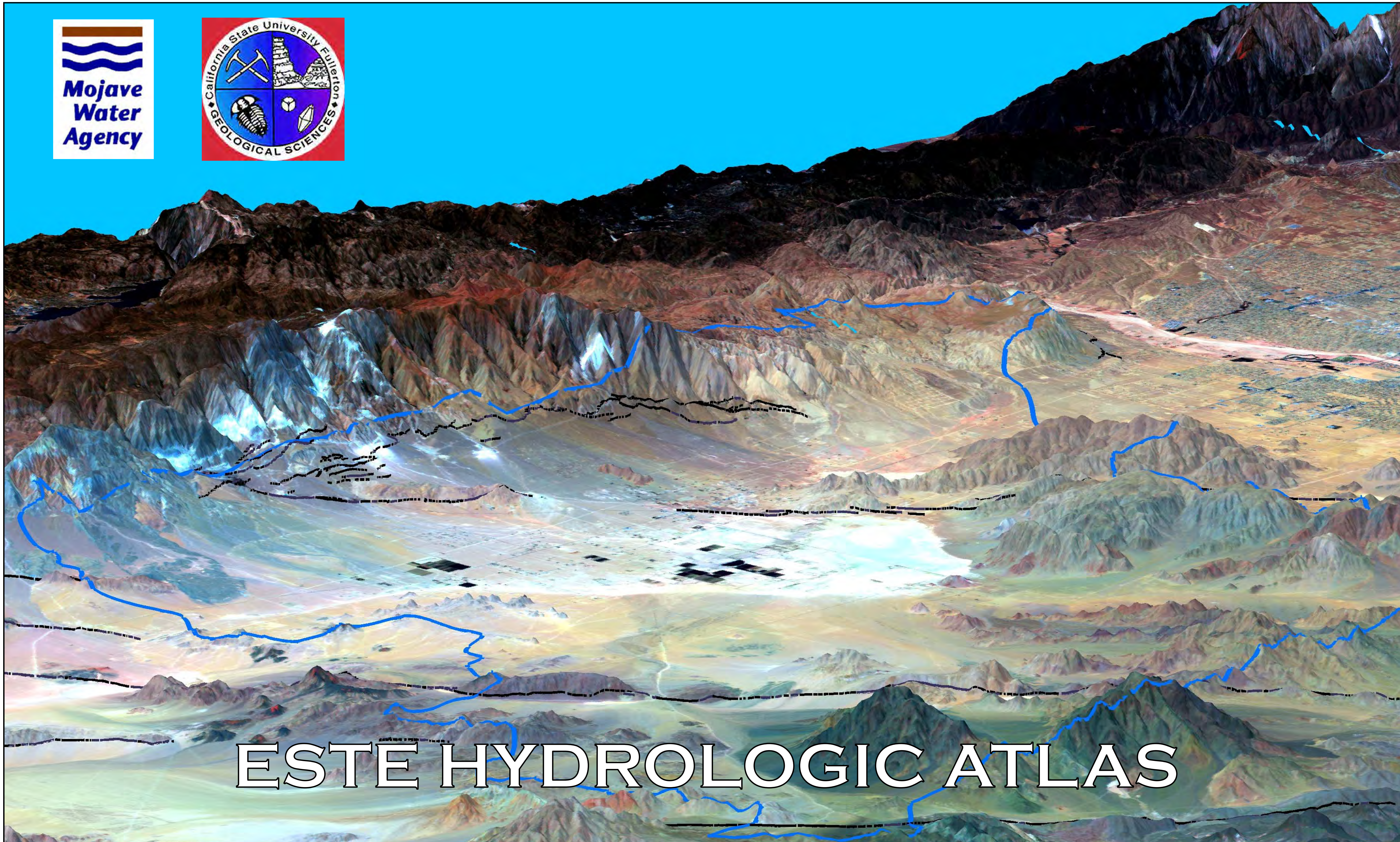


ESTE HYDROLOGIC ATLAS

Using the Atlas:

If you are interested in the Este Hydrologic Sub-basin in general, we suggest that you page through this document and spend some time on the pages that you find of interest. The Atlas is organized into numbered sections.

General Information about the Este Hydrologic Sub-basin and the region can be found on pages 3 - 11.

The **Geology of the Este Hydrologic Sub-basin**, including an overview of the sediments that make up the watershed, is presented on pages 12 - 20.

Discussions of the **Este Hydrologic Sub-basin Water Cycle** are found on pages 6 - 8.

Information regarding the **Surface Water** and **Groundwater** within the basin can be found on pages 21 - 25.

Water Quality and **Issues** surrounding the watershed can be found on pages 26 - 31.

A **Glossary of Terms** used in this Atlas can be found on pages 32 - 37.

A list of **References** can be found on pages 38 - 39.

California State University, Fullerton
College of Natural Sciences and Mathematics
Department of Geological Sciences
January 2005

Mojave Water Agency

22450 Headquarters Drive ♦ Apple Valley, CA 92307-0019
Phone (760) 946-7000 ♦ Fax (760) 240-2642 ♦ www.mojavewater.org

January 12, 2005

California State University, Fullerton
Post Office Box 6850
Fullerton, California 92834-6850

Attention: W. Richard Laton, Ph.D.
Professor of Hydrogeology

Dear Dr. Laton:

The Mojave Water Agency (MWA) has been entrusted with managing the long-term reliability of water resources within an approximately 5,000 square mile area of the Mojave Desert. Over the past two years, the MWA has worked closely with academic faculty and students of the Geological Sciences Department from the California State University at Fullerton (CSUF) to build a synergistic relationship. This commitment has resulted in the ability of professional staff from the MWA to call upon the academic resources provided by CSUF to solve groundwater resource management issues.

In order to support scientific based decision-making related to water resources management within the Este Subarea, the MWA and CSUF embarked on a data gathering mission to obtain and integrate geologic and hydrologic information available for the region. The Este Groundwater Atlas is a culmination of our efforts. This hydrogeologic assessment of the Este Subarea has provided us with information regarding available groundwater in storage, aquifer space available for water banking, basin safe yield, potential infiltration rates, groundwater flow direction(s), flow rates, and water quality data. In addition, wells identified during the course of this study have been incorporated into the MWA's Key Well Program, which is used to monitor water levels and water quality within our service area.

The findings of this collaborative endeavor between MWA professional staff and CSUF professors and students will provide the necessary tools for proper management of water resources within the Este Subarea.

Sincerely,

Kirby Brill
General Manager

laton este ltr 011205.doc/kirby/vt

Table of Contents:

Overview

Introduction

This report presents the results of a compilation of groundwater, surface water, well capacity, and water usage data from various sources and active field research. The combined data was utilized to construct a model of water-rock interactions as well as a basin-wide conceptual model. This report has been prepared by students and faculty in the Department of Geological Sciences at California State University Fullerton under contract to the Mojave Water Agency (MWA). Our report was prepared with the understanding that the results will be used to help manage the water resources of the area. It is also significant that the draft of this report was critically reviewed by members of the MWA and that their comments and recommendations were incorporated into this final report.

Purpose and Goals

This report is intended to provide information on the physiographic makeup, geomorphology, geology, stratigraphy, surface water drainage, groundwater flow, and water chemistry of the Este Hydrologic Sub-basin. The awareness of problems, potential problems, and possible solutions dealing with overall watershed issues, including those that affect our vital groundwater resources, is especially important in the Mojave Desert region were precipitation is low and demands for freshwater are high.

In order to address these issues, several goals have been considered for this investigation.

- Geologic reconnaissance of the Este Hydrologic Sub-basin.
- Developing geologic cross-sections of the basins subsurface as well as aquifer dimensions and characteristics.
- Assessing the existing surface and groundwater flow conditions within the basins.
- Assessing the water budget and flow dynamics within the basins.
- Assessing the quality of water throughout the basins.

Hydrologic Overview

The residents of Lucerne Valley and Fifteenmile Valley, San Bernardino County, California, depend solely upon groundwater pumped from the Este Hydrologic Sub-basin. Current and historic water well data reveal that groundwater levels have significantly declined over a fifty year period. This has posed a major concern for both the residents of Lucerne Valley as well as government agencies, such as the Mojave Water Agency (MWA), which is responsible for oversight of water related issues. In order to assess current groundwater conditions, a two stage approach was implemented. First, developing a strong understanding of the subsurface lithologies, structures, and depositional environments of the Este Hydrologic Sub-basin, and second, a thorough investigation of the water budget and groundwater storage for the basins.

Aquifers

The principal aquifer in the Este Hydrologic Sub-basin is the Old Woman Sandstone. This formation is composed of sandstone and conglomerate as well as lesser areas of shale, limestone, and basalt. In general, the formation is compacted and partially cemented. The formation is up to 1,400 feet (427 m) thick and is primarily encountered at depths of qpproximately 150 to 300 feet (45.7 to 91.4 m). It can be recognized in well logs by descriptors that refer to "cemented" conditions. The Old Woman Sandstone aquifer averages about 1,000 feet (305 m) thick and ranges from unconfined near the edges of the basin to semi-confined near the playas of Lucerne Lake and Rabbit (dry) Lake.

Groundwater

Groundwater flow in the Lucerne Valley groundwater basin is radial towards Lucerne (dry) Lake. Groundwater flow in the Fifteenmile Valley groundwater basin is north-northwest towards the Alto Hydrologic Sub-basin. The Lucerne and Fifteenmile Valley groundwater basins are separated from one another by the Helendale fault zone just west of the community of Lucerne Valley.

Water level changes in the Lucerne Valley groundwater basin have steadily declined since 1954 and losses have totaled nearly 450,500 acre-feet as of 2002 with an average water level drop of 77 feet (23.5 m) across the basin. However, since adjudication in 1996, these levels have begun to recover. Groundwater levels in the Fifteenmile Valley groundwater basin have not deviated greatly since recording began.

Total available groundwater storage in the Lucerne Valley groundwater basin is estimated to be 4,186,600 acre-feet, although under current well-field depths only about 2,861,000 acre-feet are available. These storage values are based on a working groundwater basin area of 58,500 acres and estimated volume of the Old Woman Sandstone aquifer.

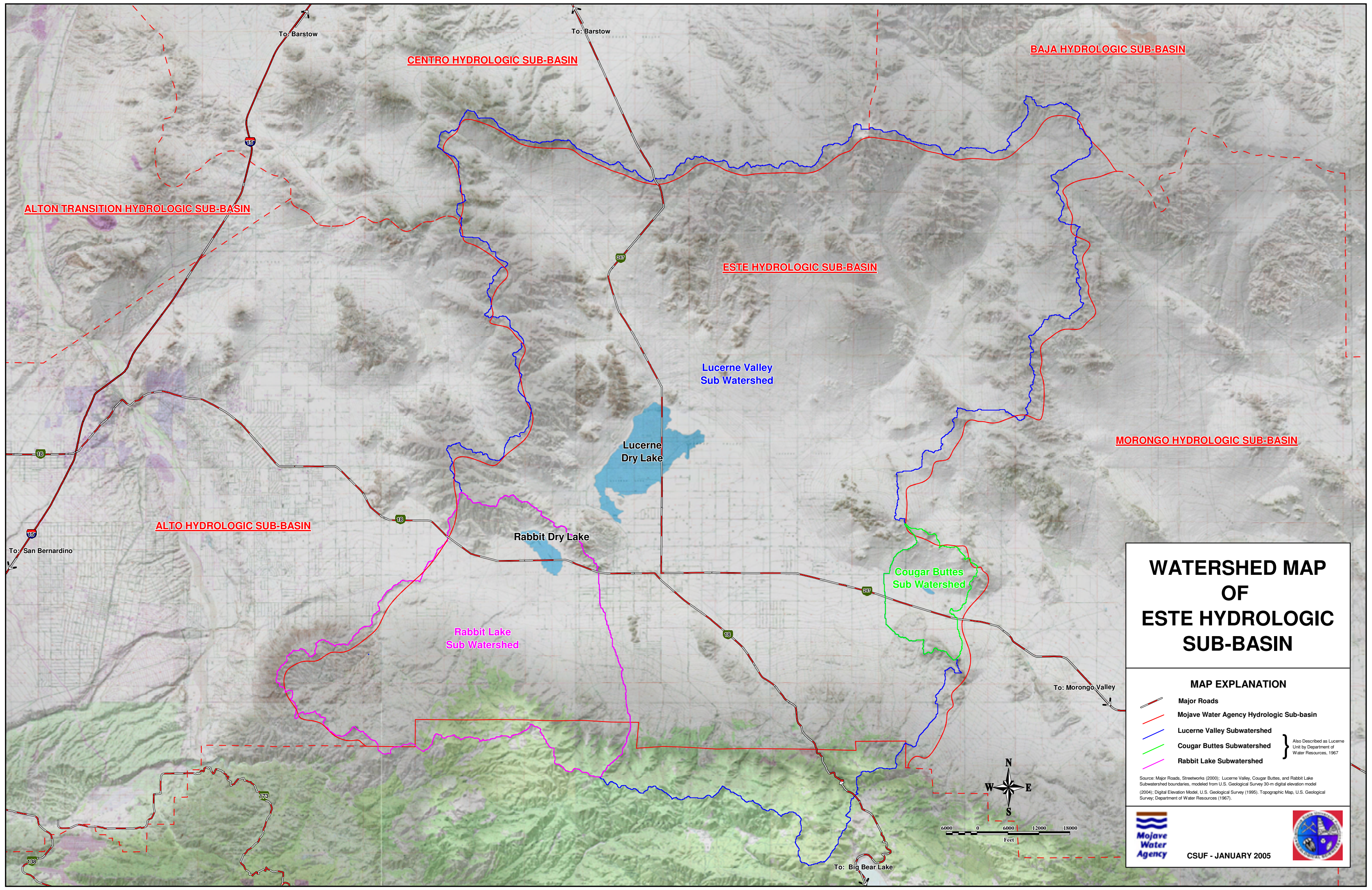
Recharge to the basin has been estimated to be 1,750 acre-ft/yr [DWR, 1967 and Brose, 1987]. Consumptive use was estimated to be between 4,640 and 8,225 acre-ft/yr [DWR, 1967 and Brose, 1987]. Recent estimates indicate that recharge maybe higher. This is based on the groundwater hydrographs associated with the MWA "Key Well Program."

Groundwater Quality

An examination of water quality shows that most of the Este Hydrologic Sub-basin contains water that is of overall good quality and meets primary drinking water standards. However, certain areas within the Lucerne Valley groundwater basin have sub-standard water quality and conditions are worsening. Generally, these areas are subject to septic, fertilizer, and agricultural runoff which may be causing the degradation of water quality. Roughly half of the water recharged into the basin is return flow from agriculture and domestic (septic) sources, which tends to degrade water quality. A source of recharge which may be further degrading water quality in the basin are the Big Bear waste water percolation ponds. If development continues without sewage control, water quality within the Lucerne Valley groundwater basin may continue to degrade, potentially contaminating deeper portions of the aquifer.

Measures to improve water quality and increase the water quantity in the Lucerne Valley groundwater basin may include artificial recharge. A potential source of water for recharge may be the Morongo Pipeline which traverses the area west to east. To increase effectiveness, water should be recharged east of the Helendale fault near the areas of outcropping Old Woman Sandstone. It appears that groundwater in the Fifteenmile Valley groundwater basin is of good quality and abundant enough to meet current demands.

An assessment of the aquifer quality, capacity, and budget are still under investigation. Refinements of aquifer capacity and budget numbers will necessitate future work consisting of additional monitoring wells, aquifer tests, computer modeling, etc.



Watershed Dimensions

Sub-Watershed	Surface Area			Elevation Relief	
	mi²	*km²*	*acres*	*ft*	*m*
Lucerne Valley	383	992	245,119	5,400	1,646
Rabbit Lake	78	202	49,920	4,787	1,459
Cougar Buttes	11	28	6,919	3,533	1,077
Este Hydrologic Sub-basin	**472**	**1,222**	**302,079**		

Este Watershed

The Este watershed is divided into three separate sub-watersheds: the Lucerne Valley, Rabbit Lake, and Cougar Buttes watersheds, covering a total area of 472 square miles (1,222 square kilometers; 302,079 acres) of varying terrain. The Este watershed includes portions of the San Bernardino, Cougar Buttes, Fry, Rodman, Ord, and Granite Mountains as well as the Lucerne, Rabbit, and Cougar Buttes dry lakes. The geopolitical boundary (outlined in red) varies slightly with respect to the true Este watershed boundary which has a total area of 443 square miles (1,147 square kilometers; 283,519 acres). The San Bernardino Mountains, within the watershed, rise to an elevation of 8,248 feet (2,514 meters) above mean sea level (amsl), which is the highest point in the watershed. Lucerne (dry) Lake is at an elevation of 2,847 feet (868 meters) (amsl), the lowest point in the watershed

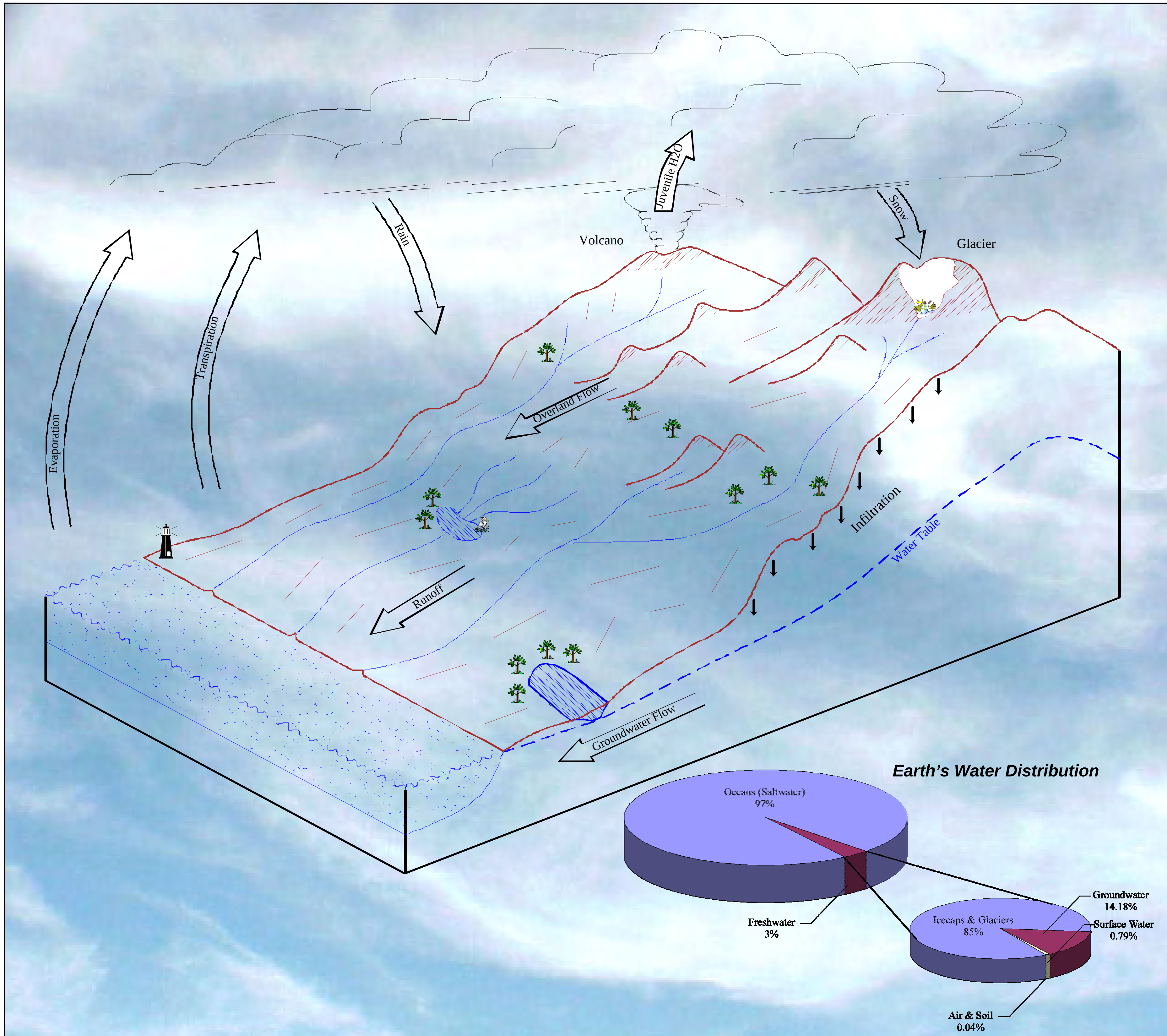
The Lucerne Valley sub-watershed covers over 383 square miles (992 square kilometers; 245,119 acres) with an elevation change of 5,400 feet (1,646 meters) and is bounded by the Ord and Rodman Mountains to the north, the San Bernardino Mountains to the south, Cougar Buttes and Fry Mountains on the east, and the Granite Mountains on the west. Parts of the eastern and southwestern boundaries of the Lucerne Valley sub-watershed are bounded by crests of alluvial fans that act as surface drainage divides separating the Rabbit Lake sub-watershed on the west and the Cougar Buttes sub-watershed on the east.

The Rabbit Lake sub-watershed covers an area of 78 square miles (202 square kilometers; 49,920 acres) with an elevation change of 4,787 feet (1,459 meters). This watershed is bounded to the north by Granite Mountains and to the south by the San Bernardino Mountains. The western and eastern edge of the sub-watershed are bounded by alluvial fan crests that act as surface drainage divides.

The Cougar Buttes sub-watershed covers an area of 11 square miles (28 square kilometers; 6,919 acres) with an elevation change of 3,533 feet (1,077 meters). This sub-watershed is bounded to north by the Cougar Buttes Mountains and to the south by the Blackhawk Landslide. On both the eastern and western margins of the sub-watershed alluvial fans act as surface drainage divides.

During periods of high precipitation, surface water drains toward Lucerne (dry) Lake in the western portion of the basin. Surface water in the Rabbit Lake sub-watershed drains towards Rabbit (dry) Lake at the southwestern base of the Granite Mountains. Within the Cougar Buttes sub-watershed, surface water drains towards the Cougar Buttes (dry) Lake at the southwestern base of the Cougar Buttes Mountains. Both Rabbit Lake and Cougar Buttes sub-watersheds are closed basins that do not discharge to the larger Lucerne Valley sub-watershed.

Hydrologic Cycle



Water on the Earth

The endless circulation of water between the oceans, atmosphere, and land is called the hydrologic cycle. The term refers to the constant movement of water above, on, and below the Earth's surface. The concept of the hydrologic cycle is central to any understanding of the occurrence, development, and management of water.

Hydrologic Cycle

The movement of water through the hydrologic cycle consists of many processes working together to keep Earth's water moving. Five processes are at work in the hydrologic cycle: condensation, precipitation, infiltration, runoff, and evapotranspiration. These occur simultaneously and except for precipitation also occurs continuously.

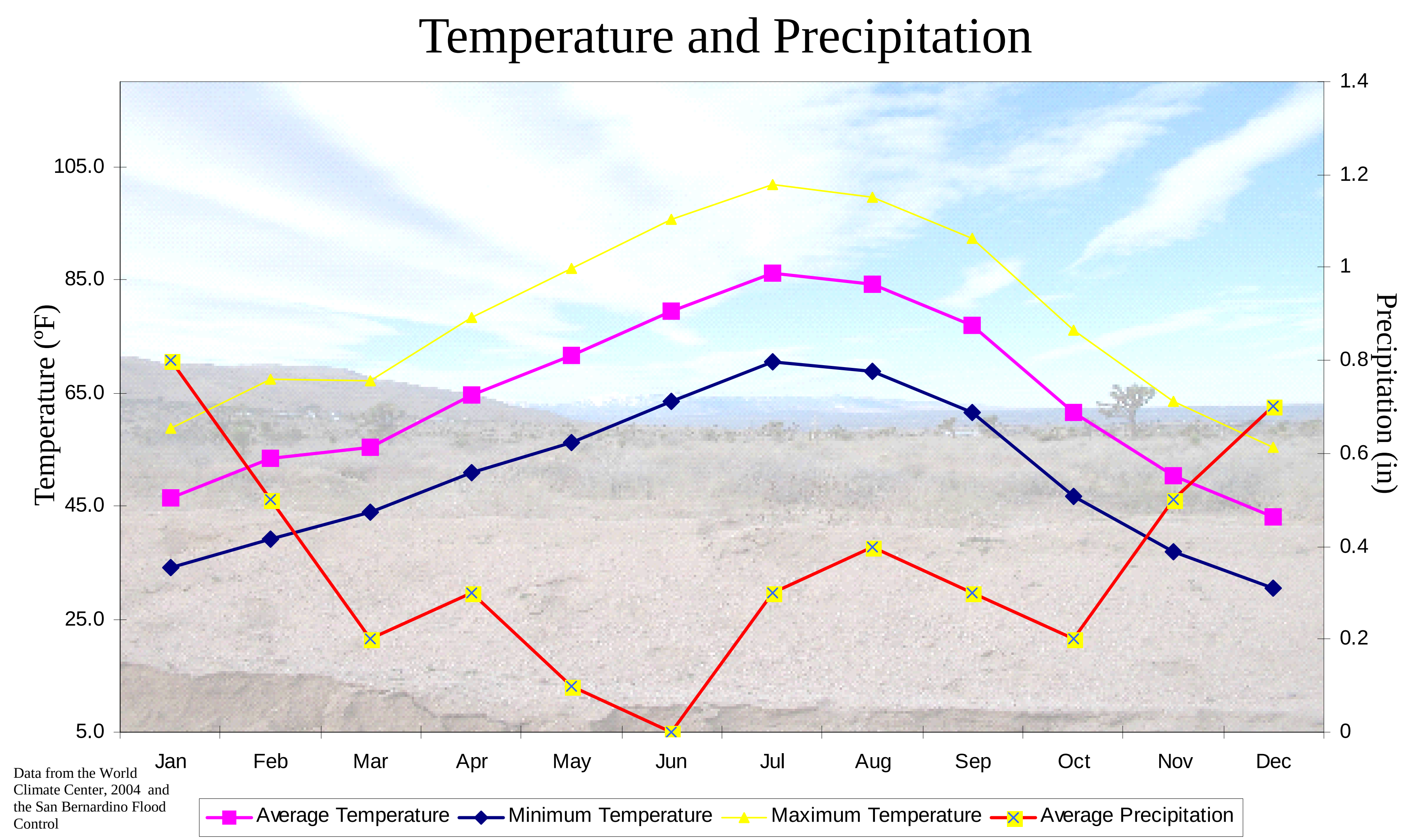
Water evaporates from the land or water surface, condenses and forms clouds. These water vapors then return to the land or water surface in the form of precipitation (rain, snow, or sleet). Precipitation falls to the surface and infiltrates the soil or flows to the ocean as runoff. Water that infiltrates the soil varies with the degree of land slope, the amount and type of vegetation, soil type, rock type, and moisture and gravity potential of the soil. The more openings in the surface (cracks, pores, joints), the more infiltration occurs. Water that doesn't infiltrate the soil flows on the surface as runoff. Precipitation that reaches the surface of the Earth but does not infiltrate the soil is called runoff. Runoff can also come from melted snow and ice.

Aquifer Recharge

As there is no major or minor constant stream flow within the Este Hydrologic Sub-basin, most water infiltrates into the ground surface or is lost to evaporation and evapotranspiration. Transpiration is extremely low in the area. Most recharge to the local groundwater system begins in the San Bernardino Mountains and moves down towards the interior of the Este Hydrologic Sub-basin as groundwater.

The Future of Water Resources

The limited control of groundwater usage within the Este Hydrologic Sub-basin can have lasting effects on future water supply and quality. Human water use is part of the hydrologic cycle and all parts of the water cycle are interconnected. The future quality of life and growth in the region depends on society's awareness of the water cycle and on the knowledge that what happens in one part of the cycle may affect another part.



Data from the World Climate Center, 2004 and the San Bernardino Flood Control

Average precipitation													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
mm	21.5	13	5.4	6.4	2.3	0.4	7.2	9.2	7.5	4.2	12.9	16.9	107.7
inches	0.8	0.5	0.2	0.3	0.1	0	0.3	0.4	0.3	0.2	0.5	0.7	4.2

Maximum Temperature													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
°C	14.8	19.7	19.6	25.8	30.6	35.3	38.8	37.5	33.4	24.6	17.5	13.1	25.9
°F	58.6	67.5	67.2	78.4	87	95.6	101.8	99.5	92.2	76.2	63.5	55.5	78.6

Minimum Temperature													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
°C	1.2	3.9	6.6	10.6	13.4	17.5	21.4	20.5	16.3	8.1	2.7	-0.8	10.1
°F	34.1	39.1	43.8	51	56.2	63.5	70.6	68.9	61.4	46.6	36.9	30.6	50.2

Average Temperature													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
°C	8.0	11.8	13.1	18.2	22.0	26.4	30.1	29.0	24.9	16.3	10.1	6.1	18.0
°F	46.4	53.3	55.5	64.7	71.6	79.6	86.2	84.2	76.8	61.4	50.2	43.1	64.4

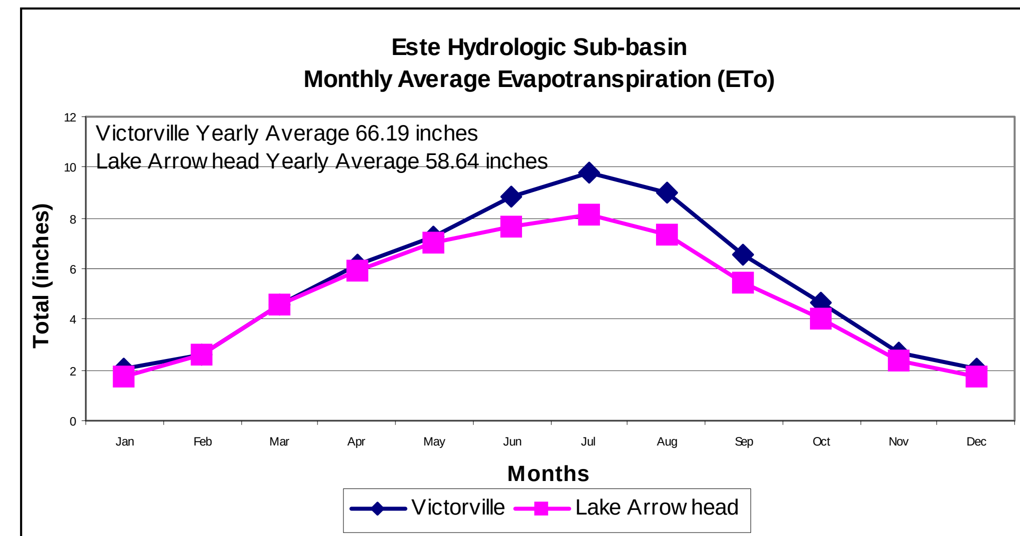
Climate

Deserts are defined as arid regions that receive 10 inches (25.4 cm) or less of rain per year [Teale, 1997]. The Mojave Desert is an arid region because it is located in the rain shadow of the east-west trending San Bernardino and San Gabriel Mountains. As winter storms pass over southern California, moist Pacific Ocean air generally travels from the southwest to the northeast. When an air mass reaches the San Bernardino and San Gabriel Mountains it begins to rise up the windward side and cools causing water vapor trapped in the air mass to condense and form either rain or snow. This process, known as orographic lifting, tends to relieve an air mass of its moisture content. As the now drier air mass continues to travel north, it descends down the leeward side and warms creating a relatively warmer, drier climate on the northern side of the San Bernardino and San Gabriel Mountains.

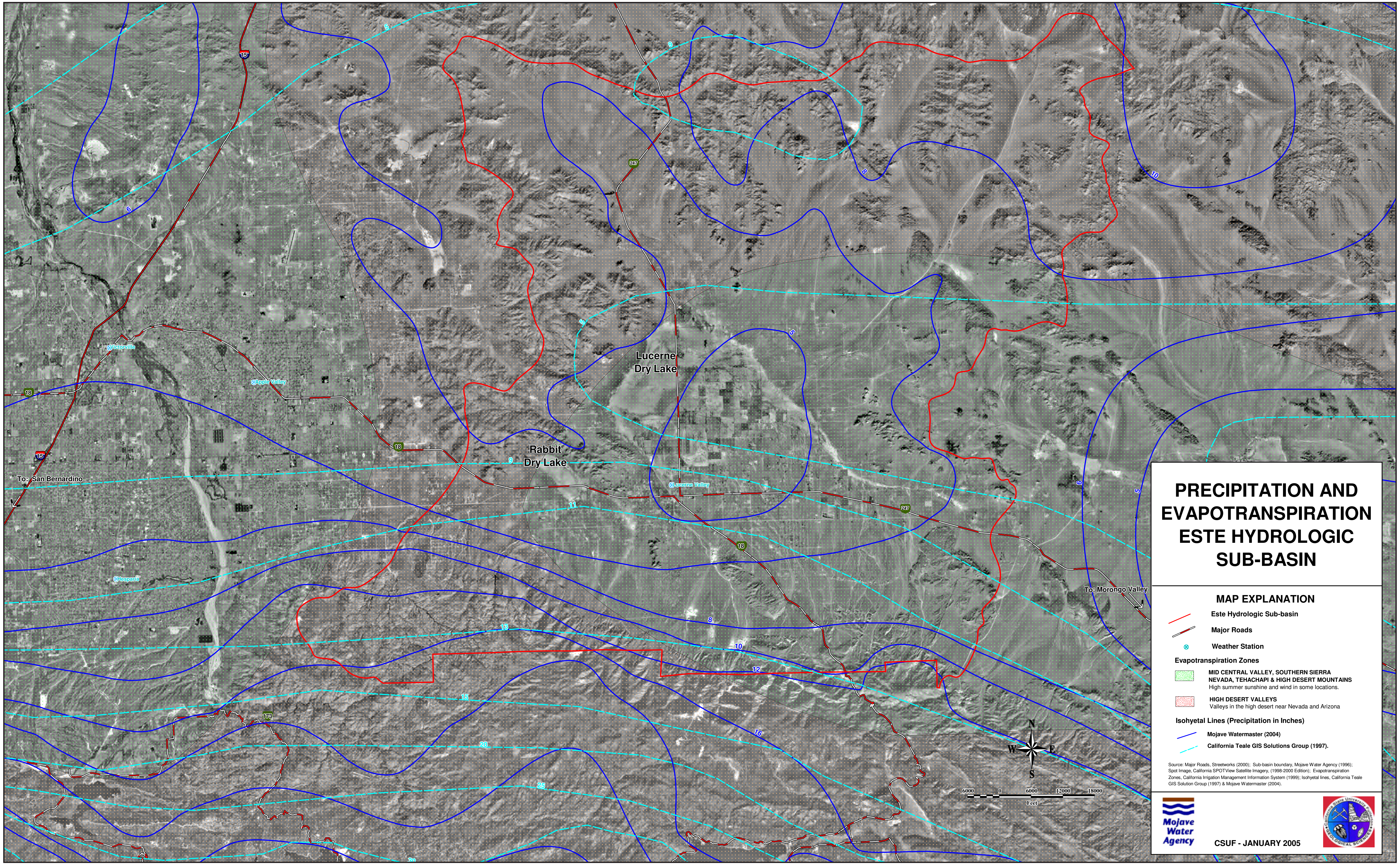
The climate of the Este Hydrologic Sub-basin can have extreme fluctuations in daily temperatures and precipitation. During the summer, when high pressure sets up over the Great Basin and low pressure is over the Gulf of California, monsoonal moisture is brought in from the Gulf of Baja and the Gulf of Mexico. Heat from the desert floor creates thermal low pressure systems that lift this warm, moist air aloft where it cools and condenses, resulting in thunderstorm cells. These cells may bring brief, sudden, torrential rain, and hail that may result in flash flooding.

Evapotranspiration

Este Hydrologic Sub-basin is located within two evapotranspiration zones, Zone 14 and 17 based on Reference Evapotranspiration [California Irrigation Management Information System (CIMIS), [2004]. Zone 14 is characterized by high summer sunshine and wind in some locations. Zone 17 is described as valleys in the high desert.



Precipitation & Evapotranspiration Map



Physiography

Geography

The Este Hydrologic Sub-basin is considered a closed *watershed* in that surface water does not generally drain from the basin(s), nor does water flow into the basin from adjoining watersheds. Large mountain ranges surround the sub-basin with protruding hills of basement rocks exposed throughout the region. The sub-basin boundaries are defined by the Ord, Rodman, and Stoddard Mountains to the north, the Granite Mountains and crests of alluvial fans in the west, Fry and Cougar Buttes Mountains to the east, and the large San Bernardino Mountains to the south. Adjacent to the mountain fronts, large alluvial fans slope towards the center of the basin where ephemeral (seasonal) streams deposit alluvial materials. The Este Hydrologic Sub-basin has a topographic low of 2,847 feet (868 m) (amsl) in Lucerne (dry) Lake and rises to 8,248 feet (2,514 m) in the San Bernardino Mountains (amsl).

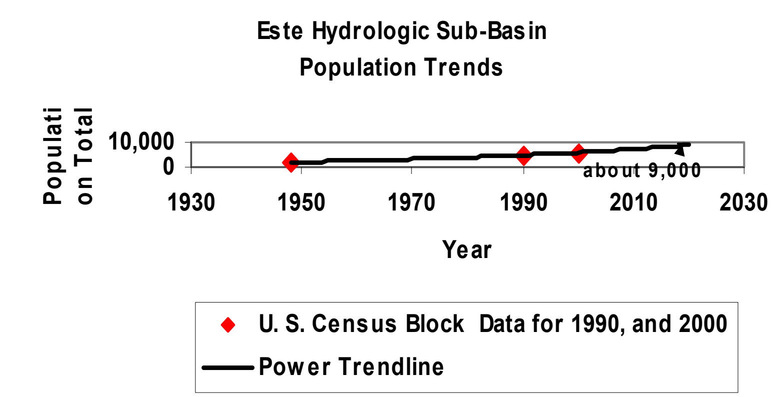
Streams and Sedimentation

As streams pass through mountain valleys they erode and transport material. Once the sediment-laden stream exits the mountain front, it drops its sediment load in the shape of a fan. Coarser material is deposited first, near the base of the mountains, which tends to yield higher porosities and higher permeabilities. As the fan spreads out, braided streams deposit coarse and medium sized sand further from the source followed by deposition of finer grained silts and clays towards low lying areas. These clays settle out in the lowest areas of the basin to eventually form playa surfaces, which in turn can serve as "seasonal lakes." The playa sediments are high in porosity but not very permeable. In general, as the grain size of alluvial deposits decrease with increasing transport, effective porosity and specific yield decrease due to increasing compaction and cementation (calcite cement), which leads to a decrease in permeability of the alluvial deposits.

Sedimentation - the removal, transport, and deposition of detached sediment particles by wind and or water.

Population

The number of residents in the Este Hydrologic Sub-basin has steadily grown since the first record of 2,000 in 1948 [Lucerne Valley Chamber of Commerce, personal communication]. Census block data, available for census years 1990 and 2000, are plotted and a power trend line was inserted. The trend line was extended to 2020 and indicates a population of about 9,000. The primary employment in the area involves mining and processing limestone. Some farming and ranching is also found in the Este Hydrologic Sub-basin [lucernevalley.org].



Land Use & Vegetation

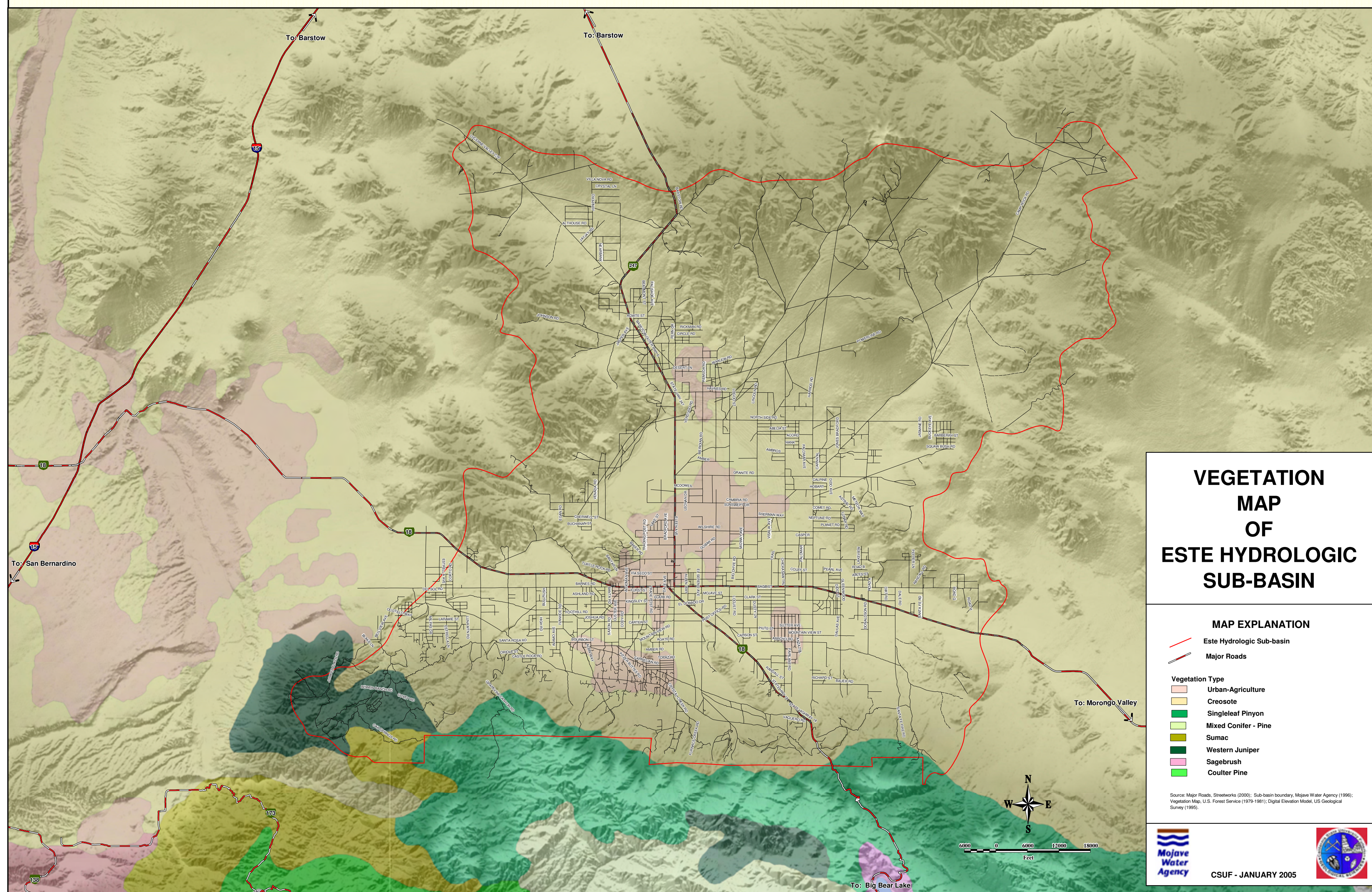
Land Use

Land use in the Este Hydrologic Sub-basin consists of farming, mining, residential, commercial, and industrial. Early in the 1900's farming and ranching began within the basin and by the early 1980's, farming had reached its peak covering much of the basin. This was determined based on groundwater hydrographs and aerial photographs. In 1961, an estimated 2,050 acres was used for some type of agriculture [DWR, 1967]. During the 1980's, for various political and private reasons, a decline in farming ensued. Today much of this area is reclaimed farmland, although some alfalfa and pistachio farming still continues along with small amounts of ranching. Land ownership throughout the study area is quite varied, with much of the land in the east controlled by the Bureau of Land Management (BLM).

Limestone mining has become a major industry within the region with large limestone quarries located along the foothills of the San Bernardino Mountains. In the early 1950's limestone mining greatly increased when Kaiser Fontana Steel Mill started operation of the first cement plant in the area. Presently, Lucerne Valley has become the largest limestone production district in the nation, producing an estimated three-million tons per year [lucernevalley.org/chamber/]. Major limestone production facilities today include Pluess-Staufer Inc., Mitsubishi Mining Company, and Pfizer Inc. Limestone.

Vegetation

The native vegetation in the Este Hydrologic Sub-basin is typical of most of the Mojave Desert region and other desert areas in southwestern United States. Dominant plants include creosote bush, yucca, joshua trees, various cacti, wildflowers, and juniper. Desert plants are typically xerophytes, which are plants that have adapted to areas of low precipitation. Xerophytes spread out their roots at shallow depths to catch any available ground moisture. Most vegetation in this region is found in areas of well-drained slopes, plains, and sandy loams. Higher mountain regions may have pinyon pines and the highest regions are temperate zone dry forests with pine, oak, and other deciduous tress.



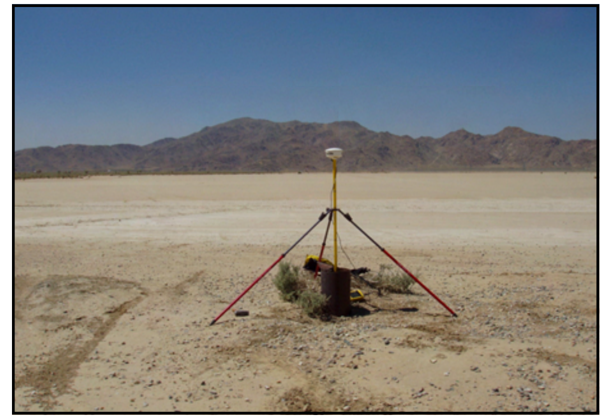
Dry Lakes

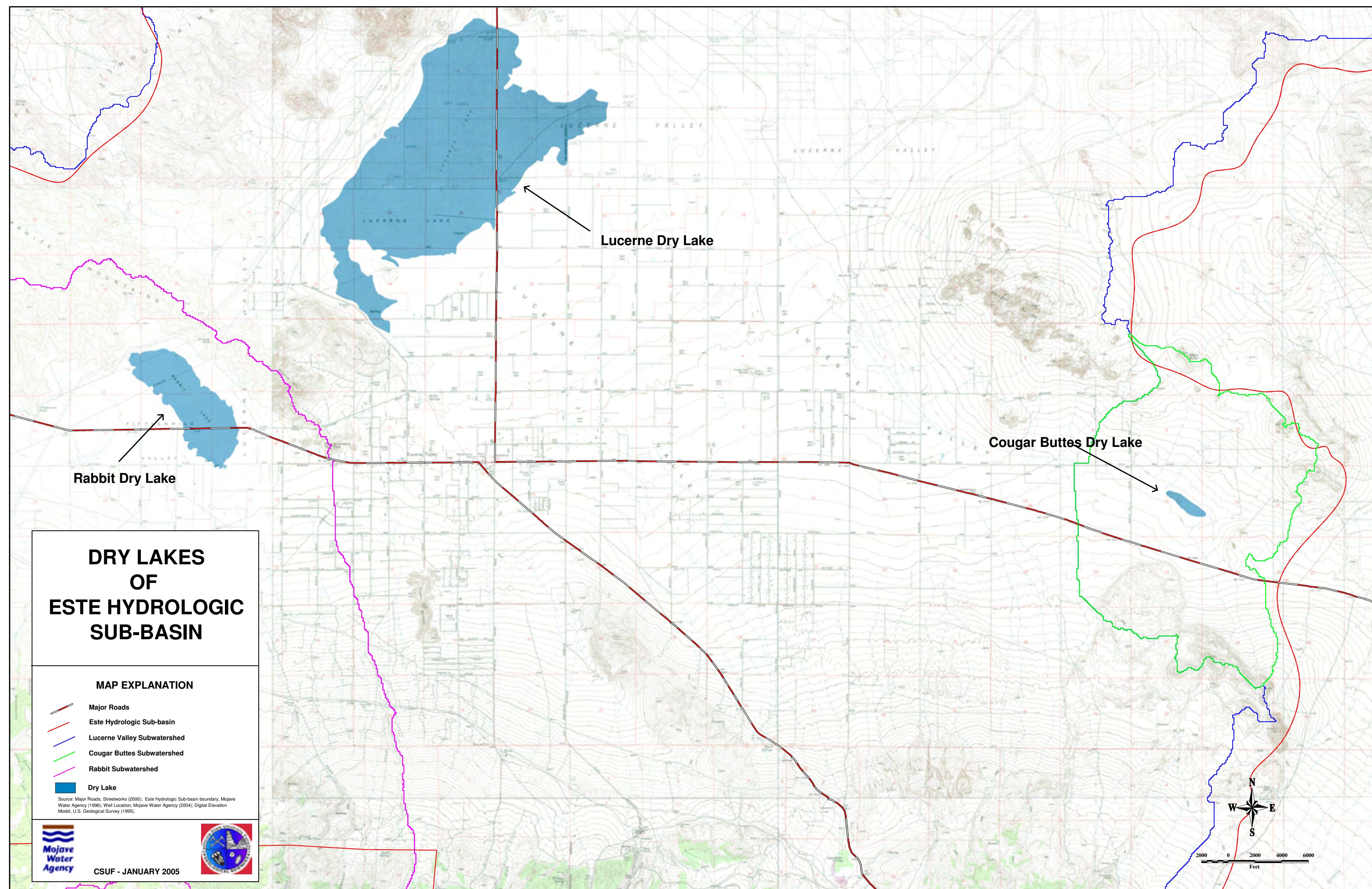
Three dry lake beds exist within the Este Hydrologic Sub-basin: Lucerne (dry) Lake, Rabbit (dry) Lake, and Cougar Buttes (dry) Lake. Each is an area of low relief where surface water may drain and/or pond. At one time in the geologic past, the dry lake beds were filled with water, but today water only collects in these regions during times of high precipitation. Large volumes of water typically do not infiltrate through the dry lake beds because of impermeable to semi-impermeable clay layers that overlie the aquifer. Small amounts of water may infiltrate, but the majority of water will stay for days or weeks until it evaporates.

Large-scale desiccation cracks are also associated with the dry lake regions. Fife [1977] indicates that 60% of Lucerne (dry) Lake has developed desiccation cracks. These cracks form irregular shaped polygons that can be traced from 200 feet to 1 mile (61 to 1,600 m) and have diameters ranging from 1 to 4 feet (0.3 to 1.2 m) [Neal et al., 1968]. Desiccation fissures can be attributed to regional lowering of the water table by both man and the natural progression towards aridity [Brose, 1987]. Fissuring is also often associated with localized differential compaction of unconsolidated sediment. Fissures formed by this mechanism are caused by stretching of the aquifer-system structure due to bending of the overlying sediment of the differentially compacted zones [Holzer, 1984].

Subsidence

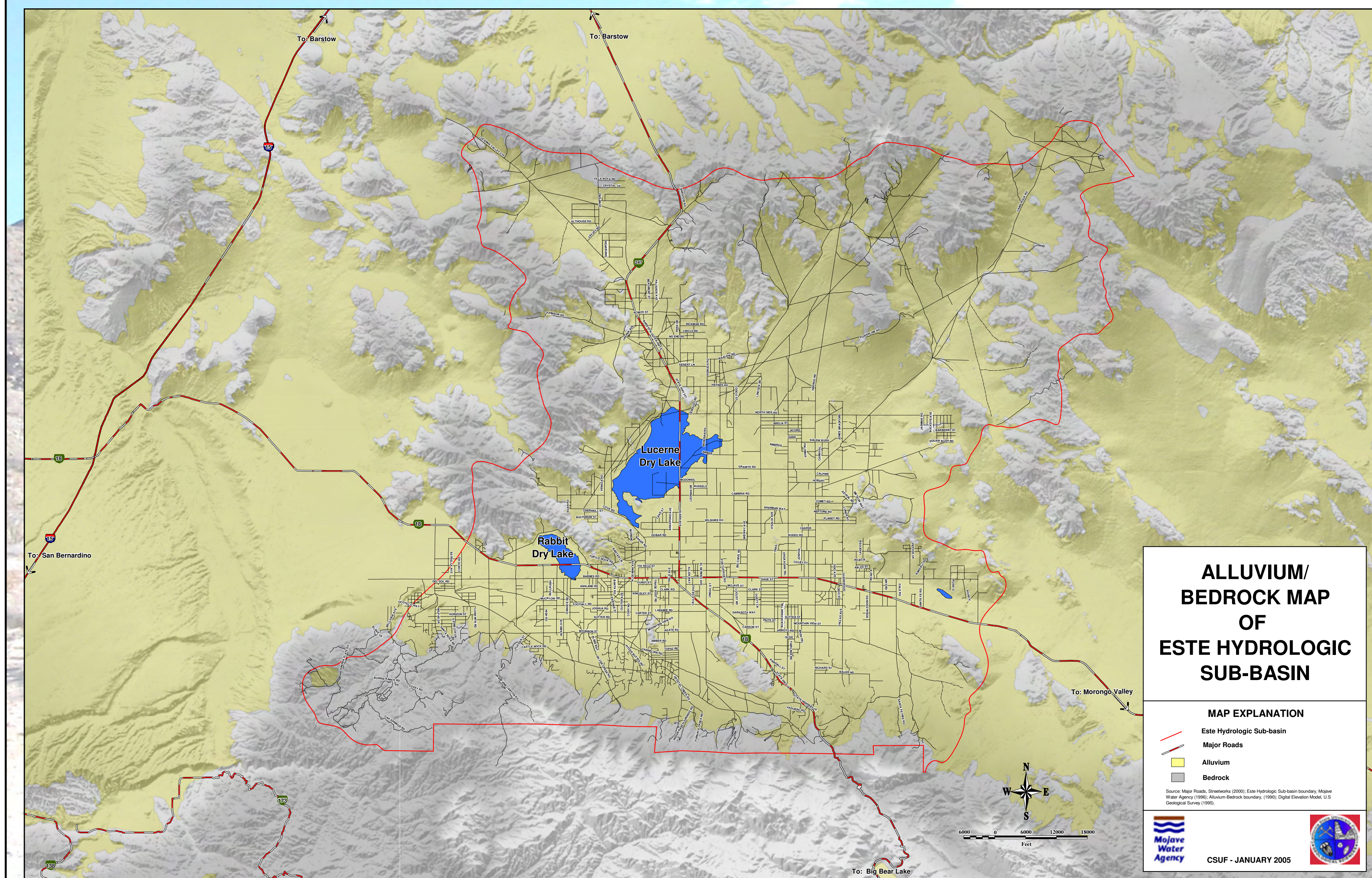
Land subsidence is a gradual settling or sinking of the ground surface with little or no horizontal movement. In basins like Lucerne Valley where the aquifer system includes fine-grained unconsolidated sediments, subsidence can occur when there is an extensive decrease in groundwater levels. The pores within an aquifer are supported by a combination of the granular fabric and the fluid pressure of the groundwater in the pore space [Meinzer, 1928]. Subsidence occurs when groundwater is withdrawn in large amounts and pore space is reduced due to the weight of the overlying sediment load. Measurements indicate that between 1969 and 1998, about two feet of subsidence occurred southeast of Lucerne (dry) Lake in conjunction with water levels declining as much as 50 feet (15 m) in the same area [Sneed et al., 2003]. Additional subsidence has not been recorded since 1998 due to stabilized groundwater levels [Sneed et al., 2003].





Geologic Setting

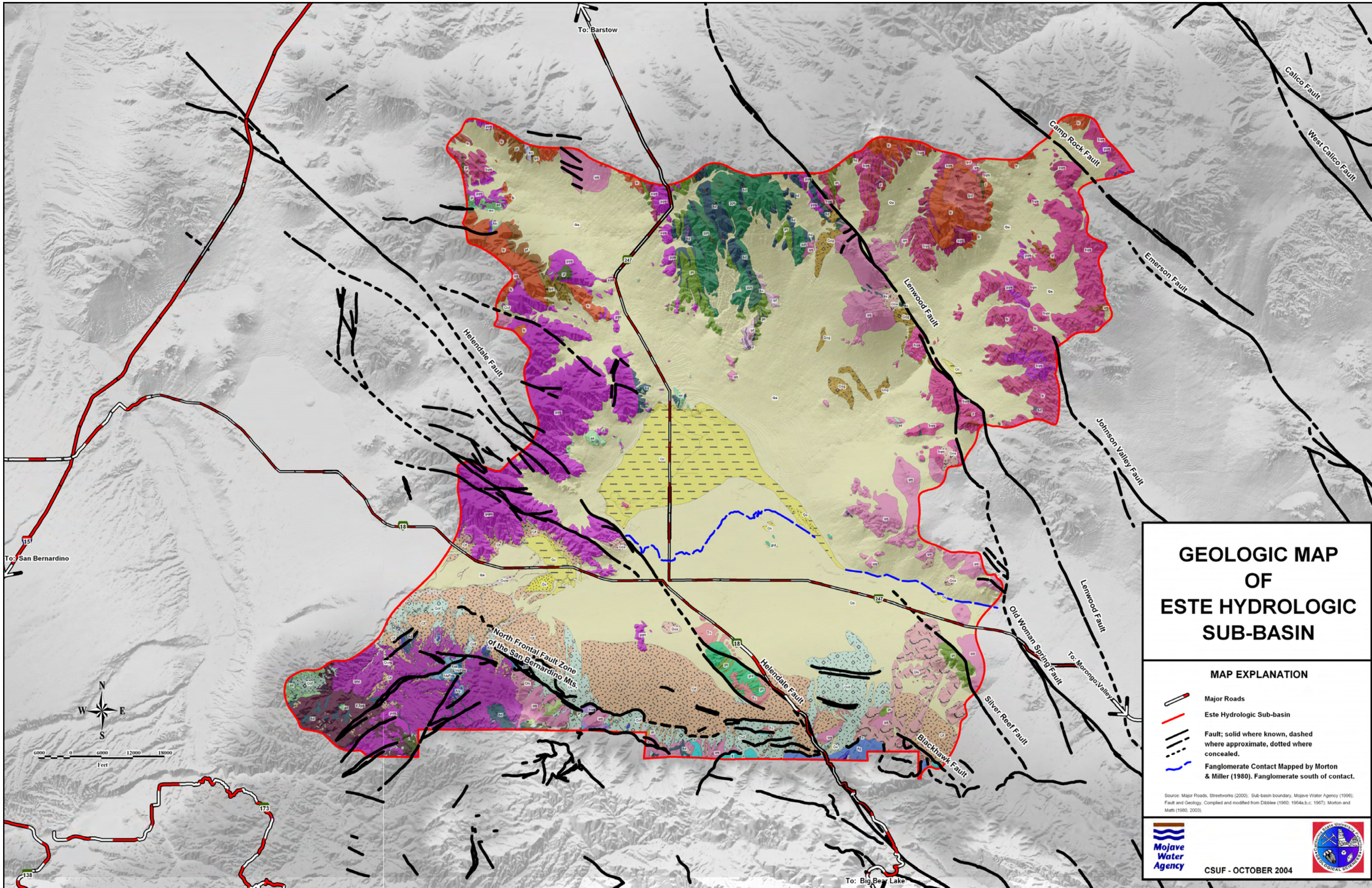
Sediments within the Este Hydrologic Sub-basin form by the erosion and transport of sediment from the surrounding mountains, and consist of coarse-to fine-grained alluvial deposits. For the purpose of this report, surface and subsurface lithologic units within and adjacent to the Este Hydrologic Sub-basin are classified into non-water-bearing and water-bearing units in accordance with DWR [1967]. Non-water-bearing rock units consist of Precambrian and Paleozoic age metamorphic and Mesozoic age igneous rocks [Dibblee, 1964a and 1964b] that comprise the surrounding mountains and underlie alluvial deposits. Water-bearing units are comprised of Quaternary age alluvial deposits (gravel, sand, silt, clay, and occasional boulders) and are present in the central portion of both valleys and along the base of the surrounding mountains [Dibblee, 1964a and 1964b] . The predominant structural features in the Este Hydrologic Sub-basin that influence the movement of water, including the location and distribution of the non-water-bearing deposits, are a set of active northwest-trending strike slip-faults: Helendale, Lenwood, Camp Rock, Old Woman Springs fault zones and the North Frontal thrust system of the San Bernardino Mountains. The North Frontal thrust system of the San Bernardino Mountains acts as a boundary to the basin aquifer at the southern edge of Lucerne Valley and Fifteenmile Valley.



ERA	IMPORTANT GEOLOGIC EVENTS IN THE ESTE HYDROLOGIC SUB-BASIN
CENOZOIC 65 my	Pleistocene deposition of older and younger surficial sediments-alluvium, fanglomerate, Blackhawk Landslide, terrace gravels, breccias, clays, and sand. Major fault activity including the North Frontal thrust system of the San Bernardino Mountains and the Eastern California shear zone. Deposition of the Old Woman Sandstone and scattered basalts throughout the Tertiary period.
MESOZOIC 245 my	Between late Jurassic (?) or early Cretaceous (?) time, several intrusions of mainly plutonic and hypabyssal igneous rocks occurred. Major deformation of pre-Mesozoic rocks causing major folding and faulting adjacent to the Este Hydrologic Sub-basin
PALEOZOIC 570 my	During the Mississippian time, the Furnace Limestone was deposited conformably on the Sargossa Quartzite. Deposition of the Saragossa Quartzite, which is unconformable on Precambrian rocks and has subsequently been intruded by quartz monzonite.
PRE-CAMBRIAN	Deposition of sedimentary rocks that have been intruded by quartz diorite gneiss and granite porphyry forming a series of metasedimentary and metamorphic rocks exposed throughout the Este Hydrologic Sub-basin.

Information based on Dibblee [1964] and Goodrich, [1978].

Geologic Map



Geologic Map Explanation

Quaternary

- Artificial fill (Afu)
- Mixed wash deposits (Qwm)
- Surficial sediments, fanglomerate (Qf) Unsorted angular to subrounded fragments.
- Surficial sediments, alluvium (Qa) Gravel, sand, and silt.
- Surficial sediments, clay (Qc) Micaceous, silty to argillaceous, playa.
- Surficial sediments, sand (Qs) Fine-grained, composed of quartz and feldspar.
- Breccia (Qb)
- Older surficial sediments, terrace gravels (Qot) Cobble-boulder gravel of mostly limestone detritus, poorly bedded, and weakly indurated.
- Older surficial sediments, older alluvium (Qoa) Cobble, gravel, and sand, poorly bedded to nonbedded.
- Older surficial sediments, older fanglomerate (Qof) Gray, poorly to well-bedded, composed of poorly sorted, sub-rounded fragments.
- Older surficial sediment, older gravel (Qog)
- Older surficial sediments, landslide rubble (Qls) Breccias dark-gray and white Furnace Limestone.

Tertiary

- Basalt (QTb) Black, massive, hard, nonvesicular. Composed of scattered irregular grains of olivine and a few small phenocrysts of plagioclase in microcrystalline groundmass.
- Old Woman Sandstone (To) Arkosic sandstone, interbedded conglomerate and siltstone. Conglomerate composed of rounded cobbles and pebbles, porphyritic and felsitic rocks, granitic rocks, quartzite,

Mesozoic

- Aplite Dike (a)
- Pegmatite (p)
- Quartz monzonite (qm) Gray-white, weathers buff, hard but friable where weathered, massive, generally equigranular, rarely subporphyritic, medium-to coarse-grained composed of quartz, potassic feldspar, plagioclase, sphene, apatite, zircon, magnetite, and (rarely) hornblende.
- Bleached quartz monzonite (wqm)
- Quartz diorite (qd) Dark-gray, massive, friable where weathered, medium-grained quartz, orthoclase, plagioclase, biotite, and hornblende.
- Porphyry complex, granite porphyry (gp) Gray, with brown iron staining on fractures, massive, hard; microcline-microperthite, others of plagioclase (oligoclase), quartz, and biotite; groundmass very fine-grained, aplitic, composed of microcline-microperthite and quartz and traces of biotite.
- Felsite (f) White, massive to rarely flow-laminated, hard but non-porcelaneous, very fine-grained felsite composed mostly of potassic feldspar and some quartz and magnetite.
- Porphyry complex, porphyritic felsite (pf)
- Porphyry complex, quartz latite porphyry (lp) Gray, with brown iron staining on fracture surfaces, very hard, massive, and rarely flow laminated.
- Diorite (d) Dark-gray, massive, fine-grained, composed mainly of calcic plagioclase and hornblende, and scattered phenocrysts of plagioclase.
- Older granitic, aplitic quartz monzonite (aqm) Buff but with brown iron staining on fractures, massive, hard, very fine-grained. Composed of quartz, orthoclase, plagioclase, sphene, biotite, muscovite, and apatite.
- Older granitic, granite a nd quartz monzonite (gqm) Nearly white but weathers buff to light gray, hard, massive except slightly gneissoid at Pitzer Butte, medium-to locally coarse-grained.
- Older granitic, biotite quartz monzonite (bqm) Light-to medium-gray, massive to somewhat gneissoid, medium grain, porphyritic.
- Older granitic, hornblende quartz monzonite (hqm) Light-gray, massive to rarely gneissoid.
- Quartz monzonite porphyry (qmp) Light-gray, tan-weathering, massive to foliated granitic porphyry. Composed of scattered phenocrysts as long as 1 cm of potassic feldspar in fine-to medium-grained groundmass of quartz, potassic feldspar, and sodic plagioclase.

Mesozoic

- Older granitic, granodiorite (grd) Light-gray, gneissoid to massive, medium-grained.
- Hornblende diorit e and gabbro (hd) Dark-gray to black, massive, medium-to coarse-grained composed of plagioclase, hornblende (partly altered to biotite, chlorite, and epidote), and small amounts of magnetite, sphene, apatite, quartz, and orthoclase.
- Schistose latitic metaporphyry or meta tuff (lps)
- Latite-andesite porphyry a nd diorite porphyry (lpb)
- Latitic porphyry coarse breccia (lpf)
- Porphyry Complex, basalt porphyry (bp) Dark-gray mafic rocks of somewhat variable composition; massive, fine-grained. Composed of scattered to abundant relict phenocrysts of plagioclase, pyroxene, and amphibole in fine-grained groundmass of mostly lathy plagioclase, with sericite, and chlorite.
- Latite-andesite porphyry and diorite porphyry (lpd)
- Porphyry complex, quartz latite (ql) Gray-white, weathers tan, with much reddish-brown iron staining on fracture surfaces; moderately hard, massive to slightly foliated parallel to indistinct flow laminae, very fine-grained, composed of quartz potassic feldspar, and plagioclase.
- Mixed granitic and metamorphic rocks (MzPm)
- Porphyritic monzogranite (Krp)
- Mixed granitic rock, gneiss, and quartzite (KJgm)
- Mixed mafic and leucocratic granitic rocks (Kml)
- Cataclastic rocks (Jcr)
- Leucocratic hornblende syenite (Js)
- Fine-grained rocks of Silver Canyon (Jsc)

Paleozoic

- Furnace Limestone, white carbonate (fl) White to pale-gray, medium-to very coarsely crystalline limestone or dolomite marble, thick-bedded to massive.
- Furnace Limestone, gray carbonate (flg) Blue-black to blue-gray, mostly fine but locally medium to coarsely crystalline limestone or dolomite marble, commonly banded with white laminae.
- Dolomite Conglomerate (fdc)
- Metasedimentary, limestone (ml) White to gray-white, medium to coarsely crystalline, thick-bedded, composed of calcite and some dolomite; adjacent to granitic contacts commonly contains epidote, garnet, and diopside.
- Metasedimentary, schist (ms)
- Porphyry complex, siliceous felsite and aplite (sf) White to light-gray, generally massive to locally faintly flow-laminated, very hard, commonly porcelaneous, aphanitic to fine-grained. Composed of quartz and sodic plagioclase.
- Metasedimentary, hornfels (mh)
- Metasedimentary, tactite (mt) Greenish to reddish-brown, massive to thick bedded, finely to coarsely crystalline, hard tactite composed mainly of garnet, diopside, epidote, and wollastonite.

Precambrian

- Gneissic, quartz diorite gneiss (gn) Gray, generally prominently banded with black laminae rich in biotite and (or) hornblende, alternating with white laminae rich in quartz and feldspars and with gray laminae of intermediate composition.
- Gneissic, granite gneiss (ggn)
- Gneissic, hornblende or biotite schist (hs)
- Granite (gr)

Methods

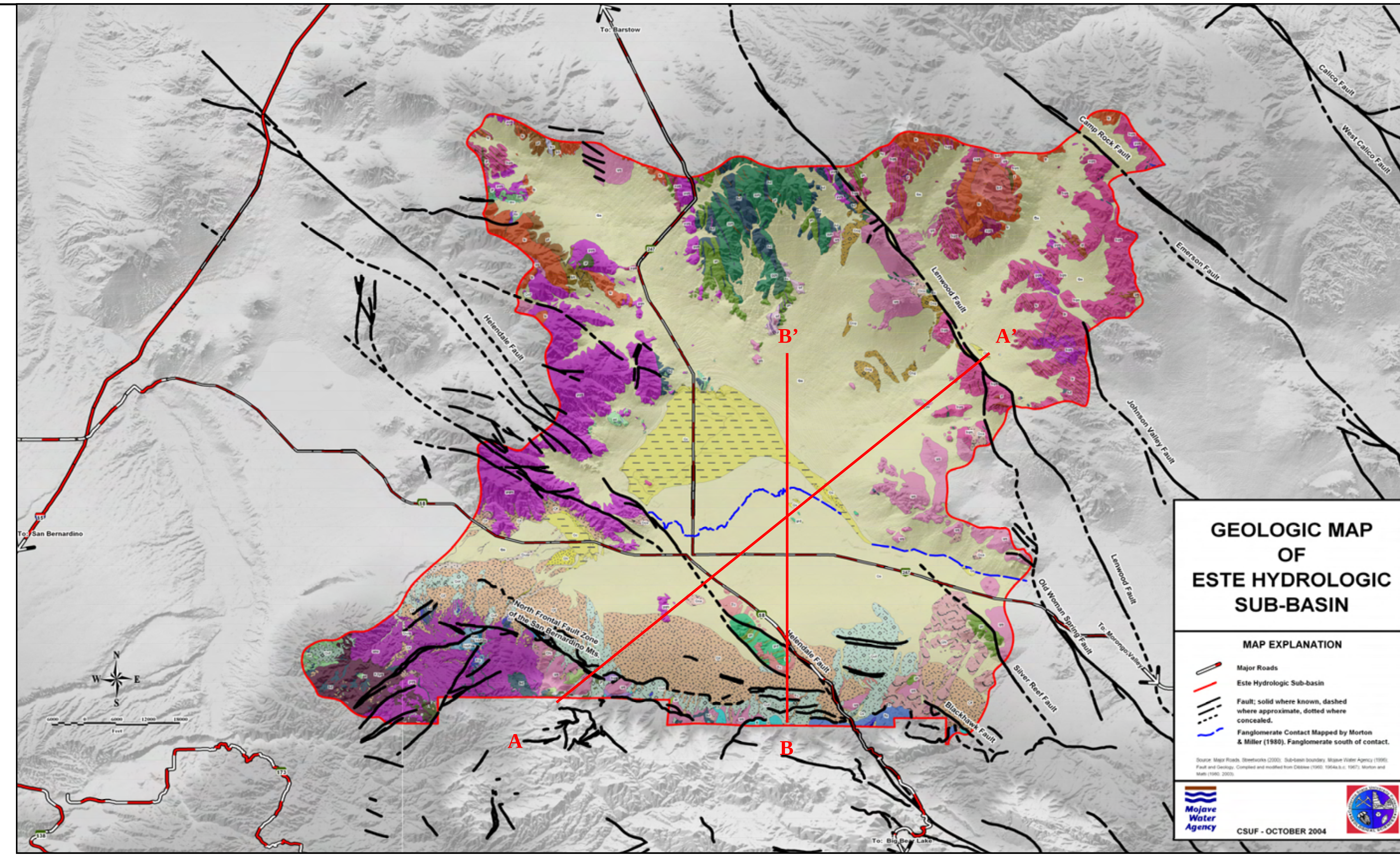
In assessing the subsurface geology of the Lucerne Valley and Fifteenmile Valley groundwater basins, the following methods were applied: (1) geologic maps of Lucerne Valley and Fifteenmile Valley [Dibblee, 1964; Sadler, 1982a; and Miller and Matti, 2003] were used to construct preliminary cross-sections; (2) all applicable driller's water well logs, oil well logs, and United States Geological Survey (USGS) monitoring well data were reviewed with respect to well location, depth of well, and detail of well log; and (3) based on well information and location, geophysical evaluations (natural gamma ray) were conducted at 14 wells using the MGX II Portable Logger with a MGX II Console.

Stratigraphy

Materials that comprise the Lucerne Valley and Fifteenmile Valley groundwater basins are derived from the surrounding mountains and consist of igneous, metamorphic, sedimentary rocks, and alluvial deposits. The geology depicted in the adjacent figure is based on mapping done by Dibblee [1960, 1964a, 1964b, 1964c, and 1967]; and Miller and Matti [2003]; and Sadler [1982a]. The surficial and subsurface distribution of both the basement rock as well as Tertiary and Quaternary sedimentary deposits are shown on cross-sections A and B.

Non-water-bearing Units

The Este Hydrologic Sub-basin is underlain and surrounded by a basement complex consisting of Precambrian (before 570 Ma) and Paleozoic (570 to 245 Ma) age metamorphic and metasedimentary rocks with Mesozoic (245 to 65 Ma) age igneous rocks [Gardner, 1941; Hewett, 1954; Dibblee, 1964a and 1964b; DWR, 1967; Goodrich, 1978; Sadler, 1982a; and DWR, 2003]. Precambrian rocks are dominated by quartz diorite gneiss and schist present within the San Bernardino and Ord Mountains. Paleozoic rocks unconformably overlying the Precambrian rocks consist of the Saragossa Quartzite, gneissic quartzite, phyllite, schist, marble, and the Furnace Limestone which is also exposed in the San Bernardino Mountains. Mesozoic granite and quartz monzonite compose the Granite and Fry Mountains. Tertiary-Quaternary (65 Ma to present) basalts are also locally found in the north and eastern areas of the study area [Dibblee, 1964a and 1964b]. Collectively, these rock units are considered non-water-bearing units because they are inconsequential in porosity and permeability. However, according to driller's logs, a limited amount of water is available from the cracks and fissures of these underlying igneous and metamorphic rocks.



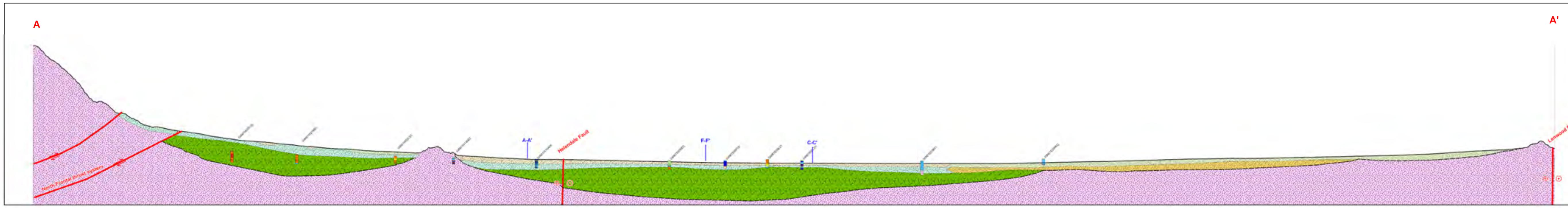
Old Woman Sandstone

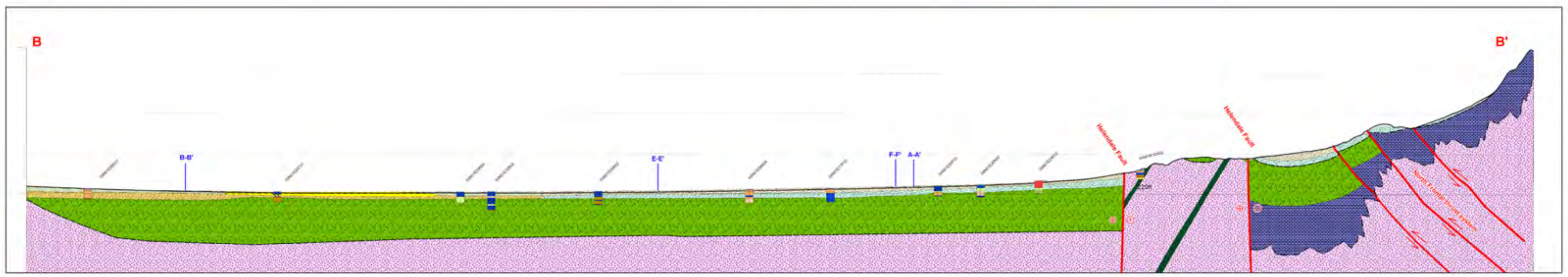
The Old Woman Sandstone, named by Shreve [1968] is exposed sporadically by faulting along the northern front of the San Bernardino Mountains. The unit is unconformable on plutonic pre-Tertiary rocks and is estimated to reach thicknesses between 600 to 1,000 feet (183 to 305 m) underlying most of the Lucerne Valley and Fifteenmile Valley groundwater basins [Dibblee, 1964a].

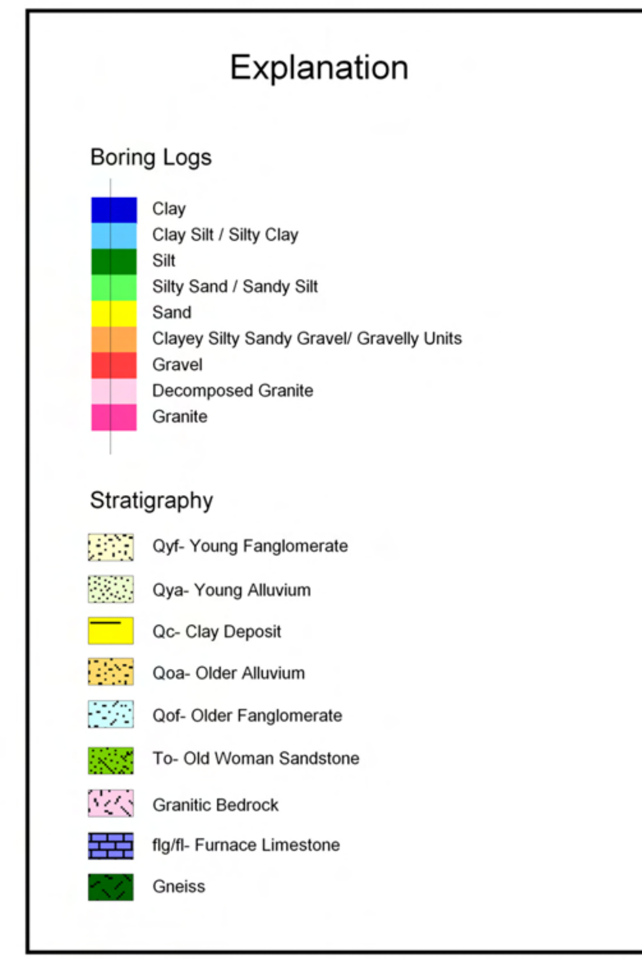
The lithology of the Old Woman Sandstone varies within the Lucerne Valley and Fifteenmile Valley groundwater basins, but generally consists of a succession of interbedded units of arkosic sandstone, conglomerate, limestone, silt and clay, and scattered basalts [Dibblee, 1964a; Shreve, 1968; and Sadler, 1982b]. Conglomerate units are composed of cobbles and pebbles of granitic rocks, quartzite, schist, gneiss, vein quartz, Tertiary andesite and basalt, and rarely Furnace Limestone, in order of decreasing abundances, within a sandy matrix [Dibblee, 1964a and Shreve, 1968]. This rock unit is identified in well logs by driller comments: "cementation" or "black rock." These terms refer to compaction and cementation of material or volcanic rock and cobbles found in the Old Woman Sandstone.

The Old Woman Sandstone is the oldest sedimentary unit in the Este Hydrologic Sub-basin and its age has been estimated by several workers to lie between the late Miocene (10 to 4 Ma) and the Pliocene (3 to 2 Ma). Dibblee [1964a] estimates the age of the Old Woman Sandstone to be late Miocene, based on the unit lying unconformably on pre-Tertiary rocks. May and Repenning [1982] suggest the age of the Old Woman Sandstone to be Pliocene in age, based on the presence of mammalian fossils (rodents and horse teeth) found 8 miles (13 km) southeast of Lucerne Valley in sandy material. Shreve [1968] and Riley [1956] also suggest the unit might be middle to late Pliocene (5 to 2 Ma) in age.

Geologic Cross-Sections







Older Fanglomerate and Alluvium

The older fanglomerate and older alluvium unconformably overlie the Old Woman Sandstone and are exposed along the foot of the San Bernardino Mountains. The older alluvium deposits underlie most of the Este Hydrologic Sub-basin, whereas the older fanglomerate unit pinches out to the north, grading into older and younger alluvium [Dibblee, 1964a]. The older fanglomerate is composed of poorly sorted, sub-rounded fragments of quartzite, granite, and Furnace Limestone approximately 500 feet (152 m) in thickness [Dibblee, 1964a and Goodrich, 1978]. The older alluvium consists of gravels and sand fragments derived from surrounding hills. Dibblee [1964a] estimated the deposits to be Pleistocene (2 to 0.010 Ma) in age and reach thicknesses up to several hundred feet.

Landslide Deposits

In the southeast portion of the study area, the Blackhawk Landslide mapped by Woodford and Harris [1928], is composed entirely of brecciated Furnace Limestone derived from the Paleozoic Furnace Formation on Blackhawk Mountain. It has an approximate thickness of 400 feet (122 m) and overlies older fan deposits [Dibblee, 1964a]. Stout [1975] has dated the slide based on radiocarbon dating of fresh water gastropod and peleypod shells in calcareous mudstone resting directly on the Blackhawk Landslide debris to have a minimum age of 17,400 ± 550 years Before Present (BP).

Surficial Sediments

The unconsolidated surficial sediments consist of younger fanglomerates, younger alluvium, and playa deposits that rest unconformably on older formations. The fanglomerates are exposed along the base of the San Bernardino Mountains and along other mountains as large fragments derived from surrounding hills which grade into younger alluvial deposits. The alluvium is composed of gravels, sand, and clay that are also derived from adjacent hills. Younger surficial deposits range in thickness from a few inches to approximately 100 feet (31 m) [DWR, 1967]. The playa deposits, which are concentrated in the Lucerne (dry) Lake and Rabbit (dry) Lake regions, consist predominantly of fine sands, clays, and silts reaching thicknesses of approximately 100 to 150 feet (31 to 46 m) [Brose, 1987].

Helendale Fault

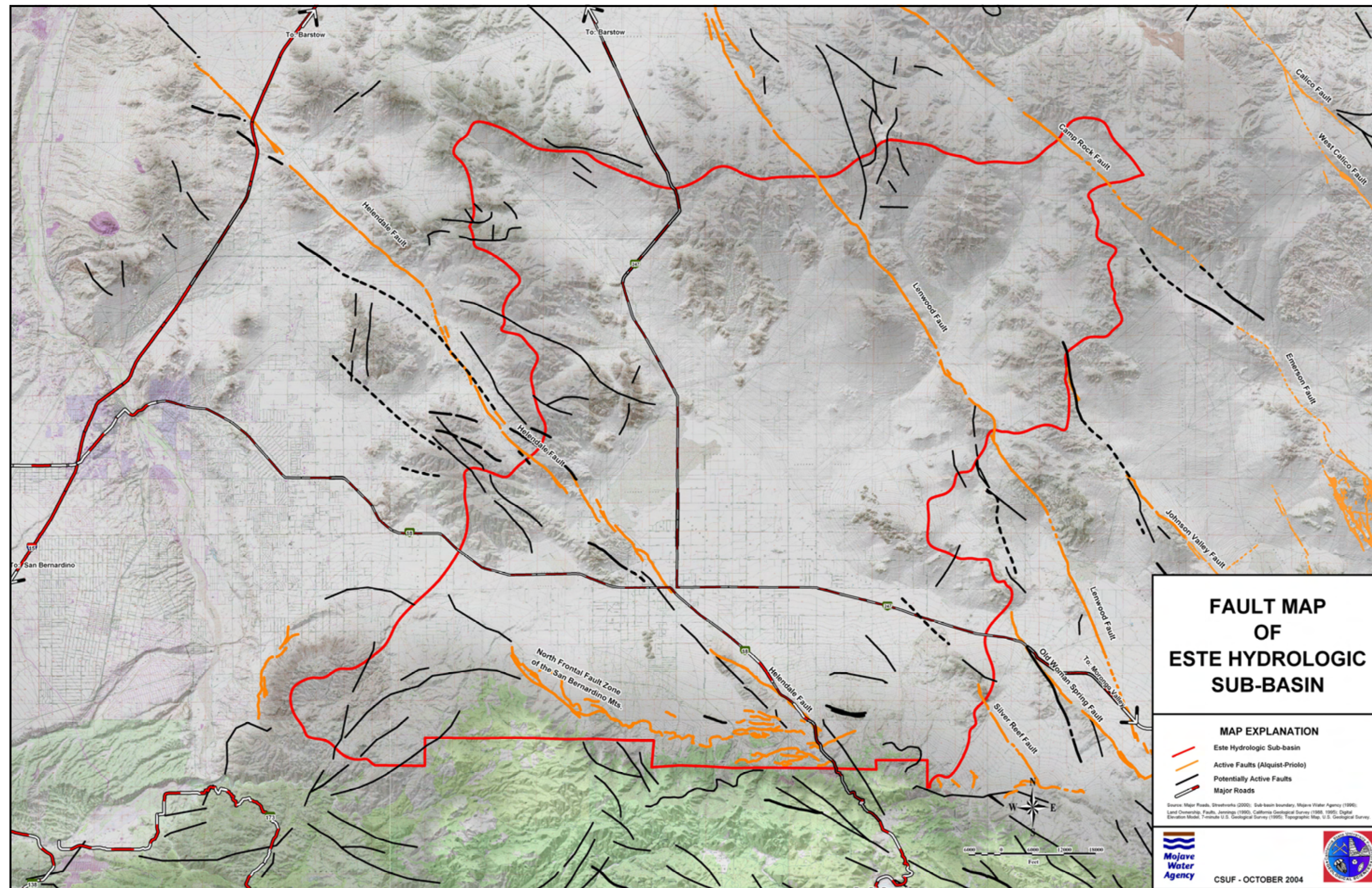
The active Helendale fault zone is a set of en echelon, right-stepping fault strands extending from the vicinity of Cushenbury Canyon in the San Bernardino Mountains northwest towards the southern flank of Kramer Hills [Bowen, 1954; and Morton et al., 1980]. The Helendale fault south of the community of Lucerne Valley is a 31 mile (50 km) zone marked by fault scarps, compressional ridges, and lines of springs [Aksoy, 1986]. Initiation of this fault has been constrained by Dokka and Travis [1990a and 1990b] to lie between ~1.5 to 0.7 Ma. Movement along the Helendale fault is evidenced by 1.2 miles (1.9 km) of displaced Pleistocene (?) aged older alluvial deposits, Mesozoic aged basement rocks, and stream courses since its initiation [Aksoy, 1986]. Additionally, Bouguer gravity field anomaly patterns across the Lucerne Valley groundwater basin correspond to the northwest structural grain of this area. Significant gravity lows along the fault trace suggest a structurally controlled basin filled with sediments, whereas gravity highs in the north and northeast adjacent to the Ord and Fry Mountains indicate a shallow basement covered by alluvial fans [Aksoy, 1986]. The gravity data supports the topographic and geologic data which indicate that there is a separation of groundwater basins between Lucerne Valley and Fifteenmile Valley.

Lenwood Fault & Camp Rock Fault

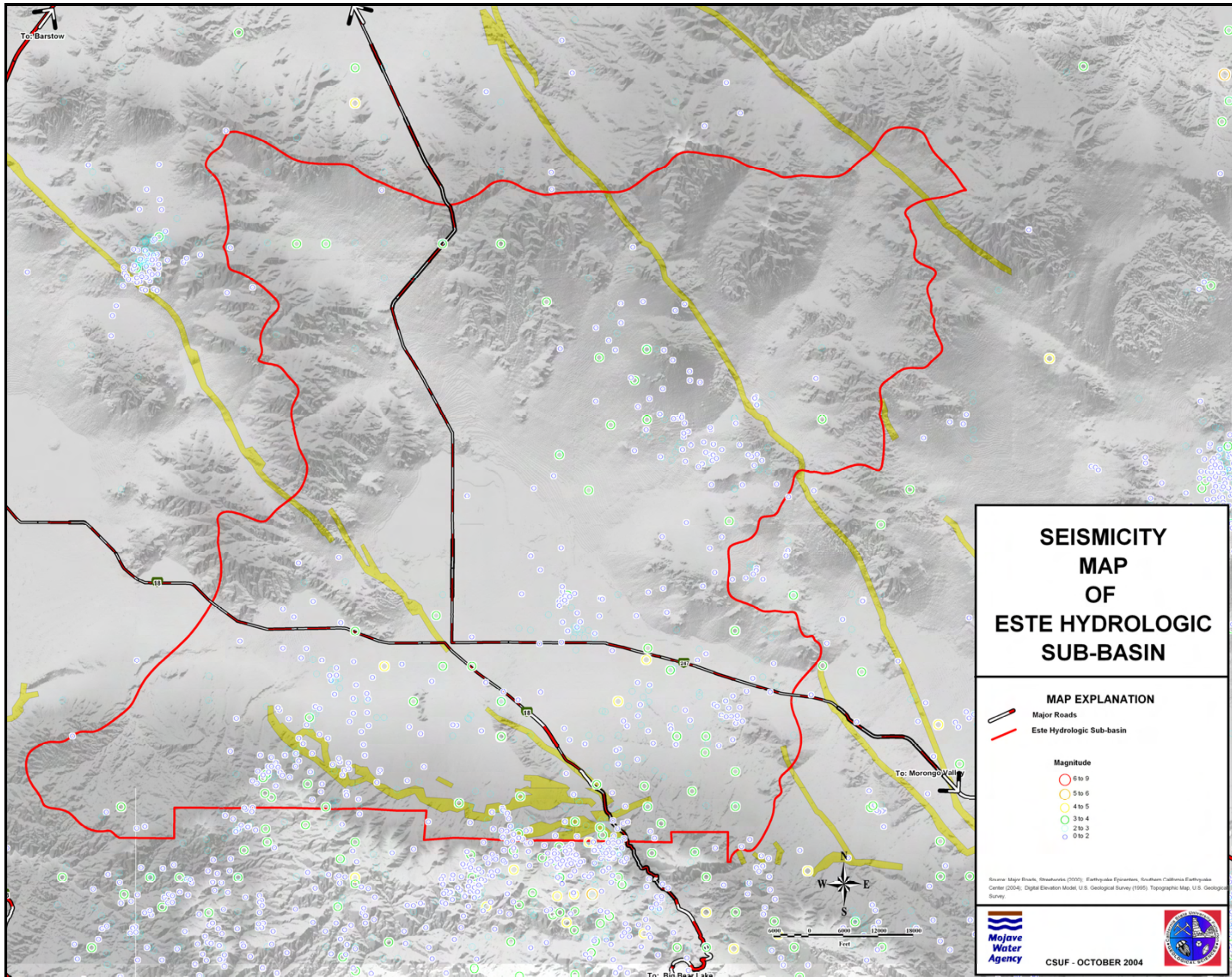
Both the Lenwood and Camp Rock faults transect the northwest portion of the Este Hydrologic Sub-basin. Characteristic of the Mojave Desert Block region and the Eastern California shear zone (ECSZ), both these faults are northwest-trending, right-lateral strike-slip faults that are late Tertiary to early Quaternary in age. The Lenwood fault extends for about 47 miles (75 km) and is part of the larger Lockhart-Lenwood fault system. The Lenwood segment of the fault intersects the eastern segment of the North Frontal thrust system. The Camp Rock fault has a length of approximately 22 miles (35 km) and is part of the Camp-Emerson-Copper Mountain fault system. According to Dokka and Travis [1990a and 1990b], the total amount of displacement along the Lenwood and Camp Rock faults, since their initiation in the late Cenozoic, has been 0.93 miles and 1.86 miles (1.5 km and 3.0 km), respectively.

North Frontal Thrust System of the San Bernardino Mountains

The North Frontal thrust system (NFTS) of the San Bernardino Mountains is a 50 mile-long (80 km) thrust system of discontinuous, overlapping scarps and folds in Pleistocene alluvium and older shear zones in bedrock. It spans a 0.6 mile-wide zone (1 km) adjacent to the northern front of the San Bernardino Mountains transecting both the Lucerne Valley and Fifteenmile Valley groundwater basins [Miller, 1987; Bryant, 1986; and Eppes et al., 2002]. These faults are the result of transpressional, right-lateral, strike-slip movement along the San Andreas fault, and subsequently are responsible for the uplift of the Big Bear plateau. The NFTS has been mapped by Dibblee [1964a] to have displaced the Old Woman Sandstone and older fanglomerates, but not younger surficial sediments. The age of the system has been constrained to the late Pleistocene [Spotila and Sieh, 2000].



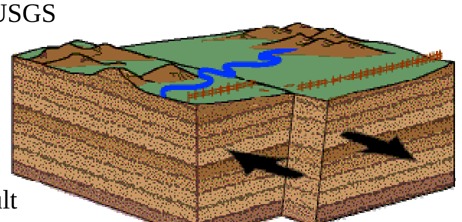
Seismic Activity



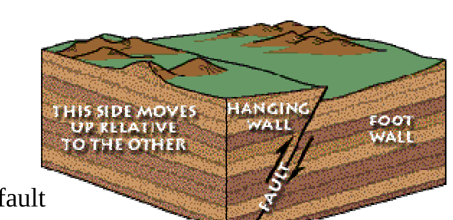
Seismicity

The Este Hydrologic Sub-basin is part of the southern boundary of the Mojave Desert block (MDB) region. Major active faults transecting the region are the Helendale, Lenwood, and Camp Rock faults. Although most of the right shear through the MDB has occurred in the eastern potion of the province, strain measurements, seismicity, and surface faulting indicate that the locus of tectonism shifted westward towards the Este Hydrologic Sub-basin between 1.5 to 0.7 Ma [Dokka and Travis, 1990a, 1990b]. These active Quaternary faults are concentrated in the southern portion of the MDB and parts of the Este Hydrologic Sub-basin. This pattern is reflected by the seismicity in the area. Historically, seismicity in the Este Hydrologic Sub-basin has been characterized by small to moderate size earthquakes (M = 3 and M = 5). A majority of these earthquakes occur either near the southern edge of the basin, along the San Bernardino Mountains, or in less active zones located in the center of the basin. Recent and fairly large earthquakes, such as the Landers (M_w = 7.3) earthquake, have occurred just north-northeast of the Este Hydrologic Sub-basin. The Landers earthquake ruptured across five separate faults: Johnson Valley, Landers, Homestead Valley, Emerson, and Camp Rock faults, causing significant damage and numerous casualties, but in a general sense it caused relatively little damage with respect to its magnitude [SCEC, 2004]. In general, the risk of casualties along faults within the Este Hydrologic Sub-basin are minimal due to the fact these faults transect areas of fairly sparse population.

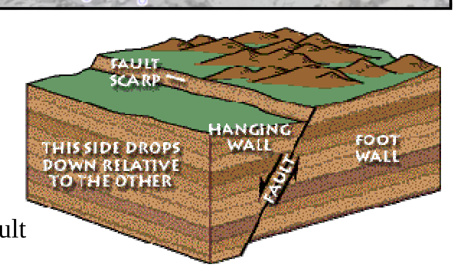
Illistrations by USGS



Strike-slip fault

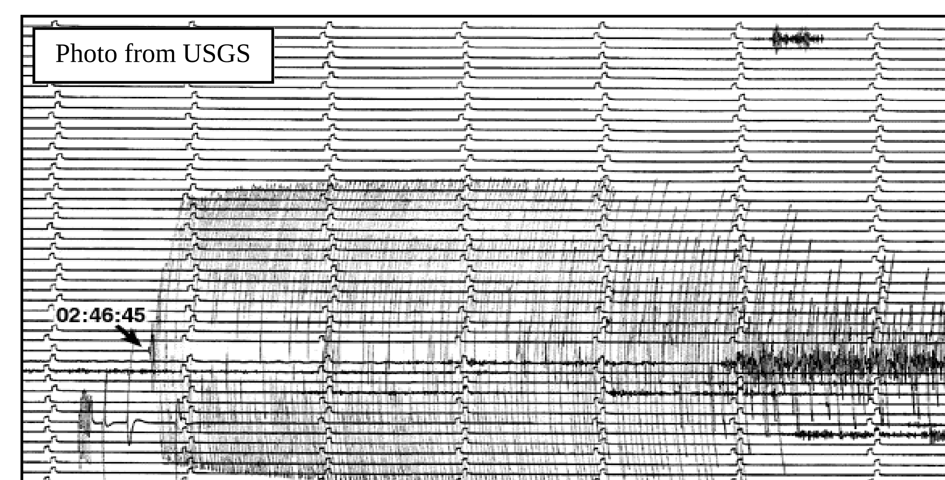


Reverse fault



Normal fault

Photo from USGS



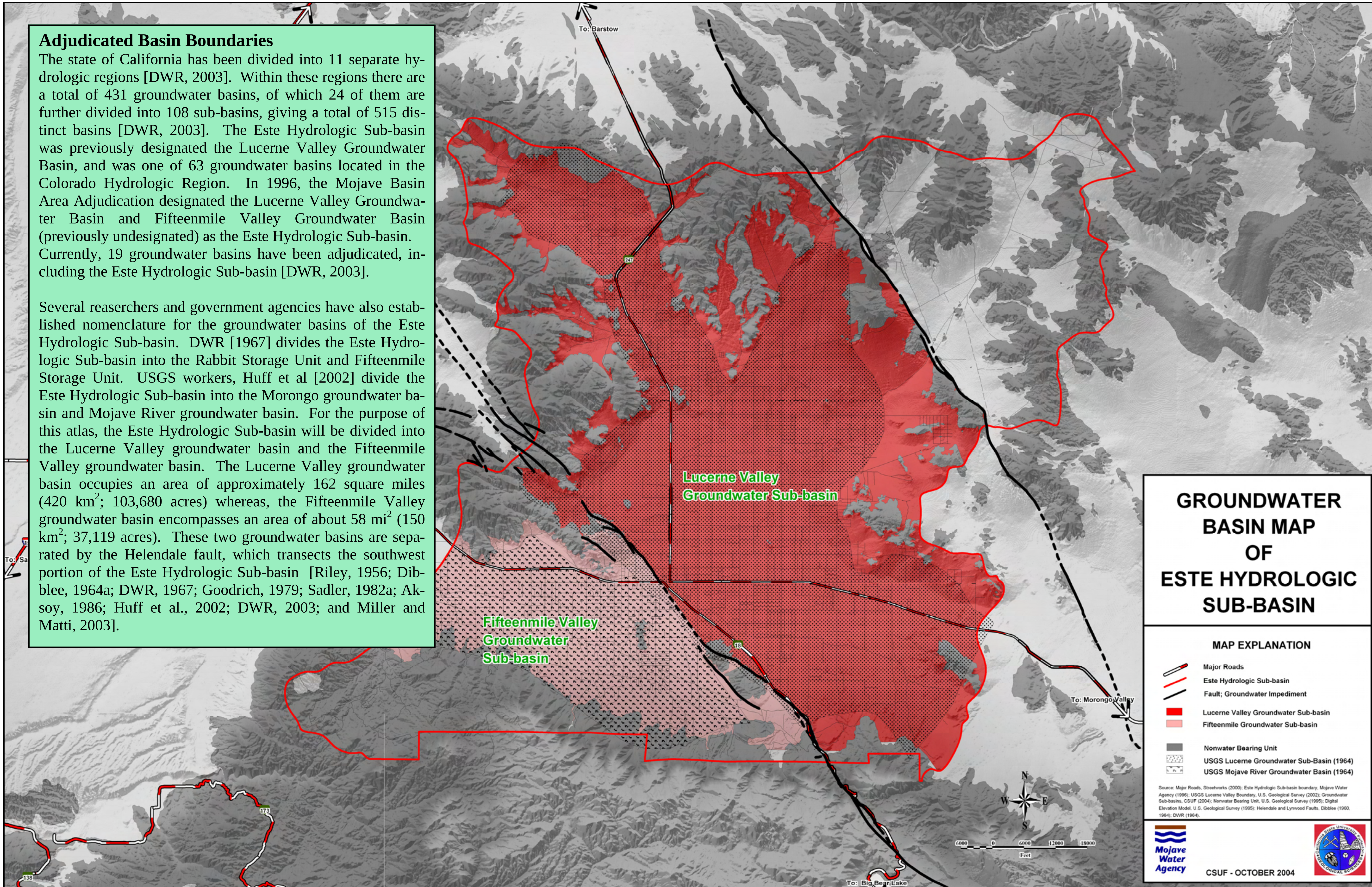
Hector Mine earthquake, Oct 16 1999, 02:46:45 PDT
Part of seismogram recorded near Palmdale, CA.

Groundwater Basins Map

Adjudicated Basin Boundaries

The state of California has been divided into 11 separate hydrologic regions [DWR, 2003]. Within these regions there are a total of 431 groundwater basins, of which 24 of them are further divided into 108 sub-basins, giving a total of 515 distinct basins [DWR, 2003]. The Este Hydrologic Sub-basin was previously designated the Lucerne Valley Groundwater Basin, and was one of 63 groundwater basins located in the Colorado Hydrologic Region. In 1996, the Mojave Basin Area Adjudication designated the Lucerne Valley Groundwater Basin and Fifteenmile Valley Groundwater Basin (previously undesignated) as the Este Hydrologic Sub-basin. Currently, 19 groundwater basins have been adjudicated, including the Este Hydrologic Sub-basin [DWR, 2003].

Several reaserchers and government agencies have also established nomenclature for the groundwater basins of the Este Hydrologic Sub-basin. DWR [1967] divides the Este Hydrologic Sub-basin into the Rabbit Storage Unit and Fifteenmile Storage Unit. USGS workers, Huff et al [2002] divide the Este Hydrologic Sub-basin into the Morongo groundwater basin and Mojave River groundwater basin. For the purpose of this atlas, the Este Hydrologic Sub-basin will be divided into the Lucerne Valley groundwater basin and the Fifteenmile Valley groundwater basin. The Lucerne Valley groundwater basin occupies an area of approximately 162 square miles (420 km^2; 103,680 acres) whereas, the Fifteenmile Valley groundwater basin encompasses an area of about 58 mi^2 (150 km^2; 37,119 acres). These two groundwater basins are separated by the Helendale fault, which transects the southwest portion of the Este Hydrologic Sub-basin [Riley, 1956; Dibblee, 1964a; DWR, 1967; Goodrich, 1979; Sadler, 1982a; Aksoy, 1986; Huff et al., 2002; DWR, 2003; and Miller and Matti, 2003].



Groundwater Basins

The Este Hydrologic Sub-basin is part of the Colorado Desert Hydrologic study area [DWR, 1967] and is herein further divided into the Lucerne Valley and Fifteenmile Valley groundwater basins. The Lucerne Valley groundwater basin is bordered to the north, northwest, east by the Ord, Granite, and Fry Mountains, respectively. The Helendale fault forms the southwestern boundary of the Lucerne Valley groundwater basin and the northeastern boundary of the Fiftennmile Valley groundwater basin. The Fifteenmile Valley groundwater basin is bordered to the north by the Granite Mountains and is open to the west.

Basin Descriptions

The materials that comprise the Este Hydrologic Sub-basin aquifers are derived from weathering and erosion of the surrounding mountains and consist of Tertiary materials, Quaternary stream alluvium, playa deposits, landslide deposits, and dune sand [Gardner, 1941; Hewett, 1954; Dibblee, 1964a and 1964b; DWR, 1967; Goodrich, 1978; Sadler, 1982a; and DWR, 2003].

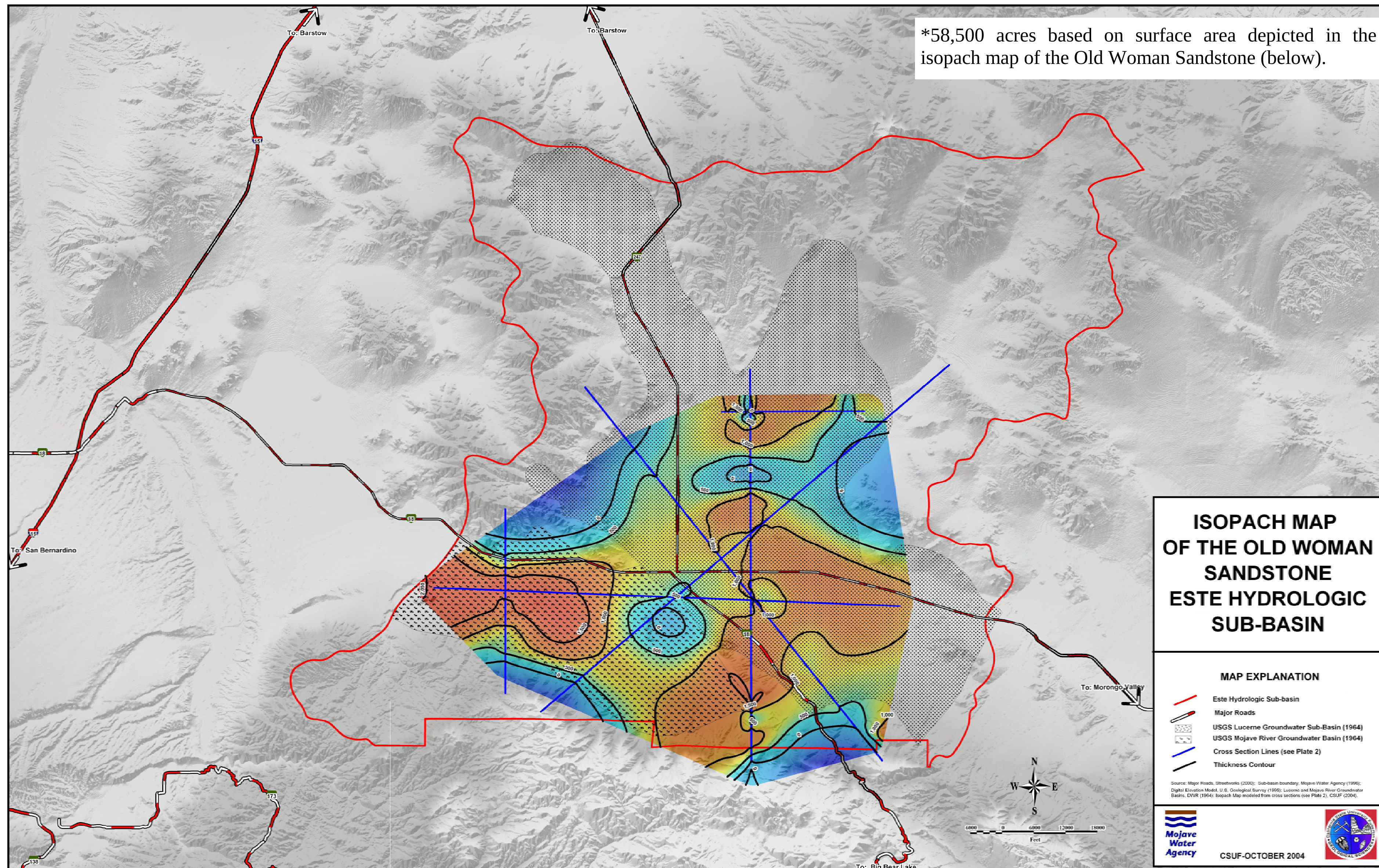
Individual beds within the alluvial and aquifer section of the constructed cross-sections are difficult to correlate. The alluvial and aquifer materials are extremely heterogeneous with interfingering and discontinuous gravels, sands, and silts across portions of the basin [Goodrich, 1978]. Current groundwater data, subsurface geology, and well log stratigraphy indicate the Old Woman Sandstone is the primary producing aquifer in both groundwater basins. The Old Woman Sandstone is distinguished in well logs by the appearance of a cemented layer approximately 150 to 300 feet (46 to 91 m) below ground surface.

The Old Woman Sandstone within the Lucerne Valley and Fifteenmile Valley groundwater basins is unconformable on plutonic pre-Tertiary rocks and varies slightly in thickness throughout both groundwater basins. This unit is estimated to maintain a thickness of 600 to 1,400 feet (183 to 427 m), where the deepest portion of the basin is through the center of Lucerne Valley. Furthermore, the estimated volume of the Old Woman Sandstone within the Este Hydrologic Sub-basin is 3.18 x 10^{12} ft^3 (7.30 x 10^7 acre-feet). This is based on an assumed groundwater basin size of 91.0 mi^2 (58,500* acres) for Lucerne Valley and 47.9 mi^2 (30,000 acres) for Fifteenmile Valley.

The total volume of the water-bearing material was determined by creating an isopach map based on the thickness of the Old Woman Sandstone as depicted in the cross-sections. Surface area for both groundwater basins was measured using the surrounding areas in which the cross-section lines transect. The variation in the average aquifer thickness is strongly based on interpretations of driller's well logs. The estimated thickness of the Old Woman Sandstone is based on water-well logs as well as geologic surface maps and cross-sections [Dibblee, 1964; Sadler, 1982a; and Miller and Matti, 2003]. This unit also contains volcanics and conglomerates which contain granitic clasts that can lead to a misinterpretation of depth to bedrock.

Both the Lucerne Valley and Fifteenmile Valley groundwater basins are dominated by a single aquifer system, but display both unconfined and confined conditions. Towards the north and south edges of the Lucerne Valley basin the aquifer displays unconfined conditions with gravels and gravelly sand deposits. Towards Lucerne (dry) Lake, silty clay deposits incised by stream gravels and sands overlie the Old Woman Sandstone and act as a confining layer, resulting in semi-confined aquifer conditions.

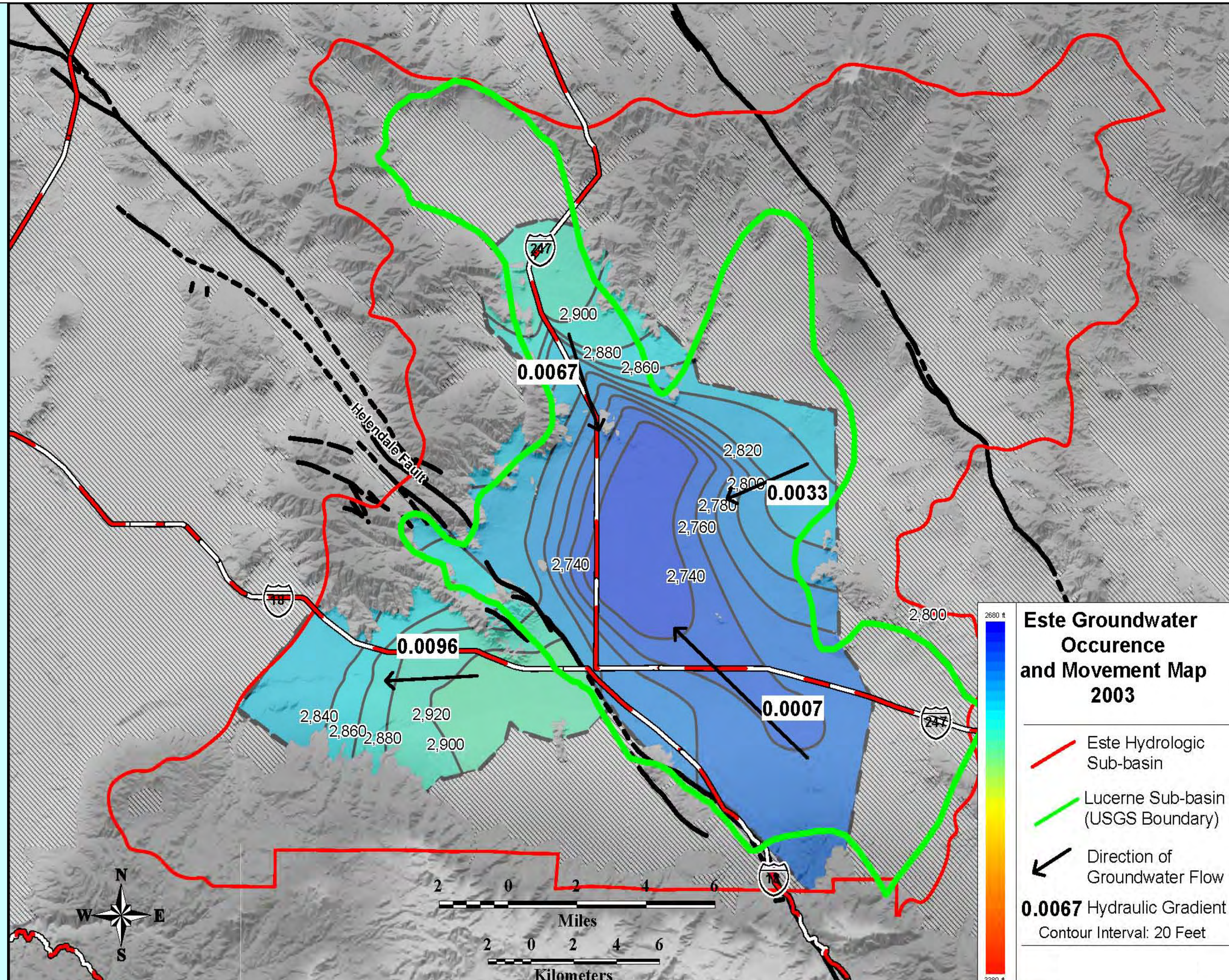
The aquifer characteristics within the Este Hydrologic Sub-basin are varied depending on the thickness and position of the water-bearing material. Varying proposed thicknesses determined by different studies, reveal that water-bearing materials range from 200 to 1,500 feet (61 to 457 m). Based on a generalized hydraulic conductivity value of 46.9 ft/day [GeoScience Support Service Inc., 1992] and the range of water-bearing material thickness of 200 to 1,500 feet (61 to 457 m), transmissivity values could vary. This is based on fine grained silts, sands, gravels, and sandstone material. This value is not unrealistic, since the basin is comprised of a variety of materials, and falls within published values for these kinds of aquifer materials [Fetter, 2001]. Future studies will help quantify both hydraulic conductivity and transmissivity values throughout the basin.



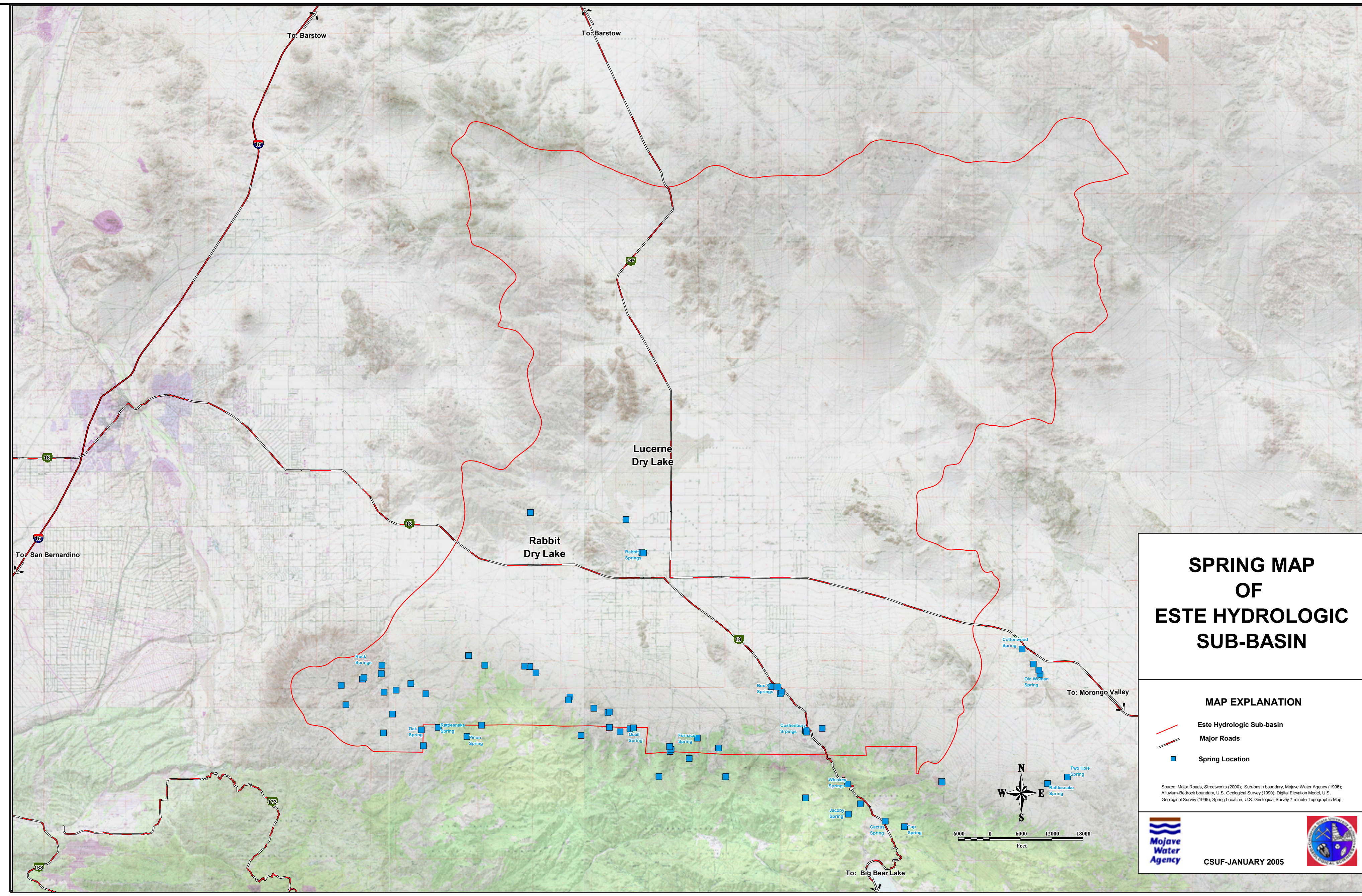
Current Groundwater Occurrence and Movement

The direction of groundwater movement within the Lucerne Valley groundwater basin has historically been from the outer perimeter towards the center of the valley [Goodrich, 1978, Schaefer, 1979; Brose, 1987]. Current groundwater levels (measurements by MWA in November, 2003) in the Lucerne Valley groundwater basin confirm the direction of groundwater flow is radially from the outer perimeter of the basin towards Lucerne (dry) Lake. The groundwater gradient from the northern portion of the basin to the south is 0.0067 ft/ft; from the eastern portion of the basin westward towards the center of basin is 0.0033 ft/ft; and from the southeastern portion of Lucerne Valley groundwater basin to the dry lake area the gradient is 0.0007 ft/ft. Within the Fifteenmile Valley groundwater basin, groundwater flow is towards the Mojave River. The groundwater gradient westward from the Helendale fault is 0.0096 ft/ft.

Groundwater flow patterns have changed little since the first available data in 1916-1917 and are probably similar to those prior to man's influence [Schaefer, 1979]. A review of contour maps for the Este Hydrologic Sub-basin area [DWR, 1967; Brose, 1987; Pirnie, 1990; USGS, 1994, 1996, 1998, 2000, and 2002] confirms this assessment. Within both basins, groundwater occurs primarily within the older alluvial deposits and the Old Woman Sandstone deposits at variable depths and to a limited extent within bedrock fractures. Groundwater elevations range from 2,900 to 2,740 feet (884 to 835 m) (amsl) in the Lucerne Valley groundwater basin and 2,920 to 2,840 feet (890 to 866 m) (amsl) in the Fifteenmile Valley groundwater basin. Depth to groundwater ranges from 100 to 250 feet (30 to 76 m) below ground surface in the central portion of the Lucerne Valley groundwater basin, 20 to 250 feet (6 to 76 m) below ground surface in the Fifteenmile Valley groundwater basin, and approximately 20 feet (6 m) below ground surface near the western side of the Helendale fault.



Groundwater & Fault Interaction



Structural Groundwater Barriers

Groundwater movement across a fault may be impeded because of one or more of the following conditions:

1. Permeable beds set against impermeable beds;
2. The zone consists of gouge (ground rock and clay) which has a very low hydraulic conductivity; and
3. Deformation of adjacent beds

Helendale Fault

The Helendale fault, which divides the Lucerne Valley and Fifteenmile Valley groundwater basins impedes groundwater flow [Goodrich, 1978; Schaefer, 1979; Brose, 1987; Stamos et al., 2001, and current data from MWA]. The figure on the previous page clearly shows the Helendale fault acting as a hydrologic barrier to groundwater flow. Water level differences across the Helendale fault range from 20 to 250 feet below ground surface (6 to 76 m) [DWR, 1967; Goodrich, 1978; Schaefer, 1979; Brose 1987; USGS, 1994, 1996, 1998, 2000, and 2002; and current data from MWA]. Because of the boundary nature of the Helendale fault, and the direction of groundwater movement in both basins, as well as the impact of well production, groundwater levels are typically higher in the Fifteenmile Valley groundwater basin. The question of whether or not groundwater is leaking across the Helendale fault from the Fifteenmile Valley groundwater basin into the Lucerne Valley groundwater basin is still under investigation.

Lenwood & Camp Rock Fault

Just north of the study area, the Lockhart-Lenwood fault system impedes groundwater flow in older alluvium and the Camp Rock-Emerson-Copper Mountain segment affects the subsurface flow within the Middle Mojave River Basin [Brose, 1987; and Stamos et al., 2001]. Both these faults have been reported by [Brose, 1987; and Stamos et al., 2001] to impede groundwater flow outside of the Lucerne Valley groundwater basin, thus separating the Este Hydrologic Sub-basin from Morongo Hydrologic Sub-basin (Johnson Valley) to the northeast.

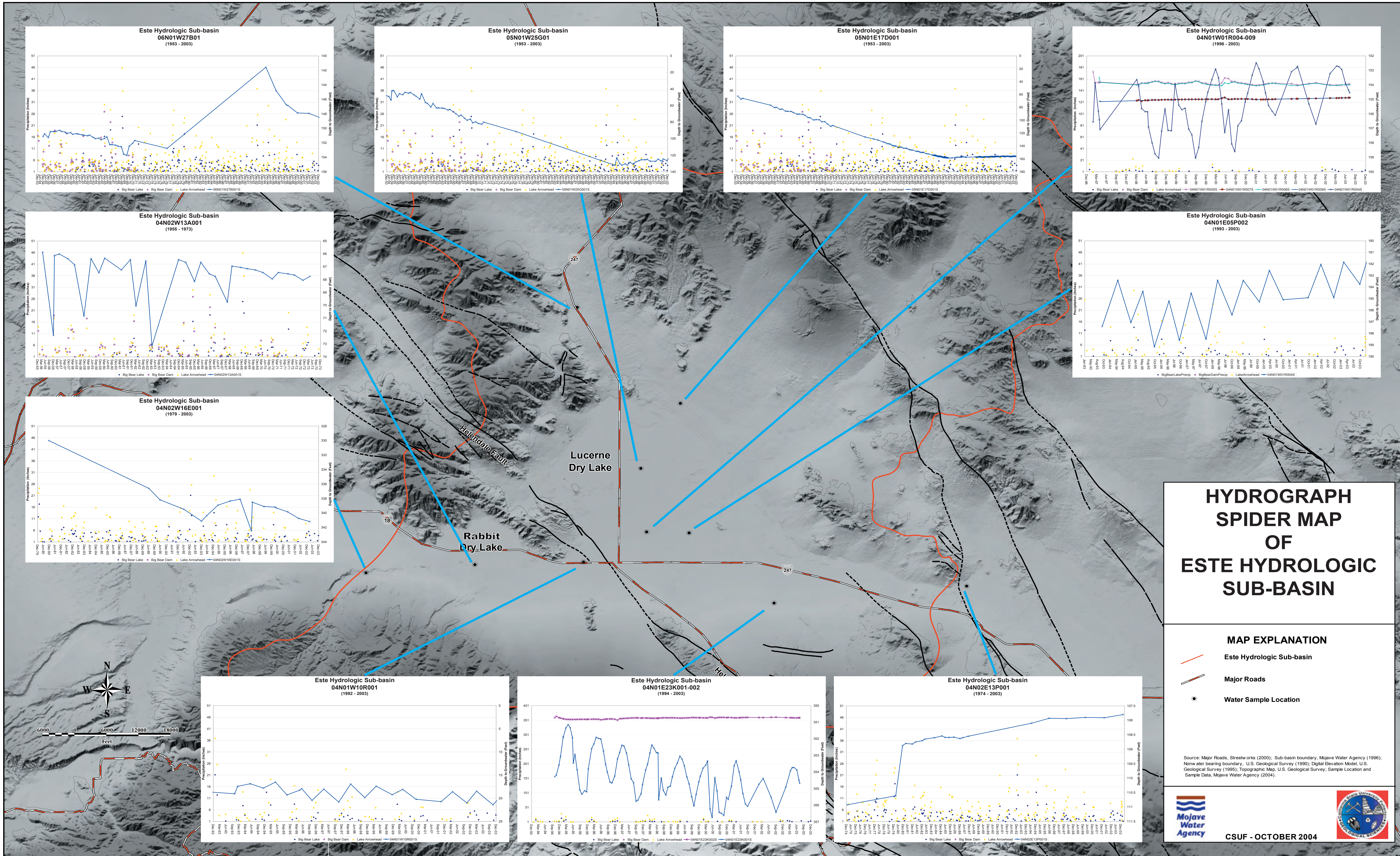
Old Woman Springs Fault

Just east of the Este Hydrologic Sub-basin, the Old Woman Springs fault zone has disrupted the basins, developing gouge zones in the alluvium and older rock, which act as impediments to groundwater flow [Bechtel Corporation, 1992]. Between the north and south branch of the Old Woman Springs fault the direction of groundwater is generally to the northwest Once it passes the north branch of the fault, groundwater movement shifts to the northeast where it flows towards the Morongo Hydrologic Sub-basin (Johnson Valley) and not the Este Hydrologic Sub-basin [Geoscience Support Service Inc., 1992].

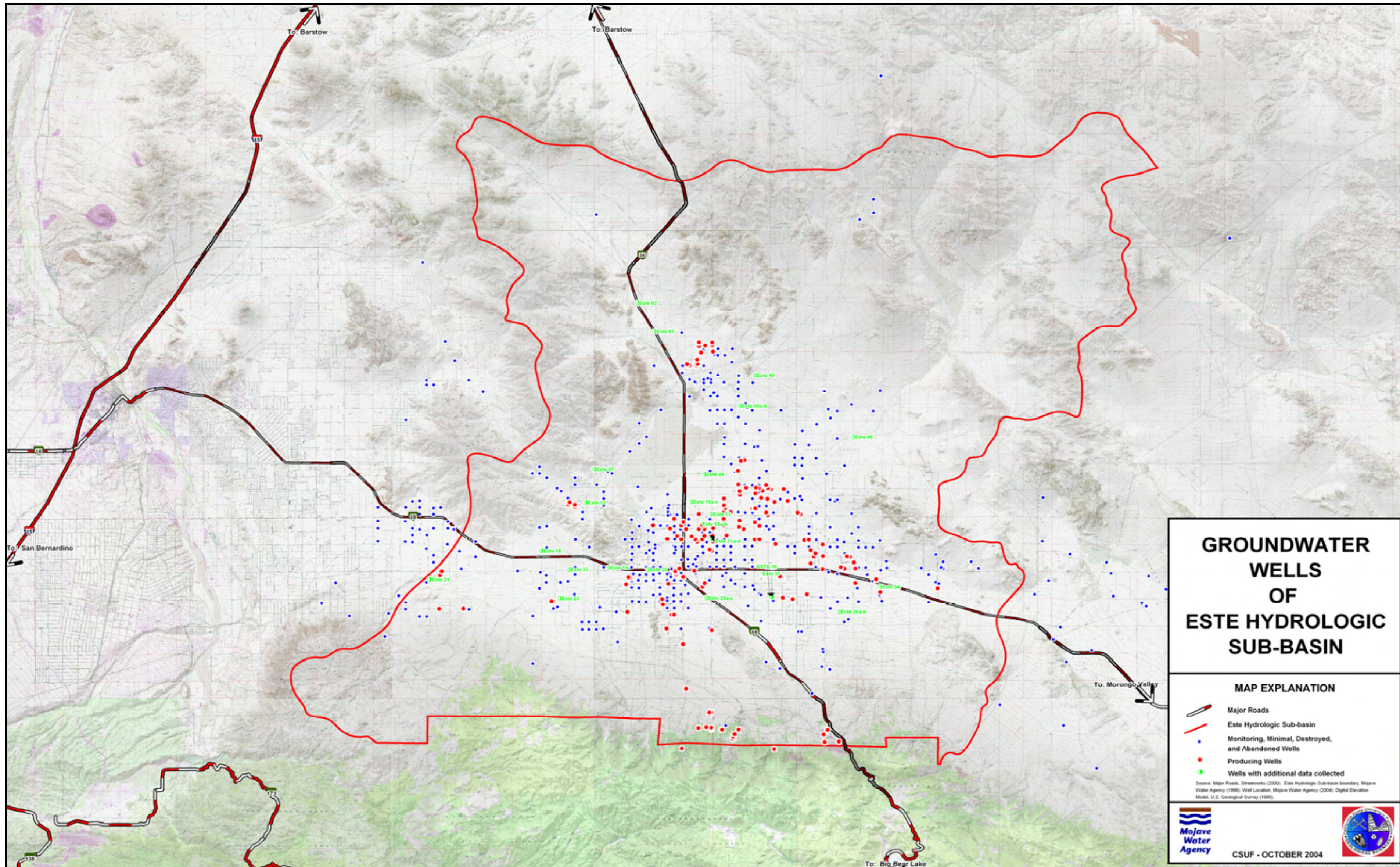
North Frontal Thrust System Faults

Recharge entering both Lucerne Valley and Fifteenmile Valley groundwater basins as subsurface flow is primarily derived from the San Bernardino Mountains. Along the San Bernardino Mountains, the NFTS is marked by a series of springs where natural barriers such as faults and jointed bedrock force groundwater to the surface at a weak point. These are evident on the map above.

Historical Groundwater Elevation



Groundwater Production



Water Production for Este Hydrologic Sub-basin

Production	DWR [1967]		Brose [1987]		Stamos [2001][1]	
Annual Production (acre-feet)	4,640	Years (1936-1961)	7,725	Years (1958-1981)	513	Years (1931-1990)
Total Production through given period (acre-feet)	116,000		177,700		30,267	

[1] Data for only the Fifteenmile Valley groundwater basin.

Last 3-Year Groundwater Production for Este Hydrologic Sub-basin

Water year (2000-2001) (acre-feet)	Water year (2001-2002) (acre-feet)	Water year (2002-2003) (acre-feet)
6,560	6,723	5,854

Source: MWA, 2004.
Note: Large producer's only (> 10 acre-ft/yr).

Groundwater Production

Water production continues to this day throughout the Este Hydrologic Sub-basin. The majority of groundwater production is occurring in the central portion of Lucerne Valley and along the base of the San Bernardino Mountains where mining is prominent. DWR [1967] determined the 25 years average (1936-1961) groundwater production was approximately 4,640 acre-ft/yr for the region. Based on this 25 year average, DWR [1967] calculated the net loss of storage in the Lucerne Valley and Fifteenmile Valley groundwater basins at 80,000 acre-feet.

Water production in the Este Hydrologic Sub-basin is listed with an average of 6,183 acre-ft/yr for the years of 1936 to 1981. In the 2002-2003 water year, production for the basin is reported as 5,854 acre-feet [MWA, 2004]. This reduction in groundwater production appears to be the result of fewer agricultural activities within the basin.

Additional reports analyzing groundwater production throughout the groundwater basins include: Brose [1987]; Pirnie [1990]; USGS [1994, 1996, 1998, 2000, and 2002].

Water Budget

Analysis of general water budgets can yield insight to the hydrologic system at work within a specific area. Water budgets take into consideration various parameters, some known and some not. These parameters include soil characteristics, weather (precipitation, temperature, and evapotranspiration), surface waters, groundwater flow, infiltration, and groundwater production. To calculate a budget for the Este Hydrologic Sub-basin, it was necessary to combine past region-wide water budgets with known site-specific parameters. This is based on highly variable assumptions averaged over several decades. Future water budget analysis will be supported be a comprehensive monitoring network (MWA Key Well Program).

The average rainfall in Este Hydrologic Sub-basin as reported at the Lucerne Valley Cemetery (controlled by the San Bernardino Flood District) is 6 inches (15.24 cm) per year. The range of precipitation is from a low of 4 inches (10.16 cm) to a high of 42.6 inches (108.2 cm) near Lake Arrowhead. Evapotranspiration ranges from a low of 58.6 inches (148.9 cm) near Lake Arrowhead to a high of 66.19 inches (168.1 cm) in Victorville. This is approximately 155 to 1,100 percent of the total precipitation. Of the remaining precipitation in excess of 8 inches (20.32 cm), only 8 to 10 percent infiltrates into the ground and provides recharge to the groundwater system [Hevesi and Flint, 2002]. The following tables break down the various components of the water budget for the Este Hydrologic Sub-basin. The data was compiled from DWR [1967], Goodrich [1978], and Brose [1987].

The annual average water budget for the Este Hydrologic Sub-basin as calculated by DWR [1967], Goodrich [1978], and Brose [1987] is net loss of 6,155 acre-ft/yr. This net loss is made up in the overall loss of storage throughout the basin. The reason for the negative value is water consumption was greater than recharge.

Water Budget Equations

Inflow = Outflow ± Changes in Storage

Inflow: *Interflow, precipitation, return flow and overland inflow*

Outflow: *Throughflow, evaporation, transpiration, surface runoff, infiltration, overland outflow and pumping*

Este Hydrologic Sub-basin Groundwater Inputs

Annual Average (acre-feet)	DWR [1967]	Goodrich [1978][2]	Brose [1987]
Surface Inflow	1,050[1]	1,050[1]	1,050[1]
Subsurface Inflow	-	-	-
Precipitation	694	-	700
Imported Water	-	-	-
Total	**1,744**	**1,050**	**1,750**

[1] Surface water runoff contributing to groundwater recharge. [2] Estimate only for the Lucerne Valley groundwater basin.

Este Hydrologic Sub-basin Groundwater Outputs

Annual Average (acre-feet)	DWR [1967]	Goodrich [1978][1]	Brose [1987]	Stamos and Predmore [1995]
Surface Outflow	-	-	-	
Subsurface Outflow	100	100	500	300 - 600
Consumptive Use	4,540	10,045	7,725	
Total	**4,640**	**10,145**	**8,225**	

[1] Estimate only for the Lucerne Valley groundwater basin.

Este Hydrologic Sub-basin Groundwater Budget Calculations

Annual Average (acre-feet)	DWR [1967]	Goodrich [1978][1]	Brose [1987]
Total Input	1,744	1,050	1,750
Total Output	4,640	10,145	7,725
Total Water Budget	**-2,896**	**-9,095**	**-6,475**

Note: Negative sign means loss of water. [1] Estimate only for the Lucerne Valley groundwater basin.

Aquifer Water Quality

General Chemistry

Groundwater is just one part of the water cycle. However, in areas such as the Este Hydrologic Sub-basin where surface waters are limited, groundwater becomes the primary source of water. Groundwater is utilized for drinking, irrigation, mining operations and many other uses. Natural waters such as groundwater acquire their chemical compositions from a variety of sources. Primarily, they accumulate dissolved and suspended constituents through contact with the gases, liquids, and solids they encounter during their passage through the hydrologic cycle.

As these waters move along hydrologic flow paths that bring them into contact with a variety of geologic materials and biological systems, the composition of surface and groundwater continuously evolves and changes on time scales of minutes to years. Rain and snow supply most terrestrial surface water and groundwater systems, as is the case in the Este Hydrologic Sub-basin. Precipitation is not pure water, but contains dissolved substances that vary in amount and composition according to location and season. Under natural conditions, rain is usually acidic because of reactions with atmospheric carbon dioxide (CO_2) and naturally occurring gaseous sulfur and nitrogen compounds. Naturally occurring organic acids may also contribute to the acidity of rain. Anthropogenic emissions (air pollution) to the atmosphere significantly increase rain acidity, creating "acid rain."

Two physical factors: the residence time and the pathways or routes along which water moves through the hydrologic system are particularly important to the relative chemical composition of the water.

1. The longer the residence time in a particular environment, the more opportunity there is for reactions between water and the materials with which it is in contact. Groundwater is particularly impacted by residence time. One positive outcome of this situation is that subsurface sediments can filter out many impurities.
2. Water pathways determine which materials water contacts during its passage through the hydrologic system. In general, waters that follow shallow pathways contact more weathered and consequently less reactive materials than waters that move along deeper pathways.

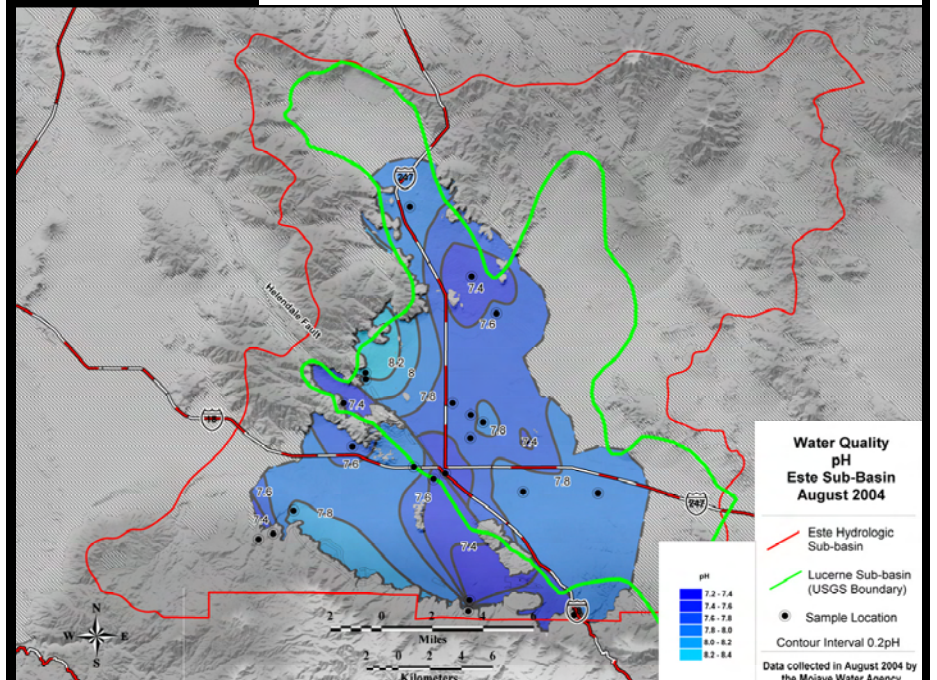
Therefore, the physical mechanisms that determine the travel time of water, and the pathways along which the water moves can strongly affect the chemical composition of water!

Este Hydrologic Sub-basin Water Chemistry

Constituent	Minimum Reading (mg/L)	Maximum Reading (mg/L)	Maximum Contaminant Level (MCL) (mg/L)	Lucerne Valley Groundwater Basin Objectives (mg/L) (RWQCB, 05/2002)
Magnesium (Mg)	3.7	96	Not Regulated	
Sodium (Na)	11	610	Not Regulated	
Calcium (Ca)	20	270	Not Regulated	
Chloride (CL)	5.1	1,200	250[2]	
Sulfate (SO_4)	20	630	250[2]	
Nitrate (NO_3)	ND	72	10[1]	10
Arsenic (As)	ND	0.004	0.05[3]	0.05
Chromium (total) (Cr)	ND	0.017	0.05	
Hardness (as $CaCO_3$)	66	1.1	Not Regulated	
Total Dissolved Solids (TDS)	260	3,400	500[2]	
pH	7.29	8.34	6.5 – 8.5[2]	6.0 – 9.0

EPA, 2004. [1] Primary MCL, [2] Secondary MCL, [3] 0.010 mg/L as of 01/23/06 ND = non-detectable

pH



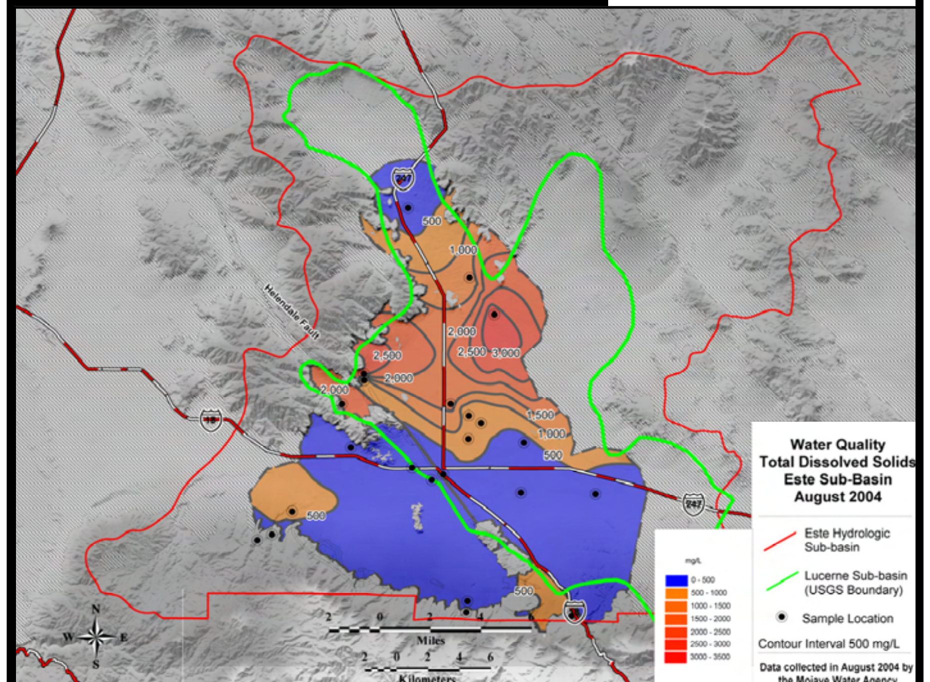
Secondary MCL	Noticeable Effects Above Secondary MCL range
6.5 – 8.5	low pH: bitter metallic taste; corrosion high pH: slippery feel; soda taste; deposits

[EPA, 2004]

pH is regulated as a secondary contaminant. The secondary maximum contaminant range for pH is 6.5 to 8.5. A low pH value results in bitter, metallic tasting water that may corrode pipes and faucets. Water with a high pH value has a slippery feel with a soda taste and may produce deposits on pipes and faucets.

The average pH reading for the study area is 7.74. Well Este 28 (pH = 7.29) had the lowest reading in the basin and well Este 07 (pH = 8.34) had the highest. Well Este 07 is located northwest of Lucerne (dry) Lake.

Total Dissolved Solids (TDS)



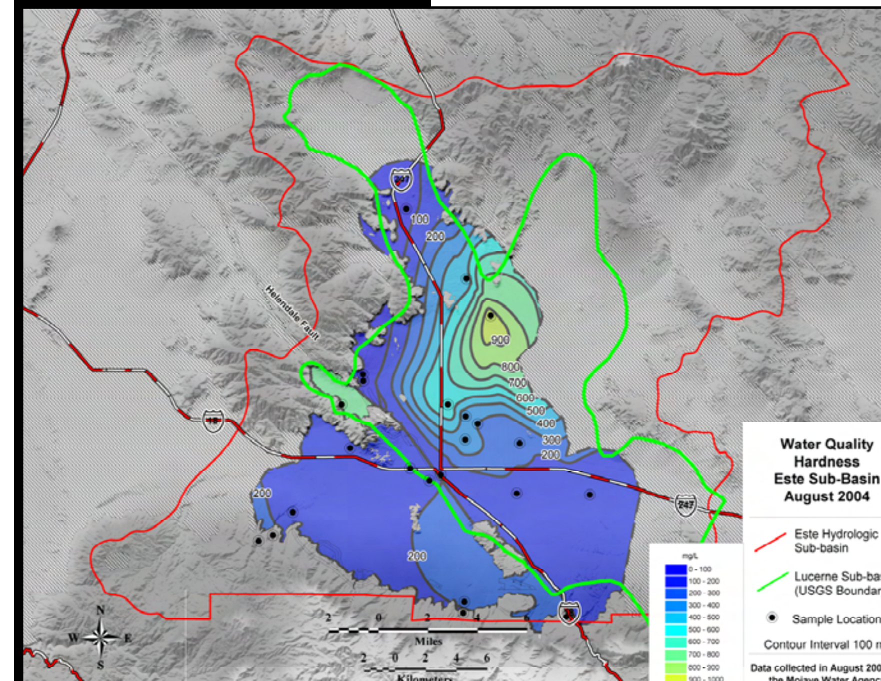
Secondary MCL (mg/L)	Noticeable Effects Above the Secondary MCL
500	hardness; deposits; colored water; staining; salty taste

[EPA, 2004]

Total Dissolved Solids (TDS) is regulated as a secondary contaminant. The secondary maximum contaminant level for TDS is 500 mg/L. A high TDS value results in hard, salty, colored water that stains and produces deposits on pipes and faucets.

The average TDS reading for the study area is 1,017 mg/L. Well Este 20 (TDS = 260 mg/L) had the lowest reading in the basin and well Este 05 (TDS = 3,400 mg/L) had the highest. Well Este 05 is located northwest of Lucerne (dry) Lake. Twelve of the 23 wells sampled throughout the study area yielded TDS values above the secondary standard of 500 mg/L. Almost half of the Este Hydrologic Sub-basin is above the secondary standard with only the Fifteenmile Valley groundwater basin and the southern portions of the Lucerne Valley groundwater basin having water below the 500 mg/L level.

Hardness ($CaCO_3$)



	Soft	Moderately Soft	Slightly Hard	Moderately Hard	Hard	Very Hard
mineral grains/gallon	>1.0	-	1.0-3.5	3.5-7.5	7.5-10.5	<10.5
$CaCO_3$	50	51-100	101-150	151-250	251-350	>350

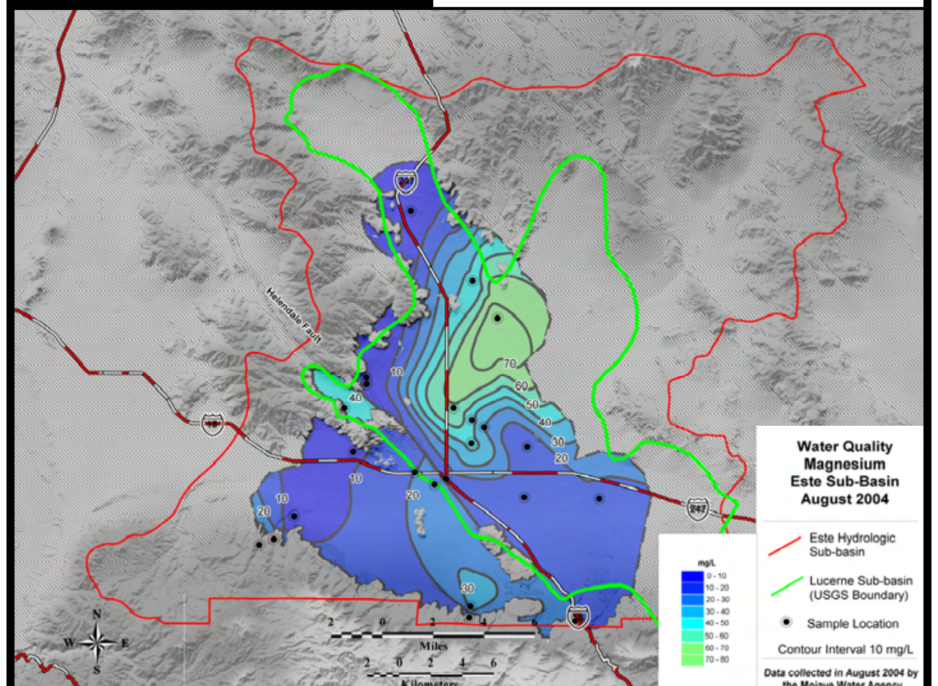
[EPA, 2004]

Hardness is not regulated and is caused when calcium, magnesium, and a variety of metals dissolve in water.

The average hardness reading for the study area is 333 mg/L. Well Este 07 (TDS = 66 mg/L) had the lowest reading in the basin and well Este 05 (TDS = 1,100 mg/L) had the highest. Well Este 05 is located northwest of Lucerne (dry) Lake.

Major Cation Distribution

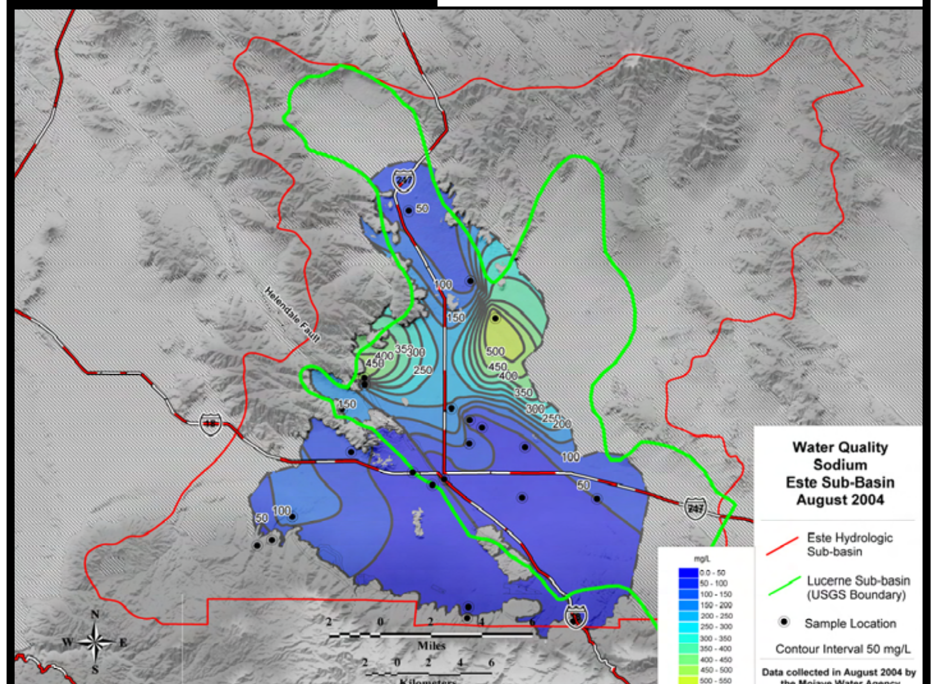
Magnesium (Mg^{2+})



Magnesium is not a regulated constituent by either the Environmental Protection Agency (EPA) or State of California for drinking water. In spite of the higher solubility of most of its compounds, the magnesium content in fresh water is generally below that of calcium, because of its lower geochemical abundance.

The average magnesium concentration for the study area is 31.2 mg/L. Well Este 07 (Mg^{2+} = 3.7 mg/L) had the lowest reading in the basin, while well Este 05 and well Este 10 (Mg^{2+} = 96.0 mg/L) had the highest. Magnesium is lowest in the Fifteenmile Valley groundwater basin and in the southern portion of the Lucerne Valley groundwater basin. Well Este 05 and well Este 10 are located northeast of Lucerne (dry) Lake.

Sodium (Na^{+})

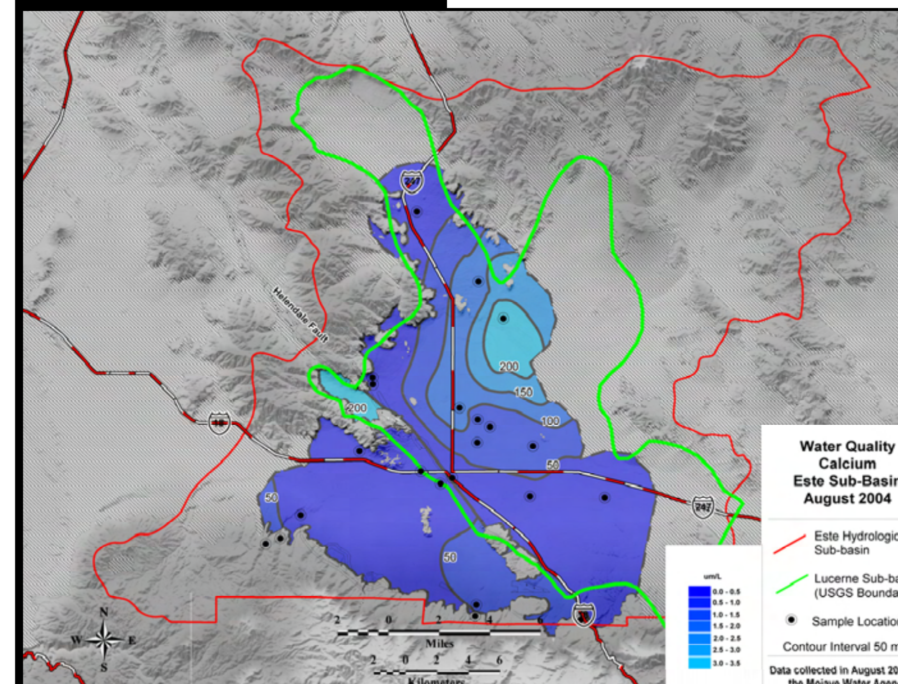


Sodium is not a regulated constituent by either the EPA or State of California for drinking water. Risks or effects include possible high blood pressure in susceptible individuals. Sources of excess sodium are primarily from septic systems.

Sodium is a major constituent of igneous rocks. Sodium is liberated during the weathering of such rocks (silicates). Sodium is generally present as Na^{+} ion in fresh water, however, complex ions and sodium ion pairs, such as $Na_2CO_3^{-}$, $NaHCO_3$(aq), and $NaSO_4^{-}$ are present.

The average sodium concentration for the study area is 139 mg/L. Well Este 28 (Na^{+} = 11 mg/L) had the lowest reading in the basin and well Este 05 (Na^{+} = 610 mg/L) had the highest. Sodium concentrations are also generally elevated on the northwest side of Lucerne (dry) Lake, but not east of the Helendale fault. Sodium is generally low throughout the Fifteenmile Valley groundwater basin and the southern portion of the Lucerne Valley groundwater basin. Well Este 05 is located northeast of Lucerne (dry) Lake.

Calcium (Ca^{2+})

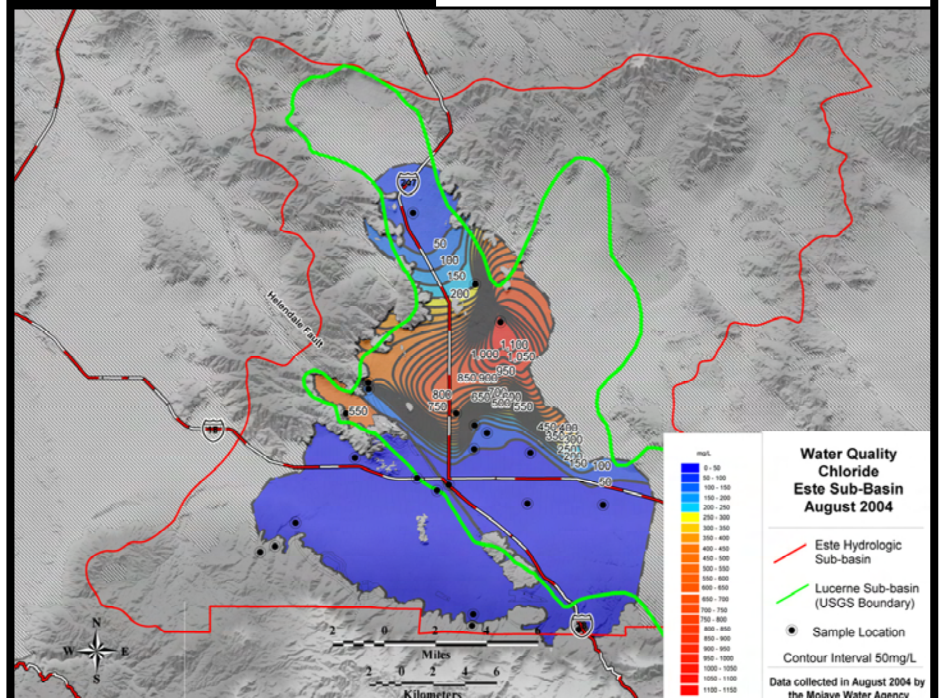


Calcium is not a regulated constituent by either the EPA or State of California for drinking water. Calcium enters the water through rock weathering, atmospheric precipitation, as salt from seawater, from industrial emissions, and also from soil fertilizer. The calcium ion is relatively large and can form complex interactions with other inorganic ions. Calcium is the most common cation in freshwater. Its content is determined by the calcium carbonate-carbon dioxide equilibrium. Calcium is removed from water by ion-exchange for sodium and other ions. The reaction of soap with calcium and magnesium leads to water hardness.

The average calcium concentration for the study area is 81 mg/L. Well Este 07 (Ca^{2+} = 20 mg/L) had the lowest reading in the basin and well Este 05 (Ca^{2+} = 270 mg/L) had the highest. Calcium concentrations are also generally elevated on the northwest side of Lucerne (dry) Lake, but not east of the Helendale fault. Calcium is generally low throughout the Fifteenmile Valley groundwater basin and in the southern portion of the Lucerne Valley groundwater basin. Well Este 05 is located northeast of Lucerne (dry) Lake.

Major Anion Distribution

Chloride (Cl^-)



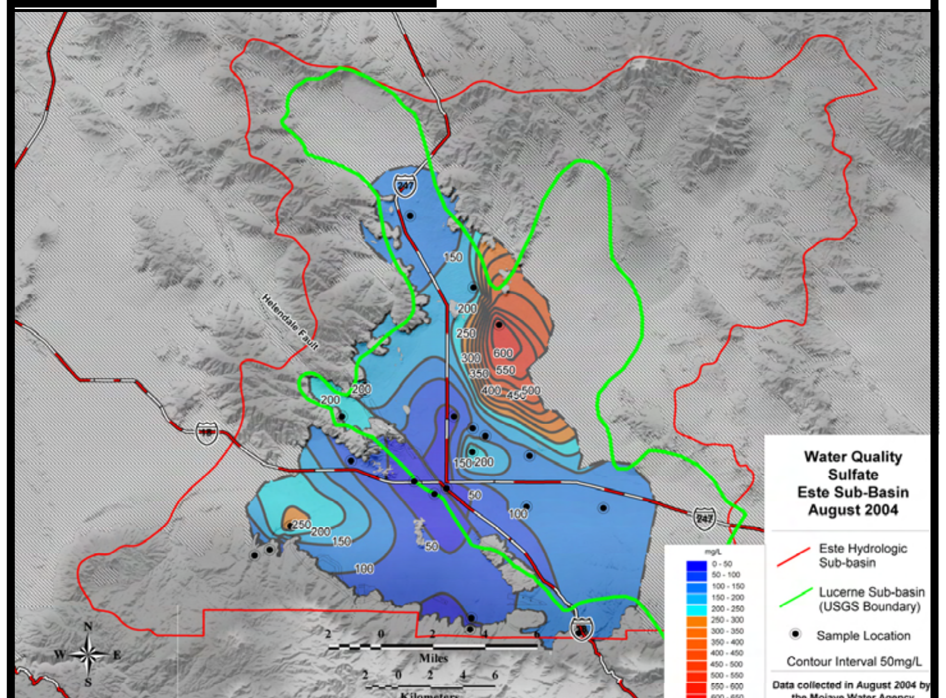
Secondary MCL (mg/L)	Noticeable Effects Above the Secondary MCL
250	Salty taste

[EPA, 2004]

Chloride is regulated as a secondary maximum contaminant by the EPA and State of California. The secondary maximum contaminant limit (SMCL) for chloride is 250 mg/L. Risks or effects include high blood pressure, salty taste, corroded pipes, fixtures and appliances blackening, and pitting of stainless steel. Sources for contamination include fertilizers, animal sewage, septic systems, and industrial wastes. A small part of chloride owes its origin to weathering of rocks.

The average chloride concentration for the study area is 244 mg/L. Well Este 38 (Cl^- = 5.1 mg/L) had the lowest reading in the basin, while wells Este 05 and Este 10 (Cl^- = 1,200 mg/L) had the highest. Six of 23 wells sampled had a chloride concentrations above the secondary standard of 250 mg/L. The majority of the elevated readings were from wells located around Lucerne (dry) Lake. Chloride is generally low throughout the Fifteenmile Valley groundwater basin and in the southern portion of the Lucerne Valley groundwater basin. Well Este 05 is located northeast of Lucerne (dry) Lake.

Sulfate (SO_4^{2-})



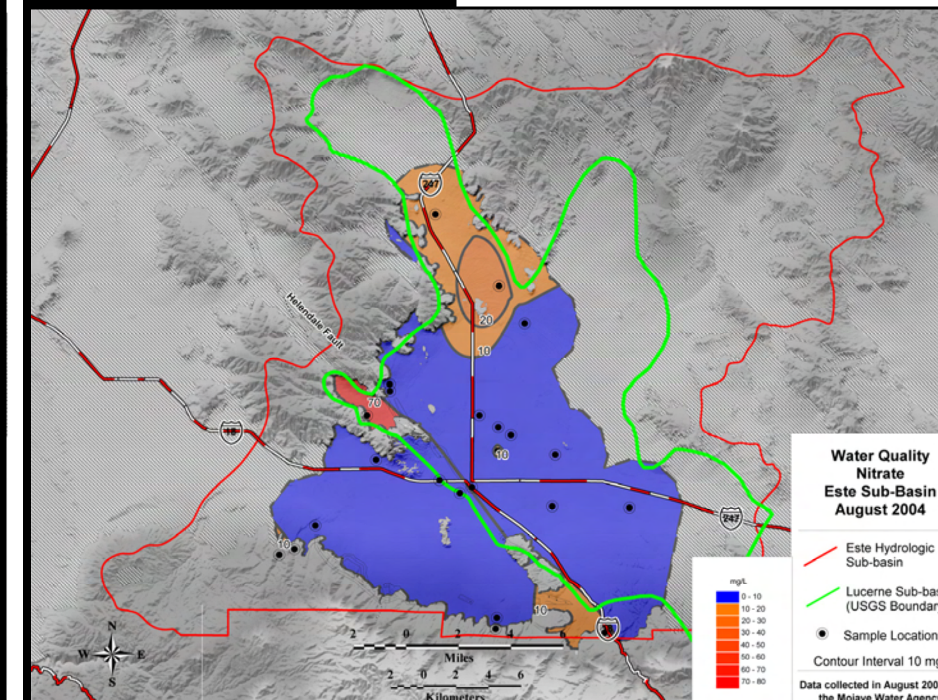
Secondary MCL (mg/L)	Noticeable Effects Above the Secondary MCL
250	Salty taste

[EPA, 2004]

Sulfate is regulated as a secondary maximum contaminant by the EPA and State of California. The SMCL for chloride is 250 mg/L. Risks or effects include bitter, medicinal taste, scaly deposits, corrosion, laxative effects, and "rotten-egg" odor from hydrogen sulfide gas formation. Sources include animal sewage, septic systems, sewage, industrial waste, natural deposits or salts. Sulfate is only a minor constituent of igneous rocks. Considerable amounts of sulfate derived from man-made air-pollutantion.

The average sulfate concentration for the study area is 169 mg/L. Well Este 10 (SO_4^{2-} = 20 mg/L) had the lowest reading in the basin and well Este 05 (SO_4^{2-} = 630 mg/L) had the highest. Three of 23 wells sampled had sulfate readings above the secondary standard of 250 mg/L. The majority of the basin is below the secondary standard, with the exception of the northeastern portion of the Lucerne Valley groundwater basin and one well on the far western portion of the Fifteenmile Valley groundwater basin. Well Este 05 is located northeast of Lucerne (dry) Lake.

Nitrate (NO_3^{2-})



MCL (mg/L)	MCLG (mg/L)	Potential Health Effects from Ingestion of Water that Exceeds MCL	Sources of Contaminant in Drinking water
10	10	Infants below the age of six months could become seriously ill; and, if untreated may die.	Runoff from fertilizer use; leaching from septic tanks, sewage; erosion of natural deposits

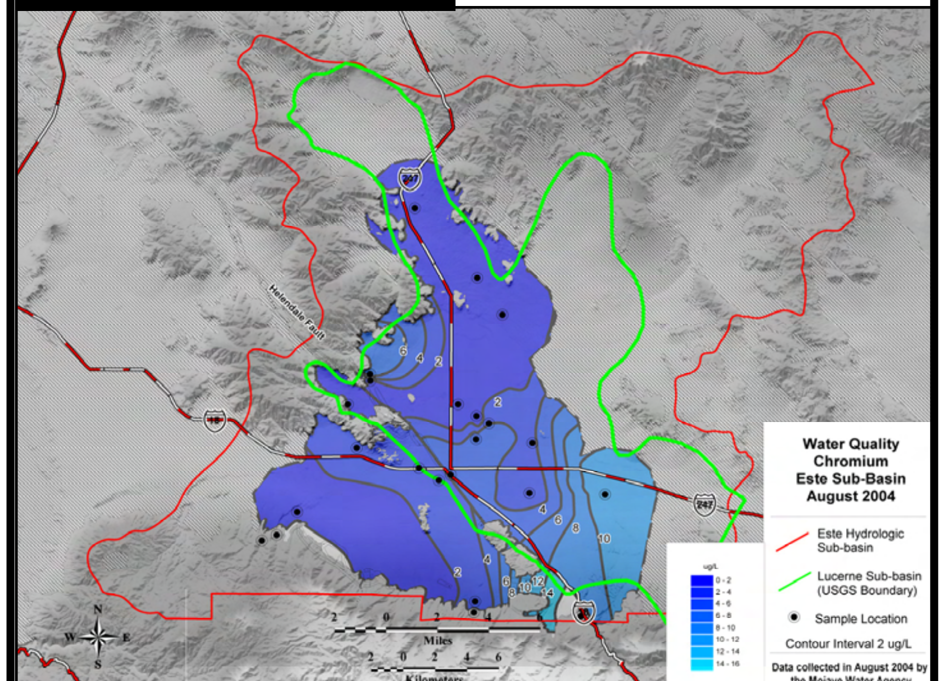
[EPA, 2004]

Nitrate has a primary MCL of 10 mg/L for drinking water. Risks or effects associated with high levels of nitrate include methemoglobinemia or blue baby disease in infants. Sources include livestock facilities, septic systems, manure lagoons, fertilizers, household waste water, and natural deposits. Nitrate is also present in fertilizer as sodium nitrate or potassium nitrate.

The average nitrate concentration for the study area is 9.23 mg/L. Wells Este 05 and Este 07 (NO_3^{2-} = 0 mg/L) had the lowest readings in the basin, while well Este 11 (NO_3^{2-} = 72 mg/L) had the highest. Five of 23 wells sampled had nitrate concentrations above the primary drinking water standard of 10 mg/L. The majority of the basin is below the primary drinking water standard, with the exception the northern portion of the Lucerne Valley groundwater basin and Cove Valley. Well Este 11 is located in Cove Valley, west of the Helendale fault and near Lucerne (dry) Lake.

Arsenic & Chromium Distribution

Chromium (total) (Cr)



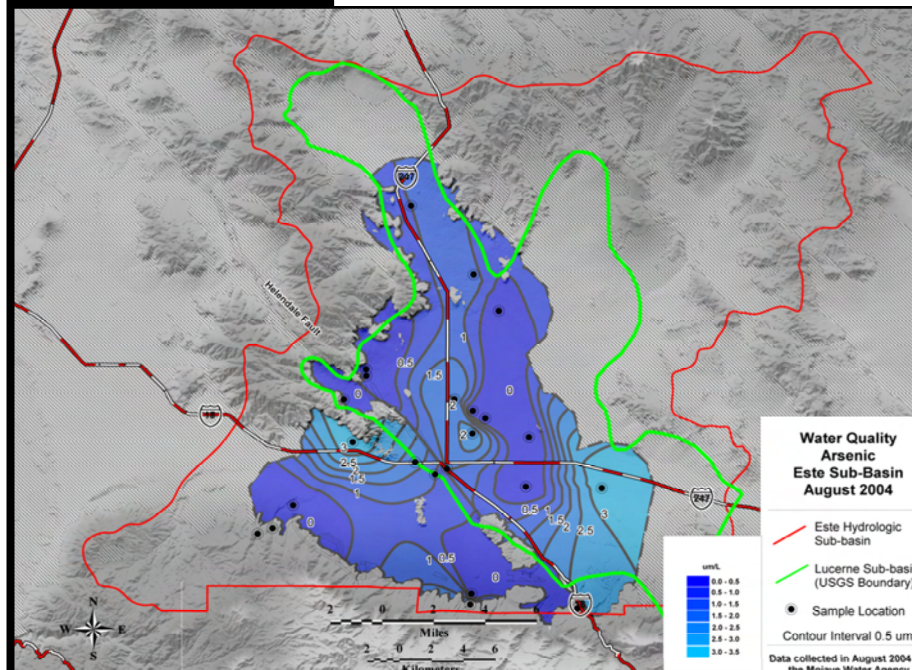
MCL (mg/L)	MCLG (mg/L)	Potential Health Effects from Ingestion of Water that Exceeds MCL	Sources of Contaminant in Drinking water
0.05	0.05	Allergic dermatitis	Discharge from steel and pulp mills; erosion of natural deposits

[EPA, 2004]

Chromium (total) is regulated as a primary contaminant. Currently the MCL for chromium (total) is 0.05 mg/L. Chromium (total) is a metal found in natural ore deposits. Chromium (total) is mostly used in metal alloys such as stainless steel, protective coatings on metal, magnetic tapes, pigments for paints, cement, paper, rubber, composition floor covering, and other materials. It is also used in wood preservatives.

The average chromium (total) concentration for the study area is 0.0032 mg/L. Wells Este 01, 04 05, 08, 10, 11, 13, and 27 (Cr = 0 mg/L) had the lowest readings in the basin, while well Este 29 (Cr = 0.017 mg/L) had the highest. None of the wells sampled had concentrations in excess of the primary drinking water standard.

Arsenic (As)



MCL (mg/L)	MCLG (mg/L)	Potential Health Effects from Ingestion of Water that Exceeds MCL	Sources of Contaminant in Drinking water
0.01 as of 1/23/06	0	Skin damage or problems with circulatory systems; may have increased risk of getting cancer	Erosion of natural deposits; runoff from orchards, runoff from glass & electronics production wastes

[EPA, 2004]

Arsenic is regulated as a primary contaminant. Currently the MCL for arsenic is 0.050 mg/L. However, as of 2006, this MCL will decrease to 0.010 mg/L. Arsenic comes from the erosion of natural deposits, runoff from orchards, runoff from glass and electronics production. Potential health risks associated with arsenic include: skin damage, problems with circulatory systems, and an increased risk of cancer.

The average arsenic concentration for the study area is 0.001 mg/L. Wells Este 05, 07, 08, 10c, 11, 13, 14, 16, 27, 28 and 29 (Ar = 0 mg/L) had the lowest readings in the basin, while well Este 10d (Ar = 0.004 mg/L) had the highest. None of the wells sampled had concentrations in excess of the primary drinking water standard.

Orpiment As_2S_3 - a source of arsenic
Photo courtesy of OSHA

acre-foot (acre-ft) - The volume of water required to cover 1 acre of land (43,560 square feet) to a depth of 1 foot. Equal to 325,851 gallons or 1,233 cubic meters.

advanced treatment - A level of wastewater treatment more stringent than secondary treatment; requires an 85-percent reduction in conventional pollutant concentration or a significant reduction in non-conventional pollutants. Sometimes called tertiary treatment.

advection - The transport of dissolved constituents (i.e., solutes), particulate/colloidal matter, and/or heat by flowing groundwater. Generally, advection is considered synonymous with forced convection.

aeration - A process which promotes biological degradation of organic matter in water. The process may be passive (as when waste is exposed to air), or active (as when a mixing or bubbling device introduces the air).

aerobic - Bacteria or processes active only in the presence of molecular oxygen.

agricultural pollution - Farming wastes, including runoff and leaching of pesticides and fertilizers; erosion and dust from plowing; improper disposal of animal manure and carcasses; crop residues, and debris.

alkalinity - The total measurable bases (OH, HCO_3, CO_3) in a volume of water; a measure of a material's capacity to neutralize acids; pH > 7.

alluvium - A general term for clay, silt, sand and gravel, or similar unconsolidated material deposited by a river as a sorted or semi-sorted sediment in the bed of the river or on its floodplain.

aqueous solubility - The maximum concentration of a chemical that will dissolve in pure water at a reference temperature.

aquifer - A consolidated or unconsolidated geologic unit (material, stratum, or formation) or set of connected units that yields a significant quantity of water of suitable quality to wells or springs in economically usable amounts. Typically is an unconsolidated deposit, or sandstone, limestone, or granite

aquifer storage - The ability of the aquifer to store water in interconnected pores and fractures. Aquifer storage is quantified by a values referred to as storativity and specific yield.

aquifer system - Two or more permeable units separated at least locally by confining units that impede groundwater movement but do not greatly affect the regional hydraulic continuity of the system.

aquifer test - A test to determine hydraulic properties of an aquifer.

aquitard - A semi-pervious geologic formation, which can store water but transmits water at an overflow rate compared to the aquifer.

area of influence - Area surrounding pumping or recharging, within which the water table or potentiometric surface has been changed due to the well's pumping or recharge; also called zone of influence.

artesian aquifer - Commonly used expression, generally synonymous with (but less favored term than confined aquifer). The term "artesian" takes its name from the basin of Artois in France. In the common usage, this implies the existence of flowing wells, but all flowing wells are not artesian nor do all artesian wells flow.

artesian - Hydrostratigraphically confined. In the common usage, this implies the existence of flowing wells, but all flowing wells are not artesian nor do all artesian wells flow.

artesian well - A well deriving its water from a confined ("artesian") aquifer.

artificial recharge - A process where water is put back into ground-water storage from surface-water supplies such as irrigation, or induced infiltration from streams or wells.

attenuation - The process of reducing a quantity of a solute or colloid in a groundwater system.

average linear velocity - The specific discharge (darcian velocity) divided by the effective porosity. The average linear velocity is an estimate of the mean rate that water molecules flow.

background level - **1.** The concentration of a substance in an environmental media (air, water, or soil) that occurs naturally or is not the result of human activities. **2.** In exposure assessment, the concentration of a substance in a defined control area, during a fixed period of time before, during, or after a data-gathering operation.

baseflow - Part of a stream discharge not attributable to direct runoff from precipitation or snowmelt, usually sustained by groundwater discharging into the stream.

basin - An aquifer or aquifer system whose boundaries are defined by surface-water divides, topographic barriers, or a structural basin in which the aquifers are isolated from adjacent aquifers.

bedrock - The solid rock beneath the soil and superficial rock. A general term for solid rock that lies beneath soil, loose sediments, or other unconsolidated material.

biological contaminants - Living organisms or derivates (e.g. viruses, bacteria, fungi, mammal, and bird antigens) that can cause harmful health effects when inhaled, swallowed, or otherwise taken into the body.

build-up - The potentiometric surface (or the water table) rise in the vicinity of recharge. It is the vertical distance between the initial and the new potentiometric surface (or the water table in the case of an unconfined aquifer) at a given point.

cap - A layer of clay, or other impermeable material installed over the top of a closed landfill to prevent entry of rainwater and minimize leachate.

capillarity - The action by which water is raised (or lowered) relative to the water surface because of interaction between the water molecules and the solids of the porous medium. Capillarity can also refer to the movement of a fluid through a porous medium due to this interaction; this is also called imbibition.

combined sewer overflows - Discharge of a mixture of storm water and domestic waste when the flow capacity of a sewer system is exceeded during rainstorms.

confined aquifer - An aquifer whose upper and per haps lower boundary is defined by a layer of natural material that does not transmit water readily and retards the vertical movement of water This material is sometimes referred to as a confining layer or confining unit. When a well is installed in a confined aquifer the water level in the well rises above the top of the aquifer.

consumptive use - That part of water withdrawn that is evaporated, transpired by plants, incorporated into products or crops, consumed by humans or livestock, or otherwise removed from the immediate water environment. Also referred to as water consumed.

cubic feet per second (cfs) - A rate of flow in streams and rivers. It is equal to a volume of water one foot high and one foot wide flowing a distance of one foot in one second. One "cfs" is equal to 7.48 gallons of water flowing each second. As an example, if your car's gas tank is 2 feet by 1 foot by 1 foot (2 cubic feet), then gas flowing at a rate of 1 cubic foot/second would fill the tank in two seconds

discharge - The release or extraction of water from an aquifer. Typical mechanisms of natural discharge are evapotranspiration by phreatophytes, springs, and drains to surface water bodies. Pumping is a man-caused discharge.

discharge, instantaneous - The discharge at a given instant of time.

discharge, mean - Arithmetic mean of discharges over a given time period.

discharge area - An area in which groundwater is discharged to the land surface.

dispersion length or dispersivity - The factor which, when multiplied by the average linear velocity estimates the coefficient of hydrodynamic dispersion; either longitudinal or transverse.

divide - A topographic high (or ridge) separating surface watersheds (catchments). A groundwater divide is an elevated area, line, or ridge of the potentiometric surface separating different groundwater flow systems.

Glossary of Terms

domestic water use - Water used for household purposes, such as drinking, food preparation, bathing, washing clothes, dishes, animals, plumbing, and water lawns and gardens. About 85% of domestic water is delivered to homes by a public-supply facility, such as a county water department. About 15% of the U.S. population supply their own water mainly from wells.

double (or dual) porosity - When two porosities may be associated with a hydrogeological system. An example is a porous rock with a fracture set and primary porosity; such a system may then have two characteristic porosities - one for the fractures and one for the porous matrix. Implied in this definition is that significant flow rates are present in both the fractures and the matrix.

down-gradient - The direction that groundwater flows; similar to "downstream" for surface water.

drainage basin - Land area where precipitation runs off into streams, rivers, lakes, and reservoirs. It is a surface feature that can be identified by tracing a line along the highest elevation between two areas on a map, often a ridge. Large drainage basins, like the area that drains into the Mississippi River contain thousands of smaller drainage basins. Also called a "watershed."

drawdown - **1.** The drop in the water table or level of water in the ground when water is being pumped from a well. **2.** The amount of water used from a tank or reservoir. **3.** The drop in the water level of a tank or reservoir.

drinking water equivalent level - Protective level of exposure related to potentially non-carcinogenic effects of chemicals that are also known to cause cancer.

drought - A prolonged period of low (lower than average) rainfall.

effective grain size (d_{10}) - The grain size corresponding to the 10% finer by weight on the grain-size distribution curve.

effective porosity ($Ø_{eff}$) - The interconnected pore space through which fluids can pass; expressed as a percent of bulk volume. Part of the total porosity will be occupied by static fluid being held to mineral surface by surface tension; so effective porosity will be less than total porosity.

effluent stream - 1. A surface stream that flows out of a lake or any branch of a larger stream. 2. A stream that intersects and receives its water form the water table.

ephemeral stream - A stream which flows only briefly after rainfall events.

evapotranspiration, actual - The evaporation that actually occurred under given climatic and soil-moisture conditions.

evapotranspiration, potential - The evaporation that would occur under given conditions if there were unlimited soil moisture.

fault - A fracture which has experienced translation or movement of the fracture walls parallel to the plane of the fracture.

normal fault - A fault in which the hanging wall moves down with respect to the foot wall.

reverse fault - A fault in which the hanging wall moves up with respect to the foot wall.

strike-slip fault - A fault in which the movement parallel to the plane of the fracture is parallel to the land (horizontal) surface.

flow rate - The rate expressed in gallons - or liters-per-hour) at which a fluid escapes from a hole or fissure in a tank. Such measurements are also made of liquid waste, effluent, and surface water movement.

fracture trace - Visible on aerial photographs, fracture traces are natural linear-drainage, soil-tonal, and topographic alignments that are probably the surface manifestation of underlying zones of fractures.

fractured formation - A fractured porous medium in which flow rates in the matrix can be assumed to be negligible. Compared with a purely fractured medium and a double porosity medium.

fresh water - Water with a salinity < 1000 mg/l of dissolved solids; drinkable or potable water is implied.

geophysical log - A detailed description of all underground features (depth, thickness, type of formation) discovered during the drilling of a well. Also called "geological log".

groundwater - **1.** Water that flows or seeps downward and saturates soil or rock, supplying springs and wells. The upper surface of the saturate zone is called the water table. **2.** Water stored underground in rock crevices and in the pores of geologic materials that make up the Earth's shallow crust.

groundwater barrier - Rock, artificial material, or geologic structures with a relatively low permeability that occurs (or is placed) below ground surface, where it impedes the movement of groundwater and thus causes a pronounced difference in the heads on opposite sides of the barrier.

groundwater basin - General term used to define a groundwater flow system that has defined boundaries and may include more than one aquifer underlain by permeable materials that are capable of storing or furnishing a significant water supply. The basin includes both the surface area and the permeable materials beneath it.

groundwater discharge - 1. The flow of water from the zone of saturation. **2.** The water quantity of water thus freed.

groundwater divide - Ridge in the water table, or potentiometric surface, from which groundwater moves away at right angles in both directions. Line of highest hydraulic head in the water table or potentiometric surface.

groundwater flow - The movement of water through openings in sediment and rock that occurs in the zone of saturation.

groundwater mound - Raised area in a water table or other potentiometric surface, created by groundwater recharge.

groundwater recharge - The infiltration of water into the earth. It may increase the total amount of water stored underground or only replenish the groundwater supply depleted through pumping or natural discharge.

hardness - A water-quality indication of the concentration of alkaline salts in water, mainly calcium and magnesium. If the water you use is "hard" then more soap, detergent or shampoo is necessary to raise a lather.

headwater(s) - **1.** The source and upper reaches of a stream; also the upper reaches of a reservoir. **2.** The water upstream from a structure or point on a stream. **3.** Small streams that come together to form a river. Also may be thought of as any and all parts of a river basin except the mainstream river and main tributaries.

hydraulic barrier - Modifications to a groundwater flow system that restrict or impede movement of contaminants.

hydraulic conductivity (K) - The volume of fluid that flows through a unit area of porous medium for a unit hydraulic gradient normal to that area.

hydraulic head (h) and gradient (Nh) - Height above a datum plane (such as mean sea level) of the column of water that can be supported by the hydraulic pressure at a given point in a groundwater system. Equal to the distance between the water level in a well and the datum plane. The gradient is the change in water table depth which causes groundwater flow.

hydrochemical facies - How the groundwater chemistry changes over space. Typically, the facies reflect the major ionic constituents.

hydrocompaction - Volume decrease and density increase caused as moisture-deficient sediments compact as they become wetted.

hydrogeologic - Those factors that deal with subsurface waters and related geologic aspects of surface waters.

Glossary of Terms

hydrogeology - The geology of groundwater, with particular emphasis on the chemistry and movement of water. These factors, along with related geologic aspects of surface waters are *hydrogeologic* factors.

hydrograph - A chart depicting either discharge or water level as a function of time.

hydrologic unit - A geographic area representing all or part of a surface drainage basin or a distinct hydrologic feature. In the U. S. these units have 8-digit identification numbers.

hydrology - **1.** The study of the waters of the Earth (or other planetary bodies). **2.** A distinct geoscience interactive on a wide range of spatial and temporal scales with the oceanic, atmospheric, and solid earth sciences as well as with many biological sciences.

hydrological cycle - The cyclic transfer of water vapor from the Earth's surface via evapotranspiration into the atmosphere, from the atmosphere via precipitation back to earth, and through runoff into streams, rivers, lakes, and ultimately into the oceans.

hydrostratigraphic unit - A formation, part of a formation, or group of formations of significant lateral extent which compose a unit of reasonably distinct (similar) hydrogeologic parameters and responses.

impermeable - **1.** Not easily penetrated. **2.** The property of a material or soil that does not allow or allows only with great difficulty, the movement or passage of water.

infiltration - The downward entry of water into soil or rock.

Influent stream - A stream that contributes water to the zone of saturation.

injection well - Refers to a well constructed for the purpose of injecting water or air directly into the ground.

interflow - Water which infiltrates the land surface and flows into a stream but never recharges the local water table.

intermittent stream - A stream which does not flow all year long.

isotope - A variation of an element that has the same atomic number of protons but a different weight because of the number of neutrons. Various isotopes of the same element may have different radioactive behaviors; some are highly unstable.

isotropy - The condition in which the properties of interest (generally hydraulic properties of the aquifer) are the same in all directions.

leaching - The process by which soluble materials in the soil, such as salts, nutrients, pesticide chemicals or contaminants are washed into a lower layer of soil or are dissolved and carried away by water.

leakage - Flow of water from one hydrogeologic unit to another. This may be natural, as through a somewhat permeable confining layer, or anthropogenic, as through an uncased well. It may also be the natural loss of water from artificial structures, as a result of hydrostatic pressure.

leaky aquifer - An artesian or water table aquifer that loses or gains water through adjacent semipermeable confining units.

lithology - Mineralogy, grain size, texture, and other physical properties of granular soil, sediment, or rock.

losing stream - A stream or reach of a stream that is losing water by seepage into the ground. Also known as an influent stream.

maximum contaminant level (MCL) - The designation given by the U.S. Environmental Protection Agency (EPA) to water-quality standards promulgated under the Safe Drinking Water Act. The MCL is the greatest amount of a contaminant that can be present in drinking water without causing a risk to human health.

maximum contaminant level goal (MCLG) - Under the Safe Drinking Water Act, a non-enforceable concentration of a drinking water contaminant, set at the level at which no known or anticipated adverse effects on human health occur and which allows an adequate safety margin. The MCLG is usually the starting point for determining the regulated.

maximum residual disinfectant level (MRDL) - The highest level of a disinfectant allowed in drinking water. There is convincing evidence that addition of a disinfectant is necessary for control of microbial contaminants.

maximum residual disinfectant level goal (MRDLG) - The level of a drinking water disinfectant below which there is no known or expected risk to health. MRDLGs' do not reflect the benefits of the use of disinfectants to control microbial contaminants.

milligram (mg) - One-thousandth of a gram.

milligrams per liter (mg/l) - A unit of the concentration of a constituent in water or wastewater. It represents 0.001 gram of a constituent in 1 liter of water. It is approximately equal to one part per million (ppm).

million gallons per day (Mgd) - A rate of flow of water equal to 133,680.56 cubic feet per day, or 1.5472 cubic feet per second, or 3.0689 acre-feet per day. A flow of one million gallons per day for one year equals 1,120 acre-feet (365 million gallons).

mitigation - Measures taken to reduce adverse impacts to the environment.

monitoring well - **1.** A well used to obtain water quality samples or measure groundwater levels and is usually larger diameter than a piezometer and is typically screened or slotted throughout the thickness of the aquifer. Also referred to as an "observation well".

non-point source (NPS) pollution - Pollution discharged over a wide land area, not from one spcific location. These pollution caused by sediment, nutrients, organic and toxic substances originating from land-use activities, which are carried to lakes and streams by surface runoff. Non-point source pollution is contamination that occurs when rainwater, snowmelt, or irrigation washes off plowed fields, city streets, or suburban backyards. As this runoff moves across the land surface, it picks up soil particles and pollutants, such as nutrients and pesticides.

orographic lifting - Lifting of air caused by its passage up and over mountains or other sloping terrain. Clouds that form in this lifting process are called orographic clouds.

outfall - The place where a sewer, drain, or stream discharges; the outlet or structure through which reclaimed water or treated effluent is finally discharged to a receiving water body.

overdraft - The pumping of water from a groundwater basin or aquifer in excess of the supply flowing into the basin; results in a depletion or "mining" of the groundwater in the basin.

overland flow - The flow of water over the land surface created by direct precipitation.

oxygen demand - The need for molecular oxygen to meet the needs of biological and chemical processes in water. Even though very little oxygen will dissolve in water, it is extremely important in biological and chemical processes.

particle size - The diameter, in millimeters, of suspended sediment or bed material. Particle-size classifications are:

- Clay - 0.0000094 - 0.00016 inch (0.00024-0.004 mm)
- Silt - 0.00016 - 0.0024 inch (0.004—0.062 mm)
- Sand - 0.0024 - 0.079 inch (0.062 - 2.0 mm)
- Gravel - 0.079 - 2.52 inch (2.0 - 64.0 mm)

perched water table - The top of a zone of saturation that bottoms on an impermeable horizon above the level of the general water table in the area. It is generally near the surface.

percolation - **1.** The movement of water through the openings in rock or soil. Percolating water infers the downward movement of water under the force of gravity. **2.** The entrance of a portion of the streamflow into the channel materials to contribute to ground water replenishment.

permeability - The ease with which a porous medium can transmit water or other fluids.

pH - A measure of the relative acidity or alkalinity of water. Water with a pH of 7 is neutral; lower pH levels indicate increasing acidity (H^+), while pH levels higher than 7 indicate increasingly basic (OH^-) solutions.

phosphates - Certain chemical compounds containing phosphorus. Phosphogypsum Piles (Stacks): principal byproduct generated in production of phosphoric acid from phosphate rock. These "stacks" may generate radioactive radon gas.

phreatic water - Synonymous with the zone of saturation.

playa - A dry (ephemeral) lake bed. Common in semi-arid areas.

plume - A three-dimensional body of fluid emanating from a point source or point sources with a chemistry or physical composition differing from the ambient groundwater, atmosphere, or surface water body.

point-source pollution - Water pollution coming from a single point, such as a sewage-outflow pipe.

pollution - When the contaminant concentration levels restrict the potential use of groundwater.

porosity - A measure of the water-bearing capacity of subsurface rock. With respect to water movement, it is not just the total magnitude of porosity that is important, but the size of the voids and the extent to which they are interconnected, as the pores in a formation may be open, or interconnected, or closed and isolated. For example, clay may have a very high porosity with respect to potential water content, but it constitutes a poor medium as an aquifer because the pores are so small.

potable water - Water of a quality suitable for human consumption.

preliminary wastewater treatment - Removal of wastewater constituents such as rags, sticks, floatables, grit, and grease that may cause maintenance or operational problems with the treatment operations, processes and ancilliary systems.

potentiometric surface - The surface to which water in an aquifer can rise by hydrostatic pressure.

prior appropriation doctrine - The system for allocating water to private individuals used in most western states. The doctrine of Prior Appropriation was in common use throughout the arid west as early settlers and miners began to develop the land. The prior appropriation doctrine is based on the concept of "First in Time, First in Right." The first person to take a quantity of water and put it to beneficial use has a higher priority of right than a subsequent user. The rights can be lost through non-use; they can also be sold or transferred apart from the land. Contrasts with riparian water rights.

radius of influence - The radial distance from the center of a wellbore to the point where there is no lowering of the water table or potentiometric surface (the edge of its cone of depression). The radial distance from an extraction well that has adequate air flow for effective removal of contaminants when a vacuum is applied to the extraction well.

rain shadow – A region of low precipitation because it is located on the leeward (windward) side of a mountain range. As a moist air mass rises to the top of a mountain range, it cools, water vapor condenses as rain, and most of the moisture is lost. Thus on the windward side (or leeward side) it is dry, often an arid desert.

recharge – The process by which water is added to the groundwater system or more precisely, enters the phreatic zone. Can be expressed as a *recharge rate* (i.e., in/yr) or a volume. A source of recharge may be provided by a *recharge basin*, an excavated pit to provide a means of allowing water to soak into the ground at rates exceeding those that would occur naturally. Another source may be a *recharge boundary*, an aquifer system boundary that adds water to the aquifer, such as streams and lakes. Such recharge produces a *recharge area* where there is a downward component of the hydraulic head as infiltration moves water downward into the deeper parts of an aquifer.

return flow - That part of irrigation water that is not consumed by evapotranspiration and that returns to its source or another body of water.

saline water - Water that contains significant amounts of dissolved salts. Salinity is defined as:

- Fresh water - Less than 1,000 ppm
- Slightly saline water - From 1,000 ppm to 3,000 ppm
- Moderatly saline water - From 3,000 ppm to 10,000 ppm
- Highly saline water - From 10,000 ppm to 35,000 ppm

salts - Minerals that water picks up as it passes through the air, over and under the ground, or from households and industry.

saturated zone (zone of saturation) - The area below the water table where all open spaces are filled with water under pressure equal to or greater than that of the atmosphere.

sediment - Usually applied to material in suspension in water or recently deposited from suspension. In the plural the word is applied to all kinds of deposits from the waters of streams, lakes, or seas.

sedimentary rock - Rock formed of sediment, and specifically: **1.** Sandstone and shale, formed of fragments of other rock transported from their sources and deposited in water; and **2.** Rocks formed by or from secretions of organisms, such as most limestone. Many sedimentary rocks show distinct layering, which is the result of different types of sediment being deposited in succession.

specific storage - The volume of water removed or added within the unit volume of an aquifer per unit change in head.

specific yield (S_y) - The volume of water that a saturated porous medium can yield by gravity drainage divided by the volume of the porous medium.

storage - Water contained within an aquifer or within a surface-water reservoir.

storage coefficient - The amount of water released from or taken into storage per porous medium column with a unit surface area per unit change in head.

storativity (S) - The volume of water released per unit area of aquifer for a unit decline in head. In a confined aquifer, S is essentially the specific storage (Ss) times aquifer thickness; in an unconfined aquifer, S is essentially equal to the specific yield.

suspended solids (SS) - Small particles of solid pollutants that float on the surface of, or are suspended in, sewage or other liquids. They resist removal by conventional means.

tertiary wastewater treatment - Removal of sesidual suspended solids (after secondary treatment), usually by granualr medium filtration or microscreens. Disinfections is also typically a part of tertiary treatment. Nutrient removal is often included in this definition.

throughflow - The lateral movement of water in an unsaturated zone during and immediately after a precipitation event. The water from throughflow seeps out at the base of slopes and then flows across the ground surface as return flow, ultimately reaching a stream or lake.

total dissolved phosphorous - The total phosphorous content of all material that will pass through a filter, which is determined as orthophosphate without prior digestion or hydrolysis. Also called soluble P or ortho P.

Glossary of Terms

total dissolved solids (TDS) - 1. All of the dissolved solids in water. **2.** A measure of the amount of material dissolved in water (mostly inorganic salts).

total suspended solids (TSS) - A measure of the suspended solids in wastewater, effluent, or water bodies, determined by tests for "total suspended non-filterable solids" (See: suspended solids).

transmissivity (T) - Rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of the aquifer under a unit hydraulic gradient and is dependent upon the transmissibility of the rock. It is equal to an integration of the hydraulic conductivities across the saturated part of the aquifer perpendicular to the flow paths. Transmissivity is related to Hydraulic Conductivity by the relationship: $T = Kb$, where T = Transmissivity, K = Hydraulic Conductivity and b = the saturated thickness of the aquifer. The coefficient of transmissiblity is the rate of flow of water at the prevailing water temerature, in gallons per day, through a vertical strip of the aquifer one foot wide, extending the full saturated height of the aquifer under a hydraulic gradient of 100-percent. A hydraulic gradient of 100-percent means a one foot drop in head in one foot of flow distance.

unconfined aquifer - An aquifer in which the water table is at or near atmosphere pressure; the aquifer may or may not be saturated to the top of the aquifer.

underflow - The flow of groundwater in the alluvial materials beneath and immediately adjacent to a stream and flowing in the same general direction as the stream. Note: this term is commonly misused as a term for interbasin groundwater flow or for a regional component of flow.

underground sources of drinking water - Aquifers currently are being used as a source of drinking water or those capable of supplying a public water system.

unsaturated zone - The zone immediately below the land surface where the pores contain both water and air, but are not totally saturated with water. These zones differ from an aquifer where the pores are saturated with water.

vadose zone - The zone between land surface and the water table within which the moisture content is less than saturation (except in the capillary fringe) and pressure is less than atmospheric. Soil pore space also typically contains air or other gases. The capillary fringe is included in the vadose zone (See: unsaturated zone).

water quality - a term used to describe the chemical, physical, and biological characteristics of water usually in respect to its suitability for a particular purpose.

water table aquifer - An aquifer whose upper boundary is the water table; also known as an unconfined aquifer.

water use - Water that is used for a specific purpose, such as for domestic use, irrigation, or industrial processing. Water use pertains to human's interaction with and influence on the hydrologic cycle and includes elements such as water withdrawal from surface and groundwater sources, water delivery to homes and businesses, consumptive use of water, water released from wastewater-treatment plants, water returned to the environment, and in-stream uses; such as using water to produce hydroelectric power.

watershed - The land area that drains water to a particular stream, river, or lake. It is a land feature that can be identified by tracing a line along the highest elevations between two areas on a map, often a ridge. Large watersheds, like the Mississippi River basin contain thousands of smaller watersheds.

well (water) - 1. An artificial excavation put down by any method for the purposes of withdrawing water from the underground aquifers. When the well extends the entire thickness of the aquifer and constructed to withdraw water from that thickness, it is said to be fully penetrating. **2.** A bored, drilled, or driven shaft, or a dug hole whose depth is greater than the largest surface dimension and whose purpose is to reach underground water supplies.

well efficiency - The ratio of the drawdown in the formation adjacent to the well divided by the drawdown in the well.

well, fully penetrating - A well drilled to the bottom of an aquifer, constructed in such a way that it withdraws water from the entire thickness of the aquifer.

well field - An area containing two or more wells supplying a public water supply system.

wellhead - The physical structure, facility, or devise at the land surface from or through which groundwater flows or is pumped from the subsurface.

well interference - The condition occurring when the area of influence of a water well (the cone of depression) overlaps that of a neighboring well or wells; as when the wells are pumping from the same aquifer.

well monitoring - Measurement by on-site instruments or laboratory methods of well water quality and levels.

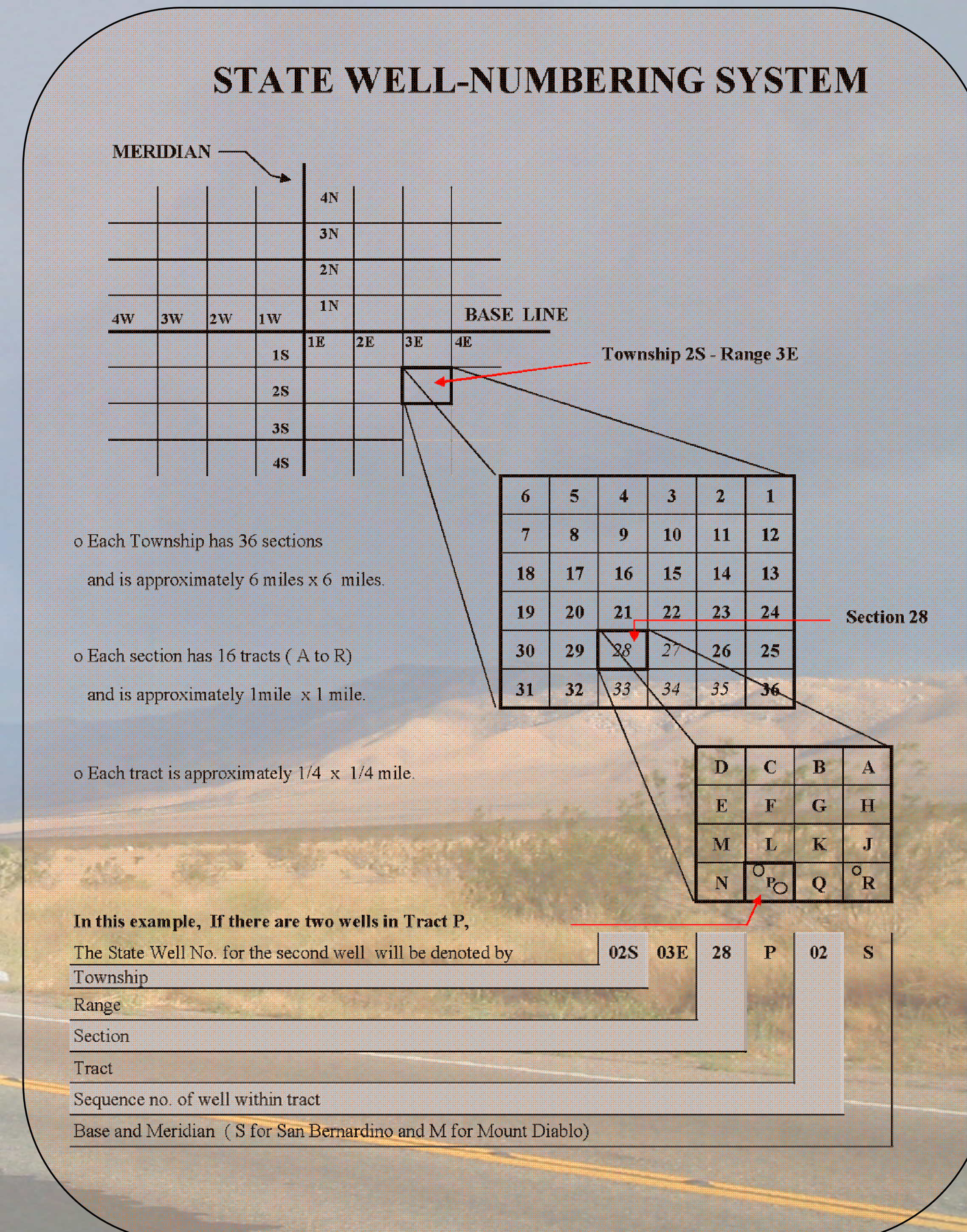
well screen - A filtering device used to permit the flow of liquid or air but prevents the passage of sediments or backfill particles.

withdrawal - Water removed from a ground or surface-water source for use.

zone of capture - Area surrounding a pumping well that encompasses all areas of features that supply groundwater recharge to the well.

Unit Conversions

units to convert	units converting to	formula for conversion
inch (in)	millimeter (mm)	# in x 24.4= # mm
foot (ft)	mm	# ft x 304.8 = # mm
mile (mi)	kilometer (km)	# mi x 1.609344 = # km
acre-foot (acf)	gallon (gal)	# acf x 325,851 = # gal
cubic-foot (ft^3)	acre-foot (acf)	# acf x .000023 = # ft^3
pound (lb)	gram (g)	# lb x 453.59 = # g
degree Farenheit (°F)	degree Celcius (°C)	°F x 5/95 = °C
part-per-billion (ppb)	microgram-per-liter (µg/L)	# ppb = # µg/L
part-per-million (ppm)	milligram-per-liter (mg/L)	# ppm = # mg/L
gallon (gal)	liter (L)	# gal x 3.79 = # L
microgram (µg)	gram (g)	# µg x 10^{-6} = # g



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U. S. Geological Survey 30 Meter Digital Elevation Model, edc.usgs.gov/geodata

World Climate Data Center, www.worldclimate.com

U.S. Geological Survey Water Resources CD-ROM.

Acknowledgements

The creation and publication of this Atlas was due to the hard work and dedication of a small group of people who combined their talents in close cooperation with the Mojave Water Agency.

California State University Fullerton

- W. Richard Laton, PhD.
  - Assistant Professor of Hydrogeology
- John Foster, PhD.
  - Professor of Geology
- Rene Perez*
  - GIS Specialist
- Tammy Surko*
  - Administrative Assistant
- Michael Blazevic*
  - Editor
- Veva Ebbs*
  - Editor
- Nicholas Napoli*
  - Graphic Design Specialist
- Mark Zellmer*
  - Graphic Design Specialist

* CSUF Department of Geological Sciences Students

Invaluable assistance and guidance was obtained from the State of California Environmental Protection Agency; the State of California Water Resources Control Board; the Lahontan & Colorado River Basin Regional Water Quality Control Board (Regions 6 & 7); the County of San Bernardino Department of Public Works; the United States Environmental Protection Agency, the United States Department of the Interior, Geological Survey (USGS) and Bureau of Land Management (BLM); and the National Oceanic and Atmospheric Administration (NOAA).

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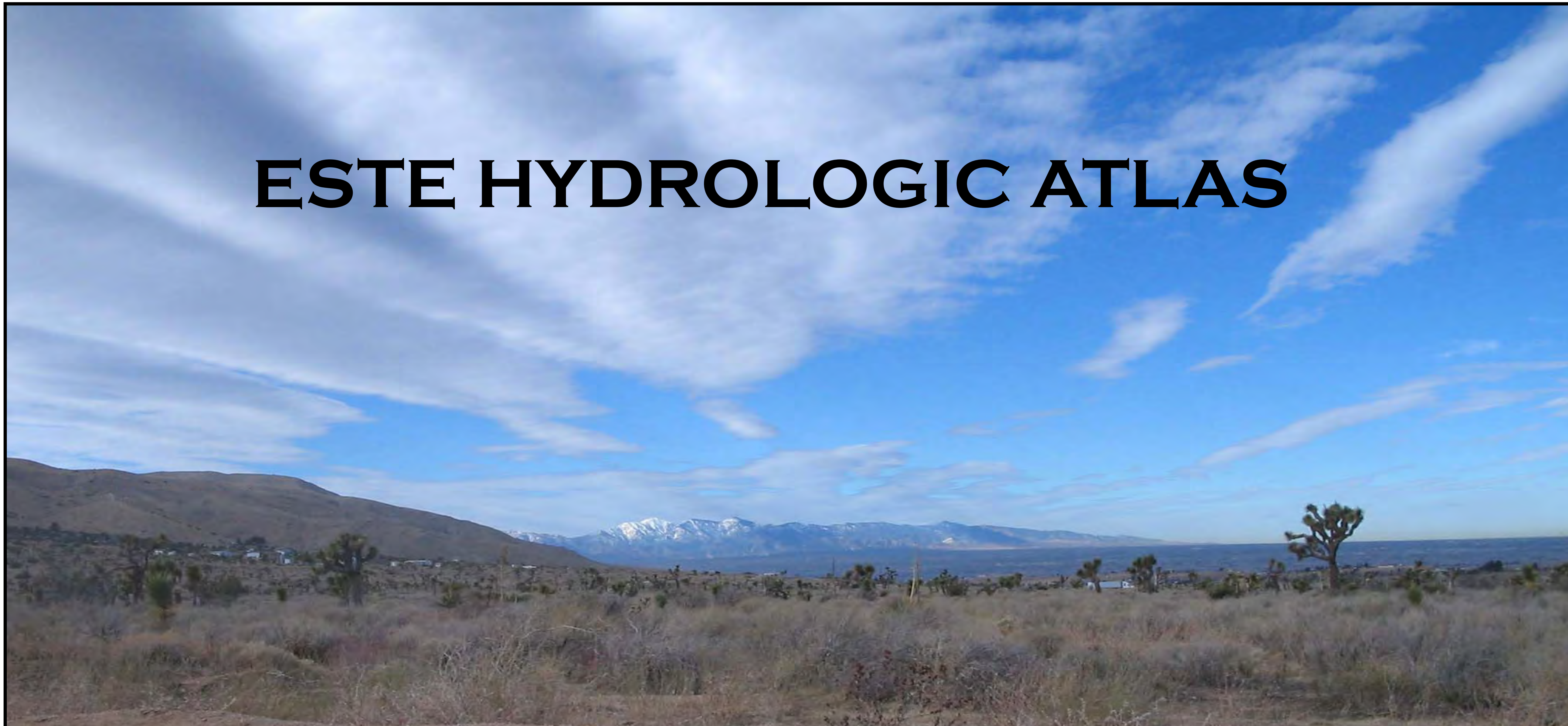

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January 2005

In Cooperation with the Mojave Water Agency