WATERSHED PROGRAMS and MONO COUNTY'S INVOLVEMENT

Within California, the U.S. Environmental Protection Agency and the state Regional Water Quality Control Boards are the principal agencies charged with minimizing water pollution and maintaining or improving water quality. These entities have been largely successful at reducing water pollution that starts at a known point, such as a sewer outfall from a city or a waste pipe from a factory. As these so-called point sources have been brought under control, the agencies found that pollution from broader areas of land was still degrading water quality. Sediment from dirt roads and bare construction sites, pesticide runoff from farms, nutrients and bacteria from livestock operations, chemicals and oil residues from urban streets are all examples of so-called non-point-source water pollution. The agencies concerned with limiting water pollution have adopted the watershed approach to studying and controlling non-point-source pollution.

In 1997, the Governor's office directed state agencies that deal with natural resources (e.g., State Water Resources Control Board and Regional Water Quality Control Boards, Department of Fish and Game, Department of Conservation, and Department of Forestry and Fire Protection) to coordinate activities on a watershed basis. In March 2000, California voters passed Proposition 13, the Costa-Machado Water Act, which included substantial grant funding for local watershed management activities. In early 2001, Mono County in cooperation with the Mono County Collaborative Planning Team responded to a request for proposals from the State Water Resources Control Board by submitting two proposals to develop watershed assessments and plans. Both proposals were successful, and scopes of work were developed and eventually approved in 2004. Work began on these projects in January 2005.

WHAT IS A WATERSHED ASSESSMENT?

The California Watershed Assessment Manual (Shilling, et al., 2004) defines a watershed assessment as "a process for analyzing a watershed's current conditions and the likely causes of these conditions." This manual lists the usual components of a watershed assessment as:

- a question or set of questions about watershed condition that puts boundaries on the assessment;
- a collection of relevant information about human and natural processes at the watershed scale;
- the identification of gaps in knowledge;
- the combination of information about various processes to reflect the integrated nature of watersheds;
- analysis and synthesis of the information regarding the watershed's condition drawn from data collections, often at various geographic scales;
- a description of how the analysis can assist with decision making in the watershed;
- a design for the collection of future monitoring data; and
- a strategy to evaluate future data and communicate that information via a status-and-trends analysis.

The fundamental concept is to describe any known problems concerning water quantity and quality and attempt to connect those problems with conditions, processes, and activities within the watershed. Such linkages between problems and potential causes can provide the basis for subsequent planning and management that attempt to address the identified problems.

PUBLICLY PERCEIVED PROBLEMS AND ISSUES

The upper Owens River watershed (aka Crowley Lake watershed or Long Hydrologic unit) was classified as a Category 1 watershed and a priority during the California Unified Watershed Assessment under the Clean Water Action Plan in 1998. The Category 1 classification was described as "candidates for increased restoration activities due to impaired water quality or other impaired natural resource goals with emphasis on aquatic systems." The upper Owens River received the priority ranking with respect to high value, high risk, and high opportunity.

WATER QUANTITY

The primary water issue within the upper Owens River watershed is supplying water for the town of Mammoth Lakes without adversely affecting aquatic habitat in Mammoth Creek or water quantity and/or temperature at the Hot Creek hatchery springs. This water supply concern has been a persistent problem since the 1970s and becomes more acute with the town's growth.

WATER QUALITY

Many of the constituents of concern (such as phosphorus, arsenic, and mercury) in the area's water are naturally occurring products of the local geology. Although the presence of such substances may limit the use of the water, natural geochemical processes are not readily addressed by watershed management practices.

Sediment has been increased above natural levels by some human activities within the watershed. Minimizing disturbance of riparian areas could significantly reduce sediment loading to the watershed's streams.

Water temperatures in some stream reaches during summer are greater than what would occur with greater shading by riparian vegetation.

AQUATIC HABITAT

The condition of aquatic habitat in Mammoth Creek and Hot Creek has been a matter of public concern since the 1970s when the amount of water diverted from Mammoth Creek for public water supply increased dramatically.

Since 1941, the upper Owens River has been used as a canal for water diverted from streams in the Mono Basin intended for export to Los Angeles. The channel of the upper Owens River and the Long Valley reservoir site were in an optimum location for moving and storing water between the Mono Craters diversion tunnel and the Owens Gorge. The associated augmented flow regime has altered the geomorphic and habitat characteristics of the upper Owens River.

RECREATION

The primary water-related recreation issues in the upper Owens River watershed are associated with recreational fishing in the Owens River and its principal tributaries. Several areas have been contaminated by indiscriminate human waste disposal.

WILDFIRE

As is the case for most of the western states, the successful suppression of fire during the 20th century has allowed fuel loads to build up to levels that create the potential for catastrophic fires in parts of the upper Owens River basin. Wildfires that both burn intensely and cover large areas constitute a threat to streams and aquatic habitat by contributing to increased erosion and sediment transport.

INVASIVE SPECIES

Although introduced trout have altered the ecology of the streams and lakes of the watershed, they are now considered an integral part of the area's waters. Other exotic species, such as the New Zealand mud snail and tiger salamander, are considered to be threats to the fish.

LIST OF ASSORTED ISSUES

The following is a simple listing of a wide array of issues of concern that have been raised by the public and agency personnel:

General

Water export
Sediment from roads
Fish habitat
Risks associated with catastrophic wildfire
Flood hazards
Exotic species

Loss of wetlands
Polluted stormwater/snowmelt runoff from paved roads and parking lots

EPA / Lahontan RWQCB list of impaired streams and lakes (303d list)

Twin Lakes	Nitrogen	Urban runoff, atmospheric deposition, construction
	Phosphorus	Urban runoff, atmospheric deposition, construction
Mammoth Creek	Metals	Urban runoff, natural sources, flow alterations
Upper Owens R.	Habitat alterations	Agriculture, grazing, flow alterations
Crowley Lake	Nitrogen	Grazing, atmo. dep., internal, natural, nonpoint
	Phosphorus	Grazing, atmo. dep., internal, natural, nonpoint

Mono County and Mammoth Lakes planning

Water for growth of Mammoth Lakes and airport
Water availability for community infill
Water quality concerns in individual wells and community supplies
Long-term effectiveness of septic tanks / leach fields
Water availability for irrigated agriculture
Erosion from construction activities

Local and specific concerns

Warm-water return flow from flood irrigation
Hot Creek Hatchery water availability and nutrient pollution
Erosion from OHV use
Erosion from trails and other recreational facilities
Loss of riparian vegetation (associated habitat loss and rise in stream temperature)
Campgrounds and other recreation facilities close to streams
Restoration of upper Owens riparian zones
Fertilizer and pesticide runoff from golf courses and gardens
Eutrophication of Crowley Lake
Water level changes in Crowley Lake reservoir with respect to recreation
Naturally occurring minerals in surface and groundwater
Coliform bacteria and nutrients from human, livestock, and pet waste
Leached pollutants from Benton Crossing landfill
Groundwater contamination by gasoline from historic tanks and spills
Change in late-summer low flows
Meadow degradation
Erosion from Mammoth Mountain Ski Area
Atmospheric deposition
Aquatic weeds in Twin Lakes
MTBE and gasoline (Lake Mary and Twin Lakes)

In April 1997, the Lahontan Regional Water Quality Control Board provided the following list of water quality problems and issues in an introductory meeting of parties interested in the upper Owens watershed:

Naturally poor water quality
- geothermal springs
- metals
- nutrients

Water quantity/quality relationships
- water diversion
- dissolved oxygen depletion (Crowley Lake)
- potential effects on Hot Creek Hatchery springs
- use of algaecides

Point source discharges of waste
- Benton Crossing landfill
- leaking underground storage tanks
- spills and leaks
- Mammoth Community Water District (MCWD) domestic sewage discharges
- hatcheries (Hot Creek and Alpers)
- onsite septic systems
- geothermal projects

Non-point sources
- metals from inactive mines
- riparian habitat loss from grazing activities
- loss of wetlands
- stormwater, erosion, and sedimentation
- recreational activity impacts
- algae blooms, fish kills, pathogens

PUBLICLY PERCEIVED KEY RESOURCES

Adequate quantity of water that is safe for drinking in existing communities
Stream ecosystems that support recreational fisheries
Restored riparian corridors along upper Owens tributaries

DRIVING QUESTIONS

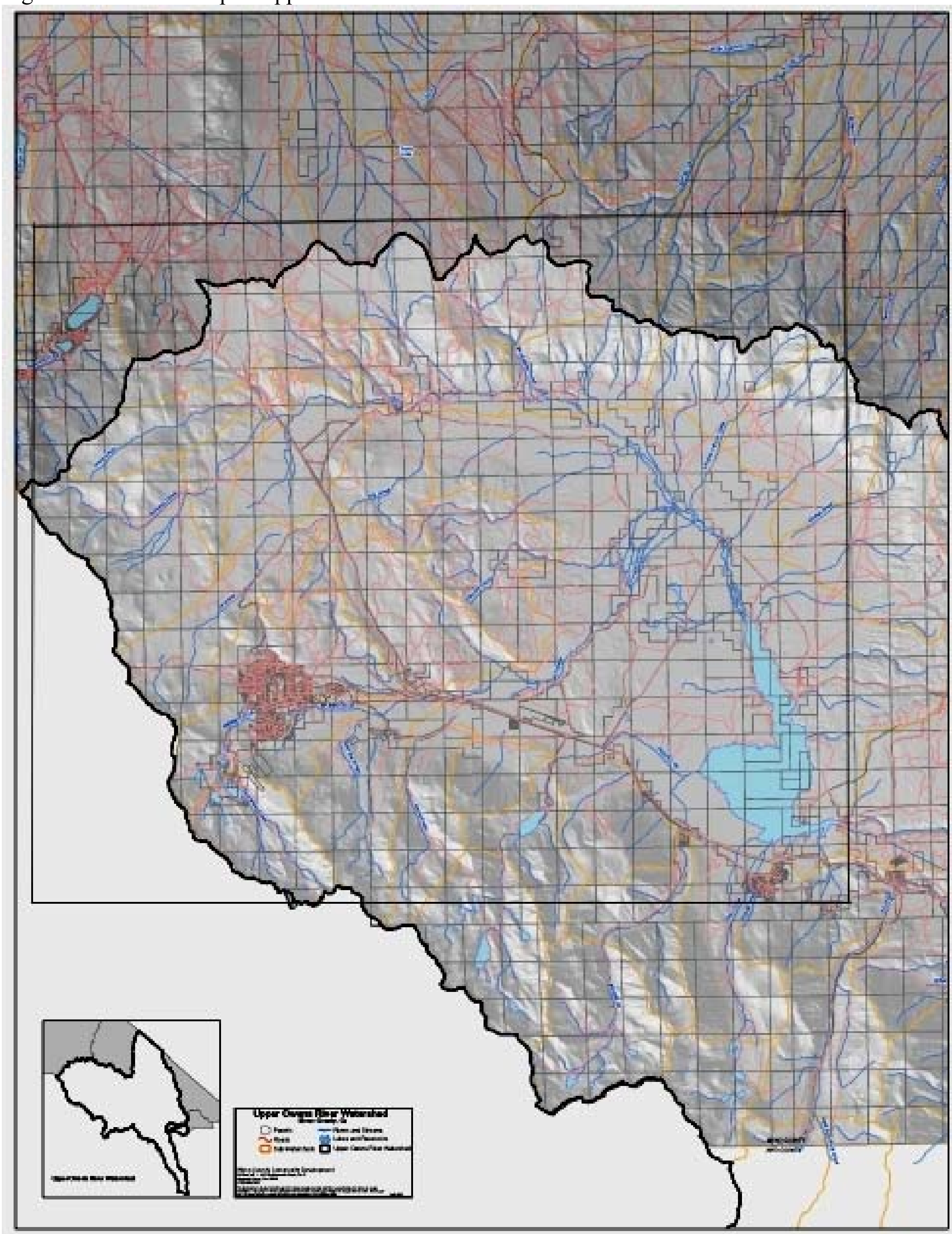
Are water supplies adequate in existing communities for present population and some growth?
Is water development for Mammoth Lakes adversely impacting Hot Creek?
Can sediment and other pollutants in stormwater runoff from Mammoth Lakes be kept out of Mammoth and Hot creeks?

WATERSHED BOUNDARIES

For the purposes of this study, the upper Owens River Basin is defined as all lands that contribute water to the Owens River above the Crowley Lake (or Long Valley) dam, which serves as the downstream end of the watershed. The dam is an arbitrary point that defines the watershed. It was selected because it has been used by the U.S. Geological Survey, the Lahontan Regional Water Quality Control Board, and the Calwater watershed delineation system to define the "Long Hydrologic Unit." The Crowley Lake dam also separates the Owens River on an engineering basis and topographically at the upstream end of the Owens River Gorge. Using the dam as the low point of the watershed, one can identify and map all lands that contribute water toward that point.

A watershed divide can be traced uphill on each side of the dam as a line that separates water that flows toward the Owens River and water that flows away from the Owens River. Eventually, these two lines will meet and form a boundary around the upper Owens River watershed. Outside of this boundary, water drains into the San Joaquin River to the west, the Mono Basin to the north, Adobe Valley to the northeast and east, and other tributaries to the Owens River downstream of Crowley Lake.

Figure 1. Overview map of upper Owens River watershed.



If we begin on the south side of the Long Valley dam, the watershed divide goes south and east to Tom's Place, where a diversion routes some of the flow from Rock Creek into Crowley Lake. Although the natural channel of Rock Creek delivers water to the Owens River below the Owens Gorge, enough water has been diverted into Crowley Lake for more than 60 years that Rock Creek can now be considered a tributary (though artificially engineered) to the Owens River above Long Valley dam. The watershed divide continues south along the Wheeler Crest and around to Mount Morgan (13,748 feet) and then meets the crest of the Sierra Nevada at Bear Creek Spire (13,713 feet). Turning sharply north and later west, the Sierra Nevada crest serves as the divide between the Owens River and the San Joaquin River and thereby between the Great Basin and the Pacific Slope.

Prominent peaks along this section of the Sierra Nevada crest include Mount Abbot (13,715 feet), Mount Stanford (12,851 feet), Red Slate Mountain (13,163 feet), Mammoth Crest (~11,000 feet), and Mammoth Mountain (11,053 feet). At San Joaquin Mountain (11,600 feet), the divide turns northeast and passes over June Mountain (10,135 feet) and then to Deadman Summit (8,041 feet) on U.S. Highway 395. The divide continues roughly east through the Indiana Summit area before following the crest of the Glass Mountains. Just north of Glass Mountain (11,123 feet), the divide turns to the southeast. The divide then trends south along the Glass Mountains and then down to the north side of the Crowley Lake dam.

Within the watershed divide described above, the following named creeks are the principal streams in the upper Owens River Basin (listed in a clockwise direction starting from the south near Crowley Lake):
Rock Creek (partially diverted into Crowley Lake via Crooked Creek)
Crooked Creek
Hilton Creek
McGee Creek
Convict Creek
Laurel Creek
Sherwin Creek
Mammoth Creek / Hot Creek
Dry Creek
Deadman Creek
Glass Creek
Owens River
McLaughlin Creek
O'Harrel Creek
Wilfred Creek

DESCRIPTIVE GEOGRAPHY

Climate

The climate of a region can be considered to be the "average" weather as well as the extremes over some period of time. We are usually limited to the historical period and then often only a few decades during which some systematic measurements of precipitation and temperature were made and recorded. The term "normal" is a convention that includes only the past 30 years. Similar to the warnings that accompany a financial investment prospectus, we should remember that past climate is no guarantee of future conditions. Nevertheless, recent climate is the best indicator we have of what to expect in the near future. Where inferences are available regarding prehistoric climate, such information is valuable to suggest the range of extremes that are possible in a given region.

The upper Owens River watershed, like most of the eastern Sierra Nevada region, is subject to the Mediterranean-type climate of California, characterized by wet winters and warm, dry summers as well as the rain-shadow effect of being on the lee side of the Sierra Nevada with respect to the prevailing southwest-to-northeast storm direction. An exception to the general rain-shadow pattern occurs when small storms travel south from eastern Oregon into Nevada and then produce upslope flow and orographic lifting on the eastern slope of the Sierra Nevada. Storms begin to affect California in October and November and occur at irregular intervals through March in most years. An average of 15 to 20 discrete storms affect central California each winter. Intervals of clear, cool weather lasting one to several days separate these storms, although an extended dry period of three to six weeks occurs in many winters. December, January, and February tend to be the months of greatest precipitation. Storm frequency and intensity decrease in April and May, although a few significant storms can occur during the spring. Rain/snow levels of 5,000 to 7,000 feet are typical for most winter storms. Midwinter rainfall is unusual at the elevation of Mammoth Lakes (~8,000 feet), although it is occurring as this section is written in December 2005. The amount of precipitation has been highly variable from year to year.

Summers tend to be dry and warm because of the dominance of high pressure and the absence of a storm track through California during the summer months. Convective thunderstorms occasionally develop when adequate moisture enters the Sierra Nevada. When the "Arizona monsoon" pattern delivers moist air farther west and north than usual, significant thunderstorms can occur each afternoon and evening for several days at a time in the eastern Sierra Nevada. The larger events of this nature have occurred in September, which otherwise tends to be dry in most years (Howald, 2000a).

The southwest- to northeast-oriented canyon of the San Joaquin River is parallel to the prevailing storm direction and directs winter storms toward Mammoth Mountain and Mammoth Pass, which have been long recognized as high-precipitation anomalies. The relatively low gap at Mammoth Pass allows some of the moisture-laden air to pass through the higher mountains and deposit more precipitation in the Mammoth Lakes area than occurs elsewhere along the eastern slope of the Sierra Nevada, where the rain-shadow effect is more pronounced (Howald, 2000a). The Mammoth Mountain Ski Area is a major beneficiary of the geographically enhanced snowfall.

Since 1987, meteorological data have been collected at SNARL, including air temperature, wind speed and direction, relative humidity, precipitation (heated tipping bucket), and solar radiation (Orr and Howald, 2000). Prior to 1987, there was a 13-year (1950 to 1972) record of air temperatures and a single year (1957-58) of precipitation data (Kennedy, 1964). Temperature and precipitation data also are available from sites at Long Valley Reservoir (Roberts and Associates, 1973).

Precipitation

Our knowledge of the precipitation regime in the watershed is based on relatively brief records from a few stations:

Location name	Elevation (feet)
Mid-Chalet MMSA	9,600
Mammoth Pass storage gage	9,300
Mammoth Pass sensor site	9,300
Lake Mary Store	8,900
Mammoth Ranger Station	7,770
Crestview	7,520
SNARL	7,080
Crooked Creek	6,800

Most precipitation in the upper Owens River watershed falls as snow from December through February. Typical distribution by month over a water year (October-September) is shown in Figure 2.

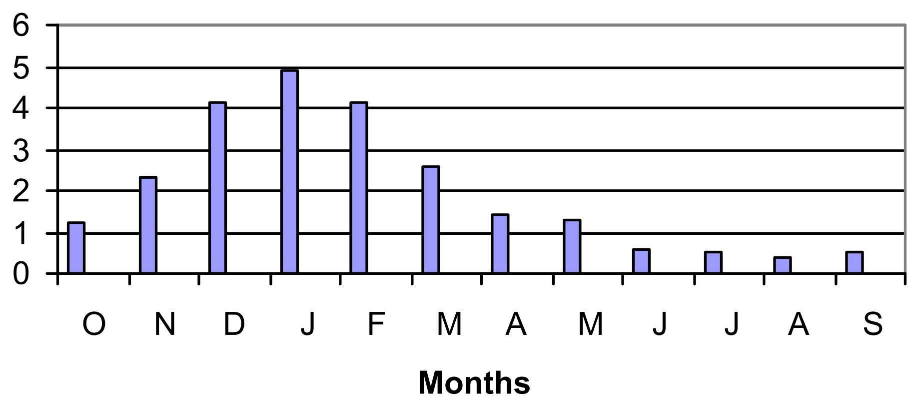


Figure 2. Monthly mean precipitation (inches) at Mammoth Ranger Station

Precipitation in the area has been summarized in various reports and environmental documents for projects. There is a rapidly decreasing gradient of precipitation with distance east of the Sierra Nevada crest because of the rain shadow effect. Precipitation amounts rise again over the Glass Mountains as terrain-induced ("orographic") uplift increases condensation in the rising air.

Annual precipitation averaged 28.9 inches over 25 years (or 29.6 inches over 38 years [Gram/Phillips Associates, 1985]) at the Lake Mary Store gage and 59.5 inches over 22 years at Mammoth Pass (California Department of Water Resources, 1973) . This difference is indicative of the steeply declining gradient in precipitation east of the crest. Lake Mary Store is less than two miles from and 400 feet lower than the Mammoth Pass site. The Department of Water Resources team estimated a watershed-wide average for the Mammoth Creek watershed (their study area was 45,080 acres in size) of 27.5 inches. The DEIR for the General Plan update for the Town of Mammoth Lakes estimates the average annual precipitation within the town as 23 inches (Town of Mammoth Lakes, 2005).

At the Mammoth Ranger Station, annual precipitation averaged 23.8 inches from 1982 to 1994 and 23.7 inches from 1994 through 2005. The average for the 1991-97 period at the Lake Mary gage was 35.0 inches. Based on the seven years of coincident record, average annual precipitation at Mammoth Ranger Station was about 66 percent of that at Lake Mary. An estimate of average annual precipitation at Valentine Camp was 25 inches (Howald, 1981). From the Lake Mary record, about 75 percent of the annual precipitation occurred during the months of October through March, and about 25 percent occurred during the months of April through September (Howald, 2000a). Curry (1996) estimated average annual precipitation in the Mammoth Lakes to Long Valley area as declining from about 20 inches in the west to 10 inches at sites farther away from the mountains.

The USFS snow study plot on Mammoth Mountain at 9,600 feet has records beginning in 1969. Average snowfall for 25 years of record through 1994 was 292 inches with 33 inches of water equivalence, on the average. Rainfall in the area is considered to contribute approximately 15 percent of the annual precipitation or 4.9 inches. Therefore, total precipitation on the north slopes of Mammoth Mountain is estimated to average about 38 inches (USDA-Forest Service, 1994).

Precipitation at the Lake Mary Store from 1946 through 1995 was summarized in a report issued in about 2000 (unfortunately the source citation was lost).

Month	Average	Min	Max
October	1.5	0.0	6.6
November	3.3	0.0	12.8
December	4.3	0.1	21.1
January	4.5	0.2	15.3
February	3.7	0.2	16.0
March	3.9	0.1	9.2
April	2.4	0.4	6.0
May	1.6	0.0	5.6
June	0.9	0.0	3.0
July	0.7	0.0	2.3
August	0.6	0.0	3.8
September	1.3	0.0	7.1
Annual	28.6	13.2	52.6

The same report also summarized the precipitation at Long Valley Reservoir (presumably the Crooked Creek gage):

Month	Average	Min	Max
October	0.3	0.0	2.7
November	1.1	0.0	5.0
December	1.6	0.0	9.7
January	1.9	0.0	10.4
February	1.6	0.0	9.0
March	1.3	0.0	6.3
April	0.6	0.0	3.6
May	0.4	0.0	2.1
June	0.3	0.0	2.2
July	0.4	0.0	3.6
August	0.3	0.0	1.8
September	0.4	0.0	2.1
Annual	10.2	2.2	22.2

Average annual precipitation at the Sierra Nevada Aquatic Research Laboratory (SNARL) was 15.1 inches from 1988 to 1998, and ranged from 8.7 to 26.6 inches (Orr and Howald, 2000). Seventy percent of this precipitation fell from November to March and was mainly snow. Summer precipitation derives primarily from thundershowers, during which rain may fall at the rate of 0.4 inches per hour or more. On average, 12 percent of annual precipitation falls during summer (Orr and Howald, 2000). Throughout the watershed, many summers have little or no measurable precipitation (Curry, 1996).

Average annual precipitation at the LADWP station near Long Valley dam is about 10 inches (Jones and Stokes, 1993; App. T).

Snowpack

Snow typically begins to fall in October, although there is the chance of at least modest snow showers in any month. The early-season snow typically melts within a few hours or days after it is deposited. Snow cover tends to be thin and discontinuous into November or December, especially under dense forest cover. As storms become more frequent and deposit greater amounts of snow, a snowpack develops with contributions from successive storms. Individual storms during midwinter can deposit less than an inch to several feet of snow. Midwinter rain is unusual in the area. However, significant rainfall occurred to high elevations in January 1980, May 1996, and January 1997 (Howald, 2000a).

In the eastern Sierra Nevada, snow depth typically reaches a maximum sometime in April, although peak accumulation sometimes occurs in May or as early as January, as in the unusual case of 1997. Although there is some melt of the snow at mid and lower elevations of the watershed during extended periods of clear weather in midwinter, especially on south-facing slopes, sustained snowmelt does not typically begin until April. Snow cover disappears from south-facing slopes first, usually in April at lower elevations and in May at higher elevations. Most of the watershed is snow-free by mid-June, but patches on north-facing slopes can linger all summer.

The water equivalence of the snowpack (the depth of water at a point if the snowpack is melted) is measured at about 400 locations throughout the snow zone of California by the Department of Water Resources and cooperating agencies (http://cdec.water.ca.gov/snow/ and http://www.nrcs.usda.gov/feature/highlights/SnoServ.html). The basic measurement involves obtaining a core sample of the snowpack and weighing it to determine the total water equivalence of the snowpack. These measurements are made near the beginning of each month in the winter to supply data for forecasting the amount of snowmelt runoff in streams between April and July. Measurements taken near the beginning of April have been found to approximate the peak accumulation of the snowpack. On the average, storms contribute little additional snowfall after April 1, and snowmelt begins to deplete the water storage of the snowpack in early

April. Therefore, the April 1 snow survey measurements have been in many hydrologic studies as a proxy for the season-long accumulation of precipitation in mountain areas where almost all of the precipitation falls as snow and accumulates throughout the winter.

There have been 10 snow courses (sites where snow is measured at designated points year after year) within the upper Owens River watershed. Six of these sites have records from the 1920s through the present.

Snow courses within upper Owens River watershed

Name	station ID code	elevation (feet)	period of record	Ave SWE Apr 1 (in)
Mammoth Pass	MAM	9,300	1928-present	41.9
Minarets No 1	MN1	8,300	1928-1966	18.4
Minarets No 2	MN2	9,000	1928-present	29.1
Minarets No 3	MN3	8,200	1966-1981	20.2
Mammoth	MMT	8,300	1928-present	20.2
Rock Creek 1	RC1	8,700	1926-present	7.5
Rock Creek 2	RC2	9,050	1926-present	11.0
Rock Creek 3	RC3	10,000	1926-present	14.7
Long Valley North	LVN	7,200	1982-1995	1.0
Long Valley South	LVS	7,300	1982-1995	4.4

The Mammoth Pass (station ID: MAM) snow course has a continuous record of 75 years (1931 to current [2006]). The long-term April 1 (peak accumulation) average at this site is 43.2 inches (differs from DWR average in the table above because of use of unadjusted data), with a minimum in 1977 of 8.6 inches and a maximum in 1969 of 86.5 inches. Data are also available from an automated snow sensor (station ID: MHP) that has weighed the snowpack at this site since 1990. Over the period of record at the MAM, MN2, and MMT sites, peak water equivalence has varied from 20 percent to 200 percent of the mean.

The long-term snow courses also allow a look at whether there have been any changes over time. A simplistic analysis compares the mean of the first half of the record to the second half. The local results run contrary to various recent claims that the snowpack of the Sierra Nevada is diminishing over time. The greater standard deviations (SD) in the second halves also suggest that variability has increased over time.

Comparison of mean April 1 SWE between first and second halves of record.

Name	1st half period	2nd half period	1st half mean	2nd half mean	1st half SD	2nd half SD
Mamm. Pass	1931-68	1969-05	41.9	44.6	15.1	19.6
Minarets 2	1929, '31, 1934-68	1969-05	28.5	31.0	10.9	14.9
Mammoth	1931-68	1969-05	19.3	21.7	9.4	11.6

Snow and influential meteorological processes have been measured at a snow research site operated by the University of California and U.S. Army Cold Regions Research and Engineering Laboratory within the Mammoth Mountain Ski Area at 9600 feet (http://neige.bren.ucsb.edu/mmsa/description.html). The site was first established in 1978 and then moved a few hundred yards in 1987. From 1978 through 1997, peak snow depths ranged from 6 to 26 feet and snow water equivalence at the peak of accumulation ranged from 28 to 98 inches (Kattelmann, 1997). Daily melt amounts from a research site on Mammoth Mountain have averaged 0.8 to 1.2 inches per day during clear spring weather. More details about the snowpack at this site can be found in the hydrology chapter.

Short-term but intensive snow surveys in the Crystal Lake subwatershed as part of an acid-precipitation study in the late 1980s (Sickman and Melack, 1989; Melack, et al., 1992) suggest that snow storage in this area is considerably less than at the Mammoth Pass snow course and that the Mammoth Pass site is not a suitable indicator of snow storage within the upper Mammoth Creek watershed.

Snow measurements were also obtained for a few years during the planning for the proposed Sherwin Ski Area south of Mammoth Lakes. Estimates of peak snowpack water equivalence based on these measurements, conducted by Snow Resource Associates, were 10.6 inches at 7,880 feet, 14.9 inches at 8,900 feet, 19.5 inches at 9,100 feet, 19.3 inches at 9,500 feet, and 17.9 inches at 10,500 feet within the proposed ski area (USDA-Forest Service, 1988b).

Typical snow depth in Long Valley ranged from 1 to 4 feet during midwinter (Kennedy, 1964).

Air temperature

Throughout the watershed, air temperatures vary markedly both seasonally and daily. There is also considerable variation between years for any given day, making averages a poor descriptor (Howald, 2000a). Records of air temperature are even more limited than those of precipitation or snowpack water storage.

The Mammoth Pass snow sensor site at 9,300 feet has records since October 1996. The mean annual temperature at this site is about 31°F. A subjective description of seasonal temperatures (°F) was obtained from examining the records from this site:

Season	Typical Daily Mean	Typical Range of Daily Max	Typical Range of Daily Min	Approximate Extremes
Autumn	40-50	40-60	20-35	0, 80
Winter	30-40	35-50	15-30	-5, 65
Spring	45-55	40-60	20-35	0, 70
Summer	55-65	60-75	40-50	10, 90

A description of air temperatures at Valentine Camp (Howald, 2000a) provides some insight into the temperature regime of the mid-elevation forest zone of the watershed. During summer, mean daily maxima ranged between 65°F and 80°F and mean daily minima ranged between 40°F and 50°F. Nighttime low temperatures, especially at ground level, can drop below 32°F at any time of year, although rarely for more than a few hours on even the coldest summer nights. Radiational heat loss in meadows and cold air drainage from surrounding uplands can result in locally low nighttime temperatures. The forest canopy maintains warmer temperatures among the trees. During winter, mean daily maxima ranged between 35°F and 45°F, and mean daily minima ranged between 15°F and 25°F. However, on many winter days, air temperatures do not rise above 32°F. In some winters, minimum air temperatures can drop to about -20°F during outbreaks of polar air (Howald, 2000a). The climatic summary for the Mammoth Ranger Station (http://www.wrcc.dri.edu) showed a similar seasonal temperature range.

At the Sierra Nevada Aquatic Research Laboratory on Convict Creek, average annual air temperatures from 1988 to 1998 ranged from 40°F to 45°F, with a mean of 43°F. The mean summer air temperature was 59°F, and the mean winter temperature was 19°F. Maximum temperatures in summer ranged from 73°F to 85°F, with summer minimum temperatures between 32°F and 43°F. July and August are typically the only frost-free months, although frost may occur at any time of the year. Winter diurnal temperature fluctuations are less than in summer. Daytime high temperatures ranged from 30°F to 52°F, and nighttime lows ranged from 0°F to 23°F. Temperatures below freezing (32°F) were recorded an average of 244 days each year (Orr and Howald, 2000). July is typically the warmest month, and January is usually the coldest (Kennedy, 1964).

Wind

Based on subjective memories and opinions, the typical wind condition throughout the watershed is calm. At least half of the time over the course of a year, there is no wind. At the other extreme, average wind speeds may exceed 30 mph for periods of a few hours with gusts significantly higher. The Mammoth Mountain Ski Area is one of the few places where wind is routinely measured within the watershed. At the snow research site near Mid-Chalet (now McCoy Station), the wind direction was out of the west-southwest more than 80 percent of the time. The persistent wind over the Sierra Nevada crest dissipates near ground level with distance away from the crest. Wind speeds tend to be highest as winter storms approach or pass north of the area. Wind speeds are also high in spring when the western Great Basin heats up while the Sierra Nevada remains snow covered. In summer, local winds increase in the afternoon as adjacent areas warm to different extents.

At SNARL in Long Valley, the typical summer pattern is for the wind to be calm from sunrise through mid-morning, with a light breeze developing around noon. Wind velocity increases through the afternoon and early evening, then decreases rapidly after sunset. Prevailing winds are usually from the west or northwest, except during storms, when they are typically from the south. The mean annual wind velocity from 1988 to 1998 was 4 mph. Stronger winds often accompany the passage of storm fronts in winter, when winds occasionally attain velocities greater than 80 mph (Nielson, et al., 1957). Periods of high (greater than 45 mph), sustained (hourly means) winds occurred at SNARL on 1.6 percent of the days during the 11-year measurement period (1988 to 1998) (Orr and Howald, 2000).

Evaporation

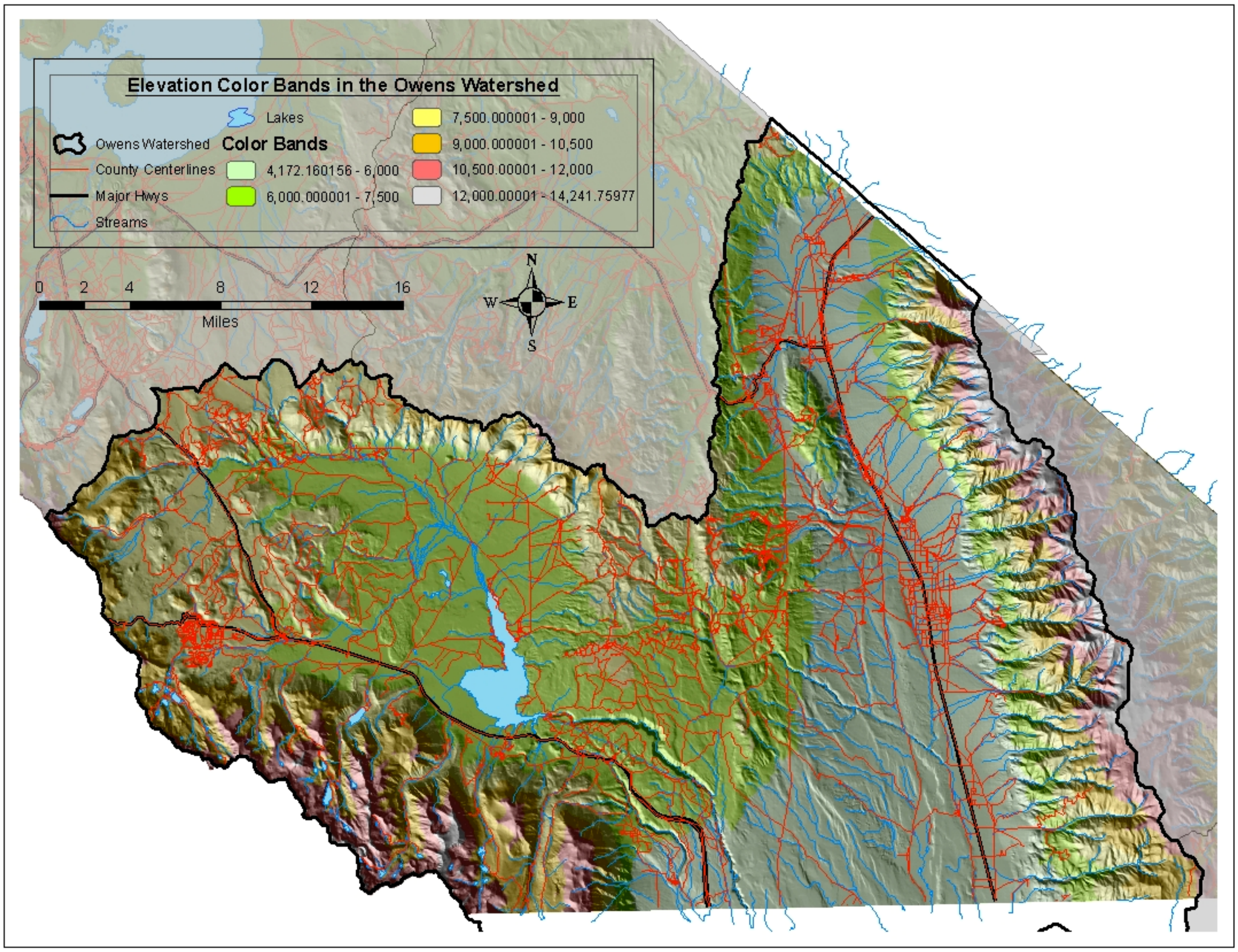
The main process of water loss to the atmosphere within the upper Owens River watershed is transpiration from trees and other plants in spring and summer. Although potential evapotranspiration (evaporation from open water surfaces and from plant cells) in the area has been estimated to be about 36 inches per year (California Department of Water Resources, 1973) if water is not limited, actual water loss to the atmosphere tends to be much less because water is not available year-round. Lakes freeze over, soil moisture varies seasonally, and most plants in the watershed go dormant in the winter. In the Mammoth Creek watershed, actual evapotranspiration was estimated to average 13 inches over the watershed area (California Department of Water Resources, 1973). Annual losses from an evaporation pan at Grant Lake (in the Mono Basin) have averaged about 38 inches per year (Gram / Phillips Associates, 1985). Evaporation has been measured by the LADWP at the Long Valley dam during ice-free months in evaporation pans both in the lake and on shore. The pan located on land had an average loss from eight non-freezing months of 41 inches, and the floating pan lost an average of 52 inches over nine non-freezing months (Jones and Stokes Associates, 1993: table 3A-4). Another study used generalized figures of 25 inches from forests, 13 inches from grasslands, and 36 inches from riparian areas to estimate actual evapotranspiration from the Mammoth Lakes basin (above Twin Lakes) as 19 inches per year (Gram / Phillips Associates, 1985). Evapotranspiration was estimated as 15 inches per year in the Dry Creek watershed (USDA-Forest Service, 1992a).

At SNARL, average afternoon relative humidity was 24 percent (Orr and Howald, 2000).

Topography

The study area includes a wide range of topographic relief. The steepest slopes are found along the Sierra Nevada on the west side of the watershed. At the extreme, small areas of the mountain front are vertical and many areas along the mountains require technical climbing skills for travel. Slopes tend to flatten out with distance from the Sierra Nevada crest. The largest areas of low topographic relief are Little Antelope Valley, Long Valley, and near the upper Owens River, upstream of Long Valley. There are several smaller areas with the word "Flat" in their name such as Smokey Bear Flat, Windy Flat (southern part of the town of Mammoth Lakes), Tobacco Flat, and Obsidian Flat. East and northeast of the Owens River, slope angles again increase as one ascends the Glass Mountains.

Figure 3. Elevation bands



Geology

The geology of the watershed influences many of the characteristics of water between its entry via precipitation and departure as releases from Long Valley dam or evaporation back into the atmosphere. There may also be a relatively small amount of water that leaves the basin as deep groundwater flow -- obviously influenced by geology as well. Some of the important influences of geology with respect to hydrologic processes include serving as the parent material for soils, which in turn control whether water remains on the surface or penetrates into the ground; storage and transport of water below the surface; chemical reactions and contributions of chemical substances to the water; potential for erosion and mass movement of soil and rocks; formation and control of stream channels; and substrate for vegetation, which removes much of the water stored in the soil.

Geology of the eastern Sierra Nevada region is well described in a wide variety of sources (e.g., Hill, 1975; Bailey, et al., 1976; Whitney, 1979; Lipshie, 1979 and 2001; Rinehart, 2003) and only a basic summary that relates to hydrology is included here. The upper Owens River watershed occupies the junction of the Sierra Nevada and Great Basin geologic provinces. The fundamental shape of the watershed is a result of the uplift (and tilt to the west) of the Sierra Nevada relative to Long Valley and the formation of the Long Valley caldera by a massive volcanic eruption about 760,000 years ago (Bailey, et al., 1976). The caldera is surrounded by Mammoth Mountain, the Glass Mountains, Bald Mountain, and Long Valley dam.

Subsequent volcanic activity, earthquakes, erosion and deposition by glaciers, and stream channel processes have contributed to the present-day landscape. From its northern end near Mono Lake, the Mono-Inyo chain of rhyolitic domes and craters extends southward for 23 miles as a series of bare or sparsely wooded volcanic domes and lava-flows to the Inyo Craters within the Long Valley caldera (Lipshie, 1979). Much of the area is covered with pumice ash produced in the most recent of the dozens of pumice eruptions that have occurred in the watershed. Recent dating establishes the last pumice eruptions at 540 to 660 years ago, and these ash deposits were a significant ecological disturbance (Millar, et al., 1996; Bursik and Reid, 2004).

A variety of rock types occupies the surface and the subsurface zones of the watershed. Granitic rock of the Sierra Nevada batholith is exposed along the Sierra Nevada front in places such as Mammoth Crest, Sherwin Creek, Hilton Creek, and Rock Creek. Metamorphosed sedimentary and volcanic rocks are found on top of the granitic rock in places where erosion did not erode down to the granitic rock, such as Laurel, Convict, and McGee creeks. Volcanic rocks such as andesite, basalt, and the rhyolitic Bishop tuff (fused ash from the Long Valley caldera eruption with an average thickness of 500 feet [Gilbert, 1938]) are found above the older metamorphic and granitic rocks in areas such as Inyo Craters, Obsidian Dome, Mammoth Mountain, Lookout Mountain, the Glass Mountains, and small localized exposures.

Lake sediments, mostly sandstone and kaolinite, originally deposited in the lake that filled the Long Valley caldera about 500,000 years ago are found north of Whitmore hot springs and Hot Creek and east of Crowley Lake (Lipshie, 1979). Glacial till from as many as eight glacial advances covers much of the elevation zone between 6,500 and 8,000 feet near the main creeks from the Sierra Nevada.

These various rock types have been further rearranged by the numerous faults in the area. The area beneath the town of Mammoth Lakes is particularly complex: interleaved layers of volcanic materials, glacial till, and stream deposits that are further stirred up by faulting. Geophysical studies suggested that there is about 400 feet of fill under the town of Mammoth Lakes, consisting of interlayered glacial deposits and volcanic rocks above granitic basement rock (Birman and Cummings, 1973). However, subsequent drilling by the water district found about 75 feet of alluvium above 100-150 feet of basalt and other volcanics above 50-125 feet of glacial till that overlies a variety of volcanic materials (Mammoth County Water District, 1981).

The magnitude 6 earthquake of May 1980 in Long Valley prompted a great deal of local geological research in the past 25 years. Dozens of scientific papers have provided a detailed understanding of the geologic history, structure, and activity of the Long Valley caldera (a roughly elliptical volcanic-tectonic depression measuring 18 miles from east to west and 10 miles from north to south). Some of this work is quite relevant to understanding groundwater storage, movement, chemistry, and interactions with surface flows (e.g., Farrar et al. 1985; Hopson, 1991). However, there is still great uncertainty about the nature of groundwater storage and movement in the Mammoth Creek / Hot Creek area.

The volcanic activity also creates a geothermal energy resource that is directly tied in with the groundwater system. The various hot springs, fumaroles and hydrothermal alteration zones are presumed to originate from a magma chamber beneath the so-called resurgent dome. The aquifer supplying this heated water is within highly fractured Bishop tuff (Hernandez, 1991). The presence of hot water at relatively shallow depths causes problems for municipal/domestic water production that seeks to avoid hot water that has a high mineral content but provides the opportunity to extract heat for generation of electricity. The development of geothermal energy near the junction of U.S. Highway 395 and State Route 203 led to the creation of the Long Valley Hydrologic Advisory Committee, a technical group that monitors wells, springs, and streams down gradient of the geothermal plant for signs of any changes that might be related to the geothermal development and/or overuse of water from Mammoth Creek in the town of Mammoth Lakes (e.g., Sorey and Farrar, 1998).

Over geologic time, the hot water circulation has contributed to concentrations of economically valuable minerals in parts of the watershed. Prospecting for gold and silver has occurred throughout much of the upper Owens River area. Several mines were developed in the Mammoth Lakes basin between 1877 and 1933. Hard rock mines were also developed in Laurel Creek, McGee Creek, and Hilton Creek. Kaolinite is excavated in Little Antelope Valley, and aggregate has been extracted in several locations. A proposal for a large-scale open-pit gold mine near the airport was floated in the mid-1990s. Mining is discussed further in the section on land use and human history.

Soils

The soils of the watershed have formed from the underlying geologic parent material and consequently vary with the rock types as well as the localized moisture regime and weathering situation, biological influences, slope position and erosion potential, and time period for soil development. Most of the soils in the watershed tend to be shallow, coarse textured, and poorly developed (USDA-Natural Resources Conservation Service, 2002). The most common texture class is probably gravelly loam. Soils found on steeper soils tend to be shallow, loose, and unconsolidated, whereas soils found on relatively level areas in meadows and other alluvial deposits tend to be deeper, better developed, and less prone to erosion. Because many areas have very young parent materials, only a few hundred to a few thousand years in age, soils tend to be incompletely developed with minimal stratification (Curry, 1996).

Within the once-proposed Sherwin Ski Area, which is somewhat representative of the steeper portions of the watershed, soils were limited to topographic benches, isolated pockets, and lower-angle swales (Inyo National Forest, 1988). On these low-angle portions of the terrain, soils up to 2 feet thick were noted, and organic layers of several inches depth were found in pocket meadows. Water holding capacity was generally less than 4 inches. Where thin soils were present on steeper slopes, they tended to be highly erodible, especially if disturbed (Inyo National Forest, 1988).

Soils of the Hilton Creek/Crowley Lake community area were described as brown gravelly silty sands to a depth of approximately 4 feet in pockets between rock outcrops. These soils are loose to approximately 2 feet and somewhat dense below. The soils are underlain by highly weathered, moderately hard volcanic tuff which becomes less weathered and harder rock at greater depth. Alluvial soils that are found adjacent to channels or in topographic swales consist of deeper, stratified, unconsolidated, loose to medium-dense gravels, sand, and silt (Gram/Phillips Associates, 1980).

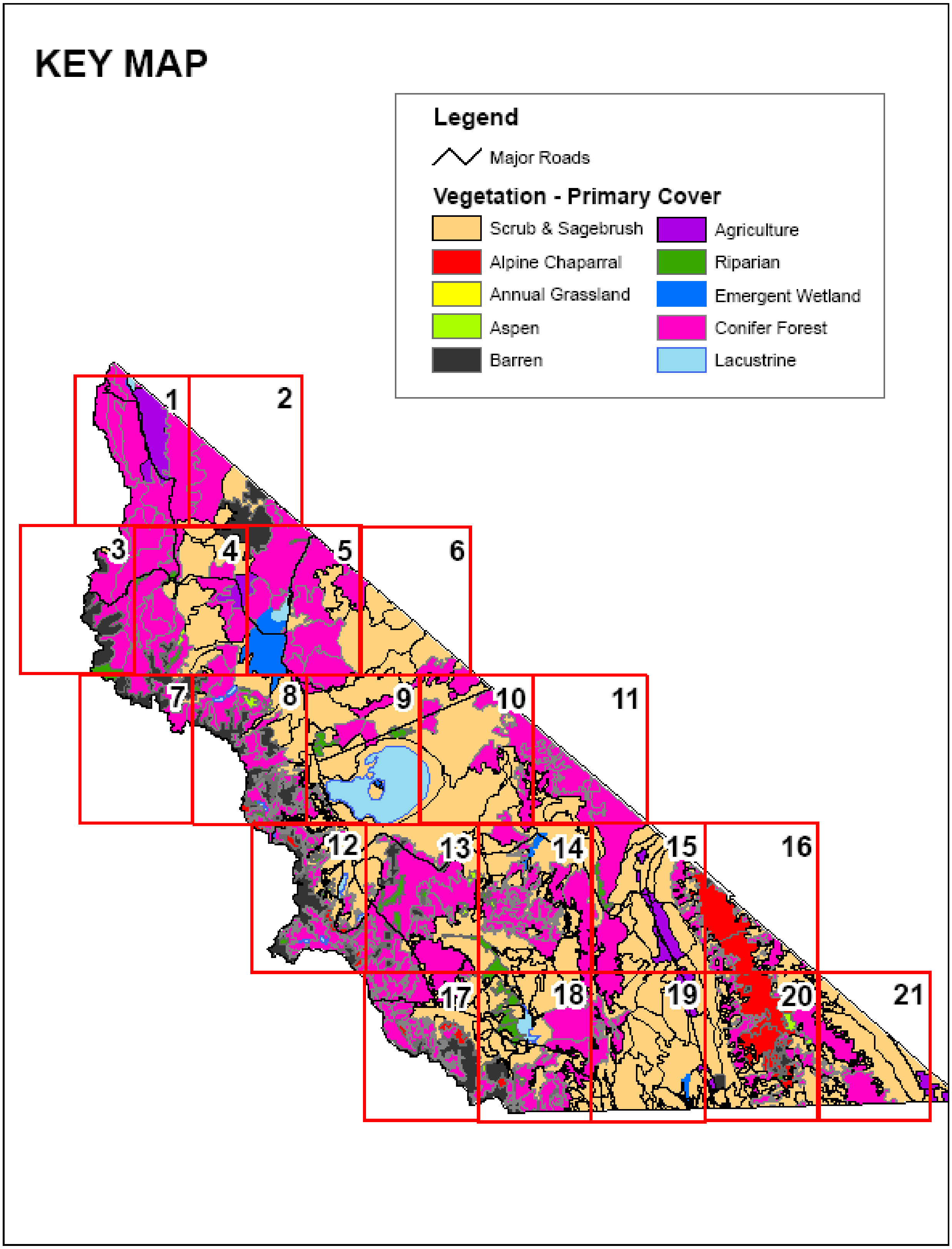
The greatest potential for soil erosion occurs with sandy soils on steep slopes where water may flow over the surface and entrain soil particles. Areas where vegetation has been removed and soils mechanically compacted (e.g, roads, trails, construction sites, off-road vehicle routes) are much more subject to erosion than undisturbed areas. Wind erosion of exposed soils can be significant during high-wind events.

A portion of the Arcularius Ranch that could have been used for additional housing under the since-rescinded 1992 specific plan was inspected for septic system suitability. The soil study and percolation tests found that the soils were generally only 3 to 5 feet deep overlying basaltic rock (County of Mono, 1992).

Upland vegetation

Distribution and type of vegetation throughout the upper Owens watershed are mainly dependent on soils, moisture availability, air and soil temperature, and sunlight. Different vegetation communities tend to be associated with elevation zones because the combination of environmental factors favoring different plants is also associated with elevation. At the Sierra Nevada crest on the western margin of the watershed, vegetation cover is sparse with the most wind-exposed locations nearly barren. In more protected locations, grasses, forbs, dwarf shrubs, and even a few whitebark pine (*Pinus albicaulis*) can be found. Moving downslope, the numbers of species and individual plants increase. In addition to the whitebark pine, mountain hemlock (*Tsuga mertensiana*) and western white pine (*Pinus monticola*) account for the tree species in the subalpine zone, which extends down to about 9,000 feet in the upper Owens watershed. These trees merge into the red fir (*Abies magnifica*)-lodgepole pine (*Pinus contorta* ssp. *murrayana*) forest. The density of trees and the litter layer of accumulated needles are much greater here than among the scattered subalpine trees. The red fir - lodgepole pine forest merges into the Jeffrey pine (*Pinus jeffreyi*) forest at about 7,500 to 8,000 feet. Some white fir (*Abies concolor*) can be found among the Jeffrey pines.

Although Jeffrey pines occur at the lowest elevations of the watershed near the Crowley Lake dam, they give way to the sagebrush scrub community dominated by bitterbrush (*Purshia tridentata*) and sagebrush (*Artemsia tridentata*) at about 7,000 feet. In this portion of the Sierra Nevada, there are patches of pinyon-juniper woodland within the Jeffrey pine belt, but there is not really a distinct band of mixed pinyon pine (*Pinus monophylla*) and Sierra juniper (*Juniperus occidentalis*) until one crosses the Owens River and ascends into the Glass Mountains. On drier sites, such as south-facing slopes, the montane chaparral community occurs in small patches of up to a few acres in area within the red fir - lodgepole pine and Jeffrey pine forests. Common chaparral plants include mountain mahogany (*Cercocarpus ledifolius*), greenleaf manzanita (*Arctostaphylos patula*), bitter cherry (*Prunus emarginata*), and snowbush (*Ceanothus cordulatus*). Aspen (*Populus tremuloides*) is found along streams and in moist soils throughout the Jeffrey pine and red fir - lodgepole pine zones (Howald, 2000; USDA-Forest Service, 1988a; Millar, et al., 1996).



KEY MAP
Legend
Major Roads
Vegetation - Primary Cover
Scrub & Sagebrush
Agriculture
Alpine Chaparral
Riparian
Annual Grassland
Emergent Wetland
Aspen
Conifer Forest
Barren
Lacustrine
1
2
3
4
5
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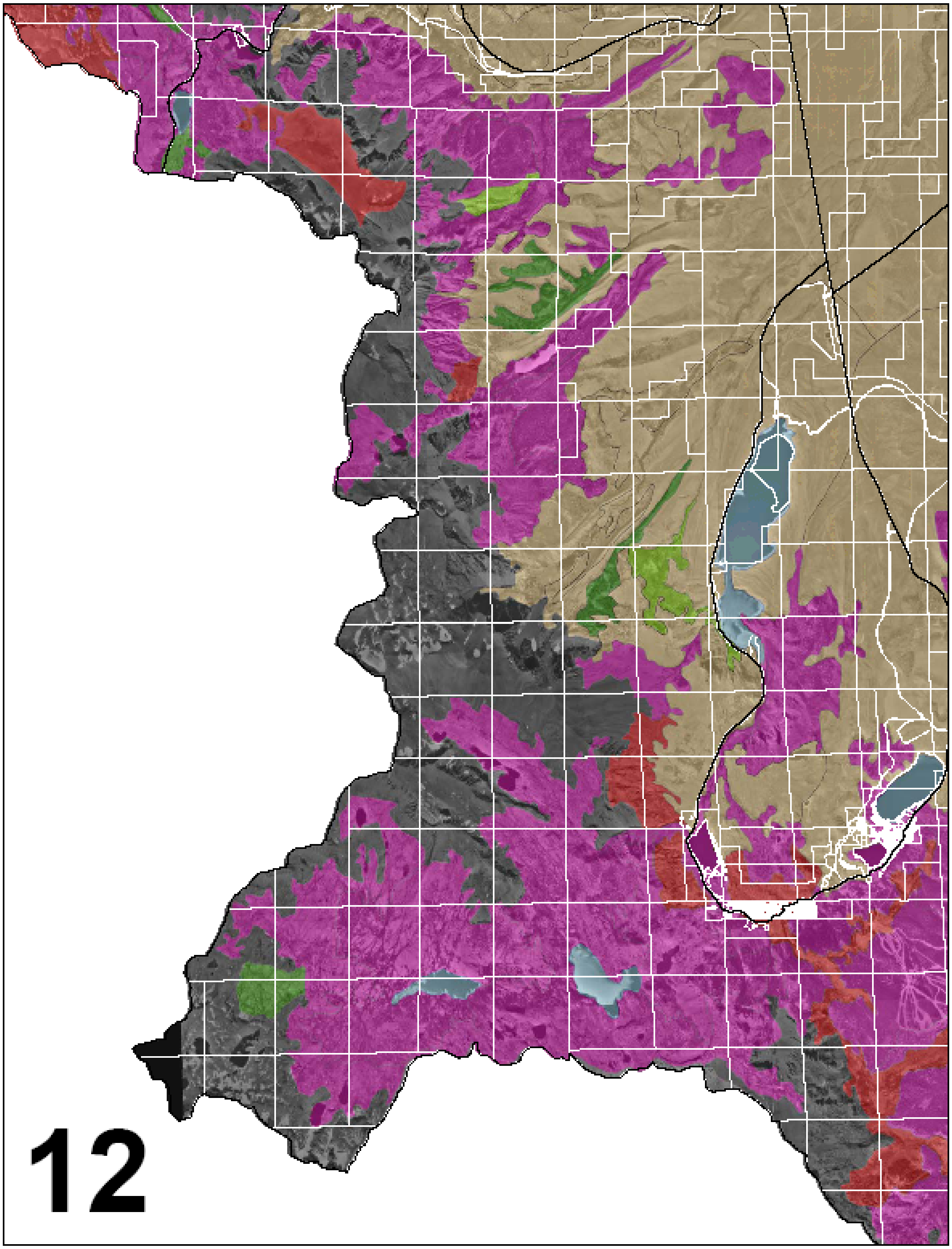
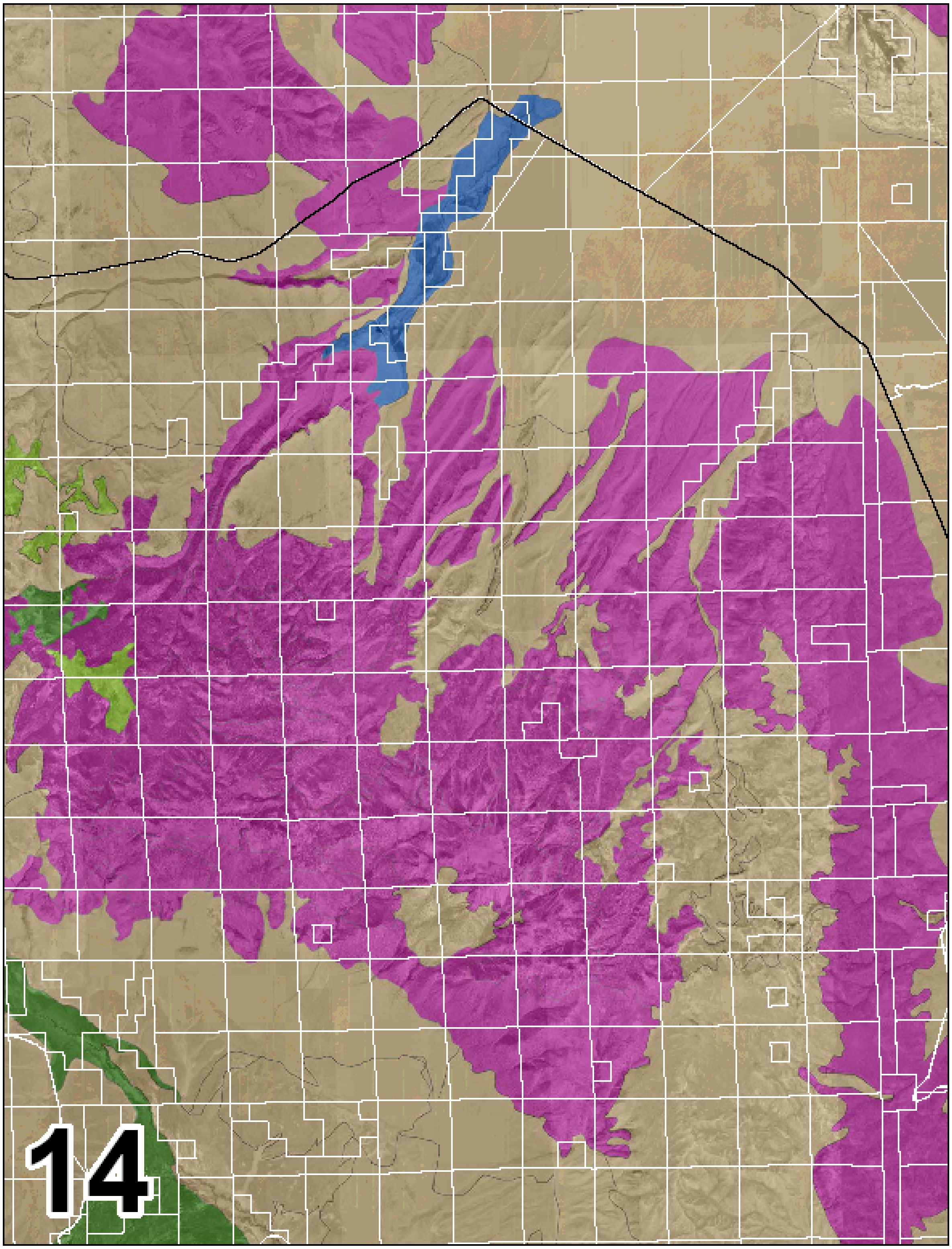
Figure 4. General vegetation types of the upper Owens River watershed.

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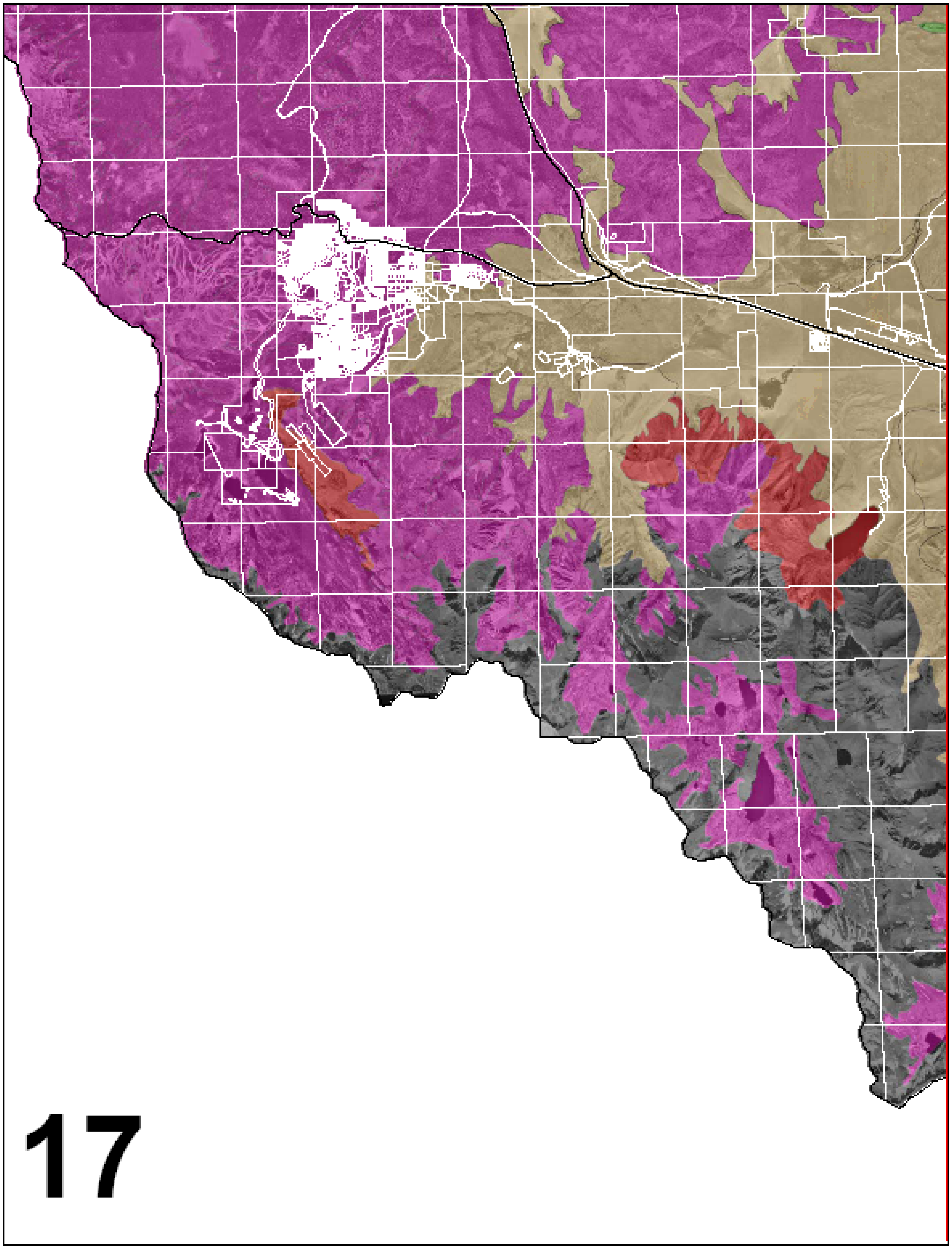
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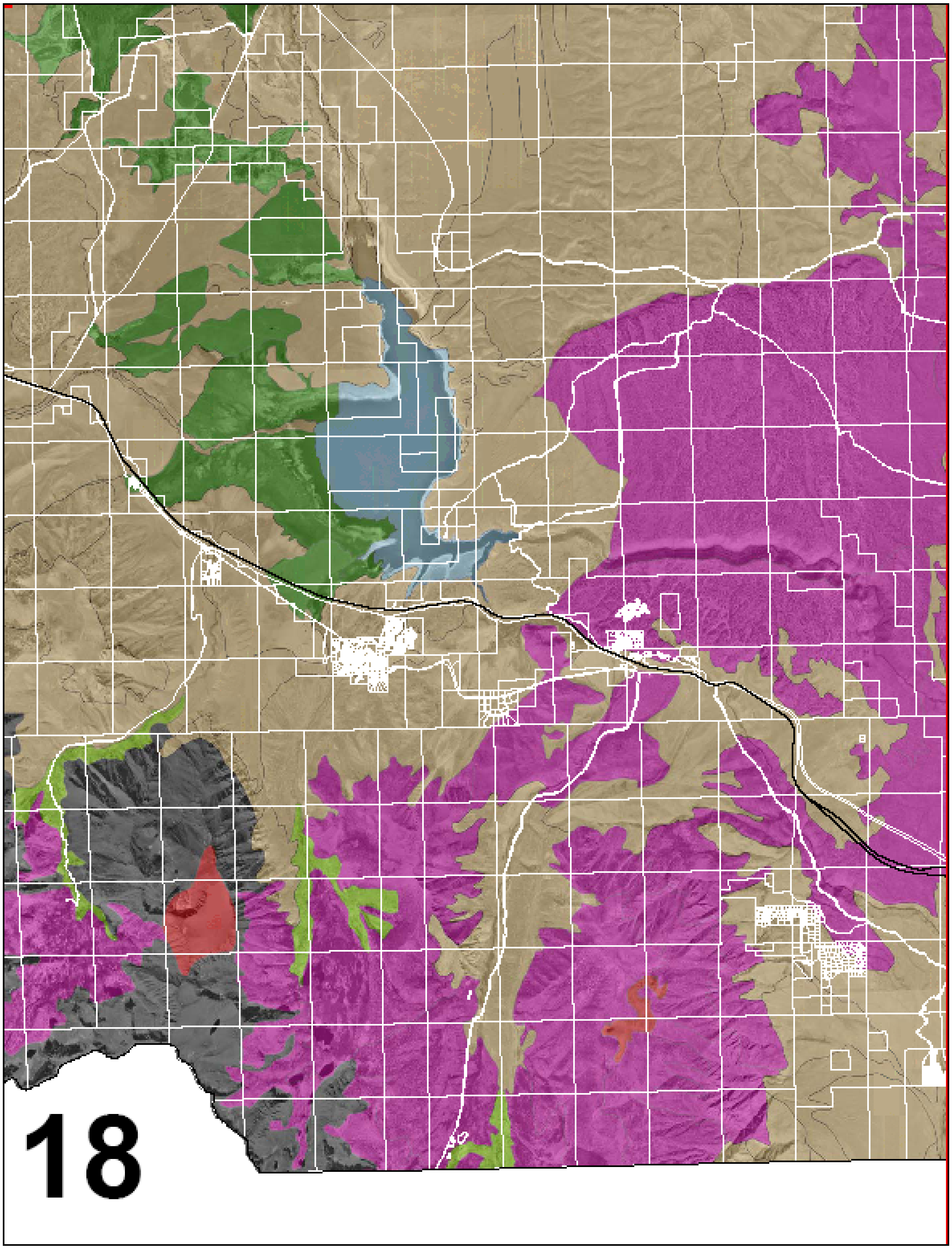
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The pure red fir stands in upper Glass and Deadman Creek watersheds are rare if not unique in the eastern Sierra Nevada (Millar, et al., 1996).

In the north-central part of the watershed, from lower Deadman Creek across to Indiana Summit, there is an unusually pure forest of Jeffrey pine that covers about 100 square miles. The combination of climate and soils favors the species in this area. This forest contains many gaps consisting of shallow depressions of barren pumice. Although the surrounding pumice-derived soils tend to be well drained, the barren depressions may hold just enough subsurface water during the snowmelt season to prevent establishment of the Jeffrey pines, which cannot tolerate saturated soil conditions for long (Howald, 2000).

Plants of the Long Valley area were described in a report (Bagley, 2002) for environmental review for expansion of the Benton Crossing landfill and in the EIR for the Lakeridge Ranch Estates (Mitchel, 1995). The principal vegetation community of Long Valley in areas that are not wetlands or meadows is big sagebrush scrub. This vegetation type is characterized by scattered shrubs with bare ground underneath and between the individual plants. Big sagebrush (*Artemisia tridentata*) is the primary species. Other typical plants include antelope bitterbrush (*Purshia tridentata*), curl leaf rabbitbrush (*Chrysothamus viscidiflorus*), rubber rabbitbrush (*Chrysothamus nauseosus*), snowberry (*Symphoricarpos vacciniodes*), desert peach (*Prunus andersonii*), thorny skeleton plant (*Stephanomeria spinosa*), and lupine (*Lupinus argenteus*) (Mitchel, 1995; Bagley, 2002). A list of the plants observed in the vicinity of the Benton Crossing landfill is included in the report (Bagley, 2002). Five plant species of concern are known to exist in the Long Valley area or in Smokey Bear Flat: Long Valley milk vetch (*Astragulus johannis-howellii*), Mono milk vetch, (*Astragulus monoensis* var. *monoensis*), Masonic rock cress (*Arabis cobrensis*), Mono Lake lupine (*Lupinus duranii*), and alkali cord grass (*Spartina gracilis*) (Bagley, 2002). While none of these species is listed as threatened or endangered, the two milk vetch species are listed as rare under the California Native Plant Protection Act.

Riparian and meadow vegetation are discussed in the chapter on riparian areas and wetlands.

Roadside vegetation along the dirt roads near Deadman Creek has receded as a result of vehicle damage. There is less vegetative cover and more compacted soil near the road than beyond a few dozen feet from the road (California Trout, 2005).

Wildfire history and risk

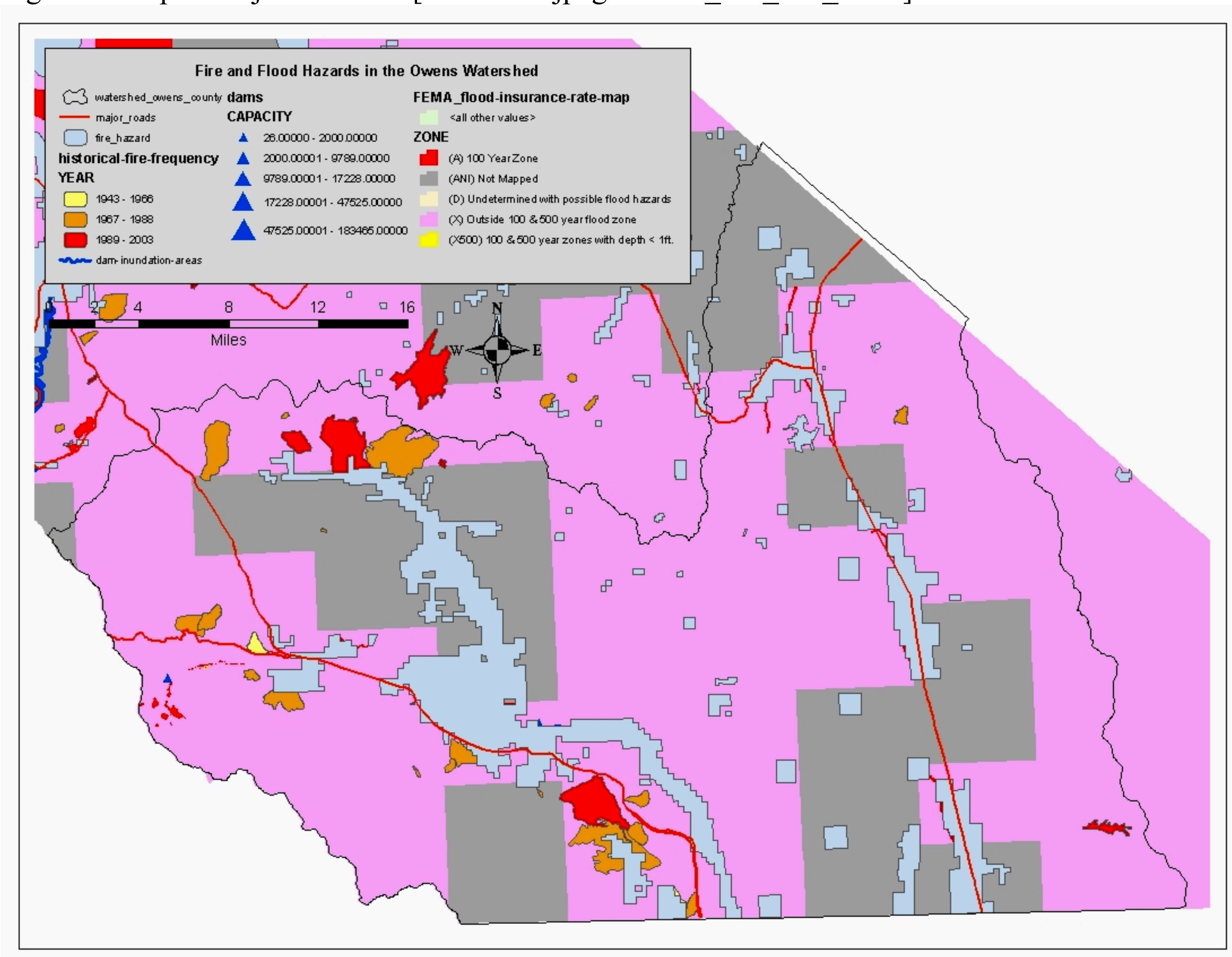
Analyses of tree stumps and cores have suggested that pre-1900 intervals between wildfires were highly variable in the upper Owens River watershed. Before active fire suppression, fires occurred in the Jeffrey pine and mixed conifer stands about every 10 to 20 years on the average, and in red fir stands about every 30 years on the average (Millar, et al., 1996). Wildfires appear to have been low intensity in both pine and fir forests; however, the structure of some red fir stands indicates that stand-replacing fires occurred. The studies of fire history show that the size, frequency, and distribution of fires changed markedly with the beginning of suppression (Millar, et al., 1996). The McLaughlin fire in 2001 burned some riparian habitat.

Fuel loading in the northwestern part of the upper Owens watershed averaged 12 tons per acre (Millar, et al., 1996).

Wildfires of the past 20 years in the upper Owens River watershed

Date	Name	Area (ac)
?-1987	Laurel	?
?-1987	Mammoth	?
8-1989	?	76
10-1990	?	55
?-1992	Rainbow	?
?-1993	Bald Mountain	544?
7-2001	McLaughlin	2714
7-2002	Birch	2549
9-2002	Piute	391
9-2003	McGee	8

Figure 5. Map of major wildfires [watershed jpegs owens_fire_and_flood]



The Inyo National Forest first proposed a fuel-reduction project in the area north of Mammoth Lakes in late 1993. A different program was implemented in 2003-05.

Wildfire has been suppressed on the Valentine Eastern Sierra Reserve (a research facility of the University of California in the Old Mammoth part of Mammoth Lakes) for perhaps as long as 150 years. Stephens (2001) found fire return periods of about three years in Jeffrey pine and 24 years in red fir - lodgepole forests of the Valentine Camp. In the absence of fire over the past century or more, fuels have accumulated to very hazardous levels, and the forest is excessively dense. The University has been engaged in a low level of forest management and fuel reduction since 1997 and recently retained a consultant to describe a desired future condition for the forest as well as a management program to attain that condition. A Timber Harvest Plan was developed to reduce stand density and remove fuels from the forest without compromising the ecological integrity of the Reserve.

Beginning in the spring of 2003, individual trees were cut and removed with a small vehicle. The five primary goals of the forest management efforts were to:
1) Retain existing old-growth trees and increase the growth of the 100- to 200-year-old trees that will replace the older trees.
2) Retain the diverse structure and species composition.
3) Enhance recruitment of Jeffrey and western white pine.
4) Minimize risk of a catastrophic insect or pathogen outbreak.
5) Reduce the fuel load to lessen the risk of catastrophic fire.

Riparian areas and wetlands

Riparian zones are the areas bordering streams and lakes that provide a transition from aquatic to terrestrial environments. As streams rise and fall, the lower parts of the riparian corridor may be inundated for days to weeks. Soil moisture is much higher within the riparian zone than farther up slope and is often saturated close to the stream. Plants within riparian corridors are adapted to the high soil moisture and occasional submergence. Depending on the nature of the soils, topography, and the stream, the riparian zone may be narrow or wide and have an abrupt or gradual transition to upland vegetation (Swanson, et al., 1982; Gregory, et al., 1991; Kattelmann and Embury, 1996).

Riparian areas are considered to be among the most ecologically valuable natural communities because they provide significantly greater water, food resources, habitat, and favorable microclimates than other parts of the landscape. The extra water alone leads to greater plant growth and diversity of species in riparian areas compared to other areas. The enhanced plant productivity, greater species richness, availability of water and prey, and cooler summer temperatures of riparian areas draws wildlife in greater numbers than in drier areas. Below the forest margin in the eastern Sierra Nevada, riparian areas are a dramatic change from the surrounding sagebrush scrub. In arid lands, streams and riparian zones are especially critical.

Streams and their adjacent riparian lands allow for the transport of water, sediment, food resources, seeds, and organic matter (Vannote, et al., 1980). Riparian corridors act as "highways" for plants and animals between natural communities that are stratified with elevation. The continuity of riparian corridors is one of their most important attributes. If the upstream-downstream connection is interrupted by a dam, road, or other development, the ecological value of the riparian system is greatly diminished.

Riparian vegetation has critical interactions with the channel-forming processes of erosion and deposition. Streamside vegetation dramatically increases the resistance of the channel to erosion and also slows the velocity of water at the sides of a stream, which allows for deposition of transported sediment. In turn, the stream provides water for plant roots, transports seeds downstream, and can remove vegetation and create openings for other plants to grow.

In the upper Owens River watershed, riparian corridors along the major tributaries cross through several upland vegetation communities in just a few miles because of the steep topography. In the headwater areas, typical riparian vegetation includes lodgepole pine (*Pinus contorta* spp. *murrayana*), aspen (*Populus tremuloides*), mountain alder (*Alnus incana* spp. *tenuifolia*), currant

(*Ribes* sp.), and willow (*Salix* sp.). Jeffrey pine (*Pinus jeffreyi*), black cottonwood (*Populus balsamifera* ssp. *trichocarpa*), and wild rose (*Rosa woodsii*) are present in some of the mid-elevation canyons. At the lower elevations below the glacial moraines, water birch (*Betula occidentalis*), Fremont cottonwood (*Populus fremontii*), and other species of willow add to the mix (Howald, 2000a and 2000b).

Along the streams of the eastern Sierra Nevada, riparian environments offer critical resources for a large, though unknown, fraction of the insect and animal species. For some, the riparian zone is primary habitat. For other species, the riparian resources of water, food, higher humidity and cooler summer temperatures, shade, and cover are used on occasion. Insects are more abundant near streams and are an important food for fish, amphibians, birds, and mammals. Open water and moist soils are both critical for amphibians. Almost all species of salamanders, frogs, and toads native to the Sierra Nevada spend much of their life cycles in riparian zones (Jennings, 1996). Birds tend to be far more numerous and diverse in riparian zones than in drier parts of the watershed. Most mammals at least visit riparian areas occasionally to take advantage of resources that are less available elsewhere in the watershed. The mammal most obviously dependent on the riparian zone is the beaver.

Riparian areas are fundamentally limited to the margins of streams, creeks, and lakes. With their restricted width (generally tens of feet on either side of a stream, wider along flatter portions of the upper Owens River), riparian areas occupy very a small portion of the landscape. An evaluation of proposed hydroelectric projects in the eastern Sierra Nevada considered riparian zones to cover less than 1 percent of the surface area of their watersheds (Federal Energy Regulatory Commission, 1986). If we assume a somewhat arbitrary 50-foot width of the riparian zone on either side of a stream and multiply that 100-foot total width by the total length of streams in the upper Owens River watershed (XX miles), the total area of riparian areas within the watershed can be estimated as XX acres or X percent of the watershed area.

Riparian vegetation along the upper Owens River consists mostly of sandbar willow (*Salix exigua*), white willow (*Salix lasiolepis*), and various grasses and forbs (Stromberg and Patten, 1991). The amount of woody vegetation tends to decrease downstream, and meadow vegetation was dominant in the reach through the Inaja Ranch for at least 80 years (Ebasco Environmental, et al., 1993). Riparian and wetland vegetation also exist in a few places created by the Mono Craters tunnel construction and irrigation ditches (Ebasco Environmental, et al., 1993).

The riparian zone of the upper Owens River changes abruptly at the confluence with the Mono Craters tunnel. Upstream, where the flow is fairly consistent throughout the year, the channel has deep undercut banks and thick riparian vegetation. Downstream of the tunnel outlet, much of the riparian vegetation was scoured away, and the channel widened considerably from the doubled discharge and rapidly fluctuating water levels (Stromberg and Patten, 1991; County of Mono, 1992). Since the importation of water from the Mono Basin was adjusted in 1990, the channel and riparian zone have been adjusting again to the lower discharge.

The primary loss of wetlands in the watershed occurred with the filling of the Long Valley dam in 1940. A natural dam at the top of the Owens Gorge, caused by the relative rise of the Volcanic Tableland fault block (Lee, 1906), led to the low gradient of the Owens River through Long Valley and consequent conditions that favored wetlands along the river channel (Smeltzer and

Kondolf, 1999). USGS topographic maps made circa 1913 during the studies by Charles H. Lee show more than 4,000 acres of wetlands within Long Valley (Smeltzer and Kondolf, 1999, esp. figure 20). Some of this area was artificially irrigated and maintained as "swamp" (Means, 1924, cited by Smeltzer and Kondolf, 1999):

"There is in [Long Valley] a large area watered for grass, much of it is kept as swamp all summer. J.C. Clausen, who has been familiar with the region for over 20 years, estimates that the losses of water in irrigation in this part of the Owens power watershed will equal or exceed evaporation losses in the proposed Long Valley storage reservoir. He estimates the irrigated area above the Owens River gorge as 10,000 acres, of which 8,500 are owned by the Eaton Land & Cattle Co. If this area is irrigated, consumptive losses are probably not less than three acre-feet per acre or 30,000 acre feet for the year. The high consumptive use is caused by the maintenance of swamps. Evaporation from swamps is over twice the evaporation from open water surfaces."

Meadows

Mountain meadows are a special type of riparian community composed of low vegetation, typically dominated by sedges. Other typical plants include rushes, grasses, and forbs. Some of these plants, especially the sedges, have very long and dense roots masses that form a sod that is very resistant to erosion. Sierra Nevada meadows range in size from a few square yards to a few square miles (Allen, 1987). Tiny "pocket" meadows can be found throughout the upper Owens River watershed at all but the highest elevations in local areas where soil moisture is sufficiently high to discourage trees and shrubs and favor sedges, rushes, and grasses. The largest meadows in the watershed are along the upper Owens River, Convict Creek near U.S. Highway 395, and Glass Creek.

Vegetation in montane meadows is dominated by herbaceous perennials such as corn lily (*Veratrum californicum*), meadow lupine (*Lupinus polyphyllus*), cow parsnip (*Heracleum lanatum*), willow-herb (*Epilobium ciliatum* and *E. halleanum*), meadow paintbrush (*Castilleja miniata*), a sedge (*Carex jonesii*), Mexican rush (*Juncus mexicanus*), and many species of perennial grasses (Howald, 2000a and 2000b).

Glass Creek Meadow is considered an ecologically important meadow because of its diversity of vegetation and associated fauna (Millar, et al., 1996). Rare species, such as Yosemite toad and willow flycatcher, have been observed in the area. The meadow has a complex structure and contains both wet and dry areas.

A distinctive form of meadow vegetation is found along the banks of Convict Creek in low-lying areas with poorly drained, fine-grained soils, such as near the Sierra Nevada Aquatic Research Lab. The waterlogged soil appears to exclude trees and to favor certain perennial herbaceous species. The most common plants in these meadows along Convict Creek are sedges (*Carex* sp.), rushes (*Juncus* sp.), western blue flag (*Iris missouriensis*), and various species of grasses (Orr and Howald, 2000).

The Forest Plan of the Inyo National Forest (1988) included an inventory of wet meadows that suggested that 90 percent were damaged or threatened by accelerated erosion. The Forest Plan also noted concern about the encroachment of shrubs and trees into wet meadows because of fire suppression.

Wetlands

Wetlands are areas that are flooded with water for enough of each year to determine how the soil develops and what types of plants and animals can live in that area. They are often called marshes, swamps, or bogs. The critical factor is that the soil is saturated with water for at least a portion of the year. This saturation of the soil leads to the development of particular soil types and favors plants that are adapted to soils lacking air in the pores for a portion of the year. The federal Clean Water Act defines the term wetlands as "those areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions."

General acceptance of the ecological values of wetlands has occurred relatively recently (National Research Council, 1995). Drainage and deliberate destruction of wetlands were widely accepted practices until the mid-1970s. California has lost a greater fraction of its wetlands than any other states. Only about 9 percent of the original wetlands (454,000 acres out of about 5 million acres) remain in California (National Research Council, 1992). The recognition of the importance of the small fraction remaining has led to a variety of regulatory efforts to minimize the further loss of wetlands. The relatively recent concept of wetlands as valuable to nature and the public at large has generated conflicts with individuals who own wetlands and don't see any personal benefit.

Important wetland functions:

- Habitat for birds, fish (when flooded), invertebrates, and mammals
- Increase in channel capacity and storage that can decrease flood peaks downstream
- Source areas for streams or groundwater recharge
- Capture of stream-borne sediment load
- Retention and transformation of nutrients, leading to lower nutrient loads downstream
- Accumulation of organic peat can trap pollutants

Investigations of wetlands in Mono County began with a study of the Bridgeport Valley in 1991 and a follow-up regional inventory (Curry, 1992 and 1993). A third study by Curry and his associates provided greater details of Mono County wetlands (Curry, 1996). Irrigated pastures along the upper Owens River meet all three jurisdictional criteria: vegetation is dominated by baltic rush, salt grass, Douglas's sedge, Canada bluegrass, and other species varying from faculative to obligate; soils have chromas of 1 or 2 and may exhibit other hydric soil indicators; and the soil is probably saturated to within one foot of the surface for at least several weeks during the early growing season. Also, saline and/or alkaline springs and groundwater seeps are found in many areas near the upper Owens River (Curry, 1996). Similar to the Bridgeport Valley, determination of what areas are wetlands solely because of irrigation and what areas are partially or entirely supported by natural hydrology is problematic. In areas where the topography is relatively flat, the floodplains and some terraces of the river and tributaries are jurisdictional wetlands. Many of these areas support willow thickets. The center of Long Valley, including the land surrounding the landfill, supports some of the most extensive complexes of meandering creeks, springs, freshwater emergent, and saline/alkaline wetlands in the county (Curry, 1996).

Figure 6. Wetlands of the upper Owens River watershed

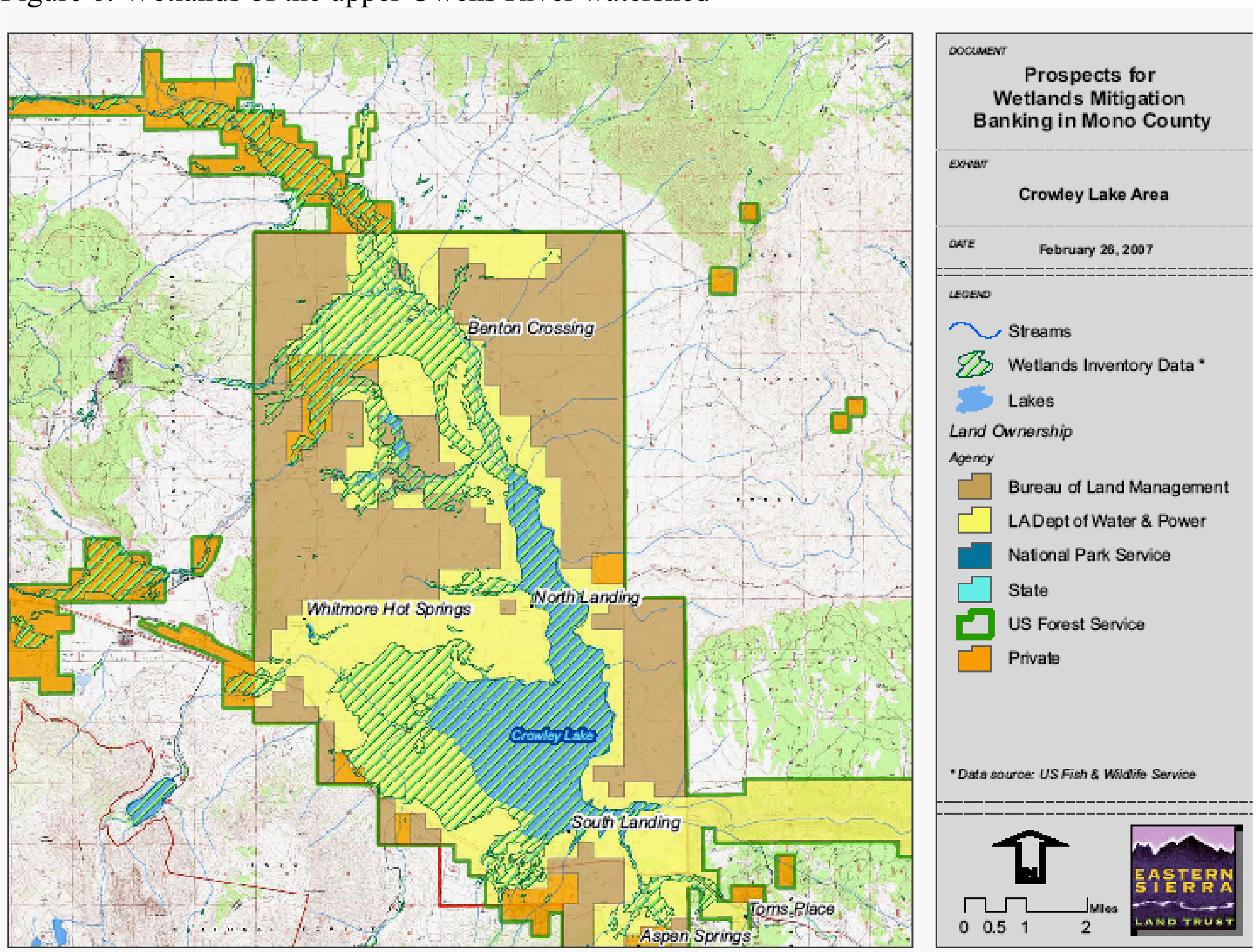
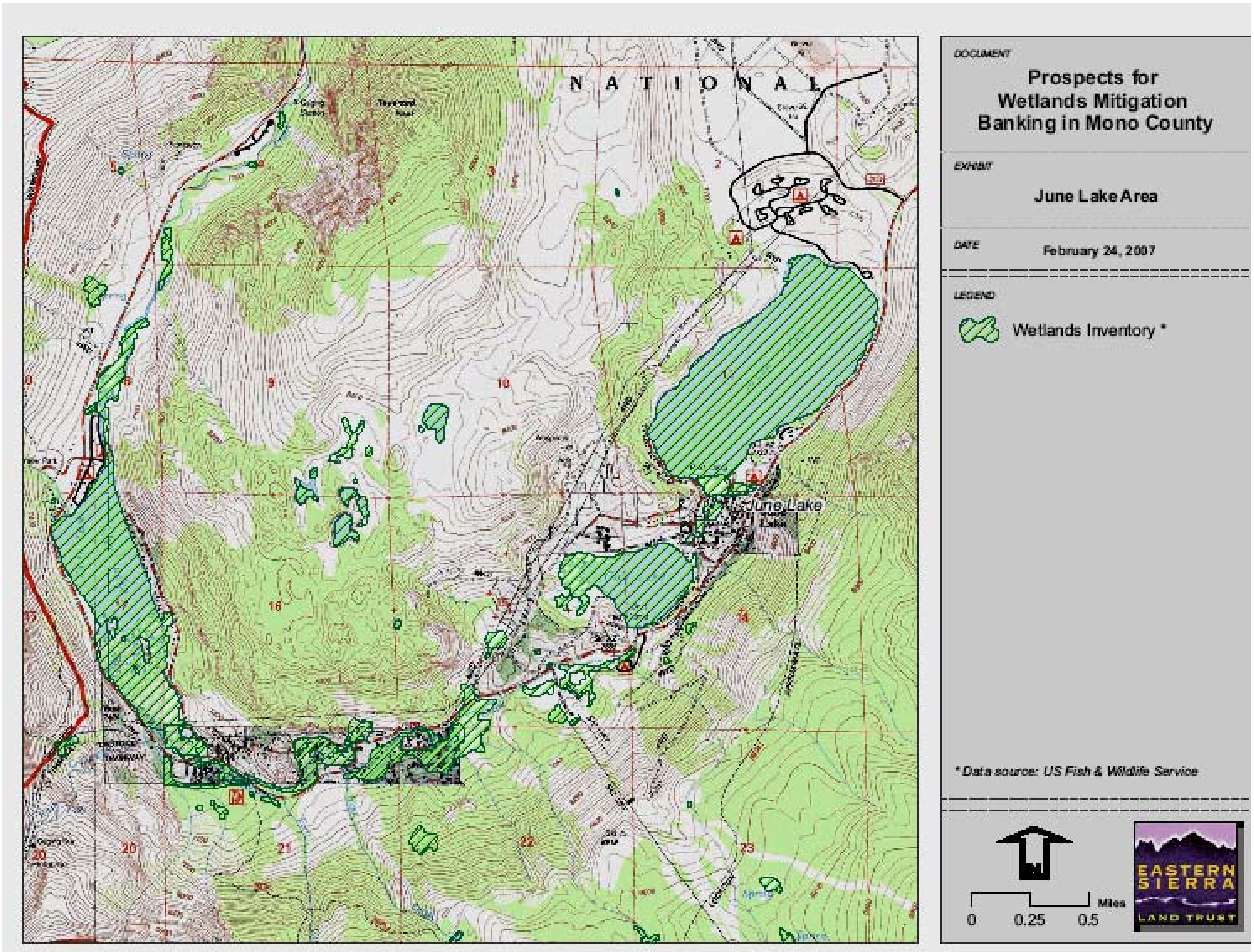


Figure 7. Wetlands of the June Lake Loop. Source: U.S. Fish and Wildlife Service data layer



The alluvial fans created by Hilton Creek and Whiskey Creek are complicated mosaics of uplands and wetlands supported by high groundwater and the numerous small creeks into which the named creeks divide (Curry, 1996). The majority of the aspen forest where houses have been built appeared to meet jurisdictional wetland criteria. Similarly, the open areas near and downhill from the old highway, extending across U.S. Highway 395 to the shore of Crowley Lake, were mostly wetlands with many upland islands. Because these wetlands are supported by high groundwater, probably perched upon bedrock near the surface, they extend across nearly the entire slope, rather than being confined to the immediate vicinity of the distributary channels (Curry, 1996). In Little Round Valley, the wetlands that occur on the slope near the old highway are confined to the immediate vicinity of the springs and small creeks. Most of the gently sloping to flat area between the transmission line and U.S. Highway 395 is probably wetland, with some upland islands. Two apparent aspen wetlands are found south of the Aspen Springs loop road. With the exception of narrow riparian thickets along the small channels into which Rock Creek divides, downhill from the Rock Creek campground, wetlands were not observed in the vicinity of Tom's Place or on the north side of U.S. Highway 395 (Curry, 1996).

Threats to riparian areas and wetlands

Perhaps the greatest threat to riparian areas is the interruption of flows of water and sediment from upstream. The dependence of riparian areas on the natural hydrologic regime cannot be overstated because that is what formed and maintains the riparian system in a given area. When water is diverted out of the stream or a dam prevents the further movement of sediment, the conditions that created and maintained a riparian corridor or wetland are altered, and the new conditions will lead to changes in the plants and animals that lived in the affected area. Furthermore, construction of reservoirs completely inundates the riparian area between the dam and the high water level.

Roads adjacent to streams may directly convert some of the riparian area into compacted and perhaps paved surfaces, eliminating any ecological values. Roads immediately upslope of a riparian area can interfere with water movement toward the stream as well as wildlife activities on that side of the stream. Road crossings of streams, whether as a bridge or culvert, interrupt the continuity of the riparian corridor and can present a barrier to movement of fish and some wildlife.

Construction within and immediately upslope of a riparian zone can destroy vegetation, compact and/or drain soils, decrease infiltration capacity of soils, increase erosion and sediment movement toward the stream, alter the shape of the channel, and act as a barrier to wildlife. Extraction of sand and gravel from channels and floodplains has similar consequences.

Wildfires rarely enter riparian areas because of the higher fuel moisture, types of trees, and higher relative humidity near streams. However, under severe fire-weather conditions (high winds, low humidity, and low fuel moisture), riparian areas can certainly burn. When riparian vegetation is destroyed by fire, the ecological values are lost for several years. Fortunately, because of the abundant soil moisture near streams, riparian areas tend to recover from fire damage far faster than adjacent uplands. Even when riparian areas avoid direct damage from fires, loss of vegetation over much of the watershed in an intense and widespread fire can lead to dramatic increases in runoff that can produce channel-scouring floods and considerable damage within the riparian zone. Therefore, unnaturally high fuel loads throughout a watershed constitute a threat to streams and riparian zones.

Overgrazing by domestic livestock has been a long-term threat to riparian areas throughout the Sierra Nevada. Cattle and sheep tend to concentrate near streams for the same reasons that native wildlife occupy and visit riparian zones -- availability of water, forage, shade, and lower temperatures. Unfortunately, large numbers of livestock occupying the riparian zone for a few days can consume or trample much of the vegetation that holds the streambanks and soil together and mechanically change the structure and porosity of the soil adjacent to the stream. Riparian areas and stream channels that have been subject to overgrazing differ dramatically in structure, form, and ecological utility from riparian areas that have been lightly grazed (e.g., Elmore and Beschta, 1987; Platts, 1991; Fleischner, 1994).

Recent studies of grazing impacts and recovery at Convict Creek and other sites have relied on biological indicators. Aquatic invertebrates and fish are known to be sensitive to a variety of grazing-related impacts, including changes in riparian vegetation, bank cover, substrate size, sedimentation, and temperature regime (Herbst and Knapp, 1995). Potential impacts of overgrazing on benthic invertebrate communities include loss of habitat through choked and silted substrate conditions, releases of suspended sediment, algal-microbial mats covering substrates, reduced dissolved oxygen, higher temperatures, and reduced leaf and wood litter as food and habitat structure (Herbst and Knapp, 1999).

Groundwater extraction

Groundwater pumping can lower a near-surface water table if the uppermost aquifer is hydraulically connected to the formation that the well(s) draw from. One area that may have been affected by pumping is in the vicinity of the Mammoth Pacific geothermal plant. Apparently, the area north of the junction of State Route 203 and U.S. Highway 395 once had wetlands and a seasonal pond as shown on the USGS "Old Mammoth" 7.5-minute map of 1983. Other areas near the geothermal facility were observed to support wetlands in the past (Farrar, in Burak, et al., 2006). These areas have been dry since the 1980s (Burak, et al., 2006).

Pollution

Chlorine added to the Whitmore swimming pool, which then ends up in the outflow from the pool, has potential to affect aquatic invertebrates in the receiving wetland that was identified as a "sensitive biological area" in the 1996 USFWS Owens Basin Wetland and Aquatic Species Recovery Plan (Lahontan Regional Water Quality Control Board, 1998).

More than 40 percent of the land parcels within the Hilton Creek community area border on, or contain within their boundaries, a stream. Surveys conducted by the Lahontan RWQCB staff in 1975 found that over 64 percent of the existing developed parcels of the community were located adjacent to surface waters or in areas of obvious seasonal or year-round high groundwater levels. Until a community wastewater collection and treatment system was built in the 1980s, the distributary channels of Hilton Creek contained high levels of coliform bacteria and detergent by-products (Gram/Phillips, 1977).

Restoration efforts

Restoration of streams and riparian areas is a developing field without a solid foundation of theory and experience to guide the efforts. Long-term monitoring and evaluation of restoration trials is essential to improving the state of the art (e.g., National Research Council, 1992; Kondolf, 1995). The single most-important step in riparian restoration tends to be the elimination of the problem or disturbance that caused the degradation in the first place. For example, in the Mono Basin, returning water to the dry stream channels was the obvious place to start. Once the streams had water again, natural processes could begin to reestablish functional channels and riparian vegetation.

Four tributaries in the upper Owens River Basin ecosystem have been the focus of research and restoration since 1992 (Los Angeles Department of Water and Power, n.d.). LADWP's valley-wide riparian restoration effort began with Convict, McGee, and Mammoth creeks as well as the upper Owens River with the establishment of grazing strategies, water management, and recreational control designed to improve riparian habitat. The goal of LADWP's stream restoration effort is to employ best management practices (BMPs) for land and water uses that establish and maintain riparian vegetation, protect water quality and improve fish and wildlife habitat while maintaining water supplies to the city. BMPs must also incorporate recreational uses as well as sustainable agriculture practices.

To allow annual recruitment of riparian plants, pasture irrigation was delayed on each of the four streams to allow snowmelt runoff flows to pass. When the flow in the creeks reached near-base conditions, controlled diversion of water into pastures was allowed.

Vehicle access to the streams for angling resulted in substantial degradation of streambanks. Roads that paralleled the streams were also a source of sediment and prevented recruitment of new vegetation. All roads within the riparian corridor were closed, and vehicle traffic on streambanks was stopped. Angler access to the four creeks was limited to walking, with access gates built into the new fence lines.

New grazing practices were prescribed, and fences installed to gain control of livestock distribution, timing of forage use and degree of forage utilization on and near the stream banks. Specific procedures were designed for each of the four streams. For example, LADWP fenced six miles of the Owens River north of Benton Crossing road during the summer and fall of 1996 and setback pastures were not grazed for five years until the desired riparian condition was achieved, and then only 30 percent to 40 percent of the forage could be grazed. Riparian zones were fenced with some sensitive areas set aside as non-use areas (Los Angeles Department of Water and Power, n.d.).

The quantity and age of cottonwoods and willow indicated vegetation changes along the streams. All streams exhibited an increase in the number of riparian plants as well as an improved age distribution. The greatest increase in riparian vegetation occurred on Convict Creek where willows and cottonwoods increased by several orders of magnitude. The most important change on Convict Creek was the increase in recruitment of new plants as evidenced by the number of sprouts at each site in 1999. The treated reach of upper Owens River had no measurable riparian vegetation in 1994. By 1999, willow and cottonwood plants were recruited to the extent that a community age structure developed with recruitment of new plants nearly equal to decadent plants (Los Angeles Department of Water and Power, n.d.).

Stream width usually decreases and stream depth increases when domestic livestock are removed or grazing is strictly controlled. The four streams in this study exhibited the following decreased stream width; Convict 18 percent, McGee 14 percent, Mammoth 30 percent, and upper Owens 22 percent. Water depth has increased on all four streams; Convict 11 percent, Mammoth Creek 49 percent, McGee Creek 3 percent, and the upper Owens 10 percent (Los Angeles Department of Water and Power, n.d.).

The Inyo National Forest attempted to improved physical channel conditions and riparian vegetation of O'Harrel Canyon Creek for the benefit of Lahontan cutthroat trout in the late 1990s. About a hundred log weirs were built across the channel in an effort to create pools and raise the local water table. By 2001, many of the structures were undercut and likely to fail under high flows (Becker, 2002). At this time, the channel was filling in with sedges and was not becoming deeper, contrary to the hope to improve habitat for the Lahontan cutthroat trout. Planting of native riparian species seemed to be more successful (Becker, 2002).

The Inyo National Forest has plans to restore an area of wetlands around Bodle Ditch between Mammoth Creek and Lake Mary outlet (Feay, 2005). These wetlands received water from Bodle Ditch and were functional until the 1980s, when the ditch was no longer used to convey water. The area was later acquired by the Forest Service (Feay, 2005).

Wetlands surrounding the naturally ephemeral Laurel Ponds were expanded when disinfected secondary-treated effluent from the Mammoth Lakes wastewater treatment plant was discharged there beginning in 1983. The Inyo National Forest regards the site as important waterfowl habitat.

The Owens Gorge, just downstream of the lowest point of the study watershed, has been the scene of a large-scale restoration effort for the past decade. In 1991, a section of the penstock that carried water from the Crowley Lake dam failed, and water had to be released into the Owens Gorge. After repairs were completed, LADWP was required to maintain water in the affected section of the Owens River, which had been essentially dry for about four decades. Experiments with flushing flows have been conducted, riparian vegetation has been successfully reestablished, and the fishery is improving.

Fish and wildlife

Fisheries

Fish, particularly trout, are a highly valued recreational resource of the streams in the upper Owens River watershed. Much of the tourism economy of the area is dependent on fishing. The streams and lakes of the watershed have hundreds of thousands of angler-days of use each season. Introduced in the late 1800s, trout have become thoroughly integrated into the aquatic ecology of the watershed.

The upper Owens River through lower Long Valley before the reservoir started filling in 1941 was regarded as a "superb stream fishery" (Pister, 1982). The subsequent lake is also a highly productive fishery. The growth rates of rainbow trout and brown trout in Crowley Lake are among the highest ever recorded for a resident trout population in a mountain environment (Von Geldren, 1989). Chironomid pupae and larvae seem to be the principal food for trout in the lake. Other important food items within the lake are cladocerans (*Daphnia* sp.), snails, and other fish.

Crowley Lake's high productivity results in trout that gain from three to 40 times their stocked weight before harvest (Milliron, 1997). In 1996, the Department of Fish and Game's fish stocking allotment for Crowley Lake was:

- 150,000 Coleman rainbow trout
- 150,000 Eagle Lake rainbow trout
- 100,000 Kamloops rainbow trout
- 25,000 Crowley Lake brown trout
- 25,000 Whitney strain brown trout

The relatively constant flow and temperature (above East Portal) and high nutrient load have made the upper Owens River a highly productive stream for trout. Where the riparian zone has not been disturbed, there is excellent cover, shade, and habitat for fish. An electroshocking survey performed by the Department of Fish and Game throughout the Arcularius Ranch portion of the Owens River in 1985 estimated a total population of more than 11,000 fish per mile. The species mix was about 85 percent rainbow trout and 15 percent brown trout. The same survey found only 3,850 fish per mile (two-thirds rainbow and one-third brown trout) in the public waters downstream of the confluence with Hot Creek (Deinstadt, et al., 1985). The upper Owens River provides critical spawning habitat for trout and Owens sucker from Crowley Lake.

The trout fishery of the upper Owens River responded favorably in general to the augmentation of flows from the Mono Basin. Ebasco Environmental and others (1993) determined that flows of 120 to 250 cfs in the upper Owens River provide optimal habitat for all life stages of brown and rainbow trout, whereas the natural flow was on the order of 60 cfs as an annual average. California Trout, a trout fishing advocacy group, supported export of some Mono Basin water into the upper Owens for fishery enhancement purposes in the early 1990s (Edmondson, 1992). A thorough history of the Mono Lake water controversies summarized the effects of altering water input to the upper Owens River: "The river had been a trout stream of national note in the 1930s. After the Mono water poured into it, the stream adjusted to the larger and much more variable flow by widening and straightening its course. As long as flows remained artificially high, fishing remained excellent. But if Mono export were permanently decreased, it seemed likely that the fishing in the upper Owens would suffer, at least for a time" (Hart, 1996:137).

Fishing regulations also play a major role in fisheries management of streams within the upper Owens River basin. For example, until 1995, the reach of the Owens River immediately above Crowley Lake was limited to catch-and-release during spawning periods. That restriction was removed by the Fish and Game Commission in 1995. In 2002, that reach was closed to all fishing during the spawning period (first and last months of the fishing season).

The Department of Fish and Game Wild Trout Project has surveyed the section of river owned by LADWP, downstream of the Inaja Ranch, since the 1980s. Surveys using backpack electrofishers have supplied data suggesting standing crops in excess of 120 pounds per acre and numbers usually greater than 5,000 fish per mile. As the largest tributary of Crowley Lake, the upper Owens River provides important spawning and rearing habitats for wild trout. The quality of the fishery has led to consideration of the upper Owens River for special wild trout management (Lentzt, 1993).

Native fishes of the Long Valley streams include Owens sucker (*Catostomus fumeiventris*), Owens tui chub (*Gila bicolor snyderi*), and speckled dace (*Rhynichthys osculus*) (Hubbs and Miller, 1948; Miller, 1973).

The principal introduced fish in the upper Owens River are rainbow trout (*Oncorhyncus mykiss*) and brown trout (*Salmo trutta Linnaeus*). Brown trout were introduced to the United States in 1883 and to California coastal waters in 1893. The best habitat for brown trout appears to be larger streams containing both riffles and deep pools with water temperatures of 53°F to 68°F (Moyle, 2002). Brown trout at different life stages select different combinations of depth, cover, and velocity in Sierra Nevada streams:
Fry: low velocity water near the banks less than a foot deep;
Juveniles: water moving up to 1.3 feet/sec and 12 to 18 inches deep;
Adults: water 2 to 12 feet deep of variable velocity (Smith and Aceituno, 1987).

Tributary streams except for the upper Owens River are closed for the first month of trout season to protect spawning rainbow, which migrate up these tributaries. DFG planting supplies only about 40 percent of the spawning rainbows and only 15 percent of the spawning browns found in the tributaries, indicating that a large percentage of the spawners are of wild origin (Matthews, 1986).

Young brown trout tend to eat drifting insects while older brown trout feed on benthic invertebrates and other fish (Moyle, 2002). Large fish mostly eat other fish. Brown trout require streams with riffles that have gravel beds for spawning. Brown trout tend to out compete as well as consume other fish and usually dominate the waters where they are introduced. The largest brown trout caught in California was from Crowley Lake in 1971 at more than 25 lb and 33 inches (California Department of Fish and Game files in Bishop office -- the record may have been surpassed).

Golden trout (*Oncorhynchus mykiss aguabonita*) is one of three subspecies of rainbow trout native to Golden Trout Creek and the South Fork Kern River. They have been transplanted throughout the Sierra Nevada and have hybridized with coastal rainbow trout and seem adaptable to a wide range of aquatic habitats. They are known to have been introduced to Mammoth, Laurel, Convict, McGee, and Hilton creeks within the upper Owens River watershed (Moyle, 2002). Golden trout feed primarily on drifting and benthic insects and larvae. They require streams with sand and gravel beds for spawning. A naturally reproducing population of introduced golden trout is present in Crystal Lake (Melack, et al., 1993).

Hot Creek fishery and hatchery

Hot Creek is often referred to as a "blue ribbon trout stream" because of its high quality fishing opportunities. The number of angler-days of use usually exceeds 6,000 (USDA-Forest Service, 1988b). It is one of only two State of California-designated wild trout streams within the Inyo National Forest. The Hot Creek fishery is comprised of a self-sustaining brown trout population, as well as rainbow trout. Because of the highly productive aquatic habitat conditions, brown trout inhabiting Hot Creek grow very fast and achieve trophy size. This high quality fishery is dependent upon consistent warm water flows from the headwater springs of Hot Creek, and high water quality and sufficient quantity from Mammoth Creek. In the mid-1970s, fishermen began to notice degradation of Hot Creek's aquatic habitat because of excessive sediment. Because of the deposition of inordinate amounts of sediment in Hot Creek in the 1970s, the numbers of naturally reproduced brown trout in the wild trout study area declined from 3,400 in 1973 to 500 in 1975 (USDA-Forest Service, 1988b). In 1980, substantial amounts of sediment precluded brown trout spawning in at least 50 percent of the Wild Trout Area. The sedimentation was widely assumed to be a result of urbanization within the town of Mammoth Lakes. Low discharge in Mammoth Creek was also thought to be a factor.

Mammoth Creek is the principal tributary to Hot Creek, or could be considered the upper part of Hot Creek above the hatchery springs. The Mammoth Creek fishery is primarily comprised of brown trout with considerable planting of hatchery-reared fish. The quality of trout habitat within Mammoth Creek has declined during the 1970s and 1980s because of increased sedimentation (USDA-Forest Service, 1988b). However, sediment quantities seem to have been steadily decreasing in Mammoth Creek since 1985 (McCarthy, 1987). The quality of trout habitat in Mammoth Creek has also been jeopardized in the past by excessive diversion. The fishery of Sherwin Creek is comprised primarily of planted rainbow trout, wild brown trout, and to a lesser extent, brook trout.

The Hot Creek fish hatchery is one of the most productive hatcheries within California. The facility raises over 600,000 catchable-size trout and 1 million fingerlings annually. In addition, trout eggs produced from this hatchery supply other hatcheries throughout the state. The relatively constant-temperature water from the four headwater springs of Hot Creek is essential to the operation of the hatchery. The volume, temperature, and quality of these springs directly influence hatchery production (USDA-Forest Service, 1988b).

In the early 1990s, the California Department of Fish and Game made a tentative proposal for building a hatchery somewhere near Big Springs. There was much public outcry against the proposal, as evidenced in letters to the Inyo National Forest.

Speckled dace (*Rhynichthys osculus*) were found at four locations in Long Valley in the 1930s and 1940s (Miller and other author, 1970). These locations were described as (1) Sulphur spring, eastern side of Long Valley, near Benton Crossing; (2) spring tributary and westernmost distributary of Hot Creek; (3) hot spring, Long Valley; and (4) feeder of Hot Creek at Hot Creek rearing station. A more recent study of the species (Sada, 1989) found the fish at Whitmore hot springs and at a spring near Little Alkali Lake, which may correspond to (3) above from the University of Michigan study in 1938. The Long Valley speckled dace appear to be declining (U.S. Fish and Wildlife Service, 1998).

The Owens tui chub (*Gila bicolor snyderi*) is a small (up to 8 inches in length) fish with a historic distribution throughout the lower gradient reaches of the Owens River (U.S. Fish and Wildlife Service, 1998; California Department of Fish and Game, 2000). One of the four known populations is located within the upper Owens watershed -- in the springs that supply water to the Hot Creek fish hatchery. The others are downstream: Owens Gorge, a reach above Pleasant Valley reservoir, and a pond and ditches at the Cabin Bar Ranch near Owens Dry Lake. It was listed as endangered by California in 1974 and by the federal government in 1985. The primary threats to the Owens tui chub are lack of sufficient habitat because of insufficient water supply, the introduction of Lahontan tui chubs that readily hybridize with Owens tui chub, and the introduction of predatory fish. Other threats include volcanic activity that could change spring flow and water quality of the springs at Hot Creek fish hatchery, and changes in spring flow and temperature of these springs resulting from development of geothermal energy and/or domestic water supply for the town of Mammoth Lakes (U.S. Fish and Wildlife Service, 1998). In an attempt to increase the total population and spread the risk to the isolated groups, the Owens tui chub was introduced to Little Hot Creek (as well as two other sites outside the upper Owens watershed). The overall population of Owens tui chub was classified as stable in 1999 (California Department of Fish and Game, 2000).

The U.S. Fish and Wildlife Service (1998) recommended four “Conservation Areas” within Long Valley to help with recovery of Owens tui chub and Long Valley speckled dace: Little Hot Creek, Whitmore, Little Alkali, and Hot Creek.

Figure 8. Conservation areas designated by U.S. Fish and Wildlife Service

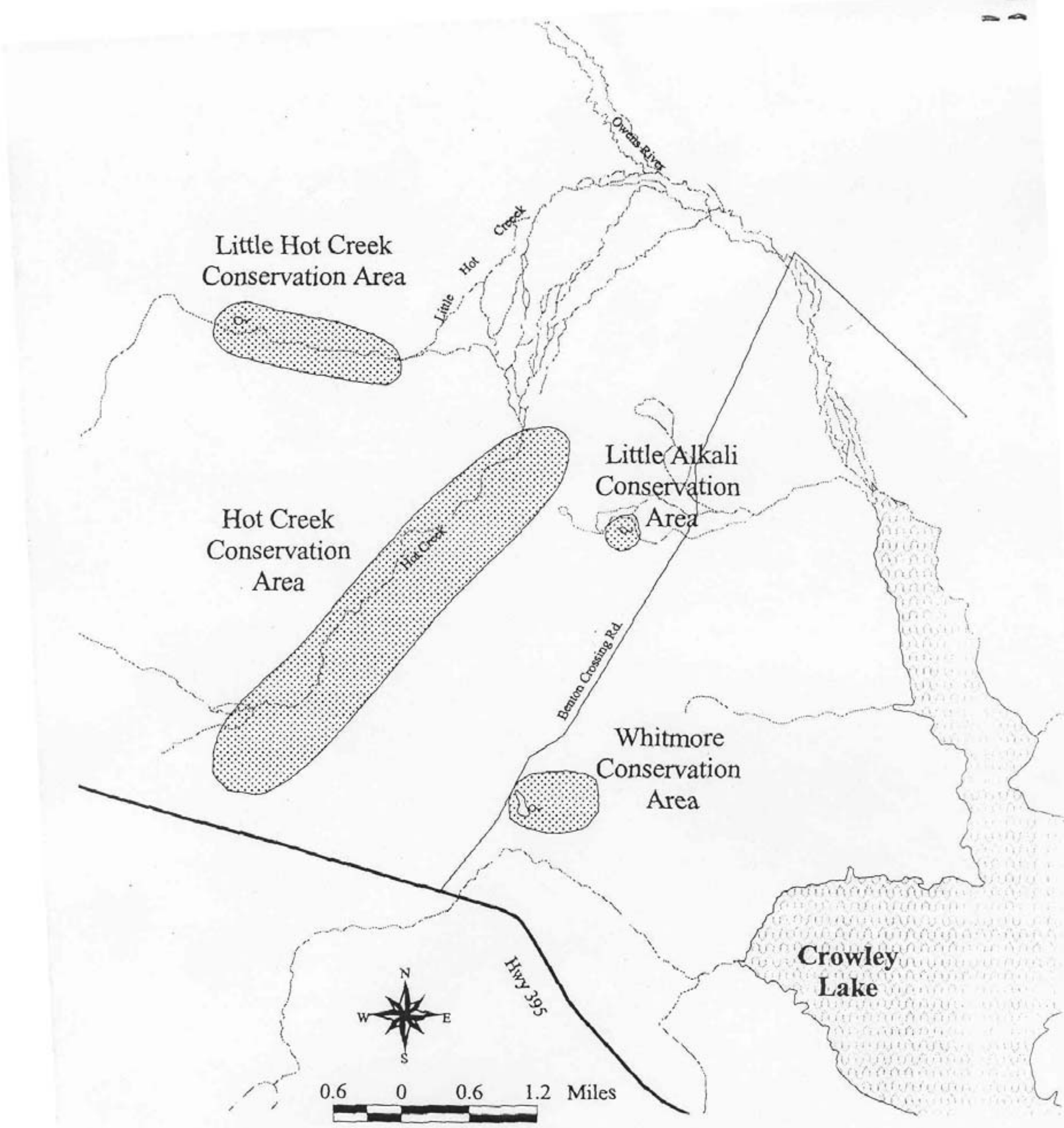


Figure 17. Approximate location of Little Hot Creek, Hot Creek and Whitmore Conservation Areas in Long Valley, Mono County, California.

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O'Harrel Canyon Creek supports a small, pure population of Lahontan cutthroat trout (*Oncorhyncus clarki henshawi*), which is a federally classified threatened species. O'Harrel Canyon Creek is not within the native range of Lahontan cutthroat trout, and this population may have been transplanted to the creek as early as 1870. The population was discovered in 1978 by California Department of Fish and Game employees and was determined to be a pure genetic strain shortly thereafter (Inyo National Forest, 1980).

Amphibians are assumed to be scattered throughout the watershed, but have been depleted by introduced trout (e.g., Knapp and Matthews, 2000). The larger populations are found in waters without fish. A complete barrier to upstream fish migration exists about 3,900 feet downstream of Glass Creek Meadow. Large numbers of juvenile Yosemite toads were found in the meadow in 1993 (Millar, et al., 1996). Yosemite toads and Pacific tree frogs have been observed in the headwaters of Deadman Creek.

There is a wealth of literature on aquatic insects in the streams of the study area that is largely the work of David Herbst (http://vesr.ucnrs.org/pages/Herbst.html) of the Sierra Nevada Aquatic Research Laboratory and his colleagues. Although this topic is beyond the immediate scope of this report (aquatic entomologists will surely disagree), there is great potential for observing changes in water quality and aquatic habitat from the baseline surveys of aquatic invertebrates performed by Herbst and others.

Exotic aquatic species

The most significant introductions of non-native species to the eastern Sierra Nevada have been trout.

Sacramento perch (*Archoplites interruptus*) were found in Crowley Lake in 1965, probably resulting from a fisherman's "hobby planting." Perch use the shallow areas of Crowley Lake for spawning and nursery purposes. Juveniles feed on small crustaceans associated with rooted aquatic plants (Milliron, 1997). Although perch eat the same food as trout, they also serve as food for trout. Consequently, perch do not seem to have a negative impact on trout populations (Milliron, 1997). A rapid drawdown of Crowley Lake in 1989 resulted in a large die-off of Sacramento perch. The fish kill probably resulted from a combination of lowered dissolved oxygen in water (because lake sediments were eroded and stirred up as tributary channels incised in response to the declining base level) and loss of shallow-water habitat. The perch population rapidly recovered in the following years (Milliron, 1997).

Although not truly exotic from a long-distance source, shrimp were apparently relocated around the waters of the eastern Sierra Nevada to augment naturally occurring food sources for introduced trout. In 1926 a plan to collect and distribute "vegetation and fish food" was described in handwritten notes as follows:

“Source: June, Gem, Silver and Grant Lakes; and Hot Creek and upper Owens near Hot Creek confluence.
Placement: most lakes in Rock Creek basin “

Shrimp were also to be harvested from Twin Lakes and moved into the lakes upstream.
This information is transcribed from handwritten notes on a poor Inyo Forest map dated 1923. There is no record whether the transfers were completed as planned. The second reference is to "shrimp planting," which suggests *Gammarus* sp. It indicates that shrimp were planted in Laurel Lake #2 about 1960 (Parmenter, 1996).

New Zealand mud snails were first discovered in the upper Owens River at Benton Crossing in November 2000. Subsequently, they were found in invertebrate samples collected in 1999, but had not been identified at the time they were collected. In March 2004, a protocol for surveying streams for New Zealand mud snails was developed. Snails were found in low densities at Alpers Ranch. Subsequent surveys in May 2004 found snails spreading at Alpers Ranch, and in the lower Owens River. In September 2004, snails were found in Hot Creek immediately below the Hot Creek hatchery. In February 2007, New Zealand mud snails were found at the hatchery itself (Reed, 2007). The mud snails apparently require high amounts of calcium in the waters they inhabit (Herbst, personal communication to D. Becker, CDFG).

Tiger salamanders have been found near the Laurel Ponds sewage effluent disposal area. In 1997, nine adult tiger salamanders were found at the Hot Creek Fish Hatchery (Bauer Environmental Services, 1998). There is a possibility that they migrated from the Laurel Pond area.

Terrestrial wildlife

In a watershed context, the animals that have the greatest impact on watershed processes are those largely unseen and unappreciated creatures that live below the soil surface and perform an immense amount of work in the soil. The activities of burrowing mammals, reptiles, insects, worms, and amphibians process organic matter and alter the physical structure of the upper part of the soil. Animals in the soil can have a huge effect on the pore space and structure of the soil and, consequently, on the infiltration capacity and water storage capacity of the soil. Human activities that impact soil organisms, such as excavation, compaction, vegetation removal, and pollution, can have secondary impacts on the water relations of the soil.

Animals that are traditionally considered as "wildlife" are primarily of interest in the watershed context with respect to riparian habitat. The eastern Sierra Nevada does not have any wildlife species with either the behavior (e.g., bison) or numbers (e.g., elk in Rocky Mountain National Park) to make substantial changes in soil properties, vegetation, or stream conditions to alter hydrologic response of the watershed. Nevertheless, all native species have ecological roles, and one could imagine some hydrologic consequences if the population of some species were drastically changed. Most wildlife species are dependent on the riparian zone, at least occasionally, for water, food, or shelter. Changes in riparian vegetation composition, density, and continuity can have serious impacts on wildlife. In the upper Owens River watershed, the stream corridors are critically important because of the lack of water elsewhere in the landscape.

Wildlife dependent on the creek water and riparian habitat include deer, sage grouse, mourning dove, blue grouse, band-tailed pigeon, white-tailed jackrabbits and cottontails. Kestrels, Ravens and possible Goshawks nest within the confluence of the creek. Red-tailed hawks, prairie falcons, and golden eagles also utilize the area as part of their habitat. A historical peregrine falcon aeyrie in the Glass Mountain Range is on record. The fish and wildlife habitat in the upper portion of the drainage is in excellent condition while the lower portion, below 7,600 feet elevation, is not in satisfactory condition (Inyo National Forest, 1980). There are two large herds of mule deer using portions of the upper Owens River watershed for winter and summer range and migration corridors. The Casa Diablo herd is relatively stable and includes about 1,300 deer. The Round Valley herd that migrates through Long Valley enroute to summer range on the western slope of the Sierra Nevada has been declining for about 20 years (Ferranto, 2006).

Beaver were not known to exist in the Owens and Long valleys when EuroAmericans began settling the area (Hall, 1947). After World War II, there was a debate within the California Department of Fish and Game about the benefits and risks of introducing beaver. There is a record of planting one male and three female beavers in McGee Creek in July 1946 (Hensley, 1951). Some of the offspring migrated to Convict Creek and were removed. By 1967, beaver were noted in the watersheds of Deadman Creek, McGee Creek, Mammoth Creek, and Hot Creek (undated addendum to Hensley, 1951). Beaver were observed in Rock Creek in 2005, but may have been removed (King, 2005, personal communication).

The old-growth forest in the Deadman Creek to Indiana Summit area is considered suitable habitat for California spotted owl and is home to a population of pine martens.

Sage grouse occupy a portion of Long Valley, and their relatively low populations have been a matter of concern. The Mono Basin area sage grouse was apparently present in "large numbers" in Long Valley in the 1800s, but the population declined substantially by the early 1900s and remains depressed a century later (Stanford Law School Environmental Law Clinic, 2005). Because the Mono Basin area sage grouse appear to be a genetically distinct population or possible subspecies, it may be suitable for listing as threatened or endangered under the federal Endangered Species Act. A petition for formal listing was filed with the U.S. Fish and Wildlife Service in November 2005 (Stanford Law School Environmental Law Clinic, 2005). If the sage grouse is listed, there could be serious constraints on land management and development of its habitat.

Land Use and Human History

Human history

The upper Owens River watershed was probably mostly occupied in the summer months by the Piute people who could find more favorable year-round conditions in the Owens Valley or to the east. The persistent snowpack and low temperatures were likely to keep Native Americans out of the area during winter and early spring. However, there is some evidence for year-round occupancy of Long Valley, at least in the 1800s (Burton and Farrell, 1992). Presumably, there were good hunting opportunities in the watershed during the snow-free part of the year, and people from adjoining areas lived at the higher elevations during the summer. Pinyon pine nuts and caterpillars of the Pandora moth were among the favored food resources of the upper Owens River watershed. The Glass Mountains and Obsidian Dome provided high-quality obsidian for projectile points and tools. The meadows around Ford Spring in the Glass Mountains were also rich in animal and plant resources (Reynolds, 1992). Archeological evidence of artifacts and sites indicate at least 6,000 years of occupation (Bettinger, 1977; Strojan and Romney, 1979). More than two dozen archaeological sites were found on the Arcularius Ranch alone (Burton and Farrell, 1992) and Figure 4 in that report shows the location of widespread sites throughout Long Valley and Mammoth Creek areas. Volcanism, including ash falls as recently as 660 and 1,210 years ago (Wood, 1977), may have affected the vegetation, wildlife, and water of the upper Owens River watershed enough to limit Native American use of the area for periods of time (Hall, 1984).

The earliest exploration of the upper Owens River watershed by EuroAmericans is uncertain. There is some possibility that members of Peter Ogden's party in 1829-30 or Joseph Walker's group in 1833-34 or the Fremont-Walker expedition in 1845 entered the watershed, but the records of their routes are not detailed enough to be sure. From 1855 to 1857, the von Schmidt surveying team was in the area. Leroy Vining began prospecting in the Mono Basin in 1852 or 1853. It seems likely that Vining or his peers came into the upper Owens River watershed soon after.

As the search for gold, and later silver, drew thousands of would-be miners to the Sierra Nevada in the 1850s, some prospectors undoubtedly examined the upper Owens River area. However, the first documented account on prospecting or mining in the area involves the legend of the "Lost Cement Mine," in which miners brought samples of red "cement-like" ore containing nuggets of gold to San Francisco that they had obtained from the vicinity of Pumice Mountain (now Mammoth Mountain) in 1857. During the summers of 1861 and 1862, a Dr. Randall and his crew searched the Mammoth Lakes area for this supposed treasure (DeDecker, 1966).

During the winter of 1861-62, the greatest floods of the historical period were observed throughout the Sierra Nevada. Although the upper Owens River watershed was probably unoccupied at the time, persistent rainfall intermixed with snow led to extreme flows in the streams entering the Owens Valley. At the peak of the floods, the Owens River was estimated to be one-fourth to one-half mile wide. The harsh winter and inundation of the Owens Valley led to violent conflicts over food between Piutes and early white settlers (Chalfant, 1933).

A group of prospectors continuing the search for the "Lost Cement Mine" in 1877 found a rich gold-silver vein in "Mineral Hill" or "Red Mountain" just east of Lake Mary (DeDecker, 1966). They called it the "Mammoth Vein" and organized the Lake mining district. During the following summer, a well-known mining investor, General George Dodge, bought the set of claims and founded the Mammoth Mining Company. Word of the new strike spread quickly, and miners rushed to the area. Mining camps were built nearby, including Mammoth City, Pine City, Mill City, and Mineral Park (Mammoth Mountain, 2005). The combined population in 1879 was thought to exceed 1,500 (DeDecker, 1966) or perhaps even 2,500 (Smith, 2003). This population was sufficient to support three newspapers. A dam was constructed at Twin Lakes to supply hydro-mechanical power. The mining boom led to construction of a wagon road from Benton, a toll road up the Sherwin Grade from Bishop, and a toll trail from Oakhurst to supply beef cattle (DeDecker, 1966). A route for a railroad over Mammoth Pass was surveyed in 1881, but the Mammoth Mine had already closed the previous year after yielding only about $200,000 (at the time) in gold and silver. The mine reopened briefly in 1895 but remained unprofitable. The Headlight and Monte Cristo mines also invested more than they yielded. The Lisbon mine may have been the most successful, operating from 1881 into the 1890s (DeDecker, 1966). The Mammoth Consolidated Mine opened in 1927 near the present-day Coldwater campground, but closed in 1933 (Mammoth Mountain, 2005).

Although the mining camps were quickly abandoned as mines failed, a few settlers stayed in the lowest camp, Mineral Park (later known as Old Mammoth). A sawmill there supplied lumber to Bishop, so we assume that immediate area was heavily logged. A resort, the Wildasinn Hotel, was established in Old Mammoth in 1905. The water wheel turbine that had been used for the ore stamp mills was salvaged and brought downhill to generate electricity for the hotel.

During the mining boom, the Owens Valley became home to farmers and ranchers and had a population of several thousand people by the turn of the century (Irwin, 1991). Some Owens Valley ranchers drove cattle and sheep into the highlands of Long Valley and the upper Owens River area for summer and fall grazing in the 1880s (Burton and Farrell, 1992). There are no records of the extent or intensity of grazing for the first few decades. When the Inyo National Forest took over administration of the forested federal lands from the Sierra Timber Reserve in 1908, one of the first tasks was to control overgrazing (Millar, et al., 1996). By 1950, grazing between Mammoth Lakes and Glass Creek was restricted to two allotments that are still active 50 years later: June Lake and Sherwin-Deadman. Although the livestock numbers have remained stable at about 1,800, the number of days of seasonal use has been sharply curtailed (Millar, et al., 1996).

Right from its beginnings, the Inyo National Forest had a charge to suppress wildfires, although available technology, resources, and personnel limited the effectiveness. A few timber sales were administered by the Inyo National Forest in the Dry Creek and Deadman Creek areas in the 1920s and 1940s (Millar, et al., 1996).

As more people in southern California accumulated wealth and leisure time in the early 1900s, the eastern Sierra Nevada including the Mammoth Lakes area became a destination for summer recreation. An automobile trip from Los Angeles required about two and a half days in 1914. A paved road along the eastern escarpment of the Sierra Nevada (close to the present route of U.S. Highway 395) would not be completed until 1931 (Irwin, 1991). Initially, the summer visitors established tent camps along Mammoth Creek and in the Lakes Basin. The tents were followed by cabins, which were popular summer residences for Bishop and southern California families. For example, the Valentine Camp in Old Mammoth was purchased between 1916 and 1918 for about $20 per acre by a group of businessmen from Los Angeles (Valentine, 2005). The Tamarack Lodge at Twin Lakes was built in 1924 and developed into a summer fishing resort in 1927. The Owens River Ranch downstream of Big Springs was originally homesteaded in the 1860s by Andrew Thompson, who built a popular fishing resort that was sold to the Alpers family in 1907. Maps for summer homes on lower Glass Creek and the Crestview Resort date to 1929 (Millar, et al., 1996). Civilian Conservation Corps workers were based at Shady Rest in the 1930s and constructed campgrounds at Hartley Springs and Glass Creek among other projects. Deadman Creek campground was built in the 1950s, and Pine Glen campground was built a decade later (Millar, et al., 1996).

As automobiles became more common, the driving public pushed for more roads and those roads, in turn, influenced land use. The original road into Old Mammoth followed the approximate route of the present-day USFS Laurel Creek/Sherwin Creek road. After highway 203 was completed in 1937, the center of activity abruptly shifted with the main access, and many businesses moved from Old Mammoth to the current Main Street/Highway 203 corridor. Growth accelerated after World War II and winter recreation began to be a potent economic force. The town's dump was adjacent to highway 203 until the 1960s.

A rope tow operated near the base of McGee Mountain, beginning in the 1930s, along with a winter resort. A few other lodges along U.S. Highway 395 also provided amenities to skiers. In 1938, Dave McCoy obtained the permit for the tow at McGee Mountain and then bought the mechanical equipment. McCoy moved the rope tow to various hills and eventually to the north side of Mammoth Mountain when the weather and road access would permit. There is a record of some 250 skiers at the Mammoth Mountain rope tow on Thanksgiving Day 1941. Recreational skiing then essentially ceased during the war.

Soon after World War II, McCoy installed the first permanent rope tow on Mammoth Mountain and brought skiers up the unplowed road with Army-surplus tracked vehicles. A small warming hut, near the present Main Lodge was built in 1947. Another rope tow was operated on the east side of Mammoth Mountain above the Valentine Camp by Hans Georg. The U.S. Forest Service granted a permit to Dave McCoy to develop the ski area after other developers avoided the area as too risky for a business venture. The first chairlift was installed in 1955. The Mammoth Mountain Inn began business in December 1958. Mid-Chalet and four additional lifts were built between 1962 and 1965. Twenty-five lifts were in service by the mid-1980s, and snowmaking equipment began to be installed in the early 1990s (Mammoth Mountain, 2005). The Intrawest Corporation purchased a one-third interest in the ski area in 1996 and increased its ownership to 58 percent in 1998. A majority interest in the ski area was sold to the Starwood Capital Group in 2005. In 2004, the resort recorded 1.5 million skier-days, second only to Vail ski area (Martin, 2005). The current special use permit with the U.S. Forest Service is valid through 2024. Additional ski area development was considered along the east side of the San Joaquin Ridge and the Sherwin Bowl during the 1970s and 1980s (USDA-Forest Service, 1988b), but the idea was eventually abandoned.

The town of Mammoth Lakes began to grow significantly in the late 1960s. In 1971, the Inyo National Forest plan stated that Mammoth Lakes was the "fastest growing community in the country" (Millar, 1996). The permanent population of the town grew from 390 in 1960 (USDA-Forest Service, 1994) to 2,900 in 1972 to 4,100 in 1980 and then approached 5,000 by the mid-1980s. The 1990 census reported a population for the town of 4,785. Another period of dramatic growth occurred in the late 1990s, and the 2000 census reported a population of 8,214. The Town of Mammoth Lakes was incorporated in 1984 with boundaries encompassing 25 square miles of mostly federal land of the Inyo National Forest. Only four square miles within those boundaries is private land.

The first general plan for the town forecast a permanent population of about 12,000 and up to 36,000 visitors at peak when all private land is developed by 2010 to 2020 (Mono County Planning Department, 1984). The Town of Mammoth Lakes was attempting to update its general plan in 2005 and 2006. One draft of the update estimated a peak population of about 60,000 when the town is essentially built out and all lodging is occupied. The peak population during holiday periods and busy weekends in 2005 was about 35,000. These large variations in population from day to day have created an unusual set of problems for planning and operations for water supply and sewage disposal as compared to municipalities with relatively stable water use.

Beginning in 1958, the Mammoth County (now Community) Water District has supplied water and wastewater services to Mammoth Lakes. Until the mid-1970s, water diverted from Mammoth Creek was adequate to meet needs of up to 1,400 acre-feet/year. In 1978, the district obtained a permit from the State Water Resources Control Board to divert additional water. The permit includes several conditions that attempt to limit the impacts of the water diversion on the Mammoth Creek fishery. Additional details about water supply for Mammoth Lakes can be found in the water use and diversions sections of the hydrology chapter.

Water use in 2004 was about 3,500 acre-feet, and water use at eventual buildout with a peak population of about 60,000 is estimated at about 4,500 acre-feet. However, that estimate is under discussion by the water district's board and staff (Kirkner, 2005). Although current sources could supply that amount in all but a prolonged drought, the district's board is seeking contingency sources for an additional 1,000 acre-feet of potential supply. Additional water could become available from additional wells within Mammoth Lakes, a well field in the Dry Creek watershed, and use of reclaimed water on golf courses.

Large-scale development of the water of the Owens River began in 1903 when the U.S. Reclamation Service began a study of water resources in the eastern Sierra Nevada.

Establishment of the Inyo National Forest was apparently linked to potential water development (Martin, 1992). Watershed protection was proclaimed as the reason for creating the Inyo National Forest by President Theodore Roosevelt in May 1907. After the lands were surveyed in 1905, one of the Forest Service employees wrote: "This addition will protect and regulate the water flow of the Owens River and its tributaries" and [the lands] "were set aside to protect the Owens River watershed, to protect the water supply of the City of Los Angeles" (Ayres, 1906; quoted in Martin, 1992).

As part of the potential irrigation project for the Owens Valley, a dam was proposed in Long Valley. Meanwhile, the City of Los Angeles and its former mayor, Fred Eaton, began to obtain land and water rights as part of a water supply scheme for Los Angeles. The story has been told in hundreds of articles and dozens of books (e.g, Chalfant, 1933; Kahrl, 1982; Nadeau, 1950). In 1932, the Los Angeles Department of Water and Power purchased Fred Eaton's ranch in Long Valley and began construction of the Long Valley dam. In the following years, the department purchased other properties in Long Valley to secure water rights of the tributaries to the Owens River. Construction of the Mono Craters tunnel began from the East Portal site in 1934. The construction camps at East Portal and Clark Canyon eventually took on attributes of a small town. Water from the Mono Basin began to flow through the tunnel in 1941, and the upper Owens River served as a canal with extra flows averaging 50,000-100,000 acre-feet per year for the next 50 years.

Interest in developing the geothermal resources of Mono-Long Valley for electricity can be traced at least to the early 1900s, but no actual drilling occurred until 1959 (Strojan and Romney, 1979).

The Arcularius Ranch was initially used for sheep grazing beginning about 1919. Cattle soon replaced the sheep. In the 1930s, a fishing resort was built on the ranch. The Arcularius Ranch covers about 1,080 acres and includes 5.5 miles of the upper Owens River. Big Springs is about 1.5 miles west of the western boundary of the ranch. The East Portal of LADWP's Mono Craters tunnel adds water to the Owens River about midway through the property.

The Inaja Land Company owns about 1,240 acres east of the Arcularius Ranch. This operation was created in the 1920s and had 25 members in the 1990s. Each member had exclusive fishing access to the Owens River within the boundaries and the right to build one cabin on the property. The land has also been operated as a cattle ranch over the years (County of Mono, 1992).

Land use

Residential

In addition to the Old Mammoth area that initially developed because of the mining boom, the areas near streams were actively used and occupied before 1900. Pastures in Long Valley were enhanced by irrigation. The largest ranches were operated by the Thomas Rickey Land and

Cattle Company and Fred Eaton (Smeltzer and Kondolf, 1999). Availability of water accounted for a disproportionate concentration of wetlands on early homesteads that became private land (Curry, 1996). The upland areas were less desirable for ranching and remained in public ownership. Ranches along the upper Owens River have remained as relatively large undeveloped parcels, and a few upland areas with access to water along the old road have been subdivided in the communities of Aspen Springs, Hilton Creek/Crowley Lake, McGee Creek, and Long Valley. Beyond these communities and Mammoth Lakes, the watershed contains only a few scattered homes.

The communities along the old road occupy active alluvial fans and previously irrigated meadows (Curry, 1996). With residential use of these fans, irrigation headgates were constructed near the fan heads to divert waters across much more of the fan surfaces than would have been the case before development. Successive distribution of water across the fan has created an unusual matrix of riparian zones, artificially maintained by residents and irrigators (Curry, 1996).

9. Land ownership in the upper Owens River watershed [watershed_jpegs owens_ownership]

Roads

Roads, particularly unpaved roads that were poorly designed and constructed and not maintained, are the principal source of human-accelerated erosion and sedimentation in the Sierra Nevada (e.g., Kattelmann, 1997) and most of the western United States (e.g., Megahan and Kidd, 1972; Reid and Dunne, 1984). Where such roads are within the riparian zone and cross channels via fords, culverts, or bridges, the eroded materials are readily transported into the channel.

Analyses of roads by Mono County's Geographic Information Systems (GIS) staff found that the total length of roads within the upper Owens River watershed is about 1,750 miles, there are more than 1,200 stream crossings by roads, and more than 120 miles of road within 100 feet of a stream.

Comparison of aerial photographs taken in 1951 with those from 1977 showed a dramatic increase in the number of roads around Hot Creek and Little Hot Creek (USDI-Bureau of Land Management, 1978).

Highway and heavy equipment maintenance facilities are located at Crestview, north of Deadman Creek; McGee Creek; Mammoth industrial park; and Mammoth Mountain Ski Area.

10. Major roads in the upper Owens River watershed. [watershed_jpegs owens_roads]

Grazing

The upper Owens River watershed may not have been as severely overgrazed in the second half of the 19th century as many other parts of the Sierra Nevada because of the greater distance to markets and population centers. Although we know that Owens Valley ranchers drove livestock into Long Valley and beyond for summer and fall grazing in the 1880s (Burton and Farrell, 1992), there is little other documentation of the extent and intensity of grazing in the upper Owens watershed before 1900. When the first rangers of the Sierra Timber Reserve arrived in Mono County in 1903, their orders were to keep trespassing sheep out of the reserve (Millar, et al., 1996). After the administration of reserve lands in Mono County passed to the Inyo National Forest in 1908, control of grazing continued to be the focus of Inyo National Forest's effort in the 1920s. Overgrazing apparently persisted through the 1940s. In 1944, the Inyo National Forest attempted to bring rangeland use, quantified by animal unit months (AUMs), closer to range productivity and resolve grazing damage to and conflicts with other resources (Millar, et al., 1996). Within six years of adopting that plan, grazing intensity on the whole forest had dropped by 40 percent.

Within the western portion of the upper Owens River watershed, there have been two allotments on the Inyo National Forest since 1950. The June Lake allotment allows 1,800 sheep to pass through the Hartley Springs area and Glass Creek Meadow for a couple of days in each direction of their route. During the 1990s, a conflict arose over use of Glass Creek Meadow when rare Yosemite toads were found in the meadow, and the area has not been grazed since that time.The Sherwin-Deadman allotment covers the area between Deadman Creek and State Route 203, west of U.S. Highway 395. This allotment allows up to 1,500 sheep, but only about 1,000 sheep grazed this area during the early 1990s (Millar, et al., 1996). Generally, the sheep are herded into the area near the junction of U.S. Highway 395 and State Route 203, are grazed in areas without much recreational use, and rely on water brought in by trucks.

O'Harrel Canyon Creek is in the Turner Cattle Allotment, which permits 700 AUMs. The creek provides approximately 50 percent of the water consumed by livestock via a water diversion and direct consumption from the creek. The water diversion has been identified as a barrier to fish movement. Adjacent grazing has reduced the vegetation canopy allowing water temperatures higher than are desirable for fish habitat. Desirable fish habitat such as overhung banks has been affected by livestock grazing (Inyo National Forest, 1980).

The Bureau of Land Management has two grazing allotments within Long Valley (#6017 Long Valley Common and #6018 Hot Creek Common) that permit up to about 400 animal unit months (cattle). The BLM estimates that about 2.7 acre-feet of water are consumed by the cattle.

The trout fishing advocacy group California Trout has long sought changes in grazing practices that would allow recovery of riparian vegetation and streambanks. In the early 1990s, this group was promoting better practices along the upper Owens River on both private land and LADWP leases (Edmonson, 1992).

The Owens River from near the lake shore upstream to Benton Crossing was fenced in 2000 to exclude livestock from the riparian corridor. The initial study of channel and vegetation response to the rest from grazing was too short (three years) to show any changes (Jellison and Dawson, 2003). Other riparian fencing projects on tributaries that began in the 1990s demonstrated considerable improvement in riparian conditions over the longer periods (Jellison and Dawson, 2003).

Recreation

The Mammoth Mountain Ski Area is potentially the largest single source of sediment within the upper Owens River watershed. Mammoth Mountain has more than 30 ski lifts on a permit area of 3,200 acres with a design capacity of 19,000 skiers at one time. Ski areas have an inherent conflict between providing good skiing conditions with shallow snow and maintaining enough vegetation to minimize erosion. The steep slopes of ski runs also allow flowing water to apply sufficient force to readily dislodge soil particles. Besides these fundamental issues common to all ski areas, the pumice and poorly developed soils on Mammoth Mountain are prone to erosion once disturbed and devegetated. The ski area has an active erosion control program and has successfully established grasses on many of the ski runs. Most of the runoff from open ski runs is also channeled through sediment detention basins in an effort to reduce the movement of sediment beyond the ski area boundaries. Hydrologic effects from snow compaction and snow making are discussed in the section on water use in the hydrology chapter.

Recreational use near the upper Owens River

The Big Springs campground has 24 spaces and a capacity of 120 people. The campground was used by 17,500 people in 1987 (County of Mono, 1992). The Alpers Owens River Ranch occupies 200 acres and 1.5 miles of Owens River frontage immediately upstream of the Arcularius Ranch. The fish rearing operation on the ranch discharges some quantity of nutrients from its operations. The nine rental cabins accommodated 825 guests in 1991 for a total of 2,888 user days. The Arcularius Ranch has 15 cabins and a lodge and estimated about 5,000 user days in 1991. The Inaja Ranch reported 434 angler days of use in 1990 along its 3.3 miles of the Owens River. The Arcularius and Sons Ranch is operated strictly as a cattle ranch on its 560 acres. LADWP estimated 12,360 angler days of use in 1987 on its portion of the Owens River above Crowley Lake (County of Mono, 1992).

The Whitmore swimming pool on the Benton Crossing road is in use from May through mid-September. Water from hot springs enters the pool and is chlorinated. Some of that chlorine flows out with the overflow water into a small channel that leaves the grounds of the pool area.

Campgrounds

Subwatershed	Name	Number of sites	RV dump station
Glass Creek	Hartley Springs	20	
	Glass Creek	50	
Deadman Creek	Deadman	30	
	Obsidian Flat Group	na	
Upper Owens River	Big Springs	24	
	Benton Crossing	75	
Mammoth Creek	Coldwater	77	
	Pine City	10	
	Lake George	16	
	Lake Mary	48	
	Twin Lakes	94	
	New Shady Rest	95	yes
	Old Shady Rest	51	
	Pine Glen	17	
	Mammoth Mtn. RV Park	144	
Sherwin Creek	Sherwin Creek	87	
Convict Creek	Convict Lake	88	yes
McGee Creek	McGee Creek	28	
Hilton Creek	South Landing	30	
Rock Creek	Rock Creek Lake	29	
	Upper Pine Grove	8	
	Pine Grove	6	
	East Fork	133	
	Palisade	5	
	Big Meadow	11	
	Iris Meadow	14	
	Aspen Group	na	
	French Camp	86	

All of the Rock Creek campgrounds are served by a RV dump station just above Tom's Place, near the sewage disposal facility. [Holiday and Tuff are outside watershed]

The Inyo National Forest has identified the need to move parking areas and campsites farther away from creeks and to improve the water supply system to campgrounds in the Mammoth Lakes basin. Sewage disposal from the campgrounds along Rock Creek and at Convict Lake was a problem in the past, but the current treatment facilities seem to function well.

There is also a BLM campground between McGee and Hilton creeks, a private campground on McGee Creek at old Highway 395, a Caltrans rest area west of U.S. Highway 395 south of Deadman Creek, and an actively used marina at Crowley Lake near Hilton Creek.

Airport

The airport east of U.S. Highway 395 and north of the Benton Crossing road (now known for marketing reasons as the Mammoth/Yosemite airport) was originally constructed by the U.S. Army during World War II and acquired by Mono County after the war. It remained an unattended landing strip through the 1950s and 1960s and was turned over to the Inyo National Forest. As use increased dramatically in the 1970s, Mono County prepared an airport master plan in 1978, resumed operation in 1980, obtained FAA grants for physical improvements in the early 1980s, and exchanged land with the Inyo National Forest to acquire title to 196 acres in 1985 and 1987. By the mid-1980s, more than 30,000 landings and takeoffs were recorded annually (Triad Engineering, 1986). The Town of Mammoth Lakes acquired the airport from the County in 1991. Water supply is met by an on-site well, and sewage is treated with a septic system and leach field. Groundwater pollution from fuel spills, oil, grease, and other industrial chemicals is a concern.

The area near the airport has been the subject of three major development proposals. In 1985, the Inyo National Forest received a request for a special use permit to develop and operate a golf course on Doe Ridge in association with a resort hotel on land owned by Mono County at the airport (Mono County ALUC and Inyo National Forest, 1986; Inyo National Forest, 1989). The overall development would have required at least 660 acre-feet of water per year, which was likely a major factor in the denial of the permit. Another hotel project for the airport property has been proposed in recent years to the Town of Mammoth Lakes, but FAA regulations may prevent such use so close to an airstrip. Across U.S. Highway 395 from the airport, an industrial park is being constructed in the former quarry after obtaining approval from Mono County in 2001. This facility is unlikely to have significant water demands or wastewater disposal needs. There is no surface drainage near the site. There could be potential for groundwater contamination depending on the ultimate industrial uses of the site.

Off-highway vehicle use

Vehicular traffic off maintained roadways has the potential to both disaggregate and compact soil, depending on soil properties and moisture conditions. Compacted soil results in less infiltration and more surface runoff than under undisturbed conditions. Loose soil grains can be transported by the augmented runoff and may end up in a stream channel. Compared to other parts of the Sierra Nevada, the potential for significantly increased erosion and sedimentation from off-highway vehicle (OHV) use is relatively small in the eastern Sierra Nevada because of the limited rainfall and snowmelt runoff. However, a critical exception to that statement occurs near and in water courses. When vehicles enter riparian areas and cross streams, there can be significant sediment movement, simply because of the presence of water. There have been anecdotal observations of OHV caused erosion in Glass and Deadman creeks in the past decade. The Inyo National Forest has attempted to address the problem through restricting vehicle use in the Glass/Hartley area.

There is a well-used motocross track in an unchanneled valley southwest of Sherwin Creek. Although there is localized erosion from the abraded and compacted tracks, sediment delivery out of the valley is not known to be a problem.

Mining

As noted above, mining began in the Mammoth Lakes basin in the 1870s and played out relatively quickly. Prospecting throughout the watershed led to active mining in a few locations, but none of the mines was particularly successful.

Old prospects and associated roads are located throughout the watershed. Mapped and named mines include:

Glass Creek	prospect on north side of Obsidian Dome
Mammoth Creek	Old Mammoth Mine
	Monte Cristo Mine
	Mammoth Consolidated Mine
Laurel Creek	west slope of Laurel Mountain
	NNW slope of Bloody Mountain
McGee Creek	Scheelore Mine
	Tiptop Prospect (north slope of McGee Mtn)
Hilton Creek	Hilton Creek Mine
Rock Creek	access to upper Morgan Creek

There are interpretative signs about mining history at the top of the Coldwater campground road and along the road connecting the Lake Mary Road and Old Mammoth Road.

The Old Mammoth Mine was reentered twice in the 20th century (Mattinen, 2000). Following World War II, American Metals Co. excavated a new adit in pursuit of copper, zinc, and lead. The mine was worked intermittently by the Beauregard family from the 1950s until 1987. In 2000, another company, Red Dog Resources, was investigating the potential of rehabilitating the Old Mammoth Mine (Mattinen, 2000).

Aggregates for construction have been mined at several locations in the watershed: north of Horseshoe Lake, between Mammoth Creek and Sherwin Creek, Sherwin Creek, lower Laurel Creek, Long Valley south of the access road to the airport, north of Convict Lake.

Kaolinite, a type of clay useful in various industrial processes, has been excavated from a pit operated by Standard Industrial Minerals in Little Antelope Valley for many years.

Proposed Long Valley gold mine

In the late 1980s and 1990s, there was a proposal by a mining company (Royal Gold, Inc. / Royal Long Valley, Inc. / Mono County Mining Company) to operate an open-pit gold mine over about four to six square miles of Inyo National Forest land between Hot Creek and Little Antelope Valley. The proposed mine was six miles east of the town of Mammoth Lakes and two to three miles north of the airport (T3S R28E, sections 14, 15, 22, 23, 24, 25, 26, and 35). The so-called Inyo Gold Project focused on a relatively low-grade ore body with about 0.2 ounces of gold per ton of ore. The ore is a hot-spring deposit where gold is disseminated along tiny fractures and between quartz grains (California Geology, 1990). An estimated 120 million tons of earth would have been excavated to uncover and extract the ore.

The ore would have to be pulverized and then treated with a cyanide solution to remove the gold. Even though there is tremendous financial incentive to prevent leakage of gold-containing leachate from the processing, the mining industry has observed a high rate of failure of cyanide leach ponds. The risk of polluting the groundwater and surface water in addition to other potential environmental impacts led to extensive public opposition to the project. Although eight phases of exploratory drilling were conducted, information on water levels was not available to the public. If the ore body contained water, that water would have to be discharged somewhere and probably would have required costly treatment. Removal of groundwater from the ore body and the excavated pit would have altered the local groundwater flow system. The mine could have also expected to have a large water demand for ore processing, but ideas for obtaining that water were not disclosed. The proposal faded out after Mono County significantly strengthened anti-pollution requirements.

In December 1998, the Mono County Board of Supervisors amended parts of the Mono County Code pertaining to mining to include more environmental safeguards. That action included a new approach to regulating adverse impacts of mining. The new ordinance requires a reclamation plan and a mining operation plan. Some of the key language of the ordinance follows: "It shall be and is hereby rebuttably presumed that any proposed processing operation located above or adjacent to surface or ground waters, or which could potentially impact such waters regardless of their location, that would use one or more of the following chemicals as a processing agent poses an unreasonable risk of environmental harm due to the toxicity of such chemicals and their demonstrated potential to cause damage to the environment: mercury, cyanide or cyanide compounds, breakdown products of cyanide, or sulfuric acid. Use of such chemicals shall not be permitted as part of any processing operation unless the project applicant can demonstrate, by substantial evidence, based on reliable scientific or engineering data, that the proposed use of such chemicals in a given project will not, under any reasonably foreseeable scenario, cause significant environmental impacts." The ordinance also requires a series of hydrological and other environmental studies for compliance with the California Environmental Quality Act.

Sewage disposal facilities are located at:
north of Mammoth Mountain Inn;
north of Lake Mary;
east of town of Mammoth Lakes -- MCWD standard activated sludge plant, but includes effluent filtration processes, and has a capacity of 1.5 MGD;
north of Convict Lake at 7,550 feet -- MCWD package-type facility capacity of 30,000 gpd;
west of Hilton Creek, south of U.S. Highway 395;
Tom's Place [out of watershed] -- USFS serving Rock Creek campgrounds -- package-type facility with a capacity of 45,000 gpd
(Gram/Phillips, 1977).

Forestry

Timber management on lands of the Inyo National Forest within the upper Owens River watershed has been a relatively small-scale activity compared to other national forests in the Sierra Nevada. Most of the harvesting has occurred in the Dry Creek, Deadman Creek, and Hartley Springs portion of the Glass Creek watershed on the west side of U.S. Highway 395 and the area northeast of Crestview. The first known timber sale in the watershed occurred in 1908, and additional small sales were recorded in the 1920s and 1940s (Millar, et al., 1996). The Forest's Integrated Use Plan of 1950 did not allow timber harvesting unless it was deemed not detrimental to recreation and scenic values (Millar, et al., 1996). In the 1960s and 1970s, eight timber sales totaling about 60 million board feet were conducted in the watershed. These harvests removed large Jeffrey pines of high value per tree until about 30 percent to 40 percent of the large trees were cut. By the late 1960s, most of the forest east of the highway had been harvested in this manner, leaving half to two-thirds of the mature trees. A few local areas had up to 70 percent of the overstory removed. These harvests left the younger trees standing, so their growth accelerated after harvest and a clearcut appearance was avoided. Planting was not known to have been done during this period (Millar, et al., 1996).

In 1979, the Inyo National Forest adopted a new plan for the area north of Mammoth Lakes that emphasized timber harvesting with only watershed consequences as a major constraint. Between 1979 and 1988, seven timber sales were harvested with about 30 million board feet of timber cut. As public and agency values shifted during the 1980s and 1990s, an old-growth forest management strategy was developed by the Inyo National Forest (USDA-Forest Service, 1992b). By 1994, the Inyo National Forest decided not to pursue a proposed salvage logging program within the San Joaquin Roadless Area (Mammoth Times, 1994). A complete list of known timber sales in the area was compiled by Dale Johnson and Bob Hawkins (appendix 2 in Millar, et al., 1996).

Land ownership and interagency cooperation

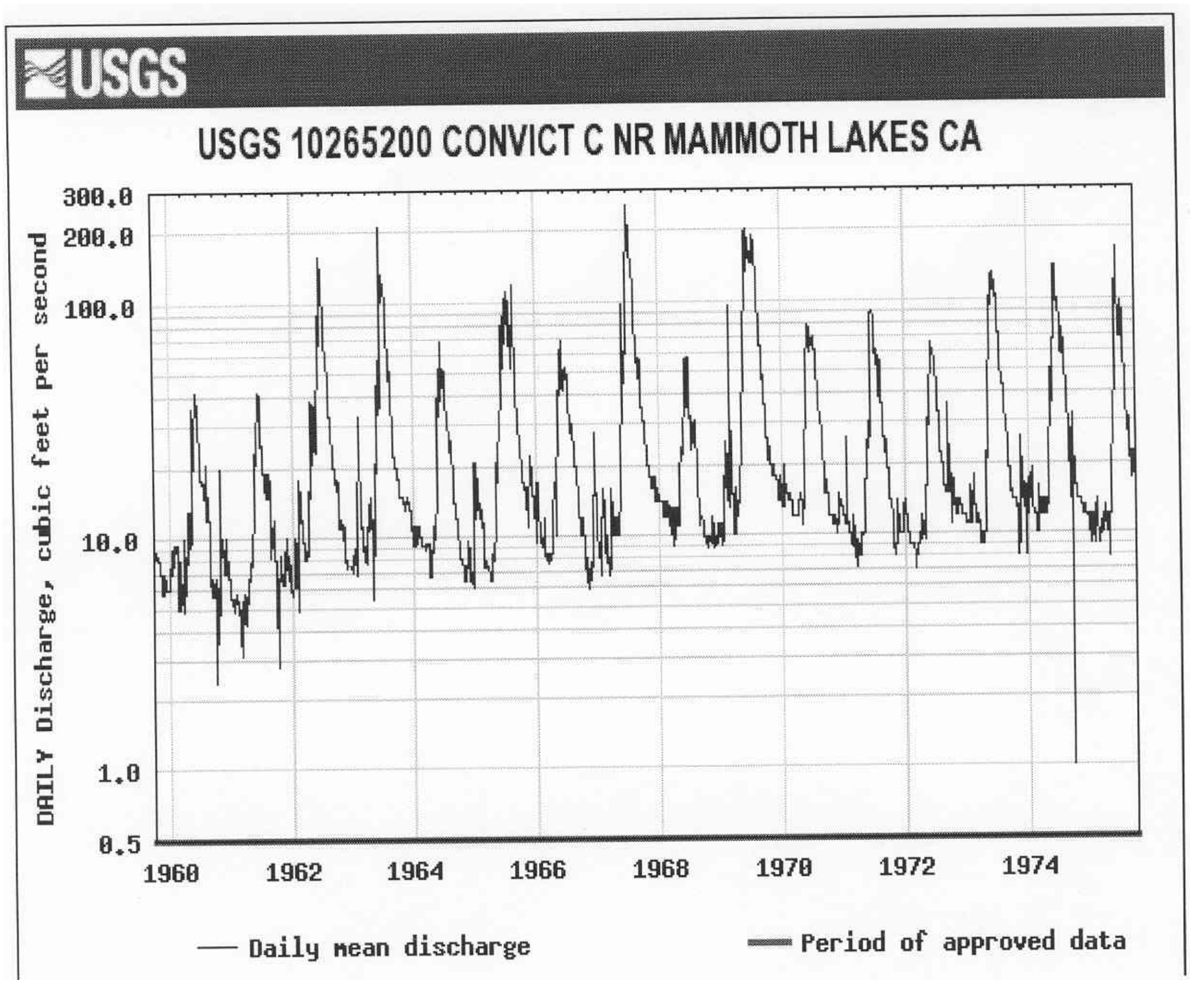
Land use planning within the watershed is fragmented with respect to the varied ownership of the land. The two federal agencies (USDA-Forest Service and USDI-Bureau of Land Management) and the Los Angeles Department of Water and Power administer most of the area of the watershed. Private land is subject to zoning and planning controls of Mono County or the Town of Mammoth Lakes. The Mono County Collaborative Planning Team has been somewhat successful in coordinating land use planning between the different agencies since its formation in 1996. Although information exchange has been its primary influence to date, there is great potential through this mechanism to affect general policies and decisions that have widespread consequences.

Part of the public land administered by the Bureau of Land Management, mostly in the vicinity of Crowley Lake, is covered by "watershed withdrawals" made by Congress and the President in the 1930s. The original purpose of these withdrawals was to prevent speculative homesteading in anticipation of acquisition by the City of Los Angeles. The particular status of these lands prevents their sale or exchange, may influence federal water rights appurtenant to these lands, and gives the BLM additional legal status with respect to any hydropower licenses within the designated area.

Descriptive hydrology

The natural streamflow of the upper Owens River is derived primarily from snowmelt runoff during spring and early summer. Discharge is quite low throughout autumn and winter, but begins to increase in April as snowmelt runoff increases and enters the main stream channels (Figure 11). Streamflow typically reaches a peak in May or early June and then recedes over the summer. By the beginning of autumn, streamflow is relatively low and remains so over the winter. An occasional warm storm that brings rain rather than snow can generate brief peaks in the hydrograph.

Figure 11. Example of annual streamflow pattern for Convict Creek



Since April 1941, streamflow in the upper Owens River has been augmented by water diverted from the Mono Basin that is bound for Los Angeles. Water collected from Lee Vining, Walker, Parker, and Rush creeks, after being stored in Grant Lake, flows through the 11.5-mile Mono Craters tunnel and enters the upper Owens River at East Portal. Estimates for the average annual water diversion from the Mono Basin include 73,000 acre-feet/year (Buchholz, 1988), 83,000 acre-feet/year for 1974 to 1989 (Lahontan Regional Water Quality Control Board, 1998), about 100,000 acre-feet/year (County of Mono, 1992), and 110,000 acre-feet/year (Winkler, 1977). The average annual streamflow of the Owens River at Pleasant Valley near Bishop increased from 245 cfs before the Mono Basin imports began (period of record 1918-1940) to 361 cfs during the first part of the period with imported water from the Mono Basin (1948-1968) (Williams, 1975). The diversion was largely halted in 1990.

The flow of the upper Owens River as it nears Crowley Lake ranges from 150 cfs in the winter to 350 cfs during snowmelt runoff (Los Angeles Dept. of Water and Power, n.d.)

Runoff generation processes

The great majority of the runoff volume in the annual cycle is produced during the spring snowmelt season. Water produced from melt at or very near the surface of the snowpack that has accumulated over the winter percolates through the snowpack and arrives at the soil surface. Depending on the degree of saturation of the soil and its infiltration characteristics, the water may enter the soil and percolate to greater depths or it may flow over the soil surface, combining with other melt water in progressively larger surface channels and eventually in a stream. Water may also flow downslope at the soil/snow interface where the soil is frozen, covered by a basal ice lens, compacted to near impermeability, or covered with an impermeable surface such as concrete or asphalt. Snowmelt that infiltrated into the soil flows between the soil particles in a saturated or unsaturated state (air may occupy some of the pore space). Water percolating through the soil may either enter the deep groundwater zone, remain stored in the soil temporarily, or emerge from the soil farther downslope onto the soil surface or within a channel. Water that has percolated deep into the ground continues to move down gradient under the influence of gravity and hydraulic pressure and may resurface in a spring, within a surface channel, or be extracted in a well. The degree of contact that flowing water as well as water in temporary storage has with mineral grains in or on the soil and other substances on the soil surface or within channels determines the chemical composition of the water and any particulate load that the water may transport. Rainfall-runoff processes function largely similar to snowmelt-runoff with the additional possibility of the rainfall intensity and physical impact altering the rate of infiltration into the soil.

Water balance

A study of water resources in the Mammoth Creek watershed estimated a water balance for a watershed area of 45,100 acres (California Department of Water Resources, 1973). The four primary terms of the water balance -- precipitation, evapotranspiration from native vegetation, evaporation from lakes, and streamflow -- were estimated as 103,250; 61,130; 1,100; and 40,540 acre-feet, respectively. The equivalent amounts expressed as an average depth over the watershed area are 27.5, 16.3, 0.3, and 10.8 inches. Snow surveys in the Crystal Lake subwatershed in the late 1980s (Sickman and Melack, 1989; Melack, et al., 1992) suggest that the DWR estimates of precipitation may be excessive. Evapotranspiration from irrigation and other urban uses was estimated as 200 acre-feet, and groundwater outflow was estimated as 180 acre-feet. The study cautioned that the evapotranspiration estimates could be in error by 10 percent to 25 percent (California Department of Water Resources, 1973). Nevertheless, this estimated water balance shows that about 60 percent of the precipitation entering the Mammoth Creek watershed is lost back to the atmosphere, and about 40 percent of the precipitation becomes streamflow.

An estimate of evapotranspiration for the 6,990-acre Mammoth Lakes basin of 19 inches per year or 11,045 acre-feet (Gram / Phillips Associates, 1985) was based in part on the California

Department of Water Resources (1973) study. Evapotranspiration was estimated as 15 inches per year in the Dry Creek watershed (USDA-Forest Service, 1992a).

Evaporation from the lake surfaces in the Mammoth Lakes basin were calculated from map-estimated surface area and an assumed evaporation rate of 36 inches per year (Gram / Phillips Associates, 1985):

	Surface Area (Ac)	Evaporation (AF/yr)
Skelton Lake	7	21
Arrowhead Lake	5	15
Heart, Barney, Woods, & Red Lakes	6	18
Hammil, Emerald, & Way Lakes	2	6
Lake Mary	103	309
Lake Mamie	18	54
Lake George	44	132
Crystal Lake	13	38
T.J. Lake	11	34
Horseshoe Lake	63	189
McLeod Lake	15	45
Twin Lakes	20	60
Total	307	921

The Gram / Phillips Associates (1985) report presented a water balance for subwatersheds of the Mammoth Creek basin (Table 4-22, page 4-38) as well as the entire watershed (28,220 ac) above the stream gage at U.S. Highway 395. The four primary terms of the water balance -- precipitation, evapotranspiration from native vegetation, evaporation from lakes, and streamflow -- were estimated as 51,000; 29,000; 900; and 17,000 acre-feet, respectively. The equivalent amounts expressed as an average depth over the watershed area are 22, 12, 0.5, and 7 inches. This study also estimated a subsurface outflow of 4,300 acre-feet (Gram / Phillips Associates, 1985).

Some water is believed to enter the upper part of the Mammoth Creek watershed from outside the surface topographic divide. Springs above Barney Lake probably have their source in Duck Lake, which is about 200 feet higher on the other side of Duck Pass. Water could be transmitted through fractures in rocks from Duck Lake (Perrine, et al., 1973). The volume of water is unlikely to be significant in the overall water balance.

In the Sorey and others (1978) hydrologic budget for Crowley Lake, total average inflow exceeded outflow by about 3.2 percent. Part of the imbalance could be attributed to unmeasured groundwater interflow in Crowley Lake. Records from 1942-1967 show that average surface inflow to Crowley Lake was 214,000 acre-feet/year, and 9,620 acre-feet/year was estimated as the loss by evaporation (California Department of Water Resources, 1967).

Streamflow averages and extremes

Although continuous recording of streamflow is perhaps the most useful of all hydrologic measurements, there is considerable uncertainty in the data, perhaps far more than most hydrologists care to admit. For example, the current stream gaging instrumentation on the upper Owens River has a 5-8 cfs margin of error or about 10 percent of mean discharge (USDA-Forest Service, 1994). The numbers are probably most accurate on an annual basis because random short-term errors tend to compensate for one another. Over shorter time periods, the errors can often exceed the signal or information that one was seeking. For example, a comparison of flow in Mammoth Creek between the gage at Twin Lakes and the one at Old Mammoth Road was inconclusive because of obvious and inferred errors in the gage records (Burak, et al., 2006).

Upper Owens River

The average annual runoff from the upper Owens River watershed is about 148,000 acre-feet per year (Jones and Stokes, 1993; App. T). Discharge from the springs in the vicinity of the Hot Creek fish hatchery is about 30,000 acre-feet per year.

Based on discharge records at LADWP's "Owens Gorge main weir," located just downstream of the Long Valley dam site, Smeltzer and Kondolf (1999) estimated that the average annual volume of streamflow produced by the upper Owens River was about 175,000 acre-feet before the Long Valley reservoir was filled.

Table 60 of the Forest Plan of the Inyo National Forest (USDA-Forest Service, 1988a:322) states that the average annual water yield is 116,000 acre-feet for Crowley Lake watershed, 41,000 acre-feet for Hot Creek, and 53,865 acre-feet for Rock Creek. A different delineation of the Crowley Lake watershed and/or not accounting for diversion from the Mono Basin may explain the discrepancy with the DWR (1967) estimate of inflow to Lake Crowley of 214,000 acre-feet.

The Owens River below Big Springs, but above East Portal, where water diverted from the Mono Basin was added until 1990, had a mean flow of 42,000 acre-feet per year (58 cfs) from 1935 through 1987 (Buchholtz, 1988; County of Mono, 1992; Edmondson, 1994). The mean flow out of the Mono Craters tunnel at East Portal was about 73,000 acre-feet, and the measured mean discharge of the Owens River below East Portal from 1935 through 1987 was 114,000 acre-feet per year (157 cfs) (Buchholtz, 1988; County of Mono, 1992). The lowest annual flow on record of the Owens at Big Springs occurred in 1961 with a discharge of 24,000 acre-feet (34 cfs).

In the first two years following the cessation of water imported from the Mono Basin, flows in the Owens River below East Portal decreased to 54,100 acre-feet (75 cfs) (County of Mono, 1992). The tunnel itself still acts as a horizontal well and collects 10,840 acre-feet to 12,000 acre-feet per year (about 15-17 cfs) (Jones and Stokes, 1993; App. T). More water flowed in Clark Canyon before the Mono Craters tunnel was constructed, and the creek was drawn as perennial on the 1914 and 1934 USGS maps (Burton and Farrell, 1992). Near Crowley Lake, the [post-1990] flows increase to an average of 126 cfs (91,300 acre-feet) (County of Mono, 1992; USDA-Forest Service, 1994).

Streamflow in the Mammoth Creek / Hot Creek watershed has been gaged at six sites by LADWP, and mean annual runoff was estimated at the five sites with shorter records based on correlation with flows at the Hot Creek at Hot Creek Gorge station (California Department of Water Resources, 1973):

Gaging Station	Estimated mean annual flow (acre-feet)
Bodle Ditch above Mammoth Mine	1,200
Mammoth Creek below Twin Lakes	7,500
Laurel Creek at the base of the moraine	3,500
Sherwin Creek at base of mountains	2,900
Hot Creek at U.S. Highway 395	13,800
Hot Creek within the Hot Creek Gorge (measured)	40,540

The Mammoth Community Water District also operates gages at:
Lake Mamie outflow (since 1981);
Twin Lakes weir (since 1984); and
Mammoth Creek above Old Mammoth Road.

The long-term average annual flow of Mammoth Creek at U.S. Highway 395 through 1992 was 23 cfs or 16,500 acre-feet.

Average monthly flows for Mammoth Creek at old Highway 395

Jan-Mar	5 cfs
April	10
May	25
June	40
July	25
August	10
Sept-Dec	6

(USDA-Forest Service, 1994)

The channel of Mammoth Creek between the gages at Old Mammoth Road and U.S. Highway 395 both gains and loses water to groundwater depending on how much water is available (wet year vs. dry year), the time of year, and different parts of the channel (Burak, et al., 2006).

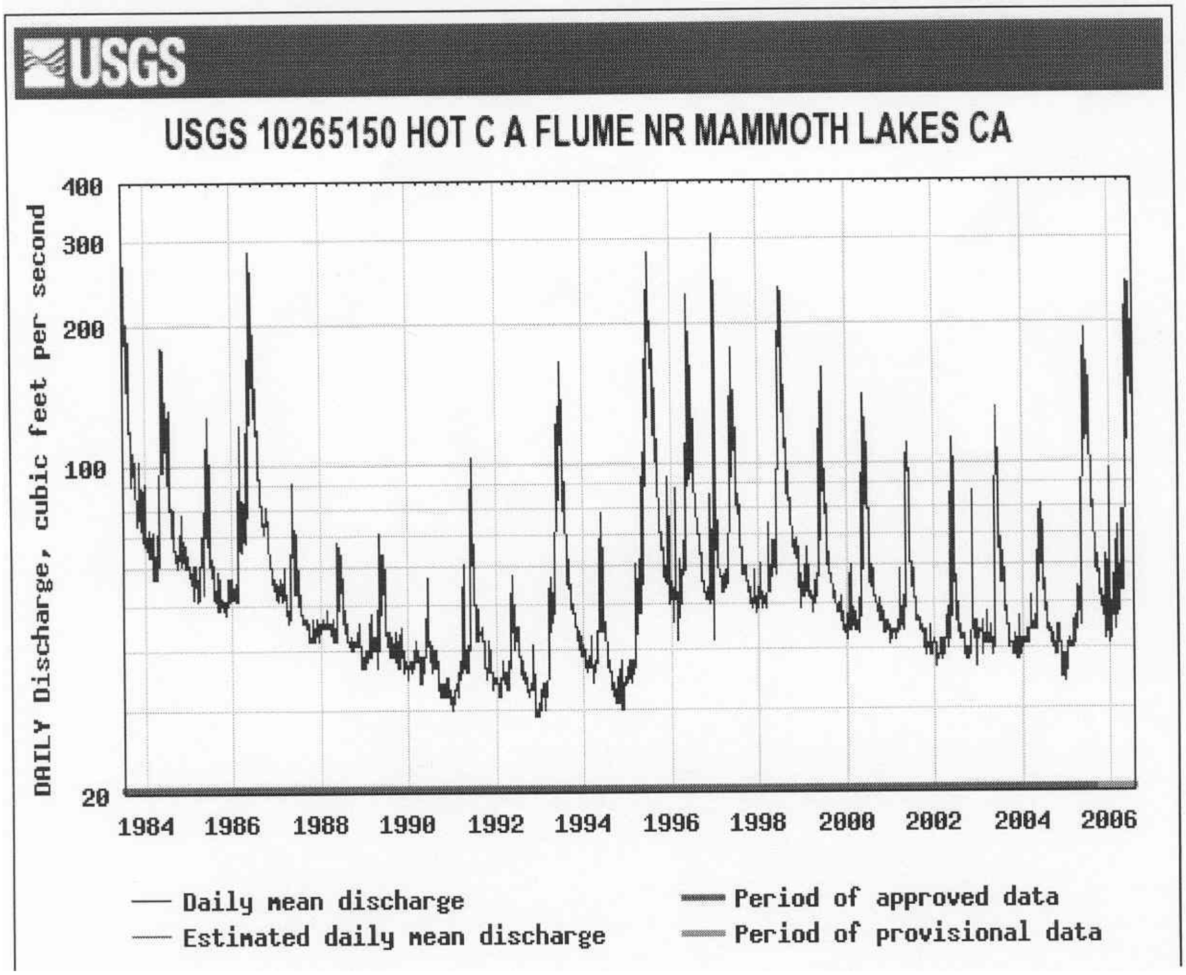
Mean, minimum, and maximum annual flows were found in an undated compilation in the Department of Fish and Game office in Bishop:

Stream	Mean	Minimum	Maximum (all cfs)
Mammoth Creek	20	5	46
Convict Creek	24	8	51
McGee Creek	28	12	56
Hilton Creek	10	4	25
Crooked Creek	4	2	7

Another Department of Fish and Game report (Smith and Aceituno, 1987) provided another set of flow values:

stream	Mean	Minimum	Maximum (all cfs)
Convict Creek	26	10	75
Glass Creek	8	2	20
Deadman Creek	6	2	20
Rock Creek	26	13	70
Upper Owens R.	30	30	70

Figure 12. Maximum and minimum flows vary widely from year to year, as illustrated by discharge in Hot Creek over the past 22 years.



As part of a study of acid precipitation in the Sierra Nevada, the small watershed of Crystal Lake (above Lake George in the Mammoth Lakes basin) was studied for a couple of years (Sickman and Melack, 1989; Melack, et al., 1992). Crystal Lake has a surface area of 12 acres and a volume of about 260 acre-feet. The watershed above the lake is 320 acres in area and ranges in elevation from 9,680 to 10,640 feet. Discharge from the watershed totaled 350 acre-feet in water year 1987 (October 1986 through September 1987) with 275 acre-feet in just May and June and 340 acre-feet in April through July. High-elevation watersheds with little groundwater storage capacity such as Crystal Lake have little hydrologic activity outside the snowmelt-runoff period of April through July. The volume of water stored in the snowpack was about 570 acre-feet (or an average of 22 inches of water over the watershed area) at the peak before the beginning of melt in April 1987 (Sickman and Melack, 1989; Melack, et al., 1992). Discharge as a percentage of estimated precipitation was 45 percent, 33 percent, and 40 percent in 1987, 1990, and 1991 (the only years with relatively complete records). Apparently, there is significant subsurface water movement out of the watershed to Lake George and/or the discharge was undermeasured (Melack, et al., 1992).

Floods and droughts

The 100-year (1 percent probability) peak flow in Mammoth Creek was estimated at 550 cfs (Environmental Sciences Associates, 1984). Some houses adjacent to the Snowcreek Meadow and immediately downstream could get wet under extraordinary flood conditions, especially if debris jammed the bridges on Minaret and Old Mammoth roads.

Records from a LADWP streamgage called Owens Gorge main weir, just downstream of the Long Valley dam site, were analyzed by Wycoff and Bundy (1936, cited by Smeltzer and Kondolf, 1999). This study estimated the mean annual flood of the upper Owens River (above the Owens Gorge) at 790 cfs and the 100-year (1 percent probability) flood at this site at 1,900 cfs. Annual peak flows recorded at the Owens Gorge main weir gage included the following before the completion of the dam (Smeltzer and Kondolf, 1999, fig. 4):

Date	Discharge (cfs)
4-16-1916	594
--	
--	
5-29-1919	680
6-22-1920	457
6-13-1921	612
6-28-1922	777
7-4-1923	462
12-30-1923	231
7-2-1925	522
11-24-1925	631
6-18-1927	585
5-15-1928	378
3-4-1929	265
3-23-1930	399
4-27-1931	158
6-30-1932	645
6-16-1933	471
3-7-1934	318
6-14-1935	510
4-15-1936	488
12-12-1936	843
6-20-1938	951
3-13-1939	295
3-23-1940	474

This short period of record (mostly during a drought period) indicates that winter rainfall-runoff or rain-on-snow runoff events exceeded the snowmelt runoff peak the following spring in three of the 23 years (water years 1924, 1926, and 1937). Combination events (rainfall plus some low-elevation snowmelt) during March also exceeded the spring snowmelt peak in five of the 23 years (water years 1929, 1930, 1934, 1939, and 1940). Snowmelt runoff from the higher elevation areas near the Sierra Nevada crest does not begin until April and peaks between late May and early July (e.g., Kattelmann, 1997).

In addition to an occasional dry year, there have been five periods over the past century in which precipitation and resulting runoff were well below average for multiple years: 1928-1934, 1959 to 1961, 1976 to 1977, 1987 to 1992, and 2000 to 2004.

There are some indications of greater variability in streamflow during recent decades as compared to most of the past century (Kattelmann, 1992 and 2001). For example, nine of the largest 10 to 13 (depending on which stream) volumes of snowmelt runoff since the 1920s have occurred since 1978 (Kattelmann, 2001). Some climatologists believe such observations are a signal of climate change.

Baseflow

The baseflow of the Owens River below the Long Valley dam site in the years prior to completion of the dam was calculated at 170 cfs (Smeltzer and Kondolf, 1999). This value corresponds to about 0.45 cfs per square mile.

Lakes

There are 56 lakes (with more than one acre of surface area each) in the upper Owens River watershed with a total combined surface area of 29 mi^2. A very detailed report on lakes of the watershed should be available from the Bishop office of the California Department of Fish and Game in 2007.

The underwater topography of some of the lakes in the Lakes Basin was measured by the California Department of Water Resources (1973), and the volumes were estimated.

	Surface area (ac)	Maximum Depth (ft)	Volume (acre-feet)
Lake George	44	190	3230
Lake Mary	103	90	2810
Lake Mamie	18	10	86
Twin Lakes	12	12	59

Groundwater

The first known studies of groundwater resources in the watershed were both completed in 1973. Birman and Cummings (1973) conducted geophysical investigations under Mammoth Lakes and Old Mammoth for the purpose of locating wells. The California Department of Water Resources (1973) conducted a comprehensive study of the Mammoth Creek watershed, but was constrained by limited data. The state's investigation estimated that the thickness of alluvial deposits ranged from about 50 feet near Camp High Sierra to about 200 feet in the area about one-half mile east of the town. Combined with an estimated specific yield of 7 percent to 10 percent, the aquifer thickness information led to an estimate of 57,000 acre-feet of water stored in the alluvium of the watershed (California Department of Water Resources, 1973). The study concluded that this volume did not constitute a reliable groundwater source. The study did not attempt to estimate water storage within the volcanic rocks, but did note that horizontal wells drilled near the Lake Mary Road yielded 20 to 125 gpm.

More than 45 wells have been drilled in the Mammoth Lakes basin since 1976 (USDA-Forest Service, 1994). The Mammoth County Water District drilled its first three wells between 1976 and 1980. The depths were 382, 630, and 354 feet. Out of 24 wells, only one yielded good quality water at pumping capacities greater than 200 gallons per minute (well #1, 600 gpm, 500 acre-feet yield). Most of this yield was believed to come from fractured volcanic rocks (Mammoth County Water District, 1981; Gram / Phillips, 1985).
Drilling since 1987 has been more effective and has resulted in the location of approximately 1,000 acre-feet (well #6 1,000 gpm and well #10, 1,200 gpm) (USDA-Forest Service, 1994).

During the summers of 1988 through 1990, MCWD drilled seven exploratory wells in the Dry Creek drainage. Six of these wells hit a cold water resource, with three in excess of 500 gpm. A sequence of overlapping basalt flows, underlain by rhyolite flows and tuffs, and overlain by glacial and alluvial gravels and a surface blanket of pumice, was found from the drilling logs (USDA-Forest Service, 1994).

Wells drilled near the airport and Convict Creek indicated a wide range of conditions in the upper alluvial deposits. Several dry holes suggested that there is not a single alluvial aquifer, but rather a series of disconnected small alluvial basins, some of which contain and transport substantial quantities of water and some that have little water (Department of Water Resources, 1973).

An Environmental Impact Report for the Arcularius Ranch (County of Mono, 1992) acknowledged that the groundwater system of the upper Owens River watershed, including Big Springs, "is not well understood at this time." The report described the hydrogeology as a "complex series of geologic layers influenced by volcanic activity and geologic faulting of the Long Valley caldera" (County of Mono, 1992: II-39).

Groundwater in the Long Valley caldera can be grouped into three basic categories: a relatively shallow cold-water system (less than 800 feet), a shallow thermal system, and a deep thermal system. The cooler waters are of excellent mineral quality while the warmer (> 80°F) waters have higher concentrations of dissolved solids (USDA-Forest Service, 1994).

An estimate of the permeability of the fractured basalt flows in the vicinity of Twin Lakes was obtained from measuring surface inflows to Horseshoe Lake, which has no surface outlet. All water entering Horseshoe Lake (after accounting for minor evaporation losses) would have to percolate through the underlying rock. Results from this study (Overturf, 1990) of a permeability value of about 60 gallons per day per square foot were fairly close to estimates of 50 gallons per day per square foot for the Mammoth Lakes Basin by Fox (1972).

Outflow from the Old Mammoth Mine has been measured at 450 gpm in July 1986 and 200 gpm in August 1973 (USDA-Forest Service, 1988).

The main aquifer for the warm springs at the Hot Creek fish hatchery is a fractured basalt flow (Lipshie, 1979). Materials filling the Long Valley caldera include interbedded volcanic rocks (lava flows and tuffs) and sedimentary deposits (lakebeds, stream deposits, and glacial outwash). Fractured lava flows tend to be more permeable than poorly sorted sediments, such as glacial materials (California Department of Water Resources, 1973:31-36). The overall circulation of shallow groundwater is from west to east. An order-of-magnitude estimate of the time required for groundwater to circulate through the system from recharge in the west to discharge at the hot springs along Hot Creek is 100 to 1,000 years (Lipshie, 1979).

The model of Sorey and others (1978) assumes that the main hot-water reservoir supplying the Hot Creek hatchery springs is in welded Bishop tuff, with the permeability resulting from pervasive fracturing. They consider the hydrologic system to consist of two subsystems: a shallow, relatively cold groundwater system in the post-caldera fill, and a deep, relatively hot groundwater system in the welded Bishop tuff and underlying basement rocks.

The geothermal wells at Casa Diablo hot springs tap a heat reservoir at relatively shallow depths (Lipshie, 1979). Pumping water from the Casa Diablo shallow aquifer may affect shallow groundwater, both hot and cold, more than would development of the primary hydrothermal reservoir at greater depth (Lipshie, 1979).

Two types of groundwater were found in sampling of nine springs and wells in Long Valley in 1972 (Willey, et al., 1974). One type has low concentrations of solutes and is believed to be derived from precipitation of the past few months to years that has not percolated very far. The second type has high concentrations of dissolved solids and is believed to have been in contact with deeper rocks for many years at relatively high temperatures. Detailed analytical results are available in Willey and others (1974).

Alluvial deposits within the Mammoth Creek / Hot Creek watershed reach a maximum (known) thickness near the airport at about 130 feet (California Department of Water Resources, 1973).

Anecdotal information from a variety of wells and other sources (most were described by the California Department of Water Resources [1973] unless otherwise cited).

Early wells for the Mammoth Mountain Inn were drilled into alluvium to depths of 92, 120, and 220 feet. These wells did not meet peak demands, were often pumped dry, and were replenished seasonally.

Glacial deposits around Mammoth Lakes were usually unreliable. Volcanic layers tended to have high transmissivity where they were jointed and fractured.

A well about 1,000 feet downhill from Convict Lake in glacial till found water at seven feet below the surface and produced about 70 gpm.

A 50-foot deep well west of the store has provided ample water for the Arcularius Ranch's domestic needs at a production rate of about 45 gallons per minute (County of Mono, 1992).

Water that leaked from the MCWD sewage treatment facility was identified in springs along Mammoth Creek near the old sheriff's substation (Sorey, 1975).

Groundwater from MCWD wells 16, 17, and 20 is filtered to remove excessive iron and manganese at a treatment plant near chair 15 (now Eagle Lodge / Juniper Springs area) (Mammoth Times, 1995a).

In 1966, a community well was installed for a subdivision in the Crowley Lake community at a site just east of the intersection of Crowley Lake Drive and South Landing Road. The well yielded approximately 200 gpm with a drawdown of almost 165 feet from a standing water level of 95 feet below ground. Water was first found at 180 feet below the surface, and then rose to 50 feet below ground during the installation of the casing (Gram/Phillips Associates, 1980).

About 11,500 acre-feet of water has been estimated to emerge in springs within Hot Creek gorge each year (California Department of Water Resources, 1973).

In the area around the Benton Crossing landfill, several wells are monitored to detect any possible contamination from materials leaching out of the landfill. Depth to the water table in these wells ranges from 18 to 30 feet below ground surface (Mono County Planning Department, 2004).

Diversions and storage

During the period of great interest in small hydroelectric projects in the eastern Sierra Nevada in the late 1970s and 1980s, the Department of Fish and Game compiled statistics about the proportion of average discharge diverted in each stream and the stream length affected by the upstream diversion on each stream (Shumway, 1985):

stream	average discharge (acre-feet)	% diverted	length affected/total (miles)
Convict	18,600	29	7.0/7.1
Crooked	9,100	63	1.1/1.4
Hilton	8,130	17	1.4/4.4
Laurel	6,180	27	4.0/4.7
Mammoth	21,900	38	8.4/11.6
McGee	22,400	29	5.4/6.6
O'Harrel Cyn	72	3	0.5/3.0
Sherwin	4,700	<1	1.0/1.7

Lake Mary, Lake Mamie, and Twin Lakes are controlled by outlet structures, and their water levels change seasonally. There is a submerged intake in Lake Mary that diverts water to the Mammoth Community Water District's filtration plant. The MCWD has appropriative water rights to 5 cfs or 2,760 acre-feet/year subject to conditions and a Master Operating Agreement with the U.S. Forest Service. A diversion from McLeod Lake is used for the Falls Tract cabins and campgrounds, and a diversion from Coldwater Creek serves the Coldwater campground (Gram / Phillips Associates, 1985). Lake Mary has a storage capacity of 606 acre-feet based on a 5.7-foot drawdown. Raising the water level by five feet with a new dam would double the storage capacity.

Raising the height of the Long Valley dam has been discussed for many years. The general idea would be to increase the high-water elevation of Crowley Lake by 10 to 20 feet. Such an increase in height would provide an additional 60,000 to 130,000 acre-feet of storage capacity (Los Angeles Department of Water and Power, 1986).

Water rights, use and management

Residential and commercial supply

The typical water-use estimate applied in the area is 440 gallons per day (gpd) for a single-family residence and 80 percent of that rate or 355 gpd for a condominium (Triad Engineering, 1994). The equivalent per capita rate is 125 gpd, assuming an average household of 3.5 people. During the summer irrigation season, daily demands typically approach 1,350 gpd per household or three times the annual average (Triad Engineering, 1994). Takata Associates (1984) used an average demand figure of 150 gallons per person per day for the Juniper Ridge project.

In the Hilton Creek/Crowley Lake community, water use in 1980 was estimated at approximately 150 gallons per capita per day. In other rural communities of Mono County, the per capita consumption ranged from 200 gallons per day to 400 gpd, but these high rates were primarily due to excessive garden and lawn irrigation. Based on the average population figures for Crowley Lake, the estimated total domestic water use in the service area was about 50 AF per year in 1980 and was projected to be 110 acre-feet per year in 1998 (Gram/Phillips Associates, 1980).

The portion of the Crowley Lake / Hilton Creek community served by the Mountain Meadows Mutual Water Company is projected to have a maximum of 338 shares, with an average daily demand of 143,000 gpd and peak summer demand of 430,000 gpd (Triad Engineering, 1994). Well capacity would need to be about 100 gallons per minute to meet the average daily demand. Storage tanks and/or greater well capacity would be necessary to meet peak demands. The study estimated that the water company would need to produce 160 acre-feet per year at build-out, roughly four times the annual demand in the early 1990s. A 1979 preliminary hydrogeologic study by Slade and Blevins for development of historical spring flows suggested the available water resource was about 25-30 acre-feet per year. The water company installed two supply wells to depths exceeding 100 feet. Another analysis involving well drawdown and recovery tests conducted by Gram/Phillips Associates in 1981 suggested the long-term supply of these wells is about 330 acre-feet per year (about 200 gpm) (Triad Engineering, 1994). Even greater capacity (up to about 400 acre-feet per year) was suggested by other studies and tests (Mitchel, 1995).

Water supply for town of Mammoth Lakes
The Mammoth Community Water District has diverted water from Mammoth Creek under SWRCB licenses 5715 and 12593 and permit 17332, which was issued on June 1, 1978. Since August 1991, the Mammoth Community Water District has also operated under Preliminary Cease and Desist Order 9P, which imposes additional instream flow requirements related to the nature of the water year. The diversion is also subject to District Board Resolution 02-114-78-02 and the Master Operating Agreement between the District and the U.S. Forest Service. Under the SWRCB permit, the MCWD is required to maintain mean monthly flows in Mammoth Creek as measured at the stream gage at U.S. Highway 395 (within the extent of natural streamflow flowing into Lake Mary) as follows:

Month	Discharge (cfs)				
	Original	C & D order 9P			
	(17332)	Dry	Normal	Wet	Beak Proposal
January	5	6.3	7.0	14.5	6.4
February	5	6.3	7.0	14.5	6.0
March	5	6.3	7.0	14.5	7.8
April	10	16.7	40.4	76.4	9.8
May	25	16.7	40.4	76.4	18.7
June	40	16.7	40.4	76.4	20.8
July	25	7.5	26.6	70.4	9.9
August	10	7.5	26.6	70.4	7.2
September	6	5.6	10.8	28.3	3.6
October	6	5.6	10.8	28.3	5.5
November	6	5.6	10.0	10.0	5.9
December	6	6.3	7.0	14.5	5.9

For Mammoth Creek, a dry year is where the total runoff measured at Old Highway 395 is 9,100 acre-feet or less. A wet year is one where total runoff is 26,450 acre-feet or greater. A normal year is between 9,100 and 26,450 acre-feet (USDA-Forest Service, 1994).

As long as minimum daily flows do not fall below 4 cfs, the District may divert up to three cfs from Lake Mary. The district has storage rights to 660 acre-feet per year. The lake must be full by June 1 and cannot be drawn down by more than three feet before September 15. Additional details about the history of water supplies may be found in Boyle Engineering (1992) and Kattelmann and Dawson (1994).

It became apparent in the late 1970s that increasing water demand could not be met solely by surface sources. The Final Environmental Impact Report on the MCWD Water Management Plan, April 1977, and the Supplement to the Water Management Plan, May 1977, presented the overall plans for supplying water to meet projected community needs. The development of groundwater sources is identified as an essential component of the overall water supply plan (MCWD Water System Master Plan, 1987).

MCWD water use data 1982-93 (acre-feet)

year	total	surface	groundwater
82	2108	1885	224
83	2269	2221	48
84	2607	2451	156
85	2506	2192	314
86	2424	2160	264
87	2106	1543	563
88	2200	1605	595
89	2746	1781	965
90	2481	1486	995
91	2212	1046	1166
92	2566	804	1762
93	2915	1653	1262

(USDA-Forest Service, 1994)

The Mammoth Community Water District has estimated water demand at build-out to be 6,000 acre-feet per year.

The combined surface water diversions and groundwater pumping have often been characterized as a gamble: if the region is not affected by severe droughts and adverse impacts are not observed downstream, then fine; if streamflow is low for several years and wells run dry, and the hatchery springs fail, then what? Where does the town go for water?

The Mammoth Community Water District (2004) prepared a water assessment and an amendment (Mammoth Community Water District, 2005) in response to the general plan update process of the Town of Mammoth Lakes. The assessment determined that there was insufficient water from existing supplies to meet demands in dry years. The existing supplies and current use were quantified as 2,760 acre-feet from surface water and 4,000 acre-feet from groundwater. The MCWD is also preparing a groundwater management plan. Groundwater levels are monitored in eight production wells and 15 monitoring wells. Streamflow is gaged at 12 locations. [See GP DEIR app E for locations]. From 1999 through 2003, the district pumped an average of 1,673 acre-feet per year with a maximum of 2,717 acre-feet in 2002. A study for the district estimated that a total volume of 3,800 acre-feet could be pumped from groundwater within the Mammoth Basin (generally within town boundaries) without significant impacts to streams or springs within the basin (Wildermuth Environmental, Inc., 2003). Total water use within the district was 2,565 acre-feet in 1992; 2,641 acre-feet in 1995; 3,287 acre-feet in 2001; and about 3,600 acre-feet in 2005 (Mammoth Community Water District, 2005). The assessment for the general plan update included forecasts of water use in 2020 ranging from 4,461 to 5,430 acre-feet, depending on the planning alternative (Mammoth Community Water District, 2005). The 2004 assessment and the 2005 amendment found that while existing supplies should cover expected demand in years with normal or greater precipitation and a single dry year, shortfalls could occur in the event of multiple years with below average precipitation.

The Mammoth Community Water District has proposed to acquire and consolidate eleven separate water rights permits (Mammoth Community Water District, 2004). These 11 permits allow diversion of 20.8 acre-feet at a variety of locations throughout the watershed. If these diversions cease and an equivalent amount of water is withdrawn directly from Mammoth Creek, there could be a variety of geomorphic and ecological consequences from those changes (Feay, 2005).

In 1992, the district imposed a water conservation program that included limiting irrigation to three days per week. This program reduced water demand by about 25 percent from June through September. The District has replaced more than 10,000 feet of old, leaking pipelines in each of the past four years and has reduced water losses of about 400 acre-feet annually (Mammoth Community Water District, 2004).

Construction and operation of a reservoir, possibly at Horseshoe Lake, has often been proposed as alternative for water management to provide carry-over storage of a greater portion of the snowmelt-runoff peak flows. However, cost and political considerations have limited the appeal of this option.

The Forest Plan of the Inyo National Forest (USDA-Forest Service, 1988) mentions municipal water systems that depend on surface water from National Forest lands. Glass Creek supplies about 16 acre-feet per year to a campground and summer home tract. Rock Creek supplies about 64 acre-feet per year to several campgrounds and two resorts. Mammoth Creek is obviously the largest supply for municipal use. The Forest Plan states that 3,750 acre-feet of water were used annually from Mammoth Creek and that the community uses "nearly a third of the water flowing from the Mammoth Lakes basin" [average annual flow at Twin Lakes is about 7,500 acre-feet]. The discrepancy between the use figure and the water rights to 2,760 acre-feet is unclear.

Three studies of groundwater resource availability in the Hilton Creek/Crowley Lake community were reported for the Mountain Meadows Mutual Water Company (Triad Engineering, 1994):

Slade and Blevins, 1979:	25-30 acre-feet/year
Gram/Phillips, 1981:	330 acre-feet/year
Kleinfelder, 1983:	407 acre-feet/year

The eventual water system demand has been estimated at 160 acre-feet/year (Triad Engineering, 1994).

Pasture and golf course irrigation

Irrigation of pastures is the primary agricultural water use in the upper Owens River watershed. From the late 1880s until the filling of the Long Valley dam in 1940, water was diverted for irrigation within Long Valley. After the turn of the century, the largest ranches were operated by the Thomas Rickey Land and Cattle Company and Fred Eaton. One study estimated that this water use reduced summer flow in the Owens River by about 75 cfs (out of ~200-400 cfs during that time of year) or about 10,000 acre-feet (Smeltzer and Kondolf, 1999).

After Crowley Lake filled, irrigation of pastures continued in some of the higher meadows. An average of 20,000 acre-feet of water is diverted for irrigation of LADWP lands within Long Valley, but some of this amount flows back into streams or re-surfaces in Crowley Lake (Jones and Stokes Associates, 1993: Appendix T). The Chance Ranch has water rights to divert up to 4,500 acre-feet. In the early 1990s, the trout fishing advocacy group, California Trout, estimated the value of water evaporated from irrigated pastures in the upper Owens River and Mono basins at about $40 million using an evapotranspiration rate of 42 inches per year (Jim Edmondson, personal communication, 1993). The group published a similar example in its newsletter for part of the Mono Basin: 11,400 acre-feet diverted on to 2,000 acres of sheep pasture along Parker and Walker creeks for 110 days. The leases generate $40,000, but at $200/acre-feet delivered to Los Angeles, the water could earn almost $23 million (California Trout, 1990). The amount of water that was used for irrigation in the Mono Basin was estimated as 63 percent to 76 percent of the above value in a report by Lane and others (1975): The average application of irrigation water to these pastures was about 10 to 12 cfs per year (equivalent to 7,200 to 8,700 acre-feet per year or 3.6 to 4.3 feet per year over a surface area of 2,000 acres).

Within the upper Owens River watershed, LADWP diverts about 20,000 acre-feet/year for pasture irrigation (Jones and Stokes, 1993; App. T). An unknown fraction of this amount flows back into the streams.

Hilton Creek is used extensively for pasture irrigation of City of Los Angeles and private properties. Agricultural water diversion was estimated to be about 3,000 acre-feet/year in the 1970s, but much of this water flows through small irrigation ditches and returns to main stream flow in the vicinity of U.S. Highway 395 (Gram/Phillips, 1977).

Irrigation of pastures on Hot Creek and Convict Creek has been identified by concerned citizens as an important fisheries management issue. Trout spawn in the flooded pastures and the fry are often unable to return to the main channel when the flows are decreased or discontinued. The return flow to the creeks usually carries considerable heat into the creek and raises the creek's temperature significantly.

The golf courses within Mammoth Lakes also require large quantities of water for irrigation. For example, water demand at the Lodestar golf course was estimated to be about three acre-feet per day (Mammoth Times, 1995b). The Mammoth Community Water District supplied an average of about 350 acre-feet of water to the Snowcreek and Sierra Star golf courses from 2002 through 2004. The Snowcreek golf course supplies another 120 acre-feet from its own well. Expansion of the Snowcreek golf course is estimated to require another 200 acre-feet of water. A project to provide recycled water for golf course irrigation has been planned by the District and could offset between 250 and 550 acre-feet of groundwater pumping if fully implemented (Mammoth Community Water District, 2004).

Residential (landscaping) irrigation was estimated in the summers of 1982 and 1983 from the difference between water delivered to households and wastewater received from households as 0.2 acre-feet in May, 1.4 acre-feet in June, 3.8 acre-feet in July, 2.7 acre-feet in August, and 2.7 acre-feet in September (Environmental Sciences Associates, 1984). Other anecdotal estimates of outdoor water have been more than twice those figures for a total of about 800 acre-feet per year (e.g.,Mammoth Times, 1992). The Mammoth County Water District imposed mandatory restrictions on outdoor water use in 1987, 1988, 1990. and 1991. Real estate interests and developers, however, asserted that resorts need attractive landscaping to maintain and promote visitation and the related summer real estate sales and vacation rentals.

Hydrologic effects of snow management

There are three types of direct snow management within the upper Owens River watershed: snow removal from roads and the consequent storage or transport and disposal of snow, snow compaction at the ski areas, and snow making at Mammoth Mountain Ski Area. Although none of these activities has any effects that would be noticeable at the scale of the entire watershed, each has some impact on the local subwatersheds where they are practiced.

Snow is removed from most of the paved roads and parking lots throughout the watershed. A few exceptions include the Lakes Basin above Twin Lakes, State Route 203 between the Mammoth Mountain Ski Area and Minaret Summit, the Convict Lake campground roads, and the Rock Creek road above East Fork. Otherwise, snow removal is a widespread winter activity on paved surfaces. The one area where the area of pavement is a significant fraction of a small subwatershed is within the town of Mammoth Lakes. Streets, sidewalks, parking areas, and driveways that are routinely plowed constitute about 10 percent of the town's developed area. Snow from those paved areas is mechanically removed at enormous cost and moved elsewhere. Snow was even mechanically removed from the Snowcreek golf course in 1998 to allow an earlier opening. The obvious consequence of rearranging the snowcover is changing the amount of melt water produced on any given day. The amount of melt produced (mostly from solar radiation in our climate) is usually expressed as a flux or a depth of water per unit time. Volumes of water depend on how much area is producing water at that rate. So, if 24 acres of snow cover produce an average of 0.5 inches per day (x 1 ft / 12 in = 0.04167 ft per day) of water, the volume of snowmelt water would be 1 acre-foot. However, if snow is removed from half the area and piled on the other half, only one-half acre-foot of water will be produced per day. If the melt rate remains constant, the 24-acre area will continue to produce snowmelt water for twice as long as it would if the area remained undisturbed. The act of piling the snow would not, in theory, alter the rate of snowmelt. However, in practice, scraping snow off the ground usually adds some dirt and other particles to the snow that are exposed on the surface as the snow melts. These contaminants allow the snowpack to absorb more solar radiation and thereby melt faster. If the snowpack surface becomes very dirty, the contaminant layer may instead shade the snowpack and reduce the rate of melt. The act of scraping snow off city streets often creates a short burst of snowmelt runoff from the residual snow on the pavement that melts rapidly once the sun heats up the pavement. Accumulations of cinders applied to the road surface also help melt the thin residual snow. If snow is trucked out of the immediate subwatershed, there will be less runoff from that area and more wherever it is disposed of.

Snow that slides off roofs or is shoveled off also results in a net reduction of snow covered area, a short burst of snowmelt from the thin snow remaining on roofs after sliding or shoveling, a decrease in snowmelt runoff volume from the lesser contributing area, and an extension of the snowmelt runoff season from the piles of deeper snow. Another theoretical consequence of the presence of homes, buildings, vehicles, telephone poles, etc. is the heating by solar radiation of this multitude of artificial surfaces that subsequently reradiate longwave radiation to the snowpack and accelerate snowmelt compared to pre-urban conditions. This energy conversion is important because while snow reflects a large fraction (typically 70 percent to 90 percent) of shortwave sunlight and absorbs only the remaining fraction, snow absorbs all the longwave radiation it receives. On the other hand, some snow receives less energy input if it ends up in the shade of structures.

Effects of suburban development on runoff during spring snowmelt and rain-on-snow events have been studied in Ontario, Canada (Buttle and Xu, 1988; Buttle, 1990). These studies found that different processes relating to suburbanization seem to produce compensating effects on the snowmelt response. During rain-on-snow events, the typical accelerated streamflow response (more water in less time and higher peak streamflow) of urban rainfall-runoff studies was observed, perhaps mostly resulting from the efficient channel network of gutters and storm sewers.

At Mammoth Mountain and Tamarack ski areas, snow is intentionally compacted by machines to improve the skiing surface and incidentally compacted by skiers. This compaction has two physical effects at different scales: (1) the topographic depression caused by compressing the snow can be filled by wind-redistributed snow, particularly on narrow ski runs and cross-country trails, and (2) the compaction increases the thermal conductivity of the snow, which allows for greater cooling of the snowpack at night (Kattelmann, 1985). The first effect results in more snow water equivalence stored on the compacted areas, so these areas tend to retain snow longer into the spring melt season than adjacent uncompacted areas. The hydrologic consequence of the second effect is that more solar radiation is used in raising the temperature of the colder compacted snow than for undisturbed snow and less melt is produced each day from the compacted snow (Kattelmann, 1986).

Another snow management technique at the Mammoth Mountain Ski Area is the application of salts (usually ammonium nitrate and calcium chloride) to the spring snowpack to temporarily harden the snow surface. As the salt dissolves in the liquid water on the snow surface, the temperature of the solution drops below freezing and the wave of subfreezing solution freezes other liquid water between the snow grains, thereby increasing the hardness of the surface. The net hydrologic effect of this treatment is uncertain because the salt solution may contribute to melt of snow grains just below the surface. The small area treated is an insignificant proportion of even a subwatershed such as Dry Creek. Much of the applied nitrate seems to be captured by the soil on the ski runs and serves to fertilize the grasses used for erosion control.

Snow making is often regarded as significant loss to the local water balance, but it is probably more important as a storage factor or change in the timing of water availability. Artificial snow making diverts streamflow in the summer or autumn into a storage reservoir or in late autumn directly into the snow-making network. This water is then discharged along with compressed air (and sometimes a nucleating agent) through a series of nozzles along the ski slopes to produce snow-like grains. Almost all the water becomes part of the snowpack; however, some is evaporated at the nozzles. The amount is uncertain, and only one set of measurements (Eisel, et al., 1986; Eisel, et al., 1990) is known to have been conducted. This study used both energy balance calculations and measured the difference between water entering the snowmaking equipment and the water equivalence of produced snow on the ground. The energy balance yielded a 6 percent loss, and the mass balance results ranged from 3 percent to 6 percent (Eisel, et al., 1986; Eisel et al., 1990). Other estimates of water loss from snow-making range from 5 percent to 40 percent, although the physics of the process suggest the low end of the range is more likely. There is also the possibility of evaporative loss on very windy days when the newly formed ice grains are entrained in the wind before falling on the snow surface. Under typical Sierra Nevada weather conditions, once the artificial snow is incorporated into the snowpack, there is little evaporation except at very wind-exposed locations (e.g., top of MMSA's Chair 1). The artificial snow then melts in the spring, and the water returns to streamflow, though possibly in a different subwatershed than where it was diverted the previous year.

Urban runoff and stormwater management

Concerns about pollution from stormwater runoff from urban areas began to be raised in the 1950s and 1960s (e.g., American Public Works Association, 1969). The principal pollutants that can be expected in urban runoff include sediment, oils and grease, rubber compounds, nutrients, pesticides, bacteria and viruses, and metals. The materials that are likely to be found on streets, gutters, and parking lots typically get removed in the first flush of stormwater runoff. The concentration of these pollutants usually depends on the time since the previous storm, and intensity and amount of rainfall (e.g., Sylvester and Brown, 1978). The efficiency of the gutter and storm sewer system can greatly affect the size and timing of peak flows collected by the system.

In the early 1980s, about 1,600 acres of the town of Mammoth Lakes' area of four square miles (about 60 percent) were considered to be impervious (Environmental Sciences Associates, 1984).

In 1984, only a few parts of the community of Mammoth Lakes had storm drains. Most of the town was drained by a combination of natural and constructed surface channels, which led to a variety of drainage problems (Brown and Caldwell, 1984). Drainage improvements within the community were usually built in response to site-specific drainage problems rather than integrated into a comprehensive drainage system. Up until the late 1980s, much of the runoff from the developed area flowed as sheet-flow to roads or flowed in unimproved channels or ditches to topographically lower channels. Culverts at road crossings were inconsistently designed and installed resulting in chronic ponding and maintenance troubles in some parts of the town. In 1976, a storm drain system was constructed from the Mammoth Slopes area to the Mammoth Ranger Station via Canyon Boulevard, Berner Street, and Main Street. The storm drain then discharged directly to Murphy Gulch (Brown and Caldwell, 1984).

In association with the Main Street storm drain, a 260,000 ft^3 siltation basin was constructed at the downstream end of the Murphy Gulch channel, approximately 1/4 mile above its junction with Mammoth Creek. The Murphy Gulch siltation basin was originally constructed to control sediment discharges from most of the developed area of the community. The basin was formed by an earth-fill dam which was originally constructed as part of an old roadway fill across the Murphy Gulch channel. At maximum ponded water level (7-8 feet deep), the basin had a capacity of approximately 260,000 cubic feet. Although the basin trapped a significant volume of silt and sediment each year, there was evidence that it did not capture enough of the sediment input. During peak runoff, sediment deposition efficiencies are drastically reduced (due to high flow-through velocities) resulting in visibly turbid effluent discharges. It appeared that these velocities are frequently high enough to actually scour and resuspend sediments that have previously deposited in the basin. The old earth-fill dam was in relatively poor condition as of 1984, and there were signs of seepage on its downstream face (Brown and Caldwell, 1984).

The drainage master plan proposed by Brown and Caldwell (1984) included construction of new storm sewers, capture of runoff that formerly went directly into Mammoth Creek, detention storage of runoff, additional local sediment retention basins, and reconstruction of the sediment retention basin in Murphy Gulch. The estimated capital cost was $18 million, and annual operating costs were estimated at $100,000 to $250,000 (Brown and Caldwell, 1984).

In 1997, following flood damage, the Town of Mammoth Lakes received a grant under Clean Water Act section 319(h) to construct a second sedimentation basin in Murphy Gulch.

Wastewater treatment and disposal

The primary wastewater treatment facility within the watershed serves the town of Mammoth Lakes and is operated by the Mammoth Community Water District. An average of 1,500 acre-feet of water was treated at the facility between 1983 and 1997 (Bauer Environmental Services, 1998). The disinfected secondary-treated effluent from the facility is piped several miles to the Laurel Ponds where it is discharged. The treated water percolates into the ground at this location or evaporates. The expansion of Laurel Ponds to more than 18 acres of surface area has been considered a benefit for waterfowl habitat by the Inyo National Forest, which administers the site. A proposal to treat some of the wastewater to tertiary standards for unrestricted irrigation use has been under consideration for several years (Bauer Environmental Services, 1998). The Mammoth Lakes wastewater treatment plant is a permitted wastewater facility as are the treatment plants of the Hilton Creek Community Services District, Mammoth Mountain Ski Area, and Convict Lake campground.

In the mid-1970s, the community of Hilton Creek/Crowley Lake had an estimated average population of 300 and was served entirely by individual disposal systems consisting primarily of septic tanks and leach fields or leach pits. Because of the presence of adverse soil and groundwater conditions, these individual systems had abnormally high failure rates for many years. Many of the disposal systems were located less than 100 feet from surface waters or in areas of shallow groundwater. Percolation rates throughout the community area are quite high, which is typical for glacial outwash soils, and range from about 2 to 10 minutes per inch. About two-thirds of the residences and at least five commercial establishments in the community obtained their domestic water supplies from the direct diversion of the surface waters of Hilton Creek. Mono County health officials were aware of problems from at least 1966. A study prepared by the Lahontan RWQCB for the county in that year reported alarming coliform concentrations at sample points in natural surface streams as well as in private water supply systems. The report attributed the majority of this contamination to the use and misuse of septic tank / leach field sewage disposal systems. Water quality sampling and public health investigations in the vicinity of Hilton Creek indicated that the continued use of individual disposal systems posed significant health hazards and adverse water quality impacts. Mono County and the Lahontan RWQCB both adopted restrictions and prohibitions on the installation of new septic tank / leach field disposal systems within the Hilton Creek service area in 1976. The Lahontan RWQCB further prohibited use of existing disposal methods after January 1, 1985 and recommended that a community sewerage system be implemented for the area (Gram/Phillips, 1977).

Descriptive geomorphology

Channel networks

The upper Owens River meanders for about 30 miles measured along the channel between Big Springs and Crowley Lake (County of Mono, 1992).

The total distance between the downstream boundary of the Inaja Ranch and the inlet to Crowley Lake is 10.7 miles. The distance between the downstream boundary of Inaja Ranch and Benton Crossing is 6.5 miles and from Benton Crossing to the inlet to Crowley Lake is 4.2 miles (Goldberg, 1988).

Figure 13. Relatively few major streams drain the upper Owens River watershed [watershed_jpegs owens_streams]

Channel processes

Few studies of channel processes (aka fluvial geomorphology) have been conducted within the upper Owens River watershed. One report describing research on gravel movement in steep streams of the eastern Sierra Nevada included study sites on McGee Creek and Rock Creek (Kondolf, et al., 1991). This study found that streambed gravels are thoroughly scoured and redeposited during snowmelt runoff events of magnitude similar to that of 1986 (Kondolf, et al., 1991). In the past 30 years, snowmelt runoff has been well above average in eight years (1982, 1983, 1986, 1993, 1995, 1998, 2005, and 2006).

Increasing the flow of the upper Owens River with water exported from tributaries to Mono Lake led to major changes in the Owens channel. These changes and possibilities for restoration are described by Ebasco Environmental and others (1993). The Owens River has an average annual discharge of 76 cfs above the East Portal of the Mono Craters tunnel (about 3.5 miles downstream of Big Springs). At East Portal, this flow was augmented with water diverted from the Mono Basin from 1941 to 1989, which increased the average flow to 168 cfs. The more-than-doubled discharge resulted in channel erosion, widening and straightening of the stream and destruction of riparian habitat downstream. The discharges from the Mono Craters tunnel also fluctuated rapidly over short periods of time. When flows were increased rapidly, aquatic vegetation was scoured, and when flows declined rapidly, the saturated streambanks caved in (County of Mono, 1992). Mature willows along the banks were killed by the higher water levels and physical erosion, and establishment of young willows was restricted downstream of East Portal in comparison to an upstream control reach (Stromberg and Patten, 1991). Much of the meandering route of the natural channel became straightened as a result of these local erosion episodes. These channel changes contributed to the estimated net loss of 1.2 miles of upper Owens River stream length (Milliron, 1987). One reach that was less affected by the augmented flows was through the Inaja Ranch property, where a ditch diverted up to 100 cfs at times and put most of that water back in the main channel near the downstream edge of the property (Ebasco Environmental, et al., 1993). Similar bank erosion processes were measured and described in the Owens River below Pleasant Valley dam where flow fluctuated greatly (Williams, 1975).

The reach of the upper Owens River below the east portal has received high flows via Mono Craters tunnel since 1941 with subsequent channel widening and downcutting (Kondolf, 1990). Recent court decisions will require more water to be delivered to Mono Lake and less diversion to the Mono Craters tunnel and the upper Owens River. The decrease in flow may be detrimental to fish habitat due to decreased water depth, cover, and questionable channel stability. In addition, the downcut channel may result in a drop in the water table, ultimately affecting riparian vegetation along the river. This vegetation provides important shading, cover, terrestrial food production, and bank stability.

Over several decades, the channel and the fishery have adjusted to the greater flows. In the relatively dry summers of 2002-04 with little water diverted through the tunnel, streamflow in the upper Owens was approximately 55-70 cfs. However, instream flow modeling results indicate 100-150 cfs is needed to sustain the trout fishery and coldwater ecology of the upper Owens River (Caltrout Streamkeepers Log, 2005).

A river channel that experiences reduced flows usually responds by narrowing, which is dependent on there being enough sediment carried by the river to build the banks (Kondolf, 1990).

A pending research project (Kondolf, 2006, personal communication) proposes to: 1) conduct surveys of the channel to document the changes that have already occurred due to augmented flows below the east portal; 2) study historical aerial photographs to document changes in channel geometry over the period of record; 3) reconstruct a natural flow regime, using existing gage records; 4) use staff gages and crest stage gages for monitoring water levels in the stream, and; 5) install piezometers along six transects across the river and its floodplain, in order to relate changes in river level to changes in the floodplain.

The reach of Hot Creek between the fish hatchery and the Hot Creek gorge is typically covered with dense aquatic vegetation that tends to trap sediment. However, in 1991, following several dry years with below-average streamflow, the plants largely disappeared during the winter (Edmondson, 1991). The above-bed mass of vegetation may have exceeded the root strength and the carpet of streambed vegetation unraveled from upstream to downstream. The timing of the event is not precisely known, nor is its relation to the rain-on-snow peak flow of March 1991. Apparently, new vegetation began growing that spring and quickly reoccupied the bed

(Edmondson, 1991).

Analyses of the older (pre-dam) sediments in the upper Owens Gorge suggest that the upper Owens River formerly delivered a large fraction of the sand and silt-sized sediment still found within the channel of the gorge, but almost all of the gravel and larger sizes of sediment were derived from the gorge itself (Smeltzer and Kondolf, 1999). Earlier studies of channels and sediment in Long Valley (Clausen, 1905, and Mayo, 1934, both cited by Smeltzer and Kondolf, 1999) indicated that sediments in Long Valley were silt-sized and readily eroded.

Surface erosion

Potential for surface erosion varies throughout the town of Mammoth Lakes with the highest potential in loose and shallow soils on steep slopes (Town of Mammoth Lakes, 2005). Thin soils on steep slopes within the once-proposed Sherwin Ski Area were found to be highly erodible, particularly if disturbed (Inyo National Forest, 1988). Soils developed from colluvium, metamorphic rock, and glacial till are believed to have the greatest erosion hazard in the area (Curry, 1972).

Vegetative cover and leaf litter reduce raindrop impact and shear stress from flowing water. Roots enhance soil strength and resistance to disaggregation and movement.

Hillslope processes

Mass movement of soils and rock on hillsides occurs as landslides, mudflows, and soil creep. Mass movements are more likely to occur in the presence of shallow groundwater under pressure and in saturated soils.

Evidence of landslides is not known to exist within the boundaries of the town of Mammoth Lakes, but the moraines near the town are considered unstable (Town of Mammoth Lakes, 2005). Bedrock slopes are considered relatively stable, but old rock glaciers and moraines can fail if saturated with water, undercut, excavated, loaded with debris from upslope, or during earthquakes (Curry, 1972).

Sediment transport

The major channels are readily capable of transporting most sediment that they collect because of their steep gradients and ample discharge. Sediment deposition has been observed to occur in the lower gradient channels such as Hot Creek near the fish hatchery. Streamflow in the upper Owens River (generally between 20 and 200 cfs) appears to sufficient to keep fine sediments in motion and avoid siltation of the bed most of the year (Ebasco Environmental, et al., 1993). There was disagreement between experts on stream habitat about whether channel maintenance flows exceeding 200 cfs were desirable in the restoration of channel and riparian conditions along the upper Owens River (Ebasco Environmental, et al., 1993; Platts, 1994).

Human influences

During the 1970s, sedimentation and associated declines in aquatic invertebrates began to be noticed in Hot Creek between the hatchery and the upper end of Hot Creek Gorge. Pools in the channel became filled, and pore space between the gravels was packed with sand. The accumulation of sediment caused concern for potential declines in the fishery in the public waters downstream of the hatchery and at Hot Creek Ranch. The Forest Service, Bureau of Land Management, and Department of Fish and Game investigated the issue but did not pursue the matter sufficiently to conclusively determine the sources of sediment or develop a course of action to reduce the sedimentation. The agencies hoped to involve the U.S. Geological Survey in the late 1970s, but work completed by the USGS has not been located. The potential sources of increased sediment included roads, trails, construction in Mammoth Lakes, overgrazing near stream channels, hatchery operations, and changes in vegetation. The sediment could also remain in the affected reaches longer if the high flows from Mammoth Creek were reduced in size and frequency.

Roadside vegetation along the dirt roads near Deadman Creek has receded as a result of vehicle damage. There is less vegetative cover and more compacted soil. Runoff from storms and consequent surface erosion have been observed to increase (Caltrout, 2005).

Water Quality

General description of water quality

"Water quality cannot be said to be bad or good but only suitable or unsuitable for the use for which it is used. The importance of individual water quality parameters changes with way the water is being used" (Clark, 1979).

The first Basin Plan for the Lahontan Region (Lahontan RWQCB, 1975) mentioned that analyses of water entering Crowley Lake found excellent quality for constituents measured except for arsenic, which sometimes exceeds federal drinking water standards. Most environmental documents relating to parts of the watershed routinely cite excellent water quality in the area's streams that is suitable for all beneficial uses. The principal exception is Mammoth Creek within and downstream of the town of Mammoth Lakes.

A major assessment of water quality in the Mammoth Creek watershed was conducted by a team of graduate students and faculty from UCLA in the summer of 1972 (Perrine, et al., 1973). This study judged the overall water quality to be excellent with respect to chemical constituents. One exception to the low chemical concentrations was relatively high concentrations of phosphorus that could contribute to excessive growth of aquatic plants, although natural sources were believed responsible. Fecal coliform bacteria counts in lower Mammoth Creek were high and believed to result from leaching from campground pit toilets in the Lakes Basin, septic systems in Old Mammoth, and pet waste. This study was conducted before the connection of the campgrounds and many of the houses in Old Mammoth to the sewer system.

Another survey of water quality was conducted in Mammoth Creek and Hot Creek in late September 1981 and May 1982 (Setmire, 1984). A few distinct changes in ionic composition were noted in Mammoth Creek as it flowed downhill and gathered water from springs and seepage through the bed: a decrease in the percentage of calcium, an increase in the percentage of magnesium and sodium, and an increase with some fluctuations in fluoride, sulfate, and chloride. Excessive growth of aquatic plants was noted in Twin Lakes and Hot Creek below the confluence with Mammoth Creek. These areas of eutrophication were judged to have natural causes (Setmire, 1985). This survey also identified apparent human-induced sediment loading between Old Mammoth and Sherwin Creek road and fecal contamination in lower Mammoth Creek and Hot Creek from cattle and humans. In 1991, a "Health Advisory" was issued for Mammoth Creek (Lahontan Regional Water Quality Control Board, 1998).

Over the entire Inyo National Forest (lands in the upper Owens River watershed are not distinguished separately), 97 percent of the water flowing off the forest was judged to meet water quality objectives as of 1988. The remaining 3 percent contained excessive sediment (USDA-Forest Service, 1988a).

Water samples from various tributaries to the Owens River have been analyzed by LADWP since the 1930s and 1940s. During the Mono Basin Environmental Impact Report process, these data were summarized along with a special water quality survey in 1991 by Jones and Stokes Associates (1993b). All except Hot Creek had low concentrations of minerals and nutrients.

Every two years, the State Water Resources Control Board submits a report on the quality of streams and lakes in California to the U.S. Environmental Protection Agency. Part of that report refers to section 303(d) of the federal Clean Water Act, which directs the states to identify priority water quality issues in individual water bodies.

303(d) list 1998

Water Body	Pollutant	Suspected Source
Crowley Lake	arsenic	natural
	nutrients	unknown
Hot Creek	metals	natural
Little Hot Creek	arsenic	natural
Mammoth Creek	metals	natural and urban runoff
Owens River	arsenic	natural
	habitat alterations	flow regulation/modification
Little Alkali Lake	arsenic	natural
Big Springs	arsenic	natural

The Usual Suspects: Wastewater Pollutants of Concern

The following list provides a concise summary of why we should care about different contaminants of water. This list is quoted and paraphrased from EDAW, 2005. Various forms of it can be traced through many water-quality publications.

Sediment and turbidity
Can smother fish eggs and benthic macroinvertebrates, can increase oxygen demand and harbor bacteria; turbidity can block sunlight that aquatic plants need for photosynthesis. In drinking water, turbidity interferes with disinfection and looks bad.

Biological oxygen demand
Can deplete oxygen in water that fish and invertebrates require, oxygen-reducing conditions in drinking water can cause taste and odor problems.

Pathogens
Bacteria, viruses, and parasites cause diseases and are transmitted by ingestion of contaminated water or shellfish or by skin contact.

Nitrogen
Nitrogen acts as a nutrient for aquatic plants that can contribute to eutrophication and reduction of dissolved oxygen; excessive nitrogen in water can impact the health of infants, pregnant women, and livestock.

Phosphorus
Phosphorus is another nutrient for aquatic plants that contributes to eutrophication and reduction of dissolved oxygen.

Dissolved inorganic salts (or total dissolved salts)
Chloride and sulfide cause taste and odor problems in drinking water; sodium, chloride, sulfate, boron, and other solutes can make water unsuitable for some uses such as irrigation.

Heavy metals
Metals such as lead, mercury, and cadmium cause human health problems; these metals can accumulate in the aquatic food chain, so fish can be a source of metals for humans;

Toxic organic compounds
Many organic compounds such as pesticides and industrial chemicals are toxic to humans and aquatic life; many such compounds become concentrated in the aquatic food chain.

Endocrine disruptor compounds
Common pharmaceutical drugs, hormones, and chemicals in cosmetics have recently been recognized as a water quality and human health issue; endocrine disruptor compounds are substances that alter endocrine system function and may damage the health of people and other animals as well as their offspring.

A list of potential contaminants and the EPA's recommended maximum contaminant level for drinking water provides a set of standards useful for comparison to measured amounts of constituents in the water bodies of the watershed. This list of "national primary drinking water standards" is copied in the water quality appendix and may be found at http://www.epa.gov/safewater/contaminants/index.html

Categories

Sediment

The Environmental Impact Statement for the Land and Resource Management Plan ("Forest Plan") of the Inyo National Forest (USDA-Forest Service, 1988a:315) states that the "primary threat to water quality on the Inyo is sedimentation." The document indicates that the most significant sources of sediment are the ski areas and rangelands, particularly wet meadows, disturbed by historic overgrazing. In a subsequent section on cumulative effects that also addresses sources on private land, the Forest Plan states that suspended sediment in Mammoth Creek during spring-summer runoff increases ten-fold between the outlet of Twin Lakes and

U.S. Highway 395.

The Inyo National Forest (1988b) has noted a significant increase in sediment and turbidity levels during peak runoff events in Mammoth Creek. These increases appear to be the result of disturbances in the developed area and the sensitivity of the local soils to disturbance. The impact of runoff from urban development is reflected in the increase in sediment and turbidity levels in Mammoth Creek as it flows through the town. Based on USFS data developed on Mammoth Creek at U.S. Highway 395, from October 1981 to September 1982, the total annual sediment discharge is estimated to be 5,100 tons or approximately 0.20 ton/acre of watershed. This sediment yield is one-third of the average for the Sierra Nevada (0.75 ton/acre) and one-tenth of the average for California (2 ton/acre) (Kattelmann, 1996). A summary of the USFS sediment and turbidity data from 1979 to 1982 is given in Triad Engineering (1986).

Another estimate of sediment transport in Mammoth Creek estimated the load as 1.8 tons/day above Old Mammoth, 23 tons per day at Sherwin Creek Road, and 12 tons per day (4,380 tons/year) at U.S. Highway 395 (Setmire, 1984). The sediment concentration at U.S. Highway 395 was 42 mg/l.

Suspended sediment and turbidity were measured in Sherwin Creek at about 7,840 feet from May through October, 1986, as part of the Sherwin Ski Area environmental impact evaluation (USFS, 1988b). The suspended sediment concentrations ranged from 1 to 22 mg/l with a mean of 7 mg/l and turbidity ranged from 0.6 to 3.5 NTU with a mean of 1.6 NTU. Sediment was greatest on the rising limb of the snowmelt hydrograph.

In 1997, the Town of Mammoth Lakes received a grant under Clean Water Act section 319(h) to construct a second sedimentation basin in Murphy Gulch.

Minerals

Total dissolved solids (TDS) were measured in samples collected from Mammoth Creek and some of the lakes in the Lakes Basin during the summer of 1972 by the UCLA team and found to be generally less than 50 mg/l, with a couple of samples abound 100 mg/l (Perrine, et al., 1973). Drinking water standards are about 500 mg/l for comparison. Measured concentrations of sodium, calcium, and magnesium were less than 10 mg/l. The Mammoth Community Water District has measured water from Lake Mary for various constituents since 1983. Values for TDS over this period have ranged from 10 to 50 mg/l with a mean of 31 mg/l. Citizen monitoring of Mammoth Creek from 2000 to 2005 has found TDS values of 32 to 168 mg/l at Minaret Road and 56 to 120 mg/l at U.S. Highway 395 (Burak, personal communication, 2006). The Lahontan Regional Water Quality Control Board has set objectives for TDS of 85/115 mg/l for Mammoth Creek at Minaret Road and 75/100 for Mammoth Creek at the U.S. Highway 395 gage.

Conductivity is often used as a proxy for TDS because it is relatively easy to measure. A few spot measurements of conductivity were made in various portions of the upper Owens River watershed during October 1985 by the Department of Fish and Game (Dienstadt, et al., 1986) [units of µS/cm]:

Owens River	120, 130, 120, 170
Rock Creek	20, 25, 30, 20, 8
McGee Creek	40, 75, 70
Mammoth Creek	77, 85, 128, 108, 115, 35
Hot Creek	580
Laurel Creek	50
Sherwin Creek	20
Glass Creek	30

Conductivity measurements by LADWP and Jones and Stokes Associates (1993b) had the following ranges (units of µS/cm):

Owens River at Big Springs	166-223
Owens River at Benton Crossing	295-560
Mammoth Creek	50-200
Hot Creek	200-650
Convict Creek	125-175
McGee Creek	56-175
Hilton Creek	24-62
Crooked Creek (1991 only)	43-128
Rock Creek	25-125

Nutrients

The nutrient budget of Crowley Lake has received greater attention than other parts of the watershed because of the eutrophic state of the lake.

Almost all (96 percent) of the observed phosphorus loading to Crowley Lake comes from the Owens River, which only provides about half of the water input to the lake (Jellison and Dawson, 2003). The known sources for this phosphorus are Big Springs and numerous sites along Hot Creek.

Estimated annual phosphorus loads to Crowley Lake (April 2000 to March 2001):
1.2 g m^{-2}
Estimated annual nitrogen loads to Crowley Lake (April 2000 to March 2001):
2.1 g m^{-2} (Jellison and Dawson, 2003).

The Owens River accounts for 79 percent of the nitrogen input to Crowley Lake and McGee Creek accounts for 13 percent (Jellison and Dawson, 2003). Ammonia, nitrate, and total nitrogen concentrations are relatively low in all other tributaries. Total nitrogen concentrations increase somewhat (a mean of 8 micro M ????) across the irrigated pastures of Convict and McGee creeks. This increase is about 6 percent of total nitrogen loading to Crowley Lake. Hot Creek fish hatchery contributes a significant amount of ammonia and total nitrogen to Hot Creek. The communities of Mammoth Lakes, McGee Creek, and Hilton Creek had little apparent effect on nutrient concentrations downstream (Jellison and Dawson, 2003). There is three to four times more nitrogen leaving Crowley Lake than enters it, presumably because of nitrogen-fixing cyanobacteria (blue-green algae) in the lake.

Nitrate concentrations were measured in Mammoth Creek in the summer of 1972 by the UCLA team and were less than 0.5 mg/l in 99 percent of the samples (Perrine, et al., 1973). Phosphate concentrations were generally less than 0.1 mg/l, although a few samples were up to 0.3 mg/l.

Sampling in the Mammoth Lakes basin in 1981 and 1982 found concentrations of total nitrogen and total phosphorus to be less than 0.9 and 0.03 mg/l, respectively (Setmire, 1984). In Hot Creek below the fish hatchery, concentrations of total nitrogen ranged from 0.9 to 1.6 mg/l, and concentrations of total phosphorus ranged between 0.12 and 0.33 mg/l. Nitrate concentrations up to 0.44 mg/l, and orthophosphate concentrations up to 0.157 mg/l were found in the springs forming Hot Creek (Setmire, 1984).

At Crystal Lake (above Mammoth Lakes), nitrate concentrations were generally below analytical detection limits with a high value of 1.1 microequivalents per liter (Melack, et al., 1993). Sulfate concentrations were also found to be low at 5.7 to 7.3 microequivalents per liter.

Effluent from the MCWD sewage treatment plant apparently leaked in 1970 and was later found in springs along lower Mammoth Creek.

There is potential, but no direct evidence, for contamination from excessive use of chemical fertilizers on gardens, lawns, and parks. Nutrients from fertilizers that are not incorporated in plant tissue can be leached from soils and enter local streams.

Metals

Metals, primarily arsenic and mercury, have been measured in the Crowley Lake water column and sediments (Lahontan RWQCB, 1994). These substances are believed to originate from natural sources resulting from the particular chemical composition of the watershed's geology. Arsenic concentrations high enough to be a health concern for fish and humans have been measured in the upper Owens River below the confluence of Hot Creek as well as in Hot Creek itself (Eccles, 1976; Ebasco Environmental, et al., 1993). A detailed study of arsenic in Crowley Lake waters confirmed the geologic nature of the sources (Jellison, et al., 2003).

When the level of Crowley Lake fell rapidly in 1989, tributary streams eroded new channels in their deltas in response to the dropping base level. Large volumes of sediments were transported into deeper areas of the lake. Stirring up these sediment deposits also released mercury that had been in storage, and elevated mercury levels were found in water samples collected by LADWP at the dam in February 1990 (Milliron, 1997). Subsequent analyses of trout tissue found no detectable levels of mercury or other heavy metals (Milliron, 1997).

Organics

Monitoring wells at the Benton Crossing landfill have detected low concentrations (about one or two parts per billion) of three volatile organic compounds (Mono County Planning Department, 2004). Although the concentrations appear to be stable and well below the so-called maximum contaminant levels, a monitoring program reports results from sampling and analysis to the Lahontan Regional Water Quality Control Board.

Temperature

Water temperatures in O'Harrel Canyon Creek in the area where fish were observed ranged from 60°F to 63°F (Wong, 1979) and 49°F to 57°F in mid-August (Kanim, 1980). Water temps reached 91°F on the lower portions of the alluvial fan (Wong, 1979).

Water temperatures were monitored at four locations on the upper Owens River between June 1 and September 30, 1991 (Ebasco Environmental, et al., 1993). The average temperatures, as well as the variation in daily temperature values, tended to increase downstream. Daily average temperatures ranged from 52°F to 65°F at the powerline crossing above Hot Creek and from 56°F to 72°F at Benton Crossing. Maximum temperatures ranged up to 80°F (Ebasco Environmental, et al., 1993).

Water temperatures in upper Mammoth Creek were measured during the summer of 1972 and found to be in the range of 54°F to 75°F and did not exceed 82°F. The daily temperature range varied within 2°F to 10°F (Perrine, et al., 1973).

Water temperatures in Convict Creek were reported for a period of four years (1977-1980) (Leland, et al., 1986). Mean daily stream temperatures in winter ranged from 33°F to 38°F and temperatures in summer ranged from 60°F to 68°F (Leland, et al., 1986).

Water temperatures in Hot Creek and Convict Creek apparently rise several degrees where warm irrigation return flow enters the creeks following flood irrigation of adjacent pastures.

Dissolved oxygen

Dissolved oxygen levels in upper Mammoth Creek were measured in the summer of 1972 by the UCLA team and found to be 6 to 8 mg/l, a range quite suitable for trout and close to theoretical saturation at the ambient temperatures of the streams and lakes (Perrine, et al., 1973). This study also found biochemical oxygen demand in Mammoth Creek was quite low, almost always below 2 mg/l. The measurements in the 1930s by Smith and Needham (1935) found oxygen levels in the lakes of the upper Owens watershed to be in the same range as those found by the UCLA team.

Dissolved oxygen was measured in Crowley Lake during August 1993 (when the lake was stratified) by the Department of Fish and Game. Below a depth of 33 to 43 feet, dissolved oxygen was only 2 mg/l (Milliron, 1997). Concentrations of dissolved oxygen between 3 to 5 mg/l restrict growth of trout, and levels below 3 mg/l can be lethal to trout after long exposure (Milliron, 1997).

Pathogens

The UCLA team measured concentrations of total coliform and fecal coliform bacteria in water samples from Mammoth Creek and lakes in the Lakes Basin during the summer of 1972. This study found a wide range of variability from 0 to 10,000 colonies per 100 ml for total coliform and 0 to 1,000 colonies per 100 ml for fecal coliform (Perrine, et al., 1973). Naturally occurring soil bacteria were believed to be the main constituent of the total coliform counts. The highest fecal coliform counts were found in lower Mammoth Creek and believed to result mainly from leaking septic systems in Old Mammoth and pet waste.

Most sites sampled by Setmire (1984) in upper Mammoth Creek had fecal coliform bacteria counts below 10 colonies per 100 ml. Mammoth Creek at U.S. Highway 395 had 250 colonies per 100 ml, and Hot Creek below the hatchery had more than 1,000 colonies per 100 ml (Setmire, 1984).

Bacterial contamination has been noted downstream of the campground on Glass Creek in late summer and autumn (USDA-Forest Service, 1998).

There have been anecdotal reports of bacterial contamination of the small channels over the Hilton Creek fan (Hilton Creek distributaries) by neighboring outhouses and septic systems. For example, a routine water sample within the Crowley Lake Mutual Water Company system tested positive for fecal coliform in November, 2002 (Mammoth Times, 2002).

pH and alkalinity

The pH of water is an index of the hydrogen ion concentration, which in turn causes water to be acidic or alkaline. A pH value of 7 is neutral, values less than 7 (increasing hydrogen ion concentration) are acidic, and values greater than 7 [to a maximum of 14] (decreasing hydrogen ion concentration) are alkaline. Lakes in the upper Owens River watershed had pH values averaging about 8.3 in an early survey (Smith and Needham, 1934). Slightly alkaline waters such as these lakes tend to have more plants and animals than neutral or acidic waters.

Alkalinity is a measure of the capacity of water to buffer changes in hydrogen ion concentration. Water with greater alkalinity is more resistant to changes in pH. Alkalinity depends on the amount of carbonate, bicarbonate, and hydroxide ions.

A study of Crystal Lake relating to acidic precipitation found that the pH of the lake was 6.7 to 6.1 and the acid-neutralizing capacity varied from 56 to 82 microequivalents per liter (µeq/l). Acid-neutralizing capacity declined rapidly during the snowmelt season as very pure runoff water entered the lake, and then slowly increased during the remainder of the year (Melack, et al., 1993).

Water imported from the Mono Basin lowered the alkalinity of the upper Owens River and consequently might have had some potential effects on the toxicity of naturally occurring metals.

Measurements of surface water quality

A few sets of analytical results from water samples collected in the upper Owens watershed are presented as examples in this section. Other data sets from the literature (such as LADWP results summarized by Jones and Stokes Associates, 1993b and Ebasco Environmental, et al., 1993) can be found in Appendix 1.

Chemical analysis of Convict Lake from Reimers, et al., 1955.

Na	0.001 g/l
CO_3	0.06
Cl	<0.01
HCO_3	0.06
SO_4	0.009
K	0.002
Dissolved Solids	0.08
B	0.01 mg/l
F	<0.1
pH	7.9

Chemical data on lake waters of Inyo National Forest (Smith and Needham, 1935)
All measurements were made in July 1934.

Name of Lake	Max. Depth (ft)	Depth of Sample (ft)	Water Temp ^oF	Oxygen ppm	Alk. ppm CaCO3	pH
Convict	138	S	59	7.9	54	8.4
		35	57	7.0		
		75	53	8.4		8.3
		93	50			
		138	49.5	5.3	60	7.3
Twin	12	S	61	9.6	9	8.7
		9	60			
Mamie	8	S	62	6.9	18	7.7
Horseshoe	60	S	60	6.4	9	7.5
		59	52	3.8	12	6.4
Mary	87	S	60	7.0	24	8.2
		28	58			
		43	56	7.6	11	
		53	47			
		87	46	5.4	11	
George	199	S	59	7.6	7	7.5
		28	57			
		43	54	7.9	6	6.4
		48	50			
		58	47			
		78	45			
		198	44	6.3	7	6.4
TJ	29	S	60	6.4	4	
		29		6.3	4	
Crystal	49	S	57	5.9	4	7.3
		38	57			
		49	57	6.1	4	7.3
Arrowhead	34	S	60	7.7	17	8.3
		29	60	7.0	17	8.3
Skelton	31	S	61	7.1	20	
		31	59	7.1	20	

Smith and Needham (1934) also measured the clarity or transparency of these lakes with a Secchi disc. The disc usually disappeared between 30 and 40 feet. Lake George had the greatest clarity at 71 feet.

Chemical analysis of water samples taken at the flume below Hot Creek gorge indicate most of the dissolved mineral load is due to discharge from thermal springs (California Department of Water Resources, 1967 and 1973; Setmire, 1984).

City of Los Angeles monitoring records for Hilton Creek during the period 1958-71 indicate the average chemical and physical constituents shown in the table below
[from Gram/Phillips Associates, 1980]:

Constituent	Concentration (ppm)
Ca	4.9
Mg	0.7
Total Hardness	15.0
Na	2.1
K	0.6
Alkalinity	19.0
SO_4	3.1
Cl	1.0
SiO_2	8.7
Fe	0.03
B	0.01
F	0.04
As	0.01
Total Kjeld N	0.11
NH_3	0.01
NO_2	0.003
NO_3	0.2
DO	9.8
BOD	1.5
Color	5.0
Turbidity	3.0
Odor	none
pH	7.8
PO_4	0.03

Iron content varied considerably from month to month and occasionally approached public health limits.

Analyses of surface water samples collected at 12 locations among the distributary channels of Hilton Creek by the Lahontan RWQCB in April and June 1975 found that detergent residues, total coliform, and fecal coliform concentrations increased from April to June, during the snowmelt runoff period, while passing through the developed area of the community (Gram/Phillips Associates, 1977).

USFS and USGS suspended sediment data from summers 1979 and 1982:
above Lake Mary, mean suspended sediment is 5 mg/l and mean turbidity is 0.6 NTU. As Mammoth Creek flows through the developed area, the suspended sediment and turbidity increase. Below Murphy Gulch, the mean suspended sediment concentration is 141 mg/l and the mean turbidity value is 86 NTU. The quality of Mammoth Creek improves, due to the settling of sediment and dilution from streams draining undisturbed areas, as the creek flows downstream past U.S. Highway 395 and the fish hatchery. Just above the hatchery, the mean suspended sediment concentration is 16 mg/l, and the mean turbidity value is 10 NTU.

Suspended sediment and turbidity data

	Suspended sed mg/l			Turbidity NTU		
	n	range	mean	n	range	mean
Mammoth Creek						
Above Lake Mary	9	0.7-18	5	15	0.2-1.0	0.6
At Old Mammoth	37	1-312	27	37	1.6-224	15
Above conf Minaret	7	20-98	60	7	12-67	35
Below conf Minaret	7	18-95	55	7	12-74	36
Above Murphy Gulch	23	3-184	44	23	3.1-131	23
Below Murphy Gulch	23	8-957	141	23	4.5-735	86
At old Highway 395	59	0.5-218	19	71	0.5-140	10
Above fish hatchery	37	1-63	16	37	2.7-33	10
MamMtn at Austria Hof	19	195-78,920	8,250	22	13-27,000	2570
MamMtn at Hut II	19	328-17,600	5,030	20	95-8,900	1350
Chair 9 watershed	13	27-8,150	822	14	7-3,380	306
Minaret Village runoff	10	22-420	154	10	69-406	190
Murphy Gulch at VC	13	0.3-11,940	2,170	14	4.0-3,500	737
Murphy Gulch at MamCr	28	5-5,690	715	29	4.5-2,790	434

These water quality data cannot be used to quantify the load of sediments reaching Mammoth Creek from various problem areas in the drainage because they represent occasional grab samples without corresponding flow data. The data do show, however, that the developed areas produce runoff with significantly higher suspended sediment concentrations and turbidity values. The data also show that the suspended sediment concentration and turbidity of Mammoth Creek increase as it flows through the developed area (Brown and Caldwell, 1984).

A long-term set of water-quality observations have been obtained by the Los Angeles Department of Water and Power beginning in 1933. Some of these measurements were summarized by Ebasco Environmental and others (1993) and presented along with their own sampling results from 1991 in Tables 44-48 of the cited report. Copies of those tables are reproduced in Appendix 1. The only constituent of concern that was noted was arsenic from Hot Creek (Ebasco Environmental, et al., 1993).

Measurements of groundwater quality

Occasional measurements of samples from wells and springs have been made over the years. Table 4 of the California Department of Water Resources (1973) report lists TDS and electrical conductivity for several dozen wells and springs. TDS values ranged from 30 to 300 mg/l for cold water sources and 500 to 1,600 mg/l for geothermal sources. Electrical conductivity ranged from 60 to 400 micromhos/cm for cold water sources and between 500 and 2,300 for geothermal sources.

The Inyo National Forest reported data about water quality from some of the wells in the Dry Creek drainage (USDA-Forest Service, 1994). Two wells that service MMSA and seven exploratory wells that were drilled by MCWD provide information about the quality of the groundwater in Dry Creek. The best water-producing zones are in the fractured rhyolites at a depth of 600 to 750 feet, and the average aquifer transmissivity is 24,000 gallons per day per foot.

Water quality data (mg/liter) compared to Title 22 of the Clean Water Standards

constituent	well 2	well 3	well 4	standard	
Ca	6.6	8.8	9.2	NA	
Mg	7.8	18	12	125	
Na	82	55	53	350	
K	15	5.8	4.7	NA	
HCO_3	266	236	198	250	
SO_4	29	30	23	250	
NO_3	2.7	0.9	2.7	10	
F	0.21	0.2	0.2	1.4	
Mn	nd	0.14	nd	50	
Fe	0.14	nd	nd	0.3	
pH	7.2	6.9	7.5		
conductivity	460	420	350		micromhos/cm
TDS	340	290	250	500	

nd = none detected
(USDA-Forest Service, 1994)

Water issuing from the Mammoth Mine adit had a TDS concentration of 95 mg/l and a spring near the YMCA camp had an electrical conductivity of 50 micromhos/cm (California Department of Water Resources, 1973).

Some of the groundwater pumped by MCWD contains arsenic in minute quantities. After blending with surface water (which does not contain detectable arsenic), the average arsenic concentration in MCWD supplies was 14 parts per billion, with a range of 0 to 37 ppb (Moynier, 2001). The drinking water standard for arsenic is 50 ppb.

Groundwater in the vicinity of the Benton Crossing landfill is monitored with a series of wells to detect any changes in groundwater quality resulting from materials leaching out of the landfill.

As of 1998, there were 12 known cases of leaking underground storage tanks (presumably gasoline or other volatile fuels) within the upper Owens watershed (Lahontan Regional Water Quality Control Board, 1998). A large gasoline spill occurred at the Mammoth Mountain garage facility on January 12, 1999 (Buckmelter, 2000). Approximately 7,500 gallons of gasoline entered the soil, and about a quarter of that amount was recovered within the first few months after the spill. A series of monitoring wells was installed to observe the plume within the groundwater.

The California Department of Water Resources provided mineral analyses for a well near the community of Hilton Creek:

pH	7.0
Ca	6.0
Mg	1.0
Na	6.0
K	1.0
HCO_3	38.0
SO_4	0
Cl	2.0
NO_3	0.5
B	0.01
F	0.1
TDS	44.0
Total Hardness	19.0

(Gram/Phillips Associates, 1980).

Some overly generalized information on groundwater quality for Long Valley between 1994 and 2003 was tabulated in a recent report of the California Department of Water Resources (2004). Two of six public supply wells tested in Long Valley exceeded the maximum contaminant levels for radiological contaminants. All four of the public supply wells tested in Long Valley exceeded the maximum contaminant level for some inorganic secondary contaminant (chloride, copper, iron, manganese, silver, specific conductance, sulfate, total dissolved solids, or zinc). The report's table do not include any more specific information.

In recent years, one of the wells supplying water to the Mountain Meadows Mutual Water Company for part of the Hilton Creek/Crowley Lake community has had concentrations of uranium sufficiently high to be a matter of concern.[citation, details ??]

Natural sources of constituents

Big Springs and Deadman Creek provide natural sources of phosphorus, which encourages abundant growth of aquatic plants in the upper Owens River and in Crowley Lake. Big Springs was found to be the primary source of phosphorus for Crowley Lake (Melack and Lesack, 1982). Hot Creek is the largest tributary to the upper Owens River and contributes additional nutrients as well as some heavy metals. Arsenic is found at high levels in some of the Hot Creek geothermal springs within the creek (Eccles, 1976; Ebasco Environmental, et al., 1993).

Human sources of constituents

Unpaved roads are the principal source of sediments from human activities throughout the Sierra Nevada (Kattelmann, 1996). That situation is likely to be the case within the upper Owens River watershed as well, although grading for residential construction may be the main source in local areas, such as the town of Mammoth Lakes. Activities that remove vegetation and leaf litter, expose soil directly to rainfall and runoff, and compact soil greatly increase the potential for erosion. If the disturbance is near a stream channel, then there is a high likelihood that the eroded sediment will be transported into a stream rather than just relocated. The Mammoth Mountain Ski Area was also identified as a major source of human-caused sediment (USDA-Forest Service, 1988a). However, erosion control efforts and sediment detention basins have presumably greatly reduced the amount of sediment leaving the ski area boundaries.

A variety of petroleum and rubber-based materials are washed off paved roads into storm sewers and small channels.

Nitrogen and phosphorus enter streams from several sources: leakage and failure of septic and sewage systems; overapplication of fertilizers on lawns, gardens, golf courses, and ski runs; release of some household cleaning products; and pet waste.

Pathogenic bacteria, such as E. coli, enter surface waters from leakage and failure of septic and sewage systems, pet waste, livestock waste, human waste from recreationists, and indiscriminate flushing of RV waste tanks.

A standard septic system uses a septic tank and a leach field. If properly designed, installed well above the water table and in adequately draining soil, constructed, and operated, then a regular septic system is capable of nearly complete removal of fecal coliform bacteria, suspended solids, and biodegradable organic compounds (EDAW, 2005). The most critical factor in determining effectiveness of septic systems for treating the contaminants above is the time that leachate takes to travel between the leach lines and the water table. Deep soils that drain slowly allow for maximum biological processing of the wastewater. Unfortunately, in most soils, septic systems are relatively ineffective for removing nitrogen, pharmaceuticals, and other synthetic organic compounds (EDAW, 2005).

The State Water Resources Control Board is currently (2006) drafting new regulations to address septic systems, also known as on-site wastewater treatment systems (OWTS). California currently lacks statewide regulations or standards on septic systems, and practices vary greatly between regional water quality control boards and local jurisdictions. Depending on what criteria are ultimately adopted, the new regulations could result in greatly increased costs for on-site wastewater disposal or building moratoriums in some areas.

Known and potential impacts of altered water quantity and quality

Water availability for human uses

The upper Owens River watershed is used as a water source for export to the city of Los Angeles. Although geologic sources contribute phosphates, arsenic, and other minerals to the water, the overall quality is still excellent and quite suitable for human consumption at its urban destination. Long Valley reservoir (Crowley Lake) provides 60 percent of the storage capacity of the Los Angeles aqueduct system. The primary impacts of the diversion of water to Los Angeles occur downstream of the upper Owens River watershed.

The transport of Mono Basin water through the upper Owens River channel until 1990 and the subsequent absence of that augmented flow, altered some recreational uses of the upper Owens River and Crowley Lake, but the primary effects have been felt in Los Angeles from the viewpoint of the water provider. The average water consumer in the service area is unlikely to have been aware of the presence or absence of the Mono Basin water.

Within the upper Owens River watershed, the principal water supply issues revolve around Mammoth Creek. Effects of the diversion for water supply for the town of Mammoth Lakes probably have been noticed only by a few anglers who have recognized declines in aquatic habitat or fishing success downstream, particularly in the mid-1970s.

Local effects of small-scale diversions on the Hilton Creek fan have been noticed by neighbors currently wishing to use water for horticultural irrigation and, during the 1960s and 1970s, for domestic use.

Riparian habitat

The upper Owens River has an average annual discharge of 76 cfs above the East Portal of the Mono Craters Tunnel (about 3.5 miles downstream of Big Springs). At East Portal, this flow was augmented with water diverted from the Mono Basin from 1941 to 1989, which increased the average flow to 168 cfs. The more-than-doubled discharge resulted in channel erosion, widening and straightening of the stream and destruction of riparian habitat downstream. These channel changes contributed to the estimated net loss of 1.2 miles of upper Owens River stream length (Milliron, 1987).

Wetlands

The overwhelming change in wetlands within the watershed was the inundation of the lower part of Long Valley beneath Crowley Lake. Several thousand acres of wetlands were lost to the reservoir (Smeltzer and Kondolf, 1999). Otherwise, within the watershed, wetlands have not been altered significantly by human-induced changes in water quantity or quality. Residential development and road construction have been more significant agents of change.

Fish and other aquatic species

Trout, native fishes and aquatic invertebrates have been impacted by the conversion of the Owens River in lower Long Valley to a reservoir, the use of the upper Owens River as a canal for imported Mono Basin water and the cessation of that additional flow, the diversion of water from Mammoth Creek, and assorted small changes in the flow regime in many parts of the watershed. The primary change in the quality of water that has obviously impacted fish and invertebrates has been increased sediment in Mammoth and Hot creeks, presumably from the town of Mammoth Lakes. Changes in sediment transport and storage also have been observed in Convict Creek and McGee Creek in association with overgrazing of the riparian corridors and the restoration of those areas in recent years.

USFS personnel measured the flow at Big Springs above the culvert in the spring of 1991, 1992, and 1993 prior to spring runoff. The results indicated flows between 18 and 20 cfs (Alpers, 1994). If wells in the Dry Creek area removed 1,500 acre-feet per year, flows at Big Springs could be diminished by about 17 percent. Such a reduction could impact the ability of migratory trout to reach the prime spawning beds in the Big Springs area (Alpers, 1994).

Edmondson, Jim, California Trout. April 25, 1994:
"The Tennant Method is a desk-top analysis used to determine instream flow needs for fish. This technique has been used by the courts, and the California State Water Resources Control Board to justify instream flow needs for fish when the U.S. Fish and Wildlife Service Instream Flow Incremental Methodology is not available. Tennant prescribes a base flow of 40% of the long-term mean as required to maintain good conditions for aquatic systems from April 1 to September 30th of each year. In the Big Springs case, this calculates to a base of 23.83 cfs from April through September.

The EA discusses potential project reductions in Big Springs flows of 4.4 cfs. This represents 18.4% of the base flow necessary to maintain fish in good condition. While 4.4 cfs may be 'difficult to detect' from a human perspective, from a trout's view this can be the difference between healthy conditions and short-term survival. These impacts become particularly bothersome in dry years, when area fishery resources are already diminished by low flow conditions."

Caltrout Streamkeepers Log 2005: "Due to limited exports during the 2002-2004 summer months, flow regimes on the upper Owens remained between approximately 55-70 cfs. However, instream flow modeling predictions suggest 100-150 cfs are needed to sustain the trout fishery and coldwater ecology of the upper Owens River."

Terrestrial wildlife

Direct impacts of altered water quantity and quality on terrestrial wildlife are not known to have been reported within the upper Owens River watershed. Presumably, there have been adverse consequences to wildlife from degradation of riparian habitat.

Discussion of risk

We rarely know with certainty what will happen if we modify some portion of our environment. If we build a road through the forest near a stream, we will probably increase sediment delivery to the stream. However, it is difficult if not impossible to say how much sediment will be delivered over some period of time and what the secondary consequences of that additional sediment will be. If we divert some portion of a stream's water or raise the concentration of some pollutant, we really don't know what will be affected or to what extent. However, we do know that there is some risk of consequences (usually negative with respect to generally accepted values) from our actions. Attempting to define how much risk is the hard part.

Except at extremes (e.g., completely drying up a stream channel) predicting the environmental impacts of most proposed projects involves a lot of uncertainty. Authors of EIRs tend to avoid admitting to uncertainty because doing so leaves the document subject to challenge as "inadequate." Unfortunately, establishing cause and effect relationships in natural systems is difficult enough after the fact when observations and measurements are available. Forecasting the probable effects of some proposed change in the environment is far more difficult. Nevertheless, the EIR process is designed to make those predictions. In this author's opinion, the best EIRs explicitly address the risks associated with a proposed project. Instead of trying to state that some action will result in some consequence, discussing the potential risks (quantified as well as possible) of the action is a more honest approach.

Many disturbances have minimal environmental impacts as long as particular natural processes or events don't interact with the disturbance. Burning leaves in the backyard is safe as long as there is no wind and humidity is high. Exposing bare soil won't lead to erosion as long as there is no rain or other runoff over the site. Adding a small amount of some pollutant to a large river probably causes little harm until the streamflow drops below the level necessary for thorough dilution. These examples illustrate that we can get away with many alterations of portions of the environment until conditions change that affect the processes interacting with the alteration or disturbance. In many cases, the probability of those changing conditions can be estimated, and the risk of negative consequences can be evaluated. If there is only a 1 in a 1,000 chance that the wind will fan a backyard leaf fire into a wildfire, people will probably accept that risk and go ahead with the burning. Most would not accept a 1 in 10 chance of high winds taking a fire out of control.

Anticipating consequences of changes to streams and their associated habitat and fauna is particularly problematic because the flow regime is generally dependent on climatic factors that involve a large random component. For example, substantial summer thunderstorms that might produce an inch or more of rainfall in a couple of hours are relatively rare in the upper Owens River watershed. So, one could perform some channel restoration work or expose bare soil at a construction site in July and August with little risk of a downpour that would destroy channel modifications or deeply erode a construction site. But, those activities would still be a gamble. The records from the few rain gages in the watershed could be used to estimate the probability of significant rainfall during the construction period and thereby estimate the risk of project failure or substantial erosion. There are many other situations where historic climatic and/or streamflow data can be used to evaluate the risk of unfavorable hydrologic conditions contributing to significant environmental consequences of some activity.

The Mammoth Community Water District and Surface Water Resources, Inc. are currently (winter 2006) preparing a "Draft Environmental Impact Report for Changes in Mammoth Creek Bypass Flow Requirements, Point of Measurement, Watershed Operation Constraints, and Place of Use." There are many issues of concern that involve a high level of uncertainty. For example, the groundwater system underlying the town of Mammoth Lakes is complex, and interactions with flow in Mammoth Creek and downstream springs are not understood. Similarly, how the fishery in Mammoth Creek responds to changes in the managed flow regime through wet and dry years cannot be predicted with certainty. Nevertheless, risks associated with the proposed actions can be described (at least in a qualitative manner) to aid in evaluation of the potential environmental impacts.

Subwatersheds

"Hartley Springs Creek"

A small water course begins in the area of Hartley Springs near Deadman Summit and flows east and then south near U.S. Highway 395. Flow is assumed to be intermittent in most years.

Glass Creek

Glass Creek originates on the eastern slope of San Joaquin Mountain and flows east through a prominent meadow en route to Deadman Creek. The Glass Creek watershed is bordered by June, San Joaquin, and White Wing mountains and extends eastward to its confluence with Deadman Creek. The watershed is approximately five miles long and 1.3 miles wide with a total area of 5.5 square miles. Elevations range from 10,112 feet on June Mountain to 7,495 feet at the confluence with Deadman Creek.

The basin can be divided into three geological sections. The upper third, including Glass Creek Meadow, consists predominantly of basalts. The middle section, extending from the edge of the meadow to the domes, is composed of granite. These granites are highly fractured with large faults. The lower section, including the rhyolite domes and extending to the end of the basin, is composed of basalt. A thick layer of popcorn pumice covers most areas of the watershed and makes geological interpretations difficult (Bade, 1991).

The Glass Creek watershed was eroded by an early glaciation event but then bypassed by recent glaciation stages (Bade, 1991). Glass Creek is isolated by two lateral moraines. Snowmelt waters from San Joaquin Mountain flow north into Yost Creek and south into Deadman Creek. Only two small moraines are found in the western portion of the watershed, and a section of Sherwin till is found in the eastern portion. Very permeable colluvium, landslide deposits, and popcorn pumice cover the steep granite and basalt walls of the Glass Creek watershed. Glass Creek Meadow is the remnants of a lake created by landslides and possible glacial till that dammed the stream. Below the landslide, at least three stream terraces have been located between the domes and the lower sections of the watershed (Bade, 1991).

Most of the surface water for Glass Creek enters through springs and seeps surrounding the meadow, and the stream gains discharge downstream (Bade, 1991). As the stream continues down the canyon, it reaches the granite bedrock, which acts as a groundwater barrier. Groundwater is forced upward, increasing stream discharge locally. Below the granite, the stream loses water until it crosses the lower basalts where discharge again increases. Discharge then decreases as Glass Creek flows through alluvium before entering Deadman Creek (Bade, 1991). Streamflow was measured in Glass Creek just above the confluence with Deadman Creek on three occasions in 1991: 2.3 cfs on June 10, 1.2 cfs on July 9, and 0.7 cfs in September (Kondolf and Vorster, 1992).

The upper sections are sandy and vegetated by lodgepole pine and sagebrush. Riparian vegetation consists mostly of willows and grass. The lowest reach flows through Jeffrey pine forest where cottonwood is the dominant riparian vegetation (Deinstadt, et al., 1985, 1986). A complete barrier to upstream fish migration exists about 3,900 feet downstream of Glass Creek Meadow. Large numbers of juvenile Yosemite toads were found in the meadow in 1993. Glass Creek contains unusually low amounts of woody debris (Millar, et al., 1996).

An entomologist described Glass Creek meadow as "the most biologically diverse meadow I have observed in the Inyo-Mono area" (Giuliani, 1990). The close proximity of several different types of habitat (forest, riparian, wet and dry meadow, streams, springs, and seeps) in and near the meadow apparently contribute to that diversity. On one occasion, 22 species of butterflies were observed, indicating a wide variety of plants in the meadow. Yosemite toad and tree frogs were found in the area along with a variety of aquatic invertebrates (Giuliani, 1990).

Glass Creek Meadow is part of the USFS June Lake Allotment. Inyo National Forest records indicate that the allotment has been grazed annually since at least 1916, and probably before the turn of the century. Vegetation in the meadow is believed to have changed from native grasses to a greater proportion of forbs as a response to heavy grazing a century ago (Millar, et al., 1996). Drier climatic conditions, absence of fire, and overgrazing appear to have combined to allow encroachment of lodgepole pines into Glass Creek Meadow and some incision of the channel, which can lead to further drying of the meadow soils. The meadow is usually grazed for approximately one week in late August or early September (Martin, 1990). Habitat improvement work, including bank stabilization and headcut repair, was performed by the Inyo National Forest in the late 1980s and possibly later. Livestock troughs were installed to reduce the amount of time that the sheep spend along the creek, allowing the bank vegetation to heal (Martin, 1990). Grazing impacts to meadow vegetation were described by Giuliani (1990).

There may be accelerated erosion and sediment transport into Glass Creek from OHV use in and adjacent to the channel. The Inyo National Forest has attempted to address the problem through restricting vehicle use in the Glass/Hartley area.

The discovery of a new species of Plecoptera (a stonefly) halted a 1979 plan by the Department of Fish and Game to chemically treat Glass Creek for the purpose of eradicating brook trout and introducing Lahontan cutthroat trout (Rice, 1980).

Brook trout were planted in Glass Creek on a yearly basis until 1955 when rainbow trout became the stocked fish for this stream. Records show that rainbow trout were stocked at least until 1963 (California Division of Fish and Game, 1938-1963). Apparently, rainbow trout did not produce a self-sustaining population; none was found in the 1979 electrofishing survey (Wong, 1979).

Deadman Creek

The headwaters of Deadman Creek are on the eastern slope of San Joaquin Mountain. Deadman Creek begins from dozens to perhaps hundreds of springs and seeps. The Inyo National Forest has documented 58 spring/seep systems in the headwaters of Deadman Creek, and 95 percent of these appear to be perennial. The creek flows east through Jeffrey pine forest and then through sagebrush flats to Big Springs, where the Owens River starts. The flat area is composed of pumice, and the channel in this area loses most of the water to infiltration (Kondolf and Vorster, 1992). When snowmelt runoff is high, the pumice around the channel fills up temporarily, and surface flow continues farther downstream. As runoff input declines, the stream discharge declines quickly and the wetted portion of the channel "retreats" upstream. The channel of Deadman Creek is typically dry where it crosses U.S. Highway 395, south of the Crestview maintenance station. There is a 20- to 30-foot wide band of riparian vegetation along Deadman Creek that becomes progressively narrower below Deadman campground. Grasses and willow are common plants within the riparian zone (Deinstadt, et al., 1985, 1986).

A fish habitat study reported the mean annual discharge of Deadman Creek as 6 cfs, the minimum monthly discharge as 2 cfs, and the maximum monthly discharge as 20 cfs (Aceituno, et al., 1984). This measurement location is not known. Streamflow in Deadman Creek just above the confluence with Glass Creek was measured on three occasions in 1991: 17 cfs on June 10, 0.2 cfs on July 9, and 0 in September (Kondolf and Vorster, 1992). Sedimentation of portions of Deadman Creek has been attributed to the road crossings of the creek and OHV use within and adjacent to the channel.

Upper Owens

The upper Owens River begins where Big Springs enters the channel of Deadman Creek about two miles east of the Crestview maintenance station on U.S. Highway 395. Big Springs greatly augments the residual flow of Deadman Creek. U.S.F.S. personnel measured the flow at Big Springs above the culvert in the spring of 1991, 1992, and 1993 prior to spring runoff. The results indicated flows between 18 and 20 cfs (Alpers, 1994). The average annual flow for Big Springs is 41,345 acre-feet/year (59.6 cfs) (USDA-Forest Service, 1992: Appendix D). The flow regime of the upper Owens River is quite unusual for a Sierra Nevada stream because it is relatively constant throughout the year, rather the typical 10- to 100-fold difference between base flow and peak flow of most upper-elevation streams in the range.

There are three possible sources for the springs in the upper Owens River, including Big Springs. Flows may come from one or a combination of each source (USDA-Forest Service, 1994):
1) Water may originate as precipitation outside the caldera in drainages similar to Deadman

Creek, Glass Creek and Alpers Canyon. These watersheds are intercepted by the caldera. Water migrates into the caldera groundwater system via the ring fracture system or porous rock units to resurface at Big Springs. Surface geology suggests that there may be some basalt flows that would move groundwater from Glass Creek, Deadman Creek, and/or Dry Creek and cause it to resurface in the Big Springs area. This is partially substantiated by chemical analyses of water samples from Big Springs which indicate detectable levels of phosphates. The closest source of phosphates seems to be located north of the caldera, possibly in the vicinity of Alpers Canyon.
2) Water may originate as precipitation within the west side of the caldera drainage boundary but outside the ring fracture system. This water would migrate into the ring fracture system and follow the ring fracture system in a northerly and easterly direction to resurface at Big Springs. Water could also move laterally across the ring fracture into the fractured rock types that occupy the west moat. This water could flow as shallow groundwater in these rocks all the way to the springs. In this context, the ring fracture is not envisioned as a barrier to groundwater movement.
3) Water may originate as precipitation within the caldera drainage boundary and within the ring fracture system. This water would migrate into the groundwater system and move across the ring fracture system via basalt and rhyolite flows of the west moat that straddle the ring fracture system or flow as shallow groundwater in the basalt flows all the way to the springs (USDA-Forest Service, 1994).

The initial reach of the upper Owens River lies in a narrow forested valley, which opens into a wide flat area covered by sagebrush about one mile downstream. The banks are rocky and stable, and riparian vegetation is well developed. Overhanging vegetation, instream vegetation and pools provide excellent cover for both adult and fingerling fish (Ebasco, 1993; Milliron, 1997). Riparian vegetation is composed of Jeffrey Pine, willow, wild rose, grasses, sagebrush and other shrubs (Deinstadt, et al., 1986)

The river has an average annual discharge of 76 cfs above the East Portal of the Mono Craters tunnel (about 3.5 miles downstream of Big Springs). At East Portal, this flow was augmented with water diverted from the Mono Basin from 1941 to 1989, which increased the average flow to 168 cfs (e.g., Ebasco Environmental, et al., 1993). The more-than-doubled discharge resulted in channel erosion, widening and straightening of the stream, and destruction of riparian habitat downstream. These channel changes contributed to the estimated net loss of 1.2 miles of upper Owens River stream length (Milliron, 1987).

The reach of the upper Owens River between Big Springs and Benton Crossing has been considered to "provide the finest trout fishing available in California" (Von Geldern, 1989). Surveys conducted by the Department of Fish and Game just downstream of the Inaja Ranch indicated standing crops in excess of 120 pounds per acre and numbers usually greater than 5,000 fish per mile (Lentzt, 1993; Milliron, 1997).

In the reach below the confluence with Hot Creek, the upper Owens River meanders through meadows and consists of runs and fast riffles with deeper water and undercut banks on the outside of stream meanders (Milliron, 1987). In the 1980s, this reach of the river was heavily grazed and banks were found to be unstable and collapsing in places. Downstream of the Benton Crossing bridge, Brown's campground contributes recreational impacts on habitat quality of the river. Heavy angler use in this campground and adjacent areas of the river has resulted in a decrease of riparian vegetation and unstable erodible stream banks (Milliron, 1987).

The flow of the upper Owens River as it nears Crowley Lake ranges from 150 cfs in the winter to 350 cfs during spring runoff (Los Angeles Dept. of Water and Power, n.d.)

The Big Springs campground has 24 spaces and a capacity of 120 people. The campground was used by 17,500 people in 1987 (County of Mono, 1992). The Alpers Owens River Ranch occupies 200 acres and 1.5 miles of Owens Ranch frontage immediately upstream of the Arcularius Ranch. The nine rental cabins accommodated 825 guests in 1991 for a total of 2,888 user days. The Arcularius Ranch has 15 cabins and a lodge and estimated about 5,000 user days in 1991. The Inaja Land Company reported 434 angler days of use in 1990 along its 3.3 miles of the Owens River. The Arcularius and Sons Ranch is operated strictly as a cattle ranch on its 560 acres. LADWP estimated 12,360 angler days of use in 1987 on its portion of the Owens River above Crowley Lake (County of Mono, 1992).

The private properties mentioned above also graze cattle. Livestock are excluded from riparian areas on two of the ranches and kept at low densities on the third ranch. Riparian vegetation and resulting trout habitat are in good to excellent condition. On the fourth ranch, grazing has eliminated much of the riparian vegetation, increased soil erosion, leading to sedimentation, organic pollution, channel incision, and fluctuation in stream temperatures, all of which result in deteriorating habitat quality for aquatic life (Platts, 1990). The ranches divert a combined total of 10 to 30 cfs for irrigation (Ebasco Environmental, et al., 1993).

The following changes were made to livestock management in the private lands along the upper Owens River:
Arcularius Ranch livestock reduced by 75% 1998
Inaja Land Company livestock removed 1999
Howard Arcularius corridor fencing 2000, 2001
Benton Crossing private land corridor fencing, 5-year rest 1996
Benton Crossing lake corridor fencing, 5-year rest 2000 (Jellison and Dawson, 2003).

The Owens River above Benton Crossing had very little riparian vegetation in 1994. Following the fence installation in 1996, some willow (*Salix* spp.) and cottonwood (*Populus* spp.) plants were observed in 1999 (Jellison and Dawson, 2003). Channels for the Owens River and some tributaries have narrowed and deepened as a result of the fencing and livestock management treatments (Hill, et al., 2002).

Dry Creek

The Dry Creek area is bordered by Mammoth Mountain to the southwest, Deer Mountain to the northwest, and Mammoth Knolls to the southeast. The watershed is about 13,000 acres in size above U.S. Highway 395 plus 2400 acres east of the highway. The length of the Dry Creek drainage is approximately 11 miles with a change of elevation of almost 4,000 feet from Mammoth Mountain (11,053 feet) to its confluence with the Owens River (7,120 feet). The stream channel carries water during and shortly after snowmelt runoff from within the ski area just above State Route 203 down to about 8,000 feet. In very wet years, surface flow in the channel persists to lower elevations.

The Dry Creek watershed has been proposed for a well field to supply up to 2,000 acre-feet of water for the town of Mammoth Lakes (USDA-Forest Service, 1994).

The ski area pumped about 190 acre-feet in 1994 from its wells in upper Dry Creek. Approximately 93 acre-feet were used for operation of the ski area, lodging, and summer irrigation, and 100 acre-feet were used for snowmaking in 1994. The net consumptive use of water by MMSA is estimated to be 116 acre-feet of the 193 acre-feet extracted (MMSA Snowmaking EA, 1991, cited by USDA-Forest Service, 1994). The remainder (77 acre-feet) is returned to the groundwater system through infiltration.

Average annual precipitation ranges from 14 to 60 inches within the Dry Creek watershed. These values are highly variable from year to year, and departures from the mean range as high as 50 percent (USDA-Forest Service, 1994). Precipitation input to the Dry Creek watershed has been estimated at about 27 inches or 29,000 acre-feet, on the average. About 15 inches (Gram/Phillips Associates, 1987; California Department of Water Resources, 1973) (or 16,000 acre-feet) is estimated to be lost to evapotranspiration. The remainder of 12 inches (or 13,000 acre-feet) is calculated as an average amount of recharge, which presumably enters the upper Owens River (USDA-Forest Service, 1994). The Dry Creek subwatershed has an unusually deep amount of soil and other unconsolidated volcanic material over much of its surface area.

The Dry Creek channel extends to a point about one-half mile south of the Arcularius Ranch (in section 29), but past field reviews have failed to find where the water physically enters the Owens River. Dry Creek was rumored to have reached the Owens River during the summer of 1983, though no evidence was found to substantiate this claim (USDA-Forest Service, 1994). During the high runoff in the summer of 2006, Dry Creek was followed by the author from the creek crossing under U.S. Highway 395 to its point of disappearance near the Owens River south of Arcularius Ranch. Discharge was crudely estimated at several points by simple velocity, width, and depth measurements (for example, surface velocity of 2 to 2.5 feet per second [reduced by a factor of 0.6 to estimate average velocity], width of 2 to 3 feet, and depth of 5 to 8 inches). Values all along the channel below U.S. Highway 395 were about 2 cfs (+/- 1 cfs) until the flat area where the stream spread out and percolated into the soil. Even within 200 feet of the end of flowing water, the channelized discharge was still about 1.5 cfs. About 50 feet from the end of flowing water, the channelized discharge was about 0.6 cfs. The flow ceased and the soil surface was dry about 30 feet south of the fence between Inyo National Forest land and Arcularius Ranch land.

The soils of the Dry Creek watershed consist primarily of pumice with small areas of shallow organic layers up to three inches thick. The susceptibility to erosion of undisturbed soil is classified as "moderate." This classification would change to high where soil is disturbed by road construction or excavation (USDA-Forest Service, 1994). The pumice surface is easily altered by rainfall or snowmelt, and moving water readily transports pumice particles downslope. In addition, sheet flow erosion throughout the area results in accumulations of pumice particles which are transported into creek channels. During years of ample snowpack and runoff, flushing flows move accumulations of previously deposited sediment (USDA-Forest Service, 1994).

O'Harrel Canyon Creek

O'Harrel Canyon Creek is a small, spring-fed stream on the western slope of the Glass Mountains above Long Valley. The creek is notable for its population of Lahontan cutthroat trout. The creek originates between 9,600 and 10,000 feet elevation. After the two upper forks join, the stream flows down a steep, narrow canyon, and then across a sagebrush covered alluvial fan. Year-round surface flows extend to 6,960 feet elevation where the stream seeps into the alluvium. The perennial part of the stream is approximately three miles long, and the intermittent portion is about two miles long. Drainage is into the Owens River, but surface flow has not been observed to reach the river, which is about a mile and a half from the area where surface flow in the creek usually ceases (Inyo National Forest, 1980; Wong, 1978).

O’Harrel Canyon Creek's watershed area is about 2.1 square miles. Streamflows were measured by the Inyo National Forest (0.48 to 0.22 cfs [Clark, 1979]) and the Department of Fish and Game (0.5 cfs [Wong, 1978]) in the late 1970s. Water quality for this watershed was found to be excellent and typical of other areas of the upper Owens River basin with little disturbance (Clark, 1979).

Between 7,600 and 10,000 feet elevation, the upland vegetation is an association of trees and shrubs. Sagebrush, bitterbrush and grasses are joined with Jeffrey pine, lodgepole pine, pinyon pine, white fir and juniper (Inyo National Forest, 1980).

The riparian vegetation associated with the creek is typical for the southern slope of the Glass Mountains. Along the lower mile of the creek, the dominant vegetation surrounding the riparian zone is sagebrush, bitterbrush, and various dryland grasses. Riparian vegetation is sparse in this area, consisting primarily of meadow grasses and willows. The riparian zone consists of aspen, cottonwood, willow, currant, water birch, wild rose, and various meadow grasses. There are no known sensitive plant species. In section 23 where hardwoods dominate, there are three areas where the creek has become incised to about 12-foot depth (Inyo National Forest, 1980). Numerous road crossings are also contributing to downstream siltation (Inyo National Forest, 1980).

A national forest grazing allotment included the O'Harrel Canyon Creek watershed at least through 1980. Creek water was diverted to a water trough for the cattle. The water diversion has been identified as a barrier to fish movement. Grazing in the riparian zone has reduced vegetative shading of the creek, which led to high water temperatures. Livestock grazing also negatively impacted the physical features of the channel (Inyo National Forest, 1980).

The creek supports a small, pure population of Lahontan cutthroat trout. This fish is a federally classified threatened species. O’Harrel Canyon Creek is not within the native range of Lahontan cutthroat trout, and this population may have been transplanted to the creek as early as 1870. During a routine stream survey of the previously unstudied O’Harrel Canyon Creek in September 1978, personnel of the Department of Fish and Game found 11 Lahontan cutthroat trout (Wong, 1978). This surprise finding led to detailed studies of the fish population over the following years and determination that it was a pure genetic strain. The 1978 surveys found that the population was healthy and occupied about 0.8 miles of the channel. The reach suitable for fish appears to be limited on the upper end by increasing channel slope and on the lower end by high water temperatures (measured up to 90°F) in summer (Wong, 1978).

Additional surveys in 1979 and 1980 generated estimates of total population of 300-450 fish (Wong, 1979) and 650 fish (Kanim, 1980), respectively. In 1981, 300 fish were captured and measured (Wong, 1981). Following the heavy snowmelt runoff year of 1983, the next survey (in 1985) observed only 13 fish (Wong, 1986). A late-autumn survey in 1986 found more fish than the previous year, which suggested the population was slowly recovering (Wong, 1987). A survey in June 1998 found that the Lahontan cutthroat trout are surviving at low densities and are reproducing (Becker and Wong, 1998).

The Inyo National Forest has recently undertaken several projects to improve habitat quality in O'Harrel Canyon Creek. Six headcuts have been stabilized along the section of stream that supports Lahontan cutthroat trout. Several pools have been created by the construction of small rock dams. An exclosure fence has been constructed along a two-mile reach of the stream. A stream road crossing has been closed by construction of a drift fence. A new water intake was constructed to eliminate the need for the weir that blocked fish passage (U.S. Fish and Wildlife Service, 1982).

Little Hot Creek

Little Hot Creek is the only named tributary to the upper Owens River that begins far away from either the crest of the Sierra Nevada or Glass Mountains. Its location is close to the geographic center of the upper Owens River watershed. Little Hot Creek has its source in the hills around Little Antelope Valley. Kaolinite clay is mined in the area. The channel near the main hot springs (water temperature of about 180°F) that initiate Little Hot Creek became eroded and incised after surrounding vegetation was removed by excessive grazing (USDI-Bureau of Land Management, 1978). The Forest Service attempted to limit further erosion by installing fencing around the channel and log structures within the channel in 1977. Little Hot Creek flows to the northeast out of the valley and then east toward the upper Owens River. Terrace deposits from the ancient lake that once filled the Long Valley caldera form the canyon of Little Hot Creek. The channel downstream passes through a marsh and alkali flat, then into distributaries of Hot Creek, which occupy a former delta of the caldera lake (Hernandez, 1991). The lowlands of this area both trap surface water and contain hot springs. The natural channel has been modified by a ditch excavated within the portion of the stream on BLM land (USDI-Bureau of Land Management, 1978).

Jeffrey pine, sagebrush, bitterbrush and juniper dominate the vegetation of the upper hills and drier parts of the Little Hot Creek watershed. Some of these plants may be aided by fracturing of the rhyolite, providing groundwater to some soils (Hernandez, 1991). Riparian plants typical of other tributaries to the Owens River are largely absent along Little Hot Creek. The old lake bed deposits are all siliceous and well-cemented, limiting vegetation to only the heartiest of plants that are adapted to such soils. Wire grasses that are tolerant of high water temperatures surround many of the hot spring areas (Hernandez, 1991).

A limited amount of discharge, temperature, and conductivity data has been collected. One study found that discharge of the principal springs was about 0.12 cfs through a 3 inch parshall flume, and the cumulative discharge for all of the springs was 0.36 cfs, measured with a 90° v-notch weir (Hernandez, 1991). Temperatures of the individual hot springs ranged from 138°F to 180°F with the springs at the hot tub area measuring 120°F. Electrical conductivity readings taken in the hot springs ranged from 2,750 to 3,950 micro-mhos (Hernandez, 1991).

Little Hot Creek does not support trout, but does contain a hybridized population of tui chub as well as mosquito fish (USDI-Bureau of Land Management, 1978).

Popularity of hot springs in the lower portion of the watershed for recreational bathing has led to excavation of new channels and compaction of soils from vehicles.

Sherwin Creek

Sherwin Creek originates in steep, talus-covered bowls immediately east of the Sierra Nevada crest. The stream channel emerges from Valentine Lake and continues north through Lost Lake, where another fork enters from the southwest, and to Sherwin Lakes. Sherwin Creek then drops steeply through a red fir - lodgepole pine forest. The slope of the channel then eases substantially, and the creek flows through a forest with increasing proportion of Jeffrey pine before its confluence with Mammoth Creek. Scrub alder is the primary riparian species. Red fir, Jeffrey pine, and aspen are also present along the stream. The lower channel has both pools created by log jams and cascades. Electrofishing surveys indicated a standing crop of 160 lb/acre of brown trout (Deinstadt, et al., 1986; Milliron, 1997).

Laurel Creek

Laurel Creek originates in a small alpine basin north of Bloody Mountain, which contains a couple of small lakes and meadows at about 9,800 feet. The creek flows north through a gentle valley before descending steeply across a glacial moraine. Another fork parallels the main channel and enters from the west below the moraine. The lowest reach lies on relatively flat terrain where the water percolates into the ground before reaching Mammoth Creek as surface flow. The meandering section in the meadows was surveyed for fish, and the results showed a standing crop of 99 lb/acre for brook trout and 6 lb/acre for golden trout, for a total of 105 lb/acre of stream surface area (Milliron, 1997). Riparian vegetation in the meadows consists of about 2/3 grasses and 1/3 willow (Milliron, 1997). An unmaintained dirt road winds up the moraine, follows the creek (usually within the riparian zone), and ends at Laurel Lakes. Substantial vegetation damage and erosion around Laurel Lakes appears related to OHV use. An old trail continues up Bloody Mountain to a mining prospect at about 11,100 feet.

Mammoth Creek

Mammoth Creek supplies a large fraction of the natural flow of the Upper Owens River. Its headwaters are on the eastern slope of the Mammoth Crest where the deepest snowpacks in the entire basin can be found. It flows north through the Lakes Basin and along the south side of the town of Mammoth Lakes, and then east to Hot Creek. The upper portions of the creek flow through montane forest and small meadows, then through sagebrush scrub with a willow-birch riparian corridor downstream of the town. After crossing U.S. Highway 395, the creek flows through meadows before reaching the confluence with the Hot Creek headsprings (Deinstadt, et al., 1986).
The Mammoth Community Water District diverts water from Mammoth Creek at Lake Mary, greatly reducing the natural flow during the drier months of the year. This water supply diversion is discussed in section 6 and is the subject of a major environmental impact report to be released by the MCWD in 2007. As part of a collaborative process between the water district, California Trout, and other interested parties, a technical committee has been formed to identify specific resources and study areas along Mammoth Creek and Hot Creek (California Trout, 2005).

The flow in Mammoth Creek has been monitored since 1932 by LADWP at a flume a short distance downstream from U.S. Highway 395. Discharge measured at this point has ranged from 3,000 to 40,000 acre-feet/year and averages about 17,000 acre-feet/year (Berkeley Group, 1987).

Much of the controversy surrounding the water district's plans for Mammoth Creek is in regard to changing the physical point of measurement of streamflow on the creek. The gage near Old Mammoth Road is proposed as the new measurement site for determining how much water can be diverted from the stream. There is concern that moving the reference point to the upstream gage would lead to less water in the channel between the town and the highway (where the LADWP gage is located).

The channel of Mammoth Creek between the gages at Old Mammoth Road and U.S. Highway 395 both gains and loses water to groundwater depending on how much water is available (wet year vs. dry year), the time of year, and different parts of the channel (Burak, et al., 2006). Continuous records of flow at the gages as well as manual spot measurements along the channel (BEAK Consultants, 1990) demonstrate that there is usually a net loss of flow between the Old Mammoth Road gage and the U.S. Highway 395 gage during dry and average years. In wetter years (indexed by a Mammoth Pass snowpack of more than 37 inches of snow water equivalence at peak accumulation), the channel tends to gain water between Old Mammoth Road and U.S. Highway 395 (Burak, et al., 2006). The years when the channel has been gaining or losing water have been tabulated by Burak, et al. (2006). Streamflow from Sherwin Creek that enters the channel just above the U.S. Highway 395 gage is really only significant in wetter years and may be sufficient to compensate for channel losses in Mammoth Creek that may occur in almost all years.

Spot measurements of flow in Mammoth Creek on May 24, 1982, and July 20, 1986, show that a portion of the flow is lost to channel infiltration in the meadows between U.S. Highway 395 and the Hot Creek fish hatchery. An unknown quantity is diverted during the summer months for local irrigation, which may account for some of the loss, depending upon the time of the year (Berkeley Group, 1987).

The quality of the water in Mammoth Creek tends to be very good above U.S. Highway 395, but begins to degrade as hot spring discharge and grazed land runoff contaminants increase downstream (Setmire, 1984). The Forest Plan of the Inyo National Forest (USDA-Forest Service, 1998a) states that suspended sediment in Mammoth Creek during snowmelt runoff increases tenfold between the outlet of Twin Lakes and U.S. Highway 395.

Murphy Gulch was a natural surface tributary to Mammoth Creek and is represented as a "blue line" stream on the USGS "Old Mammoth" 7.5-minute map of 1986. Construction of a dam to retain stormwater runoff and sediment has stopped surface flows since 1988, but some subsurface flow undoubtedly persists below the old channel (Burak, et al., 2006).

The primary surface drainage feature in the area of the Mammoth Pacific geothermal plant is an unnamed ephemeral tributary to Mammoth Creek. This channel originates near U.S. Highway 395 approximately 0.5 miles northwest of the Casa Diablo area and joins Mammoth Creek about 0.4 miles to the south. The discharge of this ephemeral stream varies seasonally from 0 to about 40 cfs. Flow rate and chemistry are dependent upon the relative contribution from the Casa Diablo hot springs located nearby. In years with above-average precipitation, the tributary flows year round. Variations in snow and rainfall amounts are the major cause of fluctuations in the flow of this stream (Berkeley Group, 1987).

Several springs are found along the lower reach of Mammoth Creek:

- Casa Diablo geyser and associated springs have an estimated discharge of 0.35 to 1.4 cfs. Chemical analyses (Berkeley Group, 1987) suggests these springs have a complex mixture of water sources.
- Colton Spring, about 1 mile southeast of Casa Diablo, appeared suddenly at approximately the same time as a large scale seismic event in 1980. Its discharge in 1985 was estimated at 0.021 to 0.029 cfs.
- Meadow Spring, located in the meadow southwest of old Highway 395, is cooler (126°F - 144°F) with low intermittent discharge.
- Chance Spring, with a temperature of 64°F-68°F, flows from a group of vents along Mammoth Creek. It has a relatively high discharge (approximately 0.81 cfs), and a chemical composition closer to that of meteoric water than other nearby springs, suggesting a small thermal water component.
- Hot Bubbling Pool, one-half mile north of the hatchery, has no surface discharge (Berkeley Group, 1987).

A study of grazing impacts on the lower reaches of Mammoth Creek before riparian fencing found that physical habitat characteristics declined progressively downstream (Herbst and Knapp, 1995).

In 1994, fencing was built on the Chance Ranch along Mammoth Creek to separate the riparian area from other pastures, and different rest-rotation schedules were set up for the riparian pastures. The riparian pastures could be grazed until 35 percent of the forage was removed, and sensitive stream sections were fenced and set aside as ungrazed areas (Hill, et al., 2002). In 2001, three large irrigation structures were constructed on the Mammoth Creek Chance Ranch to better regulate irrigation flows and prevent return irrigation flows from re-entering Mammoth Creek (Jellison and Dawson, 2003).

In Mammoth Creek, in addition to brown trout and rainbow trout, two native fish were also found: the Owens sucker (*Catostomus fumeiventris*) and Owens tui chub (*Gila bicolor snyderi*). The biomass of these more-tolerant native species was highest in the degraded Spring pasture site and lower on pastures with less physical habitat alterations (Herbst and Knapp, 1999).

MTBE (methyl tertiary butyl ether), a gasoline additive, has been found in water samples from Lake Mary.

Hot Creek

Hot Creek begins in a series of warm springs in a broad flat area at the Hot Creek Fish Hatchery. At the downstream boundary of the hatchery property, the natural and artificial channels join together and add Mammoth Creek, becoming the largest tributary to the upper Owens River. The stream flows through a meadow on BLM land for about 1.5 miles, and then through Hot Creek Ranch for 1.1 miles before entering Hot Creek Gorge. The channel through the gorge is about 2.7 miles long. The remaining 3.3 miles of the stream flows through meadows and splits into distributaries before joining the Owens River.

The four major springs contributing water to the Hot Creek fish hatchery are located at the edge of a basalt flow. These are the only sources of water for hatchery operations. Temperatures of the springs decrease from west to east at 61°F, 57°F, 55°F, and 52°F (Farrar, et al., 1985). Discharges of these springs have been measured as 12.7, 12.3, 6.2, and 4.8 cfs for a total of 36 cfs (Berkeley Group, 1987). Another estimate put the combined flow at about 20 cfs (Sorey, 1975). The combined flow is estimated to fluctuate 10 percent to 15 percent seasonally, but remains relatively constant in relation to creek flow. Discharge from all four springs contributes a significant amount of flow to Hot Creek above the gorge during periods of lowest creek flow (Berkeley Group, 1987).

A stream gage below the Hot Creek gorge has been operated since 1923. Stream flow at this flume has ranged between 25,000 and 80,000 acre-feet/year and has averaged approximately 40,000 acre-feet/year (California Department of Water Resources, 1967). The average over 49 years was 40,540 acre-feet/year (California Department of Water Resources, 1973).

Several springs discharge at varying rates along Hot Creek gorge. These are associated with a graben structure bounded by two faults (Berkeley Group, 1987). Total spring flow from this area cannot be measured directly because the major contributing vents are below the water line of the creek. However, an estimate of flow rate can be made from chemical flux correlations using the total flow of Hot Creek and its chemical load, measured at the USGS flume below the gorge (Farrar, et al., 1985). Of the total discharge of Hot Creek below the gorge, about 7,000 acre-feet/year (or an average of 9.5 cfs) are contributed by hot springs in the gorge (Farrar, et al., 1985). These springs temporarily increased discharge to about 11.6 cfs following the seismic activity in 1980 (Farrar, et al., 1985).

The thermal springs of Hot Creek have produced highly mineralized water for some 300,000 years. The ancestral Owens River carried some of the dissolved matter past Owens Lake and Indian Wells Valley into the basin of Searles Lake. The ancient mineral deposits initially released near Hot Creek are the basis of highly profitable mining operations (Smith, 2003). Arsenic is found at high levels in some of the Hot Creek geothermal springs within the creek (Milliron, 1987). Arsenic has been found at concentrations of up to 1.1 mg/l in some tributary springs, and moderate to high levels of boron, fluoride, antimony, iron, barium, aluminum, manganese, mercury, silver, and nickel have been found in other samples of water and fish tissue (Lahontan Regional Water Quality Control Board, 1994).

Geothermal development in the Hot Creek area has apparently affected flows in several thermal springs in the area: Colton Spring, a tributary to Mammoth Creek; Chance Meadow Springs; Hot Bubbling Pool, just north of Hot Creek hatchery; and the Hot Creek headsprings at the hatchery (Milliron, 1987). Future development could possibly further reduce downstream thermal springs. As aquifer pressure declines, underground conduits created by faults could collapse or calcify, permanently closing of the source of thermal waters. The effect on Hot Creek productivity is unknown (Milliron, 1987).

Up to 3 cfs is diverted for irrigation on the north side of the stream about 0.25 miles above the lower BLM boundary (USDI-Bureau of Land Management, 1978).

Grasses are the primary plants of the riparian zone (Deinstadt, et al., 1986).

Hot Creek Fish Hatchery

The fish hatchery on Hot Creek is a key facility with respect to both water quantity and quality in the Mammoth/Hot Creek watershed. All upstream water use, including surface flows, groundwater, and geothermal, raises concerns about hydrologic impacts on the springs that provide warm water to the hatchery. Nutrients generated from the hatchery operation are a major source of pollution to Hot Creek (California Regional Water Quality Control Board -- Lahontan Region, 1999).

The Hot Creek fish hatchery was created in 1928 by the Rainbow Club of Bishop. The California Department of Fish and Game took over operation of the hatchery in 1931 and has increased its production and size over the years. The hatchery produces more than 2 million fish and about 20 million eggs annually (Smith, 2003).

The Department of Fish and Game and the Lahontan Regional Water Quality Control Board have investigated water quality standards for discharge into Hot Creek. Although they have agreed that the hatchery is in compliance with present water discharge requirements, studies are under way to further determine the hatchery's impact on downstream fish habitat in Hot Creek.

Wastewater originates in the hatchery buildings, production raceways and broodstock raceways. All operations are conducted on a once-through flow basis. Although water was recirculated in the past, that process is no longer done for disease prevention. There are four spring sources for the hatchery: AB Spring, CD Spring, Hatchery I Spring and Hatchery II Spring (Larson and Associates, 2001).

Average discharge of the springs:
AB Springs 6.9 mgd (302 l/s)
CD Springs 6.5 mgd (284 l/s)
Hatchery I Spring 2.5 mgd (109 l/s)
For a total of 19.7 mgd
(California Regional Water Quality Control Board Lahontan Region, 1999).

AB and CD springs flow into four production raceways. Discharge from the raceways is directed into settling ponds I and II, then into Hot Creek over weirs and via concrete channels (Larson and Associates, 2001). Before February 1977, sludge from the raceways was discharged directly into Hot Creek (USDI-Bureau of Land Management, 1978).

Hatchery Spring I flows into a broodstock channel and the Hatchery I building, and then into McBurney Pond. This pond discharges over a weir and through a culvert to Hot Creek. The combined flow from Settling Ponds I and II and McBurney Pond constitutes the majority of the flow in Hot Creek (Larson and Associates, 2001).

Hatchery II Springs flow through a broodstock raceway and then through Hatchery II building. The discharge from the raceway is over a weir and into a natural channel for about 700 feet before it reaches Hot Creek. This discharge into Hot Creek is about 2,000 feet downstream of the other three discharges and 1,600 feet downstream of the confluence of Mammoth Creek and Hot Creek. Although there is no settling pond for this discharge, treatment is provided by settling and filtration by vegetation in the 700-foot-long channel. Discharge from this channel is typically better quality than that from the settling ponds (Larson and Associates, 2001).

Raceways are cleaned once a week in summer, less often in winter. Algae and debris (unused food and fish excrement) are suspended and carried to the settling ponds. Detention times for each pond are as follows:

Settling Pond I- 65 min
Settling Pond II- 58 min.
McBurney Pond- 78 min.

However, during a site visit, floating clumps of algae were seen entering pond 2 and flowing directly to the outlet in less than 30 minutes (Larson and Associates, 2001).

In the years 1997-2000, suspended solids were measured monthly, both a grab sample and a 24-hour composite sample. Although water quality samples show that discharge meets all of the permit requirements, some water high in suspended solids may be passing through the settling ponds (Larson and Associates, 2001).

Benthic sampling indicates that suspended organic solids are passing through ponds occasionally and often enough to result in conditions indicative of pollution downstream of the three ponds (but not discharge from the channel at Hatchery II) (Larson and Associates, 2001).

Total suspended solids data collected from 1996-98 indicate that McBurney Pond does not provide adequate retention time. The average concentration of the non-compliant samples was 14.5 mg/l (permit limit of 5 mg/l). There were six other instances reported during the 1996-98 period in which the hatchery failed to comply with the 1992-permit limit. Effluent samples are typically collected at each of the four discharge sites during cleaning operations, which increases the discharges of suspended matter (California Regional Water Quality Control Board Lahontan Region, 1999).

In the reach just downstream of the hatchery, rooted aquatic plants and deep pools provide excellent cover for fish. Banks are stable and vegetated with grasses and sagebrush (Deinstadt, et al., 1986). This reach receives heavy fishing pressure, but has a zero limit, barbless-fly regulation. This one-mile public stretch of Hot Creek is one of the most heavily fished in the U.S. with an estimated 7,000 angler-days in 1991 (County of Mono, 1992). In the 1970s, the populations of invertebrates in this reach declined as the sediment load and storage increased (USDI-Bureau of Land Management, 1978). Aquatic plants in the streambed and below-average flushing flows during snowmelt runoff apparently contributed to retaining sediment in this reach. Likely sources of the sediment were roads and trails close to the channel, a sediment pulse initially from construction in Mammoth Lakes that eventually moved from Mammoth Creek into Hot Creek, and streamside grazing in the Chance Meadow (USDI-Bureau of Land Management, 1978).

The reach of Hot Creek just upstream of its confluence with the Owens River and downstream of the hot springs in the gorge is uniformly shallow, and water quality here is influenced by the heavily mineralized hot springs upstream of the section (Deinstadt, et al., 1986). Rooted aquatic plants and undercuts provide cover, but water quality in this section is the limiting factor for brown and rainbow trout. Tui chub (*Gila bicolor*) was the most abundant fish found in this section, followed by Threespine stickleback (*Gasterosteus aculeatus*) and Owens sucker (*Catostomus fumeiventris*) (Deinstadt, et al., 1986).

Benton Crossing Landfill

Mono County's primary landfill site is located about 500 feet north of Big Alkali Lake, about a mile away from the confluence of one of the Hot Creek distributaries and the Owens River. The 95-acre landfill buried about 27,500 tons of waste in each of 2002 and 2003 (Mono County Planning Department, 2004). About 3/4 of this material was generated in the town of Mammoth Lakes. The landfill is designed and operated to minimize the infiltration of water into the waste material by covering and grading to direct storm runoff away from the buried waste. The facility does not have a liner underneath the disposal area or a leachate collection and recovery system. Monitoring wells are located both upgradient and downgradient from the landfill to detect any changes in groundwater quality resulting from contaminant leaching out of the landfill. Depth to the water table in this area ranges from 18 to 30 feet below ground surface (Mono County Planning Department, 2004). Runoff from the surface of the landfill is directed into four detention basins intended to capture sediments and minimize off-site erosion.

Convict Creek

The headwaters of Convict Creek (which was originally known as Monte Diablo Creek [Smith, 2003]) are on the north slopes of Red Slate Mountain (13,163 feet), which supports several tiny glaciers and rock glaciers. The main channel of Convict Creek forms remarkably close to the top of a pass (Corridor Pass at 11,760+ feet) that provides access to the upper part of the McGee Creek watershed. The first large lake is also high in the watershed at 10,800 feet. The creek continues almost due north to Mildred Lake where water enters from the subwatershed of Lake Dorothy to the west. The ten lakes in the Convict Creek watershed range in surface area from 5 to 170 acres and in depth from 25 to 290 feet (Baas, et al., 1976). Measurements of temperatures in these lakes during summer ranged from 39 ^{o}F to 60^{o}F and clarity measurements with a Secchi disc were 40 to 60 feet (Baas, et al., 1976). Below Mildred Lake, the creek enters a narrow canyon between Laurel Mountain (11,812 feet) and Mount Morrison (12,268 feet). A major tributary enters from the west that drains a basin with several lakes on the east side of Bloody Mountain (12,544 feet). The trail bridge at this confluence was destroyed by a flood in the 1980s. Debris flows are relatively common within the canyon and occasionally block the creek for a few hours until the temporary dam bursts. A large stand of cottonwoods occupies a riparian flat area at about 8,400 feet. The canyon opens up just above Convict Lake, and the creek turns to the east, flows through a delta with multiple channels and old cottonwoods before entering the lake.

Convict Lake has a surface area of 168 acres, a maximum depth of 140 feet, and lies at an elevation of 7,583 feet (Von Geldern and Kabel, 1960). It is heavily fished and has long been popular with summer recreationists. The lake was estimated to have a productivity of less than 15 lbs. per surface acre per season, or about 100 small wild trout per acre (Von Geldern and Kabel, 1960). In 1935, Needham (1938) estimated a return to the angler of 17 percent of a plant of 2,041 rainbow trout which averaged 5.5 inches in length. Convict Lake is the only lake on the southern part of the eastern slope of the Sierra Nevada that supported naturally occurring fish -- Owens sucker (Moyle, et al. , 1996). Sampling conducted under the Toxic Substances Monitoring Program in 1992 found "elevated" levels of selenium, silver, zinc, and nickel in Convict Lake, probably from natural sources (Lahontan Regional Water Quality Control Board, 1994).

Just downstream of Convict Lake, a resort with several cabins and a restaurant is located west of the creek, and a 88-site campground is located on the east side of the creek. Several campsites are within the riparian zone. A sewage treatment facility is situated on a terrace west of the creek about 0.8 miles downstream of the dam. A narrow riparian strip, composed mostly of Jeffrey pine, cottonwoods, and willows, follows the creek through the moraine below Convict Lake.

The Sierra Nevada Aquatic Research Laboratory is located on Convict Creek at 7,080 feet elevation. The creek has been divided into multiple channels here, and the trees drop out of the riparian zone at this elevation. This reach has relatively deep, narrow stream channels, unembedded substrate, riparian cover dominated by willow, deep-rooted sedges and grasses, and many deeply undercut banks (Knapp, et al., 1993). Cobbles compose the uppermost layer of sediment and are largely covered with bluegreen algae and diatoms (Kuwabara, et al., 1984). Willows have been thinned out by livestock grazing below SNARL. In the lower reaches, bank vegetation is composed mostly of grasses, and there are many areas of active erosion and deposition of sod into the stream with little shading of the stream (Deinstadt, et al., 1986; Milliron, 1997). There are small areas of meadow and marsh vegetation, as well as multiple channels, along the lower portions of Convict Creek before it joins McGee Creek approximately one mile west of Crowley Lake. A Caltrans maintenance station adjacent to U.S. Highway 395 is on a fan well above the lower reach of Convict Creek.

The primary stream gage on Convict Creek is operated by LADWP and is located between Convict Lake and SNARL at 7,450 feet, about two miles upstream from U.S. Highway 395. The watershed area above the stream gage is 18.2 square miles. The gage was installed in 1925, and data were published by the USGS between 1959 and 1975. Streamflow averages about 10 cfs in the winter and about 100 cfs in spring and early summer during snowmelt runoff (Los Angeles Department of Water and Power, n.d.). The USGS reported an average discharge of 24.4 cfs or 17,680 acre-feet/year over a 53-year period ending in 1978. Through 1978, the peak flow on record was 290 cfs (16 cfs/mi^2), which occurred on June 29, 1932. Snowmelt runoff peaks typically occur during June and average about 120 cfs or 6.4 cfs/mi^2.

The reach of the stream that meanders through the meadows of Long Valley above Crowley Lake has a mean annual flow of 25 cfs (Deinstadt, et. al., 1985).

The Department of Fish and Game has been conducting "spawner checks" on Convict Creek since the 1950s, mainly for rainbow trout in the spring. In April 1959, a routine check of spawning conditions in the tributaries to Crowley Lake found a mile-long section of Convict Creek was completely devoid of water. This situation was the result of excessive diversion of water into irrigation ditches. Although no single diversion was unusually large, the cumulative effect of several diversions left no flow in the creek (Pister, 1959). The many irrigation ditches off Convict Creek provide habitat for juvenile fish. However, there is high mortality every fall when the irrigation ditches cease to flow. The use of fish screens on the diversions that are used by juvenile trout has been considered (Milliron, 1997). This problem has existed for decades. In 1963, the Department of Fish and Game estimated a loss of 20,000 fish to one major irrigation diversion on Convict Creek (Pister, 1963).

The Department of Fish and Game stocks the creek with rainbow trout above SNARL (Milliron, 1997).

A study of grazing impacts on physical habitat characteristics, fish, and aquatic invertebrates of Convict Creek below the moraine was conducted in the 1990s (Herbst and Knapp, 1999). Several reaches that had varying levels of grazing use were surveyed and compared. Habitat changes observed between sites and seasonally were consistent with the observed differences in grazing impact over the study area (Herbst and Knapp, 1999).

The ungrazed SNARL reach served as a control and was found to have the most suitable and constant habitat conditions of all the study areas. The relative consistency of conditions related to the observations that channel substrate and vegetation cover changed in the grazed reaches between spring (pre-grazing) and autumn (post-grazing). The primary seasonal changes in the grazed reaches were greater embeddedness (relative lack of pore spaces between sediment particles) and more algae and aquatic vegetation (primarily Ranunculus and Elodea in this study) (Herbst and Knapp, 1999). The growth of algae and aquatic vegetation was thought to result from the greater sunlight reaching the stream in the grazed reaches that had relatively riparian vegetation. Aquatic vegetation may trap sediments as well, thus augmenting the fine particulate matter that may clog the stream bed surface. There was little or no change noted in the mean size of substrate particles or percent fine particles. None of the physical habitat characteristics changed seasonally in the control reach, and significant seasonal changes were not found in two of the pastures.

The benthic invertebrate community was observed to respond most to changes in the substrate features that changed seasonally (embeddedness and vegetation on the streambed). The Spring pasture, which seemed to have the greatest grazing pressure, was indicated as the most impaired reach by an index of the invertebrate community in both spring and fall. Using the invertebrate assay in the spring season, two of the other grazed pastures were deemed of marginal biological status relative to the other sites, and the other three grazed reaches were found to be marginal on the basis of the survey in the fall (Herbst and Knapp, 1999).

Electrofishing surveys were conducted in the fall of 1993 and fall of 1994. A composite fish-habitat quality index was significantly correlated with total trout biomass in each reach. The combined biomass of adults and juveniles was ten times greater at the ungrazed [and unfished] SNARL reach than at the degraded Spring reach (Herbst and Knapp, 1999). Though brown trout (*Salmo trutta*) dominated these surveys, rainbow trout (*Oncorhynchus mykss*) were also present. Rainbow trout usually comprised less than 5 percent of the biomass, but on three of the pastures, about 20 percent of the biomass came from rainbow trout.

Fourteen miles of new fence with well-marked public access points were installed along Convict Creek and in the surrounding meadows in 1992, creating several new pastures to provide grazing alternatives, and also providing protection from careless public use.
(Los Angeles Department of Water and Power, n.d.)

In 1994, the riparian pasture leased for cattle ranching from Convict Creek at U.S. Highway 395 to the confluence with McGee Creek, was put on a three-year rest/rotation schedule. Riparian vegetation in lower portion of Convict Creek has responded favorably to recent changes in grazing management by LADWP (Milliron, 1997)

A study of grazing impacts on Convict Creek did not find evidence of progressive downstream degradation, which was observed on lower Mammoth Creek (Herbst and Knapp, 1995)

A riparian enhancement project was also conducted upstream of SNARL, beginning in 1994. Two water tanks and water troughs were installed after livestock access to the creek was blocked by fencing. Willows and grasses were planted along the streambanks, and sagebrush adjacent to the creek was burned.

The Crowley Lake Tributary Stream Enhancement Program of the Los Angeles Department of Water and Power includes three study reaches on Convict Creek (Los Angeles DWP, n.d.; Herbst and Knapp, 1995; Jellison and Dawson, 2003; Hill, et al., 2002).

New fencing created three riparian pastures
The three pastures were grazed using a double rest-rotation system where one of the three pastures is grazed each year and the other two rested
Early grazing was allowed until 40 percent of the herbaceous riparian vegetation was used (Hill, et al., 2002).

The SNARL reach on Convict Creek has riparian vegetation consisting of willow of all age classes, deep-rooted sedges and grasses. It has not been grazed since the 1960s. The channel is deep and narrow.

The Church reach on Convict is sparsely populated with old willows, and has bare banks and banks covered with shallow-rooted sedges and grasses. The reach has been grazed on a deferred rotation basis in August and September of most, if not all, years. The channel is wide, shallow and has high bank angles.

The Middle Convict reach is sparsely populated with old willows and young willows, and has bare banks and banks covered with shallow-rooted sedges and grasses. It was grazed on a two-year rest rotation system one out of every three years. The channel is wide, shallow and has high bank angles.

Results

The impact of livestock grazing on the channel characteristics of the study reaches was shown most clearly by differences between the SNARL and Church reaches because of their close proximity. While the SNARL reach is deep and narrow with relatively unembedded substrates, heavy shading by riparian vegetation and many deeply undercut banks, the Church reach is wide and shallow with few undercut banks, more heavily embedded substrates, and very little shading by riparian vegetation.

Populations of brown trout and rainbow trout were present in all reaches and were dominated by young fish. Very few larger fish were present in any of the reaches except SNARL.

These data show that while the SNARL reach contained fewer fish than the other four study reaches, these fish were on average considerably larger than those from the other reaches. This difference is attributable to the larger amount of cover in this reach, but also may be a function of lack of fishing pressure. SNARL is the only reach that is off-limits to fishing.

Bioassessment surveys using aquatic invertebrates did not find statistically significant differences between the study reaches (Knapp, et al., 1993).

Chemical analyses of water samples found no significant water quality problems, although the Middle Convict reach had markedly higher values for phosphate, chloride, magnesium, sodium and potassium than the other reaches. These higher values were hypothesized to result from natural accretion (Knapp, et al., 1993).

McGee Creek

McGee Creek begins in the cirques along the Sierra Nevada crest between McGee Pass (11,870+ feet) and Mount Stanford (12,838 feet). Several glacierets, permanent snowfields, and rock glaciers are found on the steep, north-facing slopes just below the ridgelines. A half dozen named lakes and several tiny tarns occupy the watershed above 9,700 feet. The relatively open terrain of the upper watershed changes to a narrow canyon between large peaks at about 9,000 feet. A debris flow in summer of 2003 dammed the creek at about 8,000 feet temporarily and led to a flood when the dam burst. Below the campground at 7,500 feet, the creek is confined by a glacial moraine until it flows out onto an alluvial fan and joins Convict Creek about 1.3 miles above Crowley Lake. This lower section of McGee Creek meanders through meadows where the streambanks are destabilized, slumping and denuded of vegetation (Deinstadt, et al., 1985). In this lower reach, the main channel has become unnaturally wide and devegetated because of 120 years of season-long continuous livestock grazing (Milliron, 1997).

The west side of the McGee Creek watershed is largely metamorphic geology. A tungsten and gold mine was excavated at 11,400 feet on the southern slopes of Mount Baldwin.

The Upper McGee campground, which was within the riparian zone, was removed in the 1980s. The horse pasture at the pack station at 7,800 feet (between the trailhead parking area and campground) could be a potential source of nutrients and coliform bacteria. Several homes, a trailer park, a campground, and a trout pond are located in or near the riparian zone of Mc Gee Creek on Crowley Lake Drive (old Highway 395). Additional homes are located at the north end of this road on a fork of McGee Creek.

The mean annual discharge of McGee Creek is 30 cfs, much of which is diverted seasonally for pasture irrigation below Highway 395. The unscreened diversions cause significant fish loss (Milliron, 1997). Low flows in winter averaged 8 cfs, and discharge during snowmelt runoff averaged about 120 cfs (Los Angeles DWP, n.d.)

Water quality in the lower reach measured in 1992 did not indicate water quality problems, but non-point sources of pollution may occur undetected by standard monitoring methods (Milliron, 1997).

Electro-fishing surveys were conducted in several sections of McGee Creek in the mid-1980s (Deinstadt, et al., 1985). The sections surveyed ranged from 7,360 feet in the lower meadows above Crowley Lake to 8,080 feet elevation within McGee Creek Canyon. The Department of Fish and Game stocks the creek with rainbow trout between the campground and U.S. Highway 395 (Deinstadt, et al., 1985).

The Crowley Lake Tributary Stream Enhancement Program of the Los Angeles Department of Water and Power included two study reaches on McGee Creek (Los Angeles DWP, n.d.; Herbst and Knapp, 1999; Jellison and Dawson, 2003; Hill, et al., 2002).

The South Swamp reach of McGee Creek contains sparse riparian vegetation with some old willows and young willows, and has bare banks and banks covered with shallow-rooted sedges and grasses. It was grazed every other year on a one-year rest rotation basis. The channel is wide, shallow and has high bank angles.

The West Convict reach of McGee Creek has minimal riparian vegetation with banks covered by shallow-rooted sedges and grasses. It has been grazed all season long prior to the study. The channel is deep and narrow. A small population of three-spined sticklebacks (*Gasterosteus aculeatus*) were present in the West Convict reach.

A study of nutrient loading to Crowley Lake found that nitrogen in surface waters increases across the McGee Creek pastures (Jellison and Dawson, 2003). However, these pastures account for only 6 percent of the total measured nitrogen loading to the lake. Furthermore, the eutrophic state of Crowley Lake is unlikely to be significantly altered without reducing the inputs of phosphorus derived from natural sources along Hot Creek and the Owens River, or by taking in-lake restoration measures (Jellison and Dawson, 2003).

In 1992, several miles of new fencing were installed in the meadows bordering McGee Creek below U.S. Highway 395 to provide more pastures for grazing rotation. The riparian zone was also fenced down to the confluence with Convict Creek (Los Angeles DWP, n.d.). In 1994, the riparian pasture on McGee Creek between U.S. Highway 395 and Crowley Lake was put on a three-year rest/rotation schedule (Jellison and Dawson, 2003). Two setback riparian pastures were established with 30 percent annual utilization. The upper setback pasture was never grazed, and the lower pasture was allowed to rest for two years (Hill, et al., 2002).

A study of the influence of grazing practices on aquatic invertebrates (among other things) found there was a distinct change in the taxonomic composition between sites of different grazing intensity. There was a shift within taxonomic and functional feeding groups from more tolerant forms downstream (West Convict reach) to more sensitive equivalents upstream (South Swamp reach). The observed changes in insect fauna provide biological evidence that habitat quality has deteriorated on McGee Creek at the downstream site relative to the upstream site. Though both are within grazed areas, the lower West Convict site had twice the level of embeddedness, smaller substrate sizes, and virtually no stream shading (Knapp, et al., 1993; Herbst and Knapp, 1999).

No water quality problems are evident from the chemical sampling data. Except for slightly higher values for suspended solids outside of SNARL, there is no evidence of habitat degredation from this data. The Middle Convict reach had markedly higher values for phosphate, chloride, magnesium, sodium and potassium. These higher values may be due to natural accretion (Herbst and Knapp, 1999).

Hilton Creek

Hilton Creek begins near Mount Huntington and flows due north to Crowley Lake. The Hilton Creek Lakes occupy a stepped valley between 9,800 and 11,200 feet. The west fork of Hilton Creek, which starts on the east flank of Mount Stanford and flows through Stanford Lake, joins the main channel at Davis Lake. Hilton Creek continues in a valley between Mount Morgan and Red Mountain until crossing a broad alluvial fan south of Crowley Lake. On the fan, the creek divides into several natural distributaries, which have been further divided by landowners in the community of Hilton Creek / Crowley Lake. Many of the early residents of the area used the water from these tiny channels as their domestic water supply and constructed dozens of diversions and micro-canals. Downstream of the community, the many water courses come back together and enter Crowley Lake in about six main channels.

The Hilton Creek Community Services District consists of about 440 acres of privately owned land and two 20-acre USFS lease tracts which abut the western and southern borders of the private holdings. As of 1977, about 200 acres of private land were not subdivided or developed with the remaining 240 acres divided into residential lots mostly one-half to two acres in size (Gram/Phillips, 1977). The Sierra Springs subdivision split 80 acres into 106 lots. The Lakeridge Ranch subdivision split a 79 acre parcel into 114 residential lots.

Hilton Creek provides spawning and rearing habitat for Crowley Lake trout. No trout are stocked in this creek. Mean annual flow is 11 cfs. The creek becomes divided as it runs through the community of Crowley Lake. Water diversions by private homes in the community impact habitat quality downstream, decreasing spawning habitat for trout (Milliron, 1997).

Whiskey Creek

Whiskey Creek begins on the northwest side of Red Mountain at about 10,150 feet. The channel parallels that of Hilton Creek and passes through the east side of the community of Hilton Creek / Crowley Lake where new subdivisions have been built in the past decade.

Whiskey Creek empties into Crowley Lake at South Landing Bay. It provides spawning and rearing habitats for Crowley Lake trout. Trout are not stocked in this stream. Water diversions by homes in this area decrease flows in the stream and negatively impact trout spawning habitat (Milliron, 1997).

Whiskey Creek is not gaged, but was estimated to contribute less than 1 percent of the total inflow to Crowley Lake (Jellison and Dawson, 2003).

Crooked Creek

Crooked Creek is the southernmost tributary to Crowley Lake. The channel named on the USGS maps begins on the northeast slopes of Red Mountain and flows through the community of Aspen Springs before joining other forks from the north slopes of Red Mountain. The several forks of Crooked Creek meander through the meadows of Little Round Valley where they are augmented by water diverted from Rock Creek. One diversion from Rock Creek is just below the LADWP gaging station in the Rock Creek campground, and a second diversion is located at Tom's Place.

The fish population is seasonally dominated by Crowley Lake trout.

The long-term (1945-95) average annual runoff in Crooked Creek was 3,200 acre-feet or less than 2 percent of the measured inflows to Crowley Lake (Milliron, 1997). Crooked Creek has good habitat with undercut banks and a mean annual flow of 4 cfs (Milliron, 1997).

Rock Creek

Rock Creek is included in the upper Owens River watershed because a portion of its water is diverted into Crowley Lake via Crooked Creek. Its natural channel makes an abrupt turn at Tom's Place and runs roughly parallel to the Owens Gorge below Crowley Lake dam until joining the Owens River in the Round Valley area above Pleasant Valley reservoir. Water from Rock Creek is diverted to Crooked Creek just below the LADWP gaging station in the Rock Creek campground and again at Tom's Place. The diversions were constructed in 1964, and monthly minimum flows for the natural channel were established by the California Department of Fish and Game at that time (Brown, 1992).

Rock Creek begins in several high-elevation cirques above Little Lakes Valley. Peaks surrounding the headwaters area include Mount Starr (12,835 feet), Mount Mills (13,451 feet), Mount Abbot (13,704 feet), Mount Dade (13,600+ feet), Bear Creek Spire (13,713 feet), and Mount Morgan (13,748 feet). Small glaciers are found on the northeast slopes of Mount Mills and Mount Abbott, and permanent snow and ice patches and rock glaciers occur on other steep, shaded slopes. The glaciated terrain includes about 20 lakes with surface areas of several acres and dozens of smaller tarns and ponds. As the main channel collects water from several tributaries among the lakes, it flows almost due north for 12 miles before making a near U-turn at Tom's Place. Downstream of Rock Creek Lake (9,700 feet), the creek flows through an inner canyon below broad topographic benches. The east fork of Rock Creek, which originates on the west side of the Wheeler Crest, flows off the eastern bench and joins the main channel at about 9,200 feet. Just downstream, near the East Fork campground, the channel meanders somewhat in a broad valley flat. Rock Creek canyon tends to become progressively narrower and steeper downstream before emerging at Tom's Place.

Subalpine vegetation grows up to about 11,300 feet in the Little Lakes Valley. At lower elevations, lodgepole pine becomes the dominant tree. Aspens are common along the creek and on many slopes with shallow, wet soils. Jeffrey pine are found near the creek between 7,500 and 8,000 feet. Pinyon pine are predominant on the slopes above Tom's Place. A wildfire burned much of the pinyon pine woodland east of Rock Creek above the Holiday campground in 2002.

An old mining road connected the Rock Creek drainage with tungsten mines of Pine Creek on the south slope of Mount Morgan. A paved road has been built from Tom's Place to the trailhead at Mosquito Flat (10,200 feet). The road is within or close to the riparian zone between 7,500 and 8,900 feet. The high-elevation road access adds to the high popularity of the Little Lakes Valley for summer recreation. The foot trail to Morgan Pass follows the route of much of the old mining road. Near Rock Creek Lake, there is a resort with several cabins and restaurant, a pack station, and a campground. The resort operates a micro-hydroelectric generator on an intermittent stream west of the lake. About a mile and a half downstream, there is another resort and pack station. Down the canyon, there are another eight campgrounds, most of which are partially or wholly within the riparian zone. At the mouth of Rock Creek canyon at Tom's Place, there is a Forest Service guard station, resort with cabins and restaurant, and sewage treatment facility for the upstream campgrounds.

Crowley Lake

Crowley Lake is now the base level of the upper Owens River watershed (as defined for this study). The Long Valley dam above the Owens Gorge is the end point for the watershed, but the reservoir creates an area where tributary streams end. The Long Valley reservoir provides 60 percent of the storage in the Los Angeles aqueduct system and is critical managing flows in that system. Crowley Lake is very popular for recreational fishing, boating, and water-skiing. Off-highway vehicle use has been linked to vegetation damage and accelerated soil erosion in some lakeshore locations, such as the vicinity of Layton Springs.

Crowley Lake statistics (Milliron, 1997)

When the reservoir is full:
surface elevation 6,781 feet
surface area 5,272 acres (8.2 square miles)
length about 6 miles
maximum width about 3 miles
maximum depth 114 feet
mean depth 35 feet
volume 183,000 AF (California Department of Water Resources, 1967)

Crowley Lake is considered eutrophic, a limnology term meaning that the water body has an excessive nutrient load that results in excessive plant productivity. The lake was first classified as eutrophic in 1975 by the EPA's National Eutrophication Survey. However, trophic status depends on several factors, including nutrient concentration and loading, chlorophyll, species composition, and transparency. The relatively high transparency of the lake's water during periods when blue-green algae are in a declining phase would lead to classification of Crowley Lake as mesotrophic during those portions of the year (Jellison and Dawson, 2003).

An initial study of nutrient loading to Crowley Lake suggested that most of the phosphorus in the lake originated naturally from Big Springs and Hot Creek (Melack and Lesack, 1982). A more detailed nutrient-budget study (Jellison and Dawson, 2003) concluded that phosphorus loading to Crowley Lake greatly exceeds conventionally acceptable levels, even though the sources are natural. Because of the large natural sources of phosphorus, these authors believe that the eutrophic state of Crowley Lake cannot be remediated by changes in land management or reservoir management (Jellison and Dawson, 2003).

Relatively high concentrations of phosphorus (mostly from Big Springs and Hot Creek) and little inorganic nitrogen in the surface waters favors the production of nitrogen-fixing blue-green algae (Jellison and Dawson, 2003). The blue-green algae support much of the secondary productivity in the reservoir. Occasionally, when the algae are too abundant and subsequently die, dissolved oxygen is depleted, which in turn leads to a large-scale fish kill (Milliron, 1997). In 1983, copper sulfate was added to the lake by LADWP in an effort to control algae and thereby improve water quality for Los Angeles users and increase dissolved oxygen in the lake and downstream. Although those objectives were met, trout growth declined the following year because the overall productivity of the food chain declined (Milliron, 1997).

Evaluation of problems and issues

Problems linked to potential causes

Water quantity

The flow of Mammoth Creek has been substantially reduced by diversion to supply water for the town of Mammoth Lakes. A forthcoming environmental impact report will address this issue in detail.

Water quality

Accelerated erosion and sedimentation appears related to road and building construction and the Mammoth Mountain Ski Area. Mammoth and Hot creeks are the water bodies most affected by accelerated sedimentation. Much of the local soil erosion from construction, trails, and OHV use is unlikely to impact streams because it is not transported far from the site of erosion.

Nutrients in Hot Creek have been released from the Hot Creek fish hatchery.

Microbial contamination of streams is assumed to be caused by careless disposal of human and pet wastes. There is some uncertainty about the long-term effectiveness of household septic systems.

Trace quantities of MTBE and other constituents of gasoline are suspected in Lake Mary from boats and cars on adjacent roads. Such contamination is not known to be significant or require any action.

There is potential, but no direct evidence, for contamination from excessive use of chemical fertilizers on gardens, lawns, and parks. Nutrients from fertilizers that are not incorporated in plant tissue can be leached from soils and enter local streams.

High concentrations of arsenic and nutrients in Hot Creek and the upper Owens River appear to have natural sources, and there is little potential to reduce the amounts of these constituents.

Vegetation change

The risk of catastrophic wildfire is linked to the accumulation of dead fuels and increases in density of forests, woodlands, and shrublands in the absence of a natural fire regime.

Riparian vegetation has been lost and altered by augmented flows in the upper Owens River.

Riparian habitat has been locally impacted by the construction and presence of roads, trails, buildings, and recreational facilities (primarily campgrounds) within the riparian zone.

Wetlands have been drained, filled, and converted to other land uses with a continuing decline in wetland habitat and values.

Potential watershed problems and risks

Extensive clearing of vegetation and leaf litter for fire safety may lead to accelerated erosion.

Areas of wetlands remain at risk of drainage and conversion to other land uses.

Much land in the upper Owens River watershed could be available for development if the City of Los Angeles sold any of its properties.

Knowledge and information gaps

There is insufficient water quality data to evaluate trends and identify most sources of contaminants. However, an adequate water quality monitoring program is unlikely to be cost-effective.

The sediment budget of Mammoth Creek and Hot Creek is not understood well enough to address and predict the behavior of the sediment pulses moving through Hot Creek.

The groundwater system and stream-groundwater interactions in the Mammoth Creek watershed are not understood. Because of the complex geology underlying the town of Mammoth Lakes, the groundwater system is likely to remain poorly understood and unquantified.

The groundwater system that supplies domestic water for the community of Hilton Creek / Crowley Lake is not sufficiently understood to guarantee sufficient water of adequate quality for continued growth.

The long-term reliability of septic systems with respect to avoiding contamination of nearby wells and streams is unknown.

The long-term effectiveness of the stormwater collection and detention system for the town of Mammoth Lakes has not been demonstrated to minimize or eliminate contamination of lower Mammoth Creek and Hot Creek with sediments and other pollutants.

The hydrologic and ecologic effects of climatic variability and potential trends in climate within the upper Owens River watershed are unknown, but contingency planning seems prudent.

Summary and [over]simplifications

A watershed assessment inevitably illustrates the complexities of interactions between the hydrologic cycle, the landscape, and human activities. These complexities and associated uncertainties are not readily distilled into a few sound-bites or headlines without losing much of the critical context and qualifications. Nevertheless, such simplifications are required because few people will bother to read the entire document. So, the following summary remarks are intended to provide overview impressions and should not be used for development of policy or practices.

The upper Owens River watershed is rich in water resources and dependent aquatic life.

The runoff production processes are intact and minimally altered by human activities (at least in comparison to most of California).

Only a small proportion of the watershed is significantly disturbed with respect to hydrologic and geomorphic processes – primarily the town of Mammoth Lakes and the road network.

Riparian areas and wetlands have been reduced in extent, complexity, and ecological functions. Degraded riparian areas have potential to recover somewhat by removing or reducing the intensity of the disturbances. Existing wetlands should be conserved because they are not readily restored to their pre-disturbance condition.

There are a variety of localized impacts to streams and riparian areas that can be largely addressed by measures that detain and/or retain water, sediment, nutrients, and anthropogenic pollutants in the immediate area of the disturbance or activity.

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