Certification

This Work Plan was prepared in accordance with generally accepted professional hydrogeologic principles and practices. This Work Plan makes no other warranties, either expressed or implied as to the professional advice or data included in it. This Work Plan has not been prepared for use by parties or projects other than those named or described herein. It may not contain sufficient information for other parties or purposes.

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Acronyms and Abbreviations

Acronym	Acronym definition
AF	acre-feet
AFY	acre-feet per year
Ag	agriculture
amsl	above mean sea level
BCM	[USGS] Basin Characterization Model
bgs	below ground surface
BMP	best management practices
CA	California
CASGEM	California statewide groundwater elevation monitoring
CCR	California Code of Regulations
CFS	cubic feet per second
CIMIS	California irrigation management information system
DBS&A	Daniel B. Stephens & Associates, Inc.
DEM	digital elevation model
DPWM	Distributed Parameter Watershed Model
DTW	depth to water
DWR	[CA] Department of Water Resources
ET	evapotranspiration
ET_0	reference evapotranspiration
FT or ft	feet
GAMA	[USGS] groundwater ambient monitoring & assessment
GDE	Groundwater dependent ecosystem
GIS	geographic information system
GPS	global positioning system

GBUAPCD	Great Basin Unified Air Pollution Control District
GSA	groundwater sustainability agency
GSP	groundwater sustainability plan
HCM	hydrogeologic conceptual model
Hydrodata	hydrologic data server
LADWP	Los Angeles Department of Water and Power
LAUWMP	Los Angeles Urban Water Management Plan
OLGDP	Owens Lake Groundwater Development Program
OVGA	Owens Valley Groundwater Authority
RP	reference point (elevation)
RWQCB	[CA] Regional Water Quality Control Board
SWRCB	[CA] State Water Resource Control Board
TD	total depth
TDS	total dissolved solids
TOS	top of screen
USEPA	United States Environmental Protection Agency
USGS	U.S. Geological Survey

Executive Summary

The Owens Valley groundwater basin is large and complex hydrogeologic system consisting of an alluvial and fluvial aquifer interbedded with clayey lacustrine sediments and volcanic flows. The basin is closed both topographically and hydrologically, with the terminus located at the southern end of the valley at Owens (dry) Lake. Confined to semi-confined conditions are generally found along the axis of the valley, with unconfined conditions present along the margin. Faults intersect the groundwater basin and act as both conduits for and barriers to groundwater flow depending on the location and orientation. Groundwater is primarily sourced from runoff that infiltrates into the alluvial fans along the margins of the valley as streams flow across them. Groundwater flow is generally from the margins towards the axis of the valley, and from the north towards the south. Naturally elevated solute concentrations are present either due to leaching of volcanic deposits or evaporative concentration in the Owens Lake area. Groundwater and surface-water in the basin are highly managed by the LADWP, with the majority of extracted groundwater exported out of the basin to the south for use in Los Angeles. Groundwater is used for a variety of purposes within the basin including agricultural, municipal, domestic, ecological, industrial, and recreational uses.

Introduction

A hydrogeologic conceptual model (HCM) is a framework for understanding how water moves into, within, and out of a groundwater basin and underlying aquifer system. According to the California Department of Water Resources (DWR), the HCM fundamentally provides [DWR, 2016]:

- *An understanding of the general physical characteristics related to regional hydrology, land use, geology and geologic structure, water quality, principal aquifers, and principal aquitards of the basin setting*
- *Context to develop water budgets, mathematical (analytical or numerical) models, and monitoring networks*
- *A tool for stakeholder outreach and communication*

All groundwater sustainability plans (GSPs) are required to include an HCM (23 CCR §354.14) that contains the following information:

- Regional geologic and structural setting
- Basin boundaries
- Principal aquifers and aquitards
- Primary use or uses and general water quality for each principal aquifer
- At least two (2) scaled geologic cross sections
- Physical characteristics (e.g., topography, geology, soils, etc.)

Development of a basin HCM is an iterative process as data gaps (see Monitoring Network and Data Gaps Analysis technical memo, Appendix 3 of the Owens Valley Groundwater Sustainability Plan) are addressed and new information becomes available.

Owens Valley Hydrogeologic Conceptual Model

Numerous geologic and water resource studies have been conducted in Owens Valley since the early 1900's. A detailed review of all previous work is beyond the scope of this report, but all relevant information was reviewed during development of the Owens Valley hydrogeologic conceptual model. The sections below summarize information pertinent to HCM development.

2.1 Physiography

Owens Valley is located on the eastern side of the Sierra Nevada Mountains in California on the western edge the Basin and Range Province (Figure 2-1). The surrounding watershed is approximately 3,287 mi^2, extending from Long Valley and Benton Valley in the north to Haiwee Reservoir in the south. The Owens Valley groundwater basin is comprised of Owens Valley (6-012.01) and Fish Slough subbasins (6-012.02), which are about 1,032 mi^2 and 5 mi^2, respectively. Locally, the northern arm of the Owens Valley subbasin that contains Chalfant, Hammil, and Benton Valleys is referred to as "Tri-Valley." For the purposes of this plan, this area is included when referring to the Owens Valley groundwater basin unless stated otherwise.

Elevations in the watershed range from 14,505 ft above mean sea level (amsl) at the summit of Mt. Whitney to 3,529 ft amsl in the Owens Dry Lake portion of the watershed. Topography can be broadly classified into three categories: mountain uplands, volcanic tablelands, and valley fill. The margins of the watershed are primarily composed of the steep, mountainous uplands. The western boundary is formed by the Sierra Nevada Mountains and the eastern boundary is formed by the White and Inyo Mountains, resulting in an elongated U-shaped watershed. The volcanic tablelands located to the north of Bishop are not nearly as prominent as the mountainous uplands but form a local topographic high. Valley fill makes up nearly a third of the total watershed area, formed by deposition from the Owens River, tributaries draining the surrounding mountains, and paleolakes.

The Owens River enters the northern portion of the groundwater basin near Bishop and then meanders southward through the valley towards Owens (dry) Lake (Figure 2-2). Numerous tributaries drain the Sierra Nevada and enter the western portion of the groundwater basin. A relatively high drainage density and large volume of annual runoff has caused the alluvial fans formed by these streams to coalesce and form a broad apron or bajada that extends eastward towards the center of the valley (Danskin, 1998). In contrast, there is relatively little runoff coming into the basin from the Inyo and White Mountains as they receive less precipitation due

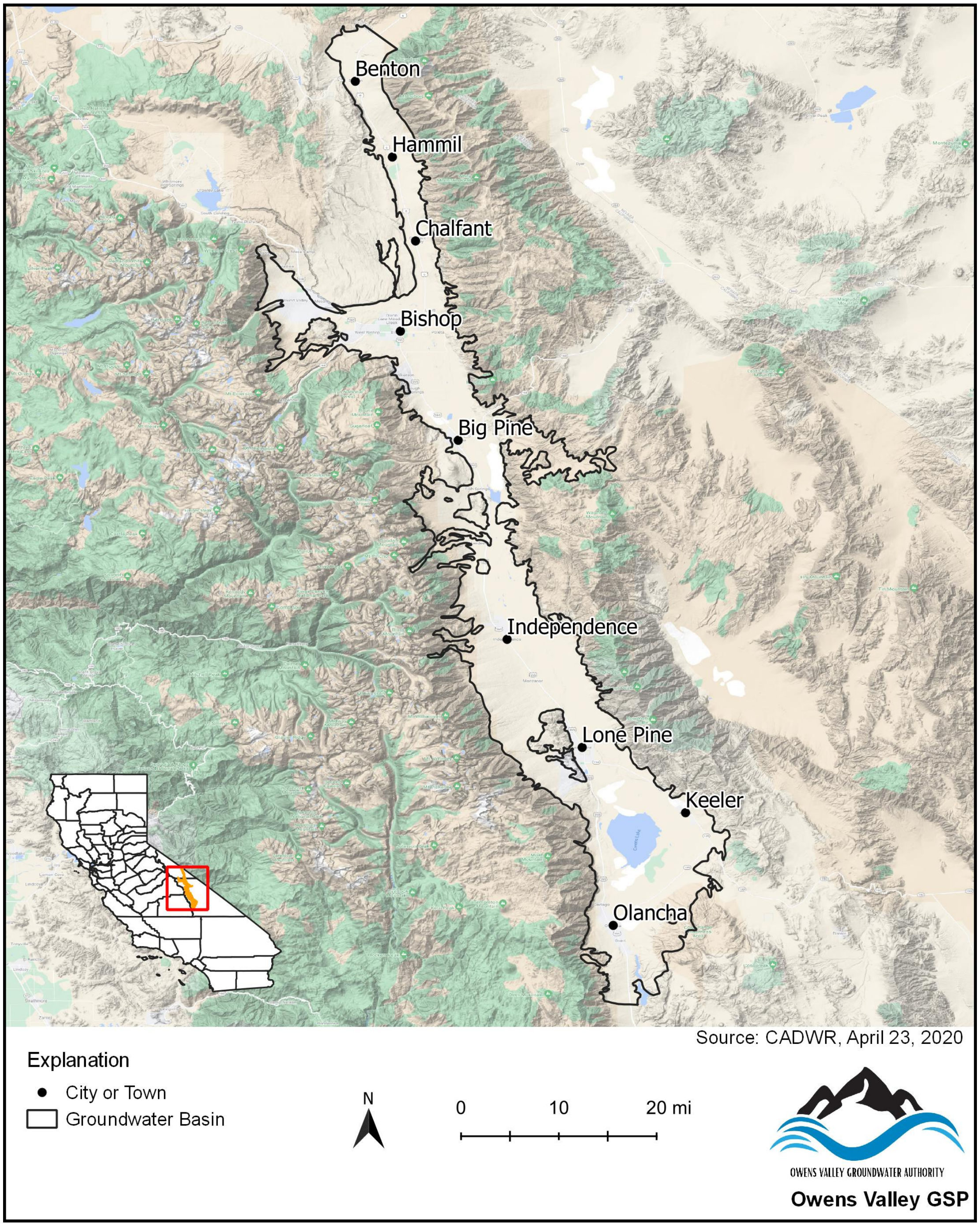

Figure 2-1. Map of the Owens Valley Groundwater Basin

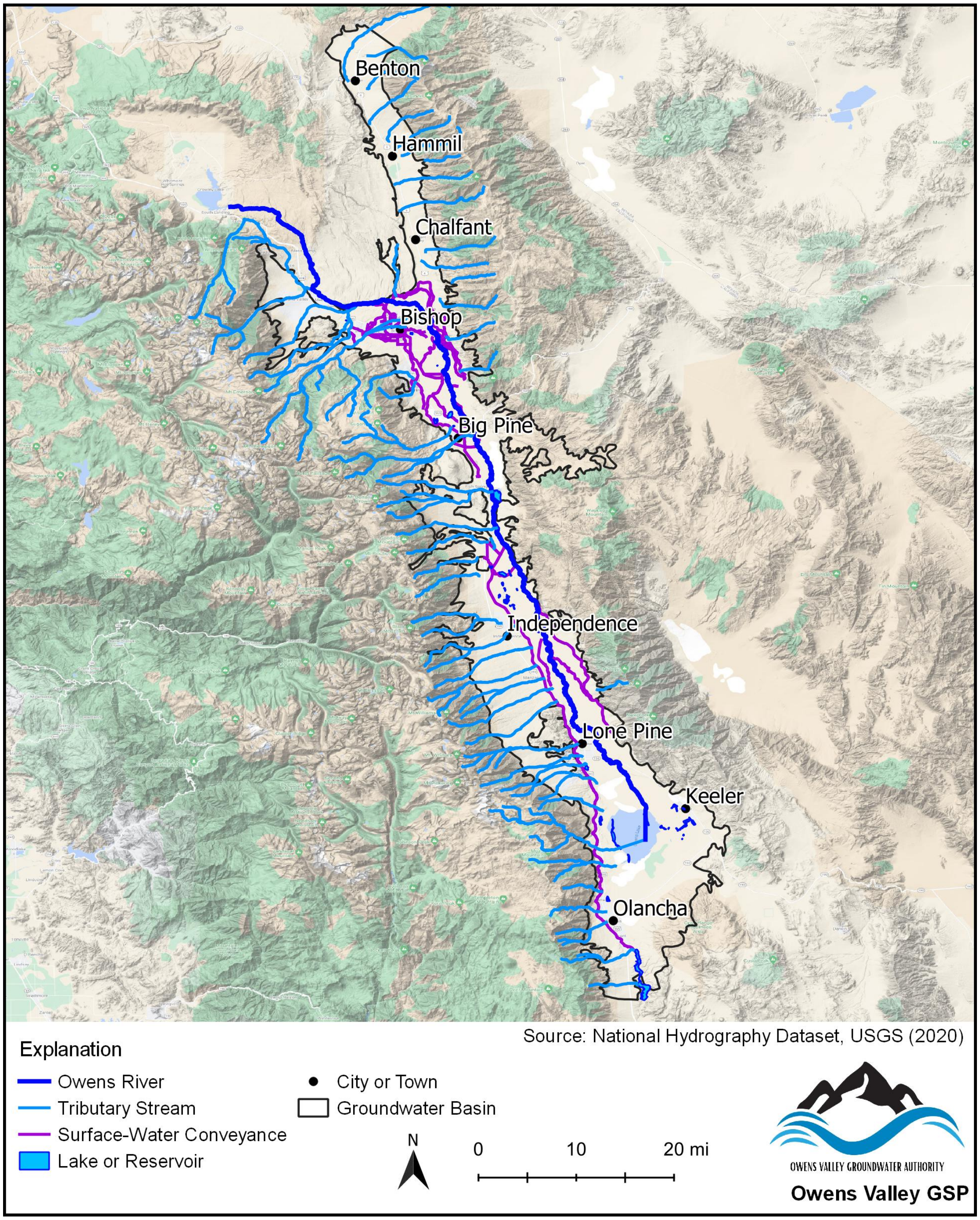

Figure 2-2. Major surface water features of the Basin

to rain-shadowing by the Sierra Nevada. Alluvial fans on the east side of the valley are not nearly as large and overlap less compared those on the west. The Owens River generally flows on the east side of the valley as a result of this asymmetrical fan configuration.

The Owens Valley is a closed basin due to the Coso Range at the southern end of the watershed preventing groundwater and surface-water outflow. Surface-water and groundwater flow toward to the south, the natural terminus of the watershed. Prior to construction of the Los Angeles Aqueduct in the early 20th century inflows to the valley generally exceeded evapotranspiration rates and formed Owens Lake, which covered more than 100 mi^2 and had depths greater than 20 ft (Danskin, 1998). Diversion of surface-water for irrigation within the valley and for export south via the Los Angeles Aqueduct significantly altered the water budget and desiccated the lake by 1926 (Saint-Amand et al., 1986). With the exception of very wet years, Owens (dry) Lake is a playa and was one of the largest sources of dust pollution in the United States due to the combination of high winds and easily erodible sediments (Gill, 1996). In recent years, LADWP has conducted extensive dust control mitigation on the lake including shallow flooding, managed vegetation, and mechanical methods like gravel cover and berm construction.

2.2 Climate

Climate in Owens Valley watershed is strongly correlated with elevation. The high elevation portions of the watershed are cooler (Figure 2-3) and receive the greatest amount of precipitation (Figure 2-4), primarily as snow from October-March. The watershed experiences a strong west-east precipitation gradient due to the "rain shadow effect" caused by the Sierra Nevada. Moist air masses moving westward off the Pacific Ocean rise when they encounter the Sierra Nevada, the rising air cools, and water vapor condenses and falls as rain or snow. As air masses descend the eastern slope, the descending air warms, clouds evaporate, and precipitation declines east of the Sierra Nevada. The combination of topography and the rain shadow effect results in highly variable precipitation in the watershed. Long-term averages of total annual precipitation (1981-2010) are about 57 inches in the Sierra Nevada, 14 inches in the White and Inyo Mountains, and 5.9 inches on the valley floor (PRISM Climate Group, n.d.).

2.3 Vegetation

Native vegetation covers most the Owens Valley watershed (Figure 2-5) as the majority of land area is owned by federal, state, or municipal entities with limited residential or industrial development. Vegetation in the Owens Valley groundwater basin varies with elevation, floristic

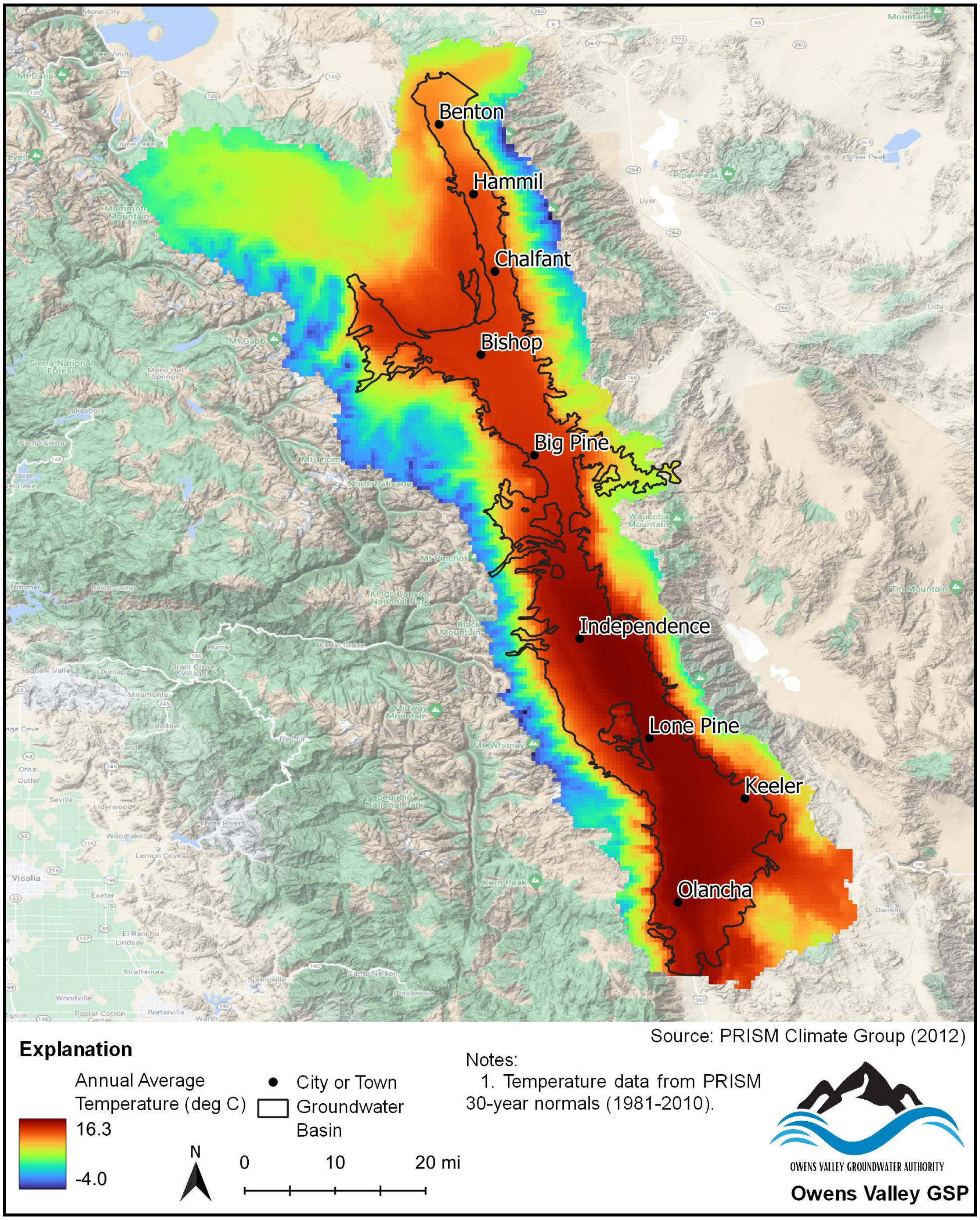

Figure 2-3 Mean Annual Temperature of the Basin,

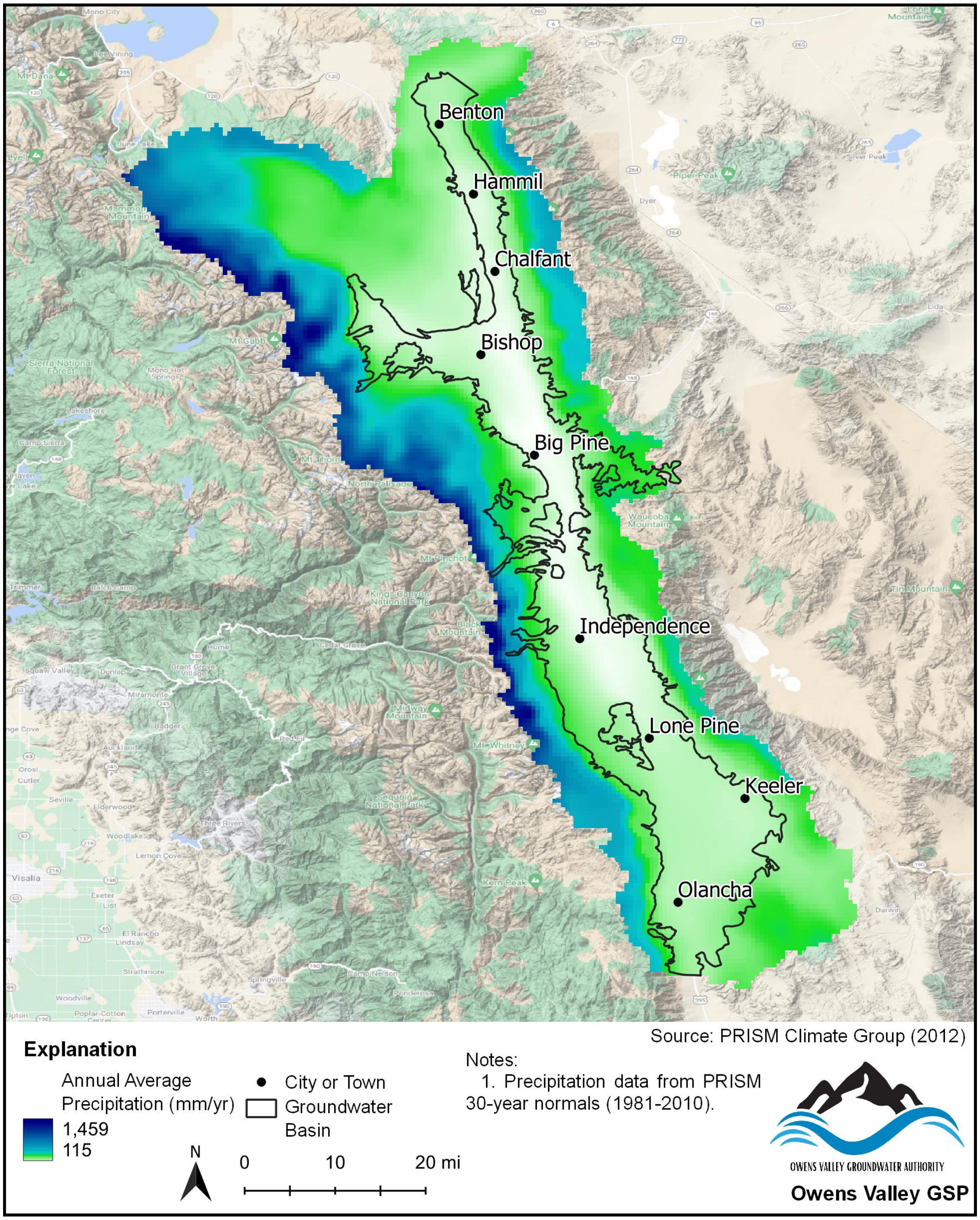

Figure 2.-4. Mean annual precipitation of the Basin.

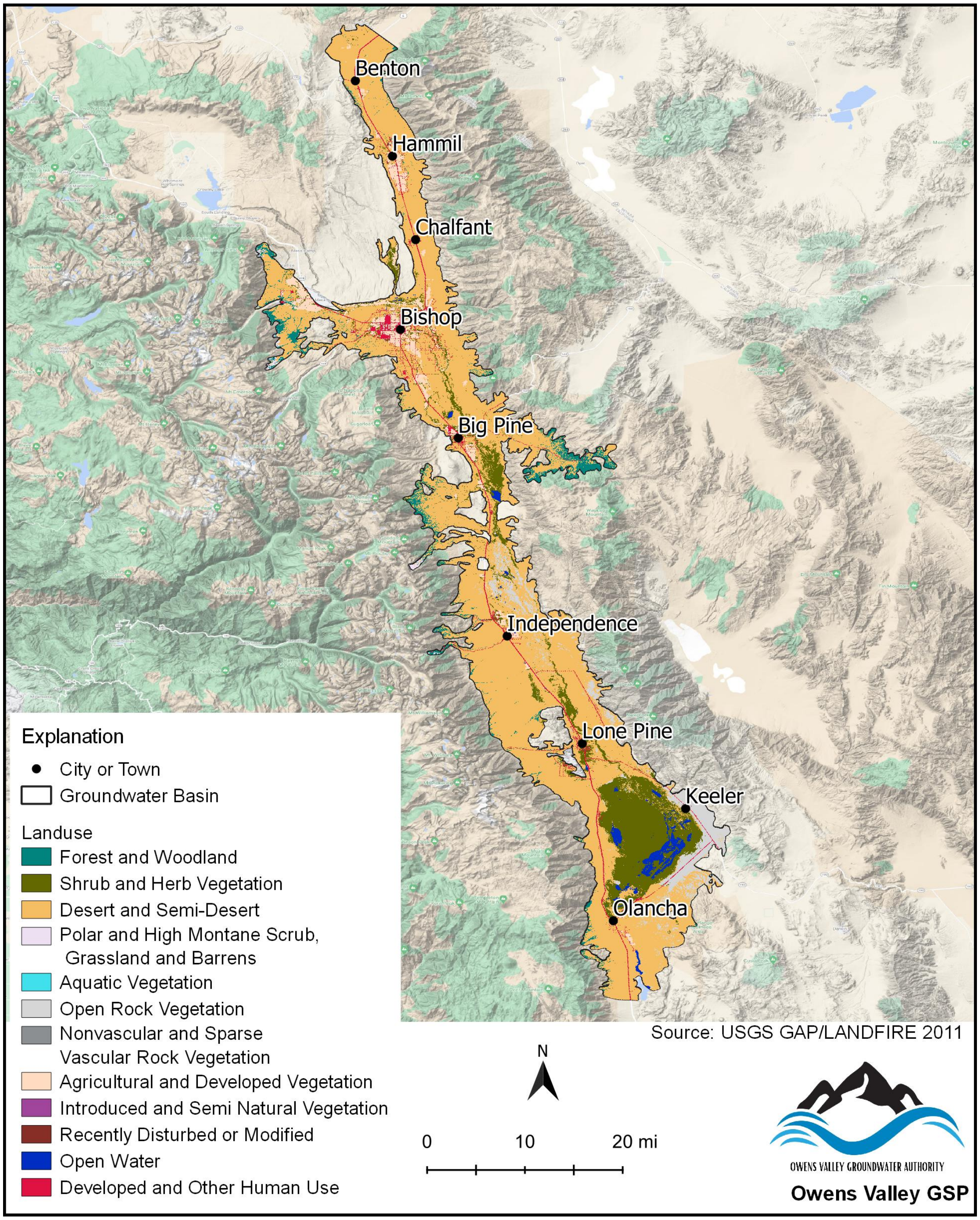

Figure 2.-5. Vegetation types in the Basin.

region, soil salinity, and water availability. Vegetation communities range from salt-tolerant shadscale scrub, alkali sink scrub, desert greasewood scrub, alkali meadow, and desert saltbush scrub on the low elevations of the valley floor, to more drought-tolerant Mojave Mixed Woody Scrub, Blackbush Scrub, and Great Basin mixed scrub on alluvial fans (Danskin, 2000; Davis et al., 1998). The groundwater basin lies on the boundary of the Great Basin and Mojave deserts; consequently, the southern part of the basin has vegetation communities such as Mojave creosote bush scrub characteristic of the hot Mojave Desert to south and the northern part of the basin has communities such as Big Sagebrush scrub characteristic of the cooler, higher elevation Great Basin Desert. Hydric vegetation communities associated with streams, springs, and wetlands occupy relatively small areas of the groundwater basin, but are important habitat resources. At higher elevations in the watershed, vegetation types include Pinyon-Juniper woodland, montane forest and meadow, subalpine forest and meadow, alpine plants, and barren terrain above timberline (Danskin, 2000).

In the arid environment of the Owens Valley, vegetation communities are mediated by hydrology. On alluvial fan surfaces, where the water table is disconnected from the root zone, plants subsist on precipitation alone. Near stream channels, ditches, canals, and along the Owens River, surface-water supports riparian communities. Areas of shallow groundwater support alkali meadow, alkali sink scrub, shadscale scrub, and desert saltbush scrub communities. Groundwater discharge zones support alkali meadow, phreatophytic scrub communities, transmontane alkali marsh and aquatic habitat.

2.4 Soils

Surficial soil data were obtained from the Natural Resources Conservation Service (NRCS) soil survey geographic (SSURGO) database. Areas of similar soils are grouped into map units, which have similar physical, hydrologic, and chemical properties. Map unit properties are assigned a range of values based on the soils contained within them.

The large geographic extent and complex geology of Owens Valley results in a wide range of soil types. A total of 467 unique soil map units were identified within the Owens Valley watershed, with 263 overlying the groundwater basin. Figure 2-6 shows a general summary of these map units classified by soil texture, which covers approximately 78% and 91% of the watershed and groundwater basin area, respectively. Areas not covered by SSURGO data include the eastern Sierra Nevada and the southeastern portion of the watershed.

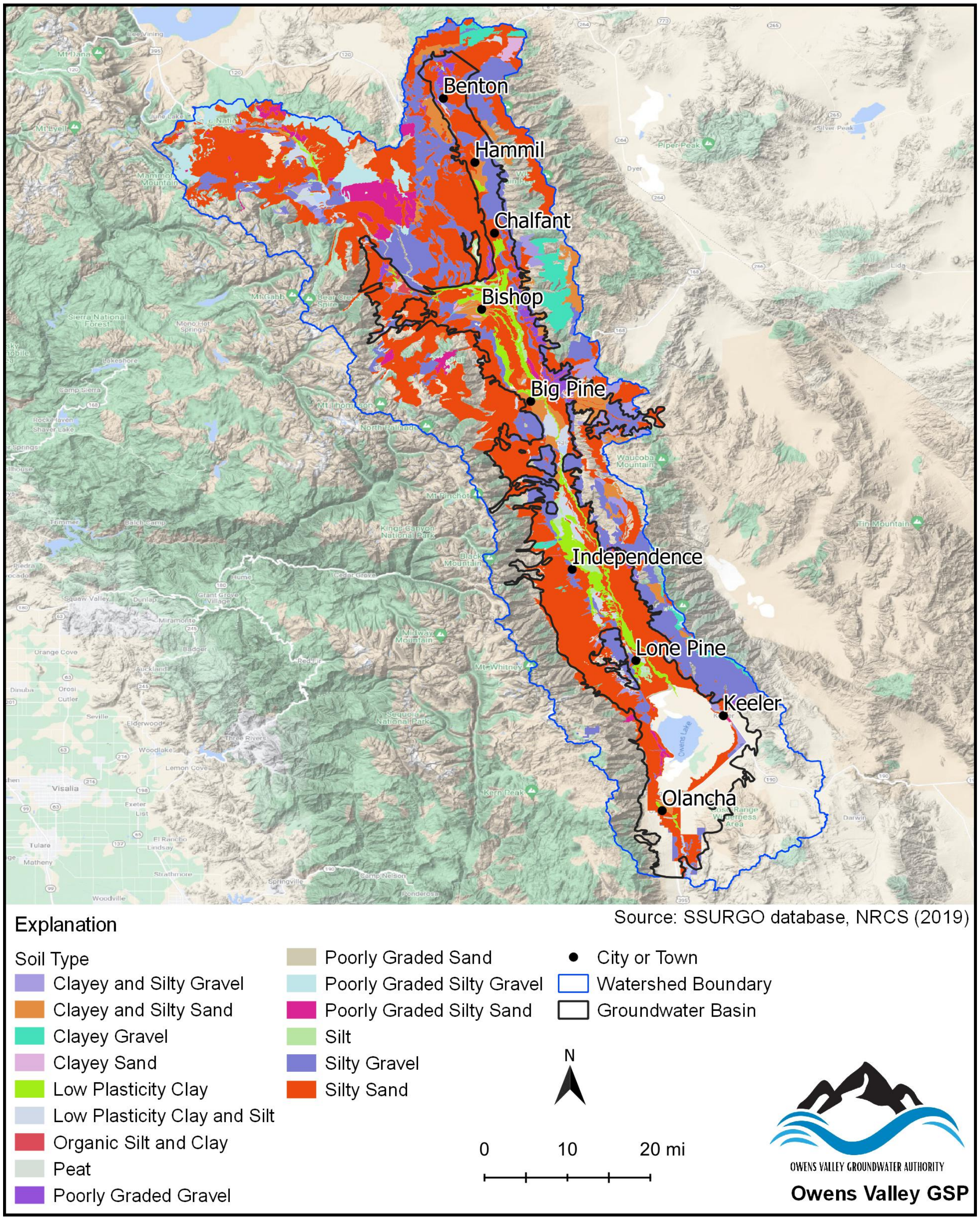

Figure 2-6. Distribution of soil surface textures in the Basin.

Table 2-1 . Summary of groundwater basin surface soil texture composition.

Soil Type	Area (acres)	Area (%)
Silty Sand	303,182	45.69
Unknown	82,501	12.43
Silty Gravel	76,900	11.59
Low Plasticity Clay	51,732	7.80
Clayey and Silty Sand	29,202	4.40
Poorly Graded Gravel	17,933	2.70
Low Plasticity Clay and Silt	17,277	2.60
Silt	10,726	1.62
Clayey and Silty Gravel	4,364	0.66
Clayey Gravel	2,888	0.44
Poorly Graded Silty Sand	2,872	0.43
Organic Silt and Clay	1,681	0.25
Clayey Sand	1,607	0.24
Poorly Graded Sand	1,457	0.22
Peat	333	0.05

Surface soil textures are dominated by sands and gravels, primarily silty sand which alone accounts for 46% of the groundwater basin area (Table 2-1). Finer grained soil textures such as silts and clays make up approximately 25% of the area and are generally located adjacent to the

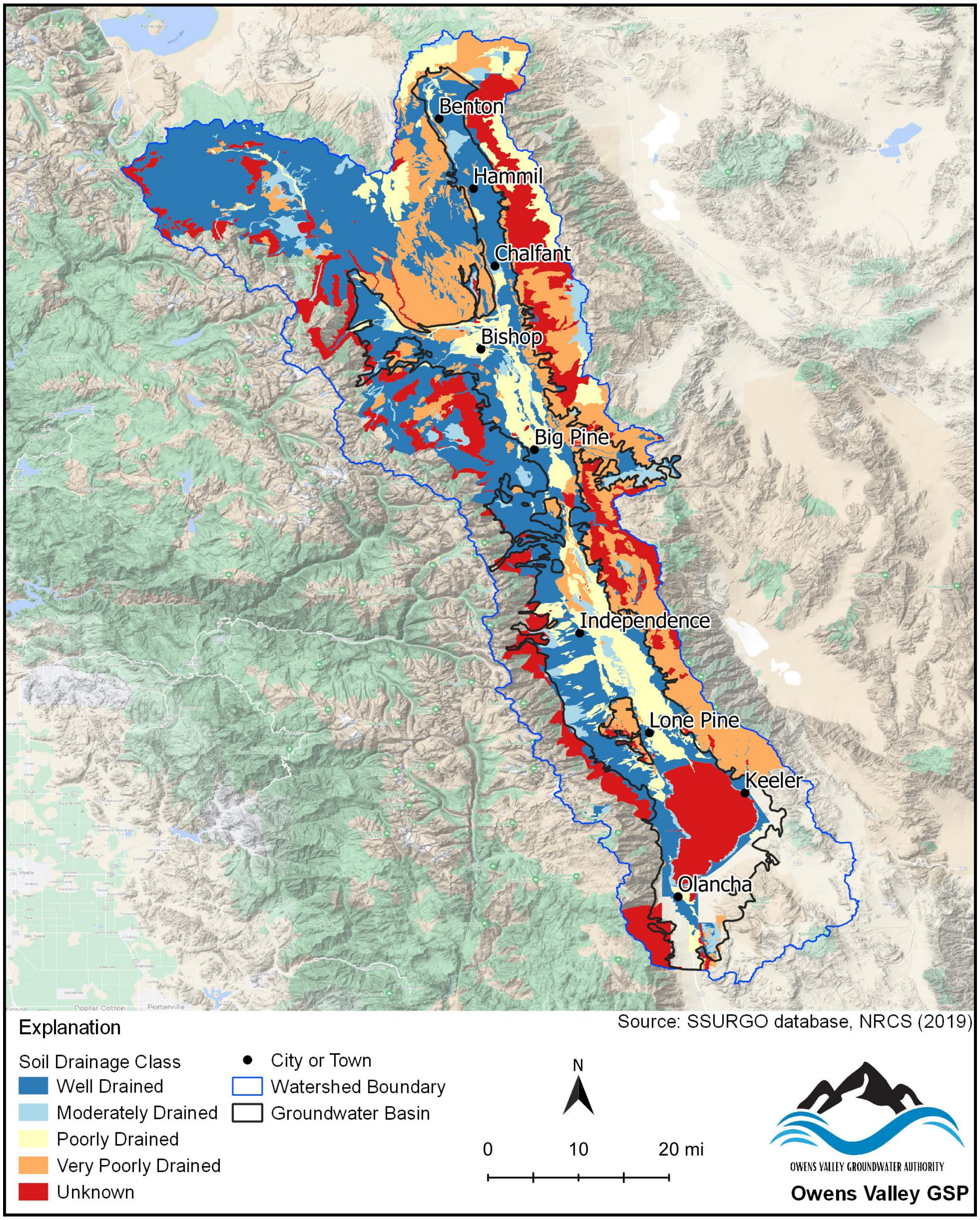

Figure 2-7. Distribution of soil drainage classes in the Basin.

Owens River. About 12% of the area is labeled “Unknown” in the SSURGO database. The majority of this category is located near Owens (dry) Lake, where soils are dominated by evaporite salt deposits (Murphy, 1997).

Figure 2-7 shows the drainage class for soils in the watershed. In general, soils located along the margins of the groundwater basin are well to moderately drained due to a combination of coarse soil textures and the lack of a shallow water table. Poorly drained soils are found primarily in areas adjacent to the Owens River, where finer textured soils and shallow depths to groundwater are found. Although the SSURGO database classifies most of the Owens (dry) Lake area as “Unknown” it can likely be considered poorly drained due to the presence of thick clay layers near the land surface (MWH, 2013) and upward vertical hydraulic gradients (MWH, 2011a).

Saturated soil hydraulic conductivity in the groundwater basin ranges over four orders of magnitude from 0.001 to 32.5 ft/day (Figure 2-8). The lowest conductivity soils are located in the Owens (dry) Lake area and adjacent to the Owens River (excluding areas of exposed bedrock). The distribution of hydraulic conductivity values are similar to the distribution of soil textures in the groundwater basin, which is expected as coarser soil textures tend to have greater hydraulic conductivities. With the exception of Owens (dry) Lake and areas adjacent to the Owens River, saturated hydraulic conductivity within the groundwater basin generally exceeds 5 ft/day. Therefore, infiltration capacity for most of the Owens Valley groundwater basin is considered to be very high.

Soil salinity in the watershed ranges from non-saline to strongly saline (Figure 2-9). In general, the high elevation areas of the watershed and the western portion of the groundwater basin have non-saline soils due to the greater amount of precipitation received. Moderately to strongly saline soils are primarily found adjacent to the Owens River where the water table is shallowest and in the Owens (dry) Lake area where strong vertical gradients move water upwards through saturated clay layers at the surface. The most saline soils in the watershed are found near Owens (dry) Lake where the basin is closed and water can only leave via evapotranspiration which increases the concentration of solutes in the remaining groundwater and salts accumulate in the sediments over time.

2.5 Geology

The geologic history of Owens Valley is a complex mixture of rifting, faulting, volcanism, and deposition, as shown in Figures 2-10 through 2-11. Owens Valley lies at the western edge of the

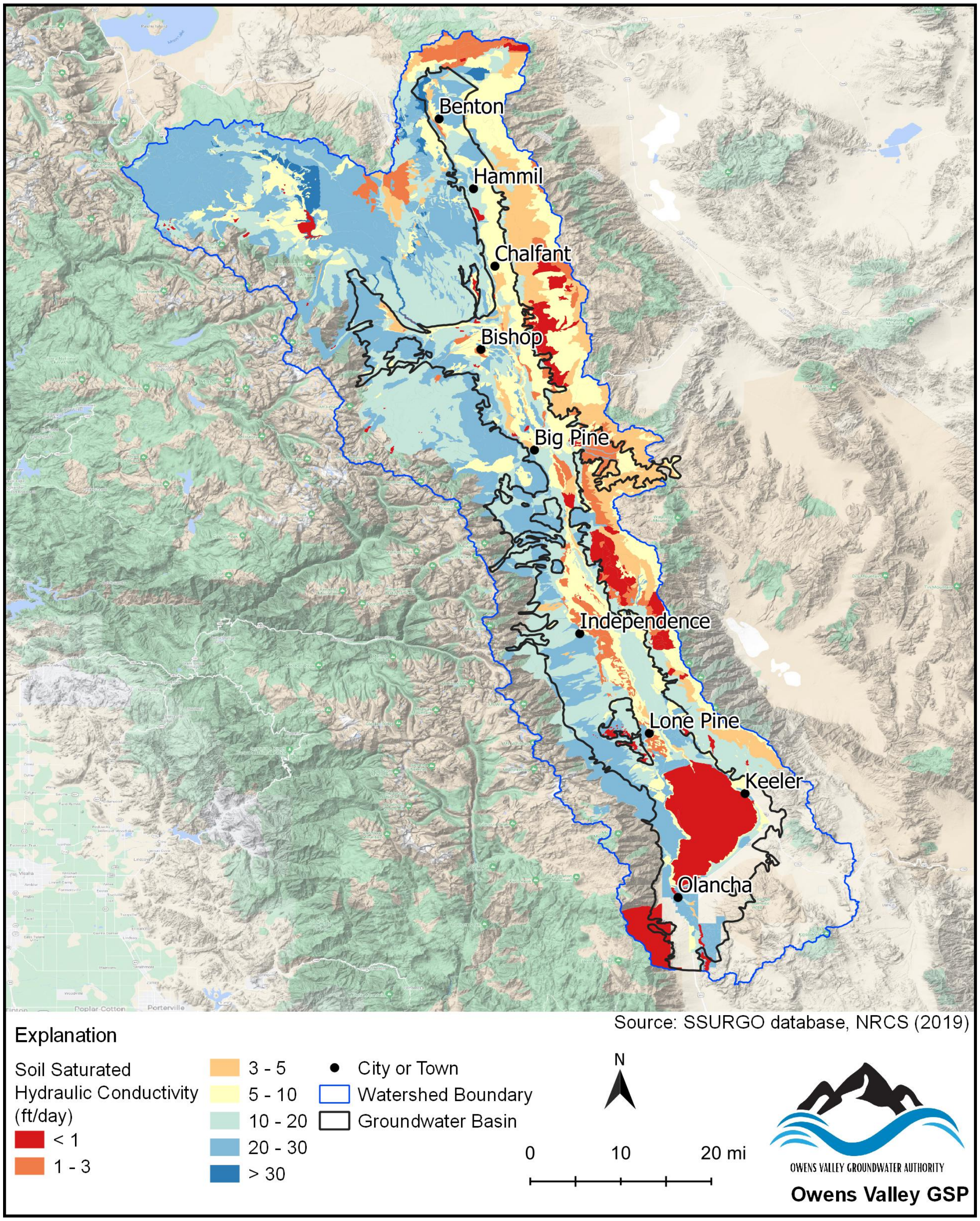

Figure 2-8. Categories of soil saturated hydraulic conductivity in the Basin.

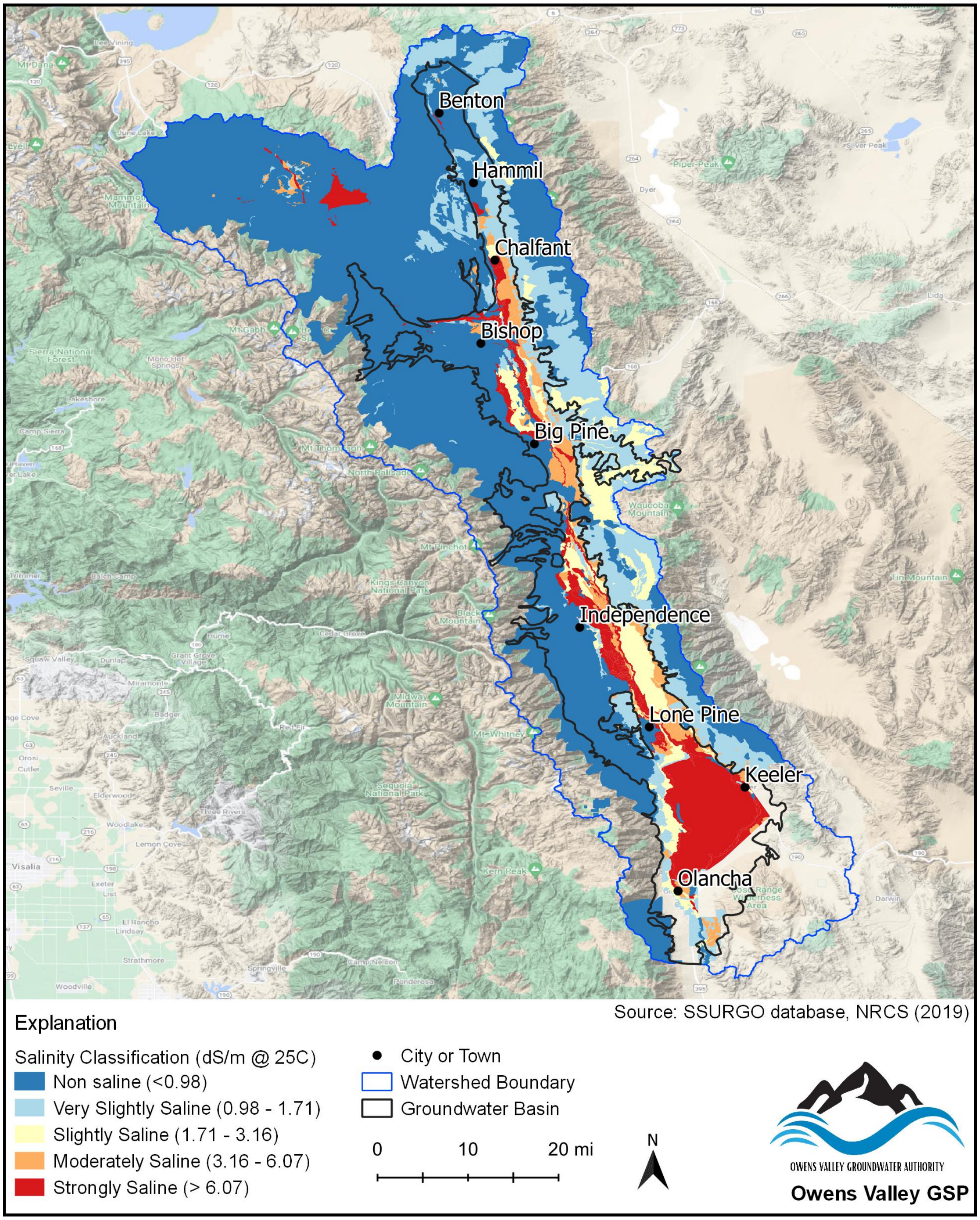

Figure 2-9. Soil salinity in the Basin.

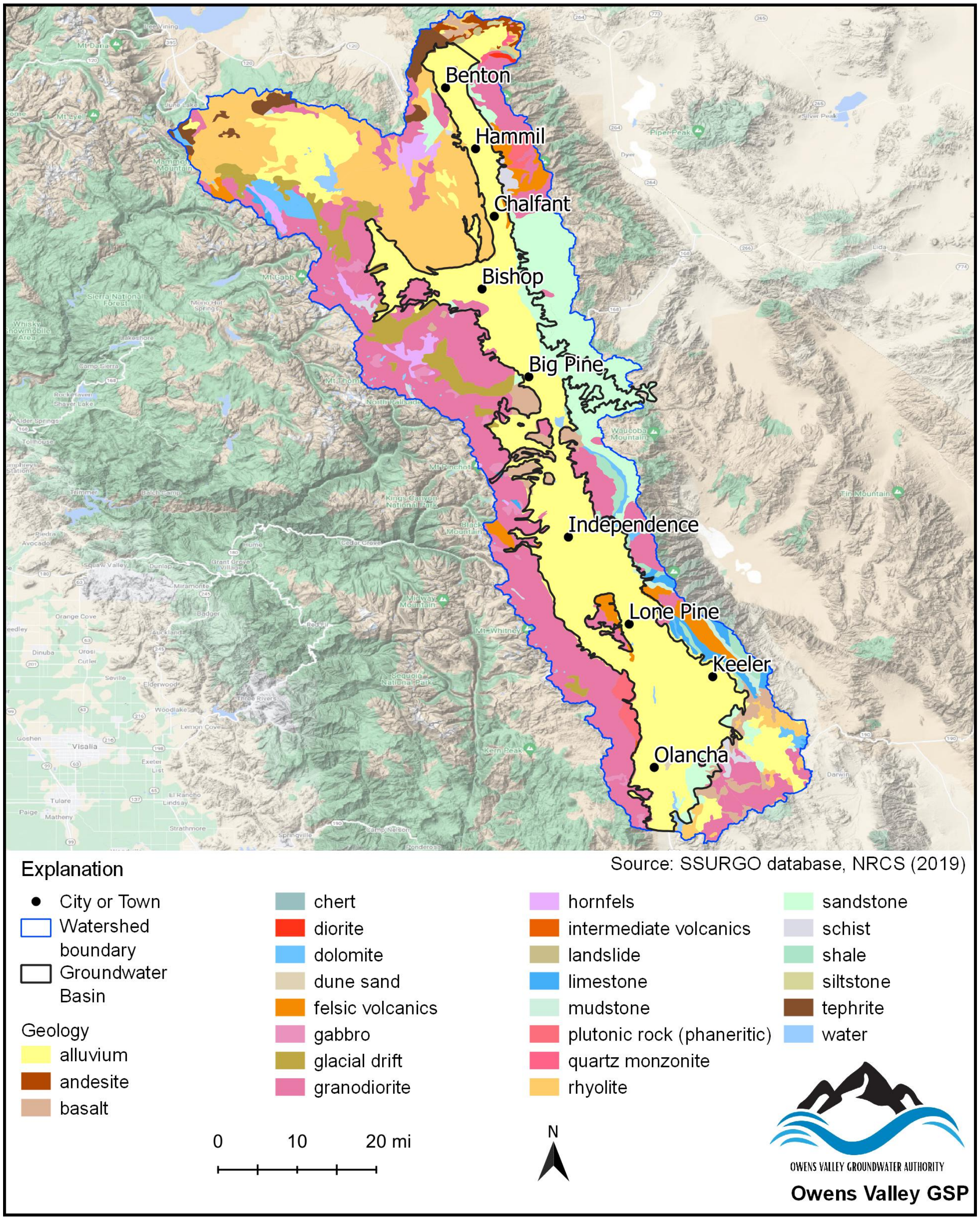

Figure 2-10. Geology of the Basin

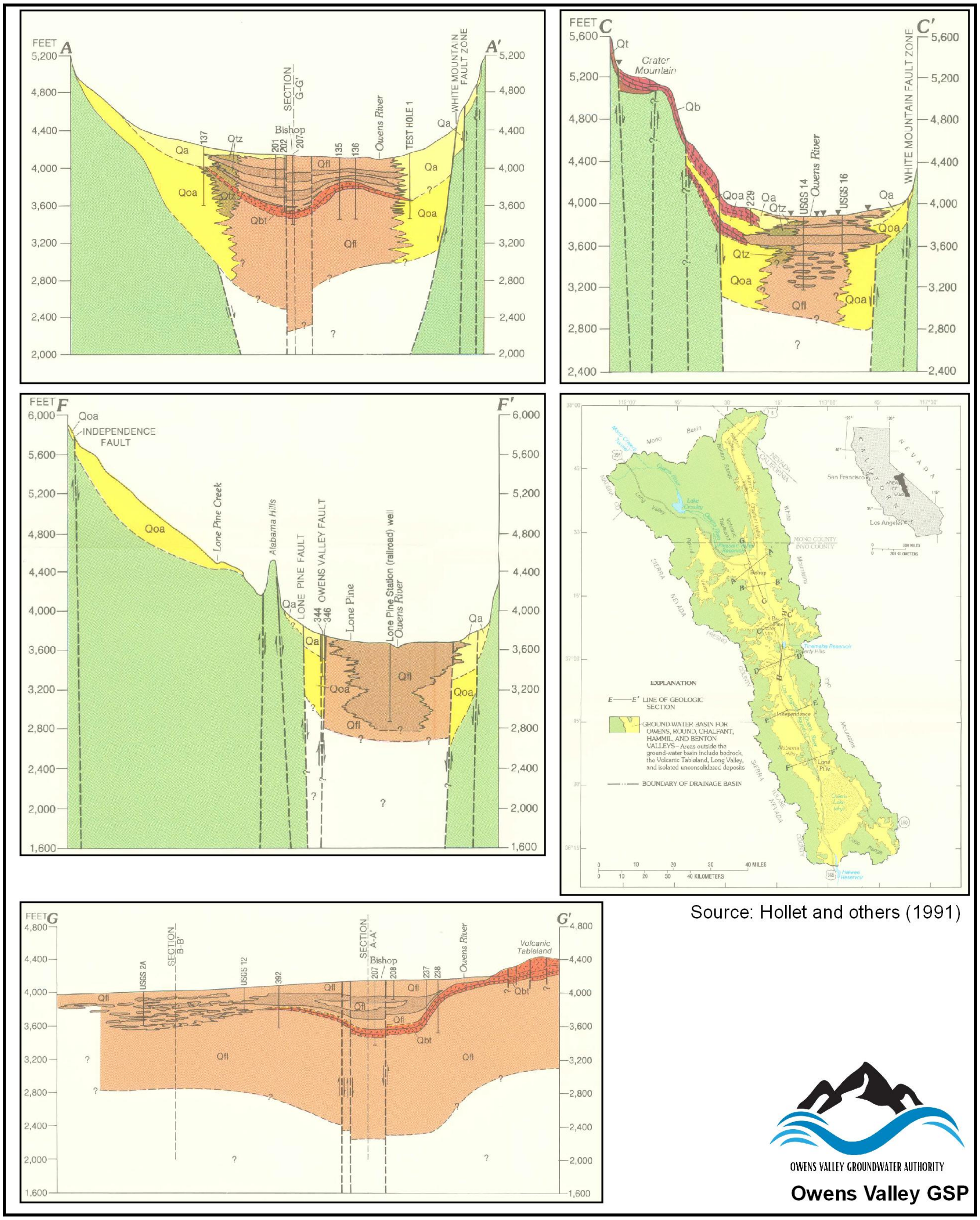

Figure 2-11. Geologic cross sections of the Basin.. Geology of the Basin

Basin and Range Tectonic Province, and the dramatic topography of the basin is an expression of the underlying tectonic processes. The Basin and Range Province is characterized by north-south oriented mountain ranges and narrow intermountain valleys bounded by normal faults, and the Owens Valley is the westernmost basin in the Province. On the west, the Sierra Nevada consists of uplifted granitic and metamorphic rocks, locally mantled by glacial and volcanic deposits. To the east, the White-Inyo Range consists of Paleozoic sediments, Mesozoic volcanic rocks, and metamorphic rocks that have been folded, faulted, and intruded by granitic plutons, and are locally mantled with Quaternary sediments and Tertiary volcanic rocks. The present topography was produced by extensional faulting that initiated in the Miocene and produced northwest trending faults (Hollett et al., 1991). A later phase producing north-south trending normal and strike slip faults initiated in the Pliocene or Pleistocene and is still active. The contact between low permeability fault-bounded mountain blocks and more permeable valley-fill material generally forms the bedrock boundaries of groundwater basin; however, the basin boundary west of Chalfant and Hammil valleys is formed by the edge of the surficial expression of the Bishop Tuff, a Pleistocene rhyolitic ignimbrite that overlies basin fill and bedrock (Hollett et al., 1991).

The Sierra Nevada and the White-Inyo Range were glaciated during the Pleistocene and Holocene. Glaciation was far more extensive in the Sierra Nevada due to its westerly position, proximal to the Pacific Ocean and incoming synoptic scale storms. Glacial moraines extend beyond the range front and into the groundwater basin in the region from Big Pine to Round Valley, contributing material to the alluvial fans flanking the Sierra Nevada (Bateman et al., 1965).

Owens Valley was formed as a result Basin and Range extensional tectonics that caused land surface parallel to the fault trace to subside. The down dropped valley block created space into which valley-fill accumulated, consisting mainly of sediment shed from the adjacent mountain blocks deposited in alluvial fans, rivers, and lakes in the valley. Basalt flows erupting from volcanoes formed due to crustal thinning as a result of the extension are interbedded with the valley-fill in some locations. Sedimentary material consists of unconsolidated to moderately consolidated alluvial fan and glacial moraine deposits adjacent to the mountain range fronts, fluvial plain deposits near the axis of the valley, deltaic deposits, and lacustrine deposits. Older alluvial fan deposits tend to be elevated and at the margins of the valleys. Sediments of the central axis of the valleys are typically fluviolacustrine, playa, and dune deposits. In well logs, these valley fill sediments are expressed as sands, gravels, boulders, and clay layers. Sedimentary strata are variable vertically and laterally. Depositional environments change over relatively short distances resulting in laterally discontinuous sand, gravel, and clay lenses. Tectonic activity and climate variations change sediment supply and depositional energy at any given point, resulting in lithologies changing over vertical distances of a few feet to a few dozen feet. Laterally extensive clay strata are present beneath Owens (dry) Lake and in the Big Pine area. Owens Lake expanded and contracted during Pleistocene glacial and interglacial periods, periodically rising above the topographic high at the south end of Owens Valley to hydrologically connect with Searles Lake and Lake Manly. Owens Lake most recently overflowed into Rose Valley and Indian Wells Valleys to the south about 3 thousand years ago (ka).

Volcanic rocks are present as valley fill near the basaltic cinder cones and flows of the Big Pine Volcanic Field south of Big Pine, in small basaltic plugs west of Bishop, and in the northern Owens Valley as Bishop Tuff. Bishop Tuff is a rhyolitic welded tuff erupted from the Long Valley Caldera 767 ka (Crowley et al., 2007), northwest of Owens Valley. Bishop Tuff dominates the land surface north of Bishop and west of Chalfant and Hammil Valleys, and is present at depth in well logs from all of these locations. The Bishop Tuff consists of basal unconsolidated pumice, overlain by a dense heat-welded zone, and a less dense gas welded zone. Where Bishop Tuff forms the groundwater basin boundary west of Chalfant and Hammil valleys, it is likely underlain by valley fill. In the Owens River Gorge, near the northwestern extent of the groundwater basin, Bishop Tuff is underlain by granitic bedrock. Hollett et al. (1991) considered that recharge to valley fill was likely to occur where the basal pumice layer of the Bishop Tuff was exposed, and that recharge through the welded zones was unlikely except along faults and fractures. Basalt flows south of Big Pine emanate from vents along the range front and are interstratified with valley-fill sediments. Basalts between Big Pine and Independence are the highest permeability aquifer materials found in Owens Valley.

Structural geology and geometry of the Owens Valley groundwater basin is dominated by faulting related to regional tectonism, with both normal and strike-slip components. Faults at the margins of the basin are generally normal faults with the basin down-dropped relative to the mountain blocks. Some mountain-downward normal faults occur locally, forming minor grabens along the range front. Faults found in the valley-fill are generally parallel to the axis of the valley. The Owens Valley Fault extends from Owens (dry) Lake to north of Big Pine. The largest recorded earthquake in the Basin and Range Province occurred on the Owens Valley Fault in 1872, with an estimated magnitude of 7.5-7.8, generated by dominantly right-lateral motion. Numerous sag ponds, sand blows, pressure ridges, and other features related to the 1872 event are present along the trace of the fault (Beanland & Clark, 1982; Slemmons et al., 2008). Other faults occur as branches of the range front faults and Owens Valley Fault. A number of springs occur along faults where the faults act as barriers to flow across the fault plane. In the Volcanic Tableland, the Bishop Tuff is broken by many north-south and northwest-southeast oriented fault scarps, the largest of which forms the eastern boundary of Fish Slough, north of Bishop and west of Chalfant Valley (Harrington, 2016).

Bedrock beneath the Owens Valley fill consists of down-dropped fault-bounded blocks at varying depths. Numerous geophysical methods have been used to define the form and depth of the bedrock surface (Danskin, 1998; MWH, 2010, 2011b; Pakiser et al., 1964), which showed that the bedrock beneath the valley is not a single down-dropped block, but rather is a series of deep basins separated by relatively shallow bedrock divides. The deepest part of the basin is beneath Owens (dry) Lake and is overlain by more than 8,000 feet of valley fill, and another deep basin is estimated to have valley-fill of about 4,000 feet thick lies between Bishop and Big Pine (Hollett et al., 1991). Other shallower basins are present east of Lone Pine and beneath Hammil Valley. These basins are separated by blocks of shallower bedrock. Valley-fill strata within the deeper portions of the basin have a “stacked bowl” configuration with the deepest part of each stratigraphic horizon occurring in the deepest part of the basin. Gravity data indicate bedrock is relatively shallow between Benton and Hammil valleys and between Laws and Chalfant Valley located east of Fish Slough subbasin (Hollett et al., 1991; Pakiser et al., 1964).

2.6 Hydrogeologic Framework

Approximately 35% of the land area and the majority of water rights in Owens Valley groundwater basin are owned by the Los Angeles Department of Water and Power (LADWP) for the purpose of exporting water from the Eastern Sierra to Los Angeles (Figure 2-12). Los Angeles has developed extensive facilities for water storage and export, land and water management, groundwater production, groundwater recharge, surface-water and groundwater monitoring, and dust control. Because of the importance of water supplied from Owens Valley to Los Angeles, LADWP monitoring is extensive and considerable study has been devoted to Owens Valley hydrology. Conversely, Chalfant, Hammil, and Benton valleys, collectively referred to as the Tri-Valley area, are less studied and monitoring is relatively sparse as LADWP owns little land in those areas.

The primary surface-water features in the groundwater basin are the Owens River and its tributaries draining the eastern slope of the Sierra Nevada (Figure 2-2). The Owens River flows

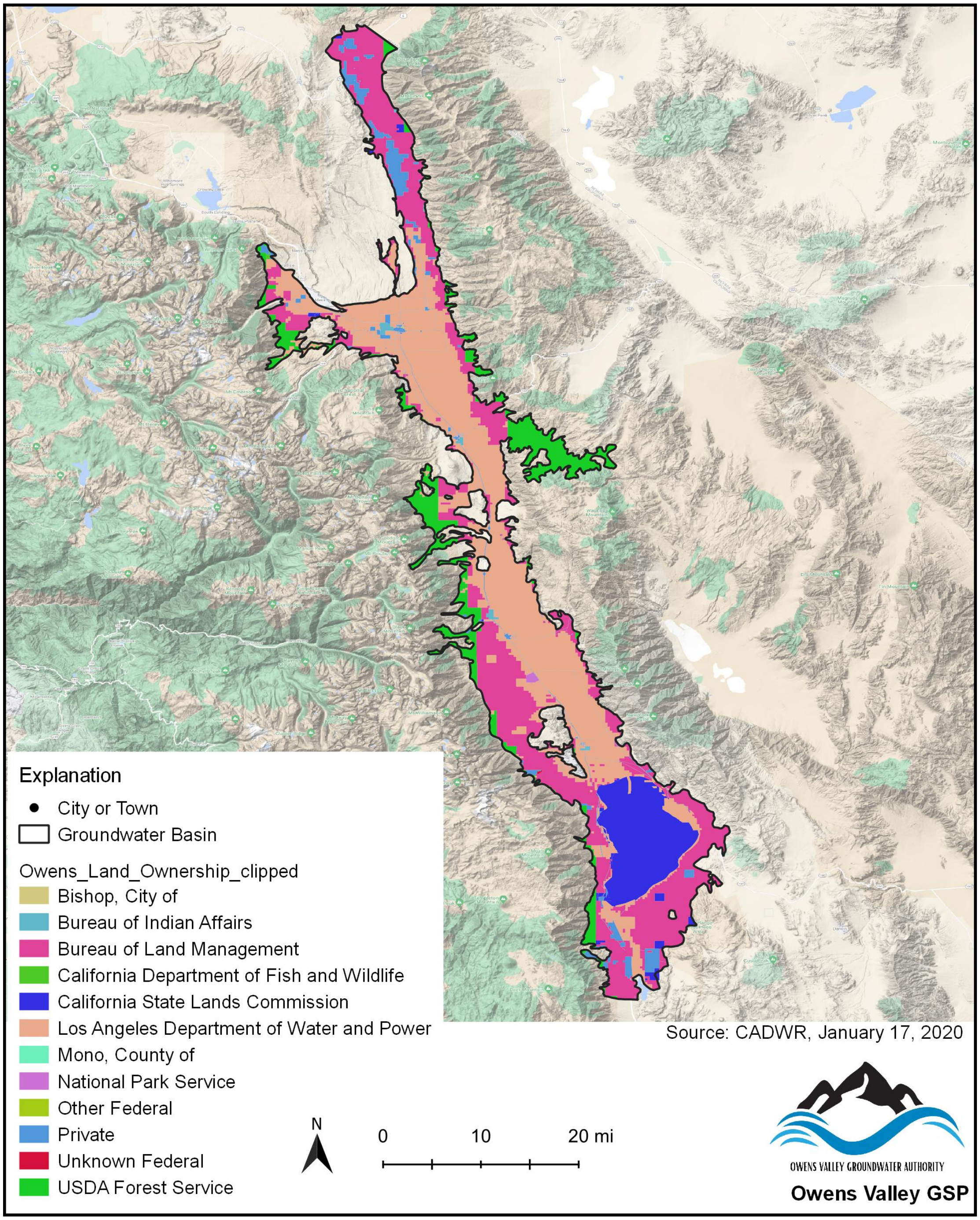

Figure 2-12. Land ownership of the Basin.

from Long Valley, enters the northwest potion of the groundwater basin, and flows south towards Owens (dry) Lake. Streams draining the high elevations of the east slope of the Sierra Nevada join either the Owens River or are diverted into the Los Angeles Aqueduct. Like many watersheds in the Basin and Range Province, the Owens Valley is internally drained with the natural terminus of the watershed at Owens (dry) Lake. Flow in the Owens River is controlled by a series of reservoirs operated by LADWP and Southern California Edison Corporation (SCE), supplemented near its headwaters by diversions through the Mono Craters Tunnel from the Mono Basin.

Streams within the Owens River watershed that have a significant amount of runoff are gaged by LADWP. The combined total of these gages is reported as a single value referred to as "Owens Valley Runoff" (OVR). Water-year (WY; period from October 1 - September 30 designated by the calendar year in which it ends) totals of OVR from 1935 - 2017 ranged from 188,000 acre-feet per year (AFY) to 835,000 AFY, with a median value of 392,000 AFY. Releases from Pleasant Valley Reservoir, where the Owens River enters the groundwater basin, had a median value of 256,000 acre-feet per year (AFY) and ranged from 75,000 to 444,000 AFY from WY 1959-2017. Numerous tributary streams drain the east slope of the Sierra Nevada and either join the Owens River or are diverted into the Los Angeles Aqueduct. The largest of these, Bishop Creek, has median annual runoff of 71,000 AFY and ranged from 35,000 to 134,000 AFY for WY 1904-2017. Non-Owens River inflows to the Owens Valley groundwater basin for all additional gaged tributaries (including Bishop Creek) ranged from 106,000 to 418,000 AFY, with a median of 181,000 AFY from WY 1988-2017.

No direct surface-water connection exists between the Tri-Valley area and the Owens River except for an ephemeral wash that occasionally flows from Hammil through western Chalfant into the Laws area during extreme runoff or precipitation events. Surface-water that enters the Tri-Valley area as runoff from the surrounding mountains, less any water lost to evapotranspiration or vadose zone storage, is believed to recharge groundwater. In wet years LADWP diverts a portion of surface flows from the Owens River into the McNally Canals, the majority of which recharges groundwater in the Laws area due to the canals intersecting coarse sands and gravels. Similarly, LADWP diverts Owens River water annually for irrigation near the communities of the Bishop and Big Pine. These diversions are more consistent than those for the McNally Canals. Flow data for Tri-Valley streams is very limited, with only one long-term LADWP gage established in the southern portion of the Tri-Valley for Piute Creek. The western slopes of the White Mountains have streams that have been described as perennial, with high flows during the snowmelt period or following intense rainstorms (PW&A, 1980). Most of these streams are either diverted for irrigation or rapidly infiltrate into the alluvial fans once they enter the valley floor. Runoff from the surrounding mountains into the Tri-Valley area has been estimated to range from about 16,500 to 27,000 AFY on average (MHA, 2001; PW&A, 1980). Results from a Distributed Parameter Watershed Model (DPWM), a rainfall-runoff model which accounts for snowpack, that simulates conditions in the Tri-Valley from WY 1995-2019 produces average inflows of about 18,000 AFY and median inflows of about 13,500 AFY (see Appendix 10 -DPWM Tech Memo).

The Fish Slough subbasin, located to the north of Bishop and to the west of Chalfant Valley in the volcanic tablelands, is a federally-designated Area of Critical Environmental Concern (ACEC) due to the presence of rare plants and animals. Although little precipitation falls directly on the Fish Slough subbasin, habitat is supported by groundwater discharged to springs and seeps along faults. Some of this discharge becomes surface-water runoff that flows approximately five miles and eventually enters the Owens Valley groundwater basin north of Bishop. Annual runoff volume from Fish Slough has steadily declined by approximately 78 AFY over the last half century. Mean annual volume reported at LADWP Station 3216 (Fish Slough at L.A. Station #2) was 6,500 AFY for WYs 1967-1976, and 3,400 AFY for WYs 2008-2017. While all the sources of groundwater discharging into Fish Slough are poorly understood, existing evidence suggests, a large portion comes from the Tri-Valley area (Jayko & Fatooh, 2010, Zdon et al., 2019).

Inflows to the Owens Valley groundwater system are primarily sourced from infiltration of surface-water into alluvial fans near the margins of the valley, with a small amount of recharge derived from direct precipitation on fan surfaces, deep percolation from irrigated agricultural fields, and seepage from losing reaches of the Owens River, Los Angeles Aqueduct, numerous Sierra creeks and irrigation ditches in the valley. Groundwater flows from recharge areas high on the alluvial fans (areas of high hydraulic head) to discharge areas on the valley floor (areas of low hydraulic head) resulting in groundwater flow directions that roughly parallel topographic gradients (Figure 2-13). Most natural groundwater discharge occurs on the valley floor in the form of spring flow, wetlands, baseflow to gaining reaches of the Owens River, evapotranspiration in phreatophytic vegetation communities, and evaporation from valley lakes, reservoirs, Owens Lake playa, and Owens Lake brine pool.

The basin boundaries are generally delineated by the contact between alluvium and the bedrock of the adjacent mountain blocks. At the south end of the basin, the boundary is defined by the topographic high between Owens Valley and Rose Valley. This portion of the basin boundary is

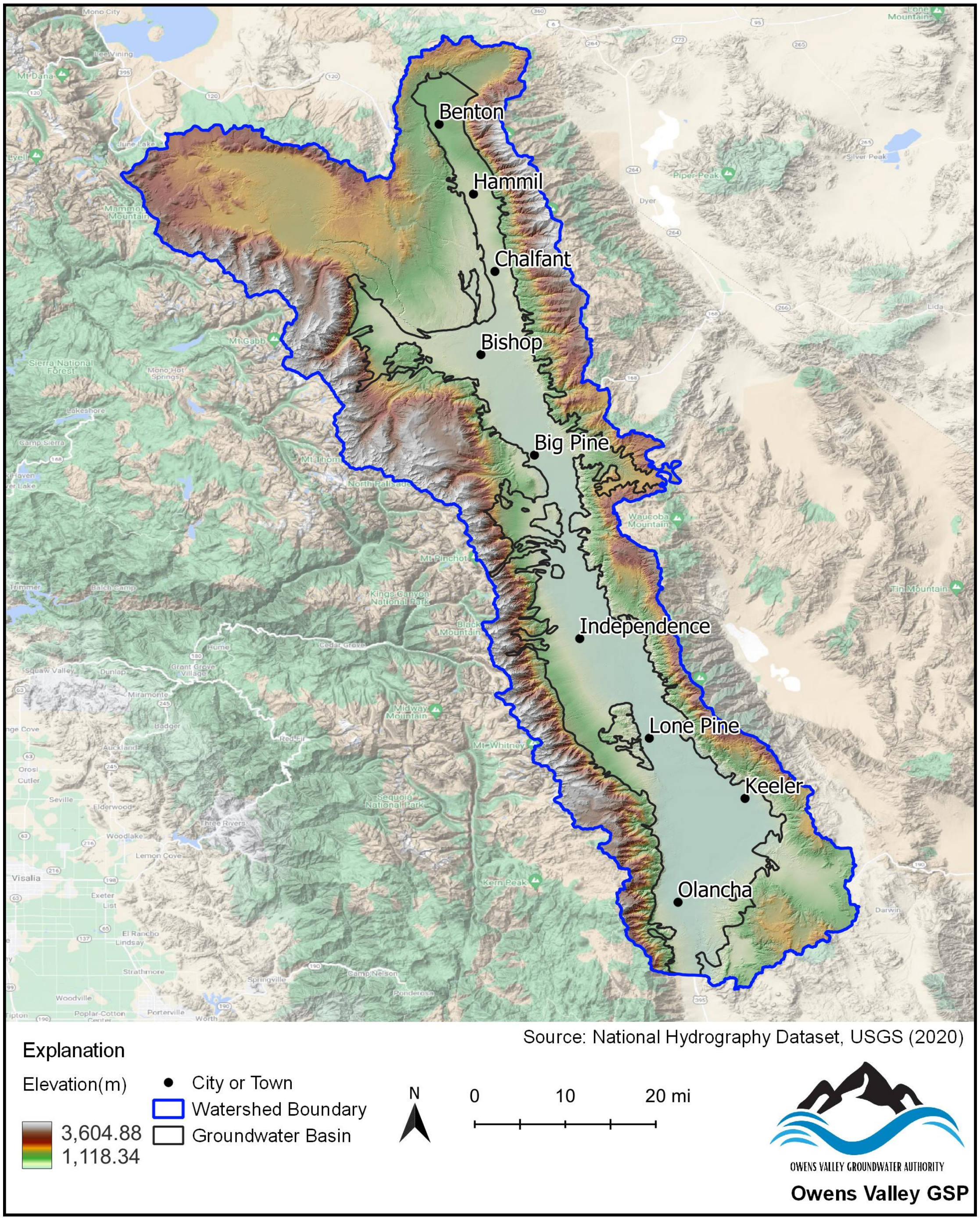

Figure 2-13. Physiography of the Basin

in alluvium and straddles north and south Haiwee reservoirs. It was previously hypothesized that a permeable pathway south to Rose Valley could exist. However, more recent potentiometric data indicate the basin is indeed closed and there is no significant groundwater outflow to Rose Valley (MWH, 2013). The boundary west of Chalfant and Hammil valleys is formed by the contact between valley-fill alluvium and the Bishop Tuff. At this boundary, the Bishop Tuff likely overlies valley fill that was present when the tuff was deposited. The northeastern boundary of Benton Valley is jurisdictional, formed by the California-Nevada state line. The bedrock boundary at the bottom of the valley fill has been characterized by geophysical methods (Pakiser et al., 1964) and, as noted earlier, reveals that the basal bedrock forms deep basins separated by bedrock highs. Shallow bedrock is present between Chalfant Valley and Laws, between Benton and Hammil valleys, and between Big Pine and the Los Angeles Aqueduct intake.

Valley fill material is highly heterogeneous and although sedimentary strata generally cannot be traced over long distances, the basin's aquifer system can be generalized into a shallow unconfined zone and a deeper confined or semi-confined zone or zones separated by confining units (Figure 2-11). A review of 251 driller's logs of wells in Owens Valley found that 89% of wells had indications of low permeability material in the well log (MWH, 2003). This three-layer conceptual model was used in numerical groundwater flow models for Owens Valley (Danskin, 1988, 1998) and the Bishop-Laws area (Harrington, 2007). The shallow zone is nominally about 100 feet thick and the transmissive portion of the deeper zone extends to approximately 1,000 feet below land surface.

Most of the valley fill is clastic material shed from the surrounding mountains, the majority of which is sand and gravel. Alluvial fan sediments are coarse, heterogeneous, and poorly sorted at the head of the fan and finest at the toe. The transition zone from fan to valley floor deposits is characterized by relatively well-sorted sands and gravels that likely originated as beach, bar, or river channel deposits. This zone is a favored location for LADWP groundwater wells because the well-sorted sandy aquifers provide high well yields and the transition zone corresponds to the alignment of the Los Angeles Aqueduct. Extraction of groundwater from the transition zone has impacted groundwater dependent vegetation such that LADWP has implemented or plans to implement a number of revegetation, irrigation, and habitat enhancement projects to mitigation the effects of groundwater pumping (LADWP and County of Inyo, 1991).

Although volcanic flows comprise a relatively small volume of the valley fill, the most transmissive aquifers in the Owens Valley occur in basalt flows between Big Pine and Independence. Historically, the largest springs in Owens Valley occur where high permeability basalt flows terminate against lower permeability sediments or are in fault contact with sediments. Most of these large springs stopped flowing shortly after 1970 due to increased groundwater pumping (LADWP and County of Inyo, 1991).

Hydraulic conductivity, determined from aquifer tests in Owens Valley and the Owens Lake area, ranges from less than 10 ft/day to over 1,000 ft/day (see Figure 16 in Danskin, 1998; Table 3-6 in MWH, 2013). Where lacustrine sedimentation has prevailed for long periods of time at Owens Lake and Bishop-Big Pine area, extensive thick clay confining layers are present. Although the clay layers are disrupted and off-set by faulting, the confined nature of the deep aquifer is evident from generally higher heads in the deep aquifer than in the overlying shallow aquifer and the presence of flowing artesian wells near Bishop, Independence, and Owens Lake. A modeling effort in the Tri Valley and Fish Slough region estimated hydraulic conductivities in the range of 0.01 to 125 ft/day, with most of the values falling in the 1 to 20 ft/day range (MHA, 2001). These values are much lower than those from the Owens Valley and Owens Lake, possibly due to model calibration artifacts.

The principal geologic structures affecting groundwater flow are the basin's bedrock boundaries and faults in the valley-fill material (Figure 2-11). The bedrock boundaries delineate the geometry of permeable valley fill. Faulting generally parallels the axis of the valley and can form barriers to groundwater flow across the faults due to the offset of high permeability layers and due to the formation of low permeability material in the fault zone resulting from fault motion (fault gouge). Evidence for faults acting as groundwater flow barriers includes emergence of springs along fault traces, sharp changes in water table elevation across faults, and reversal of vertical gradients observed in wells with multiple screened intervals on opposite sides of faults. North of the Alabama Hills, blocks of aquifer are compartmentalized by en-echelon faults, restricting lateral flow into the compartments. Recharge to individual compartments is limited to local sources such as a stream segment within the compartment or precipitation. Absent lateral inflow, effects of pumping may be more long-lasting in compartmentalized areas, because recharge in compartmentalized aquifers may be limited to direct precipitation, which provides relatively little recharge.

Due to the arid landscape, aquifers in the Owens Valley serve a variety of purposes. Irrigation and domestic water supply are the primary aquifer uses in Tri-Valley, with agriculture being the dominant use. Some portion of groundwater is likely discharged from Tri-Valley into Fish Slough which creates springs that sustain habitat for endangered species such as the Owens pupfish and the Fish Slough milk-vetch. In the central Owens Valley between Tri-Valley and Lone Pine, the majority of groundwater extractions are from LADWP for export to Los Angeles for municipal use. In-valley uses of groundwater water include irrigation for agriculture, municipal supply, domestic use, and support of phreatophytic vegetation on the valley floor. Groundwater pumped from the Owens Lake portion of the aquifer system includes relatively small volumes of water for municipal and domestic use, industrial use from a single water bottling plant, agricultural irrigation, and recreational use at an approximately 6 acre water ski pond. Natural springs and flowing artesian wells also provide localized habitat in the area.

Outside of the Owens Lake area, water quality is generally very good due to the large amount of snowmelt runoff in the largely undeveloped Eastern Sierra Nevada that recharges the groundwater aquifer combined with the limited amount of industry and agriculture in the basin itself. Arsenic is the primary constituent of concern with naturally occurring but elevated concentrations observed in localized areas, believed to be sourced from dissolution of volcanic rocks. Evaporative concentration of solutes (primarily salts) in the Owens Lake area caused by the lack of a physical outlet results in generally poor groundwater quality in the immediate vicinity of the Owens Lake area, and therefore limited pumping demand. The small number of groundwater users generally pump water from the upgradient margins of the playa, presumably sourcing the relatively low total dissolved solids (TDS) concentration of recharge water sourced from the Sierra Nevada before it mixes with the high TDS Owens Lake groundwater.

The majority of groundwater dependent ecosystems (GDEs) within the Owens Valley are composed of phreatophytic vegetation that relies on shallow groundwater as a primary water source or small wetland areas adjacent to springs or abandoned flowing artesian wells. Appendix 9 shows the extent of GDEs within the GSP area that have been identified. Note that this does not include GDEs known to be present in the valley that are located on lands owned by the LADWP (see Appendix 9 for more details), as management and protection of those GDEs are covered by the Inyo-LA Long Term Water Agreement and therefore not subject to SGMA regulations. Most of the GDEs within the GSP area are concentrated in Fish Slough and Owens Lake.

Conclusions

The Owens Valley groundwater basin is large and complex hydrogeologic system consisting of an alluvial and fluvial aquifer interbedded with clays and basalt flows. Confined to semi-confined conditions are generally found along the axis of the valley, with unconfined conditions present along the margin of the valley. Faults intersect the groundwater basin and act as both conduits for and barriers to groundwater flow depending on the location and orientation. Groundwater is primarily sourced from runoff that infiltrates into the alluvial fans along the margin of the valley as streams flow across them. Groundwater flow is generally from the margins towards the axis of the valley, and from the north towards the south. Groundwater quality in the basin is generally high; however naturally elevated solute concentrations are present either due to leaching of volcanic deposits or evaporative concentration in the Owens Lake area. Groundwater and surface-water in the basin are highly managed by the LADWP, with the majority of extracted groundwater exported out of the basin to the south for use in Los Angeles. Groundwater is used for a variety of purposes within the basin including agricultural, municipal, domestic, ecological, industrial, and recreational uses.

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