A Watershed Management Approach to Assessment Of Water Quality and Development of Revised Water Quality Standards for the Ground Waters of the Mojave River Floodplain

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Abstract

The Mojave River watershed is located in the arid high-desert region of Southern California in San Bernardino County. In the 1970s and 1980s the Lahontan Regional Water Quality Control Board (RWQCB) established numerical water quality objectives (WQOs) for several locations in the watershed. Because the Mojave River flows underground for much of its 120 miles, some of the numerical WQOs apply to both surface waters and ground waters.

In 1996 the RWQCB assembled a watershed management team of local stakeholders for the Mojave Watershed. A primary goal identified by the stakeholders was to assess the current state of water quality for the Mojave River system. A possible long-term goal is the development of total maximum daily loads as required by the Clean Water Act (CWA). The Mojave River is listed as a water quality limited segment in accordance with Section 303(d) of the CWA. Recent data indicate that numerical WQOs are being exceeded at several locations.

The watershed team has developed and implemented work plans to sample surface waters and ground waters within the watershed. The final work plans included sampling at approximately 20 ground water monitoring wells and 10 surface water locations. The plans also included a list of constituents of concern for laboratory analysis. The RWQCB and various other stakeholders funded the sampling effort. The preliminary findings of the study indicate water quality impacts are likely associated with septic leaching systems, dairies, industrial and municipal wastewater disposal practices, and irrigated agriculture. The stakeholder group is currently assessing these data and developing a plan of action that includes additional surface and ground water sampling.

Geography

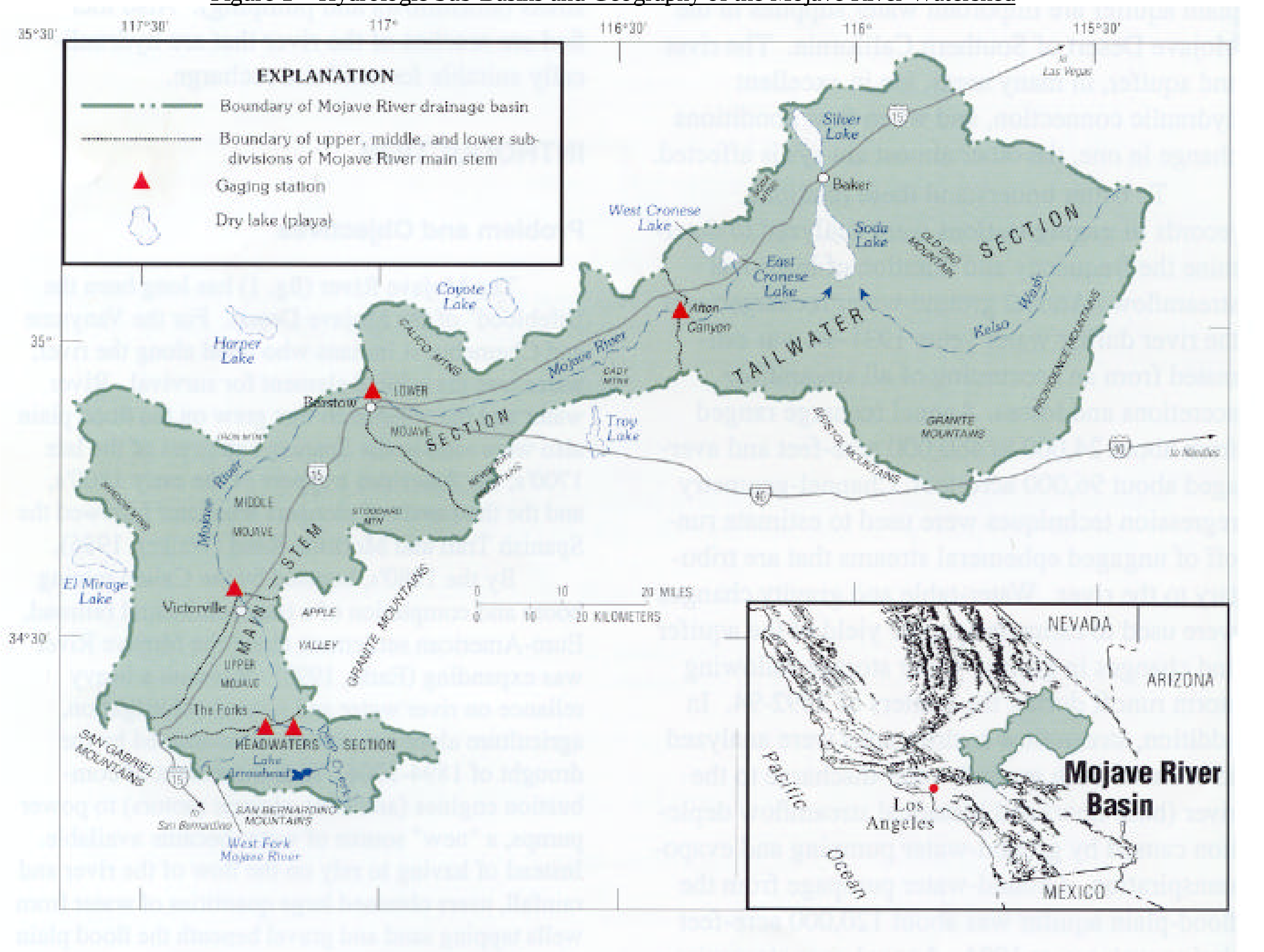
The Mojave River watershed is located entirely within San Bernardino County, and includes approximately 1,600 square miles of total drainage (Figure 1). Approximately 210 square miles of this drainage area is located in the San Bernardino Mountains, which are the headwaters for the Mojave River system. Elevations within the watershed range from approximately 8,500 feet above mean sea level (msl) at Butler Peak in the San Bernardino Mountains to 1,400 feet above msl at Afton Canyon near the terminus of the Mojave River.

Deep Creek and the West Fork of the Mojave River are located in the San Bernardino Mountains and are the two perennial tributaries to the Mojave River. Both tributaries have multiple branch tributaries within the San Bernardino Mountains. Deep Creek and the West Fork of the Mojave River converge immediately upstream of the Mojave Forks Dam, which was constructed for flood control to protect downstream land and property from damage during peak storm events. The Mojave River channel begins at the Mojave Forks Dam and extends for approximately 120 miles transecting the communities of Hesperia, Apple Valley, Victorville, Hinkley, and Barstow and finally terminating at Soda and Silver Dry Lakes near the community of Baker.

Climatology

Precipitation in the watershed includes both rain and snow. The majority of this snow falls in the upper elevations of the San Bernardino Mountains. Annual average precipitation in the San Bernardino Mountains is 42 inches, with most of the precipitation falling in the winter months. Annual average snowfall at Lake Arrowhead is approximately 80 inches. Annual average precipitation for the most arid portions of the watershed such as Afton Canyon is less than 4 inches. For the remaining portions of the watershed, annual precipitation rarely exceeds 6 inches. High intensity summer thunderstorms can produce several inches of rain over isolated areas.

Figure 1 – Hydrologic Sub-Basins and Geography of the Mojave River Watershed



Source: Modified from USGS Water-Investigations Report 95-4189

Daily temperatures in the watershed vary greatly from the higher to lower elevations. At the higher elevations, low daily temperatures in the winter are commonly below 32^{0}F with mean daily temperatures of approximately 53^{0}F. In contrast, peak daily temperatures in the summer at the lower elevations are typically above 100^{0}F with mean daily temperatures of approximately 84^{0}F. The elevated daily temperatures and low humidity in the lower elevations result in annual evaporation rates exceeding 90 inches per year.

Demographics

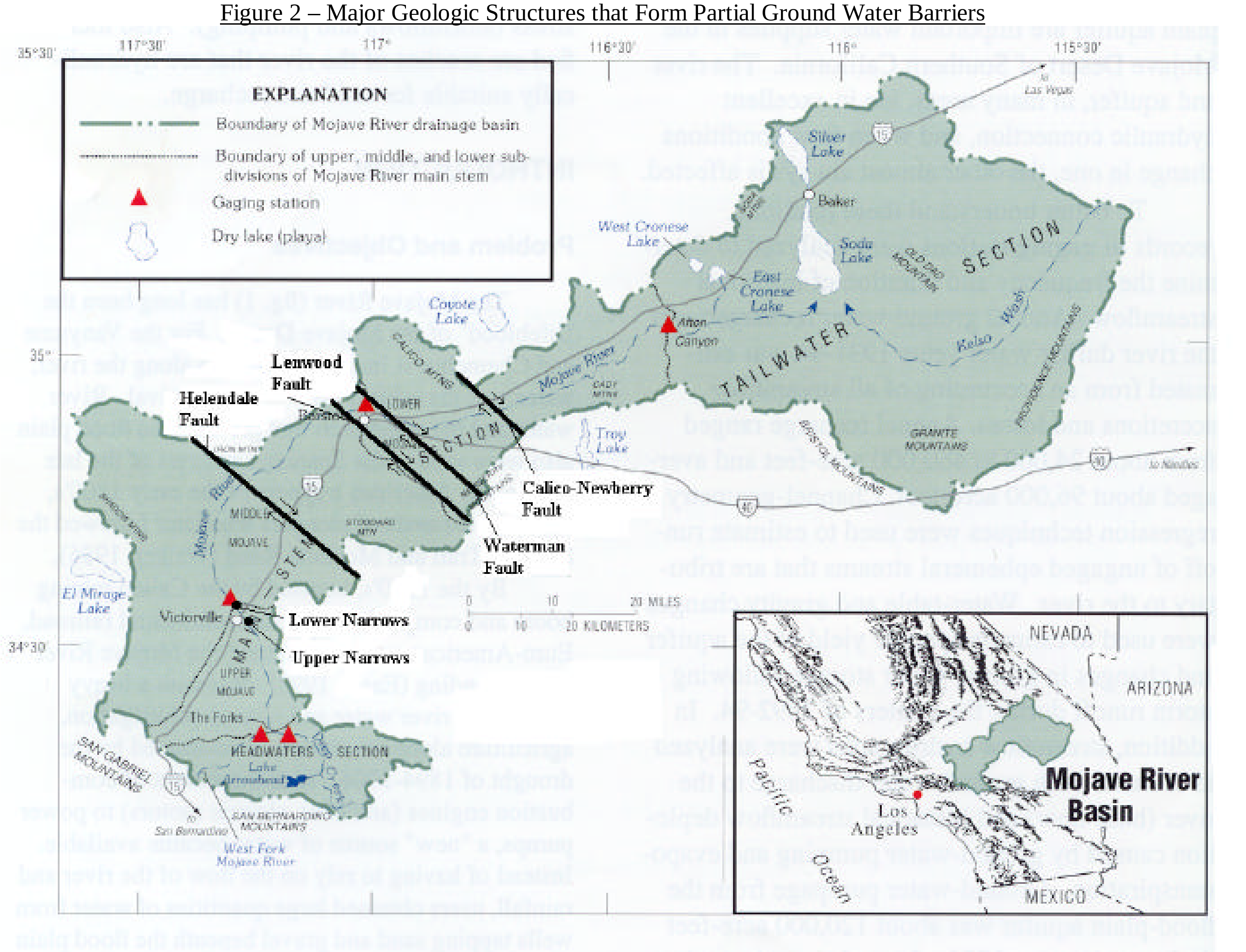
Population in the Mojave River watershed increased dramatically from approximately 6,000 people in 1930 to more than 295,000 people in 1997. Figure 1 illustrates the locations of various communities in the watershed. The majority of people live in the urbanized Upper Basin, where community populations in 1997 were (1) Apple Valley - 54,100; (2) Hesperia - 60,900; and, (3) Victorville -61,700. Significantly less people live in the primarily rural Middle and Lower Basins. The largest community in the Lower Basin is Barstow, which had a 1997 population of 22,650. Additional urban growth is expected throughout the watershed, and the projected population for the entire watershed by the year 2015 is nearly one-half million people.

Geology and Hydrology

The geology of the Mojave Watershed is a significant factor in understanding how numerical Water Quality Objectives (WQOs) can be appropriately established and implemented for the Mojave River system. The unconsolidated sediments of the Mojave Watershed generally consist of three units: (1) Tertiary and Quaternary older and younger alluvial fan deposits; (2) Quaternary older alluvium and playa deposits; and, (3) Quaternary younger alluvium and recent Mojave River alluvium. In general, the older fan and alluvial deposits are compositionally similar to the younger deposits, but are more consolidated and less transmissive.

The ground waters of the Mojave River floodplain aquifer are primarily within the younger and recent Mojave River alluvium, which consists of moderately to well-sorted course sands and gravels. Transmissivity values range from approximately 10,000 to 25,000 ft^2/day. The recent alluvium is typically less than 30 feet thick and follows the present day surface features of the Mojave River floodplain. The younger and recent alluvium form an alluvial plain that ranges from approximately 120 feet in width and 50 feet in thickness at the Upper Narrows near Victorville to several miles in width and about 250 feet in thickness immediately upstream of Barstow near the communities of Hodge and Lenwood (Figure 2). The Mojave River floodplain sediments are underlain and laterally bounded by the older and more consolidated alluvial fan and playa deposits. In some cases, the older sediments are absent and the floodplain sediments are in direct contact with bedrock.

Figure 2 – Major Geologic Structures that Form Partial Ground Water Barriers



Source: Modified from USGS Report 95-4189

Hydrologic Sub-basins

Previous hydrologic studies have separated the Mojave River watershed into sub-basins based on hydrologic features. This paper references the five hydrologic sub-basins discussed in USGS Report 95-4189. The five sub-basins are illustrated on Figures 1 and 2, and are described as: (1) Headwaters – tributaries above the Mojave Forks dam; (2) Upper Basin - Mojave Forks Dam to the Lower Narrows at Victorville; (3) Middle Basin - Lower Narrows to the Waterman Fault at Barstow; (4) Lower Basin - Waterman Fault to Afton Canyon; and (5) Tailwater - Afton Canyon to Silver Dry Lake. The five sub-basins include the both the floodplain aquifer and the regional aquifer systems. The floodplain aquifer generally follows the surface expression of Mojave River. The regional aquifer is located within alluvial and lakebed deposits that generally bound and underlie the floodplain.

The regional aquifer discharges ground water into the floodplain aquifer in some locations, but does not receive significant recharge. Ground water is pumped extensively from the regional aquifer for domestic, municipal, industrial, and agricultural use. The regional aquifer is in a condition of significant overdraft in some locations because of the imbalance between demand and natural recharge. Because the Regional Water Quality Control Board (RWQCB) has not established specific numerical WQOs for the ground water in the regional aquifer, this paper focuses primarily on the hydrology and quality of the Mojave River floodplain aquifer.

Hydrologic Effects of Geologic Structures

Bedrock within the watershed typically does not transmit large quantities of water, but plays an important role in the hydrogeology of the Mojave River system. Bedrock forms a topographic high along the Mojave River channel at the Upper and Lower Narrows near Victorville and at Afton Canyon, and is relatively impermeable at these locations. The bedrock acts as a ground water barrier, forcing ground water to the surface of the Mojave River channel. The Mojave River flows for several miles downstream of these locations before infiltrating back into the course sands of the river channel. Ground water in the floodplain aquifer is extremely shallow both upstream and immediately downstream of these bedrock structures, promoting vegetation and evapotranspiration.

Quaternary faults in the Mojave Watershed are: (1) sub parallel to the San Andreas and Garlock Fault systems; (2) trend in a northwest to southeast direction; and (3) are right-lateral strike-slip faults. These faults are the Helendale, Lenwood, Camp Rock/Harper Lake (e.g, Waterman), and Calico/Newberry Fault systems (Figure 2). Recent unpublished studies completed by the United States Geologic Survey (USGS) also suggest an unnamed fault exists on a similar northwest to southeast trend in the Victorville area that is near parallel to the Mojave River channel. Where these faults intersect the river channel, they typically act as partial barriers to ground water flow, forcing ground water to the land surface on the upgradient side of the fault. Ground water elevations are typically several feet lower on the downgradient side of these faults.

Base flow is ground water from the floodplain aquifer that is forced to the surface of the river channel at geologic structures such as bedrock or faults. Between 1931 and 1994, annual stream flow measurements at locations with geologic structures included: (1) the Lower Narrows at Victorville - 54,000 afy; (2) Barstow - 18,000 afy; and (3) Afton Canyon - 7.5 afy. Data collected since 1930 indicate that approximately 37 % of the annual surface water at the Lower Narrows is base flow. The remaining surface water at the Lower Narrows is storm water runoff from the headwaters and surrounding intermittent stream channels. Gauging station observations indicate that storm water rather than base flow constitutes the majority of gauged surface water at Barstow and Afton Canyon.

Overdraft of the Mojave River Floodplain Aquifer

Watering holes along the Mojave River were important water supply features for the pioneer settlers in the mid to late 19th century. The Mormon and Spanish trails followed sections of the Mojave River and relied upon these sources of water. Recorded locations include Lanes Crossing (river mile 20), Point of Rocks (river mile 34), Fish Pond (river mile 60), Forks of Road (river mile 70) and Camp Cady (river mile 82). The source of water at these locations was primarily the floodplain aquifer where geologic structures such as bedrock or faults forced ground water to the surface.

Early population development along the Mojave River floodplain was sparse and primarily agricultural. Between 1936 and 1960, human population increased in the watershed from 6,150 to 51,400. Table 1 illustrates the changes in water demand from the Mojave River floodplain aquifer between 1936 and 1960.

Table 1 – Historical Water Demand in Acre-Feet per Year

	1936			**1960**		
	Upper	*Middle*	*Lower*	*Upper*	*Middle*	*Lower*
Agricultural	11,250	5,950	1,200	21,700	17,150	8,150
Urban	200	100	250	2,950	900	2,050
Industrial	250	0	200	1,400	0	700
Totals	11,700	6,050	1,650	26,050	18,050	10,900
	1936 total - 19,400			*1960 total – 56,000*		

Beginning in about 1952, the watershed has changed from an agricultural to an urban setting. More than 339,000 people currently live in the Mojave Watershed and rely primarily upon ground water resources for municipal and domestic supply. Total ground water production from the floodplain aquifer has increased to an estimated 120,000 afy, which is significantly greater than natural and artificial recharge. Approximately 100,000 afy of ground water is extracted from the floodplain aquifer in the Upper and Middle Basins, and more than half of this use is for municipal and domestic supply.

Overdraft in the Upper and Middle basins has significantly lowered ground water levels in the floodplain aquifer. The lower ground water levels in the Upper Basin have resulted in decreased base flows measured at the Lower Narrows because less ground water is being forced to the surface at the Upper Narrows (Figure 2). Base flows at the Lower Narrows have steadily decreased from an annual average of 26,000 afy in the 1930s and 1940s to only 11,000 afy in 1993. The reduction in base flow at the Lower Narrows indicates that less water is being recharged from the Upper Basin to the Middle and Lower Basins.

In the 1990s, water users in the Lower Basin filed suit against upstream users. The suit was ultimately settled through a formal adjudication of the ground water basins. The adjudication includes requirements for reduced pumping throughout the watershed, and importation of water from California's aqueduct system. The adjudication is based in part on minimum base flow requirements at the Lower Narrows downstream of Victorville. If base flows are below the minimum annual value, then upstream users must purchase imported water to supply downstream users. Users that exceed their adjudicated pumping rights must also purchase imported water for recharge. The adjudication has been appealed to the State of California Supreme Court, and a final decision is pending. In the interim, most elements of the adjudication are being implemented though a stipulated agreement with users that are party to the judgment. Those parties that filed an appeal and did not sign the stipulated agreement are not currently bound by the judgment.

The Mojave Water Agency (Agency) has legal responsibility for implementing the requirements of the judgment. The Agency's strategy to abate the overdraft conditions is to reduce ground water extraction from the floodplain aquifer, and to recharge the floodplain aquifer with Bay/Delta water. The Agency currently has more than 20,000 acre-feet of water rights through California's Bay/Delta aqueduct system. Pipelines are being constructed to transport water from the aqueduct to recharge basins along the Mojave River floodplain. Bay/Delta water is currently being discharged to recharge areas along the Mojave River channel near Hesperia and Barstow. Additional recharge infiltration basins are planned downstream of Barstow as the pipeline is extended.

The quality of the Bay/Delta water plays an important role in the assessment of water quality in the flood plain aquifer and the potential development of revised WQOs. Depending on the location of the recharge basins and the seasonal/annual changes in water quality, the Bay/Delta water may be of higher or lower quality than the native ground waters of the floodplain aquifer. Regardless, eliminating overdraft conditions may improve water quality in some areas by reducing the recharge of naturally poor quality water from the older and deeper sediments. Reducing overdraft conditions will likely also improve and/or restore riparian vegetation along the Mojave River channel. Riparian vegetation provides valuable habitat for various species of birds and mammals.

Development of WQOs

WQOs for the surface and ground waters of the Mojave River watershed are established in the Water Quality Control Plan for the Lahontan Region (Basin Plan). WQOs are both numerical and narrative, and are established for the maintenance of high quality waters and the protection of beneficial uses. The beneficial uses of the ground waters of the Mojave River floodplain aquifer include municipal and domestic supply, industrial supply, agricultural supply, and freshwater replenishment.

Published water quality data for the Mojave Watershed dates back to 1908, when the USGS collected a surface water sample at the Lower Narrows near Victorville. Most of the water quality data for the watershed was collected by the USGS between 1944 and 1972; the USGS generally collected monthly surface water samples at three locations on the Mojave River upstream of Victorville, and at numerous locations in the headwaters tributaries. In 1975, the RWQCB used these data to establish numerical WQOs. Numerical WQOs were established at most locations for TDS, nitrate as NO_3 (e.g., nitrate), chloride, sulfate, boron, phosphate and fluoride. The WQOs were developed in terms of annual averages and 90th percentile values, and were intended to ensure maintenance of the existing quality of surface waters for the Mojave River and its headwaters tributaries. Table 2 below illustrates 14 of the 25 numerical WQOs contained in the Basin Plan for the Mojave River and its tributaries. The WQOs are generally listed in order of the headwaters area to the terminus of the Mojave River.

In 1981, the RWQCB revised numerical WQOs for TDS and nitrate in the Upper Basin in anticipation of dairies moving from the Santa Ana River Watershed to the headwaters along the West Fork of the Mojave River near the Mojave Forks Dam. The goal of the new and revised WQOs was to prohibit water quality degradation from waste discharges associated with the dairies. The TDS and nitrate WQOs were removed for the Mojave River at the Forks Dam, and a new standard for TDS and nitrate was added closer to the expected dairy locations at the West Fork of the Mojave River at the Highway 173 Crossing. TDS and nitrate WQOs were also added for the Mojave River at the Lower Narrows below Victorville.

There was also concern that dairies could relocate from the Santa Ana River Watershed to areas along the Mojave River downstream of the City of Victorville. Under contract with the RWQCB, the California Department of Water Resources (DWR) conducted a study and determined that the area most vulnerable to dairy waste discharges would be an approximate one-mile corridor along the Mojave River floodplain. In response to the findings of the study, the RWQCB established WQOs in 1983 at four new locations for sections of the Mojave River that *"flow underground in a confined channel."* The four numerical WQOs were established: (1) at the City of Barstow; (2) on the upstream side of the Waterman Fault; (3) on the upstream side of the Calico-Newberry Fault; and (4) immediately upstream of Camp Cady Ranch. Camp Cady Ranch is immediately upstream of Afton Canyon. The hypothesis was that surface water samples could be collected at these locations without constructing ground water monitoring wells because ground water is forced to the surface on the upstream side of geologic structures. These samples would then be considered as representative of the local ground water conditions. The numerical WQOs were established as instantaneous maximums for TDS and nitrate, and were based on historical ground water data collected primarily from domestic and municipal production wells within one mile of the Mojave River channel.

Table 2 - Numerical WQOs for the Mojave River and Tributaries (mg/L)

Location	TDS	Chloride	Sulfate	Boron	Nitrate (NO_3)
Lake Arrowhead	78/107	7.7/9.1	2.4/3	.04/.05	--
Lake Gregory	87/95	11/12	5.3/7.7	.30/.30	--
Deep Creek below Lake Arrowhead	83/127	9.1/16	1.3/4.9	.05/.07	.20/.60
Deep Creek above the Mojave Forks Dam	184/265	10.6/16	31.3/55	1.66/2.6	.60/2.0
East Fork of the West Fork of the Mojave River	140/200	12.7/22	10.7/17	.23/.40	--
West Fork of the Mojave River above Silverwood Lake	219/336	8.4/13	34/53	.26/.40	--
Silverwood Lake	220/440	55/110	20/110	--	--
West Fork of the Mojave River below Silverwood Lake @ Highway 173 Crossing	245	--	--	--	6
Mojave River at the Mojave Forks Dam	--	55/100	35/100	1.5/2.5	--

Mojave River at the Lower Narrows below Victorville	312	75/100	40/100	0.2/0.3	5
Mojave River at Barstow (*)	445	--	--	--	6
Mojave River at the Waterman Fault (*)	560	--	--	--	11
Mojave River at the Calico-Newberry Fault (*)	340	--	--	--	4
Mojave River at Camp Cady Ranch (*)	300	--	--	--	1

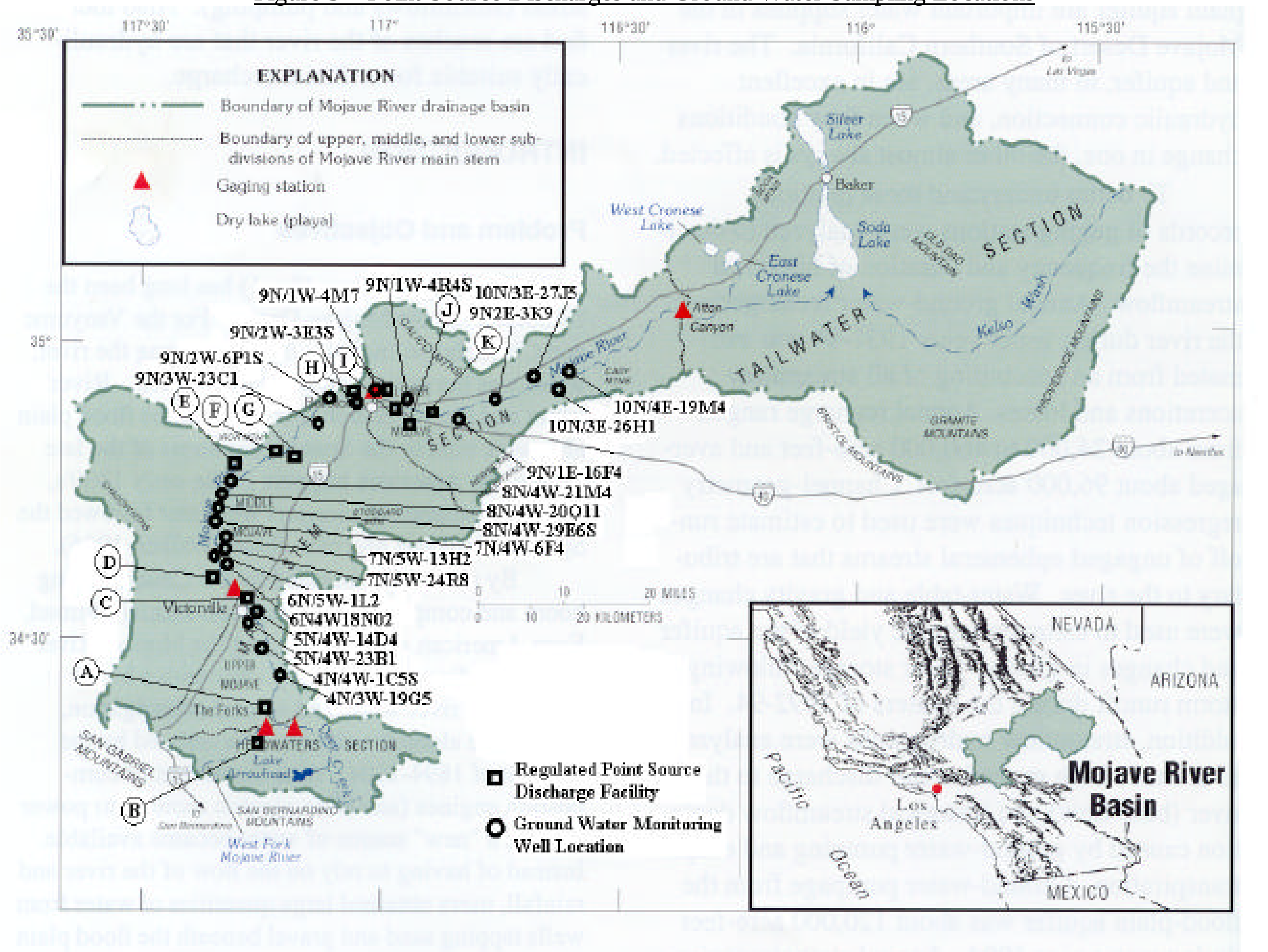
Single numbers represent instantaneous maximum
Double numbers represent annual average/90th percentile value
(*) - For ground waters that flow underground in a confined channel

The WQOs established at the Waterman Fault are unique in that they take into consideration water quality degradation associated with historic waste discharges near the Community of Barstow. The plume of contaminants was commonly referred to at the "Barstow Slug", and was reportedly caused by industrial discharges by the railroad industry and municipal discharges by the local community wastewater treatment plant. A plan was developed by the City of Barstow in the 1980s to pump the contaminated ground water from the floodplain aquifer and construct a pipeline to deliver the extracted water several miles downstream for industrial reuse. The WQOs at the Waterman Fault were developed in consideration of this plan, and were essentially cleanup levels for the remediation project. The project was never implemented, primarily because of water rights disagreements associated with the conveyance of ground water from the Middle to the Lower Basin.

A study completed in 1990 suggests that the plume of organic contaminants associated with the industrial discharges has naturally attenuated and no longer poses a threat to the beneficial uses of the river system. Subsequent studies completed by the USGS in 1996 strongly suggest that beneficial uses are severely impacted by historic discharges of inorganic contaminants associated with the former industrial and municipal discharges. The primary contaminants are TDS and nitrate. These studies suggest that on-going municipal discharges to a wastewater reclamation field and a golf course in the Barstow area continue to degrade of the ground water of the floodplain aquifer.

Limited trend monitoring has been completed in the Mojave River watershed since 1983 when WQOs were last established for the Mojave River watershed. Trend monitoring has been limited primarily because of the RWQCB's regulatory emphasis on permitting requirements for point source discharges. The general concept of this regulatory approach is that requirements for trend monitoring should be limited if the point source discharges are adequately regulated. Most surface and ground water monitoring completed since 1983 has been conducted by regulated facilities in accordance with permit monitoring requirements from the RWQCB. Samples collected by regulated facilities include waste effluent, and surface and ground water in the immediate vicinity of waste effluent discharges. The point source discharges along the floodplain aquifer are illustrated on Figure 3. Tables 3A and 3B list the permit monitoring requirements for these point sources.

Figure 3 – Point Source Discharges and Ground Water Sampling Locations



Modified from USGS Report 95-4189

Table 3A – Effluent Monitoring Requirements for Point Source Discharges to the Floodplain Aquifer

Facility	Fig. 3 ID. (#)	TDS	SO_4	Chloride	MBAS	Nitrate	Metals	VOCs (*)
Crestline CSD	A	X	X	X	X	X	X	X
Lake Arrowhead CSD	B				X			
Southdown Cement	C							X
Victor Valley WWTF	D	X	X	X	X	X	X	X
Silver Lakes WWTF	E	X	X	X	X	X		
Barstow WWTF	I	X	X	X	X	X	X	X
Yermo Annex WWTF	J	X	X	X	X	X	X	X
Nebo Annex WWTF	K	X	X	X	X	X	X	X

Table 3B – Ground Water Monitoring Requirements for Point Source Discharges to the Floodplain Aquifer

Facility	Fig. 3 ID. (#)	TDS	SO_4	Chloride	MBAS	Nitrate	Metals	VOCs (*)
Crestline CSD	A	X	X	X	X	X		X

Lake Arrowhead CSD	B	X	X	X	X	X		X
Southdown Cement	C							X
Victor Valley WWTF	D	X	X	X	X	X	X	X
Silver Lakes WWTF	E	X		X	X	X		X
Osterkamp Dairy	F	X				X		
N&M Dairy	G	X				X		
B&E Dairy	H	X				X		
Barstow WWTF	I	X			X	X		X
Yermo Annex WWTF	J	X		X	X	X		X
Nebo Annex WWTF	K	X		X	X	X		X

CSD – Community Services District
WWTF – Wastewater Treatment Facility
(*) – Analysis may include purgeable, base/neutral and/or acid extractable volatile organic compounds
(#) – See Figure 3 for Illustration of Point Source Discharge Facilities by Identification Letter

Water Quality Limited Segment

Section 303(d) of the federal Clean Water Act generally requires that a water body be listed as a water quality limited segment if one or more assigned beneficial uses are impaired. The Mojave River was previously listed because petroleum and solvent contaminants were present in ground water near Barstow. The 1996 water quality study documented in USGS Report No. 96-4301 supports the 303(d) listing for TDS and nitrate at Barstow. Data collected by the RWQCB and presented in this paper also supports the 303(d) listing for the Mojave River in the Barstow area.

Trend monitoring completed during the RWQCB's study also suggests that surface WQOs are being exceeded for TDS and nitrate at other locations along the Mojave River. These locations include (1) the Upper Narrows at Victorville; (2) the West Fork of the Mojave River at Highway 173; and (3) the Calico-Newberry Fault. In consideration of the recent data collected by the stakeholder group and the USGS data collected from the Barstow area, the 303(d) designation remains in place for the Mojave River.

The Clean Water Act requires that the RWQCB develop Total Maximum Daily Loads (TMDLs) for all water quality limited segments. The Mojave River is currently listed as a priority among numerous water bodies in the Lahontan Region for development of TMDLs. The data collected and presented in this paper are the initial steps toward the development of TMDLs for the Mojave River.

Development of the Watershed Management Initiative

In 1995 the State of California conducted a review of the regulatory programs implemented by the State Water Resources Control Board (State Board) and the nine RWQCBs. One of the recommendations of the review process was for the State Board and RWQCBs to focus regulatory activities using a "holistic" watershed approach rather than using the more traditional and fragmented regulatory programs. On this recommendation, the State Board and RWQCBs developed the Watershed Management Initiative. In 1996 the Lahontan RWQCB selected five watersheds as high priority, including the Mojave River.

One of the first tasks for the Mojave River watershed stakeholder group was to develop a watershed plan. A series of meetings were hosted by the RWQCB and attended by representatives of various stakeholders such as wastewater treatment plants, dairies, local and State government and municipal water purveyors. Through these meetings, the stakeholder group developed numerous goals and priorities to assess and potentially improve water quality. The first version of the plan was circulated for public comment in December 1996. Subsequent revisions to this plan have been developed and also circulated for public comment.

Several subgroups of stakeholders were assembled to address specific goals outlined in the watershed plan. Subgroups were developed on a volunteer basis from the various stakeholders. Two subgroups were developed to address water quality planning issues. The first subgroup (Headwaters Subgroup) focused on collecting and assessing surface water quality data for the headwaters of the watershed. The general goal for this Headwaters Subgroup was to determine if existing surface water quality was consistent with numerical WQOs established in the RWQCB's Basin Plan. In May 1997, the Headwaters Subgroup began collecting surface water data on a monthly basis at eight locations.

The second stakeholder subgroup (River Subgroup) was developed to focus on the surface waters and ground waters of the Mojave River system downstream of the headwaters. This area of the river system is complicated by the above-described geology and hydrology. Numerous meetings of the River Subgroup were held in 1998 to develop a sampling and analysis plan with a goal of assessing the overall condition of surface and ground water quality. As discussed below, the four existing WQOs were only one element of the planned assessment. Ultimately, a plan was finalized and implemented in February 1999. The initial plan included eight quarters (two years) of sampling at four surface water and 18 ground water monitoring locations. This plan was later modified in consideration of field conditions and data collected during the first sampling event, and the changes and associated rationale for the modifications are discussed below.

Development of Sampling Locations

The Headwaters Subgroup selected eight locations for surface water sampling based on locations where the RWQCB previously established numerical WQOs in the Basin Plan. The River Subgroup selected four additional surface water sampling locations based on the availability of perennial surface water and the availability of historical data. The four locations for the River Subgroup are along the Mojave River at: (1) the Mojave River Forks Dam; (2) the Upper Narrows; (3) the Lower Narrows; and (4) Afton Canyon. Surface water is typically available at these locations throughout the year, although the volume of flow is subject to the effects of seasonal variations and possible drought conditions. As noted in Table 2 above, numerical WQOs have only been established at the Lower Narrows among these four locations.

Ground water sampling locations for the River Subgroup were developed in consideration of several factors. The first factor was concern regarding the accuracy of the four existing numerical WQOs for ground waters that "*flow underground in a confined channel*." These WQOs were established assuming that base flow surface water could be collected at these locations and would be representative of ground water conditions. Overdraft throughout the watershed has resulted in rare base flows at Barstow, the Waterman Fault, the Calico-Newberry Fault and upstream of Afton Canyon at Camp Cady. More recent ground water studies conducted by the USGS also indicate that a comparison of ground water and surface water quality is questionable because of the complicated hydrogeology throughout the watershed. Lastly, instantaneous maximum WQOs for TDS and nitrate may not take into account seasonal and annual variations in water quality caused by wet and dry conditions. Therefore, one of the identified goals of the sampling effort was to collect ground water data at these locations to compare against the existing numerical WQOs.

The second factor was the point source discharges of waste along the Mojave River as illustrated on Figure 3. The River Subgroup recognized that historical effluent and receiving water (surface water and ground water) data are available for these facilities, and continue to be collected in accordance with permit requirements. Accordingly, the River Subgroup opted to focus sampling efforts away from these facilities. Data collected by the River Subgroup would then be assessed in concert with the data from the permitted facilities.

The third factor was suspected non-point sources of pollution that could discharge waste to the Mojave River through surface flow or ground water pathways. Non-point sources identified by the River Subgroup included storm water discharges, agricultural return flow and septic leaching disposal systems. The River Subgroup selected areas for ground water sampling where non-point sources are known or suspected. A separate subgroup was developed to collect storm water samples at outfalls to the Mojave River, and to begin the assessment of potential impacts associated with storm water discharges. The storm water assessment has not been implemented.

The last factor in selecting ground water sampling locations was the availability of reliable ground water sampling points. The River Subgroup recognized the economic infeasibility of installing a large number of new monitoring wells throughout the Mojave River watershed for the purpose of water quality studies. Fortunately, the USGS has installed numerous ground water monitoring wells throughout the Mojave Watershed during the last decade to implement a series of hydrology studies for the Mojave Water Agency. The focus of the Agency's studies has been to develop a detailed mathematical hydrologic model for the watershed to facilitate the adjudication and long-term resource management. In several locations, the USGS installed clusters of two-inch diameter polyvinyl chloride wells screened at various intervals within the floodplain aquifer. Well borings were typically continuously cored and assessed using various geophysical techniques. Detailed borehole logs and well construction details are available for each well. Data collected by the USGS and the Agency included horizontal and vertical ground water gradients, stable ground water isotope chemistry, and a limited data set for inorganic and organic ground water chemistry. The isotope data is important because ground water of recent age suggests recent recharge, indicating that the water is from the floodplain aquifer rather than the regional aquifer.

The River Subgroup received permission to use the Agency's wells, and developed the following six general criteria for optimum well selection: (1) the well was installed by the USGS on behalf of the Agency for hydrologic studies during the last 10 years; (2) the well screen length would be no longer than 40 feet; (3) the well screen intersects the ground water table; (4) ground water chemistry data is already available for the well; (5) the well is within or immediately adjacent to the river floodplain; and, (6) geologic information and/or ground water stable isotope data is available and indicate that the well is screened in the floodplain aquifer.

Staff of the RWQCB reviewed the geologic and isotope data in coordination with staff of the USGS to ensure wells being sampled were within the floodplain aquifer. Wells with short screen lengths that are screened across the water table surface were chosen where possible because the effects of waste discharges are expected to be observed in the upper portions of the aquifer. Note that the six criteria were optimal for well selection, and not all wells chosen for the RWQCB's water quality study met all of the criteria.

Development of Constituents of Concern

Constituents of concern (COC) for the Headwaters Subgroup were chosen based on the existing numerical WQOs in the RWQCB's Basin Plan as illustrated above in Table 2. No additional COCs were selected because other contaminants are not known or suspected in the headwaters area. The River Subgroup developed a list of COC based on: (1) the existing WQOs contained in the Basin Plan; (2) the existing water quality database for surface and ground waters; (3) known and suspected point and non-point source waste discharges; and, (4) naturally occurring constituents that could be elevated in the environment because of geologic conditions. The list of COCs selected by the River Subgroup were VOCs, dissolved priority pollutant metals, radon, methylene blue additive substances (MBAS- i.e., detergents) and the inorganic monitoring parameters TDS, sulfate, chloride, boron, fluoride, and nitrate.

Because of sampling and funding limitations, only MBAS and the inorganic monitoring parameters were scheduled for ground water sampling during each quarterly event. These constituents are inexpensive for laboratory analysis, and sample collection does not require special techniques or equipment. VOCs, priority pollutant metals and radon were planned for one quarterly event each year during the two-year study. Ground water samples were analyzed for radon during the second quarter 1999 sampling event, and these data are discussed in this paper. Laboratory analysis of surface and ground waters for dissolved priority pollutant metals was planned for the third quarter 1999 event, but these data are not available for this paper. Laboratory analysis of ground water samples for VOCs was planned for a subsequent event provided that low flow well purging equipment could be obtained.

Data Collection

The Headwaters Subgroup initiated surface water sampling in May 1997. Monthly samples have been collected at the eight locations, with the exception of conditions where no water was available for sampling. The laboratory analytical data for these samples indicate that WQOs are not being exceeded in the tributaries to Deep Creek and the West Fork of the Mojave River. WQOs are being exceeded for TDS and nitrate at the West Fork of the Mojave River at Highway 173. The possible source(s) of these conditions are discussed below. The Headwaters Subgroup plans continued trend monitoring for sampling locations.

The River Subgroup initiated surface and ground water sampling in February 1999. During this first event, samples were collected at three surface water stations and 18 ground water monitoring wells. The three surface water locations were (1) the Mojave River at the Forks Dam; (2) the Mojave River at the Upper Narrows; and, (3) the Mojave River at the Lower Narrows. A second quarterly event was initiated in June 1999, and included four surface water stations and 22 ground water monitoring wells. The fourth surface water sampling location was the Mojave River at Afton Canyon.

Figure 3 illustrates the ground water monitoring well locations selected for the first and second sampling events. Table 4 lists these wells and describes well construction details, historical water levels and general location. Monitoring wells are listed in order from upstream to downstream locations. Minor modifications to the sampling program were made between the first and second events to address issues related to well access, well construction and ground water chemistry. A discussion below regarding the findings of the sampling effort provides a brief rationale for the minor changes in the sampling locations.

Table 4 – Construction Details for Ground Water Monitoring Wells

State ID #	Top of Perforation (ft.)	Bottom of Perforation (ft.)	Well Casing Diameter (in.)	Depth to Water (ft.)	Location
04N/03W-19G005S (*)	75	95	2	36-68	APPLE VALLEY
04N/04W-01C005S	60	80	2	19-38	HESPERIA
05N/04W-23B001 (*)	0	9.5	2	4	VICTORVILLE
05N/04W-14D004S	30	50	2	13-17	VICTORVILLE
06N/04W-18N02	10.2	14.8	2	3-7	ORO GRANDE
06N/05W-01L002S (*)	15	25	2	10	HELENDALE
07N/05W-24R008S	45	50	2	8-12	HELENDALE
07N/05W-13H002S	15	25	2	1-5	HELENDALE
07N/04W-06F004S (*)	15	20	4	3	HELENDALE
08N/04W-29E006S	45	50	2	8-13	HELENDALE
08N/04W-20Q011S	30	50	2	8-10	WILD CROSSING
08N/04W-21M004S	30	40	2	8-11	WILD CROSSING
09N/03W-23C001S	57	77	2	52-72	HODGE
09N/02W-06P001S	75.5	95.5	2	55-67	HINKLEY
09N/02W-03E003S	100	120	2	33-53	HINKLEY
09N/01W-09D008 (#)	60	80	2	51-54	BARSTOW
09N/1W-4M007S (*)	41.7	81.7	2	20-37	BARSTOW
09N/01W-04R004S	20	40	2	8-17	BARSTOW
09N/01E-16F004S (*)	130	150	2	101-143	NEBO
09N/01W-11K105 (#)	70	90	2	9	NEBO
09N/01W-12N007 (#)	60	80	2	7-25	NEBO
09N/02E-03K009S	45	65	2	41-58	YERMO
10N/03E-27J005S	35	45	2	24-38	HARVARD HILL
10N/03E-26H001 (*)	14.7	24.7	2	22	HARVARD HILL
10N/04E-19M004 (*)	9.5	19	2	12	MANIX

(*) – Well was not sampled during the first quarter 1999 event but was sampled during the second quarter 1999 event
(#) – Well was not sampled during the second quarter 1999 event but was sampled during the first quarter 1999 event

Sampling Procedures

Staff of the RWQCB completed all ground water sampling activities. Sampling was conducted in accordance with USGS Open Publication 95-399, Ground Water Data Collection Protocols and Procedures for the National Water Quality Assessment Program: Collection and Documentation of Water Quality Samples and Related Data. In general, wells were purged of a minimum of three well volumes and until field parameters of electrical conductivity, temperature and pH were stable. Purging and sampling were completed with either a two-inch submersible electric pump or by hand with a Teflon$_{TM}$ bailer. All ground water samples were transported to a California certified analytical laboratory for analysis. The sampling and chain of custody procedures are documented in the two quarterly monitoring reports published by the RWQCB, including requirements for well purging, data recording, sample collection and sample preservation.

Radon was added to the sampling program during the second quarter at the request of several municipal water supply stakeholders. Procedures for radon sample collection were conducted in accordance with methods prescribed by the contract laboratory. After complete well purging and field parameter stabilization, a plastic container was continuously filled with water from the well. Each amber glass sample bottle was submerged in the container while additional water was pumped (poured if hand bailing) into the container. Once the sample bottle was completely full, it was capped under water with zero headspace. The sample bottle cap was sealed with electrical tape to minimize the risk of air infiltration and/or radon decomposition.

First Quarter 1999 Data

Table 5 below illustrates the surface and ground water data collected during the first quarter of 1999. Monitoring points are listed in order from upstream to downstream locations. Data is denoted where concentrations exceed numerical WQOs contained in the Basin Plan and/or California Primary Drinking Water Standards.

Table 5 – First Quarter 1999 Ground Water and Surface Water Quality Data (mg/L)

Sample ID#	TDS	Nitrate as NO_3	Chloride	Sulfate	Fluoride	Boron	MBAS
West Fork of the Mojave River at Highway 173 (*)	170	**<u>8.1</u>**	22	16.5	0.38	ND	--
Mojave River at Forks Dam (*)	152	ND	8.3	19	1.3	0.15	--
4N/4W-1C5S	150	2.7	13	20	0.5	ND	ND
5N/4W14D4	600	37.4	62	97	0.5	0.4	ND
Mojave River at the Upper Narrows (*)	268	1.26	33	34	0.43	0.18	--
Mojave River at the Lower Narrows (*)	296	0.70	37	34	0.42	0.14	--
6N/4W-18N02	380	ND	39	58	0.3	0.1	ND
7N/5W-24R8S	610	ND	100	150	0.4	0.2	0.06
7N/5W-13H2S	380	ND	66	73	0.6	0.3	NA
8N/4W-29E6S	860	ND	76	380	0.5	0.3	NA
8N/4W-20Q11	670	ND	82	190	0.5	0.2	NA
8N/4W-21M4	**1040**	ND	130	380	0.5	0.3	NA
9N/3W-23C1	310	9	39	56	0.4	ND	NA
9N/2W-6P1S	240	5	25	33	0.7	0.2	NA
9N/2W-3E3S	250	6	24	32	0.4	0.1	NA
9N/1W-9D08	**2310**	**64**	460	**780**	1.4	5.7	ND
9N/1W-4R4S	**1570**	**57**	240	280	0.5	0.9	0.14
9N/1W11k15 (WF)	**<u>730</u>**	**<u>10</u>**	140	180	0.5	0.7	0.11
9N/1W12N7 (WF)	**<u>1130</u>**	**<u>11</u>**	230	320	0.5	1.0	0.14
9N/2E-3K9S (CN)	**<u>480</u>**	**<u>19</u>**	25	120	0.3	0.2	ND
10N/3E-27J5	**3070**	**90**	240	**1280**	0.3	0.8	0.1

(*) – surface water sampling location
bold denotes samples exceeding California Primary Drinking Water Standards
<u>bold and underline</u> denotes samples exceeding numerical WQOs established in the RWQCB's Basin Plan
(WF) – well data is compared against the WQOs established at the Waterman Fault
(CN) – well data is compared against the WQOs established at the Calico-Newberry Fault

Without additional data, the stakeholder group was reluctant to associate data from a specific well to one or more known or suspected point or non-point sources. The stakeholders made the following four modifications between the first and second quarter to refine the sampling program:

1. Well 05N/04W-23B001 was added to the sampling program to evaluate concentrations of nitrate (37.4 mg/L) and TDS (600 mg/L) detected at well 05N/04W-14D004S near the Upper Narrows. These values do not exceed established standards, but are significantly elevated in comparison to up-gradient and down-gradient samples.

2. Wells 09N/01W-09D008S, 09N/01W-11K015S, and 09N/01W-12N007S were removed from the sampling program. Data from the first quarter confirmed ground water degradation in the floodplain aquifer associated with historic and

current wastewater disposal practices in the Barstow area (see USGS Report 96-4301). Additional data will be necessary outside the scope of the stakeholder study to determine the nature and extent of the water quality degradation.

3. Wells 09N/01W-04M007S (4M7) and 09N/01E-16F004S (16F4) were added to the sampling program to evaluate water quality upstream (4M7) and downstream (16F4) of the Barstow area.

4. Wells 10N/03E-26H001 and 10N/04E-19M004 were added to the sampling program to evaluate the elevated concentrations of nitrate and TDS near the Calico-Newberry Fault at wells 09N/02E-3K009S and 10N/03E-27J005S.

Second Quarter 1999 Data

Table 6 below illustrates the surface and ground water data collected during the second quarter of 1999. Data is denoted where concentrations exceed numerical WQOs contained in the Basin Plan and/or California Primary Drinking Water Standards.

Data Observations

Staff of the RWQCB reviewed the data collected during the first and second quarters of 1999, and the recent and historical data collected from individual permitted waste discharge facilities. These data were compared to numerical WQOs, where established. Preliminary conclusions were developed regarding spatial and temporal trends in water quality, and the potential sources of observed ground water degradation. The following is a summary of eleven observations made by staff of the RWQCB, beginning with upstream sampling locations and working sequentially downstream. The data and several of the observations were published in two quarterly monitoring reports that were circulated among the stakeholders for review and comment. The data and observations were also presented and discussed with the stakeholders during a meeting hosted by staff of the RWQCB in August 1999.

1. ***West Fork of the Mojave River -*** A surface water sample collected from the West Fork of the Mojave River at Highway 173 exceeded the numerical WQO for nitrate during both the first and second quarter of 1999. Crestline CSD has been collecting a monthly surface water sample at this location since June 97 in accordance with permit monitoring requirements. These data indicate: (1) five instances where the WQO for nitrate was exceeded; and, (2) six instances where the WQO for TDS was exceeded, which occurred during low flow conditions in the summer and fall months.

   The WQOs for TDS and nitrate were established based on data collected prior to construction of Silverwood Lake, and may not take into account the effects of Bay/Delta water discharges that have replaced the natural flow of high quality surface water from the headwaters. The source(s) of nitrate in the surface water may include grazing activities along the Mojave River on Los Flores Ranch, and permitted discharges of treated domestic wastewater to reclamation fields and percolation ponds by Crestline CSD. The source(s) of TDS and nitrate in surface water requires further evaluation, including periodic sampling of potential sources of water quality degradation. This WQO may require modification to accommodate existing discharges of Bay/Delta water.

2. ***Mojave Forks Dam to Bear Valley Road Crossing -*** Ground water samples collected between the Mojave Forks Dam and the Bear Valley Road Crossing (Well 04N04W01C005S) indicate water quality similar to surface water samples from the headwaters areas along the West Fork of the Mojave River and Deep Creek. No WQOs are established over this section of the Mojave River. TDS concentrations in the two wells sampled in this area during the first and second quarter sampling events ranged from 150 to 180 mg/L. The concentration of nitrate in the two wells ranged from 2 to 2.7 mg/L. These data suggest that agricultural and urban activities in this area are having a limited measurable impact on water quality in the floodplain aquifer.

3. ***Bear Valley Road Crossing to the Upper Narrows -*** No WQOs are established over this section of the Mojave River. Groundwater samples collected during the first and second quarter of 1999 immediately upstream of the Upper Narrows at well 05N04W14D004S (14D4) contained elevated concentrations of TDS and nitrate. The maximum concentration of TDS and nitrate at this location was 600 and 39.6 mg/L, respectively. Well 14D4 is located on the east side of the Mojave River. A ground water sample collected during the second quarter 1999 at well 05N04W23B001 (23B1) contained TDS at a concentration of 360 mg/L, and nitrate was not detected in this sample. Well 23B1 is located on the west side of the Mojave River and immediately upstream of well 14D4. Water quality data

from well 23B1 is generally consistent with ground water conditions at upgradient sampling locations between the Mojave Forks Dam and the Bear Valley Road Crossing.

The source(s) of the elevated TDS and nitrate at well 14D4 requires future evaluation. One possible source is several hundred domestic septic leaching disposal systems located on the east side of the Mojave River at private residences. These septic systems are located on fractured bedrock. Septic leaching systems may be a dominant source of recharge to the floodplain aquifer in this area because base flow has decreased due to overdraft in the floodplain aquifer. Although the RWQCB prohibits the construction of additional septic leaching systems at this location, the existing systems may be one cause of the degradation.

Table 6 – Second Quarter 1999 Ground Water and Surface Water Quality Data (mg/L)

Sample ID#	TDS	Nitrate as NO_3	Chloride	Sulfate	Fluoride	Boron	MBAS	Radon pCi/L
West Fork of the Mojave River at Highway 173 (*)	230	**<u>8.55</u>**	29	21	0.44	0.11	--	--
Mojave River at the Forks Dam (*)	190	ND	45	63	1.8	ND	--	--
4N/3W-19G5	180	2.0	22	20	0.3	ND	--	370 ± 20
04N/04W-1C005S	150	2.0	13	17	0.3	ND	ND	390 ± 20
05N/04W-23B001	360	ND	24	3.9	0.5	ND	ND	100 ± 20
05N/04W-14D004S	600	39.6	71	120	0.4	0.4	ND	340 ± 20
Mojave River at the Upper Narrows (*)	790	ND	47	63	0.7	0.6	--	--
Mojave River at the Lower Narrows (*)	**<u>390</u>**	ND	46	61	0.4	0.1	--	--
06N/04W-18N02	350	ND	36	58	0.4	0.1	ND	130 ± 20
06N/05W-1L002S	410	ND	67	68	0.4	0.1	ND	173 ± 14
07N/05W-24R008S	690	ND	110	150	0.5	0.3	ND	240 ± 20
07N/05W-13H002S	410	ND	71	73	0.6	0.3	ND	240 ± 20
07N/04W-6F004S	420	2	58	71	0.4	0.3	--	508 ± 18
08N/04W-29E006S	710	ND	65	290	0.6	0.3	ND	330 ± 20
08N/04W-20Q011S	490	ND	49	79	0.6	0.2	--	450 ± 30
08N/04W-21M004S	390	ND	36	69	0.4	0.3	--	290 ± 20
09N/03W-23C001S	310	8	35	64	0.3	0.1	--	640 ± 30
09N/02W-6P001S	270	7	28	51	0.4	0.1	--	570 ± 30
09N/02W-3E003S	210	5	25	31	0.4	0.1	--	470 ± 30
09N/01W-4M007 (B)	280	**<u>52</u>**	26	65	0.6	0.2	ND	380 ± 20
09N/01W-4R004S	**1540**	**51**	220	**560**	0.4	0.8	ND	550 ± 30
09N/01E-16F004	690	5	120	170	0.5	0.3	ND	580 ± 30
9N/02E-3K009S (CN)	**<u>560</u>**	**<u>21</u>**	28	140	0.2	0.2	ND	240 ± 20
10N/03E-27J005	**3300**	**110**	290	**1610**	0.2	0.9	0.06	230 ± 20
10N/03E-26H001	390	2	29	78	0.4	0.1	--	160 ± 20
10N/04E-19M004	470	2	93	69	0.5	0.4	--	190 ± 20
Mojave River at Afton Canyon (*)	**1260**	ND	190	91	4.9	2.8	--	--

(*) – surface water sampling location
bold denotes samples exceeding California Primary Drinking Water Standards
<u>bold and underline</u> denotes samples exceeding numerical WQOs established in the RWQCB's Basin Plan
(B) – well data is compared against the WQOs established at Barstow
(CN) – well data is compared against the WQOs established at the Calico-Newberry Fault

4. ***Upper Narrows -*** A surface water sample collected from the Mojave River at the Upper Narrows above Victorville contained TDS at a concentration of 790 mg/L during the second quarter of 1999. While this location does not have an established numerical WQO in the Basin Plan, the observed water quality conditions could be associated with the elevated TDS noted downstream at the Lower Narrows. The elevated concentration of TDS at the Upper Narrows may also be linked to water quality degradation noted in well 14D4 as discussed above.

5. ***Lower Narrows -*** A surface water sample collected from the Mojave River at the Lower Narrows below Victorville during the second quarter of 1999 contained TDS at a concentration of 390 mg/L. This concentration exceeds the numerical WQO for TDS at this location of 312 mg/L as prescribed in the Basin Plan. Further evaluation is necessary to determine the possible source(s) of the elevated TDS, which may include the observed conditions at the Upper Narrows and well 14D4.

6. ***Lower Narrows to the Helendale Fault -*** No WQOs are established for this section of the Mojave River. Groundwater samples collected from eight wells between the Lower Narrows and the Helendale Fault generally exhibit similar water quality conditions. During the second quarter of 1999, TDS concentrations ranged from 270 to 710 mg/L with an average concentration of 536 mg/L. Nitrate concentrations were non-detectable with the exception of one well with a detection of 2 mg/L. Chloride concentrations ranged from 36 to 110 mg/L, with an average concentration of 62 mg/L. The spatial consistency of these data may be attributed to the treated effluent from the Victor Valley WWTF, which has quality similar to the observed ground water conditions. The treated effluent is consistent in quality and provides a significant portion of recharge to this section of the river system. Another factor may be the absence of concentrated urban and agricultural inorganic pollutant sources to the floodplain aquifer in this area. However, urban and potentially industrial growth in this area is expected in the future. Existing overdraft of the floodplain aquifer in this area is contributing to lower water levels and loss of riparian vegetation. The overdraft conditions could make this section of the river system highly susceptible to possible future waste domestic, commercial and industrial wastewater discharges because the depleted aquifer would provide limited dilution and attenuation capacity.

7. ***Helendale Fault to Barstow -*** Data collected from three wells between the Helendale Fault and Barstow contained low TDS but elevated concentrations of nitrate as compared to samples collected upstream of the Helendale Fault. WQOs are established at Barstow for TDS and nitrate at concentrations of 445 and 6 mg/L, respectively. TDS concentrations in the three wells during the second quarter of 1999 ranged from 210 to 280 mg/L, and nitrate ranged from 5 to 8 mg/L. These data indicate that the WQOs at Barstow are being achieved for TDS, but may be exceeded for nitrate. Likely sources of nitrate include waste discharges at three dairies located along this section of the Mojave River. Ground water monitoring conducted in accordance with permit monitoring requirements at two of these dairies indicates concentrations of nitrate in shallow ground water exceeding 200 mg/L. Additional regulatory activities at these dairies are necessary to evaluate possible sources for the observed conditions, and to ensure future compliance with permit requirements and the WQOs for TDS and nitrate at Barstow.

8. ***Barstow to the Waterman Fault -*** During the first quarter 1999, wells sampled in the Barstow area exhibited elevated concentrations of nitrate, TDS, chloride, sulfate and MBAS. WQOs for TDS and nitrate are established downstream of Barstow at the Waterman Fault at concentrations of 560 and 11 mg/L, respectively. Concentrations of nitrate in the four wells ranged from 11 to 64 mg/L, exceeding the WQO for nitrate in all four wells and the California Primary Drinking Water Standard of 45 mg/L for nitrate in two of the four wells. Concentrations of TDS in the four wells ranged from 730 to 2310 mg/L, exceeding the WQO for TDS in all four wells and the California Primary Drinking Water Standard for TDS of 1000 mg/L in three of the four wells. These data clearly indicate that the WQOs for TDS and nitrate at the Waterman Fault continue to be exceeded.

   The observed water quality degradation is likely attributed to historic and on-going discharges of domestic wastewater and agricultural return flow as discussed briefly in this paper above and as documented in USGS Report No. 96-4301. Four sampling locations were eliminated from the second quarter 1999 sampling event because no further data collection was necessary to document the water quality conditions. Further discussions are necessary with parties that formerly discharged and continue discharging waste in the area to evaluate necessary remedial actions to abate the affects of current and historic waste discharges and to attain compliance with the WQOs for TDS and nitrate.

9. ***Waterman Fault to Well No. 9N/1E-16F4 -*** During the second quarter of 1999, well 09N01E16F004 (16F4) was added to the sampling program to evaluate the downgradient extent of water quality degradation observed in the Barstow area. No WQOs are established for this section of the Mojave River. In contrast to the shallow ground water in the Barstow

area (less than 20 feet below ground surface) depth to ground water downstream of the fault at well 16F4 exceeds 130 feet below ground surface. TDS and nitrate concentrations at well 16F4 were 690 and 5 mg/L, respectively. There are no identified sources of TDS and nitrate between the Waterman Fault and well 16F4. These data suggest that some degraded ground water may be migrating beyond the Waterman Fault and impacting the aquifer downstream of Barstow.

10. ***Calico-Newberry Fault to Afton Canyon* -** Groundwater samples collected during the first and second quarter of 1999 from two monitoring wells immediately upgradient and downgradient the Calico-Newberry Fault contained elevated concentrations of nitrate and TDS. The WQOs for TDS and nitrate at the Calico-Newberry Fault are 340 and 4 mg/L, respectively. During the first quarter of 1999, the concentration of nitrate in the two wells ranged from 19 to 90 mg/L. The concentration of TDS in the two wells ranged from 489 to 3,070 mg/L, respectively. These data indicate that the WQOs for TDS and nitrate at the Calico-Newberry Fault are being exceeded.

    Two wells were added further downgradient of the Calico-Newberry fault during the second quarter of 1999 to evaluate the spatial extent of TDS and nitrate in the ground water of the floodplain aquifer. The concentration of nitrate in both down gradient wells was 2 mg/L, and the concentration of TDS ranged from 390 to 470 mg/L. These data suggest that the WQO for nitrate may only be exceeded in a localized area near the Calico-Newberry Fault. However, the WQO for TDS may be exceeded over a larger downgradient area. Agricultural fields are located immediately adjacent to and within the Mojave River channel near the Calico-Newberry Fault. Regulatory activities are necessary in the area of these agricultural fields to evaluate the nature of the ground water degradation, and to work with stakeholders in the area to improve soil nutrient management practices.

11. ***Radon* -** Concentrations of radon ranged dramatically across the project area, and no concentration pattern was noted. Many of the wells exceeded a 1991 United States Environmental Protection Agency proposed drinking water concentration limit for radon of 300 pCi/L. No drinking water standard has been set for radon as of the date of this paper. Municipal and domestic water users should review these data in consideration of possible future regulatory standards for water public water supply.

Conclusions and Recommendations

Ground water degradation was noted in surface water and ground water throughout the Mojave River watershed, including violations of drinking water standards and numerical WQOs established in the RWQCB's Basin Plan. In a few instances, the degradation appears to be associated with known and regulated waste discharge activities such as dairies and domestic wastewater treatment plant discharges in the Barstow area. However, in most cases the water quality impacts are likely associated with non-point sources of pollution such as septic leaching disposal systems and agricultural activities. Some of the WQOs established in 1983 for sections of the Mojave River that flow underground may also have been set without full understanding of the complex hydrology and hydrochemistry of the area.

Overdraft of the floodplain aquifer also plays an important role in water quality planning. The loss of dilution capacity magnifies the impacts of both permitted and unauthorized waste discharges. Overdraft may also increase the potential for recharge of the floodplain aquifer with poor quality ground water from the older and deeper sediments.

As the watershed enters the 21st century, the area is struggling with its identity as a rapidly growing urban area with insufficient water supply to meet municipal needs. The Mojave Water Agency is implementing plans for artificial recharge of the floodplain aquifer using Bay/Delta water. Alternative water supplies such as reclaimed wastewater are being closely evaluated by the larger cities as a possible source of golf course and landscape irrigation water. Treated wastewater from various domestic, commercial and industrial sources has been and will continue to be discharged to the floodplain aquifer as permitted by the RWQCB. Each of these activities has the potential to increase the daily load of salts and other pollutants into the floodplain aquifer. Because ground water is also extracted from the floodplain aquifer for municipal and domestic uses, the local community water supply agencies may see an increase in the salinity of source water. Wastewater treatment plants would then also see an increase in the salinity of waste influent and effluent.

The author makes the following six recommendations for water quality planning and long-term management in the Mojave River watershed. These recommendations are being made by the author, and do not necessarily represent the opinions or proposed activities of the RWQCB.

1. Continue quarterly ground water monitoring in accordance with the sampling plans developed by the Headwaters and River Subgroups. Efforts should be made to modify the plans as necessary to add or delete monitoring points to fill data gaps. Frequent meetings should be held with the stakeholder groups to discuss the data and to coordinate the evaluation efforts.

2. Closely evaluate sources of observed water quality degradation at the West Fork of the Mojave River near Highway 173, at the Upper and Lower Narrows near Victorville and at the Calico-Newberry Fault. Regulatory activities should be taken as deemed necessary to ensure land use and waste disposal activities are consistent with regulations, plans and policies of the RWQCB.

3. Aggressively pursue regulatory actions as deemed necessary to investigate and remediate sources of observed water quality degradation in the Barstow area. A long-term goal should be to achieve compliance with the existing WQOs for the Waterman Fault, or to modify the WQOs in accordance with an approved implementation plan.

4. Aggressively implement a non-point source control program for the entire watershed to ensure agricultural and urban land users are utilizing appropriate best-management practices. This program should include dairies, irrigated agriculture, wastewater reclamation projects and municipal and industrial storm water discharges.

5. Develop a geographic information system (GIS) for water quality data and integrate this system with the GIS systems of other stakeholders such as land use agencies and the Mojave Water Agency. This effort should focus on effectively sharing and evaluating data with other stakeholders.

6. Begin the development of TMDLs for the watershed, taking into full account all point and non-point source discharges to the watershed. Considerations should include existing and future discharges of Bay/Delta water to the floodplain aquifer from Silverwood Lake and recharge basins.

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