TECHNICAL STAFF REPORT

for

Revised Sodium-Related Standards for the Carson and Walker River Watersheds

California Regional Water Quality Control Board
Lahontan Region
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Executive Summary

The California Regional Water Quality Control Board, Lahontan Region (Water Board) is considering amendments to Chapter 3 of the *Water Quality Control Plan for the Lahontan Region* (Basin Plan) to revise water quality objectives for "Percent Sodium" for surface waters of the Carson and Walker River watersheds. (These watersheds are located in Alpine and Mono Counties, respectively, and are the headwaters of larger internally drained watersheds in Nevada.) The Percent Sodium objectives would be replaced with new objectives expressed as "Sodium Adsorption Ratio" (SAR). Percent Sodium and SAR are both criteria for protection of crops and soils against the impacts of excess sodium in irrigation water. The Basin Plan protects irrigation water quality as part of the Agricultural Supply beneficial use. Both Percent Sodium and SAR are ratios of the concentration of sodium in relation to concentrations of other constituents, and they do not set limits on the concentration of sodium itself. SAR is currently more widely used as a criterion for irrigation water than Percent Sodium, and it is calculated differently.

This staff report provides the technical background for the plan amendments. It reviews historic SAR data for the affected watersheds, and irrigation water quality criteria related to sodium. The proposed SAR objectives, expressed as annual averages, are based on criteria in the scientific literature. They are also close to historic SAR values in the affected waters, and will be compatible with the State of Nevada's downstream standards. Where ambient water quality is better than the new SAR objectives, it will be protected under the state Nondegradation Policy. Significant increases in ambient sodium concentrations will also be prevented because the existing objectives for Total Dissolved Solids (TDS) for surface waters of the Carson and Walker River watersheds are not proposed for change (TDS includes sodium).

The proposed plan amendments would eliminate the need to develop Total Maximum Daily Loads (TMDLs) for two reaches of the West Fork Carson River that are in violation of the current Percent Sodium objectives, by providing alternative objectives that are fully protective of the Agricultural Supply beneficial use. The Water Board already has authority under state and federal laws to control point and nonpoint source discharges of sodium in the Carson and Walker River watersheds. No new implementation measures are proposed as part of these Basin Plan amendments.

Introduction

The California Regional Water Quality Control Board, Lahontan Region (Water Board) is the state agency that sets and implements water quality standards for waters east of the Sierra Nevada crest and in the northern Mojave Desert. State water quality standards include designated beneficial uses, and narrative and numerical water quality objectives set to protect those uses. California's "objectives" are equivalent to the federal term "criteria." Standards also include the California State Water Resources Control Board's (State Water Board's) Nondegradation Policy (Resolution 68-16), and standards promulgated by the U.S. Environmental Protection Agency (USEPA) for certain toxic pollutants. State water quality standards for surface and ground waters of the Lahontan Region are contained in the 1995 *Water Quality Control Plan for the Lahontan Region* (Basin Plan), as amended.

The Water Board is considering Basin Plan amendments to replace the numerical "Percent Sodium" objectives for surface waters of the Carson and Walker River watersheds in California with new narrative objectives for Sodium Adsorption Ratio (SAR). Both of these parameters are criteria for protection of irrigation water quality. This report provides the technical justification for the plan amendments. Potential environmental and socioeconomic impacts of the proposed amendments are addressed in a separate California Environmental Quality Act (CEQA) substitute environmental document (California Regional Water Quality Control Board, Lahontan Region, 2006). Pursuant to Health and Safety Code Section 57004, preliminary drafts of the plan amendments and supporting documents were reviewed by an external scientific peer reviewer from the University of California/California State University system. Changes were made in this technical staff report in response to peer review comments.

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Action by the Water Board on the plan amendments and substitute environmental document is tentatively scheduled at the Board's July 2006 meeting. Information on the time and place for the meeting will be available on the Water Board's web page at http://www.waterboards.ca.gov/lahontan in late June 2006. The existing Basin Plan can be accessed through links on this web page. If adopted by the Water Board, the amendments will require further approvals by the State Water Board, the California Office of Administrative Law, and the U.S. Environmental Protection Agency, Region IX (USEPA).

Proposed Action

Most of the surface waters of the Carson and Walker River watersheds are designated for the Agricultural Supply (AGR) beneficial use. This use is defined in Chapter 2 of the Lahontan Basin Plan as: *"Beneficial uses of waters used for farming, horticulture, or ranching, including, but not limited to, irrigation, stock watering, and support of vegetation for range grazing."*

Relatively high concentrations of sodium in irrigation water can have adverse impacts on soil structure, affecting the availability of water to crops, and can also affect the availability of plant nutrients such as calcium. Excess sodium can also be toxic to plants, and some crops are more sensitive to sodium than others. Sources of sodium in the Carson and Walker River watersheds include natural weathering of rocks and soils, geothermal inputs from hot springs, and human sources such as road salt, agricultural drainage, and wastewater disposal to land.

Chapter 3 of the Lahontan Basin Plan contains numerical water quality objectives for "Percent Sodium" to protect water quality for irrigation in the Carson and Walker River watersheds. Copies of Basin Plan Tables 3-13 and 3-14 are included in Appendix 1 to this staff report. The proposed plan amendments would replace existing numerical objectives for Percent Sodium with narrative objectives for Sodium Adsorption Ratio (SAR). Percent Sodium is calculated as:

$$\frac{(Nax100)}{Na + Ca + Mg + K} = \%Na$$

The formula for SAR is

$$SAR = \frac{Na}{\sqrt{\frac{Ca + Mg}{2}}}$$

In the equations above, Na = sodium concentration; Ca = calcium concentration, Mg = magnesium concentration, and K = potassium concentration. All concentrations are expressed as milliequivalents per liter. [1] As a ratio, SAR has no units. Because they are calculated differently, Percent Sodium and SAR are not directly comparable.

The proposed new SAR objectives are summarized in Table 1. (The Basin Plan amendments would add separate narrative objectives for each watershed, rather than a single table of numeric objectives.) Each SAR value would apply to an entire water body including tributary surface waters in California. The new objectives would be expressed as annual averages, and would include direction that the SAR calculation be done using data for dissolved rather than "total" constituents. The new objectives would also specify that higher SAR values that may occur locally in waters influenced by natural (e.g., geothermal) sources would not be considered to be in violation of the objectives.

Table 1. Summary of Proposed New Water Quality Objectives for Sodium Adsorption Ratio (SAR).

Water Body Name	Proposed SAR Objective (Annual Averages)
West Fork Carson River	1
East Fork Carson River	2
Bryant Creek	1
West Walker River	2
Topaz Lake	2
East Walker River	2

Except for Bryant Creek, the Lahontan Basin Plan does not contain numeric objectives for Percent Sodium for streams that cross the California-Nevada state line independently of the main forks of the Carson and Walker Rivers. Examples of streams without Percent Sodium objectives are Indian Creek in the Carson River watershed and Desert,

[1] Milliequivalents per liter (meq/L) are units of mass related to molecular weight and ionic charge of specific ions. Conversion factors for the ions in SAR are: Na+ =23.0 mg/meq, Ca++ =20.0 mg/meq, and Mg ++ = 12.15 mg/meq (Bauder *et al*. 2005).

Sweetwater, Rough, and Bodie Creeks in the Walker River watershed. New SAR objectives are not being proposed for these streams.

The specific SAR numbers in Table 1 were selected to be below the sodium toxicity threshold in the agricultural literature (SAR = 3) and to be compatible with Nevada's standards for downstream waters. Irrigation water criteria and the relationship between California Nevada and California standards are discussed in greater detail below.

The new SAR objectives would be implemented through the Water Board's existing permitting and enforcement authority for point and nonpoint source discharges. No new implementation measures are proposed as part of the plan amendments.

It is important to recognize that SAR is a ratio of different constituents rather than a concentration. The Basin Plan does not contain water quality objectives for sodium concentration *per se*. However, sodium is among the salts included in water quality objectives for Total Dissolved Solids (TDS), expressed in milligrams per liter (mg/L) concentrations. No changes in TDS objectives are being proposed in these Basin Plan amendments. This will effectively prevent significant increases in sodium concentration over historic levels.

The proposed amendments also include a number of editorial changes to the Basin Plan. These changes do not require technical justification and will not be discussed further in this staff report.

Purpose of and Need for Basin Plan Amendments

Percent Sodium is no longer widely used as a criterion for irrigation water. For example, it is not mentioned in the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service *NRCS National Irrigation Handbook's* discussion of irrigation water quality (USDA, 1997). The proposed change from Percent Sodium to SAR would modernize water quality objectives for the Carson and Walker River watersheds, and make them more compatible with Nevada's SAR standards. If approved, the proposed amendments would also allow two segments of the West Fork Carson River to be removed from the Clean Water Act Section 303(d) list of waters requiring Total Maximum Daily Loads (TMDLs). (TMDLs are remedial strategies to ensure the attainment of water quality standards.) Expression of the new SAR objective for the West Fork Carson River as an annual average rather than a mean of monthly means (a rolling average) would make it easier to understand and facilitate assessment of the effectiveness of management practices. The addition of language regarding natural sources to the new SAR objectives would avoid the need for future Section 303(d) listing and TMDL development for certain water bodies and water body segments that have naturally high SAR levels.

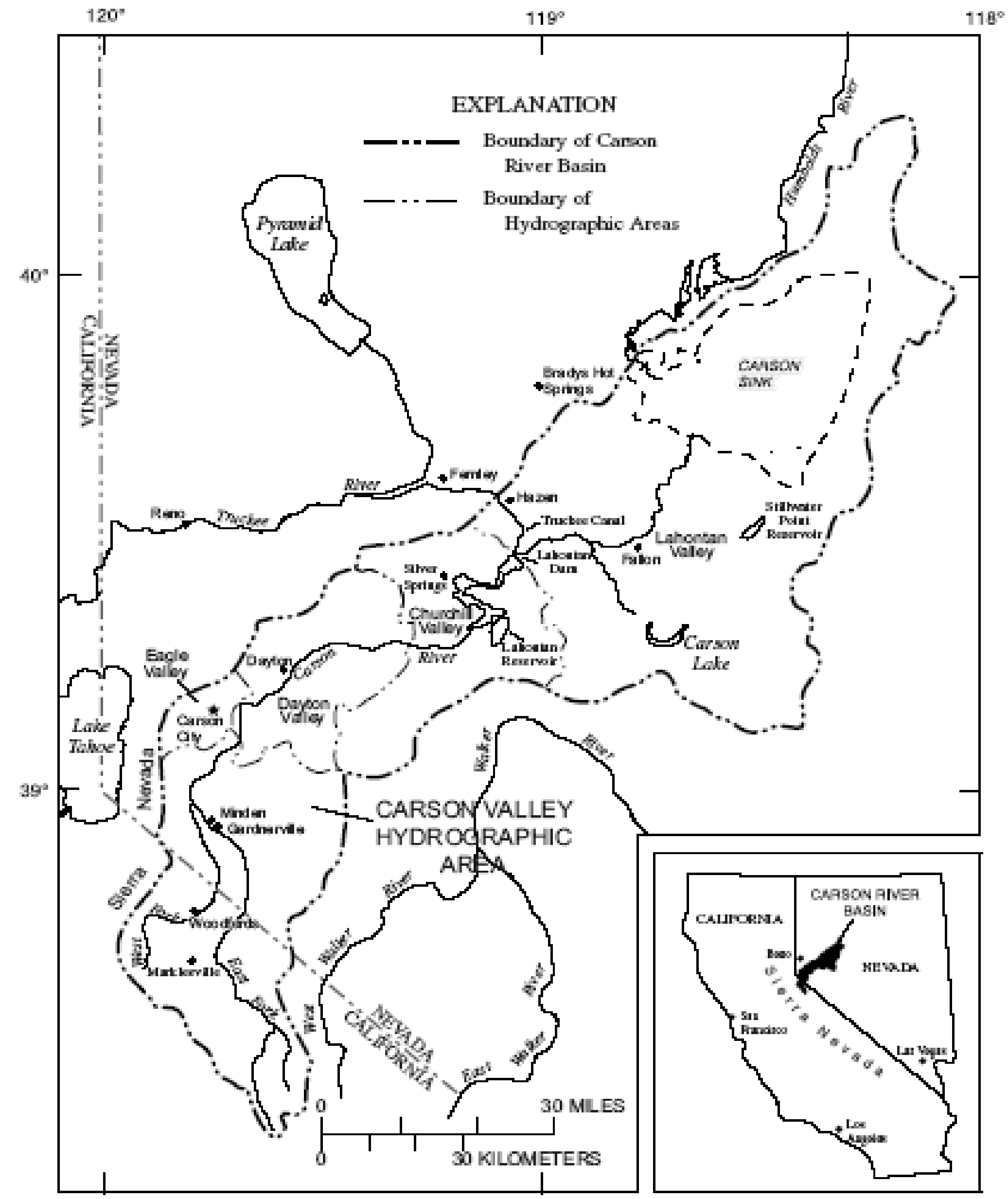

Figure 1. Map of Carson River Watershed. Source: Maurer *et al*., 2002

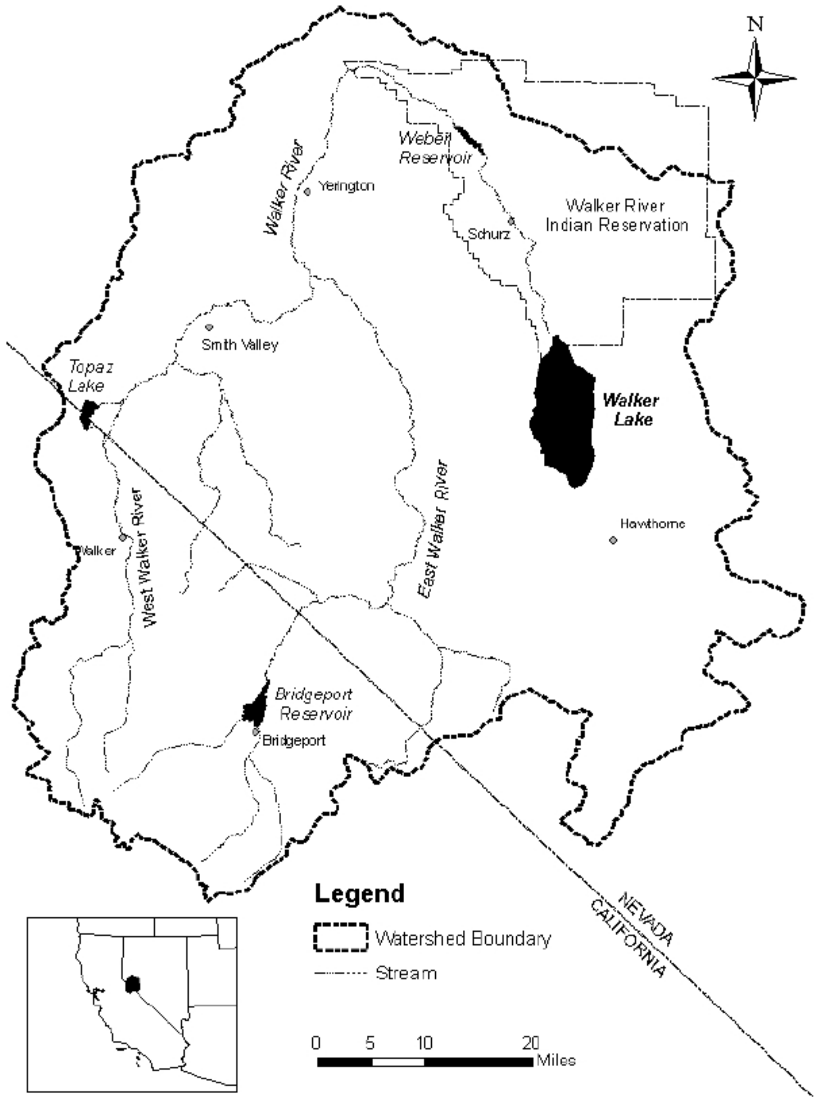

Figure 2. Map of Walker River Watershed. Source: NDEP (2005).

Affected Watersheds

The following discussion focuses on characteristics of the Carson and Walker River watersheds related to irrigation water quality, and on agricultural uses in these watersheds. For additional information, see the “Environmental Setting” section of the draft substitute environmental document for the proposed amendments (California Regional Water Quality Control Board, Lahontan Region, 2006).

The Carson and Walker River watersheds are adjacent to each other, with headwaters located in Alpine and Mono Counties in California. The largest portions of both watersheds, and most of the irrigated lands, are in Nevada. Figures 1 and 2 show the entire watersheds. More detailed maps of the California portions of these watersheds, from the existing Basin Plan, are included in the Appendix to this staff report.

The California watersheds include numerous small headwater lakes and streams. Each river has two main forks in California, with several small streams that cross the state line independently of these forks. Both watersheds are internally drained, and the terminal waters in Nevada are remnants of prehistoric Lake Lahontan. The two watersheds share similar environmental characteristics and histories of human land use. The California watersheds are transitional between Sierra Nevada and Great Basin environments (in terms of geomorphology, geology, vegetation, etc.).

Headwaters are located near the Sierra Nevada crest, with the highest peaks ranging from about 10,000 to over 12,000 feet. There are several smaller mountain ranges in these watersheds in California, the Carson Range, Sweetwater Mountains and Bodie Hills. Irrigated lands in California are located at elevations between about 4600-6500 feet. (Carson Valley Conservation District, 1996; Rockwell and Honeywell, 2004).

The geology of these watersheds is complex, including a mixture of volcanic, intrusive igneous (granitic) and metamorphic rocks. The region is seismically active, and geothermal springs associated with faults are found in both watersheds. Glaciation has been an important factor at higher elevations. Lower elevation valleys where irrigated agriculture occurs are filled with glacial till, recent alluvium, and/or lacustrine sediments. Many irrigated valley soils have seasonal high water tables and are subject to flooding (DWR 1957, 1992; Carson Valley Conservation District, 1996; Alvarez and Seiler, 2004).

The Carson and Walker River watersheds are located in a “rain shadow.” Precipitation falls mainly as winter snow at high elevations, although intense summer thunderstorms can occur. Total annual precipitation ranges from up to 70 inches at the highest elevations to about 8 to 10 inches near the state line. There are extreme year-to-year variations in precipitation. In the Carson River watershed, three of the five wettest and three of the five driest years on record occurred between 1982 and 1995. Between 1980 and 1996, April 1 snow water content varied from 36 to 206 percent of average in the Carson River Basin and 40 to 227 percent of average in the Walker River Basin (Nevada

Division of Water Resources chronologies; California Department of Water Rights, 1992); Alvarez and Seiler (2004), Carson Valley Conservation District (1996).

Although irrigated lands in California are at lower elevations with relatively mild climates, temperature extremes and short growing seasons limit the types of crops that can be grown. In the Carson Valley portion of Alpine County, the average annual temperature is 48-50^{o} F., and the average annual frostfree period is 100 to 120 days. Record temperatures at a nearby Nevada station range from -24 to 107^{o} F (Carson Valley Conservation District, 1996). Bridgeport, in the East Walker River watershed at an elevation of 6,420 feet, has a shorter growing season with an annual average of 51 frost-free days (California Department of Water Resources, 1992).

As with precipitation, there are drastic year-to-year variations in river flows. Table 2 summarizes historical data showing ranges in annual flows. These data were compiled before a major flood event in 1997.

Table 2. Annual Flows in the Carson and Walker River Watersheds. acre-feet. Sources: Nevada Division of Water Resources, Carson and Walker River Chronologies

U.S. Geological Survey Gaging Station Location	Period of Record	Average Water Year (acre-feet)[2]	Low Water Year (acre-feet)	High Water Year (acre-feet)
West Fork Carson River at Woodfords	1901-1995	79,640	18,900	109,950
East Fork Carson River Below Markleeville Creek, CA	1960-1995	255,560	60,600	585,690
West Walker River Below Little Walker River	1938-1994	183,890	47,280	388,370
West Walker near Coleville	1903-1994	195,470	53,940	484,340
East Walker near Bridgeport	1992-1994	102,080	28,020	290,300

Ranchers constructed a number of small high elevation reservoirs in both the Carson and Walker River watersheds in the late 19th and early 20th centuries. Larger reservoirs (Topaz Lake and Bridgeport Reservoir) were constructed in the 1920s. Recycled wastewater exported from the Lake Tahoe Basin supplements natural water supplies for agriculture in the Carson River watershed. The South Tahoe Public Utility District (STPUD) currently exports 5,200 acre-feet per year of treated wastewater to Alpine County, where it is stored in Harvey Place reservoir and used for irrigation. The irrigated areas in the Carson, Antelope and Bridgeport Valleys in California include systems of ditches and canals (STPUD, 2002).

Water rights in the Carson and Walker River watershed have a long and controversial history, outlined in the Nevada Division of Water Resources' online watershed

[2] One acre-foot (the amount of water that could cover one acre to a depth of one foot) equals 325,851 U.S. gallons.

chronologies, and in the California Department of Water Resources *Walker River Atlas* (1992). Surface water rights in both the Carson and Walker River watersheds are adjudicated, and reservoir releases and diversions are managed through federal watermasters under court decrees.

The Carson River ends in the Carson Sink. The sink includes lakes, marshes, wetlands, agricultural lands, desert playas, and Lahontan Reservoir. A temporary terminal lake can form during extremely wet years. A lake with a surface area over 330 square miles formed in the Carson Sink in 1984. The terminal wetlands of the Carson River are important as habitat for migratory birds. There are several wildlife refuges, and the Lahontan Valley wetlands have been designated part of the Western Hemispheric Shorebird Reserve network. Increases in TDS over natural levels have occurred due to hydromodification and agricultural return flows. Together with other contaminants from upstream sources, the TDS increase threatens wildlife and aquatic life uses of the wetlands (Lemly *et al*., 2000; Lahontan Audubon Society).

Walker Lake, the terminal lake of the Walker River system, historically supported the Lahontan cutthroat trout. The lake level has dropped over 140 feet since 1882, and its TDS concentration has increased from about 2500 mg/l in 1882 to about 15,900 mg/L in December 2004. The sodium concentration was about 31 percent by volume (4100 mg/L) in Walker Lake in 1994 (Nevada Division of Water Resources *Walker River Chronology*). The increase in TDS has been primarily due to reduced lake volume as a result of upstream diversions for agriculture and other uses, but TDS loads from the Walker River and local sources have also been implicated. The TDS increase and other environmental conditions have stressed the fishery and other aquatic life, and the trout fishery is now maintained through hatchery plants. A TMDL for TDS in Walker Lake was approved by the Nevada Division of Environmental Protection (NDEP) and the USEPA in 2005. It sets a long-term average target of 12,000 mg/L TDS in Walker Lake to provide “sufficient support” for the stocked fishery use. It also includes a load allocation for the Walker River: a maximum annual average TDS concentration of 500 mg/L, consistent with Nevada’s TDS standard. (For comparison, the maximum sodium concentrations recorded at NDEP’s “state line” monitoring stations in California are 17 mg/L for the West Walker River and 20 mg/L in the East Walker River.) The TMDL is to be implemented through Nevada’s ongoing water quality control programs, but does not address water rights issues. An estimated additional 13,000 to 31,000 acre-feet per year would be needed to maintain the existing lake level.

The Carson and Walker River watersheds in California are mostly in public ownership (U.S. Forest Service, U.S. Bureau of Land Management, tribal lands, state parks, etc.). Resource extraction uses (including mining, logging and range livestock grazing) were much more intensive in the 19th and early 20th centuries than they are at present. Outdoor recreation on public lands is currently very important to local economies. There are a number of small, unincorporated communities including Markleeville and Woodfords in the Carson River watershed, and Bridgeport, Walker, Coleville, and Topaz in the Walker River watershed. Bridgeport is the largest community with a population of 843 (Rockwell and Honeywell, 2004). Much of the remaining private land, located mostly in the eastern portions of both watersheds, is in agricultural use (Carson Valley Conservation District, 1996; Nevada Division of Water Resources Carson and Walker River chronologies).

Agriculture in the Carson River watershed began with Native American tending, seeding and transplanting of native species (Sierra Nevada Alliance, 2004). The Carson River corridor became a major emigrant route to California in the 1850s, and ranching and dairy operations were started to supply travelers. The Carson Valley Conservation District (1996) identified about 8,000 acres of private agricultural land in the upper Carson River watershed in Alpine County; of this, 824 acres was prime farm land used for legumes and grasses for hay production. Irrigated acreage in the Douglas County, Nevada portion of the watershed was used for alfalfa, grains and garlic production and irrigated pasture for livestock production. Maurer *et al*., (2004) identified native pasture grasses, alfalfa, and some garlic and onions as the major crops in the Carson Valley.

European agriculture in the Walker River watershed also began in the late 1850s, and ranches provided food supplies to miners. Irrigated pasture and hay are also the most important crops in the California portions of the Walker River watershed. Irrigated crops in the Nevada portion of the watershed include alfalfa, grains, and limited production of vegetables such as onions and potatoes (California Department of Water Resources, 1957, 1962).

The Nevada Farm Bureau's web page states: "alfalfa hay accounts for over half of the total value of crops produced in the state. Much of the alfalfa is marketed to dairies in California and a significant quantity is exported overseas." The web page also states that a variety of other high value crops are gaining in importance to Nevada agriculture including potatoes, onions, garlic and alfalfa seed.

Sources of Sodium

Natural sources of sodium in the Carson and Walker River watersheds include weathering of rocks and soils, evaporative concentration in terminal lake basins, and geothermal sources. The Nevada Division of Water Resources' Walker River Chronology states that there are large natural salt deposits in upper basin valleys including Antelope Valley [in the West Walker River watershed]. Topaz Reservoir occupies the site of a former natural "Alkali Lake."

In a special study of the West Walker River watershed published in 1957, the California Department of Water Resources (DWR) concluded: "The mineral quality of water in the region was found to be generally good. The major exceptions are the waters from hot springs, associated with the numerous faults of the area, and the artesian ground water zone in Antelope Valley." The hot springs include "numerous highly mineralized hot springs, including Fales Hot Springs" that are tributary to Hot Creek, a tributary of the Little Walker River," and springs tributary to the West Walker river between the town of Topaz and the Topaz Lake diversion dam.

The East Fork Carson River and East Walker River watersheds in California also include geothermal springs. Grover Hot Springs is tributary to Hot Springs Creek and thence to Markleeville Creek and the East Fork Carson River. Soda Cone in the upper East Fork watershed is an inactive geothermal spring, and place names such as “Poison Creek” are possible indicators of geothermal influence. (Searches of topographic maps at http://www.topozone.com show two Poison Creeks in the East Fork Carson River watershed and two in the Walker River watershed.) There are also hot springs in the segment of the East Fork Carson River between Hangman’s Bridge and the state line. The East Walker River watershed includes Buckeye Hot Springs near Buckeye Creek, and Travertine Hot Springs near Bridgeport.

Potential human sources of sodium in the affected watersheds include wastewater, agricultural drainage, and road salt. There are no point source discharges of domestic wastewater to surface water in these watersheds. However, sodium from wastewater disposed to land may reach surface waters. Salt is used for winter maintenance of roads and highways, and many highways in the Carson and Walker River watersheds follow stream corridors. Human loading of sodium to surface waters of these watersheds cannot be precisely quantified, and has probably changed over time. For example, the use of wastewater for irrigation in the Carson Valley began in 1970, and the volume of wastewater applied has increased over time. As discussed below, historic SAR and sodium concentrations in most surface waters in the California portions of the two watersheds are relatively low in relation to irrigation water quality criteria. However, few of the monitored waters can be considered “pristine.”

Historic Water Quality

Water Board staff initially considered basing the new SAR objectives on historic site-specific water quality data, rather than on criteria from the scientific literature. However, limitations in data quantity made this alternative infeasible. The following is a summary of representative historic data on SAR and related parameters to put the proposed objectives into perspective. It is not an exhaustive review; some sources include only one or a few samples for some stations in the Carson and Walker River watersheds. Likewise, no attempt has been made to summarize all available data on Percent Sodium. Table 6 includes data from one reference that provided SAR and Percent Sodium values for the same water bodies, and additional historic Percent Sodium data are summarized in Table 9.

Sources of historic data include, but are not limited to:

- Online databases (U.S. Geological Survey NWIS and USEPA Legacy STORET databases, and online monitoring data in table format from the Nevada Division of Environmental Protection (NDEP)

- Electronic files provided by the South Tahoe Public Utility District (STPUD) and the University of Nevada, Reno Desert Research Institute

- Documents in the Water Board's library, including older summaries of monitoring data collected by the California Department of Water Resources (DWR)

- The Water Board's Surface Water Ambient Monitoring Program (SWAMP) database.

The public entities listed above are assumed to have acceptable quality assurance/quality control (QA/QC) programs for sample collection and analysis, and to have used acceptable QA/QC procedures in the past. However, methods may have changed over time. Water Board staff did not attempt to document sampling and analytical procedures for the datasets summarized below. For purposes of the proposed Basin Plan amendments, the major limitations of the available data are: (1) the lack of long-term records, including lack of recent data for many stations; and (2) limited sampling frequencies at most stations.

DWR and USGS sampled for SAR or its constituents in the Carson and Walker River watersheds more or less routinely between about 1958 and the 1970s. After that time, the available USGS and DWR data were collected as part of short-term special studies. The "West Fork Carson River at Woodfords" station has the longest sampling record, extending from about 1958 through the present with a few data gaps. Samples have been collected by different agencies during this time. In contrast, there are no recent data for the East Fork Carson River at Markleeville. Nevada's "Stateline" station for the East Fork is at Riverview, Nevada, several miles downstream from the state line. The Nevada segment of the East Fork between the state line and Riverview is probably influenced by agricultural drainage, and may not be representative of conditions between Markleeville and the state line. Except for a recent USGS special study (Rockwell and Honeywell, 2004), the only recent data for the Walker River watershed have been collected by NDEP.

Sampling frequencies (numbers of samples per year) have varied among agencies and over time within datasets collected by the same agencies. Many of the early USGS and DWR samples were collected only twice a year. The best data in terms of sampling frequency are from the STPUD's monthly sampling of the West Fork Carson River. The NDEP datasets initially involved quarterly sampling, but NDEP has recently switched to twice yearly sampling.

Most of the data summarized in the tables below were reported as SAR or Percent Sodium in the original sources. In a few cases, Water Board staff calculated SAR from data for its constituents, using standard conversion factors (Bauder *et al*., 2005 Chapman and Pratt 1961). SAR values from some sources have been rounded to reflect the degree of precision in the USGS NWIS database. Copies of the original data will be included in the administrative record for the Basin Plan amendments.

Tables 3 and 4 summarize SAR data for the Carson and Walker River stations with larger datasets, including the water bodies with numerical Percent Sodium objectives in the

Lahontan Basin Plan. Table 5 summarizes preliminary data from a recent water quality study of the upper Carson River watershed sponsored by the Carson Water Subconservancy District. Samples for the West Fork Carson River and its tributaries were collected at stations upstream of the Woodfords station with results presented in Table 3. Some samples were also collected for the East Fork Carson River and tributaries upstream of the Markleeville station in Table 3. Table 6 summarizes data from the DWR (1957) study of the West Fork Carson River for surface waters and a few ground water stations. Table 7 includes data for the East Walker River watershed from a recent USGS study. Some of the tables include data on Percent Sodium, sodium ion concentrations, and/or specific conductance (EC) for comparison with the existing water quality objectives and irrigation water criteria.

Examination of Tables 3 through 7 leads to the following conclusions:

- Almost all SAR values are less than 1, indicating that the proposed new SAR objectives (annual average values of 1 or 2, with specific exclusions for natural sources) are attainable. The discussion of irrigation water quality criteria, below, puts these low SAR values into perspective in terms of salinity and sodium toxicity hazards to crops.

- The lowest SAR values (0.2 or less) are found at higher elevation stations closer to the headwaters. Examples are the Hope Valley stations in the upper West Fork Carson River watershed (Table 5) and Robinson Creek below the Twin Lakes outlet (Table 7). Higher SAR values at downstream stations may reflect cumulative sodium loading from multiple tributaries and/or from human sources. The limited available data do not provide enough evidence to support conclusions about cause and effect.

- The highest SAR and Percent Sodium values occur in the West Walker River watershed at or near geothermal sources. For example, Table 6 includes a single sample from Fales Hot Springs with an SAR value of 21.2, and Percent Sodium at 87 percent.

- Among the stations with long-term data (Tables 3 and 4), the West Fork Carson River at Woodfords has the best quality in terms of SAR (a long-term average of 0.3). This may be related to the lack of geothermal sources in the watershed upstream of Woodfords.

Table 3. Summary of Sodium Adsorption Ratio (SAR) Data for the Carson River Watershed

STATION NAME	PERIOD OF RECORD	# OF SAMPLES	MEAN SAR (OF ALL SAMPLES)	MAX ANNUAL MEAN SAR	MIN ANNUAL MEAN SAR	MEAN ANNUAL MEAN SAR	DATA SOURCE[1]
West Fork Carson R. HU							
West Fork at Woodfords	1958-1972	45	0.3				DWR
West Fork at Woodfords (filtered)	1960-1974	76	0.3	0.3	0.2	0.3	USGS
West Fork at Woodfords (unfiltered)	1984-2002	224	0.3	0.3	0.2	0.3	STPUD
West Fork at Paynesville (unfiltered)	1984-2002	226	0.3	0.4	0.3	0.3	STPUD
West Fork at Paynesville (unfiltered)	1992-2003	19	0.5				NDEP
West Fork at Paynesville (filtered)	1999-2003	7	0.5				NDEP
West Fork at Stateline (unfiltered)	1984-2002	211	0.3	0.4	0.3	0.3	STPUD
East Fork Carson R. HU							
East Fork at Highway 4	1958-1974	44	0.4				DWR
East Fork below Markleeville Creek (filtered)	1965-1970	12	0.5				USGS
East Fork at Riverview NV (unfiltered)	1992-2003	21	0.7				NDEP
East Fork at Riverview NV (filtered)	1999-2003	9	0.9				NDEP
Bryant Creek at Doud Springs NV (unfiltered)	1997-2003	32	0.4				NDEP
Bryant Creek at Doud Springs NV (filtered)	1998-2003	25	0.5				NDEP

[1]USGS = U.S. Geological Survey, STPUD = South Tahoe Public Utility District, NDEP = Nevada Division of Environmental Protection; DWR = California Department of Water Resources

Table 4. Summary of Sodium Adsorption Ratio (SAR) Data for the Walker River Watershed

STATION NAME	PERIOD OF RECORD	# OF SAMPLES	MEAN SAR (OF ALL SAMPLES)	MAX ANNUAL MEAN SAR	MIN ANNUAL MEAN SAR	MEAN ANNUAL MEAN SAR	DATA SOURCE[1]
West Walker River HU							
West Walker R. below Little Walker (filtered)	1960-1980	81	0.7	2.5	0.3	0.8	USGS
West Walker R. above Topaz Lake (filtered)	1990-1996	13	0.8				USGS
West Walker R. at Topaz Lane (unfiltered)	1992-2003	23	0.8				NDEP
West Walker R. at Topaz Lane (filtered)	1999-2003	9	0.7				NDEP
Topaz Lake (unfiltered)	1993-2003	20	0.7				NDEP
Topaz Lake (filtered)	1999-2003	9	0.8				NDEP
East Walker River HU							
Upper Twin Lake	1978-1979	5	0.2				DWR
Lower Twin Lake	1978-1979	5	0.2				DWR
East Walker R. below Bridgeport Reservoir (filtered)	1958-1980	99	0.8	1	0.5	0.7	USGS
East Walker R. at Stateline [2] (unfiltered)	1992-2003	22	0.8				NDEP
East Walker R. at Stateline (filtered)	1999-2003	9	1				NDEP

[1]USGS = U.S. Geological Survey, STPUD = South Tahoe Public Utility District, NDEP = Nevada Division of Environmental Protection; DWR = CA Dept. of Water Resources. Twin Lakes data are from DWR (1980).
[2] The NDEP "stateline" station is located in California, below Bridgeport Reservoir and above the actual state line.

Table 5. Sodium and SAR Data for Selected Carson River Watershed Stations. Unpublished data from University of Nevada Reno Desert Research Institute (DRI) sampling sponsored by Carson Water Subconservancy District. Data provided by Dr. David McGraw.

Station Location and DRI Station Number	**Sampling Date**	**Na (mg/L)**	**SAR Value**
West Fork Carson River Watershed			
Alhambra Mine Creek below Red Lake Creek (Hope Valley) RC1-WQ1	5/28/2004	2.5	0.22
Alhambra Mine Creek below Red Lake Creek (Hope Valley) RC1-WQ1	6/3/2004	2.1	0.18
Alhambra Mine Creek below Red Lake Creek (Hope Valley) RC1-WQ1	6/25/2004	1.9	0.16
Alhambra Mine Creek below Red Lake Creek (Hope Valley) RC1-WQ1	7/23/2004	1.4	0.12
Alhambra Mine Creek below Red Lake Creek (Hope Valley) RC1-WQ1	10/12/2005	2.6	0.19
West Fork above Alhambra Mine Creek (Hope Valley) WF10-WQ1	5/28/2004	0.9	0.04
West Fork above Alhambra Mine Creek (Hope Valley) WF10-WQ1	6/03/2004	1.0	0.13
West Fork above Alhambra Mine Creek (Hope Valley) WF10-WQ1	6/25/2004	1.0	0.12
West Fork above Alhambra Mine Creek (Hope Valley) WF10-WQ1	7/23/2004	1.6	0.16
West Fork above Alhambra Mine Creek (Hope Valley) WF10-WQ1	10/12/2005	1.4	0.15
West Fork below Willow Creek (Hope Valley) WF7-WQ1	4/30/2004	1.4	0.16
West Fork below Willow Creek (Hope Valley) WF7-WQ1	5/28/2004	2.9	0.32
West Fork below Willow Creek (Hope Valley) WF7-WQ1	6/3/2004	1.7	0.18
West Fork below Willow Creek (Hope Valley) WF7-WQ1	6/25/2004	1.9	0.19
West Fork below Willow Creek (Hope Valley) WF7-WQ1	7/23/2004	2.3	0.20
West Fork below Willow Creek (Hope Valley) WF7-WQ1	11/4/2004	4.0	0.33
West Fork below Willow Creek (Hope Valley) WF7-WQ1	1/27/2005	3.8	0.32
West Fork below Willow Creek (Hope Valley) WF7-WQ1	4/19/2005	3.1	0.29
West Fork below Willow Creek (Hope Valley) WF7-WQ1	5/17/2005	2.1	0.23
West Fork below Willow Creek (Hope Valley) WF7-WQ1	10/12/2005	2.9	0.27
West Fork at Hwy 89 bridge before Blue Lakes Road (Hope Valley) WF8-WQ1	5/28/2004	1.4	0.16
West Fork at Hwy 89 bridge before Blue Lakes Road (Hope Valley) WF8-WQ1	11/04/2004	3.0	0.24
West Fork at Hwy 89 bridge before Blue Lakes Road (Hope Valley) WF8-WQ1	1/27/2005	2.8	0.23
West Fork at Hwy 89 bridge before Blue Lakes Road (Hope Valley) WF8-WQ1	4/19/2005	2.2	0.21
West Fork at Hwy 89 bridge before Blue Lakes Road (Hope Valley) WF8-WQ1	5/17/2004	1.8	0.20
Hawkins Creek HC1-WQ1	6/03/2004	1.5	0.18
Hawkins Creek HC1-WQ1	6/25/2004	1.6	0.17

Table 5. (continued)

Station Location and DRI Station Number	Sampling Date	Na (mg/L)	SAR Value
East Fork Carson River Watershed			
East Fork at confluence of Silver and Wolf Creeks EF7-WQ1	5/27/2004	3.0	0.31
East Fork at Hangman's Bridge EF4-WQ1	5/27/2004	3.2	0.32
Monitor Creek MC1-WQ1	5/27/2004	11.0	0.26
Monitor Creek MC1-WQ1	6/24/2004	13.0	0.27
Markleeville Creek below Grover Hot Springs MKC3-WQ1	5/27/2004	3.9	0.28
Markleeville Creek Bridge (or campground) MKC2-WQ1	5/27/2004	3.3	0.39

Table 6. SAR and Percent Sodium for Selected Stations in the West Walker River Watershed. (California Department of Water Resources, 1957)

Station	Sampling Date	SAR	Percent Sodium
West Walker River	8/30/1955	0.3	18
Fales Hot Springs	11/3/1955	21.2	87
Hot Creek	8/9/1956	9.4	78
Little Walker River above Hot Creek	8/9/1956	0.2	15
Little Walker River below Hot Creek	8/30/1955	1.9	59
West Walker River above Walker	8/3/1954	0.7	36
West Walker River above Walker	8/4/1955	0.7	38
Mill Creek	9/4/1955	0.4	16
Lost Cannon Creek	8/4/1955	0.6	38
Little Antelope Valley Outlet Creek	8/4/1955	0.9	28
Slinkard Creek	8/4/1955	0.4	15
Topaz Intake Canal	8/4/1955	1.4	42
Topaz Lake Near Outlet	8/4/1955	0.7	34
A. Sciarani artesian domestic well	8/30/1955	16.5	96
F. Chichester artesian stock well	8/30/1955	5.9	81

Table 7. U.S. Geological Survey Data from the East Walker River Watershed. Source: Rockwell and Honeywell (2004). The USGS "East Walker River at Bridgeport" station is upstream of Bridgeport Reservoir, and the "East Walker River near Bridgeport" station is downstream of the reservoir.

Station	**Date**	**EC µS/cm[3]**	**Na (mg/L)**	**% Na**	**SAR**
Buckeye Creek near Bridgeport	4/12/2000	ND	1.63	17	0.2
Buckeye Creek near Bridgeport	9/14/2000	87	3.29	16	0.2
Buckeye Creek near Bridgeport	1/11/2001	102	3.83	16	0.3
Buckeye Creek near Highway 395	5/11/2000	59	2.68	20	0.2
Buckeye Creek near Highway 395	9/13/2000	132	5.84	20	0.4
Buckeye Creek near Highway 395	1/10/2001	143	6.56	21	0.4
Buckeye Creek at Bridgeport Reservoir	5/9/2000	62	4.13	28	0.4
Buckeye Creek at Bridgeport Reservoir	9/12/2000	193	17.1	39	1.0
Buckeye Creek at Bridgeport Reservoir	1/12/2001	146	9.29	29	0.6
Swauger Creek near Bridgeport	5/11/2000	120	8.72	30	0.6
Swauger Creek near Bridgeport	9/13/2000	149	11.8	35	0.8
Swauger Creek near Bridgeport	1/9/2001	132	10.8	35	0.7
Robinson Creek at Twin Lakes Outlet	5/10/2000	58	1.97	15	0.2
Robinson Creek at Twin Lakes Outlet	9/14/2000	49	1.72	16	0.2
Robinson Creek at Twin Lakes Outlet	1/11/2001	52	1.91	15	0.2
Robinson Creek at Highway 395	5/11/2000	60	2.44	18	0.2
Robinson Creek at Highway 395	9/13/2000	82	2.96	16	0.2
Robinson Creek at Highway 395	1/10/2001	96	3.32	15	0.2
Robinson Creek at Bridgeport Reservoir	5/9/2000	88	3.59	17	0.3
Robinson Creek at Bridgeport Reservoir	9/12/200	123	5.38	19	0.3
Robinson Creek at Bridgeport Reservoir	1/12/2001	152	6.54	19	0.4
Green Creek near Bridgeport	9/13/2000	58	1.86	16	0.2
Green Creek near Bridgeport	1/10/2001	77	2.89	17	0.2
Virginia Creek near Bridgeport	5/10/2000	87	5.09	25	0.4
Virginia Creek near Bridgeport	9/13/2000	108	6.60	27	0.5
Virginia Creek near Bridgeport	1/10/2001	127	8.43	30	0.6
East Walker River at Bridgeport	5/10/2000	166	10.2	26	0.6
East Walker River at Bridgeport	9/12/2000	187	11.0	26	0.6
East Walker River at Bridgeport	1/11/2001	145	8.76	25	0.5
East Walker River near Bridgeport	5/10/2000	214	19.1	38	1.0
East Walker River near Bridgeport	9/12/2000	175	13.4	33	0.8
East Walker River near Bridgeport	1/11/2001	187	13.5	30	0.7

Background for Existing Percent Sodium Objectives

Water Quality Standards. California's water quality standards include designated beneficial uses, narrative and numeric water quality objectives, and a Nondegradation policy (State Water Resources Control Board Resolution 68-16) that calls for maintenance of existing high water quality unless specific findings can be made.

[3] Specific Conductance, or Electronic Conductivity (EC) is a measure of salinity, based on the fact that a saline solution conducts an electric current. The modern units for EC are "Siemens", but some of the sources referenced in this staff report use an older term, "mhos." One milliSiemen per centimeter (mS/cm) = 1000 microSiemens per centimeter (µS/cm). The equivalent older terms are millimhos (mmho/cm) and micromhos (µmho/cm).

Table 2-1 in the Lahontan Basin Plan summarizes designated beneficial uses of the surface waters affected by the proposed amendments. (The Basin Plan does not distinguish between existing and potential beneficial uses.) Most waters of the Carson and Walker River watersheds are designated for the following uses: Municipal and Domestic Supply (MUN), Agricultural Supply (AGR), Ground Water Recharge (GWR), Water Contact Recreation (REC-1); Non-Contact Water Recreation (REC-2); Commercial and Sportfishing (COMM), Cold Freshwater Habitat (COLD), Wildlife Habitat (WILD), and Spawning, Reproduction and Development. Additional uses apply to some waters, such as the "Water Quality Enhancement" (WQE) and Floodwater Retention (FLD) uses for wetlands. Basin Plan amendments adopted in 2000 removed the MUN from Hot Creek and Fales Hot Springs in the West Walker River watershed in recognition of naturally high concentrations of toxic constituents from geothermal sources.

Some of the water quality objectives in the Lahontan Basin Plan are based on scientifically-derived criteria for protection of specific beneficial uses (for example, ammonia toxicity criteria for the protection of aquatic life, and state Maximum Contaminant Levels for protection of drinking water). Other objectives are more stringent than published criteria because they reflect historical background water quality. The existing water quality objectives for Percent Sodium in surface waters of the Carson and Walker River watersheds are based on historic water quality data and antidegradation considerations, and they are more stringent than the irrigation water criteria for Percent Sodium available at the time they were adopted.

Both state and federal antidegradation regulations provide for the protection of water quality that is better than numerical limits set in standards, unless specific findings can be made to allow degradation. (These regulations, and federal guidance, are summarized on Basin Plan page 3-14.) The California Nondegradation Policy requires findings that lowering of water quality is consistent with maximum benefit to the people of the state, and that it will not unreasonably affect present and probable future beneficial uses. The antidegradation section of the federal water quality standards regulation (40CFR 131.12) allows lowering of water quality under some circumstances if a state finds that it is "necessary to accommodate important economic or social development"; however, instream beneficial uses must continue to be protected. The federal regulation also allows designation of "Outstanding National Resource Waters" (ONRWs) where no long-term degradation can be allowed. Examples of waters that qualify for designation as ONRWs include waters in state and national parks and wildlife refuges, waters of exceptional recreational or ecological significance, and designated federal and state wild and scenic rivers. California has not formally designated any ONRWs in the Carson and Walker River watersheds, but the many lakes and streams located in federal wilderness areas and state parks, and the state "wild and scenic" segments of the West Walker and East Fork Carson Rivers would probably qualify for designation.

Site-specific standards have not been established for all waters of the Lahontan Region. Site-specific beneficial uses and/or water quality objectives for a given water body apply to upstream tributary water bodies unless these waters have their own site-specific standards. The current Percent Sodium objectives for the Carson and Walker River watersheds apply upstream of the stations with numeric objectives. The proposed SAR objectives will apply to entire water bodies and their tributaries upstream from the state line.

History of Percent Sodium Objectives. Although the SAR concept had been developed by the 1950s (USDA, 1954), Percent Sodium was used as a criterion for irrigation water in state and federal publications on the Carson and Walker River watersheds through the early 1970s (e.g., California Department of Water Resources, 1957; USDA Soil Conservation Service, 1971). Percent Sodium and SAR were both included in an early State Water Board criteria document (McKee and Wolf, 1963) used by Lahontan Water Board staff in Basin Planning.

The Water Board's 1975 *Water Quality Control Plan for the North Lahontan Basin* (subsequently replaced by the current regionwide Basin Plan) summarizes the history of water quality objectives for specific water bodies. Percent Sodium objectives were first established in separate water quality policies, all adopted in 1967, for the West Fork Carson River, East Fork Carson River, East Walker River, and West Walker River and Topaz Lake, and the West Fork Carson River. Such policies were required for interstate waters under the Federal Water Pollution Control Act of 1965. The policies cited a then-current 60 percent figure as the Percent Sodium threshold of concern for agricultural impacts. The Water Board adopted a separate plan for the Bryant Creek watershed, including a 50 percent maximum Percent Sodium objective, in 1970. Basin Plans were developed following the adoption of California's Porter-Cologne Water Quality Control Act in 1969. An interim plan received state approval in 1971 but was disapproved by the USEPA. The 1975 North Lahontan Basin Plan, approved by EPA in 1976, contained more stringent numeric objectives than the 1971 plan for a number of constituents, including Percent Sodium. The 1975 objectives were expressed as annual means and 90th percentile levels. The latter term means that no more than 10 percent of all samples should exceed the 90th percentile value. The current site-specific water quality objectives for most surface waters of the Carson and Walker River watersheds are the same as those in the 1975 North Lahontan Basin Plan. The format of the objectives table was revised, and footnotes and maps were added in the 1995 Lahontan Basin Plan. Table 8 illustrates the evolution of water quality objectives for Percent Sodium.

Part II of the 1975 North Lahontan Basin Plan includes summaries of the water quality data used to develop objectives. Data for Percent Sodium are summarized in Table 9 (Percent Sodium data were not provided for Topaz Lake or Bryant Creek). Note that sample numbers were limited. No detailed discussion of the rationale for specific 1975 objectives was provided, but the Carson and Walker River objectives appear to reflect the monitored mean and maximum values in Table 9.

Table 8. Historical Percent Sodium Objectives for the Carson and Walker Rivers (data from the 1967 policy documents and 1975 North Lahontan Basin Plan)

Water Body	1967 Policies	1971 Interim Plan (Maximum)	1975 North Lahontan Plan (Annual mean/90th Percentile
West Fork Carson River	< 40	40	20/25
East Fork Carson River	<45	45	25/30
Bryant Creek Basin	-	50	-/50
West Walker River	<60	60	25/30
Topaz Lake	<60	60	25/30
East Walker River	<50	50	30/35

Table 9. Summary of Data Used to Develop 1975 Percent Sodium Objectives[1]

Water Body Name	Years	# of Samples	Percent Sodium Values (%)		
			Mean	**Max**	**Min**
West Fork Carson River at Woodfords	1964-70	17	20	24	16
East Fork Carson River near Markleeville	1964-70	18	25	30	20
West Walker River near Coleville	1960-71	17	21	28	15
East Walker River near Bridgeport	1964-70	18	26	36	17

[1]Data from Chapter 14 of California Regional Water Quality Control Board, Lahontan Region (1975). Sources of data are not specifically cited.

In 1983-84, the Water Board updated the 1975 numerical water quality objectives for the West Fork Carson River. The staff report (California Regional Water Quality Control Board, Lahontan Region, 1983) reviewed a larger dataset (114 sampling events for Percent Sodium between 1958-1980). Important changes from the 1975 plan included the addition of a “Stateline” station and expression of numerical objectives as “means of monthly means.” The Stateline objectives were calculated using the ratio between concentrations observed at Woodfords and Paynesville in 1981. The amended numeric objectives for the West Fork Carson River were carried forward in the 1995 Basin Plan.

“Means of monthly means” are rolling averages computed by taking the average of all data collected during a given month over the period of record for each month of the year (e.g., mean of all samples collected during January between 1958-1980, mean of all samples collected during February between 1958-1980, etc.) and computing a long-term annual mean as the average of the monthly mean data.

The 1983 staff report for the Carson River plan amendments provided the following rationale for use of means of monthly means:

"Mean of monthly mean objectives are proposed because they are more representative of actual water quality than the present annual average objective. An annual average can be weighted toward a particular month or season if most of the monitoring occurs during that time. A mean of monthly means value weights all the monthly data equally, producing a more representative water quality value."

Compliance with Percent Sodium Objectives. In 2001, Water Board staff used the STPUD's dataset for the West Fork Carson River to calculate mean-of -monthly mean values for several constituents, to assess compliance with objectives. Calculated means of monthly means for Percent Sodium were 21.7 percent at Woodfords and 23.0 percent at Paynesville, in violation of the objectives for both stations (20 percent). These violations led to Section 303(d) listing of the two affected reaches of the river. Due to the limitations in sampling frequency discussed above, there are not enough recent data available to determine the current status of compliance with Percent Sodium objectives for other water bodies in the Carson and Walker River watersheds. Limited data (see Table 6) show that the objectives are violated in geothermal and geothermally-influenced surface waters, highlighting the need for a natural sources exclusion in the new SAR objectives.

Irrigation Water Quality Criteria

Sodium in irrigation water can affect crops both as a component of salinity, and as the cause of toxicity or nutrient deficiency ("sodicity") problems. While high SAR levels can be detrimental, low SAR values together with low salinity can also create problems by decreasing the rate of infiltration of water into soil. The criteria summarized below should be considered approximate rather than absolute thresholds because the extent of problems can vary with soils, climate, crop species and varieties, and irrigation practices (Ayers and Westcot, 1985).

Salinity. As noted above, salinity can be measured either as TDS or as EC. Dissolved salts form positively or negatively charged ions, called cations and anions respectively. The most common cations in irrigation water are calcium, magnesium, and sodium, and the most common anions are chloride, sulfate, and bicarbonate (Grattan, 2002). At low concentrations, some of these ions serve as plant nutrients. However, when high levels of salt accumulate in the root zone, plants have increasing difficulty in extracting water from soil. This can result in slow or reduced growth and visible symptoms such as wilting and color change, similar to those of drought. Shallow water tables can increase salinity problems since salt from ground water can move up to the root zone (USDA, 1997; Ayers and Westcot, 1985).

A widely used set of irrigation water quality guidelines (USDA, 1997) predicts that, in terms of salinity as it affects crop water availability, there should be no restriction on use of irrigation water with EC less than 0.7 mmho/cm [700 μmho/cm] or TDS less than 450 mg/L. However, tolerance to salinity varies among crop species and varieties. The USDA (1997) handbook includes the following salt tolerance thresholds (expressed as the EC of irrigation water, and qualitative salt tolerance ratings based on reductions in yield, for crops grown in the Carson and Walker River watersheds:

Alfalfa, 2.0 mmho/cm [2,000 μmho/cm], moderately sensitive
Potato, 1.7 mmho/cm [1,700 μmho/cm], moderately sensitive
Onion, 1.20 mmho/cm [1,200 μmho/cm], sensitive

The effects of salinity can vary with crop growth stage. Salt tolerance can be very low for germinating and small seedlings, and usually increases as the plant grows and matures (USDA, 1997).

The salinity of surface waters of the Carson and Walker River watersheds that are used for irrigation in California is much lower than the salt tolerance thresholds above. For example, the long term average EC for the West Fork Carson River at Woodfords is about 68 μmho/cm (California Regional Water Quality Control Board, Lahontan Region 1983, and STPUD data). Rockwell and Honeywell (2004) measured ECs ranging from 49 to 214 μS/cm (μmho/cm) in the Bridgeport Valley area of the East Walker River watershed. Most of the existing water quality objectives for TDS in the Carson and Walker River watersheds (see the Appendix to this staff report) are based on historical water quality. These objectives range from 45 mg/L to 145 mg/L, well below the 450 mg/L threshold for restrictions on use in the irrigation water guidelines. (The 305 mg/L objective for Indian Creek Reservoir is based on the quality of treated wastewater exported to the reservoir in the 1970s, and is in need of revision since the reservoir no longer stores wastewater.)

Salinity and Infiltration. Although high salinity is detrimental to soil structure and water availability to plants, very low salinity in irrigation water can also cause infiltration problems regardless of the SAR value, and indirectly affect crop production. Infiltration problems differ from salinity problems in that they reduce the quantity of water entering the soil for later use by crops, while salinity problems reduce the availability of water stored in the soil. Reduced infiltration can lead to surface soil crusts and crop emergence problems (Ayers and Westcot, 1985).

Either high SAR or low salinity (measured as EC) can lead to dispersal of soil aggregates, resulting in reduced water infiltration and anoxia in the root zone. In some cases, low salinity irrigation water can dissolve and leach most soluble minerals, including calcium, from the surface soil, leading to nutrient deficiencies.

Infiltration problems are evaluated by using SAR and EC together. While high SAR leads to infiltration problems, severe infiltration problems can also occur when SAR is relatively low (between 0 and 3), and EC is very low (less than 0.2 mmho/cm, or 200 μmho/cm) (USDA, 1997). Grattan (2002) cites the case of the very pure water of the Friant-Kern canal in the eastern San Joaquin Valley, with an EC of 0.05 mmho/cm (equal to 50 μmho/cm) and a SAR value of 0.6. Such water causes infiltration problems even when applied on soils with high sand content.

Infiltration problems due to low salinity or high SAR can be addressed by applying gypsum (calcium sulfate) to irrigation water or soil. Gypsum dissolves into calcium and sulfate ions, that increase water salinity and reduce SAR. Calcium cations displace sodium cations adsorbed to soil particles, improving soil structure and water infiltration rate, and increasing the availability of calcium as a nutrient.

Historical data indicate that many surface waters in the upper Carson and Walker River watersheds in California have EC and SAR values lower than the literature thresholds for severe infiltration problems. However, no infiltration problems due to low salinity of irrigation water have been identified for these watersheds in publications reviewed by Water Board staff (e.g. USDA Soil Conservation Service, 1971; Cobourn and Swanson, 2004). (Some irrigated areas of the upper Carson and Walker River watersheds may have low infiltration rates due to high groundwater tables.) Water Board staff also consulted with Edward Blake, a soil scientist at the U.S. Natural Resources Conservation Service's Minden, Nevada office, by telephone. Mr. Blake was not aware of any specific infiltration problems attributable to low EC of irrigation water in the Carson and Walker River watersheds, although he mentioned the use of gypsum in portions of the lower watersheds in Nevada.

Sodium Toxicity and Nutrient Deficiency. Toxicity from sodium and certain other ions can occur when the ions are taken up with soil water, move through the plant via the transpiration process, and accumulate in leaves at damaging concentrations. With sprinkler irrigation, leaves may also take up sodium directly. The degree of damage depends on factors such as sodium concentration, the type and growth stage of the crop, and the rate and duration of water use. Toxicity may occur even when salinity is low. Symptoms of sodium toxicity include leaf burn, scorch and dead tissue at the outer edges of leaves. Trees and other woody perennial crops have been considered more sensitive to susceptible to sodium toxicity than annual crops (Ayers and Westcot, 1985; USDA, 1993). However, recent research has created uncertainty whether injury to these crops is due directly to sodium toxicity or indirectly to calcium deficiency in the root zone. Calcium is needed for maintenance of the integrity of root cell membranes, and their capacity for selective ion uptake.

The USDA (1997) irrigation guidelines predict no restriction in use of irrigation water from sodium toxicity for surface irrigation if SAR is less than 3, or for sprinkler irrigation if the sodium concentration is less than 3 meq/L. Slight to moderate restrictions in use may occur for surface irrigation if SAR is between 3 and 9 or sodium concentration is greater than 3 meq/L. The USDA (1993) has also identified relative crop tolerance to foliar injury from sprinkler irrigation, as ranges of sodium concentrations causing injury. Crops sensitive within specific ranges of sodium concentration include:

.

Almond, apricot, citrus, Plum: less than 5 meq/L
Grape, pepper, potato, tomato: 5-10 meq/L
Alfalfa, barley, maize, sorghum: 10-20 meq/L
Sugar beet, sunflower: over 20 meq/L

Using these USDA thresholds and a standard conversion factor of 23 mg/meq of sodium, the sodium concentrations that could cause injury to alfalfa, one of the most important crops in the Carson and Walker River watersheds, would range from 230 to 460 mg/L. The thresholds for injury to potato, another crop grown in these watersheds, would be 115-230 mg/L. Available data indicate that sodium concentrations in surface waters of the Carson and Walker River watersheds in California are well below the threshold for injury from sprinkler irrigation. (See Tables 5 and 7 above.) In addition, dissolved sodium concentrations reported by NDEP range from 3 to 7 mg/L for the West Fork Carson River at Paynesville to 12 to 25 mg/L for the East Walker River at Stateline.

Proposed California Objectives for SAR

Comparison of historical water quality data for the Carson and Walker River watersheds and the irrigation water quality criteria summarized above indicates that (except for geothermally influenced areas), surface waters in California have low levels of salinity and sodium concentrations, and low Percent Sodium and SAR values. Historical water quality and the proposed new SAR objectives are below the literature thresholds for adverse salinity effects and sodium toxicity to even the most sensitive crops.

Rationale for Specific Features of Proposed SAR Objectives. The proposed objectives are based on thresholds in the agricultural literature, rather than on historical water quality data, because of the data quantity problems summarized above. (An alternative with objectives based on historical quality is considered in the substitute environmental document for the proposed amendments.) Because of this emphasis on criteria, the objectives are proposed to apply to entire surface water bodies and their tributaries, rather than at specific monitoring stations.

The new SAR objectives are proposed to be expressed as annual averages rather than means and 90th percentile values, or means of monthly means. The available data do not allow prediction of the expected degree of seasonal and annual variation in SAR; this would be needed to set 90th percentile objectives. The expression of water quality objectives as means of monthly means has proved counterproductive since it was developed in the 1980s. Means of monthly means are inappropriate for use in Section 303(d) assessment in that they use all historical data and do not account for improvements in water quality over time due to the implementation of point and nonpoint source controls. Determining compliance with objectives based on means of monthly means requires lengthy calculations, and the concept is difficult to explain to dischargers and other stakeholders.

The specific SAR values in the proposed objectives (see Tables 1 and 10) were chosen be less than the literature threshold of 3. They were set at the value of 2 except for water bodies where Nevada’s water quality objective is 1. (See the discussion of interstate issues below.)

The proposed natural sources exclusion language in the narrative SAR objectives is necessary because natural sources are not controllable. Lack of this language could result in the need for Section 303(d) listing and TMDL development for water bodies where standards are violated only because of natural sources. Both processes would consume limited Water Board resources without benefit to water quality or beneficial uses. The USEPA allows states to include natural sources exclusion language in their water quality standards, and a number of states, including Nevada, have adopted such language.

As noted above, the use of irrigation water with very low salinity (EC) can lead to severe infiltration problems, even when SAR is low. No changes are being proposed in the existing water quality objectives for TDS (based on historical TDS levels), and the new SAR objectives alone will not be sufficient to prevent infiltration problems. However, the low salinity of most surface waters of the upper Carson and Walker River watersheds is natural, and desirable in terms of protecting aquatic life and riparian vegetation adapted to low salinity conditions. Because gypsum can easily be applied to irrigated lands to remedy infiltration problems, it is not necessary to set water quality objectives for upstream waters at levels that would increase salinity in order to enhance the Agricultural Supply beneficial use.

Where waters of the Carson and Walker River watersheds in California have SAR values better than the proposed objectives, that quality will be required to be maintained unless findings can be made under the state Nondegradation Policy to allow lower water quality. Since the difference between the objectives and historical quality is on the order of one SAR unit or less, intensive monitoring and modeling would probably be required to predict how much degradation would occur from a specific discharge. (The Lahontan Basin Plan prohibits direct discharges to surface waters of the Carson and Walker River watersheds except for limited circumstances such as restoration projects.) These factors, and the fact that existing objectives for TDS are not proposed for change, make it likely that existing water quality better than the SAR objectives will be maintained.
SAR and Percent Sodium are criteria developed specifically for the protection of irrigation water, and the proposed Basin Plan amendments will not directly affect any other beneficial uses or the water quality objectives that protect those uses. By maintaining water quality at or near historic levels in terms of sodium and other constituents of SAR, the new objectives will protect water quality for other beneficial uses (e.g. municipal supply, aquatic life and wildlife habitat uses) that could be affected by significant increases in sodium concentrations.

Implementation. No new implementation measures are proposed in the Basin Plan amendments. Implementation of the new objectives will occur through the Water Board's existing authority to control point and nonpoint source discharges. The objectives may be reflected in future new or revised water quality permits, conditional waivers of permits, enforcement orders, and/or water quality monitoring programs. (The current Percent Sodium objectives are cited as receiving water limits in several existing permits for discharges in the Carson and Walker River watersheds, but there are no effluent limitations for Percent Sodium in these permits.) As part of the ongoing Clean Water Section 305(b)/303(d) assessment process, Water Board staff will review available monitoring data to determine compliance with the objectives.

Interstate/tribal issues. The federal water quality standards regulation (40 CFR 131.10[b]) states:

> *"In designating uses of a water body and the appropriate criteria for those uses, the State shall take into consideration the water quality standards of downstream waters and shall ensure that its water quality standards provide for the attainment and maintenance of the water quality standards of downstream waters."*

Therefore, the Water Board must consider how the new SAR objectives will affect beneficial uses of downstream waters in Nevada and tribal lands, and whether they are compatible with downstream water quality standards.

Nevada began to develop and adopt water quality standards in the 1960s (Pahl, 2004). These standards are located in Nevada Administrative Code Section 445A. Nevada has separate beneficial uses for "Irrigation" and "Watering of Livestock," both of which are included in California's single Agricultural Supply use. Nevada's SAR standards for surface waters of the Carson and Walker River watersheds are summarized in Table 10, below.

There are two levels of numeric standards for many surface waters in Nevada: "Water Quality Standards for Beneficial Uses," based on use-specific criteria, and "Requirements to Maintain Existing Higher Quality" (RMHQ) standards based on monitored water quality and antidegradation considerations. For surface waters of the Carson and Walker River watersheds with site specific standards, Nevada's beneficial use standard for SAR is an annual average of "≤8" (less than or equal to 8). The background for this number is not clear, but it probably comes from an older USEPA water quality criteria document (Randy Pahl, NDEP, personal communication). Nevada's RMHQ standards for SAR at state line stations in the Carson and Walker River watersheds range from ≤ 1 to ≤ 2 (annual averages). There are no adopted tribal water quality standards in the California portions of the Carson and Walker River watersheds, although the Washoe Tribe is in the process of developing its own standards (Joy Peterson, personal communication).

The proposed California SAR objectives are compatible with the Nevada RMHQ standards summarized in Table 10, and more stringent than the Nevada Beneficial Use standards for the West Walker River and Topaz Lake (Nevada does not have RMHQ standards for these waters). Nevada's standards are expressed as "less than or equal to" values. As noted above, water quality "less than" (better than) California's new objectives will be protected under the Nondegradation policy.

The California objectives are based on criteria thresholds that will protect even sensitive crops against the impacts of sodium toxicity, and should thus protect current and future crops grown in Nevada that are irrigated with water from California. (The Nevada Farm Bureau's online summary of Nevada crops includes some sodium-sensitive crops such as fruit trees and berries, but does not indicate where in Nevada they are grown. They are not included as important crops in the Carson-Walker River literature reviewed by Water Board staff.)

In evaluating compliance with downstream standards the Water Board must consider not only numeric limits for protection of irrigated agriculture, but cumulative impacts on beneficial uses of terminal waters. As noted above, increases in salinity in the waters of the Carson Sink and Walker Lake are of concern in relation to important aquatic life and wildlife uses. Salts can be expected to accumulate naturally over geologic time in internally drained terminal waters. However, water diversions and other human activities have drastically increased salinity in these waters. By maintaining historic or near-historic SAR levels in California waters, the proposed SAR objectives will prevent significant cumulative increases in salinity loading to the terminal waters from California sources.

Conclusions and Recommendation. It is appropriate to replace the obsolete Percent Sodium objectives for the Carson and Walker River watersheds with new objectives based on irrigation water quality criteria. The change will protect beneficial uses in California, Nevada and tribal lands, and will increase consistency with Nevada standards. The new objectives will avoid the need to develop Percent Sodium TMDLs for two segments of the West Fork Carson River. The addition of natural sources exclusion language will avoid the need for Section 303(d) listing and TMDL development for geothermally influenced waters elsewhere in the affected watersheds. Water Board staff's separate draft substitute environmental document concludes that approval of the Basin Plan amendments will not have any significant environmental or socioeconomic impacts. Approval of the amendments is recommended.

Table 10. Comparison of Existing Nevada SAR Standards with Proposed California SAR Objectives for Carson and Walker River Watersheds. (Cited Nevada standards are those applicable at the state line. Historic SAR values are from Tables 3 and 4.)

Water Body	NV SAR Standard (Requirement to Maintain Existing Higher Quality)- Annual Average	NV SAR standard (Beneficial Use Standard)- Annual Average	Historic Annual Average SAR	Recommended CA SAR Objective (Annual Average)
West Fork Carson River	$\leq$ 1	$\leq$ 8	0.3	1
East Fork Carson River	$\leq$ 2	$\leq$ 8	0.5	2
Bryant Creek	$\leq$ 1	$\leq$ 8	0.5	1
East Walker River	$\leq$ 2	$\leq$ 8	0.8	2
West Walker River	None	$\leq$ 8	0.8	2
Topaz Lake	None	$\leq$ 8	0.8	2

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Appendix

Basin Plan Tables and Figures for the Carson and Walker River Watersheds

(The following tables are from an in-progress reprinted edition of the Basin Plan, and include some format changes from the 1995 originals.)

Table 3-14
WATER QUALITY OBJECTIVES FOR CERTAIN WATER BODIES
EAST & WEST FORK CARSON RIVER HYDROLOGIC UNITS

See Fig. 3-7	Surface Waters	Objective (mg/L except as noted)[4]								
		TDS	Cl	SO_4	Total P	B	% Na	Total N	TKN	NO_3-N
1	West Fork Carson River at Woodfords[1]	55	1.0	2.0	0.02	0.02	20	0.15	0.13	0.02
2	West Fork Carson River at Stateline[1]	70	2.5	2.0	0.03	0.02	20	0.25	0.22	0.03
3	Indian Creek Res.[1]	305	24	-	0.04	-	-	4.0	-	-
4	East Fork Carson River[2]	80 100	4.0 6.0	4.0 8.0	0.02 0.03	0.12 0.25	25 30	0.20 0.30	-	-
5	Bryant Creek Basin[2,3]	140 200	15 25	35 50	0.02 0.03	0.20 0.50	- 50	0.20 0.30	-	-

1 Values shown are mean of monthly mean for the period of record.
2 Annual average value/90th percentile value.
3 In addition, the following numerical water quality objectives shall apply specifically to surface waters of the Bryant Creek Basin:

Parameter	Maximum Value (mg/l except as noted)
Turbidity (NTU)	15
Alkalinity, total as $CaCO_3$	70 (minimum)
Acidity, total as $CaCO_3$	10
Dissolved Iron	0.5
Manganese	0.5
Color, PCu	15
Aluminum	0.1
Copper	0.02
Arsenic	0.05

4 Objectives are as mg/L and are defined as follows:

B	Boron	NO_3-N	Nitrogen as Nitrate
Cl	Chloride	TKN	Nitrate, Total Kjeldahl
N	Nitrogen, Total	P	Phosphorus, Total
% Na	Sodium, Percent		

$$\frac{(Na x 100)}{Na + Ca + Mg + K} = \%Na$$

Na, Ca, Mg, and K expressed as milliequivalents per liter (meq/L) concentrations.

SO_4	Sulfate
TDS	Total Dissolved Solids (Total Filterable Residue)

Figure 3-7
WATER QUALITY OBJECTIVES FOR CERTAIN WATER BODIES
CARSON RIVER HYDROLOGIC UNITS

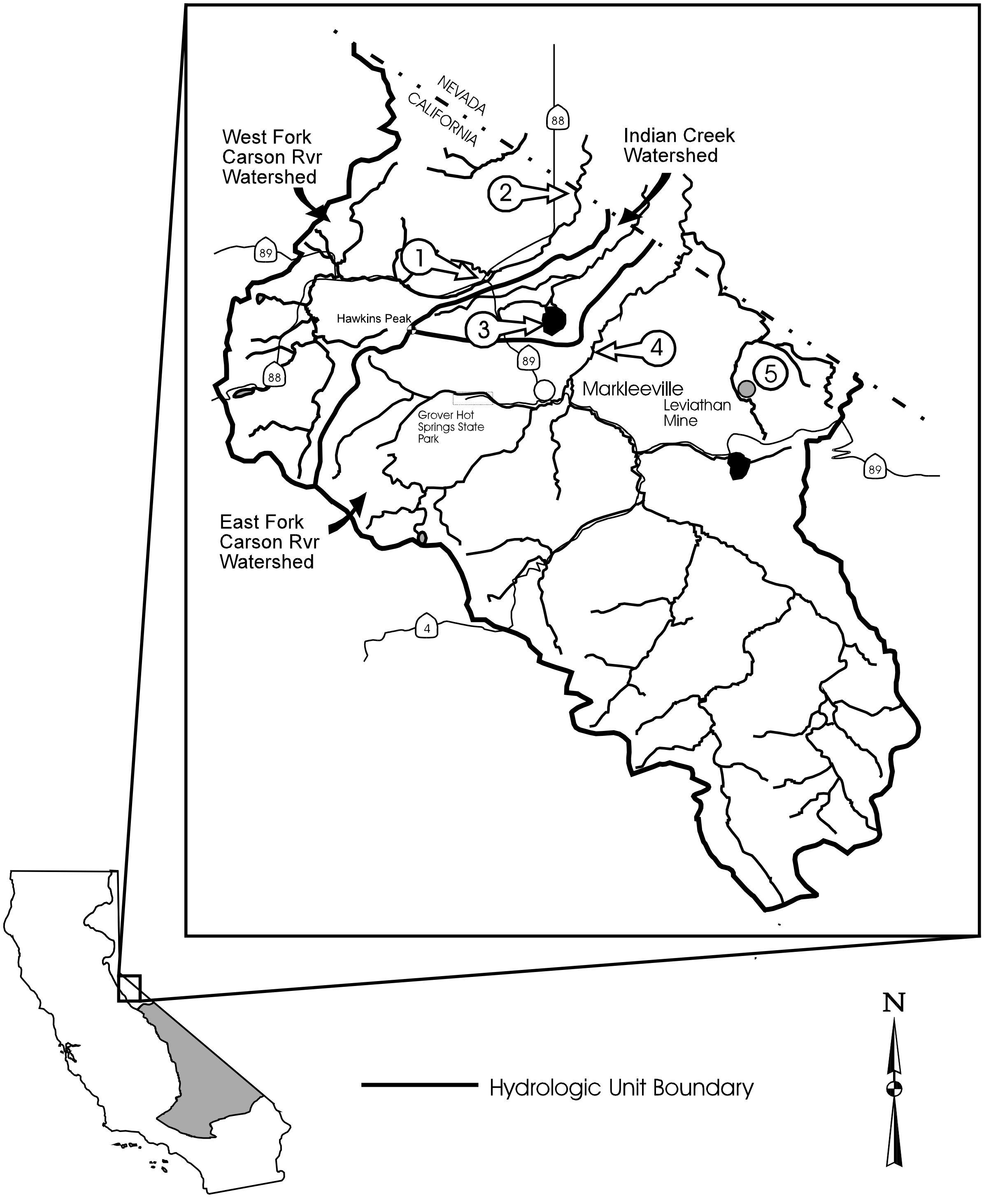

Table 3-15
WATER QUALITY OBJECTIVES FOR CERTAIN WATER BODIES
WEST & EAST WALKER RIVER HYDROLOGIC UNITS

See Fig. 3-8	Surface Waters	Objective (mg/L except as noted)[1,2]						
		TDS	Cl	SO_4	% Na	B	Total N	Total P
1	Topaz Lake	90 105	4 7	-	25 30	0.10 0.20	0.10 0.30	0.05 0.10
2	West Walker River at Coleville	60 75	3.0 5.0	-	25 30	0.10 0.20	0.20 0.40	0.01 0.02
3	East Walker River at Bridgeport	145 160	4.0 8.0	-	30 35	0.12 0.25	0.50 0.80	0.06 0.10
4&5	Robinson Creek & all other tributaries above Bridgeport Valley	45 70	2.0 4.0	-	-	-	0.05 0.10	0.02 0.03

1 Annual Average value/90th Percentile Value

2 Objectives are as mg/L and are defined as follows:

B	Boron
Cl	Chloride
N	Nitrogen, Total
P	Phosphorus, Total
% Na	Sodium, Percent

$$\frac{(Na x 100)}{Na + Ca + Mg + K} = \%Na$$

(Na, Ca, Mg, K expressed as milliequivalents per liter or meq/L concentrations)

SO_4	Sulfate
TDS	Total Dissolved Solids (Total Filterable Residue)

Figure 3-8
WATER QUALITY OBJECTIVES FOR CERTAIN WATER BODIES
WALKER RIVER HYDROLOGIC UNITS