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**Indian Wells Valley Water District and
the Brackish Groundwater Resources Study Group**

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INDIAN WELLS VALLEY HYDROGEOLOGIC CONCEPTUAL MODEL **TRADITIONAL HCM**



INDIAN WELLS VALLEY HYDROGEOLOGIC CONCEPTUAL MODEL TRADITIONAL HCM

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Abbreviations

AEM	Airborne ElectroMagnetic
AF	Acre foot
Bgs	Below ground surface
BLM	Bureau of Land Management
DEM	Digital Elevation Model
DOI	Depth of Investigation
DMS	Data Management System
DWR	Department of Water Resources
ECSZ	Eastern California Shear Zone
GAP	The Stanford Groundwater Architecture Project
GSP	Groundwater Sustainability Plan
HCM	Hydrogeologic conceptual model
IWV	Indian Wells Valley
IWVGA	Indian Wells Valley Groundwater Authority
IWVWD	Indian Wells Valley Water District
km	Kilometers
LCI	Laterally Constrained Inversion
m	Meters
m a.s.l.	Meter Above Sea Level
mya	Million years ago
ms	Milliseconds
MUDP	The Environmental Technology Development and Demonstration Program
NAWS	China Lake Naval Air Weapons Station
NPV	Net present value
PFC	Primary Field Compensation
QC	Quality Control
SCI	Spatially Constrained Inversion
SGMA	Sustainable Groundwater Management Act
SVM	Searles Valley Minerals
SWRCB	State Water Resources Control Board
TEM	Time-domain (transient) ElectroMagnetic
ybp	Years before present
WLB	Walker Lane Belt

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1. INTRODUCTION

This report provides a description of the basin setting, as well as the data collection, compilation and assimilation techniques that were used to develop a three-dimensional (3-D) hydrogeologic conceptual model (HCM) of the Indian Wells Valley (IWV) groundwater basin (Basin). The HCM has been developed to support a Brackish Groundwater Resources Feasibility Study (currently underway), and the Stanford Groundwater Architecture Project (GAP). Further details on the Stanford GAP project are included in Section 1.2.3 below.

1.1 Basin Setting

The Basin, located at the southeast terminus of the Sierra Nevada Mountain Range, is listed as California Department of Water Resources (DWR) Bulletin 118 groundwater basin number 6-54, and comprises approximately 600 square miles in area. The DWR has categorized the Basin as subject to critical conditions of overdraft (DWR Bulletin 118 Interim Update 2016), and the Basin has been categorized as a High Priority Basin under the Sustainable Groundwater Management Act (SGMA).

The basin is the home of the City of Ridgecrest, community of Inyokern, and the China Lake Naval Air Weapons Station (NAWS). The City of Ridgecrest was incorporated in 1963, covers 21 square miles and currently has a population of approximately 33,900. NAWS China Lake was established in 1943 and is now the largest U.S. naval facility in the world, covering a total of 1,735 square miles in three counties (Inyo, Kern, and San Bernardino), approximately 250 square miles of which are inside the Basin. The NAWS is the main employer in the valley, with a workforce of military, civilians, and contractors totaling more than 7,500.

The predominant land use in the region, aside from the City of Ridgecrest and developed portions of NAWS, is open space managed as public lands by the Bureau of Land Management (BLM), or under the authority of the U.S. Navy as part of NAWS China Lake. Just over 80 percent of the region consists of publicly-owned lands, including 53.5 percent managed by the BLM and 26.9 percent under military administration (Kern County, 2012). Desert vegetation predominates on the open space lands. Rural residential, agriculture, commercial, and industrial uses are present along the SR 178 corridor. Rural residential development is predominantly present along the Brown Road corridor north of SR 178, and in the unincorporated area of College Heights located east of Ridgecrest. There are approximately 4,120 acres of land dedicated to active agricultural production within the Basin, with 917 additional acres of land undergoing agricultural development. The primary crops grown in the area are alfalfa (approximately 1,650 acres) and pistachios (approximately 2,470 acres).

Average annual precipitation in the valley varies from 2 to 6 inches, although in some years the basin receives no precipitation. Surface elevation in the central Indian Wells Valley ranges from 2,150 to 2,400 feet above sea level. The basin comprises 597 square miles of land area and is filled largely with unconsolidated clays, sands, silts and gravels extending to depths of over 2,000 feet throughout most of the basin. Based on peer-reviewed scientific reports, Indian Wells Valley is considered a closed, internally drained basin bounded by outcrops of igneous and metamorphic basement rock complexes. Subsurface inflows from outside the watershed (for example, from the Kern River Plateau) and subsurface outflows are both negligibly small.

The hydrologic contributing watershed for the basin comprises approximately 600 square miles (384,000 acres) and extends west to the crest of the Sierra Nevada Mountains and north and east to the Coso Range and Argus Range respectively, and the El Paso Mountains on the south. China

Lake, a perennial playa lake, is situated in the central northeastern valley and is the primary natural groundwater discharge point.

Groundwater supplies over 95 percent of water used in Indian Wells Valley, and groundwater pumping has been the largest discharger in the basin for over 50 years. The remainder is supplied by recycled water for irrigation of the Navy golf course and City of Ridgecrest alfalfa fields. Average annual inflows were estimated from 7,600 to 10,900 acre-feet per year (AFY), with estimated pumping of 23,700 AFY for an average annual storage change of approximately 16,300 AFY in 2013 (Todd 2014). This annual storage change is reflected in chronic groundwater level declines of 1 to 2 feet per year that have been documented in the basin for some 50-plus years. Associated with the groundwater level decline is degrading water quality, with the majority of wells showing increasing concentrations of total dissolved solids (Todd 2014). Desert Research Institute (DRI) conservatively modeled the basin over the five-year period of 2011-2015 with an estimated average annual recharge rate of 7,650 AFY, average annual evapotranspiration of 4,850, inflow from Salt Wells Valley of 50 AFY, and average annual pumping estimated at 27,740 AFY for an average annual storage change of approximately 24,990 (DRI 2019). The multi-decadal, chronic declines in groundwater levels and storage are increasing pumping costs, and likely to cause more shallow wells to go dry. Additional impacts will include a continued degradation of water quality, and increasing the potential to cause land subsidence, although there is no evidence of groundwater extraction related subsidence to date.

The HCM project has been conducted through the funding and in-kind services provided by the following Brackish Groundwater Resources Group partners:

- Indian Wells Valley Water District
- Coso Geothermal
- Searles Valley Minerals
- Mojave Pistachio
- Meadowbrook Dairy

The HCM project is also co-funded as part of the Stanford Groundwater Architecture Project (GAP), through an agreement between the State of California Department of Water Resources, State Water Resources Control Board, Kingdom of Denmark, and three local agencies (Indian Wells Valley Water District, Butte County, and San Luis Obispo County).

1.2 Description of Studies

This section provides a description of historical and current studies of the basin.

1.2.1 Historical Studies of the Indian Wells Valley Groundwater Basin

The Indian Wells Valley has been studied extensively, with numerous early investigations primarily focused on better understanding groundwater in the area (Moyle 1963; Kunkel and Chase 1969; St. Amand 1986; Berenbrock and Martin 1991; USBR 1993; Berenbrock and Schroeder 1994; Tetra Tech EM Inc. [TtEMI] 2003). The Indian Wells Valley Groundwater Project (USBR 1993) resulted in the drilling of ten deep monitoring wells to depths of up to 2,000 feet below ground surface (bgs). The tectonic history of the Indian Wells Valley has also been of significant interest (Von Huene 1960; Zbur 1963), while neotectonic surface features were mapped by Roquemore (1981) as well as Roquemore and Zellmer (1987). The Indian Wells Valley was the focus of four deep borings and geophysical studies sponsored by the Naval Air Weapons Station Geothermal Program Office (Monastero et al., 2002). In addition, several hundred shallow

(<300 feet bgs) borings and groundwater monitoring wells have been completed as part of the Navy's Installation Restoration Program (IRP) during environmental restoration activities at NAWC China Lake since 1984 (TtEMI 2003), with the data providing detailed insight into the shallow stratigraphy of the facility.

During the Navy's base wide hydrogeologic characterization project, sediment and rock cores were collected from 26 soil borings that were drilled in the Indian Wells Valley, 17 borings in the Salt Wells Valley, and 4 borings in the Randsburg Wash Area in greater than 1,000 feet of Quaternary sediments (TtEMI 2003). These exploratory borings were used to guide monitoring well placement in the Indian Wells Valley and the Salt Wells Valley; 16 wells were completed in the Indian Wells Valley and 9 wells were installed in the Salt Wells Valley. Several hundred boring logs from water wells, previous exploratory borings, and the Navy's IRP wells and borings, were also used to assess groundwater conditions. Some of these new well logs were more detailed than those from previous efforts due to extensive continuous coring efforts (versus typical grab samples of drill cuttings every 10 feet) and detailed lithologic logging. A limited set of laboratory and isotopic carbon analyses were performed for some exploratory borehole soil samples. The lithologic data collected during the Navy's basewide study should be considered a more detailed and comprehensive drilling program, providing the highest quality of geologic data collected to date, resulting in a more complete interpretation of the basin-wide depositional environment and history of the sediments as they relate to the current and past groundwater conditions. Sufficient detail was achieved to provide an improved understanding of the Quaternary history of the study area. The basis and framework for the hydrogeologic conceptual model of the Indian Wells Valley is summarized in the base-wide study report (TtEMI 2003).

Additionally, in 2001-2002, the Eastern Kern County Resources Conservation District (EKCRCD) obtained an AB303 grant on behalf of the Indian Wells Valley Cooperative Groundwater Management Group. The grant funding was used to support several tasks including: survey of wells used for groundwater monitoring, to develop a GIS management system to archive, track and present data, and to develop a website to allow public access to information. Funding was also used to develop a conceptual groundwater model based on existing groundwater information collected during earlier studies conducted throughout the IWV. The conceptual model and compiled information were documented in a final report titled "Groundwater Management in the Indian Wells Valley Basin" (EKCRCD June 2003).

In 2006-2007, nine boreholes were drilled, and eight monitoring wells completed, and one well destroyed in the southwest portion of the Indian Wells Valley groundwater basin China Lake area as part of an AB 303 grant awarded to the Indian Wells Valley Cooperative Groundwater Management Group (IWVCG TAC, 2008). Wells were drilled using mud rotary drilling methods with periodic cuttings samples collected and recorded, geophysically logged, and completed to depths between 380 feet to 1,045 feet bgs. Wells were sampled for water quality, isotopic analysis and age dating. Chemical data, isotopic data, flow path analysis, and equilibrium and mass transfer modeling were used to update the Basin hydrogeologic conceptual model, thereby answering some questions raised by earlier investigators regarding the distant recharge potential (Kern River Plateau) and a closed versus open basin model.

Brown & Caldwell (B&C) (2009) developed a refined hydrogeologic conceptual model of the Basin and implemented that information into a groundwater flow model in MODFLOW. The three-dimensional (3D) conceptual model was not preserved and is not available for use. The structure of the B&C 2009 groundwater flow model was used as the basis for an updated model developed by the Desert Research Institute (DRI) in 2014. The DRI model was funded by and under the direct oversight of the US Navy.

Currently, the Basin is being investigated by the Indian Wells Valley Groundwater Authority as part of the requirements of the Sustainable Groundwater Management Act (SGMA), passed in 2014. The SGMA requires that groundwater agencies develop groundwater sustainability plans, including sections on basin setting, groundwater conditions, and hydrogeologic conceptual models, to be adopted and submitted to the California Department of Water Resources by January 31, 2020.

1.2.2 Brackish Groundwater Resources Feasibility Study

A Brackish Groundwater Resources Feasibility Study (FS) is being conducted by Aquilogic, Inc. at the request of the IWV Brackish Groundwater Study Group (the Study Group). The Study Group is comprised of the following members:

- Indian Wells Valley Water District (IWWVD)
- Coso Geothermal Company (Coso Geothermal)
- Searles Valley Minerals (SVM)
- Mojave Mutual Water Company (Mojave Mutual)
- Meadowbrook Dairy (MBD)

The objective of the Study Group is to develop brackish groundwater as a supplemental source of water supply in IWV. The objective of the FS is to identify and quantify brackish groundwater resources and evaluate the feasibility of developing these resources as a potential alternate source of water supply in IWV. The FS is proceeding in the following phases:

1. Collate, evaluate, and summarize current information pertinent to brackish groundwater in the IWV groundwater basin
2. Obtain grant funding for new data collection
3. Gather new data to fill data gaps
4. Using pertinent data (new and existing), evaluate the feasibility of developing brackish groundwater, including:
 - a. Quantifying the resource
 - b. Quantifying extraction rates that can be sustained for an extended period without producing undesirable results
5. Identifying brackish groundwater extraction well locations
6. Optimizing pipeline routing
7. Evaluating treatment technologies
8. Assessing alternative brine disposal options
9. Preparing conceptual designs for a field pilot program to investigate various treatment technologies
10. Develop conceptual designs for a full-scale brackish groundwater program
11. Develop cost estimates for brackish groundwater delivery (capital, annual operation, total net present value [NPV], and NPV costs per acre-foot [AF] delivered)

Currently, the study is in the modeling phase with DRI providing groundwater flow and fate & transport modeling services. The FS will be completed in 2019 and is expected to support current GSP tasks and be incorporated as one of the alternative water supply alternatives in the GSP.

1.2.3 Stanford Groundwater Architecture Project (GAP)

The Stanford Groundwater Architecture Project (GAP) is a two-year program designed to define the optimal workflow for the acquisition of aerial electromagnetic (AEM) data in California to

support the development of more detailed and improved hydrogeologic conceptual models (HCMs). The project lead is Stanford University and major project funding partners are the California Department of Water Resources (DWR), and State Water Resources Control Board (SWRCB). Three local agencies where local basins have been selected for areas to implement the GAP are Butte County, Indian Wells Valley, and San Luis Obispo County. In each of the three areas, the same workflow will be used, identifying and addressing the challenges specific to working in the three different areas selected. What will emerge are processes and methodologies that will be transferrable to other regions throughout California.

The defined steps in the workflow are summarized below:

1. Project management and dissemination of results: development of a system for project management, allowing for the flow of information among all project members, tracking of progress, revision of timelines as needed, and dissemination of results. An essential component is engagement with water managers and policy makers, so that throughout the project they track, and highlight, ways in which the workflow feeds directly into SGMA implementation.
2. Engagement with local agency: This step involves working closely with the local agency to clearly identify groundwater management questions and objectives, and to communicate with the public. The direct link to SGMA implementation has to be established.
3. Project Geo Data Management System (GeoDMS): A project GeoDMS will be established, enabling data sharing between members and to project partners and stakeholders. The GeoDMS will be cloud-based and include a series of robust and scalable databases, GIS publishing functionalities and general data management tools.
4. Compilation of existing data: There is a need for an accessible, high quality database of all available logs (drillers logs and geophysical logs) and other data, for the interpretation of the AEM data and integration with the AEM data to develop the conceptual model. The process of acquiring, assessing and digitizing drillers logs and geophysical logs is a challenging part of developing this workflow in California.
5. Identifying data gaps and AEM survey design: Using available data, collaborate with the local agencies to identify where AEM data are needed, and to plan the AEM survey.
6. Acquisition of AEM data: While standard practices have been developed for data acquisition, there could be logistical issues, unique to California that must be addressed.
7. Data analysis and inversion: There is the need for robust methods of data analysis and inversion that can provide both the large-scale mapping of subsurface properties to depths of ~500 meters (~1,640 feet) and the higher resolution shallow mapping of properties needed to guide recharge efforts.
8. Geophysics to hydrogeology transform: A methodology must be developed that can transform the geophysical property measured with the AEM system (electrical resistivity) to the desired subsurface information, e.g. mapping of aquifer and aquitard units, and any structural features.
9. Model development through data integration: A computational framework is required that can integrate the AEM data with other available data to generate the hydrogeologic conceptual model, and from that, the groundwater model to inform decision-making.
10. Uncertainty analysis: There is the need to quantify uncertainty and rigorously account for its propagation through the workflow that leads to the development of the conceptual model. The conceptual model is used as the basis for the development of the groundwater model, so uncertainty must be quantified in such a way that it informs decision-making.

This report completes the traditional HCM for the Indian Wells Valley, along with the data management system delivery under a separate report and includes items 1-8 outlined above. Remaining steps for the IWV will be completed in 2019. The overall GAP is expected to be completed in 2020.

1.2.4 Indian Wells Valley Groundwater Sustainability Plan

The Indian Wells Valley Groundwater Authority (IWVGA) was formed in 2016 in response to the mandate that groundwater sustainability agencies be formed in all Sustainable Groundwater Management Act priority basins. The IWVGA is in the process of developing a groundwater sustainability plan (GSP) for the basin. The GSP is required to be completed, undergo a public review, be adopted and submitted to DWR by January 31, 2020.

2. REGIONAL GEOLOGIC AND STRUCTURAL SETTING

2.1 Regional Geologic Structural Setting

The Basin lies within the northern portion of the Eastern California Shear Zone (ECSZ) (Figure 2-1 Simplified Tectonic Map – Western U.S. Cordillera.) Stockli et al., 2006). The ECSZ and Walker Lane Belt define a broad zone of active deformation that straddles the boundary between dominantly east-west extension in the Basin and Range province and dominantly northwest-right-lateral shear directed along the Pacific–North American plate boundary to the west (Monastero et al., 2002). The interaction between extension and transcurrent shear has resulted in a complex array of northwest striking dextral faults, northwest-striking and northeast-striking normal faults, and east-northeast-striking left-lateral faults that accommodate intraplate strain east of the Sierra Nevada and into western Nevada. The nature and extent of these types of faults are evident in the Basin.

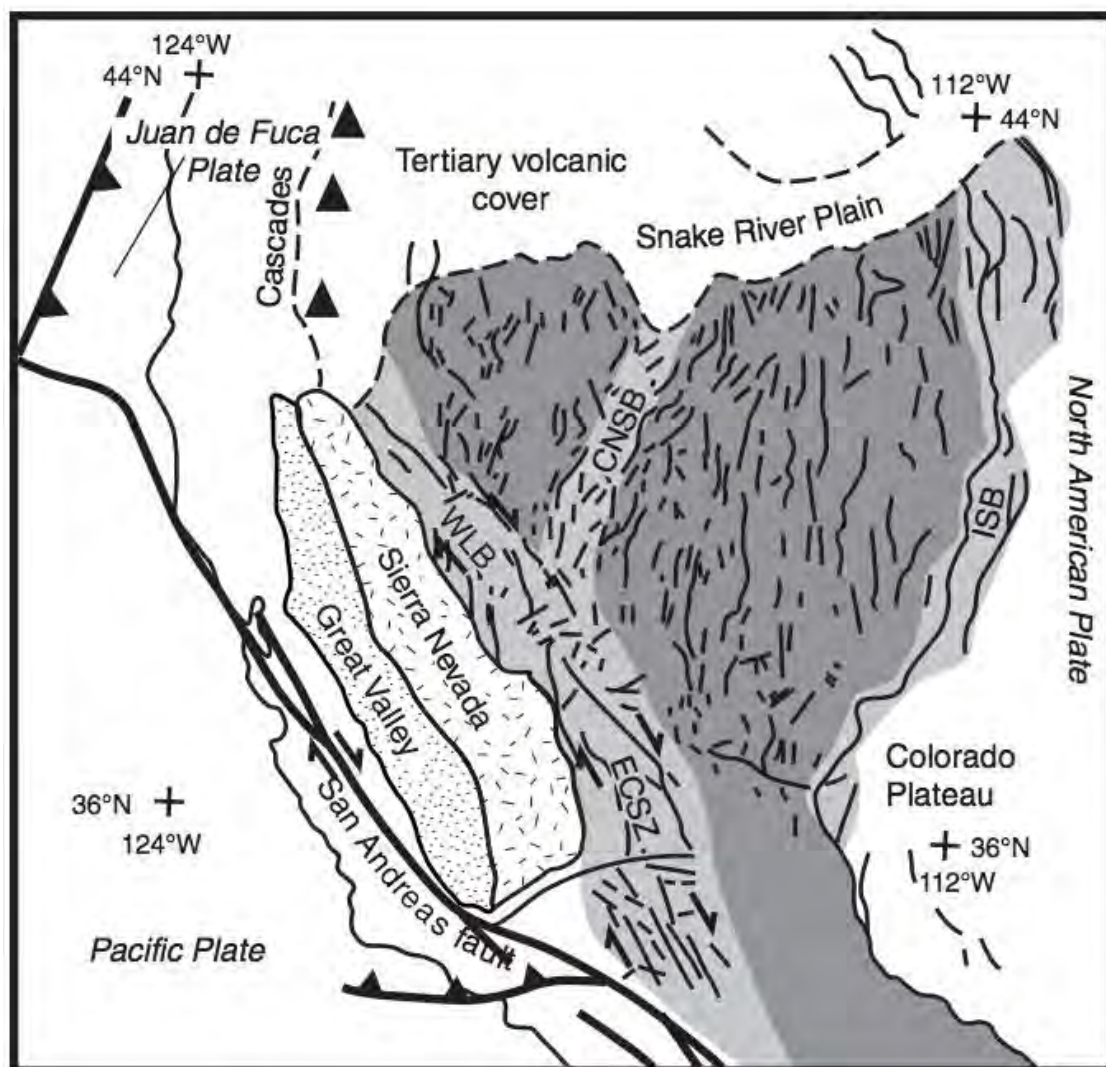


Figure 2-1. Simplified Tectonic Map – Western U.S. Cordillera.

Simplified tectonic map of the western part of the U.S. Cordillera showing the major geotectonic provinces and modern plate boundaries. Basin and Range extensional province in dark gray; light gray: Central Nevada Seismic Belt—CNSB; eastern California shear zone ECSZ; intermountain seismic belt ISB; Walker Lane Belt WLB (Stockli et al. 2006)

The Basin consists of two areas: the China Lake area and the El Paso area to the southwest (Figure 2-2). Structurally, the Indian Wells Valley is a half-graben formed by downward movement on the west side of the China Lake area along the Sierra Nevada frontal fault, where historic movement down dropped the west side of the basin by some 3,000 meters (Monastero and others 2001). Over 7,000 feet of valley fill sediments are present in the western portion of the China Lake area, which shallows to the east with an average depth of basin fill sediments of approximately 2,000 feet. The basin is bounded on the north by the Coso Range, on the east by the Argus Range and El Paso Mountains, and on the south by the Garlock Fault and the El Paso Fault. Major faults cutting across the basin are right-lateral dominated and include from west to east, the Sierra Nevada frontal fault, the Little Lake Fault Zone, the Airport Lake Fault Zone and the older Argus Frontal Fault.

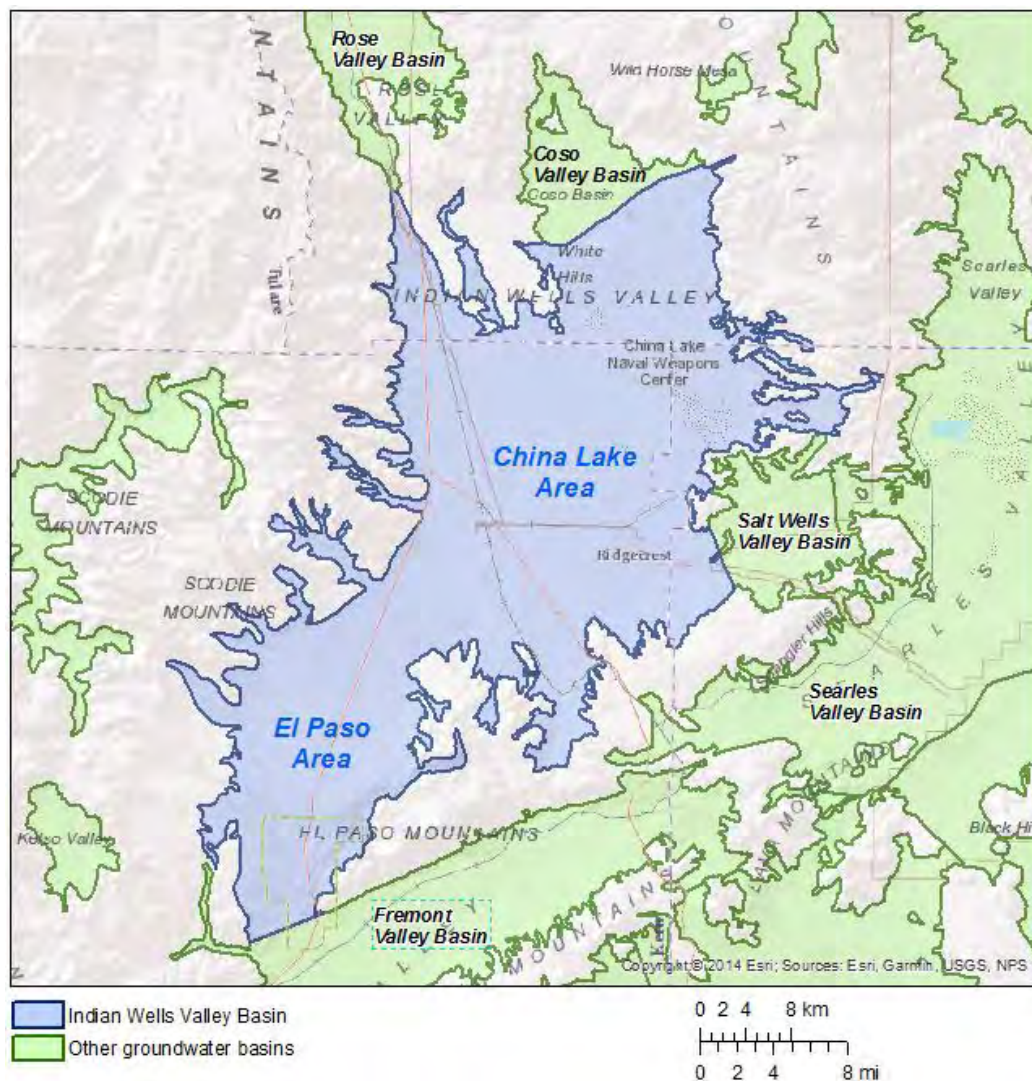


Figure 2-2. Indian Wells Valley Groundwater Basin and Areas.

The Basin as a whole is structurally controlled by a series of mostly active faults, including the Sierra Nevada Frontal Fault to the west, which runs along both the China Lake and El Paso areas. The Airport Lake and Argus Range faults to the east, and the Little Lake Fault to the north-northwest are major faults within the China Lake area. An unnamed fault separates the China

Lake area from the El Paso area to the southwest, and the Garlock fault further to the southwest forms the boundary of the Basin on the far south in the El Paso area.

The Basin floor is flanked by a series of broad coalescing Pleistocene-age pediments and recent alluvial fans and drainages (Rosenthal et. al. 2017). On the western and southern sides of the valley, these low-gradient fans extend for several kilometers into the basin. Along the northwestern edge of the valley, distal portions of the eastward-oriented fans are truncated by a complex of well-defined channels and ephemeral washes that mark the former course of the ancestral Owens River. The largest channels include extensive large boulder-derived-levees including Sierra Nevada granite and Coso basalt, which are indicative of very high-energy conditions. The former river channels are less pronounced as they enter the basin, giving way to a broad delta formation, partially obscured by Holocene-age alluvial fans and aeolian deposits (Rosenthal et. al. 2017). On the southwestern edge of the valley, Little Dixie Wash occupies a broad segmented fan and channels providing runoff from five eastern Sierra Nevada tributaries including, Freeman Canyon, Cow Heaven Canyon, Sage Canyon, Peak Horse Canyon, and Bird Spring Canyon.

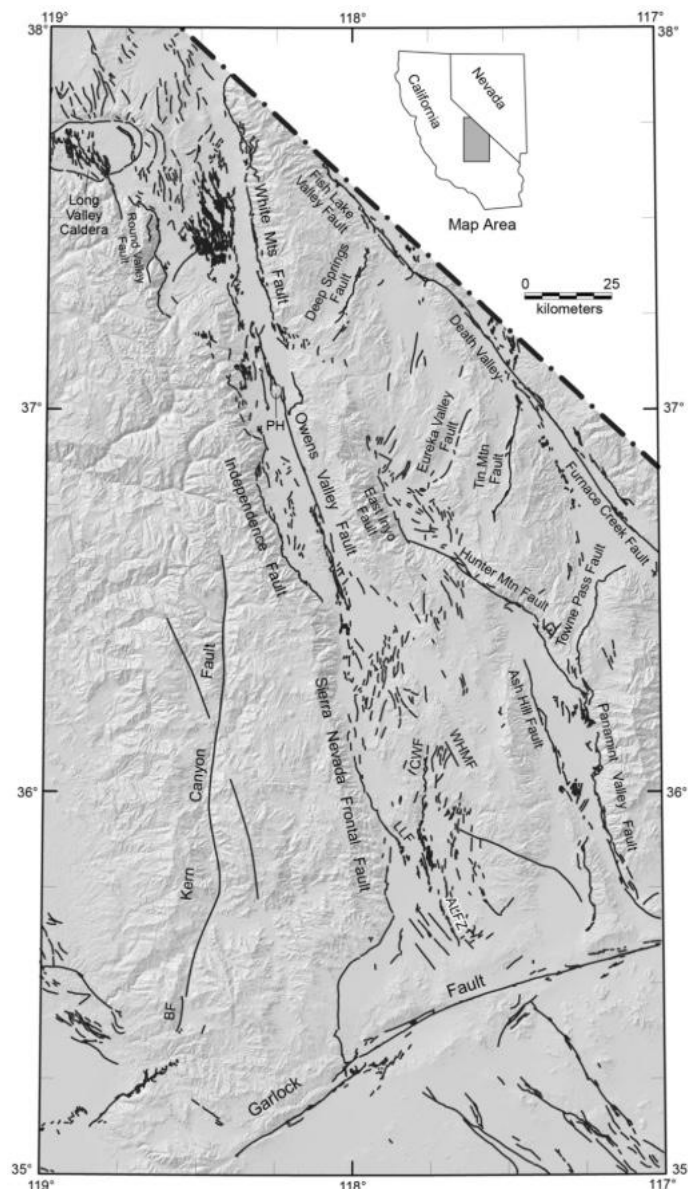


Figure 2-3. Map showing Quaternary faults in east-central California.

Abbreviated fault names are as follows: ALFZ = Airport Lake Fault Zone; BF = Breckenridge Fault; CWF = Coso Wash Fault; LLF = Little Lake Fault; PH = Poverty Hills; WHMFZ = Wild Horse Mesa Fault Zone. (Stevens et al., 2013)

2.2 Geologic History and Stratigraphy

The stratigraphic units in the vicinity of the Indian Wells Valley range in age from Paleozoic to Quaternary (Table 2-1). An uplifted plutonic and metamorphic Mesozoic granitic basement complex underlies these basins, some of which also daylights/outcrops in highlands surrounding the basin. The Sierra Nevada batholiths and the associated low-angle frontal fault bound the western edge of the Indian Wells Valley. Structurally, the Indian Wells Valley is a half-graben formed by downward movement on the west side of the China Lake area along the Sierra Nevada frontal fault (Monastero and others 2001). Basin fill sediments include the Paleocene Goler Formation, and the Miocene Ricardo Group that consists of the Cudahy Camp Formation and Dove Springs Formation that filled Indian Wells Valley from the south (Cox 1982; Loomis and Burbank 1988). Tertiary continental sedimentary and volcanic deposits of the White Hills sequence and Coso formation make up the majority of the fill, which ranges from about 1,000 feet to

approximately 7,000 feet thick. Miocene to Quaternary volcanics also crop out on the perimeter of the basin and, in a few places, flow into the valley. Pleistocene to Holocene sediments occupy the upper remaining basin fill and are the primary source of groundwater extracted in the basin.

Unit	Age	Sierra Nevada	Stratigraphic Unit	Thickness (feet)	Lithology	Occurrence	Hydrologic Properties
Mt	Quaternary		Holocene surficial and playa deposits	± 25 to ± 300	Playa deposits (silly sand), eolian (well sorted) sand, younger fan deposits, and alluvium	Playa deposits of China, Satellite, Mirror, North Dry, and Airport Lakes. Windblown sand mostly adjacent to playas and west side of Angus Range. Some thicker alluvial fans on basin margins.	Mostly above water table. Saline water where evaporation occurs in saturated playas. Young fans may have water table developed within permeable sands.
0.01			Unnamed basin fill and lacustrine sediments includes	Sediments ± 300 to ± 2,000	Lacustrine deposits - silt and clay with occasional sandy and/or calcareous horizons	Beneath present playas and past lakes, which extended outward into alluvium during periods of high levels. Mid-Pleistocene Christmas Canyon Formation in southern Teague Wash and western Pilot Knob Valley.	Low permeability. Forms semi-confined layer in central Indian Wells Valley. Sandy layers can be good producers, especially to south.
			Aluvial, Quaternary fan, and lacustrine deposits	Volcanic flows ± 100	Deposits of the gentle bajadas of the gentle bajadas	Occupies gentle bajadas between playas (and/or lakes) and the fan deposits. Topographic slope generally less than 30 ft/mi.	Moderate to high permeability. Primary water bearing unit of Indian Wells Valley. Includes parts of water table and deep aquifers.
2.6			Coso Formation	± 300 to ± 4,500	Fan deposits - highly variable, poorly sorted; sandy to boulder conglomerates, locally includes very poorly sorted mud flows, deposited on the steep fan heads. Includes intermediate and old alluvial fans and delicate deposits on major drainages.	Tongues extending from perimeter of basin. Present where topographic slope generally greater than 100 ft/mi, especially large at foot of Sierra Nevada. Fan-delta where fans prograde into Delta where large streams or rivers enter basin (Owens River and ancestral Owens River).	Highly variable permeability. Primary recharge area of Indian Wells Valley, highest quality groundwater (low total dissolved solids).
5.0			White Hills Sequence and Coso Volcanics	± 700	White Hills Sequence includes lacustrine, fan-delta, debris flow, mega-breccia, and alluvial deposits. Fan and lacustrine deposits, basalt flows, andesite, and myolite.	Outcrops in White Hills anticline, identified under Pleistocene basin fill and lacustrine sediments. Likely begins in Miocene.	Highly variable permeability, deepest portion of deep hydrogeologic zone in Indian Wells Valley, water quality unknown.
			Black Mountain Basalt	Flows ± 100	Olivine basalt flows and intrusions.	West and north of Coso Range. Coeval with mid-Pleistocene White Hills Sequence.	Highly variable.
23			Ricardo Group	± 6,500	Fluvial, lacustrine, and pyroclastic sedimentary rocks and lava flows.	Southeast edge of Indian Wells Valley (western El Paso Mountains).	Impermeable unless fractured.
56			Collier Formation	± 7,000	Fanglomerate and alluvial gravel, sand, and clay.	2 formations: (1) Dove Springs Formation crops out in El Paso Basin and is tentatively identified at depth in central Indian Wells Valley and (2) Cuddey Camp Formation crops out in El Paso Basin, Teague Wash, and at depth in central Indian Wells Valley (20 to 15 mibp).	Generally low permeability, however, poorly indurated sandy to gravelly horizons may contain considerable water.
66			Tertiary continental rocks	Unknown	Primarily quartz monzonite to granodiorite of Sierra Nevada batholith with granitic to mafic dikes.	El Paso Mountains and Basin, southwest corner of Indian Wells Valley, found beneath central Indian Wells Valley.	Generally impermeable unless fractured. Carbonates may contain solution cavities.
252			Jurassic Basement Complex	Unknown	Marine clastic, carbonate sedimentary and metasedimentary rocks, and metavolcanics.	Underlies valley and outcrops in surrounding mountain ranges. Independence Dike Swarm of both Jurassic and Cretaceous ages.	Generally impermeable unless fractured. Carbonates may contain solution cavities.
541			Paleozoic sediments	± 4,500	Marine clastic, carbonate sedimentary and metasedimentary rocks, and metavolcanics.	Outcrops in Sierra Nevada, El Paso, and Angus ranges as roof pendants above granitic rocks.	Generally impermeable unless fractured.

Table 2-1. Stratigraphic Age and Regional Structure. Modified after Tetra Tech. Age reference: GSA Geologic Time Scale v. 5.0, The Geological Society of America (GSA), 2018

2.3 Paleozoic Sediments and Permian to Jurassic Basement Complex

Paleozoic sediments consisting of deformed and metamorphosed marine clastic, carbonate sedimentary and metasedimentary rocks, and metavolcanics exist as roof pendants on top of the Jurassic-Cretaceous Basement Complex of granitic rocks of the Sierra Nevada and Argus Mountains, and Permian gabbro to granite and Jurassic quartz diorite to quartz monzodiorite plutons of the El Paso Mountains. The complex of intrusive rocks forms the basement of the Basin.

The Paleozoic sediments are considered to have been deposited in an early, arc-related basin-fill remnant along an evolving passive continental margin, with shallow shelf platform and continental margin sedimentary deposits accumulating between about 540 to 250 million years ago (mya). Initiation of subduction along this area is indicated by the discontinuous belt of Permian to Triassic arc-related plutons, extending from the El Paso Mountains terrane southward.

During the Triassic period, roughly 250 mya, the passive continental margin transitioned to an active continental margin with the breakup of the supercontinent Pangaea and the formation of the Atlantic Ocean, pushing the North American plate to the west and north. The western margin of ancestral North America began to override the Pacific Plate oceanic crust and a subduction zone formed along the coast. As the Pacific oceanic plate sank beneath the North American continental plate, subducted rock materials melted into magma as multiple bodies of plutons, beginning in the Jurassic Period, roughly 170 mya. Magma generated by subduction processes began to move upward, some of which reached the surface and erupted to form new volcanoes and intruded as dykes and sills. An extensive volcanic arc developed across the greater California region and deep below the surface, a series of igneous intrusions gradually became emplaced. These large-scale, dominantly granitic igneous rock intrusions comprise the cores of the many plutons of the Sierra Nevada and many of the ranges throughout the Mojave region, which formed continuously between Late Triassic to mid-Cretaceous (220-80 mya) but was variably active with two episodes of high magmatic volume placement in the Jurassic (160 to 150 million years ago) and again in mid-Cretaceous time (about 100 to 85 million years ago) (Ducea, M., 2001).

Subduction-zone-related magmatic intrusion and volcanism largely ended in the region in Late Cretaceous time. Erosion and re-deposition were the dominant processes throughout the early part of the subsequent Tertiary Period.

2.4 Goler Formation

The Paleocene age Goler Formation is a fluvial clastic sedimentary deposit which lies unconformably on Permian to Jurassic age plutonic basement rocks, believed to have been deposited in a pre-existing "Goler" basin and landscape prior to the formation of the El Paso basin area of the Indian Wells Valley groundwater basin. Recognized and well-studied as the only formation that has yielded a diverse assemblage of Paleocene vertebrates, the Goler Formation in this region is as much as 6,500 feet thick, which thins northeastwardly, and is a homocline structure, dipping an average of 15 to 20 degrees northward. The basal unit of the Goler Formation is a conglomerate that is much as 500 feet thick and is composed of rounded cobbles of quartzite, chert, hornfels, porphyries and granitic rocks in a sandy matrix. Above the basal conglomerate, the remainder of the formation is comprised of buff to red arkosic sandstone with some interbedded green to red siltstone that grades laterally to the east to cobble conglomerate. The Goler Formation was uplifted and tilted northward along a normal fault at the current location of the Garlock Fault and eroded to a fairly flat plain until Miocene time (Cox, 1982).

There is very little Eocene and no Oligocene deposition documented in the Indian Wells Valley basin. This is believed to be a result of the change from convergent to divergent plate boundary geometry along western North America approximately 30 mya. This change subsequently included the birth and initiation of right lateral movement along the San Andreas fault zone some 15 to 20 mya.

General uplift and erosion occurred in the Mojave Desert Block with the formation of the Basin and Range province, between the Sierra Nevada and the Rocky Mountains. This Basin and Range extension, or tectonic stretching, relieved pressure on the underlying upper mantle decreasing the melting point of hot rocks where partial melting may occur. Eventually fractures occur, and molten magma pours through the cracks extruding flows of volcanic rocks at the surface. This mechanism helps explain the Neogene volcanics of the Indian Wells Valley groundwater basin and surrounding terrane, including the Eagles Crag, Coso, Black Hills volcanic deposits and Coso geothermal resources.

2.5 Ricardo Group

The Ricardo Group, which unconformably overlies the Goler Formation, is a 1,700 meter- (5,600 feet) thick sequence of Miocene volcanic rocks and continental sedimentary rocks deposited between 19 and 8 mya in an elongate, fault bound trough, referred to as the El Paso basin (Loomis and Burbank, 1988; Whistler et al., 2009). Uplift of the El Paso Mountains along the dip-slip El Paso Fault has tilted to the west and north Cenozoic terrestrial sedimentary and volcanic rocks revealing exposures of Ricardo Group sediments in the Red Rock Canyon and beyond (Loomis and Burbank, 1988). Structurally, the Ricardo Group forms a homocline that dips west or northwest an average of 10 to 20 degrees that formed during late Miocene or late Pliocene (Cox and Diggles, 1986). Eight members of the Ricardo Formation have been described in descending order listed below (Dibblee, 1967), broken into the Cudahy Camp and Dove Spring Formation (Loomis and Burbank, 1988). The Cudahy Camp Formation consists largely of volcanoclastic sediment, derived from the east as flows, and south as meandering streams during two distinct depositional episodes in the Miocene (Loomis and Burbank, 1988; Monastero et. al., 1997). The Dove Spring Formation consists primarily of fluvio-lacustrine, volcanic and volcanoclastic rocks, with deposition in the lower portions resulted primarily from meandering, intermittent streams feeding into a semi-permanent lake in the center of a broad basin interspersed with volcanic deposits, while upper portions become coarser as alluvial fans propagated into the basin fill (Whistler et. al., 2009). A sediment source has been inferred to be the southeast from an elevated Mojave Block south of the Garlock Fault based on paleocurrents, and the source for volcanics identified as Lava Mountain to the southeast for the lower two thirds of the Dove Spring Formation. The uppermost Dove Springs member is considered to have a Sierra Nevada sources to the west and north (Whistler et. al., 2009).

Dove Spring Formation – primarily fluvio-lacustrine, volcanic and volcanoclastic rocks:

1. Gravel and sand, granitic, grey-white, weakly consolidated
2. Sandstone, granitic, light gray, grades directionally into nodular clay, conglomerate and fanglomerate
3. Conglomerate and sandstone, interbedded, gray to pink, chiefly volcanic with minor granitic detritus
4. Basalt interbedded with sandstone and clay, light to greenish gray, chert and limestone near base
5. Sandstone, prominently stratified, light gray, interbeds of green clay and tuff breccia

6. Conglomerate, pink gray, volcanic detritus composition, interbedded light gray to green sandstone

Cudahy Camp Formation:

7. Tuff breccia, white to pink, thick bedded to massive, with Black Mountain basalt beds near top
8. Conglomerate, greenish gray to reddish buff, granitic to metamorphic detritus composition, some interbedded sandstone

2.6 Black Mountain Basalt

The Black Mountain Basalt consists of numerous flows of sub-alkaline olivine-augite basalt more than 100 feet thick that cap summit areas of Black Mountain, throughout the Black Hills, and on buttes to the east. Structural relations indicate that the Black Mountain Basalt dis-conformably overlies the upper tuff unit of the Ricardo Group. Detailed mapping (Cox and Diggles, 1986) has revealed that the basalt is also disconformably overlain by the middle part of the Ricardo Formation (cherty mudstone unit) at one location, 2.7 miles northwest of the east summit of Black Mountain, making it Miocene to Pliocene in age; elsewhere superjacent strata have been stripped away by erosion.

Late Miocene or the beginning of the Pliocene, about 7 to 5 mya, marks the beginning of significant uplift along the Sierra Nevada frontal fault that resulted in the formation of the Indian Wells Valley half graben and related clastic deposition of a significant amount sediments including the Coso Formation and volcanics, and the White Hills Sequence. Coarse debris eroded off the western margin into the basin in the form of megabreccia, avalanche and debris flows, alluvial fans prograded westward from the Argus Range and eastward from the Sierra Nevada, and lacustrine and fluvio-deltaic sediments dominated the central portion of the China Lake area. Volcanic rocks periodically extended into the basin from the north and northeast.

2.7 Coso Formation

The Coso Formation has been mapped as Late Tertiary sedimentary and volcanoclastic rocks that predate Quaternary alluvial deposits at the south end of Owens Valley and in the Coso Range. Age dating indicates that the Coso Formation was deposited between 6.0 to 2.5 mya (Bacon et. al., 1982). The distribution of the Coso Formation is generally in the Coso Range and to the north.

2.7.1 Coso Volcanics

The Coso volcanic field is just north of the Indian Wells Valley groundwater basin, where approximately 35 km³ (8 mi³) of volcanic rocks have erupted and overlie principally Mesozoic rocks. The Coso volcanics range in age from ~4 to 0.04 Ma and vary in composition from basalt to rhyolite. Pleistocene rhyolitic domes are the major volcanic features, which are cut by numerous normal faults that reflect late Cenozoic and ongoing extension (Wohletz et al., 1992). The Coso range is a horst block immediately east of the Sierra Nevada range in eastern California, covered by a veneer of ~400 km² (154 mi²) of mostly lava flows and domes of late Cenozoic age. The geothermal system developed in a Mesozoic basement of dominantly granitic plutons and subordinate mafic plutons and metamorphic rocks associated with the Sierra Nevada batholith. Late Tertiary and Quaternary volcanic rocks drape over the basement.

The oldest lavas, alkalic basalt flows, are the most voluminous and flat basin terrain. These lavas are overlain by Pliocene andesite, dacite, rhyodacite, and rhyolite flows and tuff. Andesite and dacite occur as parts of polygenetic volcanoes in which dacite flows, shallow intrusive masses, and pumice are interlayered with andesite flows and cinders. Rhyodacite is found in widespread pumice fall and lava flows, and Pliocene rhyolite forms a nonwelded pumiceous ash flow that is intercalated with sedimentary volcanoclastic rocks of the Coso Formation. The youngest volcanic rocks are Pleistocene in age and consist of contemporaneous alkalic basalt and high-silica rhyolite (Bacon et al., 1980). Most basalt vents are marked by partly eroded cinder cones that fed one or more lava flows on the east, south, and west sides of the rhyolite field.

2.8 White Hills Sequence

The White Hills area was mapped initially by Kunkle and Chase (1969) as a gentle southeast plunging anticline, which separates the Indian Wells Valley from the Coso Basin to the north. The Pliocene White Hills Sequence was described by Kunkle & Chase (1969), although not named as such, to include older lacustrine and older alluvial deposits generally occurring in the north and eastern portions of the China Lake area. Older alluvial sediments are composed of lenticular deposits of semi-indurated silt, gravel and boulders, that may be undeformed to moderately deformed. The lithology has been described as generally void of volcanics, with granodiorite boulders with interbedded silt and fine to coarse granitic gravel. Northern and western exposures are generally pebble-boulder conglomerate, with boulders up to 3 feet in diameter, and coarse sand matrix.

Older lacustrine deposits are predominantly silt and silty clay interbedded locally with thin beds of impure limestone, calcareous sandstone, conglomerate and indurated sand. The older lacustrine sediments are in part interbedded with and in part overlie the older alluvial deposits and underlie basalts that flowed the north-northeast. The lacustrine sediments include very fine-grained diatom-bearing clastic sediments and interbedded thin limestone with Ostracods. These older lacustrine deposits were believed to have been formed in an ancestral lake that was probably part of an early glacial-lake system that connected Owens, China, Searles, Panamint and Death Valleys prior to the more well-studied Late Pleistocene pluvial cycles.

Monastero expands the extent of the White Hills sequence underlying the Pleistocene and overlying Pliocene sediments, with chronostratigraphic-equivalent deposits further west to the Sierra Nevada Frontal Fault on the basis of age dating of basalts identified in boreholes and seismic lines, and bracketing the sequence within two seismic reflector-mapped horizons ("D and B"). The White Hills sequence, should therefore be more appropriately named a "stage" under International Commission on Stratigraphy guidelines (International Subcommission on Stratigraphic Classification of the International Commission on Stratigraphy, 1994).

Five western subsurface facies were identified including debris flow/avalanche, alluvial fan, fan delta, lacustrine, and alluvial plain or sheet flood. Based on a combination of seismic reflection characteristics, data collected during drilling and outcrops, Monastero's interpretation suggests low-angle normal fault proximal (SNFF) syntectonic deposition from the bottom up and from the SNFF eastward, of a sequence slump blocks, landslides and debris flows (See Figure 2-4). Moving up section, these deposits grade into what is interpreted as an alluvial fan to then lower energy, fluvial dominated alluvial fan depositional environment.

Central subsurface White Hills facies include claystone, possibly tuff, silty sandstone and sandstone with local limestone beds consistent with lacustrine and fluvial depositional environments. Eastern facies are dominated by westward progradation from the Argus Mountains of multiple sequences of alluvial fans and fan deltas, which appear to grade into fluvial and

lacustrine deposits. Finally, the White Hills sequence appears to thin and disappear to south represented as a lacustrine depositional environment, taken together with the rest of the White Hill sequence, extends some 20 km in a north-south direction. Presence of the White Hills Sequence is not indicated in the El Paso area.

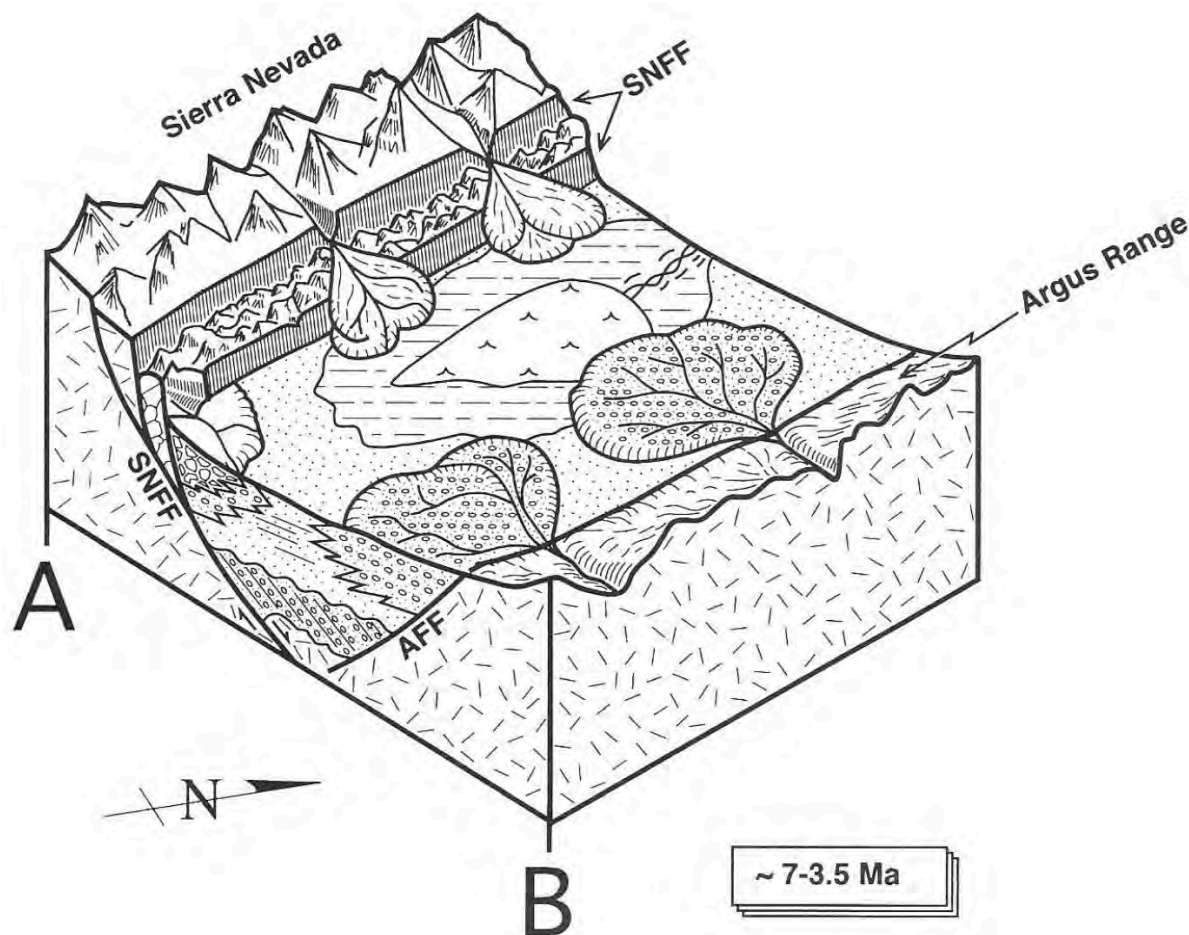


Figure 2-4. Indian Wells Valley Geologic Conceptual Model during the late Pliocene and Miocene. (Monastero et al., 2001)

Between the late Pliocene to early Pleistocene, estimated between 3.5 to 2 mya, movement along the Sierra Nevada frontal fault shifted from dominantly normal (dip-slip) to right-lateral strike-slip (Monastero 2002). As a result, the Quaternary sediment thickness depended upon erosion and subsequent deposition mechanisms to achieve the stratigraphic thickness in the China Lake area.

2.9 Quaternary - Pleistocene to Recent

The uppermost sediments of the Basin are primarily Pleistocene to Holocene unconsolidated, coalescing alluvial-fluvial and lacustrine deposits with minor eolian sands present. Together, Pleistocene to Holocene sediments are estimated to be 1,200 to 1,800 feet thick in the western and central portions of the China Lake area of the Basin, thinning to 300 feet to the east (Monastero et al., The Pleistocene and Holocene sediments are not as well characterized in the El Paso area of the Basin, but are on the order of few hundred feet thick and generally thin to the south. These Pleistocene and Holocene sedimentary deposits incorporate the principal aquifers within the Basin utilized for groundwater supply.

The Pleistocene history of the China Lake area of the Basin is dominated by deposition from the forceful flow of the ancestral Owens River system, which periodically propelled significant water into the Owens and Indian Wells valleys and beyond at various times along a south to south easterly course. Coarse-grained alluvial fans spread out eastward, westward and northward from the margins, fluvial sand and gravel deposition occurred along the ancestral Owens River when it made its course intermittently through the basin depending upon the glacial-interglacial period, and delta sedimentary sequences of sand and silt were deposited in the northwest portion of the basin associated with the Owens River.

The China Lake area of the Basin also contains significant thicknesses of lacustrine clays, with interbedded delta sands and silts and fluvial sands and gravels. These clay dominated sequences are over 1,000 thick in the central portion of the China Lake and thin radially outward.

The present-day China Lake playa represents the dry remnant of one of several large lakes that existed along the Owens River system during wetter climatic periods of the Pleistocene Epoch. During wet periods, the Owens River flowed from its headwaters near Mono Lake through a series of lakes, including Owens Lake, China Lake, Searles Lake, Panamint Lake, and Manly Lake (Death Valley) (Figure 2-5). The first two lakes, Owens Lake and China Lake, were settling ponds for the sediment-laden Owens River. The heaviest flow in the Owens River took place during periods of Sierra Nevada glacial advance, with increased precipitation providing runoff. Cooler, wetter winters and summers increased river flows, but also significantly delayed melting of the Sierra Nevada snow pack, maintaining more constant flow through the summer. During the intervening drier interglacial periods, river discharge was insufficient to maintain flow through the entire chain of lakes. As a result, thick evaporite deposits accumulated in several of the lakes downstream of China Lake, particularly Searles Lake. Recent researchers have identified at least 19 glacial-interglacial cycles that occurred in the Owens River drainage between 52,500 and 23,500 ybp, each lasting about 1,500 years. The highest stands of documented China, Salt Wells-Searles pluvial lakes are shown in Figure 2-6. This helps to outline the approximate location of underlying lacustrine sediments in the basins.

Sedimentation during the Holocene has been relatively minor and sporadic compared to the rapid deposition that occurred during the previous wet Pleistocene climate. Holocene deposits range from a few feet thick in the area surrounding the China Lake playa, to over 200 feet of alluvial fan deposits overlying lacustrine sediments along the margins of the basin. In many areas of the China Lake playa, most of the Holocene sediments have been removed by wind erosion.

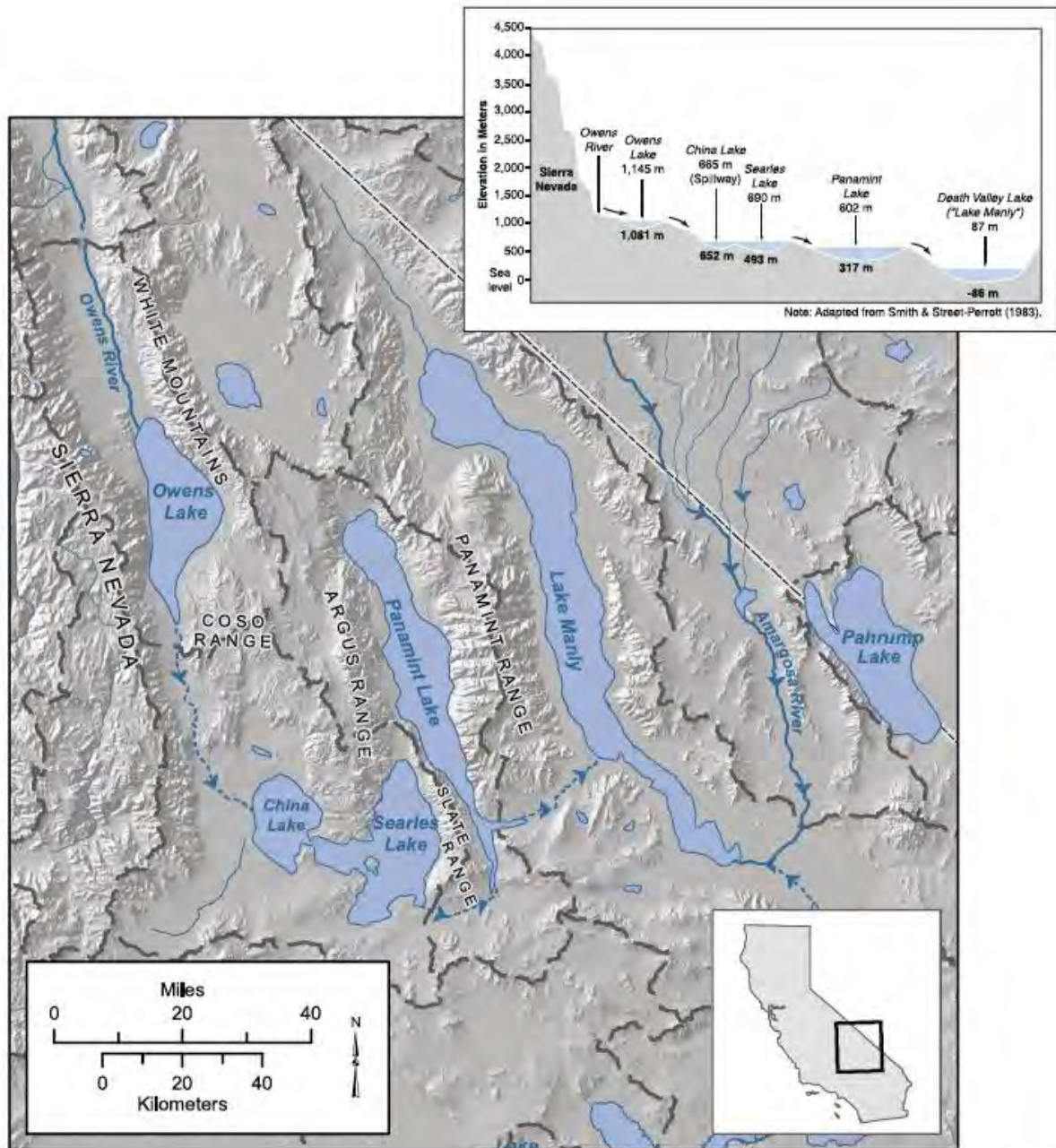


Figure 2-5. Ancestral Owens River hydrologically connected pluvial lakes(Rosenthal et al., 2017).

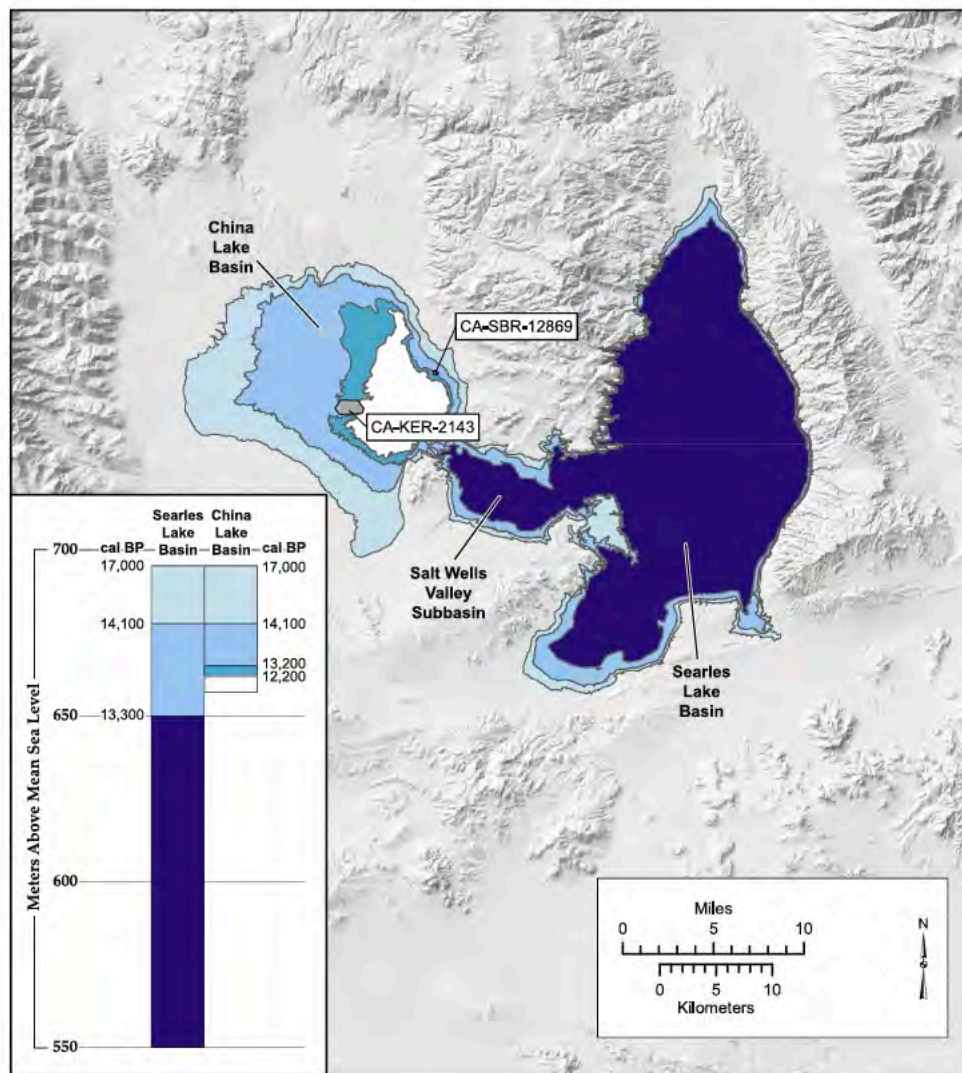


Figure 2-6. High stands of China, Salt Wells and Searles pluvial lakes.

3. AVAILABLE DATA

The following chapter provides a brief description of the data that was used in the development of the HCM. A more detailed description can be found in the Data Inventory Report for the Indian Wells Valley (*work in progress*).

3.1 Wells used in the development of the HCM

In total, there are approximately 1,050 wells within the Indian Wells Valley groundwater basin with a lithological description and a minimum well depth of 30 feet below ground surface (bgs) (9.2 meters). Of the 1,050 wells:

- 41 wells have a depth of over 1,000 feet (304 m),
- 89 wells have a total depth of 350 to 1,000 feet (106 m to 304 m), and
- 920 wells have a depth of 30 to 350 feet (9.2 to 106 m).

As provided in the Data Inventory Report, the coordinates of the wells have varying precision. Many of the wells have coordinates as center of tracts or center of section often resulting in two or more wells having the same coordinates. Within the Basin, there are 39 unique coordinates for the 41 deep wells, 82 unique coordinates for the 89 intermediate wells, and 388 unique coordinates for the 920 shallow wells, for a total of 509 wells with unique coordinates.

The placement of the unique coordinates for the wells in the Basin can be seen on Figure 3-1. The highest concentration of wells is in the center and along the northwestern margin of the basin. In the northeastern part of the basin, which lies within the China Lake Naval Weapons Center, the density of wells used in the HCM is relatively sparse, with wells being relatively shallow (Table 2-1). The southwest part of the basin between the Scodie and El Paso Mountains (also called the El Paso area of the Indian Wells Valley groundwater basin) has very few wells containing a lithological description, with only a single well along the southeastern boundary (Figure 3-1).

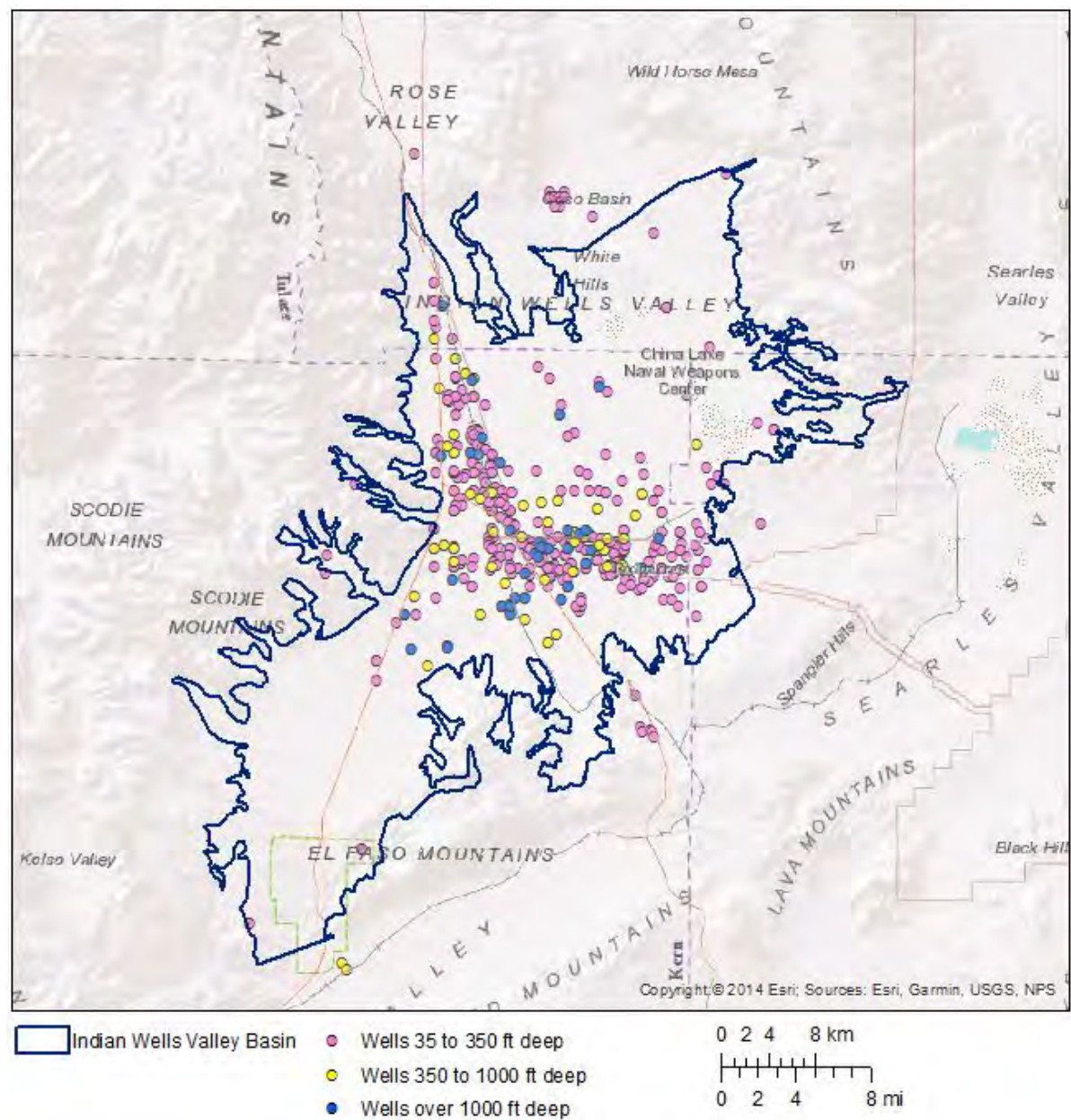


Figure 3-1. Map showing the location of the wells that were used in the interpretation of the HCM. Each dot represents locations of wells within a specified depth range. There may be several wells with the same coordinates.

3.2 Total Dissolved Solids measurements

Total dissolved solids (TDS) is an important water quality input to the development of the HCM, as the Brackish Groundwater Resources study is focused on groundwater with higher TDS (greater than 1,000 mg/L), a measure of the salinity of the groundwater. Resistivity collected by SkyTEM (described in Section 3.7) and WalkTEM (described in Section 3.6) is dependent upon a combination of subsurface lithology and the groundwater salinity. With this information, it is possible to determine whether the measured resistivity is primarily controlled by lithology or by groundwater salinity.

In total, there were 2,025 unique TDS measurements collected within the Basin. These samples were collected through various projects, with sample dates ranging from 1980 to 2018. There were 27 TDS measurements taken in 2018 through the Brackish Water Project.

The TDS samples collected in the Basin come from a total of 174 different wells where the sampling depth is known, as seen Figure 3-2. Wells where TDS has been measured in the Indian Wells Valley groundwater basin. Of these wells, 32 have TDS measurements from nested monitoring wells where more than one depth interval was sampled.

For wells where several TDS samples have been sampled over time, only the most current sample result for each depth interval was used in the development of the HCM and the interpretation of the lithologic and water quality data.

Similar to the well lithology data network, there is good coverage of TDS measurements in the central and northwestern part of the Basin. The northern and southwestern part of the Basin have very few measurements.

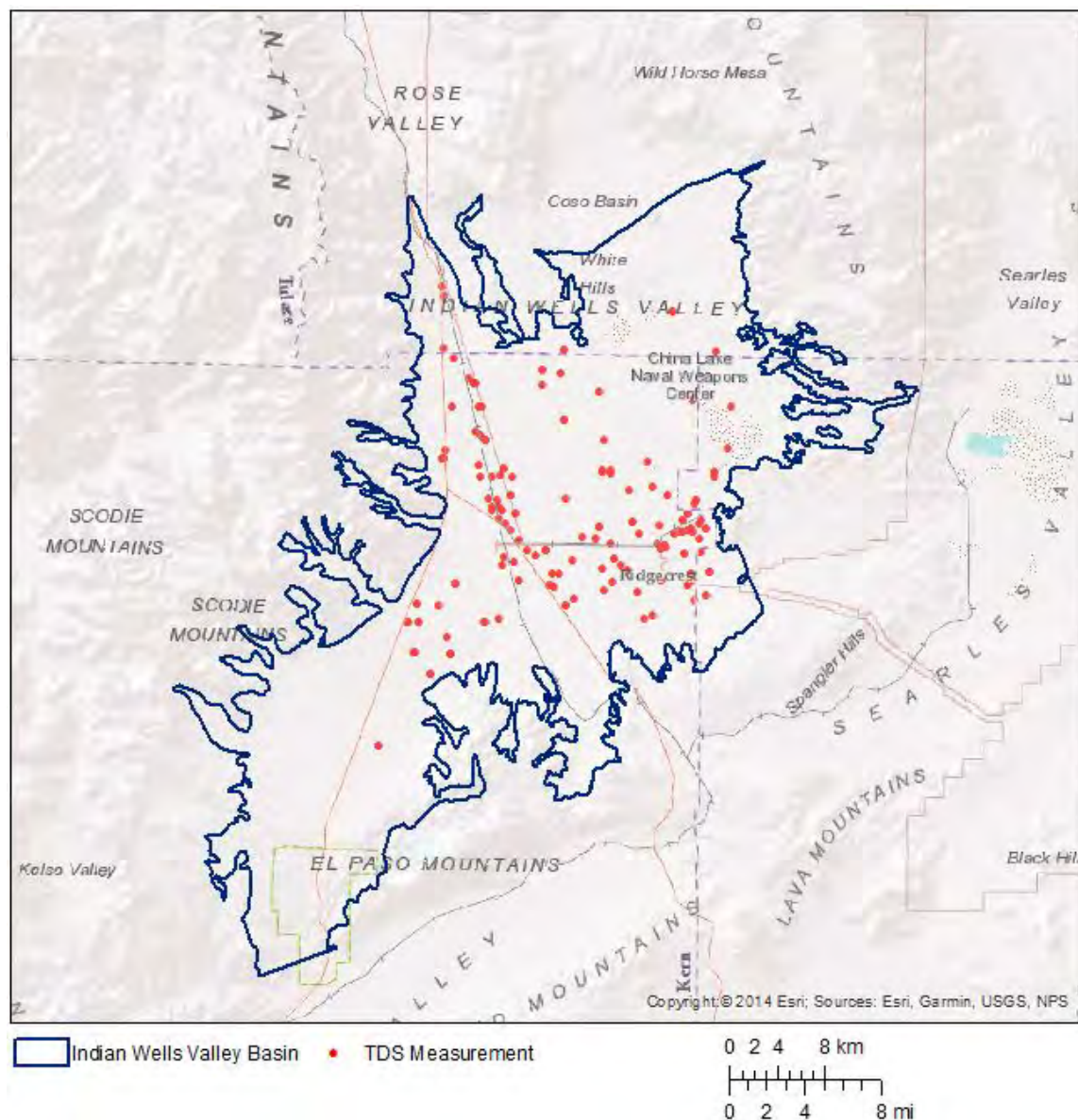


Figure 3-2. Wells where TDS has been measured in the Indian Wells Valley groundwater basin.

3.3 Water level measurements

Groundwater measurements associated with the Kern County Water Agency (KCWA) groundwater monitoring program were used in the development of the HCM. Specifically, groundwater level measurements from October 2017 and March 2018 were included in the modeling software.

In total, there were measurements utilized from 111 different wells, distributed across 338 isolated screened depth intervals. The placement of the wells with water level measurements is shown on Figure 3-3. Location of the groundwater level measurement data included in the Kern County groundwater monitoring program.

The groundwater level measurements received were not associated with a specific screen interval, but rather only the well. Thus, if a well had more than one measurement, it was not possible to determine which screen interval the measurement came from. Therefore, it is not possible to

associate the different groundwater level measurements with a specific aquifer or to determine the groundwater horizontal or vertical gradient at the wells with multiple screens.

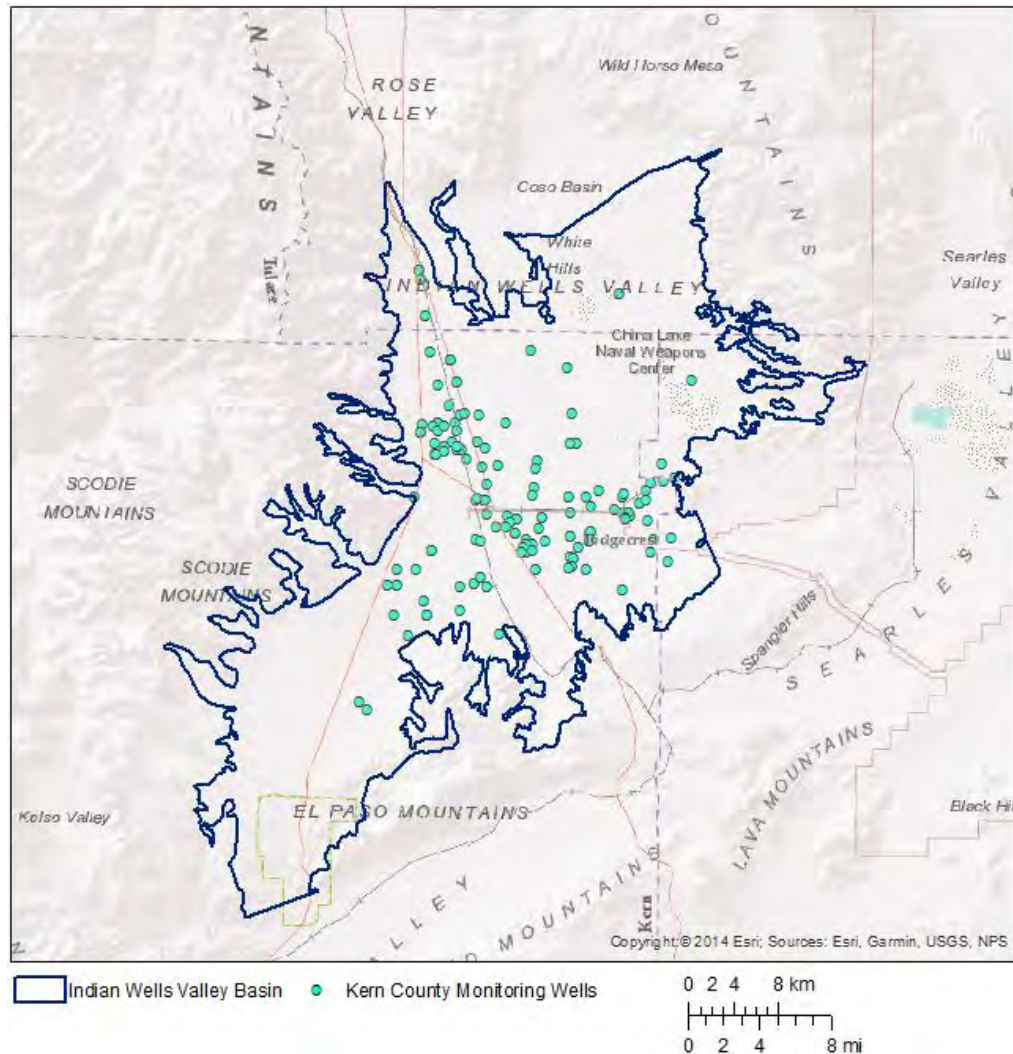


Figure 3-3. Location of the groundwater level measurement data included in the Kern County groundwater monitoring program.

3.4 E-logs

Data for 61 geophysical logs within the Basin were obtained and included in the development of the HCM. The geophysical logs include gamma, natural gamma, induction, neutron, caliper, sonic and electrical resistivity. However, not all log types were conducted for each well. The most common logs available include gamma, induction and electrical resistivity.

The location of the wells with electric logs is shown on Figure 3-4.

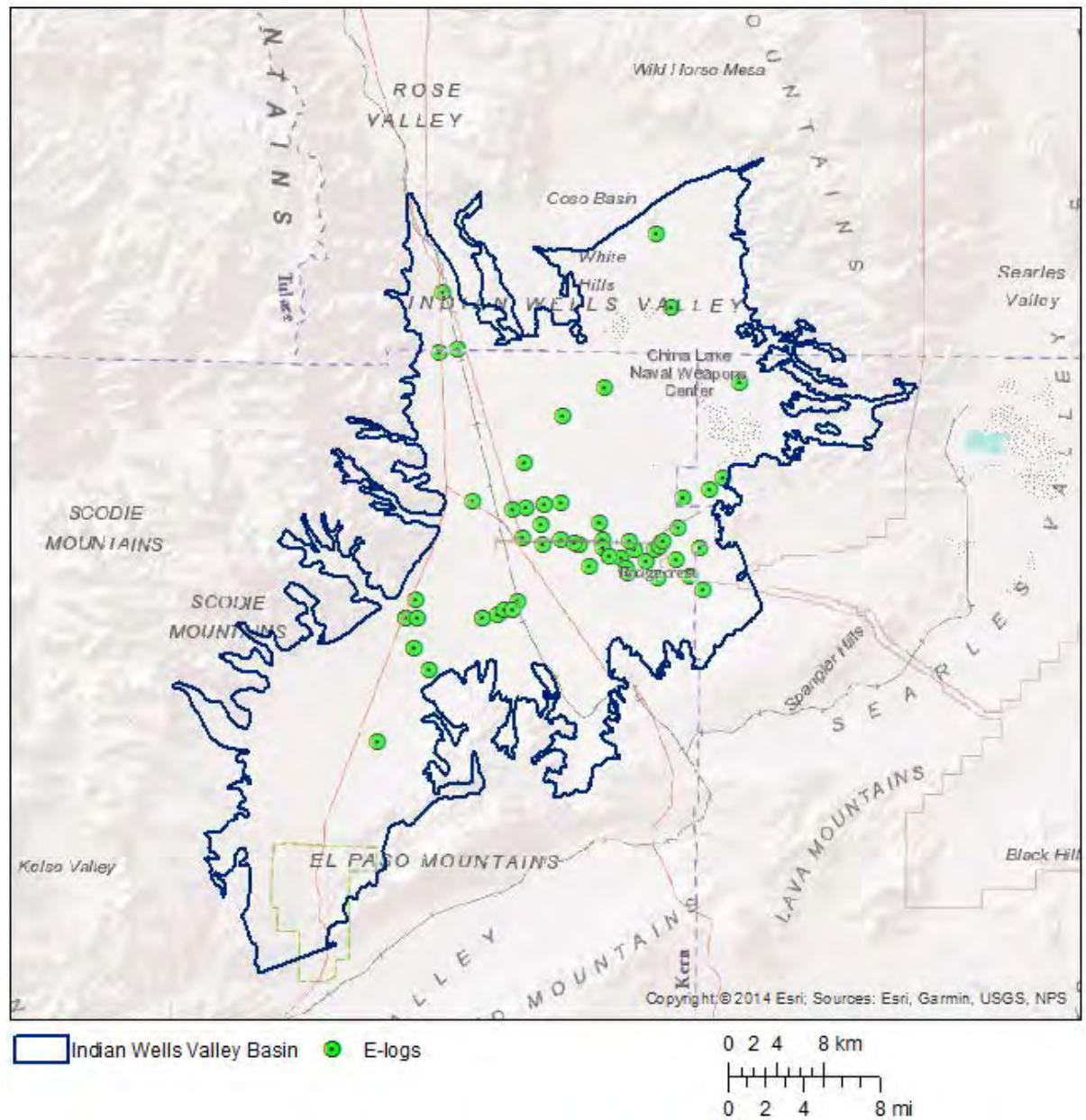


Figure 3-4 Location of the electric logs available in the Indian Wells Valley groundwater basin.

3.5 Seismic Lines

A seismic survey consisting of a total of 10 seismic lines was conducted in association with the geothermal exploration project (Monastero, 2002). Digital images for all 10 lines were obtained in the form of PDF files and included in the modeling software. The seismic sections obtained were visualized in two-way travel time, with data of up to 3 seconds displayed in the sections. A depth conversion of the seismic sections, accounting for changes of velocity in the different geological units, was not available. Therefore, based upon the data from the seismic section, an average velocity of 7,000 ft/sec (2,130 m/sec) was used to convert the two-way travel time to depth under the surface. The location of the 10 lines is shown on Figure 3-5.

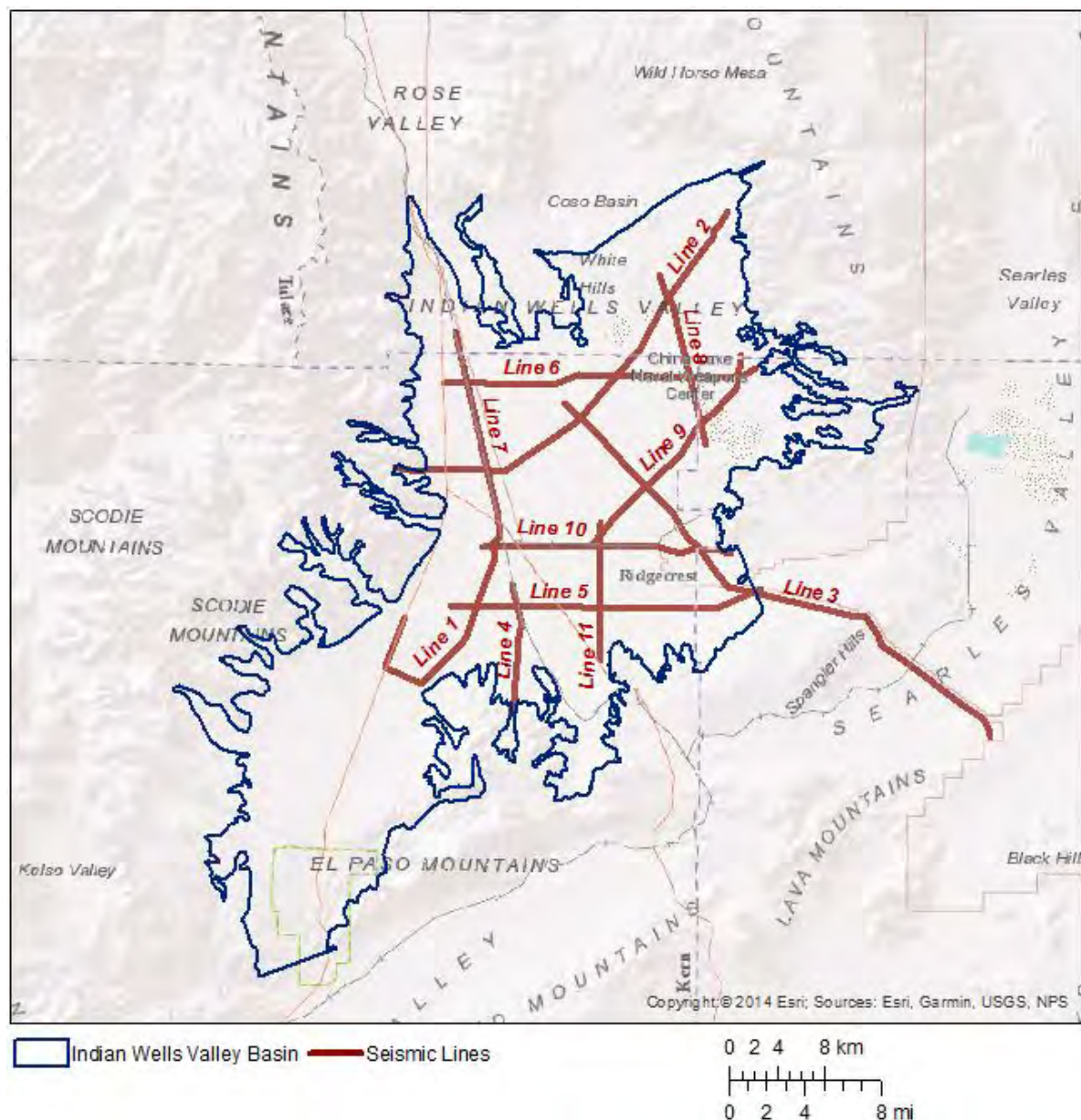


Figure 3-5. Location of the seismic lines in the Indian Wells Valley groundwater basin.

3.6 WalkTEM

Stanford University conducted a ground-based time domain electromagnetic survey using the WALKTEM system with the purpose of evaluating the suitability of the method to resolve the hydrogeology within the basin. The soundings were conducted around the city of Ridgecrest and near existing wells. The data has been integrated in the development of the HCM.

The location of the WalkTEM soundings is presented on the map below, see Figure 3-6. Location of the WalkTEM soundings.

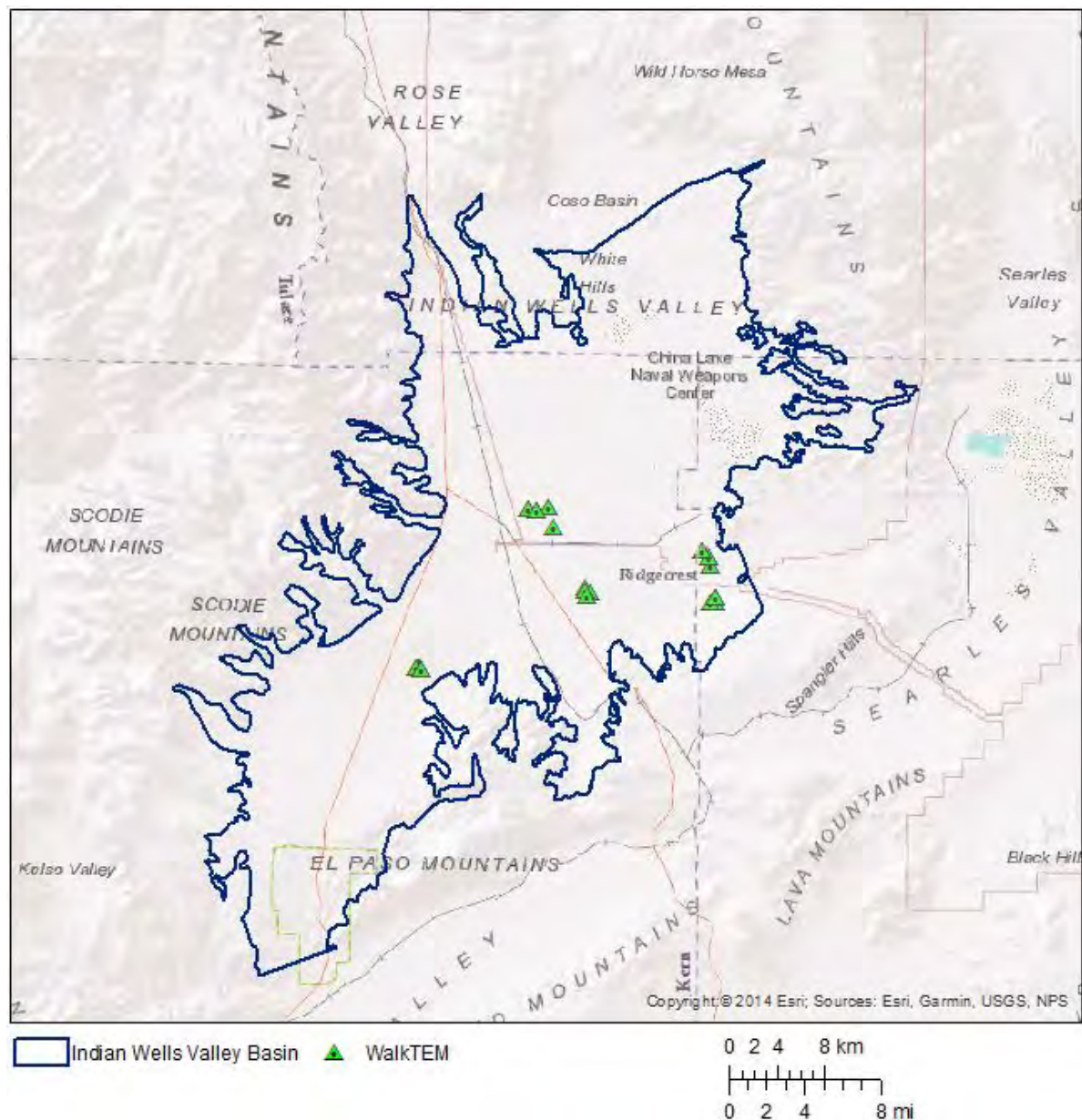


Figure 3-6. Location of the WalkTEM soundings.

3.7 AEM Survey

The Indian Wells Valley (IWV) aerial electromagnetics (AEM) survey was carried out November 8 through 12, 2017 with the SkyTEM 312M system. A total of 800-line km (500-line miles) of data was collected as shown in Figure 3-7. The line spacing was 4,100 feet (1,250 m) and 8,200 feet (2,500 m), and the alignment of the flight lines are directed primarily along north-south, east-west and northeast-southwest directions.

The survey plan was designed based on an evaluation of selected deeper wells, understanding of the regional and basin-specific geology, knowledge of the extent of brackish water, a ground-based geophysical transient/time-domain electromagnetic (TEM) survey, seismic sections, and understanding of the regional structure and known faults within the basin. The line directions and spacing were also chosen to cross the main geological structures with the purpose of achieving generally long, straight survey lines. Within the China Lake Naval Air Weapons Station property, the Navy only allowed a few lines striking west-east. The line spacing was determined with the objective of covering the entire basin and obtaining the highest resolution in the areas where most of the groundwater is being extracted. An additional significant focus was the boundary between the China Lake and El Paso areas, where current groundwater flow model calibration has been challenging, hence, there is a higher density of SkyTEM survey lines in this area.

The company SkyTEM Surveys conducted the AEM survey, collected the data and documented the data collection in a technical report (2018, SkyTEM Surveys). The data underwent quality control and thereafter a more in-depth processing and modelling process where noisy data due to interference from man-made installations (eg. powerlines, metal fences, etc.) were masked out of the data set. The resulting dataset were then used as the basis for an inversion process where the obtained field data were modelled. A detailed description of this procedure can be found in the SkyTEM technical report (2018, Stanford University and Ramboll). The output from this processing is what has been used as the SkyTEM data input into the development of the HCM.

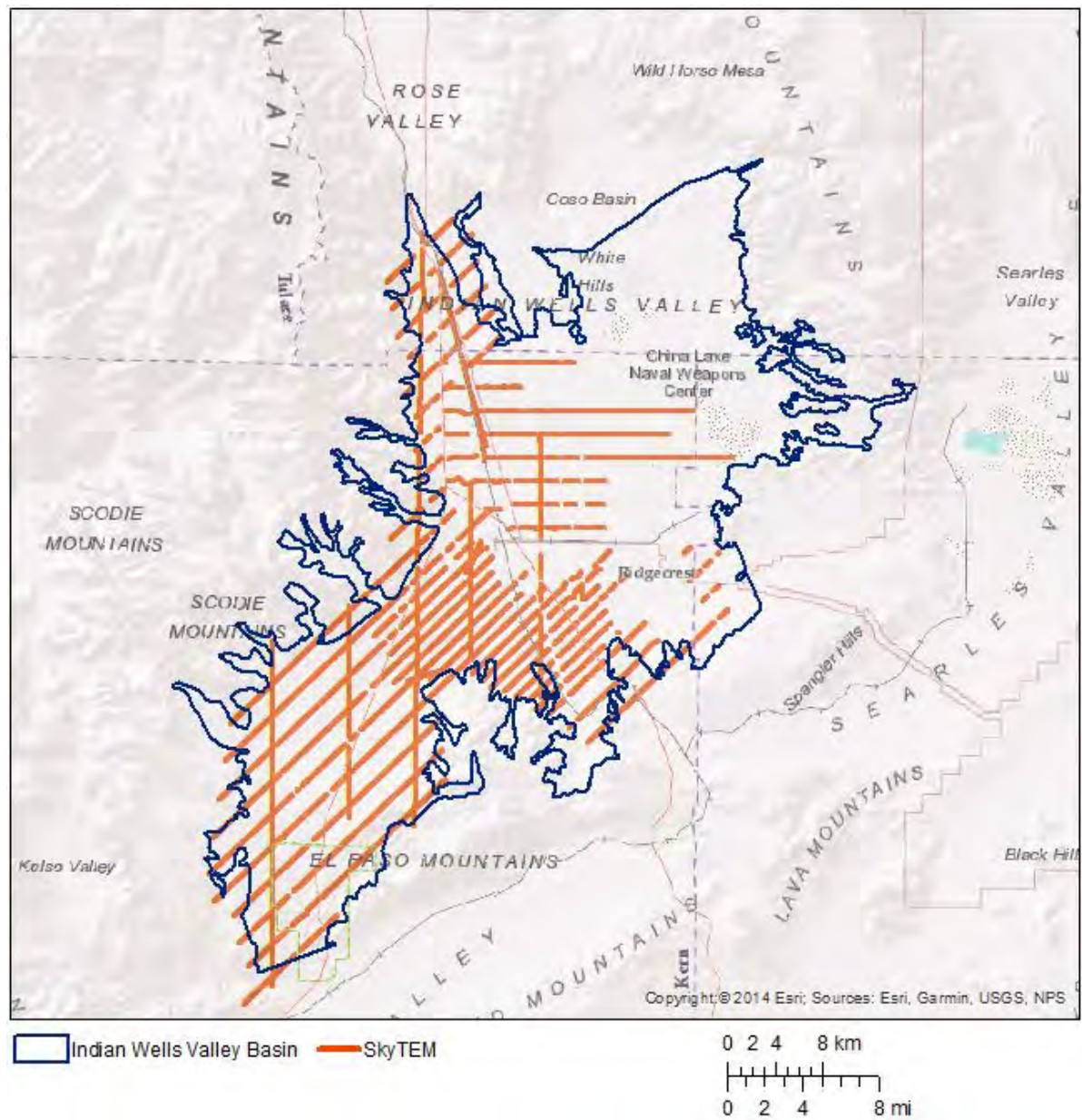


Figure 3-7. AEM (SkyTEM) survey lines in the Indian Wells Valley Basin.



Figure 3-8. SkyTEM system during takeoff at Inyokern Airport.

4. HYDROGEOLOGIC CONCEPTUAL MODEL DEVELOPMENT

The hydrogeologic conceptual model (HCM) for the Indian Wells Valley groundwater basin has been developed as a digital multi-layered model. The primary objectives are to define and map out the different aquifers and aquitards as hydrogeologic zones in the basin using all the available data in a computer software package that can be maintained and readily updated as new data become available. This chapter describes the framework for the HCM including the workflow and data interpretation.

4.1 Model software and structure

The HCM is a 3D digital model constructed with the modeling software GeoScene3D by I-GIS (www.i-gis.dk). GeoScene3D allows for the input of different types of well data from the GeoGIS database, including lithology, water level, water quality (TDS) and information regarding well construction and screen placement. GeoScene3D also allows for the inclusion of geophysical data, including aerial electromagnetic resistivity (SkyTEM), WalkTEM resistivity, seismic data and borehole electrical logs.

The model is set up as a layer model, where the boundaries between the basin's defined hydrogeological zones. The digital elevation model (DEM) used in the model was developed using data from the 2000 Shuttle Radar Topography Mission, made available by NASA and compiled by de Ferranti (2014). The DEM utilized a 100 x 100 m grid.

The surfaces of the layers in the model are interpolated from surface interpretation points using Natural Neighbor in ESRI ArcMap. The raster surface consists of 100 m grids, with the grids snapped to the DEM. The hydrogeologic zone thicknesses were calculated using simple raster math in ESRI ArcMap.

The GeoScene3D model and all GIS reporting uses the spatial reference WGS84 UTM Zone 11N.

4.2 Workflow Process

The development of the HCM was conducted in 6 steps:

1. Data acquisition and review of previous studies;
2. Project set-up in GeoScene3D software;
3. Development of the framework of the model from which interpretations are based upon;
4. Development of the 3D layer model;
5. Presentation of draft results and draft report comments and adjusting the interpretations based upon the received feedback; and
6. Submission of the final 3D HCM and report.

A diagram illustrating the work flow is presented on Figure 4-1. The following section provides more detail on the steps within the workflow. After the HCM work is concluded, the digital model can then be used in a groundwater flow model, as indicated by the dashed line in Figure 4-1.

4.2.1 Data acquisition and review of previous studies

Data associated with well construction, lithology, water level, water quality and electrical logs were used in the modeling process and were assembled and digitized into a GeoGIS database. The process for the development of the GeoGIS database for the Indian Wells Valley groundwater

basin, including the specific sources, data format, quality control and challenges in the collection and digitizing of the data, is described in detail in the Data Inventory Report for the Indian Wells Valley. The available geophysical data available for the HCM include the SkyTEM, ground-based WalkTEM, seismic, gravity and aeromagnetic data.

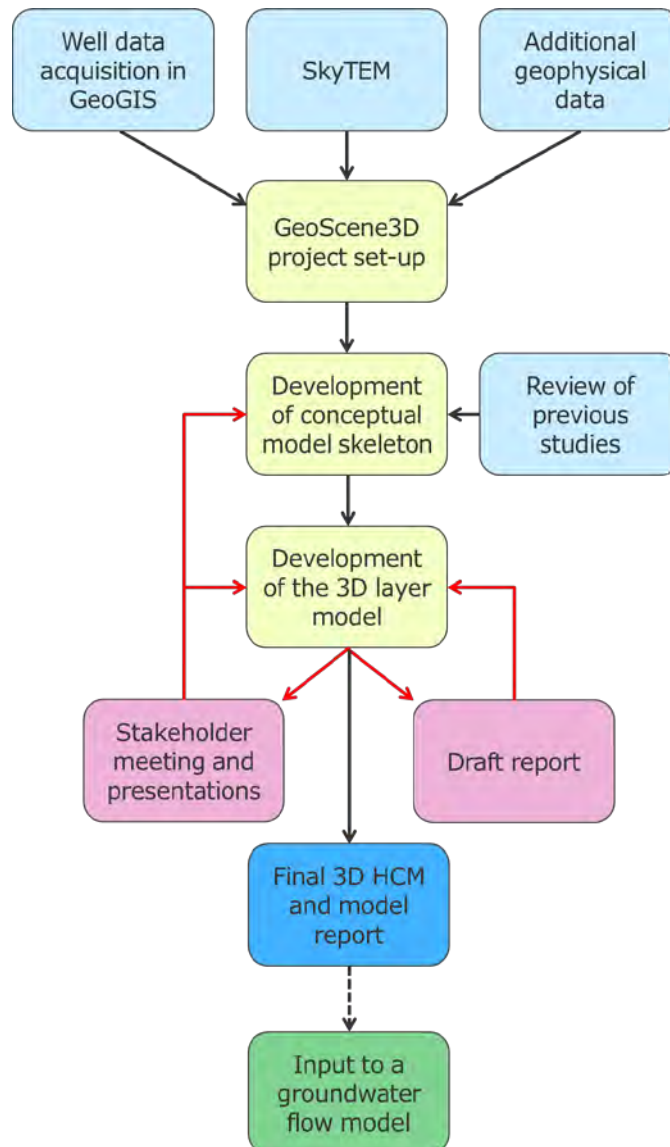


Figure 4-1. Diagram illustrating the workflow in the development of the HCM.

The light blue fields indicate input to the modelling process, the light green fields show the modelling process as conducted in GeoScene3D, the light red fields and arrows show the iterative process with stakeholders, and the dark blue field shows the final product. The dashed line and the green box illustrate that the model can afterwards be used in a groundwater flow model for the basin.

A full review of the previous geologic and hydrogeologic studies conducted in the Basin was performed. This provided a background on the basin geology and hydrology as well as the different competing hydrogeologic interpretations.

4.2.2 GeoScene 3D project set-up

A GeoScene3D project containing a scene extent covering the entire Indian Wells Valley groundwater basin was set-up. All available data, as described in Section 4, were loaded into the

modeling software. The digitized well lithology descriptions were simplified into basic descriptors that include clay, sand, silt, gravel, cobbles, boulders, sandstone, limestone, basalt, granite and fill. The associated color scale used to display lithology is presented Table 4-1. The color scale for the SkyTEM data was optimized to heighten the resistivity contrasts seen in the unconsolidated sediments within the basin. The color scale for the SkyTEM and WalkTEM data is presented on Figure 4-2.

Table 4-1. Interpreted lithology.

Based upon the descriptions from the driller's logs, and thematic color scale for the interpreted lithology used in the GeoScene3D software. The colors in this scale apply to all cross-sections presented in this report.

Lithological description from the driller's logs	Interpreted lithology	Thematic color
Fill, Top	Fill	Dark gray
Sand as the first descriptor, then followed only by gravel, cobble, boulder or rock (coarse sediment types)	Sand	Yellow
Gravel as the first descriptor, then followed by sand, cobble, boulder or rock (coarse sediments)	Gravel	Light red
Sand as the first descriptor, then containing clay or silt as a secondary descriptor	Clayey sand/silty sand	Orange
Clay or silt as the first descriptor, then containing sand and/or gravel as a secondary descriptor	Sandy clay/sandy silt	Brown
Clay and/or silt as the only descriptors	Dark brown	Dark brown
Tuff	Tuff	Tan
Basalt	Basalt	Black
Granite	Granite	Light gray
Conglomerate	Conglomerate	Purple
Sandstone	Sandstone	Dark red
Bedrock	Likely granite or basalt	Blue
Limestone	Limestone	Green
Unknown	Unknown	White

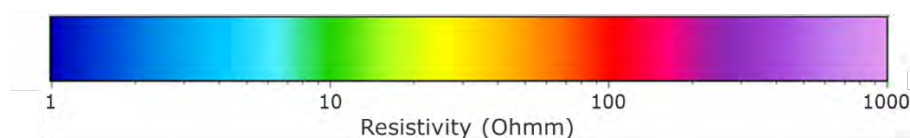


Figure 4-2. Thematic color scale for the AEM (SkyTEM) data.

Note that the scale is logarithmic.

A Microsoft Access database for the storage of the data interpretation points was created. A network of west to east cross-section at 3,300 ft (1,000 m) intervals across the basin was created. A network of cross-sections placed along the SkyTEM flight lines was created.

4.2.3 Development of the HCM framework

After the set-up of the modeling software, a conceptual framework for the HCM was developed. The framework was used to develop the geometry of hydrogeologic zones (aquifers and aquitards) that were observed in the basin. Once the general structure of the HCM was determined, interpretation of the data to map out the hydrogeologic zone boundaries was possible.

The general conceptual framework of the HCM was determined through a screening of well lithology and geophysical data. Particularly the well lithology compared to the SkyTEM data were used in categorizing the different hydrogeologic zones observed in the basin. The conceptual framework was then compared with previous hydrogeologic studies conducted in the Basin to confirm the different zones honor the previous geological descriptions of the basin. The framework was thereafter adjusted to provide the best fit between the newly collected and assembled data and the previous studies.

4.2.4 Development of the 3D layer model

The development of the 3D layer model includes the following steps:

1. Locating interpretation points where the boundaries between the different hydrogeologic zones can be seen in the geophysical and well data;
2. Interpolation of the boundary surfaces;
3. Quality control checks of the interpreted surfaces against the data and surface adjustment where needed.

The locating of interpretation points was conducted on the cross-section network established across the basin. All data within a buffer of 1,650 ft (500 m) were shown on the cross-section. The 1,650 ft buffer allows all available data to be viewed and interpreted on the nearest cross-section. In addition to the interpolation on the west-east cross-section network, the SkyTEM data were interpreted on the cross-sections placed along the SkyTEM flight lines.

Interpretation points were located where a boundary between two hydrogeologic zones was observed. For example, an interpretation point was placed on a well where the lithology showed a change between predominately coarse sediments and predominately fine sediments. For the SkyTEM data, an interpretation point was placed where a change in the resistivity due to a change in lithology was observed.

The data displayed in the modeling software is up to 1,600 feet from the cross-section where the interpretation points are located. Therefore, the points were snapped to the data (either to a well or geophysical data), allowing the interpretation point to be placed at the precise coordinates of the data source. This is important, as it prevents potential spatial errors when interpreting the data and allows for a more robust interpolation of the hydrogeologic surface boundaries.

Once all data have been interpreted, the points for each layer were exported to ArcMap. The surfaces for each boundary are interpolated using the natural neighbor routine in ArcMap. The interpolated surfaces are then imported back to the modeling software.

In the final step, the interpolated surfaces were quality control checked to evaluate how well the surfaces matched the data in the model. This was done on both the west to east trending cross-section network on which the interpretations took place, as well as north-south trending cross-

sections. Quality control using north-south trending cross-sections is particularly important to ensure that there are not significant jumps in the interpolated surfaces perpendicular to the direction in which the interpretation took place. This helps to minimize potential errors in the interpretation of the hydrogeologic zone boundary.

In the instances where the interpolated surfaces did not fit the data, the surfaces were adjusted. This was done by adding additional data points (pseudo or control points), through a re-interpretation of the surface (moving interpreted points higher or lower) or by adding control points where data was not present. This was done to create a smooth interpolation of the surfaces between the data points.

Once the new points were placed, the surfaces were re-interpolated and quality control checked. This was an iterative process, repeated multiple times until a reasonable fit between the data and the interpolated hydrogeologic zone boundary surfaces were achieved.

4.2.5 Presentation of draft results

The draft results of the 3D model were presented at several Brackish Water Project meetings. The presentation of the draft results allowed for experts within the group to comment on and provide input into the model development and provide comments on how the model can be improved. After each meeting, the model interpretation was revisited and the received comments were taken into consideration.

Two public meetings were held to present the draft results of the model. The first public meeting was held in July 2018 and allowed for public comment on the provisional results. Taking these comments in consideration, specific elements of both the conceptual model framework and hydrogeologic zone interpretation were reconsidered. The second public meeting was held in March 2019 where the modeling results and draft report were again presented. This allowed stakeholders an additional opportunity to provide comments on the final model.

4.3 Data interpretation

As summarized above in section 4.2.4, the data in the model were interpreted to create the hydrogeologic zone boundary surfaces. This section provides examples on how the different data types were interpreted in the development of the HCM.

Figure 4-3 shows the interpretation of the well lithology and the SkyTEM resistivity data. Well BR-2 in the figure illustrates how the boundaries between different hydrogeologic zones were interpreted. The interpretation points, represented by a small square on the well in the figure, were placed at the boundary where the well lithology changes from sand to clay. A second point was also placed where the lithology changes again from sandy clay to clayey sand.

Resistivity from the SkyTEM data, which can provide information on lithology and groundwater salinity, were interpreted using the following guidelines:

- Resistivity over 100 Ohmm represents granite.
- Resistivity from 70 – 300 Ohmm represents unsaturated sediments.
- Resistivity from 15 – 70 Ohmm represents predominately sand and gravel in the saturated zone under relatively freshwater conditions. As the resistivity in this range decreases, either the clay content or groundwater salinity may be increasing.

- Resistivity from 3 – 15 ohmm represents clayey deposits with freshwater or sandy layers with brackish water (over 1,000 mg/L TDS).
- Resistivity under 3 ohmm represents predominately clayey deposits with brackish water or possibly sandy layers with high salinity (over 10,000 mg/L TDS).

Figure 4-4 shows the color key in the interpretation of the SkyTEM data for this project. On Figure 4-5 interpretation points based on the SkyTEM data (squares on the SkyTEM data) and the resultant surface can be seen.

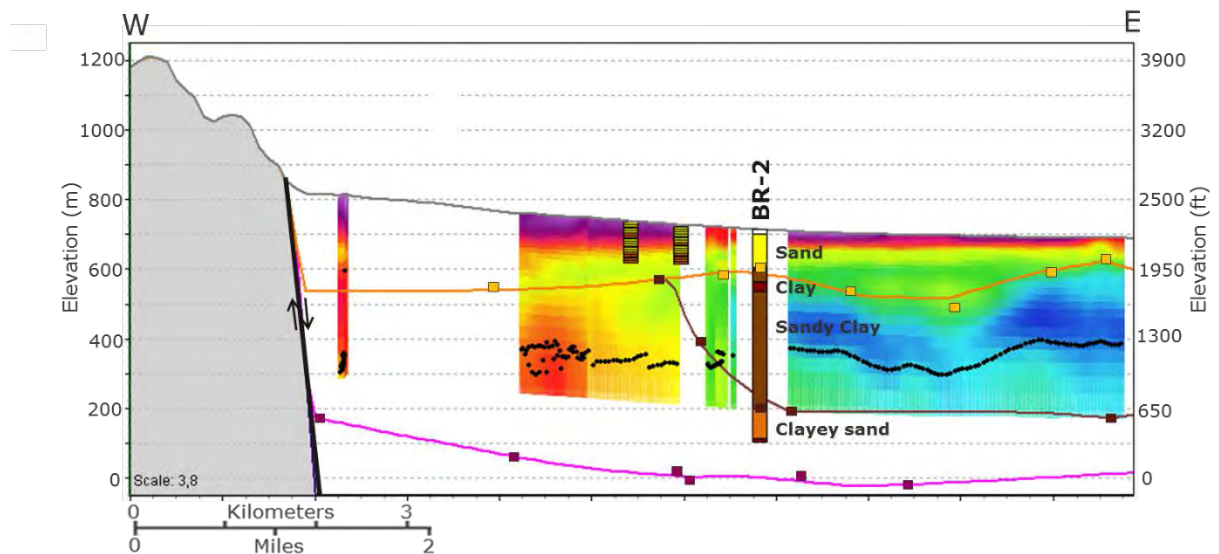


Figure 4-3. Cross-section showing SkyTEM resistivity measurements combined with the lithology from the three different wells.

The squares show where the interpretation points were placed in relation to the data. The small black dots show the depth of investigation (DOI) for the SkyTEM data. The lithology for well BR-2 is provided. The colored lines show the interpreted hydrogeologic zones, which will be discussed later in the report.

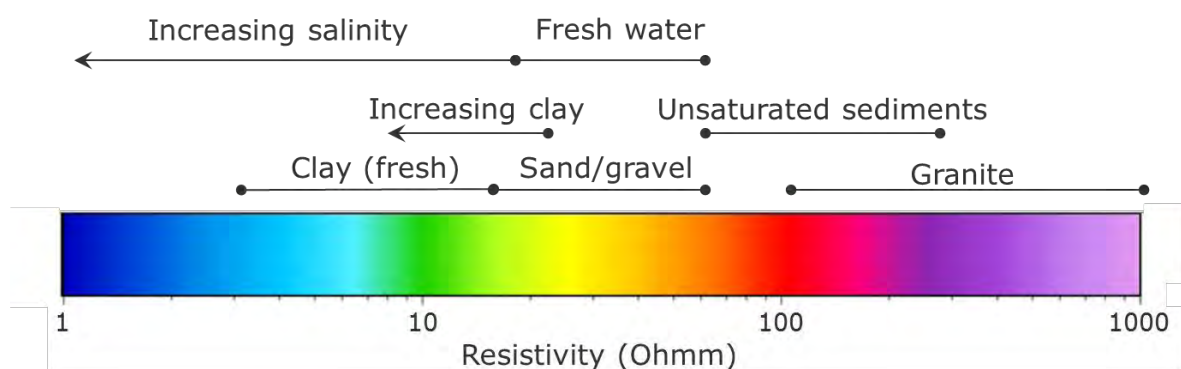


Figure 4-4. Key showing the translation from resistivity to hydrogeology.

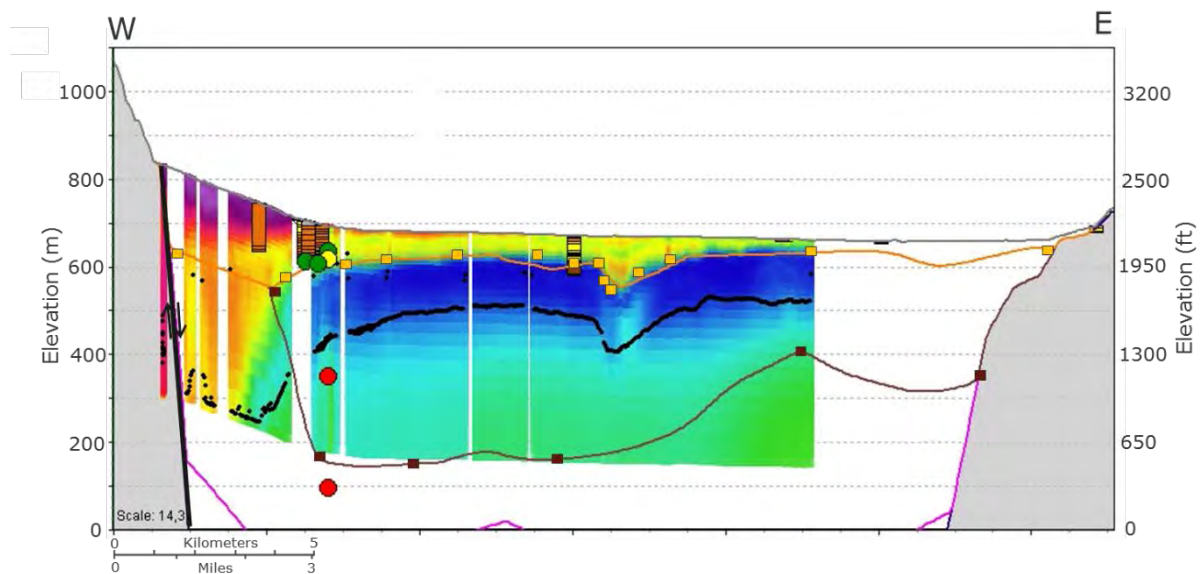


Figure 4-5. Cross-section showing SkyTEM resistivity measurements combined with lithology and measured TDS (large circles).

The squares show the interpretation points placed with respect to the data. The small black dots show the depth of investigation (DOI) for the SkyTEM data. The colored lines show the interpreted hydrogeologic zones, which will be discussed later in the report. Note that the well with the TDS measurements does not have a lithological description.

Data from the SkyTEM survey extends down to a depth of approximately 1,600 feet (500 m). However, the SkyTEM data have a depth of investigation (DOI), calculated during the processing of the SkyTEM, where below this level the uncertainty in the electrical signal is high enough that changes in resistivity may not be representative of changes in either geology or groundwater salinity. The DOI is shown on Figure 4-3 and Figure 4-5 as the small black dots. Other data sources were used when interpreting the resistivity below this level.

Figure 4-5 shows an illustration of the SkyTEM data interpretation combined with the TDS measurements. In the shallow zone, the wells show clayey sand with relatively fresh water (TDS below 1,000 mg/L). This is also seen in the SkyTEM data, which shows resistivity of 30 to 40 ohmm (yellow to yellow-orange colors in the SkyTEM data Figure 4-5). Below this zone, there is an abrupt change in the SkyTEM data, where the resistivity becomes very low (under 3 ohmm, represented by dark blue colors). This is interpreted as both a change in the lithology, where clay becomes more dominant, combined with a significant increase in groundwater salinity. The TDS in MW-7 well confirms this interpretation, where salinity in the groundwater increases with depth to over 3,000 mg/L.

Figure 4-6 shows an example of the electrical log data used in the interpretation of the HCM. The well log in the figure is from TTIWV-SB1, located in the northwestern part of the Indian Wells Valley basin. The log includes the natural gamma. The gamma radiation measurements from the gamma log in the figure shows the highly complex interbedded nature of the deposits, which is typical in the basin. Figure 4-6 illustrates the detail of the thickness of the interbedded sediments in which the gamma log is able to distinguish, as opposed to the coarser scale that the resistivity from SkyTEM is able to show. Additionally, this borehole is one of the higher quality drilling data collected from coring continuously during drilling. There is very good correlation between the natural gamma measurements and the recorded lithology from the drillers log.

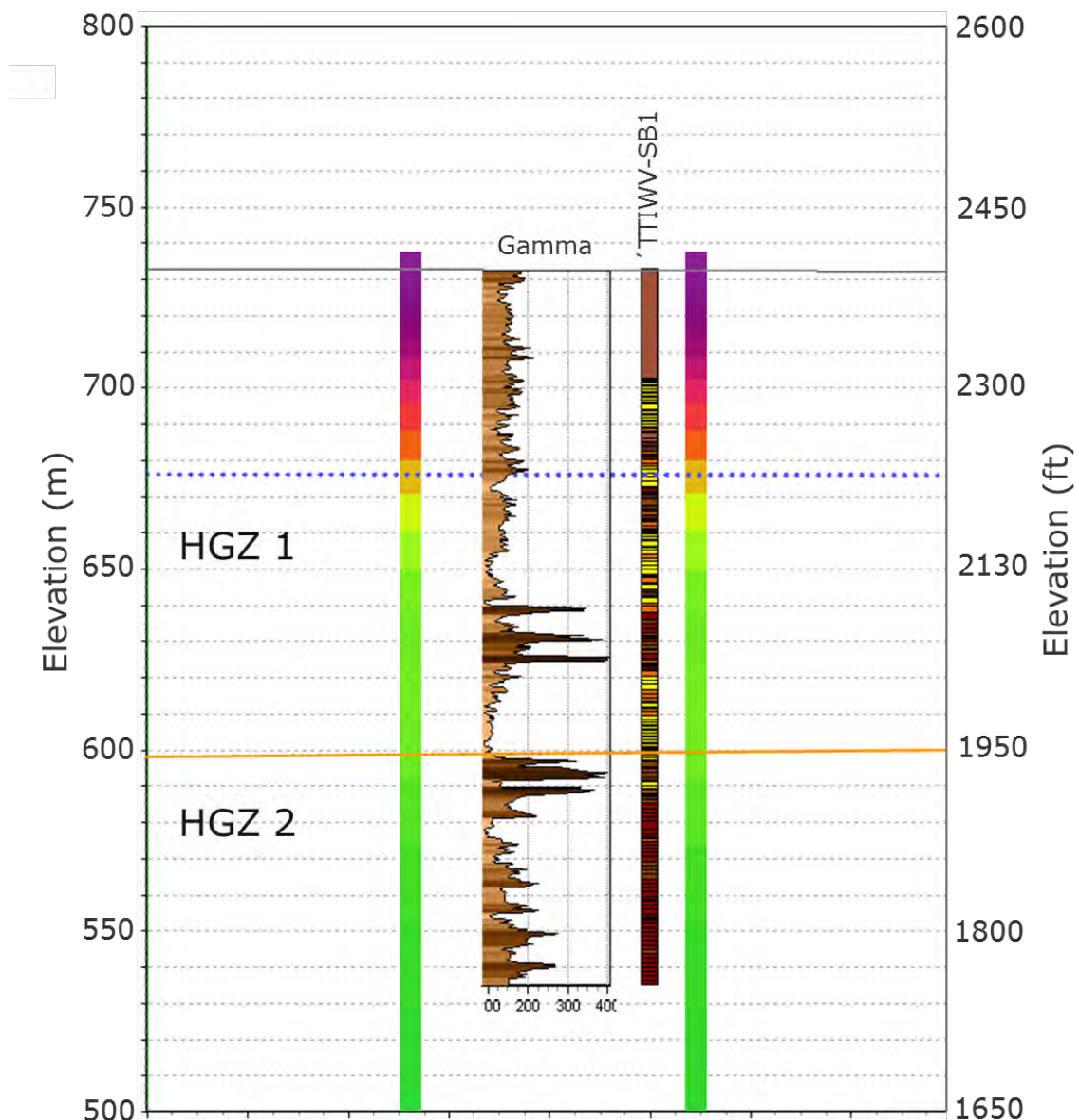


Figure 4-6. Example of well log from well TTIWV-SB1 in GeoScene3D used for the interpretation of the HCM. The gamma signal is filled, with the darker the fill the higher the clay content. The colored bars show the SkyTEM resistivity and the dotted blue line shows the interpolated water table from the SkyTEM data. The bottom of HGZ 1 is the orange line and the bottom of HGZ 2 is the brown line.

Figure 4-7 shows SkyTEM resistivity data together with the electrical log, lithological description, TDS and water level measurements from well BR-10 (located in the northwestern part of the basin). This figure provides a good example of how the different data sets were used together in the interpretation of the HCM. In this case, the drillers log shows predominately sand and gravel down to an elevation of 1,900 feet (575 m), where after there is an increase in silt and clay content. The gamma log, on the other hand shows that there is relatively clay-free materials down to an elevation of 1,650 feet (500 m), where after there is a slight increase in clay until an elevation of 1,475 ft (450 m). At this point there is a 160 foot (50 m) thick horizon with significantly more clay. Of note on this borehole is that the well was logged from samples collected from cuttings, as compared to some of the higher quality drilling data collected from

coring continuously during drilling. The SkyTEM data shows a lower resistivity beginning at 1,900 feet (575 m), indicating an increase in clay materials. This corresponds with the lithological log. Thus, the interpretation of the bottom of the upper aquifer (HGZ 1) at 1,800 feet (550 m) is based upon the SkyTEM and drillers log. The relatively low gamma measurements (albeit slightly increasing gamma in the upper portion of HGZ 2) likely indicates a higher silt than clay content until 1,475 feet (450 m), where clay becomes more abundant.

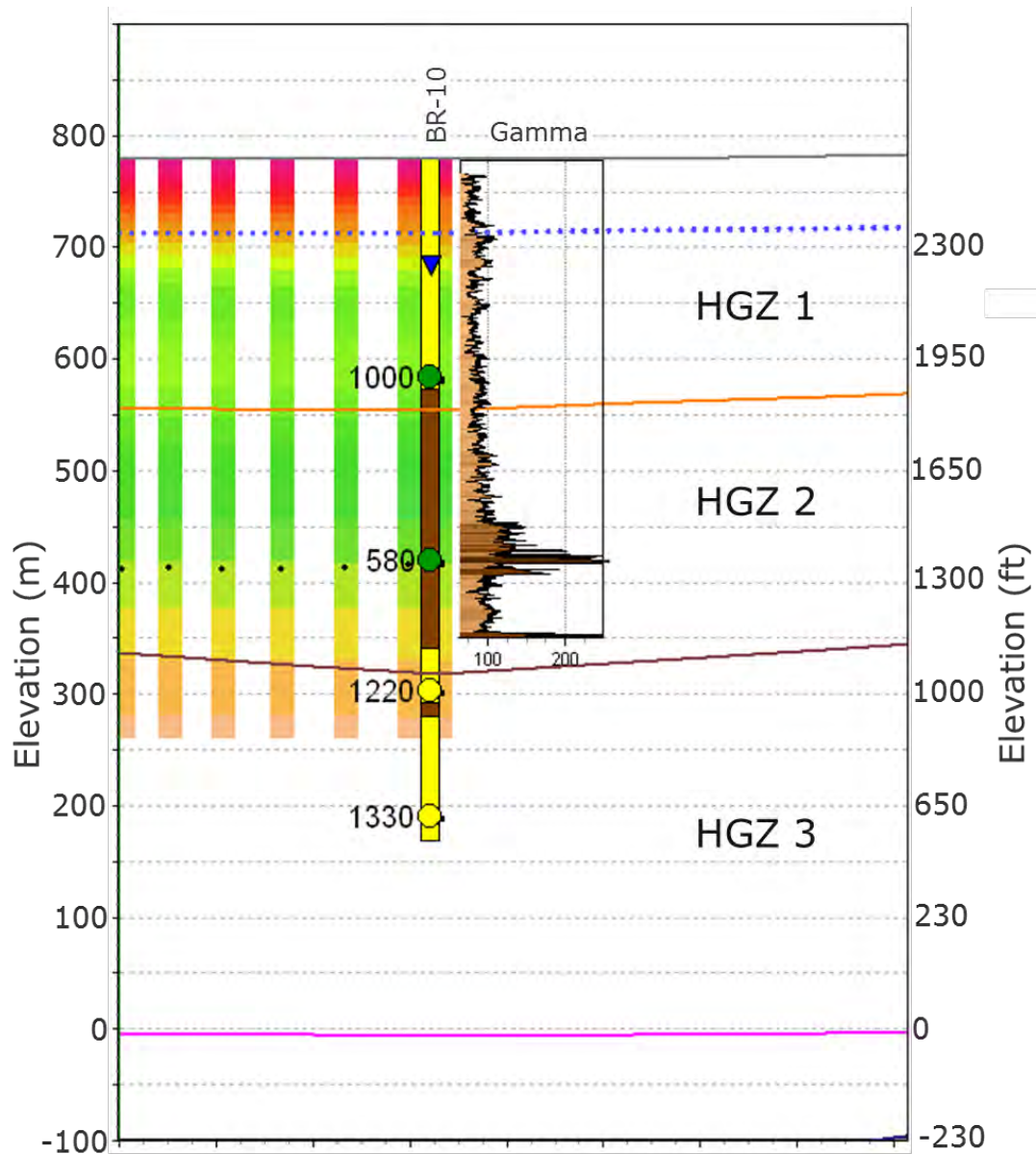


Figure 4-7. Illustration of the interpretation of available data sources in GeoScene3D software. The figure shows the lithological log, gamma log, TDS measurements (circles with concentration in mg/L) and water level (March 2018) measurements from well BR-10 along with the SkyTEM resistivity. The gamma signal is filled, with the higher the clay content, the darker the fill. The colored bars show the SkyTEM resistivity with the small black dots showing the depth of investigation. The dotted blue line shows the interpolated water table from the SkyTEM data. The bottom of HGZ 1 is the orange line, the bottom of HGZ 2 is the brown line and the bottom of HGZ 3 is the pink line. The inverted blue triangle shows the water level measured in March 2018.

Figure 4-8 shows an example of an interpreted seismic section displayed in GeoScene3D. The seismic sections were used predominately for the interpretation of the bottom of the basin (granite, thick basalt deposits) and for the estimation of the boundary between the unconsolidated sediments and the semi-consolidated to consolidated sediments (sandstone, limestone and conglomerate). In the interpretation of the seismic section, key wells that extend to the bottom of the basin (SNORT 1 and SNORT 2) were used to define the reflectors representing the two surfaces. These reflectors were carried through the network of seismic lines (Figure 4-8).

There is a large amount of uncertainty associated with the interpretation of the seismic lines. The lines were received as uninterpreted PDF files which were incorporated into the GeoScene3D modeling software as picture files (TIFF files), affecting the overall quality of the line. The official interpretation of the seismic lines from Monastero (2002), including the location of the faults, basement boundary and internal geological structures were not available. Because there is not additional information on the bottom of the basin, a preliminary interpretation of the seismic lines was conducted, with interpretation points placed on the seismic lines following the reflectors. When compared to the cross-sections published by Monastero (2002), the depth to the basin bottom fit relatively well. However, a much more accurate and detailed mapping of the basin floor could be achieved with a more detailed interpretation of the seismic lines.

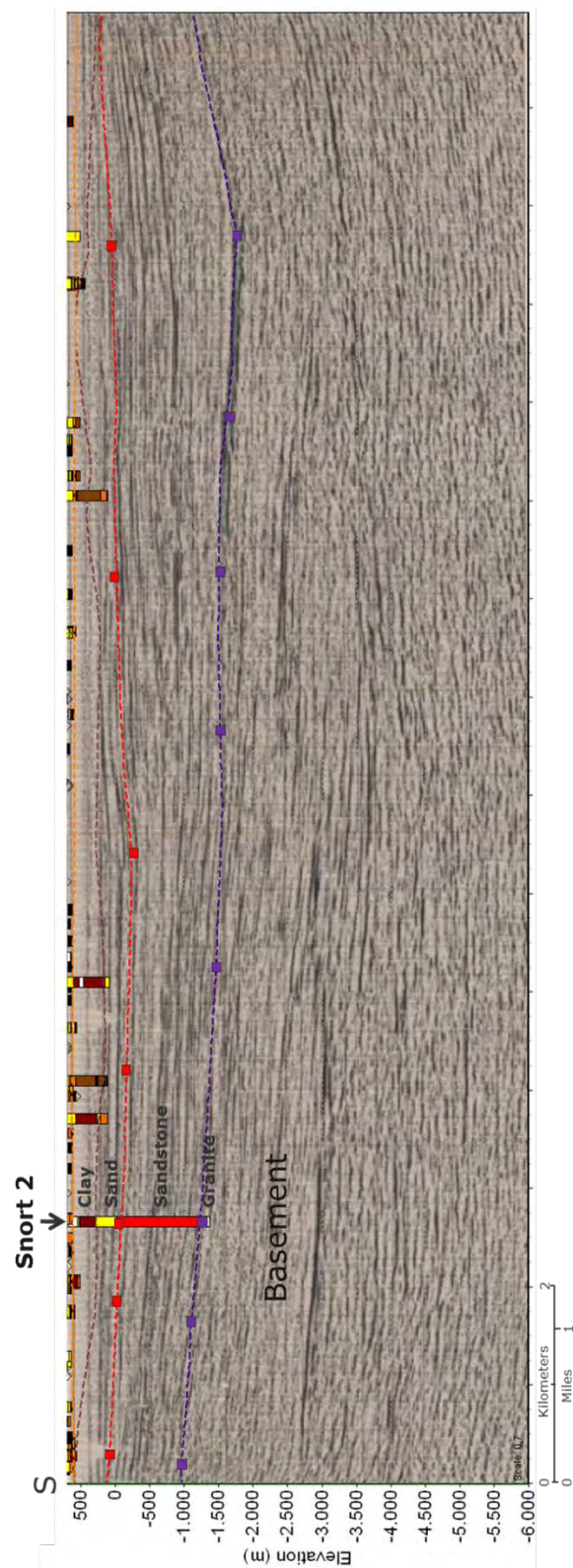


Figure 4-8. Seismic section nr. 7 (Monastero, 2002)), displayed as two-way travel time, with well lithology and interpretation.

The dashed purple line shows the interpreted boundary of the basement (granite). The purple and red squares show where interpretation points were placed on the seismic line. The deepest well in the area is the SNORT 2 well, which is the only well on the section which reaches the granite basement.

5. BASIN GEOMETRY

5.1 Surface Geology

The geological map produced by the California Geological Survey (CGS), showing the mapped geology in the Basin and surrounding area, is illustrated on Figure 5-1. The groundwater basin boundaries are defined, in general, by the edge of the spatial extent of the alluvial deposits in the area. The northern two-thirds of the basin are mapped as Pleistocene to Holocene alluvium, lake, playa and terrace deposits, unconsolidated and semi-consolidated sediments. In the southwest area of the Basin, the surface deposits consist of older Pleistocene alluvium, lake and terrace deposits (symbol Qoa on Figure 5-1). The southerly part of the basin contains Pliocene-Pleistocene semi-consolidated to consolidated sedimentary rocks (symbol QPc on Figure 5-1). Based upon the surface geology, the Indian Wells Valley groundwater basin has two different geological zones: the China Lake area which contains the Holocene alluvium, lake, and playa deposits, and the southwestern portion of the El Paso area between the Scodie and El Paso Mountains, which contain the older Pleistocene alluvial deposits (hereafter called the El Paso area).

The geological units on the western and eastern margin of the basin consists of Mesozoic granite, granodiorite and quartz diorite. In the northern and southeastern margin of the basin there are Quaternary volcanic rocks, including basalt flows and pyroclastic rocks. The southern margin also contains outcrops of the Tertiary continental sedimentary rocks, including the Ricardo and Goler Formations.

The faults that have been mapped in the Basin are also shown on Figure 5-1. The Sierra Nevada frontal fault (SNFF) is the major fault in the area and generally defines the western edge of the groundwater basin. There are several NW-SE striking faults throughout the China Lake area, two of which divide the basin with older alluvium (Qoa) and recent alluvium (Q) on either side of the fault. In the northern part of the basin, smaller N-S striking faults are mapped.

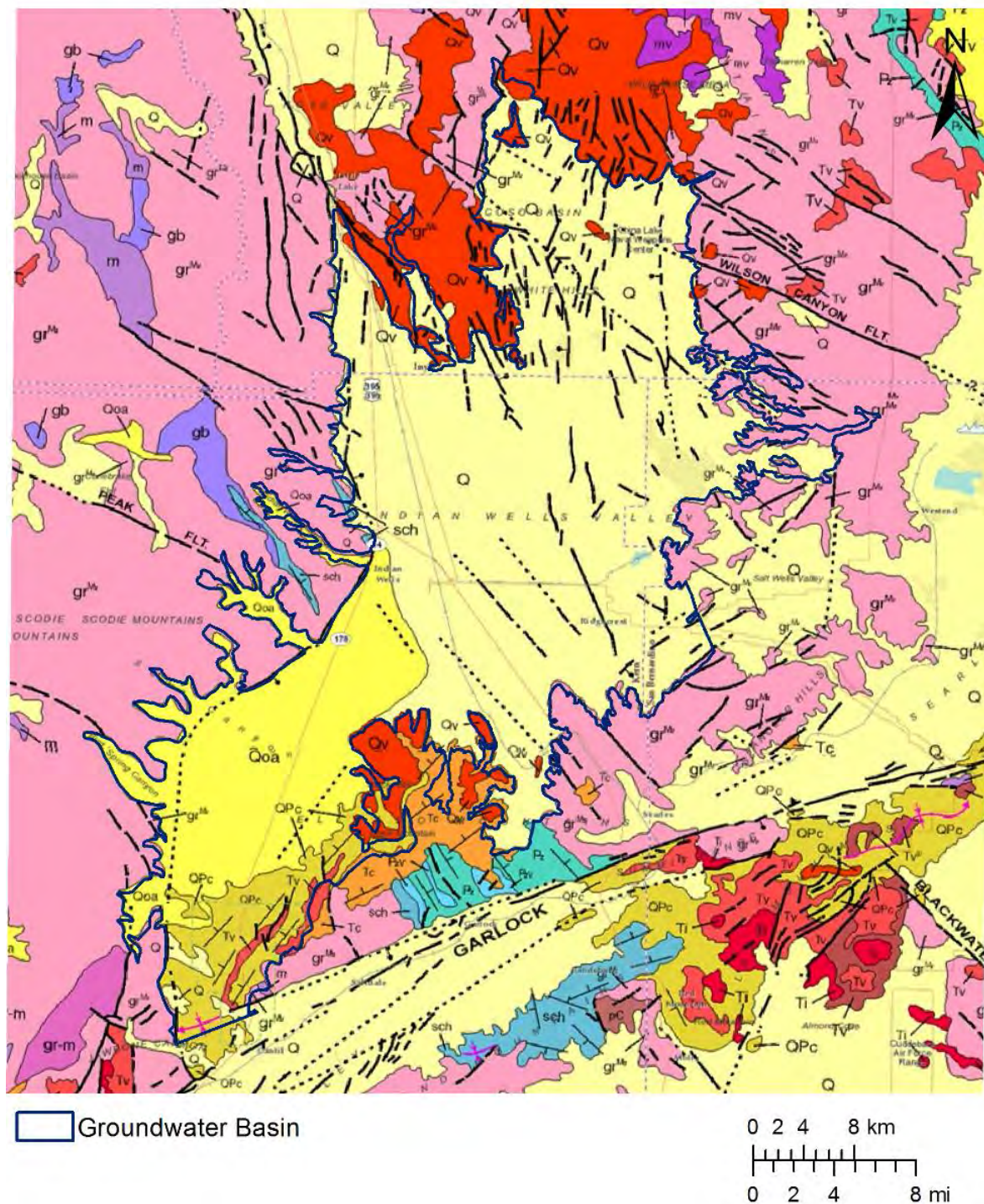


Figure 5-1. Geological map from the California Geological Survey, covering the Indian Wells Valley groundwater basin.

Explanation - California Geological Survey, Geologic Data Map No. 2

Compilation and Interpretation by: Charles W. Jennings (1977)

Updated version by: Carlos Gutierrez, William Bryant, George Saucedo, and Chris Wills

DESCRIPTION OF MAP UNITS	
QUATERNARY DEPOSITS	
Qs	Extensive marine and nonmarine sand deposits, generally near the coast or desert playas
Q	Alluvium, lake, playa, and terrace deposits; unconsolidated and semi-consolidated
Qls	Selected large landslides
Qg	Glacial till and moraines. Found at high elevations mostly in the Sierra Nevada and Klamath Mountains
Qoa	Older alluvium, lake, playa, and terrace deposits
QPc	Pleistocene and/or Pliocene sandstone, shale, and gravels deposits; mostly loosely consolidated
QUATERNARY VOLCANIC ROCKS	
Qrv	Recent (Holocene) volcanic flow rocks; minor pyroclastic deposits
Qrvr	Recent (Holocene) pyroclastic and volcanic mudflow deposits
Qv	Quaternary volcanic flow rocks; minor pyroclastic deposits
Qvr	Quaternary pyroclastic and volcanic mudflow deposits
TERTIARY SEDIMENTARY ROCKS	
Tc	Undivided Tertiary nonmarine sandstone, shale, conglomerate, breccia, and ancient lake deposits
P	Pliocene marine sandstone, siltstone, shale, and conglomerate; mostly moderately consolidated
M	Miocene marine sandstone, shale, siltstone, conglomerate, and breccia; moderately to well consolidated
Mc	Miocene nonmarine sandstone, shale, conglomerate, and fanglomerate; moderately to well consolidated
Oa	Oligocene marine sandstone, shale, and conglomerate; mostly well consolidated
Oac	Oligocene nonmarine sandstone, shale, and conglomerate; mostly well consolidated
E	Eocene marine shale, sandstone, conglomerate, and minor limestone; mostly well consolidated
Ec	Eocene nonmarine sandstone, shale, and conglomerate; moderately to well consolidated
Ep	Paleocene marine sandstone, shale, and conglomerate; mostly well consolidated
TERTIARY VOLCANIC ROCKS	
Tv	Tertiary volcanic flow rocks; minor pyroclastic deposits
Tvr	Tertiary pyroclastic and volcanic mudflow deposits.
Ti	Tertiary intrusive rocks; mostly shallow (hypabyssal) plugs and dikes
TERTIARY PLUTONIC ROCKS	
gr ^{ti}	Cenozoic (Tertiary) granitic rocks - quartz monzonite, quartz latite, and minor monzonite, granodiorite, and granite; found in the Kingston, Panamint, Amargosa, and Greenwater Ranges in southeastern California
MESOZOIC SEDIMENTARY AND METASEDIMENTARY ROCKS	
TK	Sandstone, shale, and minor conglomerate in coastal belt of northwestern California. Previously considered Cretaceous, but now known to contain early Tertiary microfossils in places
K	Undivided Cretaceous sandstone, shale, and conglomerate; minor nonmarine rocks in Peninsular Ranges
Ku	Upper Cretaceous sandstone, shale, and conglomerate
Kl	Lower Cretaceous sandstone, shale, and conglomerate
KJf	Franciscan Complex: Cretaceous and Jurassic sandstone with smaller amounts of shale, chert, limestone, and conglomerate. Includes Franciscan melange, except where separated
KJf _m	Melange of fragmented and sheared Franciscan Complex rocks
KJf _s	Blueschist and semi-schist of Franciscan Complex
J	Jurassic shale and sandstone; minor conglomerate, chert, slate, limestone, and pyroclastic rocks
T	Triassic shale, conglomerate, limestone, dolomite, sandstone, slate, hornfels, and quartzite; minor pyroclastic rocks
sch	Schists of various types; mostly Paleozoic or Mesozoic age; some Precambrian
ls	Limestone, dolomite, and marble whose age is uncertain but probably Paleozoic or Mesozoic
MESOZOIC METAVOLCANIC ROCKS	
Msv	Undivided Mesozoic volcanic and metavolcanic rocks. Andesite and rhyolite flow rocks, greenstone, volcanic breccia and other pyroclastic rocks; in part strongly metamorphosed. Includes volcanic rocks of Franciscan Complex: basaltic pillow lava, diabase, greenstone, and minor pyroclastic rocks
mv	Undivided pre-Cenozoic metavolcanic rocks. Includes latite, dacite, tuff, and greenstone; commonly schistose
MESOZOIC PLUTONIC ROCKS	
gr th	Mesozoic granite, quartz monzonite, granodiorite, and quartz diorite
um	Ultramafic rocks, mostly serpentine. Minor peridotite, gabbro, and diabase; chiefly Mesozoic
gb	Gabbro and dark dioritic rocks; chiefly Mesozoic
gr	Undated granitic rocks
PALEOZOIC SEDIMENTARY AND METASEDIMENTARY ROCKS	
Pt	Undivided Paleozoic metasedimentary rocks. Includes slate, sandstone, shale, chert, conglomerate, limestone, dolomite, marble, phyllite, schist, hornfels, and quartzite
Pm	Permian shale, conglomerate, limestone, dolomite, sandstone, slate, hornfels, and quartzite; minor pyroclastic rocks
C	Carboniferous shale, sandstone, conglomerate, limestone, dolomite, chert, hornfels, marble, and quartzite; in part pyroclastic rocks
D	Devonian limestone, dolomite, sandstone, and shale; in part tuffaceous
SO	Silurian to Ordovician sandstone, shale, conglomerate, chert, slate, quartzite, hornfels, marble, dolomite, and phyllite; some greenstone
C	Cambrian sandstone, shale, limestone, dolomite, chert, quartzite, and phyllite; includes some rocks that are possibly Precambrian
PALEOZOIC MIXED ROCKS	
m	Undivided pre-Cenozoic metasedimentary and metavolcanic rocks of great variety. Mostly slate, quartzite, hornfels, chert, phyllite, mylonite, schist, gneiss, and minor marble
PALEOZOIC METAVOLCANIC ROCKS	
Psv	Undivided Paleozoic metavolcanic rocks. Mostly flows, breccia, and tuff; includes greenstone, diabase, and pillow lavas; minor interbedded sedimentary rocks
PALEOZOIC PLUTONIC ROCKS	
gr ^h	Paleozoic and Permo-Triassic granitic rocks in the San Gabriel and Klamath Mountains
PRECAMBRIAN ROCKS	
pC	Conglomerate, shale, sandstone, limestone, dolomite, marble, gneiss, hornfels, and quartzite; may be Paleozoic in part
pCc	Complex of Pre-cambrian igneous and metamorphic rocks. Mostly gneiss and schist intruded by igneous rocks, may be Mesozoic in part
gr ^c	Precambrian granite, syenite, anorthosite, and gabbroic rocks in the San Gabriel Mountains; also various Precambrian plutonic rocks elsewhere in southeastern California
SYMBOL EXPLANATION	
Contact between geologic units - approximately located	
Fault traces - solid where well located, dashed where approximately located or inferred, dotted where concealed, and queried where continuation or existence is uncertain. Ball and bar on downthrown side (relative or apparent). Arrows indicate direction of lateral movement (relative or apparent)	
Thrust fault (barbs on upper plate)	
Regional strike and dip of stratified rocks	
Regional strike and dip of stratified rocks (overturned)	
Anticlinal fold	
Synclinal fold	
Monoclinial fold	

5.2 Groundwater basin structure

The Indian Wells Valley groundwater basin is bounded on the sides and bottom by the impermeable basement rocks of predominately granite and basalt. The structure of the western side has been mapped using the SkyTEM data combined with the few wells near the edge of the basin that reach the granite. In the China Lake area, the bottom and eastern edge of the basin was mapped entirely from the seismic data collected in the basin and correlated with two deep key wells that penetrated to the bedrock: SNORT 1 and SNORT 2. In the El Paso area, only the SkyTEM data show the western and eastern margin of the basin; there are no wells or other data sources that penetrate down to the bedrock. Therefore, the bottom of the El Paso area mapped out in this portion of the Basin is only estimated.

Figure 5-2 shows the elevation of the basement rocks defining the bottom of the Indian Wells Valley groundwater basin. The bedrock is deepest in the western part of the China Lake area, where it reaches to elevations of approximately 5,000 feet (1,500 m) below sea level. Figure 5-3 shows a west to east oriented cross-section across the China Lake area. The cross-section shows the SNORT 2 well located in one of the deeper parts of the basin, where the well reached the granite at an elevation of 4,265 ft (1,300 m) below sea level indicating the thickness of the basin is about 6,900 feet at this location.

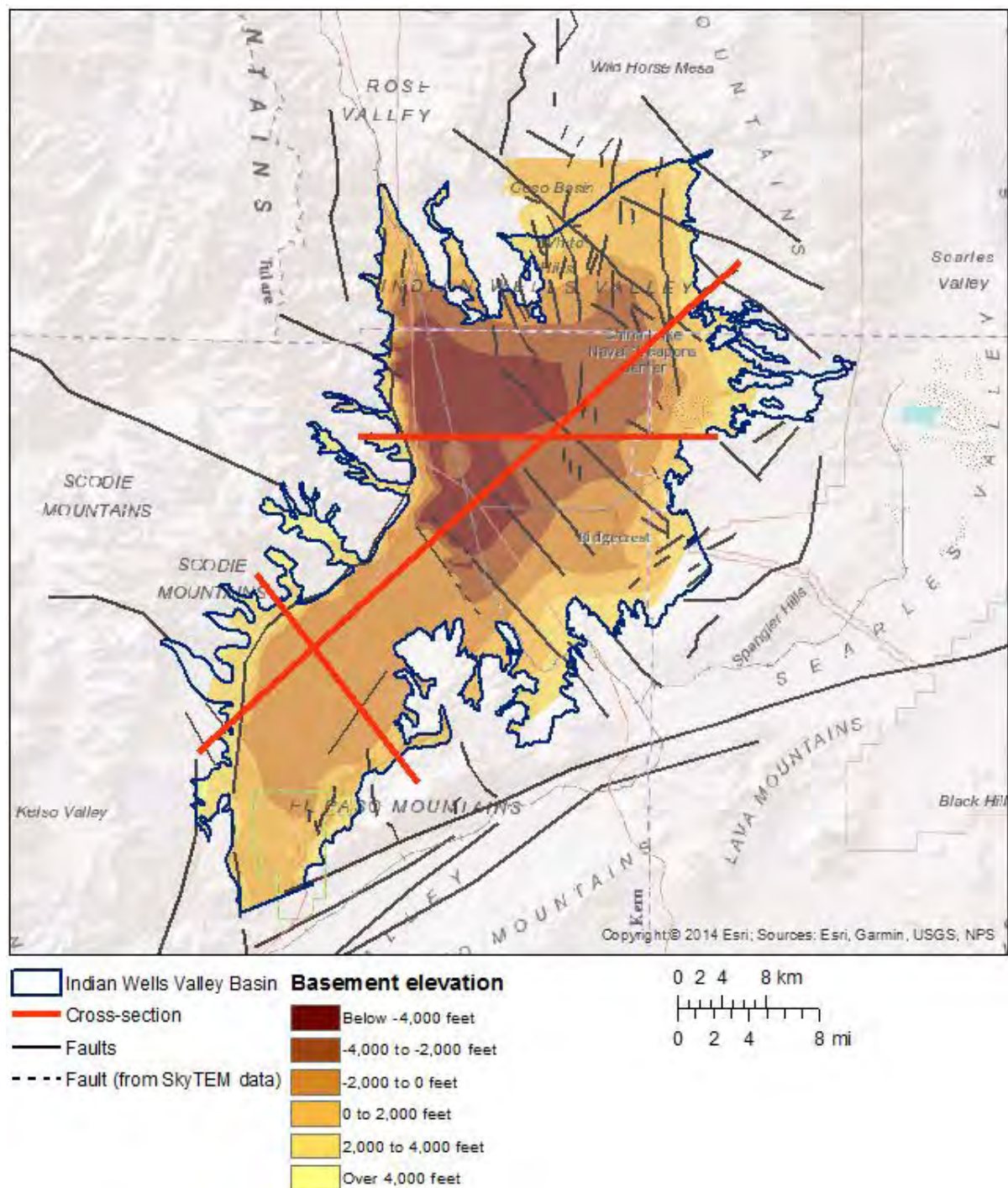


Figure 5-2. Elevation of the basement (granite / bedrock) for the Indian Wells Valley groundwater basin. The black lines show the location of the faults mapped out by the USGS. The dashed black lines show an extension of two mapped faults, based upon SkyTEM data. These two faults define the boundary to the El Paso area, which encompasses the southwest portion of the Indian Wells Valley groundwater basin. The red lines show the location of the three cross-sections cutting across the basin. Elevations are with respect to mean sea level.

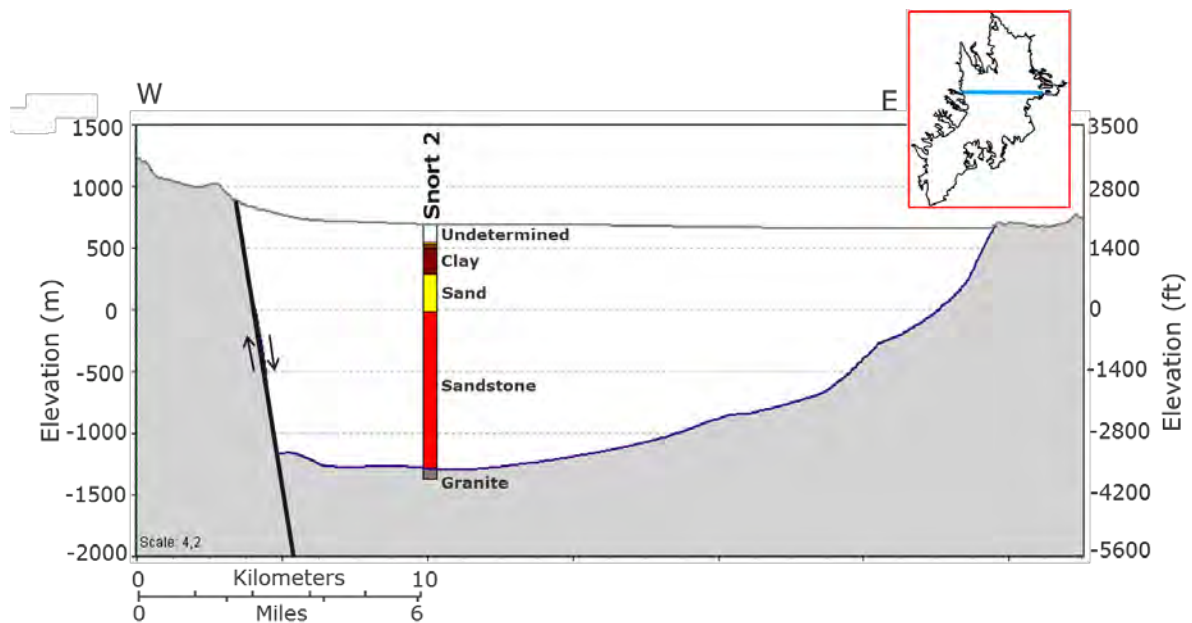


Figure 5-3. Cross-section from west to east showing the structure of the China Lake area.
The Sierra Nevada frontal fault defines the western boundary of the basin. The SNORT 2 well is one of the few wells in the basin that reaches the granite in the basin floor.

The interpolation of the top of the bedrock does not show the numerous faults that are known to exist in the bedrock. These faults can be seen in several of the seismic sections and extend from the bedrock into the consolidated Pliocene deposits, with observed off-sets of as much as 660 feet (200 m). Correlation between the basement faults was not possible due to lack of data between the seismic lines, as resistivity measurements did not penetrate deep into the consolidated sediments and only penetrated the basement on the margins of the basin. The result is a simplified, relatively smooth bottom to the Indian Wells Valley basin. Correlating the faults in the basement is one area where the HCM can be improved in the future.

In the El Paso area, the bedrock elevation is estimated to be higher than in the China Lake area, at an elevation of only about -1,000 feet (-310 m) (Figure 5-2 and Figure 5-4). The thickness of the sediment above the bedrock is approximately 4,100 feet. The shallower basement in this area is assumed due to the presence of older alluvium (Qoa) and the Pliocene-Pleistocene sediments (QPc) at the surface, indicating that vertical movement along the Sierra Nevada frontal fault was much less or did not occur significantly in this area. Further evidence for the higher elevation of the basement comes from the off-set along the two NW-SE striking faults coincidental with the northerly extent of the older alluvium deposits (Qoa), which is seen in SkyTEM resistivity (the SkyTEM lines across this boundary can be seen in Appendix 1). In fact, the SkyTEM data indicate that these two faults likely extend further southeast and northwest than the surface geological map shows, as indicated by the dashed black lines on Figure 5-2.

Figure 5-4 shows a cross-section across the entire Basin, where the faults defining the boundary between the El Paso area and the China Lake area are observed. The total off-set between the two faults is estimated to be approximately 3,000 feet (980 m). However, there are no data that extend deep enough to determine the actual off-set along these faults. To determine the actual off-set, the depth to the basement in the El Paso area needs to be obtained.

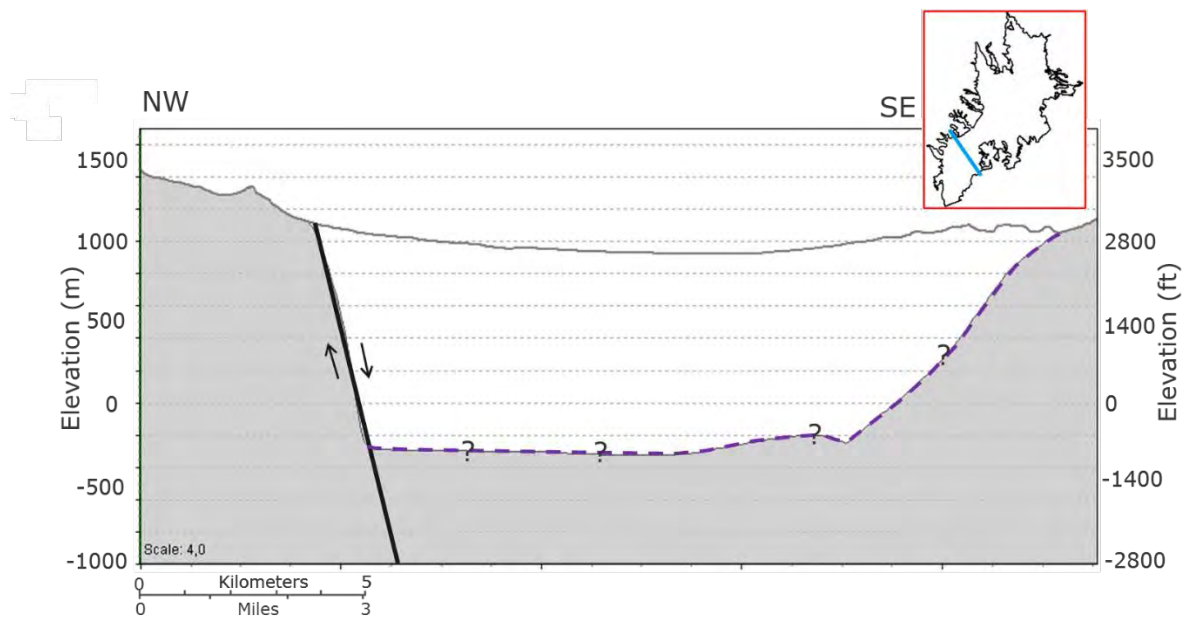


Figure 5-4. Cross-section from northwest to southeast showing the structure in the El Paso area. The Sierra Nevada frontal fault defines the northwestern boundary of the area. The bottom of the basin is only estimated as there are no wells or geophysical surveys that can be used to determine the basin bottom.

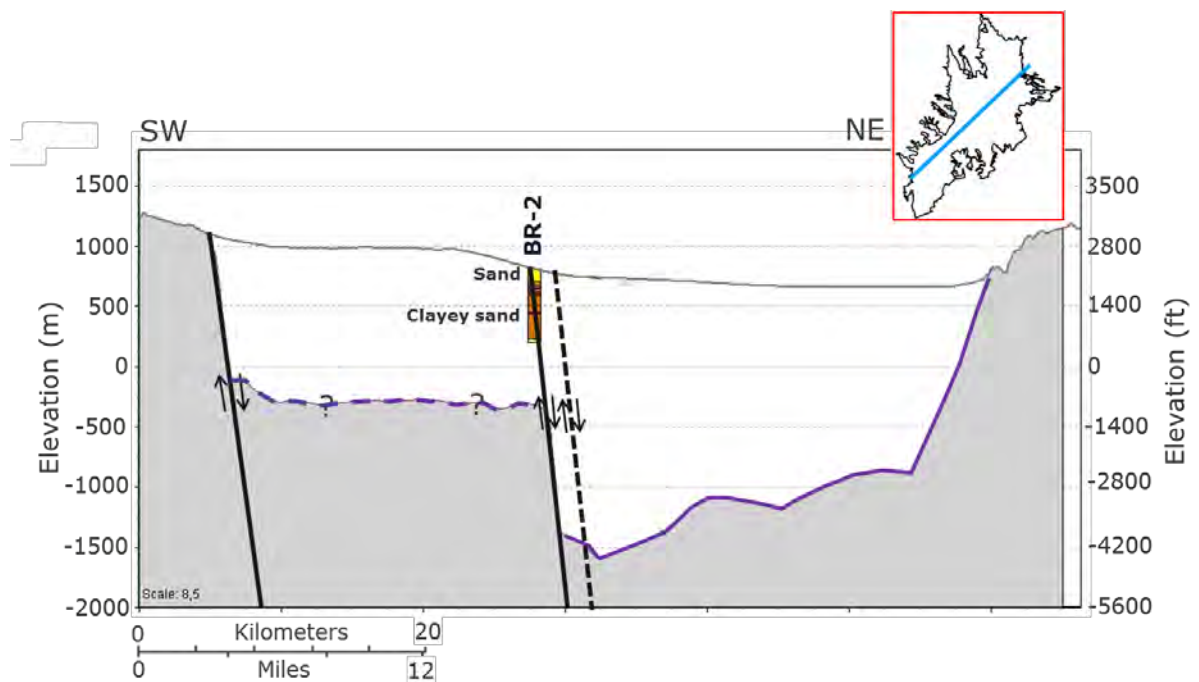


Figure 5-5. Cross-section across the entire Indian Wells Valley groundwater basin, from southwest to northeast. The Sierra Nevada frontal fault is shown in the southwestern part of the cross-section. The fault dividing the China Lake area to the north and the El Paso area to the southwest is shown in the middle of the cross-sections. The dashed line shows an inferred extension of a second fault based upon SkyTEM data. Well BR-2, shown on the cross-section, is one of the deepest wells in the area. The bottom of the basin southwest of the mid-basin fault is estimated.

6. PRINCIPAL AQUIFERS AND AQUITARDS (HYDROGEOLOGIC ZONES)

This chapter provides a description of the principal aquifers and aquitards observed in the Basin. Section 6.1 provides an outline of the conceptual framework for the HCM, which forms the basis for the interpretation of the data and the development of the layer model. Section 6.2 provides a detailed description of the physical properties for the different hydrogeologic zones. Section 6.3 describes the different hydrogeologic features observed in the groundwater basin and the relative groundwater flow within the basin. Finally, Section 6.4 describes the water quality observed in the different hydrogeologic zones in the basin.

6.1 Conceptual framework for the HCM

The development of the conceptual framework of the aquifers and aquitards within the Indian Wells Valley HCM is based upon a combination of well lithology, e-logs, seismic data and SkyTEM resistivity. Due to the highly interbedded nature of the unconsolidated to consolidated sediments, it was not possible to define individual, mappable aquifers and aquitards in the basin. However, the well lithology and SkyTEM data shows that the basin can be divided up into hydrogeologic zones based upon the predominant sediment type and consolidation.

As previously mentioned, the Indian Wells Valley groundwater basin can be divided up into two different geologic regions (or areas) based upon the surface geology: the China Lake area and the El Paso area (see Figure 5-1). This division can also be observed in the well lithology and SkyTEM data. Therefore, separate conceptual frameworks have been developed for the China Lake area and the El Paso area.

In the China Lake area of the Indian Wells Valley groundwater basin, there are four different hydrogeologic zones (HGZ) defined. Figure 6-1 provides an illustration of the four HGZs. HGZ 1 is the shallowest zone which consists primarily of unconsolidated sand and gravel with minor amounts of silt and clay. HGZ 2 lies below HGZ 1 and consists primarily of clay and silt deposits with lesser amounts of sand. HGZ 3 is a deeper zone consisting of unconsolidated to semi-consolidated sand and gravel with lesser amounts of clay and silt. HGZ 4 is the zone directly overlying the basement and consists predominately of consolidated deposits, described in the SNORT 1 and SNORT 2 wells as sandstone, limestone and conglomerate. These deposits are likely the Ricardo and Goler formations or equivalent.

In the El Paso area, there are two distinctly different hydrogeologic zones observed (Figure 6-2). El Paso Zone 1 (EPZ 1), like HGZ 1 in the China Lake area, consists primarily of unconsolidated sands and gravels with minor amounts of clay. The second zone in the El Paso area (labeled EPZ 2). The top of this zone consists of the Pliocene-Pleistocene semi-consolidated to consolidated sedimentary rocks (mapped as QPc by the California Geological Survey). Underneath this unit are the Miocene Ricardo and the Eocene Goler Group (mapped as Tc by the California Geological Survey). These rocks crop out at the surface in the southern and eastern margin of the area (Figure 6-2). The boundary between these units cannot be seen in either the few boreholes that penetrate the boundary or the resistivity from the SkyTEM survey, and thus is only estimated on Figure 6-2.

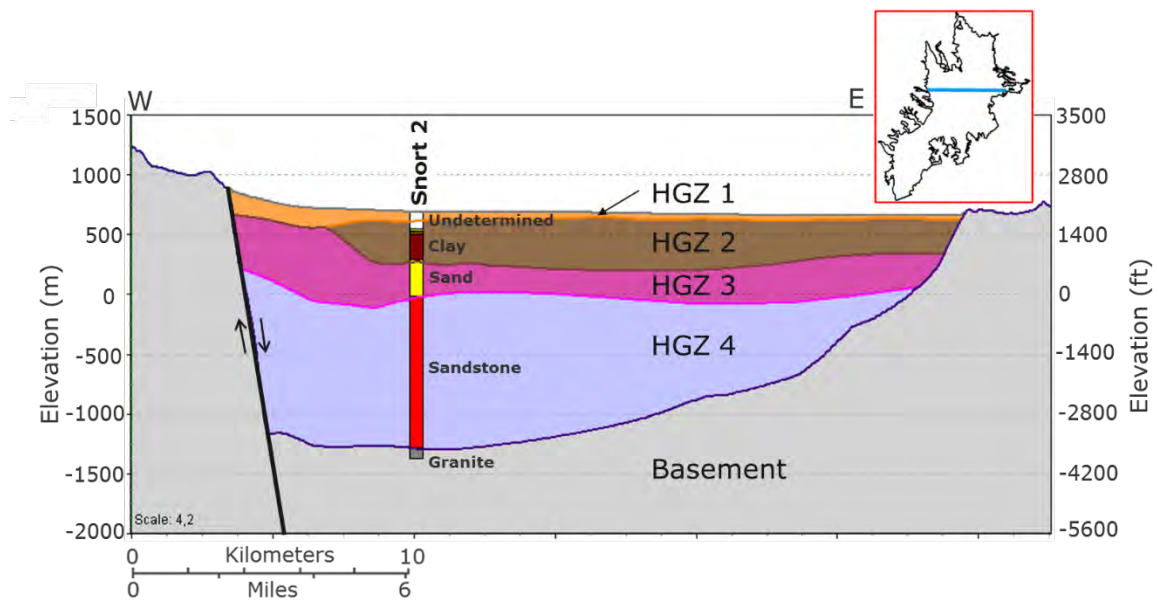


Figure 6-1. Cross-section across the China Lake area showing the four different hydrogeologic zones within the valley.

The SNORT 2 well shows the general lithology of zones, though HGZ 1 is not recorded in the SNORT 2 well. The location of the figure is given Figure 5-2.

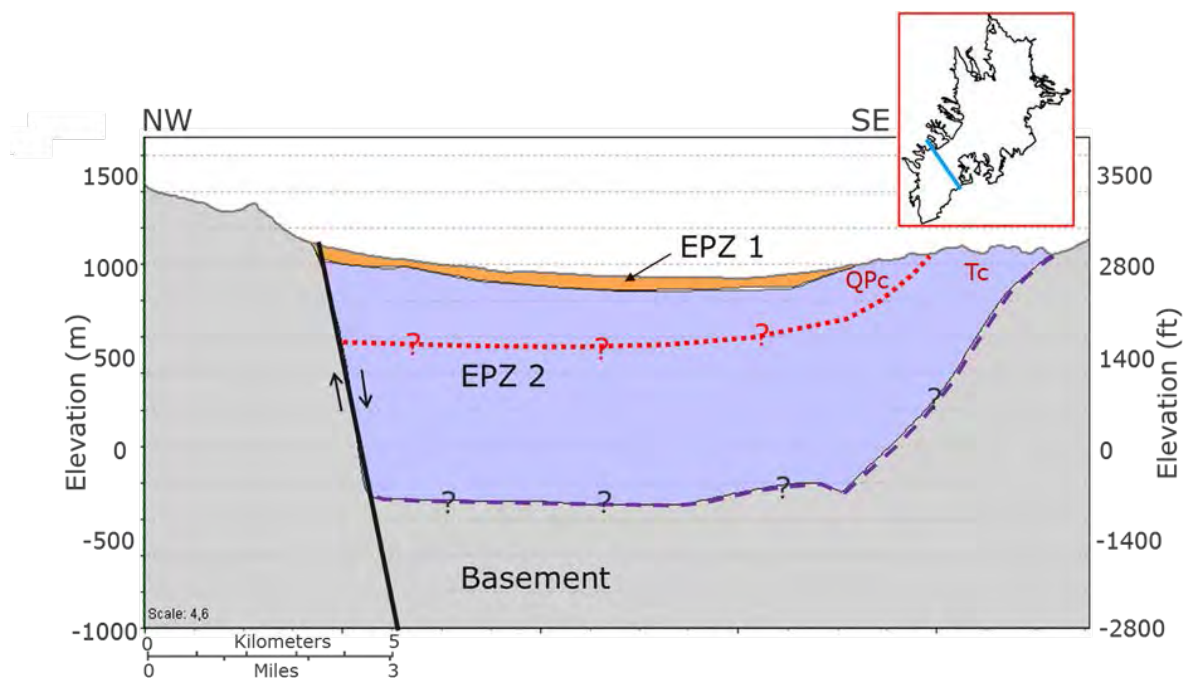


Figure 6-2. Cross-section showing the three different hydrogeologic zones mapped in the El Paso area.

EPZ 1 (predominately sand and gravel) and are underlain by the semi-consolidated to consolidated Pleistocene sediments (EPZ 2). QpC indicates where the semi-consolidated to consolidated Pleistocene/Pliocene sediments, and Tc indicates where the Miocene Ricardo Group crops out on the southeastern margin of the El Paso sub-basin, as indicated on the California Geological Survey map (see Figure 5.1). The red dotted line indicates a very approximate boundary between the younger QpC and older Tc sediments, as it was not possible to map the actual boundary from the resistivity or lithological data. The location of the figure is given on Figure 5-2.

6.2 Physical Properties

This section provides a detailed description of the physical properties observed within the different hydrogeologic zones. For each hydrogeologic zone, the predominating lithology and interpreted depositional environment is described and the thickness of each zone is also presented.

6.2.1 Predominating lithology and interpreted depositional environment

Hydrogeologic zone 1 (HGZ 1) – China Lake area

HGZ 1 is composed predominately of coarser sediments, with sand and gravel being the most common. The sand layers are, however, often interbedded with thinner layers of clayey sand and/or sandy clay. This is illustrated on Figure 6-3, where sand layers in HGZ1 are broken up by black lines, which show where the thin layers of clayey sand are seen in the wells. HGZ 1 is an unconfined aquifer, where the depth to the water table varies from over 500 ft below ground surface (bgs) near the Sierra Nevada, to less than 100 ft bgs towards the center of the valley. HGZ 1 is the equivalent to the upper aquifer defined by Kunkel and Chase (1969) and the shallow hydrogeologic zone defined in the AB303 report (Tetra Tech, 2003). SkyTEM data generally shows HGZ 1 with resistivity of 20 – 60 ohmm in the saturated zone (yellow-green, yellow and orange colors on the cross-sections), and 60 – 120 ohmm (red-orange to dark red in the cross-sections).

HGZ 1 is interpreted to be composed of younger alluvial deposits (Holocene), with some older alluvial deposits in the deeper sections. Near the mountains, particularly on the edge of the Sierra Nevada frontal fault, the younger alluvial deposits of HGZ 1 are likely coarse fan deposits with thin layers of silt and clay with megabreccias also observed (Kunkel and Chase, 1969 and Monastero et al., 2002). Further away from the mountains, the younger alluvial deposits become thinner and are likely derived from cloud bursts which swell the streams causing sheet flooding, carrying the coarser sediments into the valley (Kunkel and Chase, 1969). The top part of HGZ 1 consists of a thin layer up to 100 ft. thick of modern alluvial-fan, lacustrine and playa deposits with some local eolian sand (Monastero et al., 2002). The deeper older alluvial deposits progress from fan to deltaic deposits. The numerous transgressions and regressions of the Paleo-lake within the basin has created an interfingering of the coarser deltaic sediments of HGZ 1 and finer lacustrine sediments that dominate HGZ 2 (Lahee, 1963 and Tetra Tech, 2003).

Hydrogeologic zone 2 (HGZ 2) – China Lake area

HGZ 2 is generally characterized by finer sediments, with clay and silts dominating the sequence as shown on Figure 6-3. Thus, HGZ 2 is generally interpreted as being an aquitard in the groundwater basin. In general, HGZ 2 is characterized by having a resistivity of 5 – 15 ohmm (blue to green colors) when it is fresh, and resistivity of as low as 1 ohmm when the water in zone is brackish to saline.

In spite of being characterized by dominating finer sediments, there are zones often seen within HGZ 2 where the sediments become coarser – clayey sand or even thicker sand or gravel lenses (sand stringers). There are several wells with relatively good yield that are screened within the layers of coarser sediments in HGZ 2.

The cross-section shown on Figure 6-3 provides a good illustration of the interbedded nature of HGZ 2. On the figure, the wells show a zone of clayey sand, or even sand, in the middle of HGZ 2. This layer is also observed in the SkyTEM data, where an increase in resistivity (5-15 ohmm) can be seen in this interval. While developing the HCM for Indian Wells Valley groundwater basin, an attempt to correlate these zones of coarser materials was made. However, these zones were seen to pinch out when observed along a SkyTEM transect and could not be correlated between the

SkyTEM transects. It was not possible to correlate the layers of coarser sediment from the lithological descriptions.

The interbedded nature of the sediments is further illustrated through the electric log for well 26S40E22P01, which is shown on Figure 6-4. In this illustration, there are numerous thinner layers within HGZ 2 where the gamma shows coarser sediments (lower gamma values). These layers, however, do not correlate well with the lithology mapped out in well 26S40E22P03, which lies just 300 feet to the west.

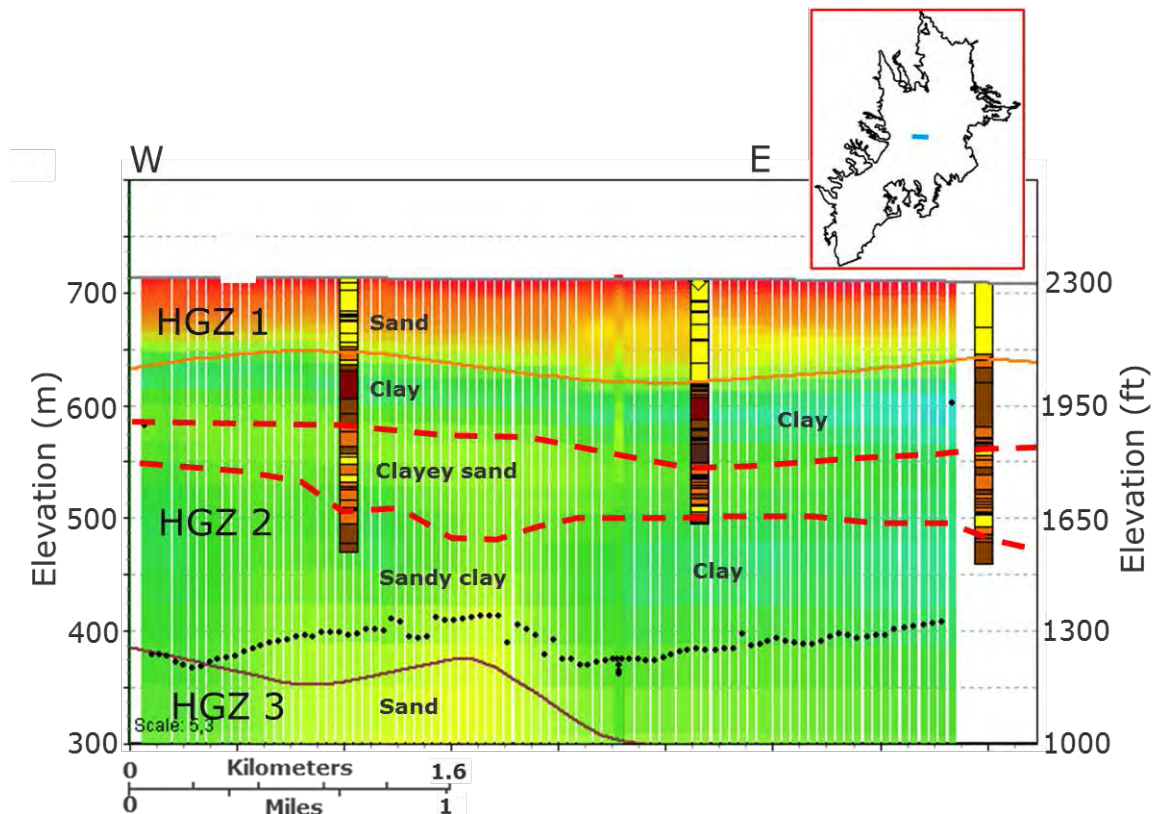


Figure 6-3. Profile showing the lithologic nature of HGZ 1, which consists primarily of sand and gravel, and of HGZ 2, which consists of primarily finer sediments. However, both the well lithology and SkyTEM show that within HGZ 2 there are zones with coarser material – shown by the dashed red line on the profile. The orange line shows the bottom of HGZ 1, the brown line shows the bottom of HGZ 2 and the small dots show the depth of investigation for the SkyTEM data.

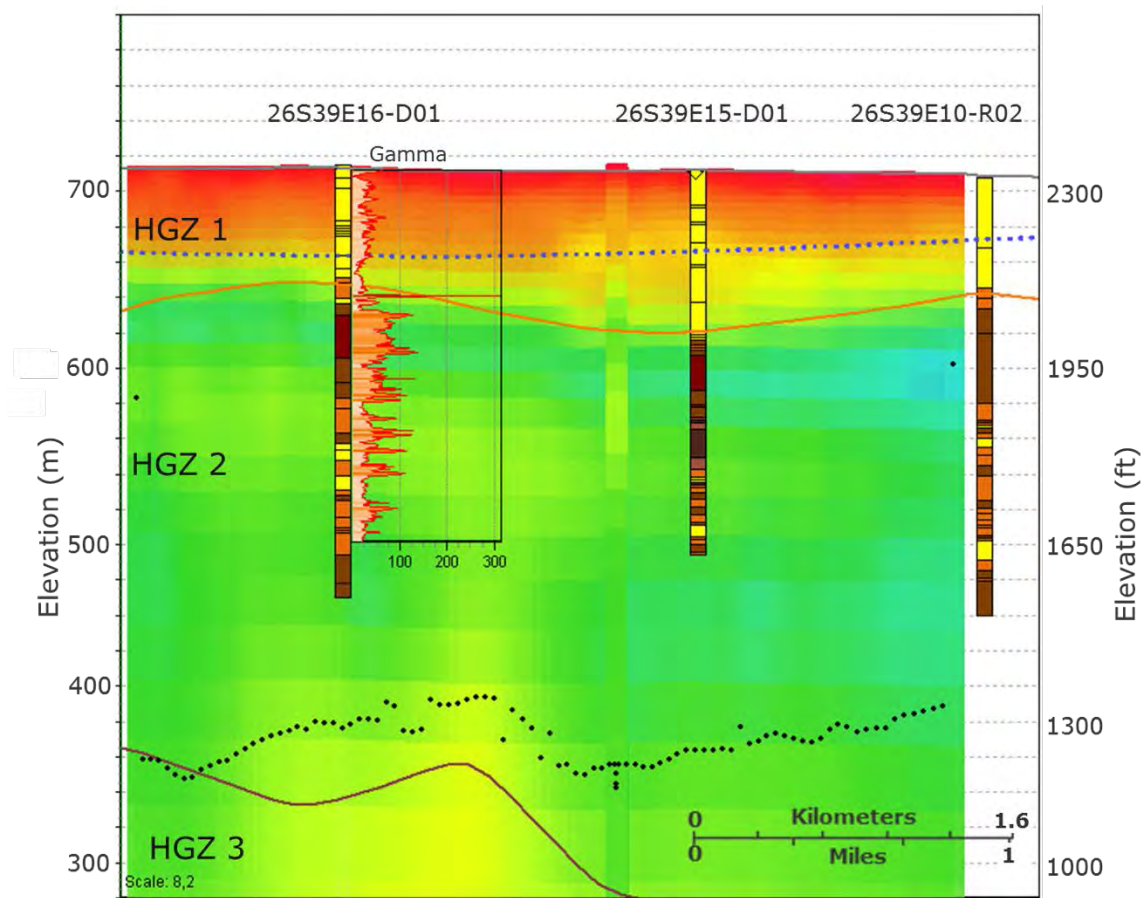


Figure 6-4. E-log (gamma) and lithology for well 26S39E16-D01.

Gamma signal is colored from dark brown (coarser sediments) to light brown (finer sediments). The well lithology is located approximately 300 feet to the west and is 26S40E22P03.

HGZ 2 is interpreted to be primarily lacustrine sediments. The fresh water lacustrine deposits are found primarily in the western part of the basin, whereas the playa deposits, in particular, are found in the eastern portion of the basin, underlying China Lake and the other playa lakes in the valley (Kunkel and Chase, 1969). The coarser sand lenses are likely fluvial sediments deposited during the regression of the Pleistocene lake, allowing the coarser materials to be deposited on top of the finer lacustrine sediments (Tetra Tech, 2003). During these periods, erosion into the lacustrine deposits occurred, leaving coarser fluvial deposits as isolated lenses in the buried channels. These coarser sediments within the lacustrine and playa lake deposits are the local aquifers within HGZ 2. On the southern margin of the basin, the relatively thick HGZ 2 deposits could also be interbedded flood plain and overbank deposits associated with alluvial fans from the Spangler Hills and Little Dixie Wash drainage.

Hydrogeologic zone 3 (HGZ 3) – China Lake area

HGZ 3 is characterized by coarser sediments, predominately sand and clayey sand deposits. The zone is predominately mapped from the wells that penetrate deep enough to reach HGZ 3 and show the change from finer to coarser sediments. Though HGZ 3 generally lies below the depth of investigation for the SkyTEM data, the transition from low to higher resistivity in the deeper SkyTEM data can be used to approximate the upper boundary for HGZ 3. HGZ 3 is interpreted to be the lower aquifer defined by Kunkel and Chase (1969) and the regional aquifer defined by Tetra Tech (2003).

HGZ 3 is interpreted as being composed of older alluvium of Pliocene and Pleistocene (Kunkel and Chase, 1969). The lower sediments in HGZ 3 occur at the same elevation as upper part of the Ricardo Formation, as mapped out by Zbur (1963) and Dutcher and Moyle (1973). The bottom of HGZ 3 is not well defined, as it is only penetrated by a few wells within the basin. The sediments within HGZ 3 are interpreted to be a combination of alluvial fan, deltaic, and fluvial deposits. Near the Sierra Nevada frontal fault, there are also megabreccia and coarse, poorly sorted avalanche and debris-flow deposits associated with the frontal fault (Monastero et al. 2002). These deposits are likely associated with the White Hills sequence.

Hydrogeologic zone 4 (HGZ 4) – China Lake area

HGZ 4 is defined as the transition from the unconsolidated/semi-consolidated sediments to consolidated sediments. The top of HGZ 4 is only mapped based upon observations in the few wells that reach the zone (particularly SNORT 1 and SNORT 2) combined with the seismic sections. Without more wells penetrating to the top of HGZ 4, the upper boundary is very uncertain.

HGZ 4 corresponds to the lower part of the Ricardo Formation and the Goler Formation as mapped out by Zbur (1963) and Dutcher and Moyle (1973). The Ricardo Formation, which unconformably overlies the Goler Formation, is composed predominately of fluvial conglomerate and sandstone interbedded with lava flows and pyroclastic sedimentary rocks (Kunkel and Chase, 1969). The upper unit of the Ricardo Formation has also been described as semi-consolidated to unconsolidated. Similarly, the Goler formation is primarily composed of conglomerate and sandstone, with local shale units and some thin marine deposits in the upper part (Kunkel and Chase, 1969).

The deposits in both formations are poorly sorted and are generally considered non water-bearing. However, there could locally be zones of well sorted and/or fractured sandstone that could be water-bearing. Kunkel and Chase (1969) report that two of the wells that reached this depth did provide low-yielding wells, and there are three wells with TDS measurements that are screened within this zone.

El Paso zone 1 (EPZ 1) – El Paso area

EPZ 1 is composed predominately of coarser sediments, most commonly sand and gravel. The sediments are mapped out at the surface as older Pleistocene alluvial deposits. In the areas near the canyons exiting the Sierra Nevada mountains, EPZ 1 will be predominately comprised of fan deposits. Away from the canyons in the center of the area, EPZ 1 is likely composed predominately of fine-grained sheet flood deposits as observed in HGZ 1. EPZ 1 is an unconfined aquifer. Depth to the water table in EPZ 1 in the El Paso area varies from 150 feet to 350 feet bgs, based upon monitoring Kern County Monitoring Wells and SkyTEM resistivity.

There are only 14 wells in the entire El Paso area which have lithological descriptions. Therefore, the interpretation of EPZ 1 is predominantly reliant upon the SkyTEM data collected. Similar to HGZ 1, EPZ 1 is mapped where SkyTEM resistivity is 20 – 60 ohmm in the saturated zone (yellow-green, yellow and orange colors on the cross-sections), and 60 – 120 ohmm (red-orange to dark red in the cross-sections).

EPZ 2 – El Paso area

EPZ 2 is composed of Pliocene-Pleistocene loosely consolidated sedimentary rocks, including sandstone, shale and gravel deposits. The lower parts of EPZ 2 include the upper part of the Ricardo Formation, which crop out at the margins of the El Paso sub area. The deposits cemented to different degrees, and it is unknown to what extent they are fractured. According to Kunkel and

Chase (1969), the units are likely low-yielding and likely not considered a viable aquifer in the area.

There are even fewer wells in the El-Paso area penetrating into EPZ 2, and none that reach the bottom. The top of this unit is mapped solely based on available SkyTEM data, particularly where a decrease in resistivity was observed. However, the resistivity within this zone varies widely, likely due to the changing lithology in the units, from sandstone and conglomerates to shales. Lateral mapping of the shale/sandstone layers within this zone was attempted. However, because the SkyTEM lines were flown parallel to the strike and dip of these units, as measured in the nearby outcrops, it was not possible to determine lateral extent between the SkyTEM lines. In addition, the internal boundary between the younger QPc sediments and older Ricardo Formation cannot be seen in the resistivity data.

The SkyTEM data extends to a maximum depth of 1,200 feet and does not reach the base of these units. Therefore, the bottom of this basin is unknown and only represented as an estimate in this report.

6.2.2 Hydrogeologic zone thickness

The following section describes the aquifer thickness for each of the hydrogeologic zones.

HGZ 1

Figure 6-5 shows the thickness of HGZ 1 in the China Lake area. The alluvial deposits are thickest along the Sierra Nevada front, where they reach thicknesses of over 500 feet. These are interpreted as coarse alluvial fan and fluvial deposits along with megabreccias, avalanche and debris flows from previous normal faulting. The thick deposits of HGZ 1 continue from the Sierra Nevada front through the southern margin of the China Lake area along the faults dividing the China Lake area from the El Paso area. Here the HGZ 1 deposits are also over 500 feet thick and are likely coarse fluvial deposits from the paleo Owens River. This corresponds with the interpretation by Kunkel and Chase (1969), who hypothesized that the paleo Owens River in the Pleistocene could have run out of the basin just east of Ridgecrest.

In the north, HGZ 1 is also seen to be relatively thick, consisting primarily of coarse alluvial fan deposits from the Coso Range and Wild Horse (Figure 6-5). However, in the area around Coso Basin, SkyTEM was not collected and the interpretation is based upon the few wells with lithological descriptions from the area. Therefore, there is a large amount of uncertainty associated with this interpretation. SkyTEM indicates that there is likely a residual channel coming out of the basalt flows on the southern flank of the Coso Range, right at the boundary of Inyo and Kern County. Here, the high resistivity extends to as much as 1,500 feet bgs, indicating coarser sediments, likely sand and gravel, filled with fresh groundwater.

The deposits of HGZ 1 thin out towards the lower elevations in the China Lake area, becoming very thin in and around the playa lakes (Figure 6-5).

It should be noted that the thickness of HGZ 1 appears to be somewhat controlled by the observed faults in the central portion of the valley (Figure 6-5). Particularly the NW-SE trending faults appear to affect the deposition of the coarser alluvial materials. These faults could act as hydrological barriers, as reported in several previous studies, in part due to the control on the depositional environment in the valley.

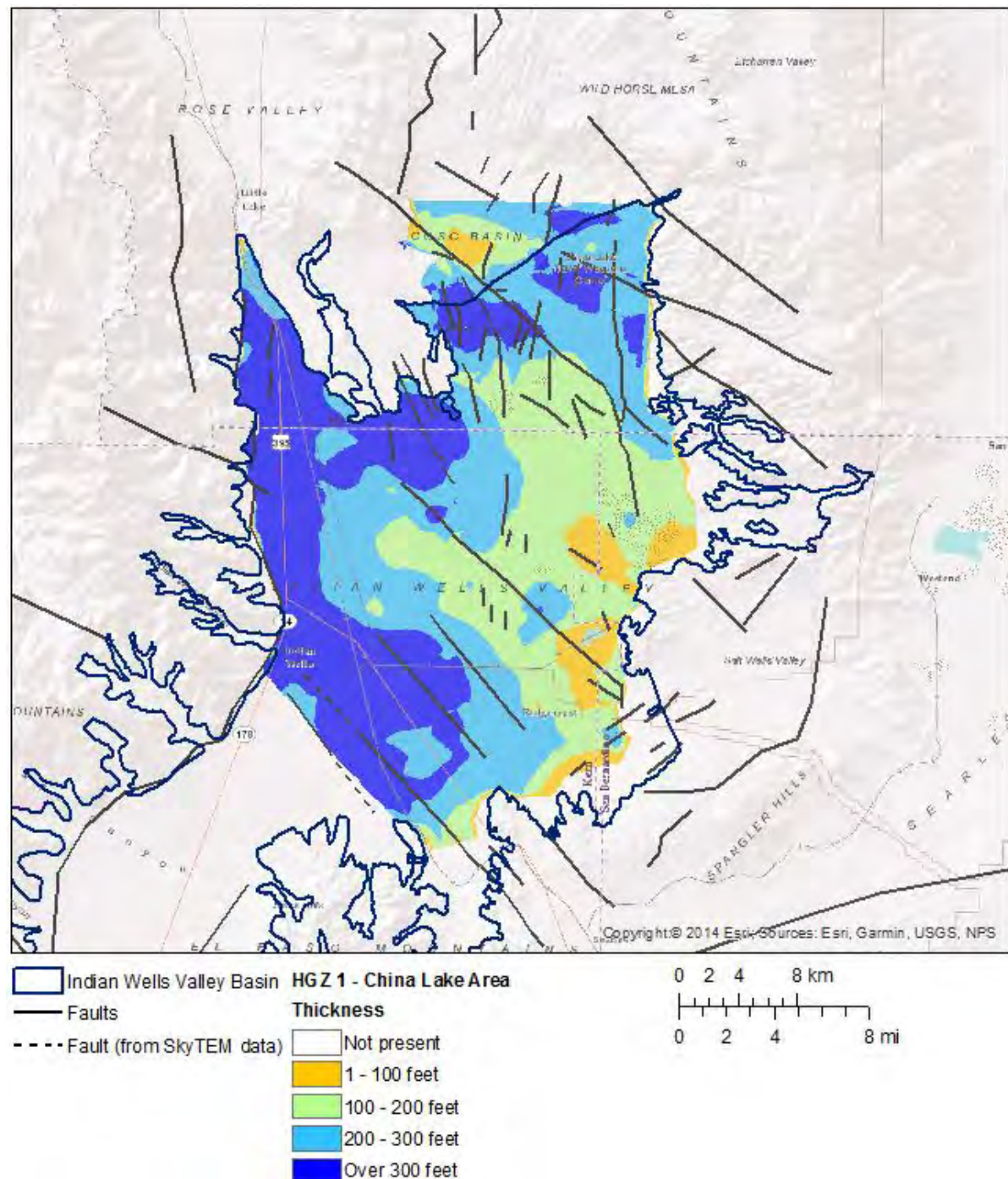


Figure 6-5. Thickness of the HGZ 1 in the China Lake area of the Indian Wells Valley groundwater basin.

HGZ 2

Figure 6-6 shows the thickness of HGZ 2 in the China Lake area. HGZ 2 is thickest in the central part of the China Lake area, where it is as much as 1,500 feet (500 m) thick. The zone thins out slightly in the eastern margins of the basin and under China Lake, where it has thicknesses of 650 – 1000 feet (200 – 300 m). HGZ 2 is thinner in the northern part of the basin, around the Coso Range and Coso Basin. However, data defining the thickness in this portion of the basin are few, as only a few area wells penetrate the unit and SkyTEM data was unavailable. Thus, the thickness calculated for HGZ 2 in this area is uncertain.

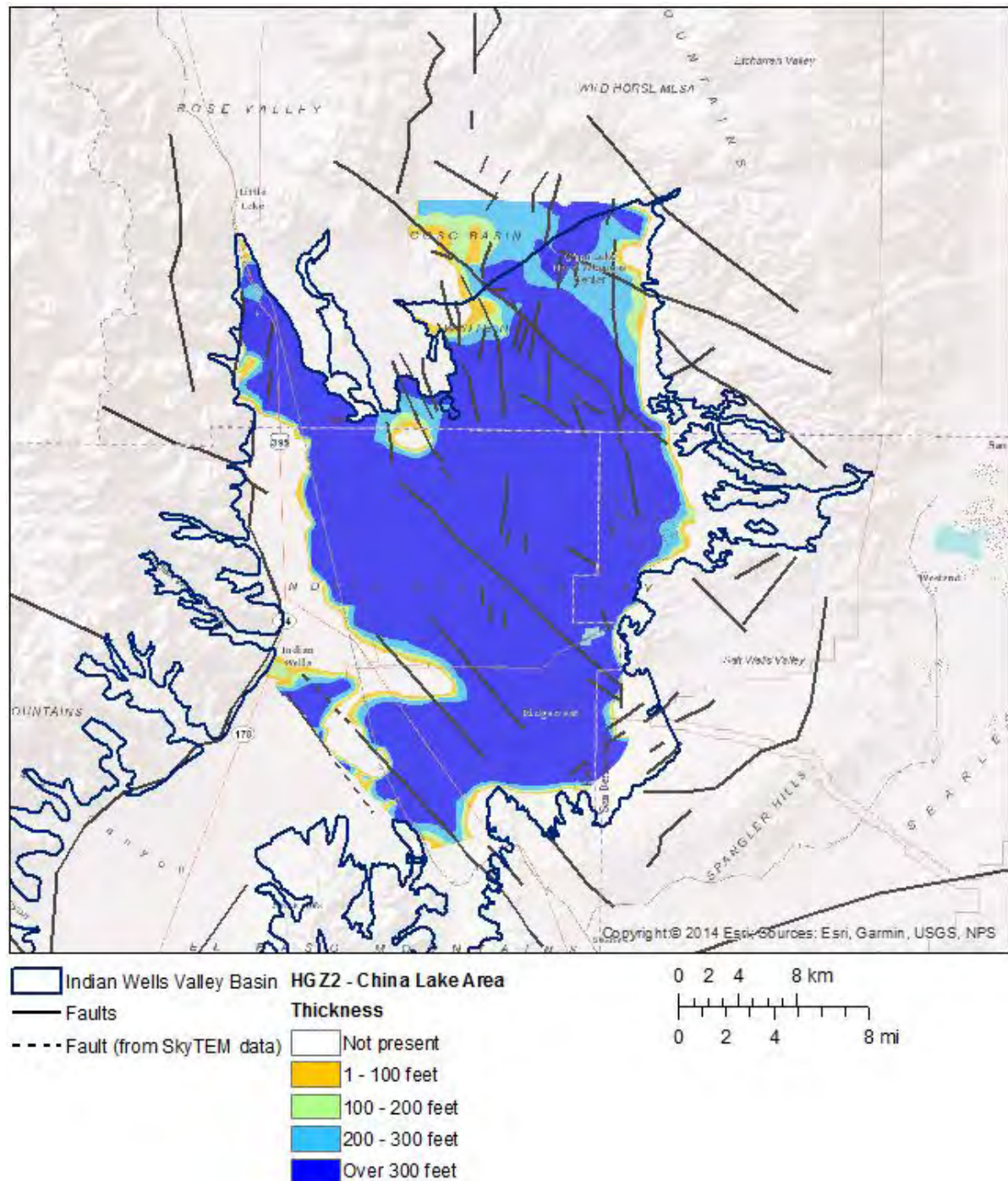


Figure 6-6. Thickness of HGZ 2 in the China Lake area of the Indian Wells Valley groundwater basin.

On the western margin of the basin, starting at about 1 to 1.5 miles east of US 395, HGZ 2 thins out quickly becoming completely absent along the Sierra Nevada front (Figure 6-6). HGZ 2 remains absent from the Sierra Nevada front in an arc extending approximately 5 miles along US 395 from Inyokern towards Ridgecrest. The absence of HGZ 2 extends further from this arc to between the two faults that define the boundary between the China Lake area and the El Paso area.

In the northern part of the basin, at the southern extent of the basalt flows, HGZ 2 is absent. This coincides with the thick residual channel coming out of the Coso Range.

Not coincidentally, the thickness of HGZ 2 is also somewhat influenced by the observed faults in the basin. Again, this underlines the hypothesis that the faults could act as local hydrological barriers within the China Lake area.

HGZ 3

HGZ 3 is seen to be the thickest around the Sierra Nevada front, where it reaches thicknesses of as much as 1,600 feet (500 m), as seen on Figure 6-7. The zone thins out towards the center of the basin, coincident with the thicker deposits of HGZ 2. The zone becomes thicker again along the eastern part of the China Lake area, reaching thicknesses of around 1,100 feet (350 m). The zone is observed to be over 1,100 feet (350 m) thick along the southern margin of the China Lake area, between Inyokern and Ridgecrest.

Apart from the Coso Basin area, the top of HGZ 3 is reasonably well-defined from well and SkyTEM data. However, the base is defined solely on the basis of a few wells in the basin that reach HGZ 3, and the preliminary interpretation of the available seismic data. Therefore, the actual thickness of HGZ 3 is uncertain but these efforts represent the best estimation that can be made at this time with existing data. A more detailed mapping of the transition between HGZ 3 and the consolidated deposits of HGZ 4 will provide better detail of the lower boundary of HGZ 3 and a more accurate map of the thickness of the lower aquifer in the China Lake area.

HGZ 4

HGZ 4, is relatively thick throughout the China Lake area. The thickness is best described in the SNORT 1 and SNORT 2 wells, where the conglomerate and sandstone reach combined thicknesses of about 4,000 feet (1,200 m) (Figure 6-1). The preliminary interpretation of the seismic sections indicate that HGZ 4 could be as much as 6,000 feet (1800 m) thick. However, this has a high level of uncertainty, and a more detailed mapping of the thickness is required to refine this estimate.

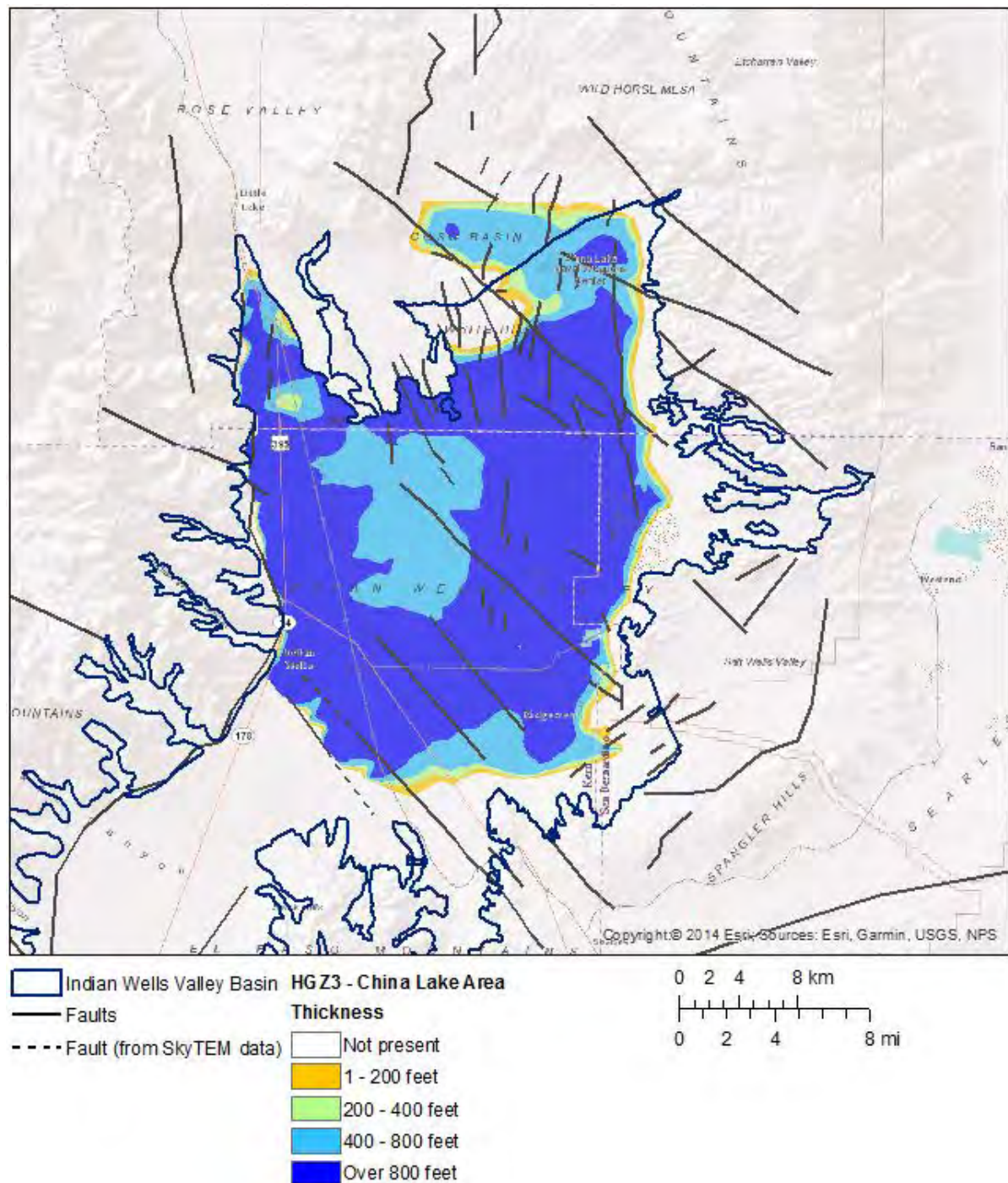


Figure 6-7. Thickness of HGZ 3 in the China Lake area.

EPZ 1 – El Paso area

The thickness of the older alluvial sediments of EPZ 1 varies widely in the El Paso area, as shown on Figure 6-8. The sediments are seen to be thickest at the mouth of Freeman Canyon, where they reach thicknesses of over 500 feet. In addition, the deposits are over 350 feet thick at the mouth of Bird Spring Canyon. These deposits are interpreted as alluvial fan deposits coming out of the two canyons. EPZ 1 along the Sierra Nevada front thins out significantly between these two canyons. This indicates that the ephemeral stream coming out of Sage Canyon has been more erosional in nature with no significant coarse fan deposits associated with the stream.

In the middle of the El Paso area, the deposits, though thinner than at the mouth of Freeman Canyon and Bird Spring Canyon, are still 150 – 350 feet in thickness (Figure 6-8). These are likely coarser flood deposits where the coarse material has been carried into the area during times of heavy precipitation.

EPZ 1 is completely absent in the southern 1/3 of the area. This is where QPc is mapped out at the surface and the older alluvium deposits are not present.

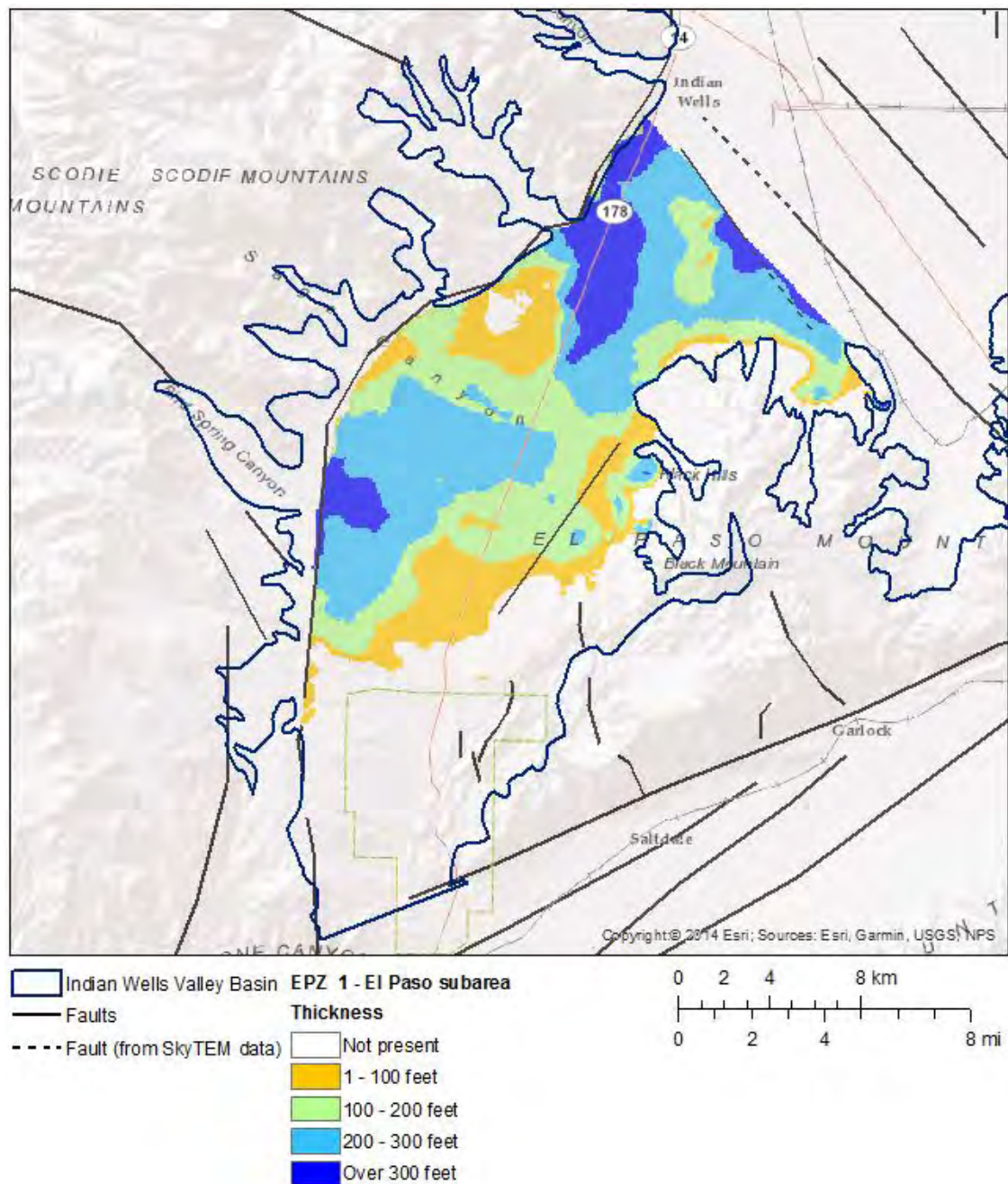


Figure 6-8. Thickness of EPZ 1 in the El Paso area.

EPZ 2 – El Paso area

The thickness of the hydrogeologic zone EPZ 2 in the El Paso area will not be detailed in this report. Though the top of EPZ 2 is reasonably well-defined by well and SkyTEM data, currently there is no data on the base of EPZ 2, which is only estimated in this project. Because of the complete lack of data, no thickness for this zone has been estimated.

6.3 Hydrogeologic features

The hydrogeologic features observed in the Indian Wells Valley groundwater basin that have an impact on groundwater recharge, storage and flow in the basin include buried channels, coarse fan deposits, areas with hydrological contact between HGZ 1 and HGZ 3, and mapped hydrological barriers (Figure 6-9). This section provides a more detailed description of the features which will influence the groundwater flow, including describing the evidence for the mapping of these features.

6.3.1 Buried channel or deltaic deposits

In the northern part of the groundwater basin, a thick deposit of coarser sediments starting at the mouth of a canyon is observed coming out of the Coso Range, right on the boundary between Inyo and Kern County. This feature is interpreted as being either a buried channel coming out of the Coso Range to the north or alternatively, deposited as a delta entering paleo China Lake (Figure 6-9).

This feature is directly observed in the SkyTEM data, where relatively high resistivity is observed to a depth of 1,400 feet (430 m) bgs (Figure 6-10). The coarse deposits are restricted laterally, with lower resistivity (HGZ 2) seen on both sides of the feature. The coarse sediments at depths of over 500 feet (160 m) below the surface, extend approximately 3 miles (5 km) into the valley.

The relatively high resistivity at depth indicates that the feature's core is likely filled with coarse gravel and sand deposits with very little, if any, clay materials. The core extends to more than 1,000 feet (300 m) below the surface. The high resistivity also indicates that there is fresh water at depth. The wells that are screened within this structure (though at relatively shallow depths) all have TDS concentrations below 1,000 mg/L, confirming the presence of fresh water in the sediments.

Due to the deep and laterally limited nature of the feature, it is interpreted to be controlled laterally, at least in part, by the two north-south trending mapped faults (Figure 6-10). Though much of the area with sand and gravel extends as much as 1.2 miles, the area with the highest resistivity (about 50 ohmm as indicated by the orange colors on Figure 6-10) fall directly between these two faults as they are mapped at the surface.

This feature is interpreted to be sediments deposited in a deltaic environment. As the high energy stream enters the paleo China Lake during the Pleistocene, coarse gravel is deposited first (resembling fluvial deposits), right at the mouth of the canyon. Thereafter, the delta transitions to sand and then to silt and clay further away from the canyon, in a lacustrine environment. This depositional model fits the resistivity data. The delta is likely controlled by the faults observed at the surface and in the resistivity data (Figure 6-10).

However, an alternative possibility is that the feature consists of fluvial deposits in a paleochannel coming out of the Coso Range. In this case, a paleo channel would have existed between the two faults during wetter times. The channel carried the coarser sediments out of the mountains,

depositing gravel and coarse sand when the stream reached the valley floor. Sand was then deposited on the flanks (as seen by the yellow colors on the outside of the faults in Figure 6-10). As the stream continued into the valley, the finer sediments were deposited until the stream reached paleo Lake China.

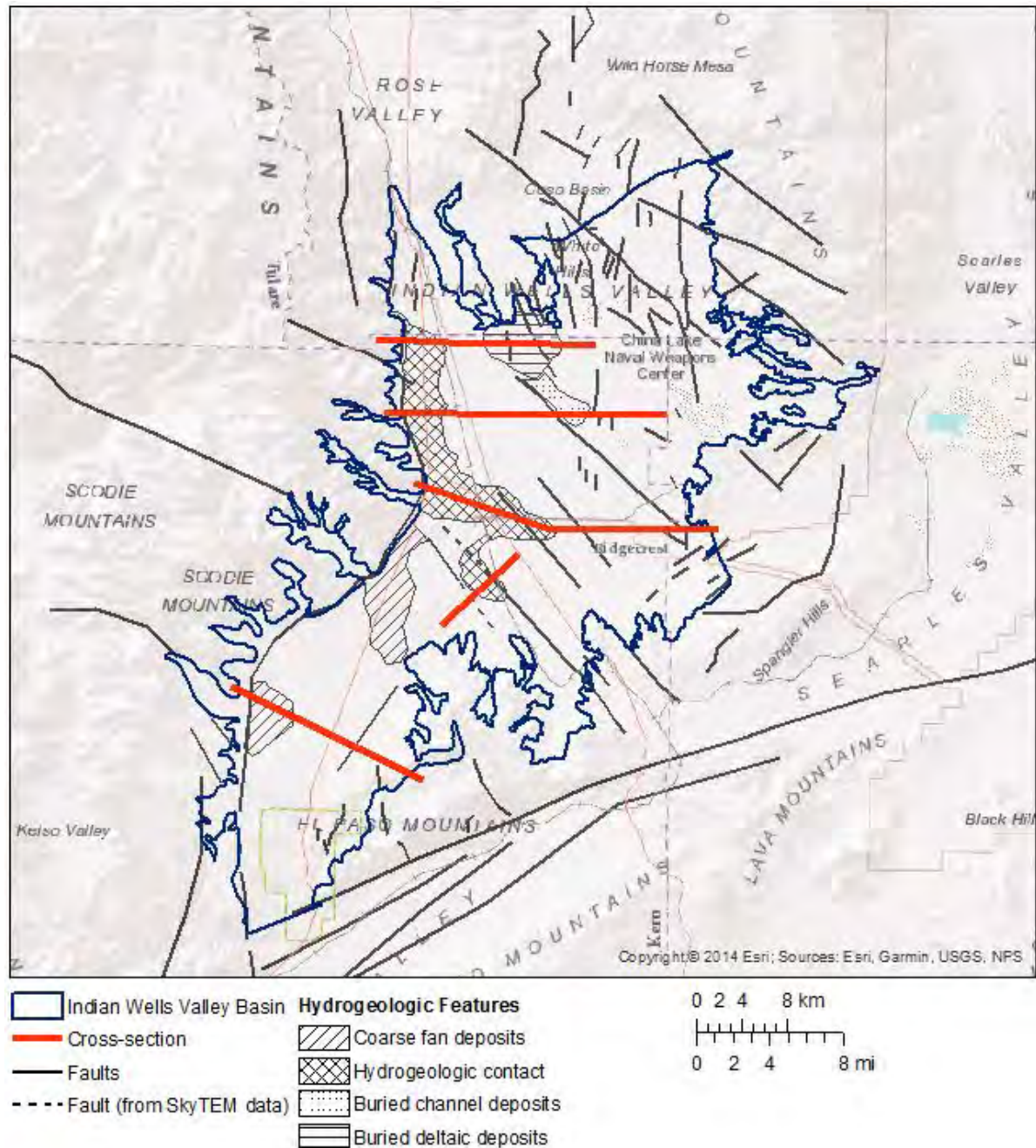


Figure 6-9. Map showing the observed hydrogeologic features in the Indian Wells Valley groundwater basin. The red lines show the location of the cross-sections for (north to south) Figure 6-10, Figure 6-11, Figure 6-12, Figure 6-13, and Figure 6-14.

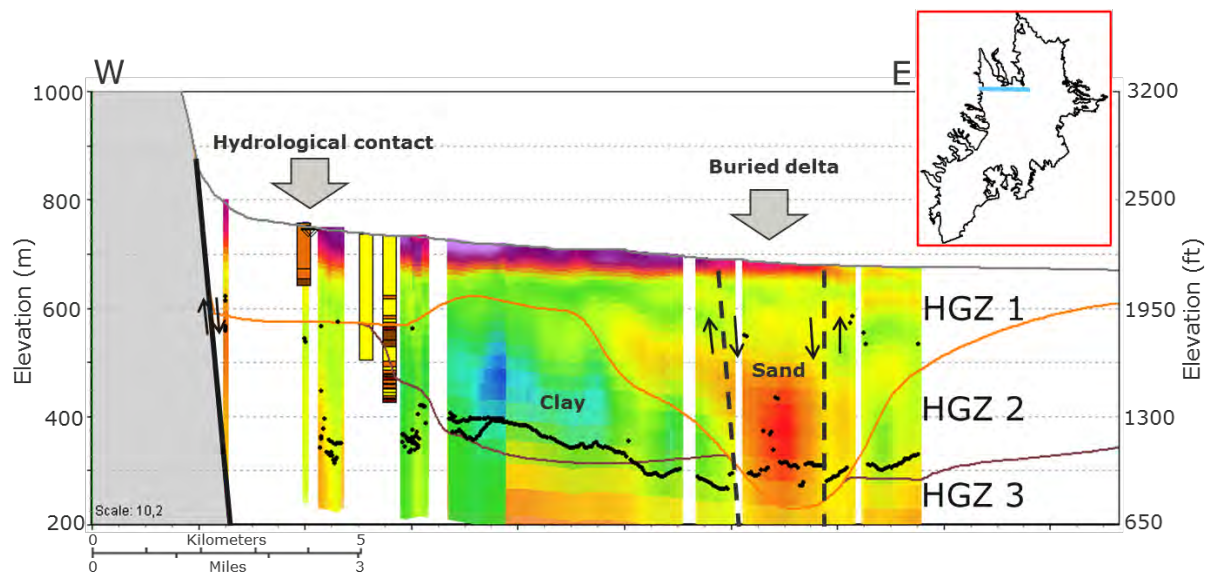


Figure 6-10. Cross-section showing the well lithology and SkyTEM data.

In the west, direct hydrological contact between HGZ 1 and HGZ 3 is seen both in the well lithologies and SkyTEM data. In the center of the profile, a structure composed of coarser material, interpreted to be a buried delta deposit. At this location there is also direct hydrological contact between HGZ 1 and HGZ 3. The dashed lines show the interpreted faults bounding the structure. The orange line shows the bottom of HGZ 1, the brown line shows the bottom of HGZ 2 and the small dots show the depth of investigation for the SkyTEM data.

A shallower buried remnant channel continues from the buried delta feature, towards the southeast as shown on Figure 6-11. This channel is much shallower, only extending depths of approximately 400 feet (120 m) bgs (Figure 6-11). The channel is observed in the SkyTEM data, where resistivity inside the channel is about 50 ohmm (yellow-orange color in Figure 6-11). The SkyTEM indicates that the channel is filled with fresh water, which is confirmed by a single well screened within the channel (TDS concentration of 720 mg/L). The sediments surrounding the channel have a resistivity of below 2 ohmm (dark blue colors on Figure 6-11) suggesting a combination of finer sediments and saline water. The presence of fresh water within this shallow channel suggests that a higher groundwater flow with low TDS concentrations within the residual channel is keeping the aquifer fresh.

The mapped channel coincides with, and is likely controlled by, a NW-SE trending fault. The fault could have presented a weakness within the surrounding clay deposits, allowing a channel to be preferentially cut into the surrounding sediments and subsequently filled with coarser sediments. In all, the channel extends approximately 350 feet (105 m) into the surrounding finer lacustrine sediments. The channel was mapped with SkyTEM and was shown to extend an additional 3 miles (5 km) southeast from the deeper channel/delta deposits, before it is no longer observed in the SkyTEM data.

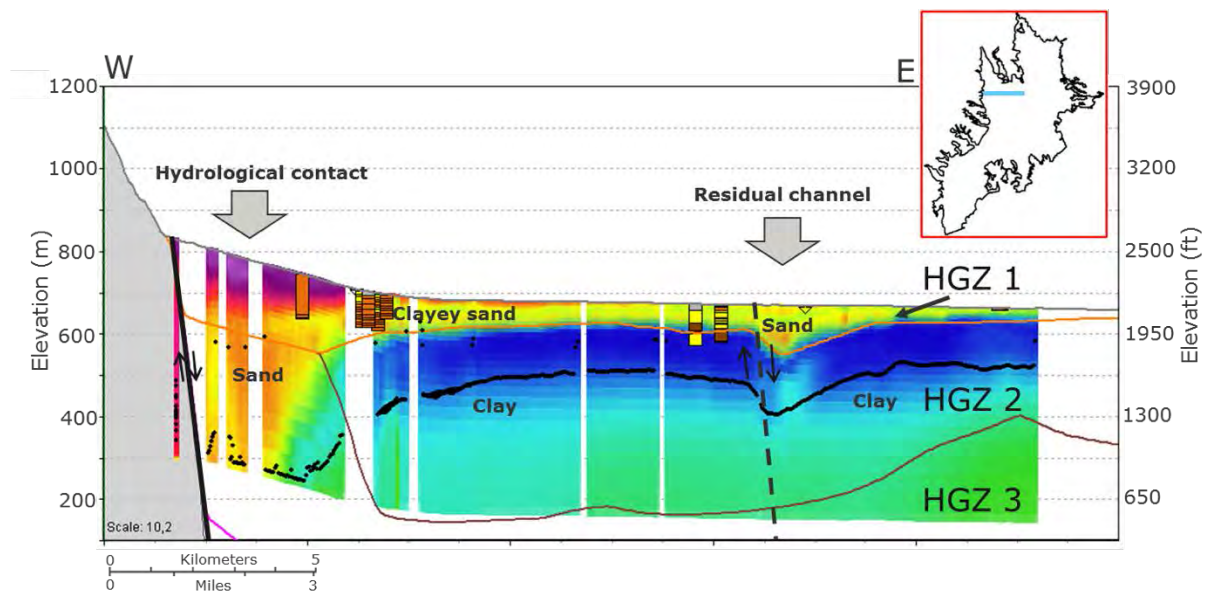


Figure 6-11. Cross-section showing the well lithology and SkyTEM data.

In the west, direct hydrological contact between HGZ 1 and HGZ 3 is seen both in the well lithologies and SkyTEM data. In the center of the profile, a residual channel that has eroded into the clayey material in HGZ 2 is observed in the SkyTEM data. The orange line shows the bottom of HGZ 1, the brown line shows the bottom of HGZ 2 and the small dots show the depth of investigation for the SkyTEM data.

6.3.2 Hydrological contact

In the areas where HGZ 2 is not present, there is direct hydrological contact between the shallower aquifer (HGZ 1) and the deeper aquifer (HGZ 3). Hydrological contact between these two zones is most prominent along the Sierra Nevada frontal fault, from approximately the County line to the boundary with the El Paso area (Figure 6-9). In this area, the sediments are most likely a combination of coarse alluvial fan sediments, coming directly off the Sierra Nevada front and fluvial deposits from the paleo Owens River during wetter periods. Both the SkyTEM and wells in this zone show that the coarse materials extend more than 1,600 feet (500 m) bgs (see Figure 6-12 and Figure 6-13).

Both the SkyTEM resistivity and the water level measurements show that the depth to the groundwater table is high; the depth to the water table is as much as 600 feet (180 m) from the surface. However, due to the direct hydrological contact between the two hydrogeologic zones, this region will be the primary recharge zone for the basin in general, and specifically for HGZ 3.

The area with direct hydrological contact between HGZ 1 and HGZ3 continues along the southern margin of China Lake area, swinging westward towards around Inyokern towards Ridgecrest (Figure 6-9). The sediments in this area are generally not as coarse as along the mountain front, where there is often observed clayey sand is observed in drilling logs. This is illustrated in the cross-section as shown on Figure 6-12, which runs through the middle of the mapped hydrological contact. Here, the SkyTEM resistivity measurements show predominately sand (yellow colors in see Figure 6-12) and clayey sand (yellow-green colors in see Figure 6-12). On the flanks of the area with hydrological contact, the resistivity decreases (darker green colors as shown on Figure 6-12) towards the east, where HGZ 2 is again present. This is confirmed by the well lithology.

Kunkel and Chase (1969) first hypothesized that many of these deposits were of fluvial origin, deposited by the paleo Owens River. In this depositional model, the ancient river would have

come out of the Rose Valley to the north, followed the mountain front, turning towards Ridgecrest, and exiting the valley east of Ridgecrest. The SkyTEM and well data, showing predominately sand and clayey sand with some locally thick gravel deposits, support this interpretation.

There is an additional belt in the China Lake area hydrological contact between HGZ 1 and HGZ 3, extending along the fault dividing the China Lake area and the El Paso area (Figure 6-9). This is connected to the area with hydrological contact via a thin channel. The hydrological contact here is shown on the cross-section in Figure 6-13. This is also interpreted as coarser fluvial deposits, where the river deposition was controlled by the two faults. However, it is uncertain where the paleo-river would have drained out of the valley. There are two potential passes south of Ridgecrest, but both passes today are significantly higher than the pass out of the valley just east of Ridgecrest. The stream could have entered into the paleo China Lake, thus transitioning to finer sediments at the end of the stream channel.

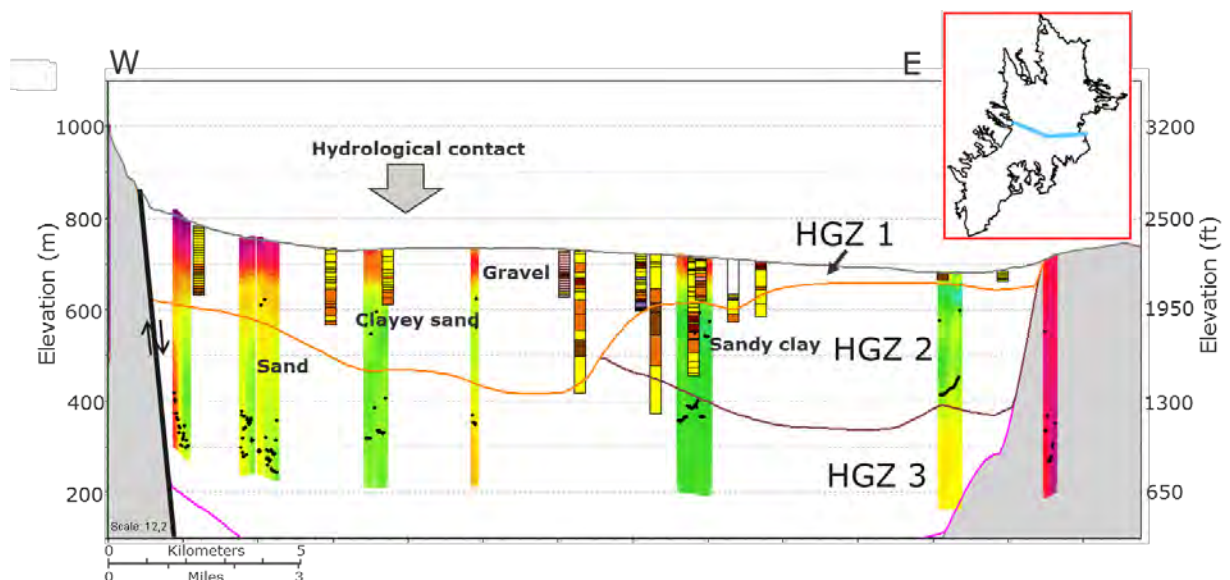


Figure 6-12. Cross-section showing the well lithology and SkyTEM data.

In the west, direct hydrological contact between HGZ 1 and HGZ 3 is seen both in the well lithologies and SkyTEM data. In the center of the profile, a residual channel that has eroded into the clayey material in HGZ 2 is observed in the SkyTEM data. The orange line shows the bottom of HGZ 1, the brown line shows the bottom of HGZ 2 and the small dots show the depth of investigation for the SkyTEM data.

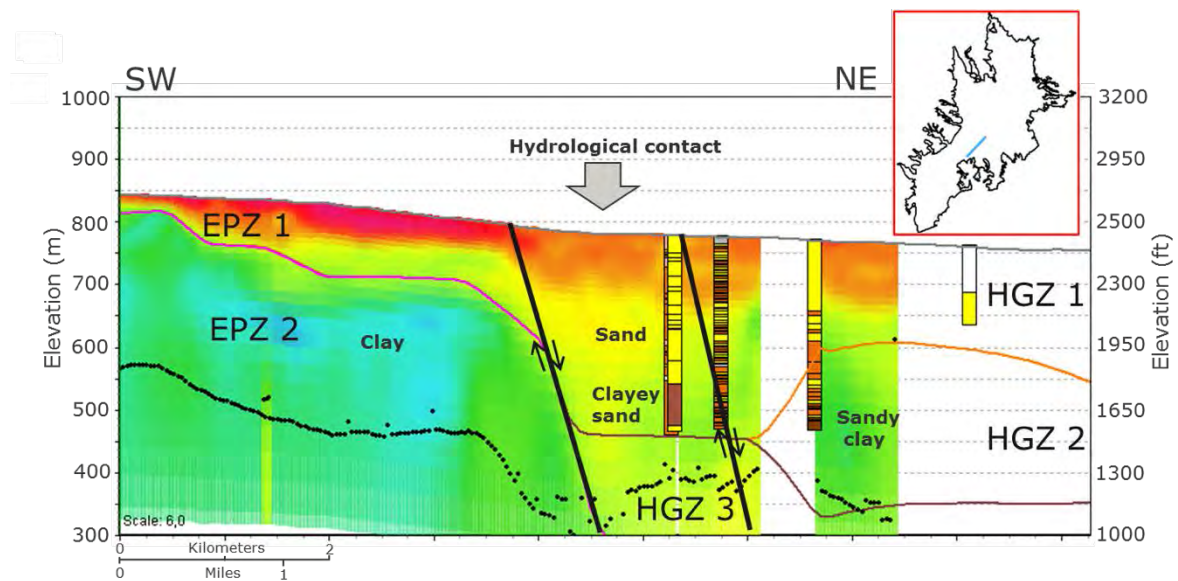


Figure 6-13. Cross-section showing the well lithology and SkyTEM data.

The two interpreted faults dividing El Paso area (southwest) from the China Lake area are seen in the middle of the cross-section. To the northeast of the faults there is direct hydrological contact between HGZ 1 and HGZ 3, likely a paleochannel where coarser materials were deposited. The orange line shows the bottom of HGZ 1, the brown line shows the bottom of HGZ 2 and the small dots show the depth of investigation for the SkyTEM data.

6.3.3 Alluvial fan deposits in the El Paso area

Two separate alluvial fans are mapped in the older alluvium in the El Paso area; one coming out of Freeman Canyon in the northern part of the areas, and one coming out of Bird Spring Canyon (Figure 6-9). The cross-section in Figure 6-14 shows the profile and interpretation of the fan coming out of Bird Spring Canyon and Figure 6-15 shows the interpretation of the fan coming out of Freeman Canyon. In both fans, the coarser fan deposits are observed in the SkyTEM data, where resistivity in the saturated zone ranges from 30 to 50 ohmm (yellow to orange colors in Figure 6-14). These deposits overly the QPc deposits consisting of finer sediments, as indicated by a resistivity of 5 – 15 ohmm (green to yellow-green colors in Figure 6-14).

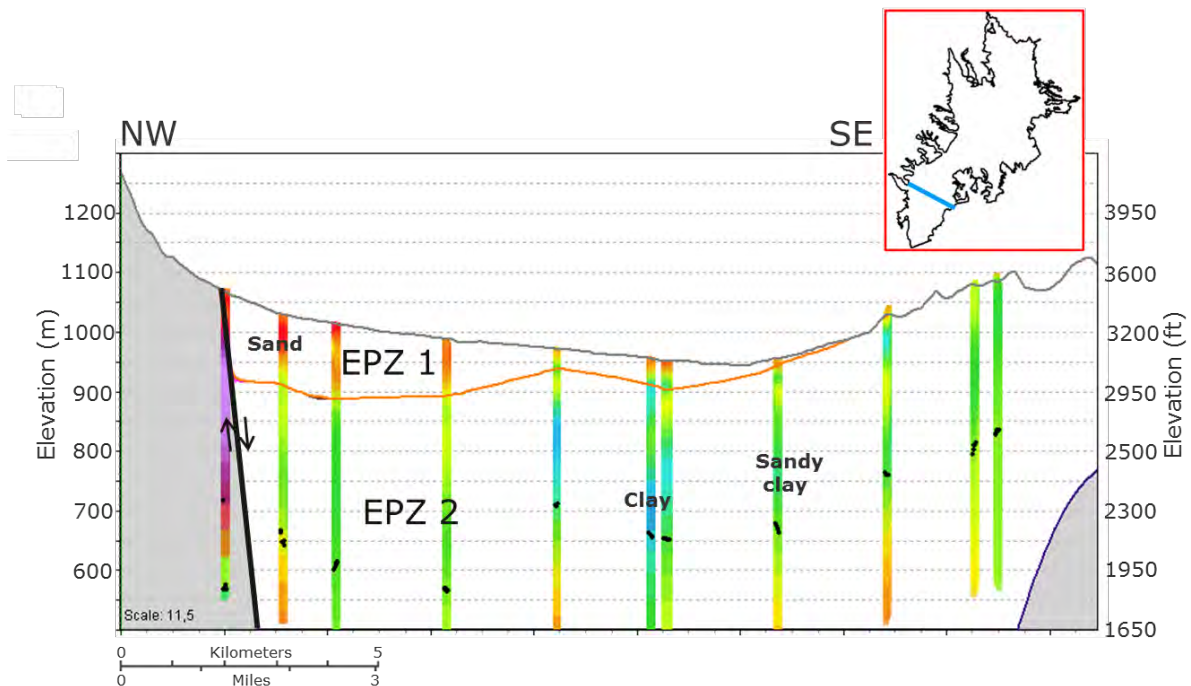


Figure 6-14. Cross-section showing the interpreted SkyTEM data in the El Paso area.

The deposits of the coarser EPZ 1 material is interpreted as fan deposits coming off of the Sierra Nevada frontal fault. The uneven terrain to the southeast is where the semi-consolidated to consolidated QPc units outcrop. The orange line shows the bottom of HGZ 1 and the small dots show the depth of investigation for the SkyTEM data.

6.3.4 Potential barriers to groundwater flow

The most prominent structure in the Indian Wells Valley groundwater basin, which poses a barrier to groundwater flow, occurs right at the boundary between the China Lake area and the El Paso area. Just to the southwest of the fault that divides the China Lake area from the El Paso area, SkyTEM data show an area containing low resistivities (5 – 10 ohmm) that come within 100 feet (30 m) of the surface (Figure 6-15). Resistivity in this range indicate finer deposits, likely consisting of clay and shale. A map showing the SkyTEM resistivity at an elevation of 2,500 feet (770 m) shows the spatial extent of the hydrological barrier (Figure 6-16). The mapped barrier coincides with the previously reported horizontal flow barrier, as suggested by Clark (1999) and Kern County (2008).

The SkyTEM data also shows that the barrier influences groundwater flow in the valley. Resistivity from the SkyTEM can be used to approximate the groundwater table in the area of the barrier seen within the Freeman Canyon fan; resistivity over 60 ohmm (red and purple colors in Figure 6-15) show where the sediments remain unsaturated, whereas resistivity between 20 and 60 ohmm (yellow to orange colors) show the saturated zone. Using this relationship in the SkyTEM data, the groundwater table within the Freeman Canyon fan is seen to decrease towards the northeast, as it approaches the barrier (Figure 6-15). However, at the barrier, the water table is seen to be as much as 100 feet (30 m) lower than the top of the barrier. This suggests that the barrier is holding the water back and it is likely diverting groundwater around the barrier towards the north.

In addition to the horizontal flow barrier at the boundary between the China Lake area and the El Paso area, previous studies, beginning with Kunkel and Chase (1969), have suggested the faults within the basin could pose a hydrological barrier to groundwater flow. However, Tetra Tech (2003) disputed this, indicating that groundwater level measurements from the Fence Line Monitoring Project do not show this. This study has not looked at whether or not the faults will pose a barrier to groundwater flow. However, several faults are seen to affect the depositional environment in the basin, particularly seen in the location of the paleo-channel deposits and the thickness of the three upper hydrogeologic zones. The abrupt change in the sediments will influence the groundwater flow in the basin. This data could be incorporated into the flow models for the groundwater basin.

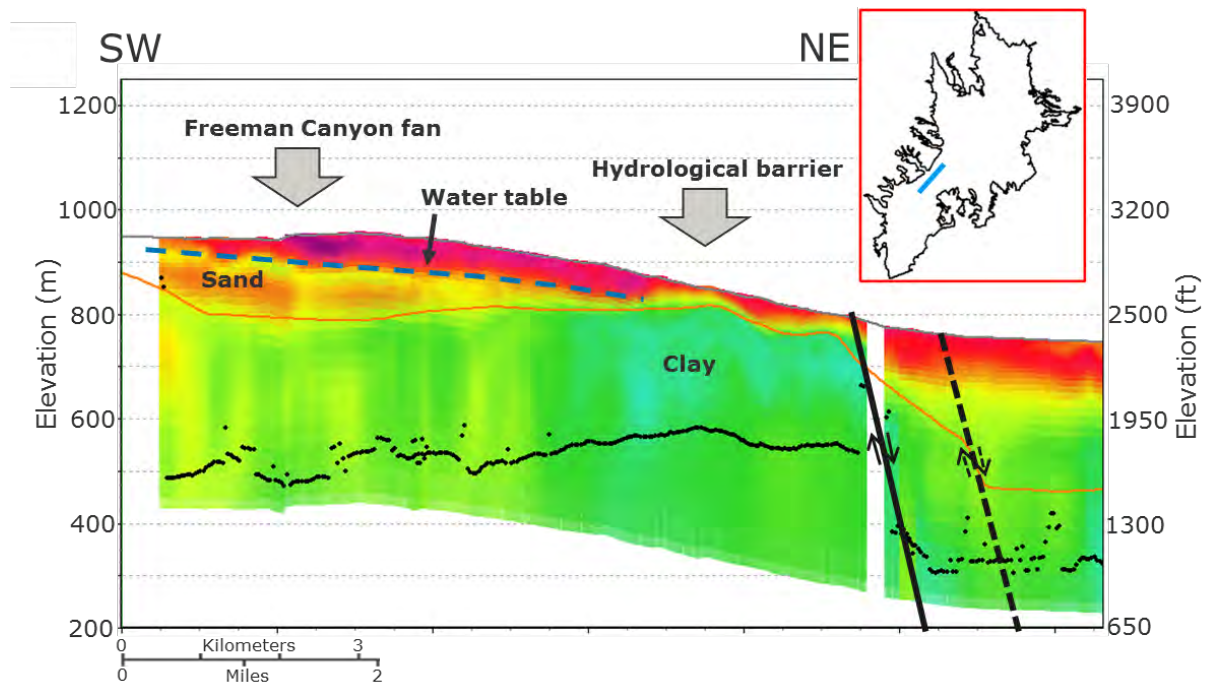


Figure 6-15. Cross-section showing the SkyTEM data, where the resistivity shows fine materials nearly reaching the surface. This is interpreted as a hydrological barrier. The barrier occurs just southwest of the two faults defining the boundary between the China Lake area and the El Paso area. The black dots represent the depth of investigation in the SkyTEM data. The dark blue dashed line shows the approximate location of the water table in EPZ 1, as mapped by SkyTEM resistivity.

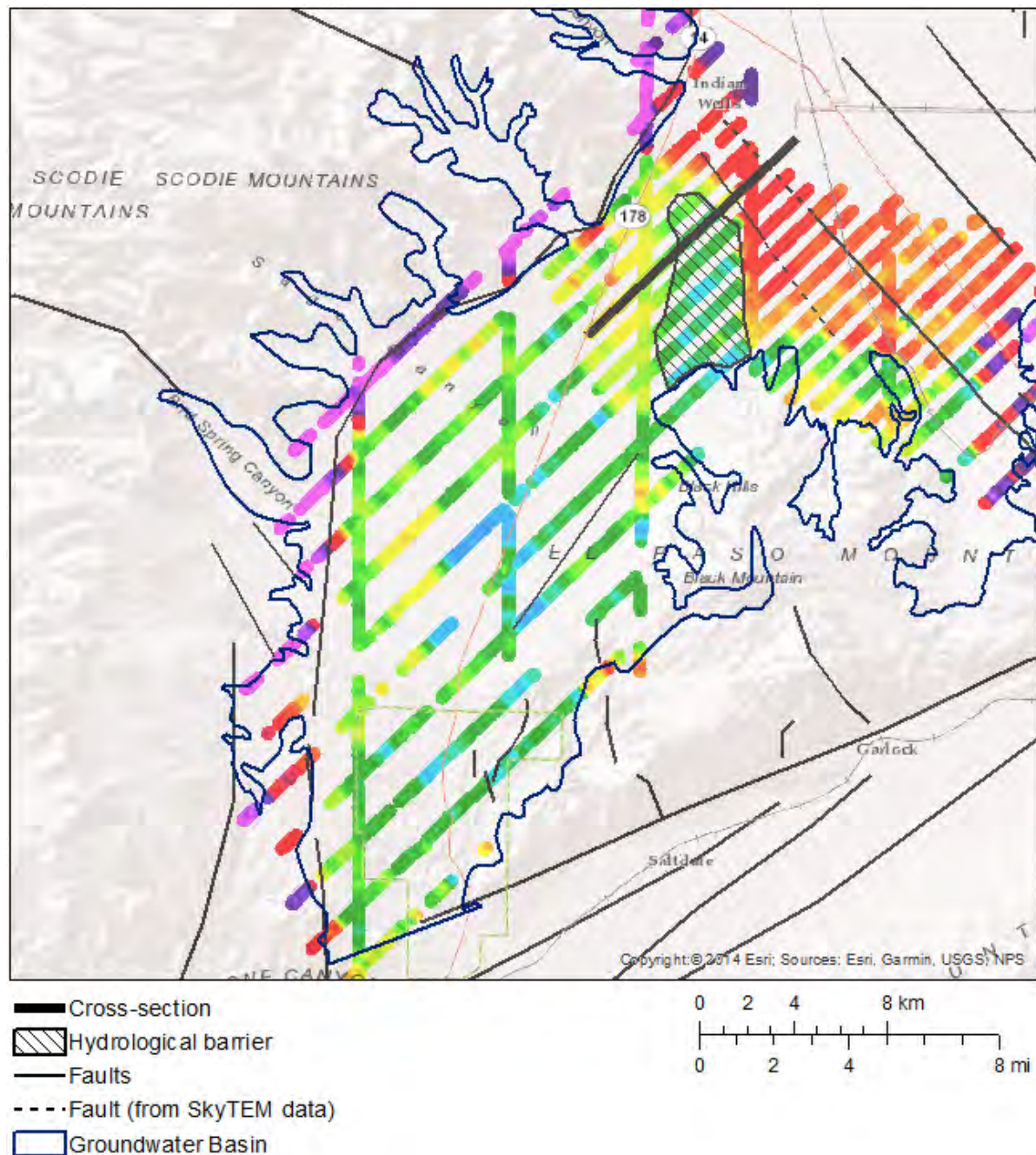


Figure 6-16. Map over the El Paso area showing mean SkyTEM resistivity from an elevation of 760 – 780 m above sea level.

The SkyTEM data shows that low resistivity indicating fine grained materials are present very close to the surface, forming a hydrological barrier between the El Paso area and the China Lake area. The thick black bar shows the placement of the cross-section shown on Figure 6-15.

6.4 Groundwater Quality

As part of the Brackish Water Project, all measured values of total dissolved solids (TDS), as a measure of groundwater salinity, were collected and incorporated into the GeoGIS well database for the groundwater basin. The TDS values, where the screened intervals are known, were divided up into the different hydrogeologic zones. This section describes the distribution of brackish water for each hydrogeologic zone within the groundwater basin.

6.4.1 HGZ 1 and EPZ 1

Figure 6-17 shows the distribution of TDS within HGZ 1 in the China Lake area and EPZ 1 within the El Paso area. In the China Lake area, brackish and saline water is observed primarily in the eastern and part of the basin. The most saline water occurs, as expected, in the sediments below China Lake, where TDS concentrations exceed 10,000 mg/L. In the western and southcentral part of the China Lake area, the water remains fresh with TDS concentrations remaining below 1,000 mg/L.

The distribution of the TDS concentrations within HGZ 1 in the China Lake area show a direct relationship to the presence of HGZ 2. In the areas where HGZ 2 is not present and there is direct contact between HGZ 1 and HGZ 3, TDS concentrations do not exceed 500 mg/L (Figure 6-17). However, along the margins of these areas where HGZ 2 is again present, TDS begins to rise, with concentrations generally between 500 and 1,000 mg/L. In the residual channel/deltaic deposits in the norther part of the basin, the groundwater also remains relatively fresh, with TDS concentrations between 500 and 1,000 mg/L. The low salinity seen in these waters is likely due to a higher throughflow of groundwater.

Groundwater with a TDS of over 1,000 mg/L is considered brackish groundwater, which for HGZ 1 occurs in the eastern and northern part of the basin. In the El Paso area, EPZ 1 also has low TDS concentrations. All seven wells screened within EPZ 1 have TDS concentrations of between 250 and 1,000 mg/L indicating the presence of fresh water.

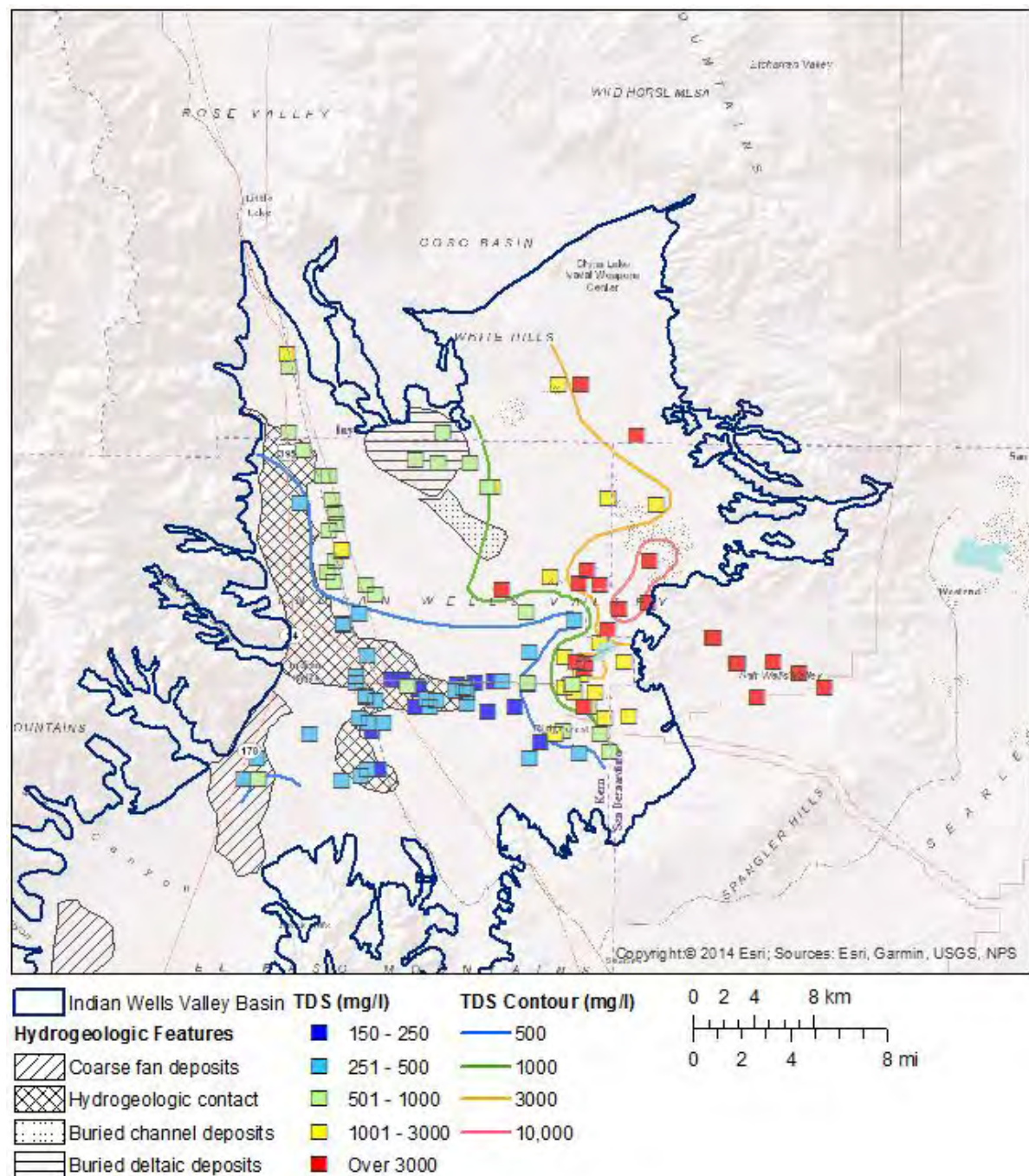


Figure 6-17. Map of the measured TDS values observed in wells screened within HGZ 1.

Note that the lowest TDS values tend to be located in the areas where there is direct contact between HGZ 1 and HGZ 3 or where there is observed coarse fan deposits.

6.4.2 HGZ 2

Figure 6-18 shows the distribution of TDS within HGZ 2 in the China Lake area. Although this zone is considered an aquitard, there are still numerous wells that are screened in the relatively thinner sand and gravel layers internally within HGZ 2.

The highest salinities in HGZ 2 are seen in the northeastern part of the basin, where they are generally above 10,000 mg/L (Figure 6-18). HGZ 2 in the central part of the basin contains

brackish groundwater, where TDS concentrations range between 3,000 and 10,000 mg/L. In the area immediately north and south of Ridgecrest, TDS is seen to range from the upper limit of fresh water to moderately brackish, with concentrations between 1,000 and 3,000 mg/L.

Similar to the pattern seen in HGZ 1, groundwater salinity in HGZ 2 is lowest around the margins where there is direct contact between HGZ 1 and HGZ 3. Here, TDS concentrations remain, apart from one exception, below 1,000 mg/L. The region of lower salinity in HGZ 2 continues in a band from Inyokern to Ridgecrest, where TDS is less than 1000 mg/L, and even lower than 250 mg/L in three wells (Figure 6-18). This band of lower salinity in HGZ 2 is also likely due to a lower salinity recharge source and higher groundwater flow through the coarser sediments.

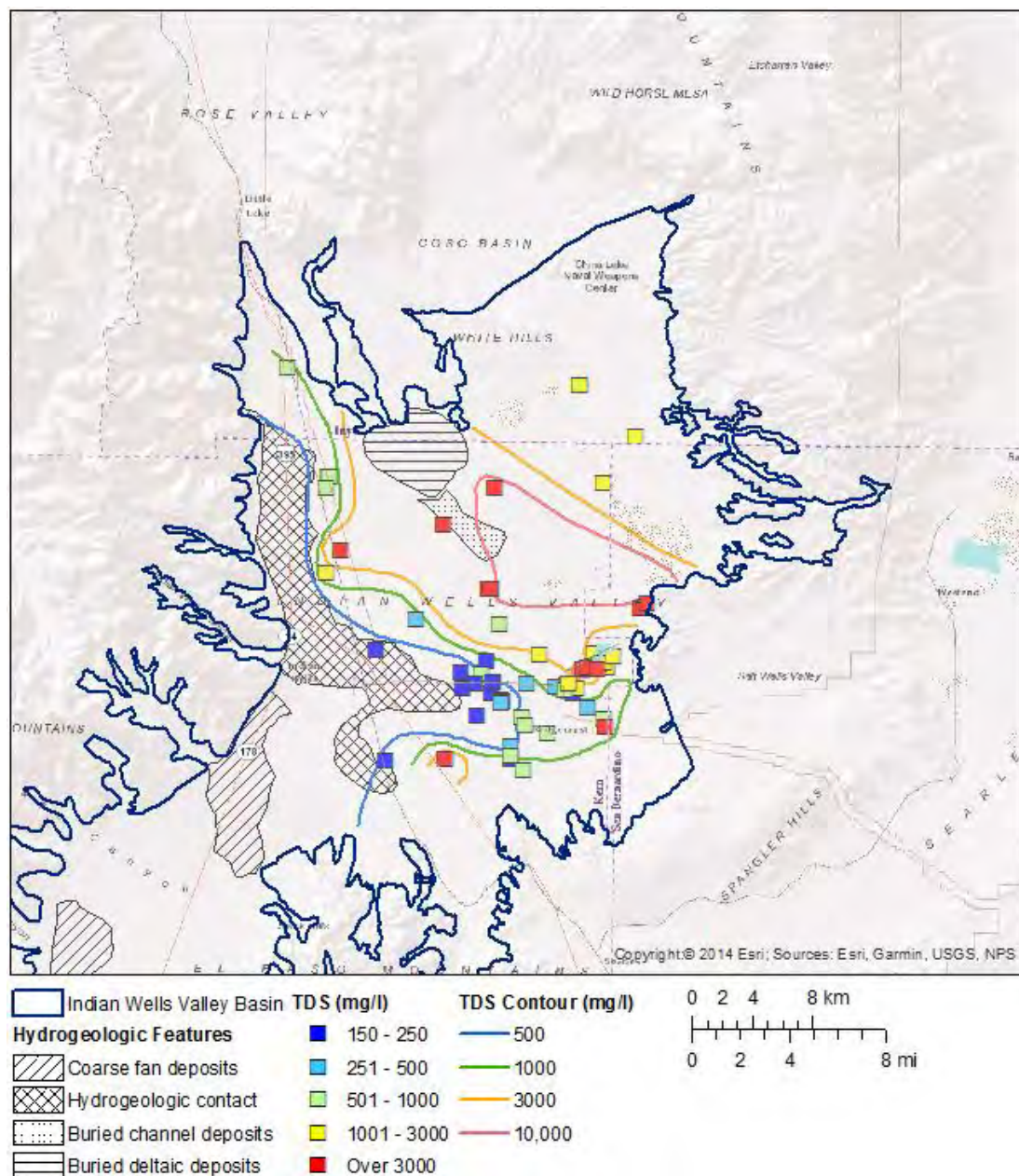


Figure 6-18. Map of the measured TDS values observed in wells screened within HGZ 2.

6.4.3 HGZ 3 and HGZ 4

In total, there are only 11 wells that are screened within either HGZ 3 or HGZ 4 (Figure 6-19). The measurements here generally follow the same pattern as in HGZ 2, with higher salinity in the central part of the basin and south of Ridgecrest, and lower salinity where there is direct contact between HGZ1 and HGZ 3. At Ridgecrest, the salinity in HGZ 3 is a little higher than in either HGZ 1 and HGZ 2, with TDS concentrations reaching 1,150 mg/L. In the El Paso area, there is a single measurement from a well screened within the EPZ 2 unit on the northern margin of the area. TDS in this well was measured at 280 mg/L, indicating fresh groundwater.

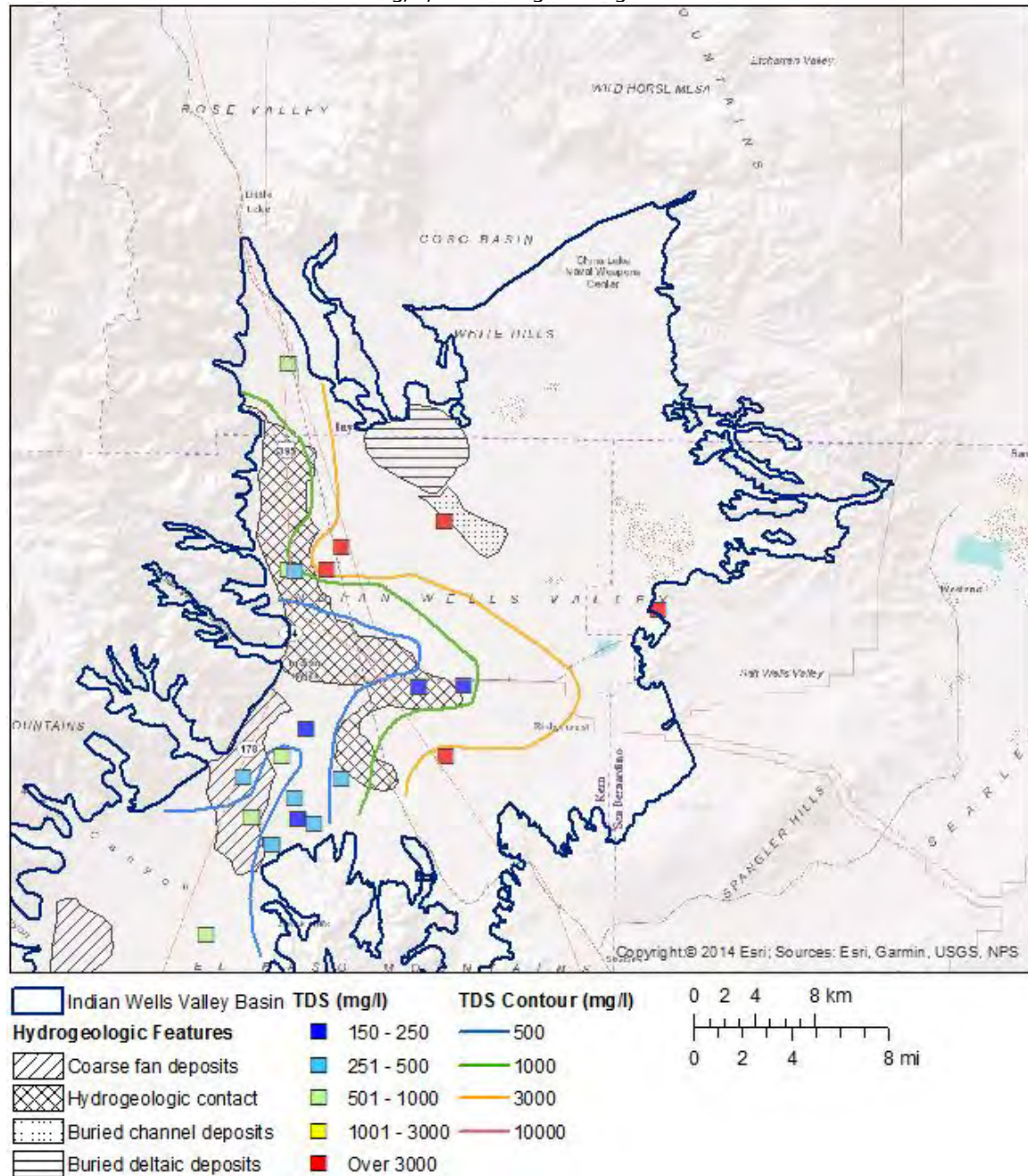


Figure 6-19. Map of the measured TDS values observed in wells screened within HGZ 3 or HGZ 4.

7. HCM UNCERTAINTY AND DATA GAPS

7.1 Model uncertainty

The uncertainty involved in the resultant HCM is directly associated with the availability and geographic distribution of data used. In this case, the data used for HCM development includes well lithology, electric well logs, resistivity data collected by the SkyTEM survey, along with water quality and seismic data. Figure 7-1 shows the density of data used in the development of the HCM in units of numbers of wells with lithological or e-logs per square mile. The map indicates where there are wells between 350 and 1,000 feet deep and wells that are over 1,000 feet deep, in relation to the SkyTEM data collected. This map provides a good analysis with regard to the uncertainty associated with the development of the HCM.

The HCM for the Basin is the most robust in the central and northwestern part of the basin. This is the area with the greatest density of wells with a lithological description (including the deeper wells), as well as coverage from the SkyTEM survey (Figure 7-1).

The uncertainty in the HCM is much higher in the northeastern part of the Basin, including the China Lake Naval Base and Coso Basin. Here the number of interpretable wells decrease significantly, often with several miles between the wells, and very few wells extending deeper than 350 feet. There are only a few SkyTEM lines that extend into this area.

In the portion of the Basin between the China Lake area and the El Paso area, the number of wells decrease, however, this area has the highest density of SkyTEM data (state spacing of lines). In this specific area, there are considered to be sufficient wells for control points, including wells deeper than 1,000 ft, to correlate the resistivity from the SkyTEM survey with. Therefore, the HCM in this area is also considered robust.

The remaining part of the El Paso area has good SkyTEM data coverage, however, the area has almost no wells with which the SkyTEM data can be correlated. The SkyTEM data does provide good detail of the upper 500 to 1,000 feet in the area. However, below this level the interpretation becomes much more uncertain. There are no data that extend down to the bedrock, so the depth of the Basin in this area remains unknown.

7.2 Data gaps

The primary data gap in the Basin is the lack of deeper wells with lithological descriptions and geophysical data in the El Paso area. As there is no information on the thickness and hydrology associated with the QPc deposits. Establishing of one or more wells extending to the basement rocks will help define the bottom and the hydrology of the deposits within the Basin. The deeper wells could also be used to improve the interpretation of the SkyTEM data in the El Paso area.

There is also a lack of geological and geophysical data in the northern part of the Indian Wells Valley Basin, including the area covered by the major part of the China Lake Naval Base. This includes both geophysical surveys and particularly deeper wells. More information in this area would greatly improve the HCM for the Basin.

In general, there is relatively good coverage of TDS concentration measurements in HGZ 1 and HGZ 2 in the central and western portion of the Indian Wells Valley. However, there are fewer TDS measurements available and a general lack of resistivity measurements from the SkyTEM

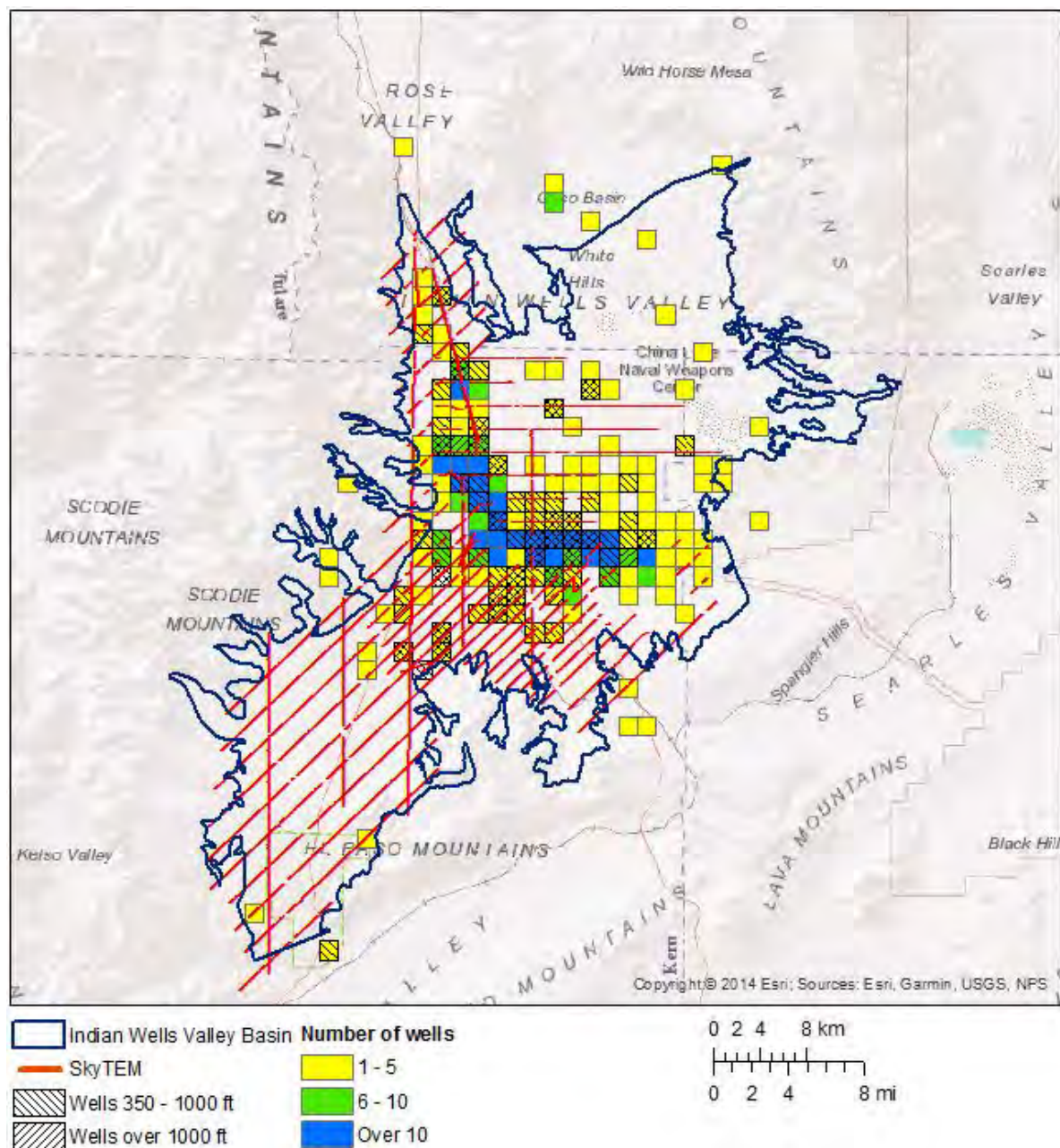


Figure 7-1. Map showing the number of wells per square mile and SkyTEM data within the Indian Wells Valley groundwater basin. The map provides an estimation of the uncertainty of the HCM. Areas without a colored box indicate that there are no wells within that square mile. Boxes with no diagonal lines indicated that all wells within that square mile are shallower than 350 feet.

survey in the northern and eastern part of the China Lake area. Therefore, there is a high level of uncertainty with regards to the groundwater salinity in this area. Collecting TDS measurements from additional wells and combining this with supplemental resistivity measurements will allow for a better modeling of the distribution of brackish water in both HGZ 1 and HGZ 2 in the northern and eastern part of the basin.

There is an overall gap in data on groundwater salinity in the deeper hydrogeologic zones, HGZ 3 and HGZ 4. There are relatively few TDS concentration measurements from these zones and SkyTEM soundings often did not penetrate deep enough into these areas to provide accurate measurements of resistivity in these two zones. Filling this data gap would be difficult, because of

the limited number of wells reaching these depths, and the fact that the surface and airborne geophysics cannot penetrate to these depths. However, any additional TDS and electrical log information in these two zones can greatly improve the assessment of groundwater salinity in the deeper hydrogeologic zones.

In the El Paso area, there is relatively good coverage of SkyTEM resistivity, but very few TDS measurements to which the resistivity can be compared. Although the TDS measurements in the El Paso area indicate that groundwater salinity remains relatively low, there is a great deal of uncertainty associated with this assessment. Therefore, any additional TDS measurements could be combined with the SkyTEM resistivity to provide a better assessment of groundwater salinity in the area.

The final significant data gaps include missing well-construction data and tying together lithological descriptions from wells with TDS and water level measurements. There are wells where both water levels and TDS measurements have been measured, but the lithological descriptions could not be located. Several of these wells extend deeper than 1,000 feet, according to the screen information from the TDS measurements.

The screen intervals for the water level measurements reported in the Kern County monitoring wells are not reported. Thus, the water levels for the different hydrogeologic zones were not assessed. Identification of the screened intervals in these wells would make it possible for the development of zone-specific potential maps and a groundwater flow direction analysis. Locating the lithological descriptions from these wells will help improve the interpretation of the HCM.

7.3 Recommendations for future data collection

To fill the identified data gaps, a number of recommendations for collection of additional data are provided. These include:

- Collect aquifer parameters (hydraulic conductivity, storativity) from existing wells via aquifer pumping tests, throughout the Basin to reduce uncertainty in the groundwater flow model. There is very little aquifer parameter data in the Basin, and even less information on HGZ3.
- Conduct a phased exploration program in areas in the Sierra Nevada frontal fault zone and in the Basin along the eastern Sierra Nevada to evaluate potential fracture flow and mountain block recharge.
- Drilling deep wells in the El Paso area. Ideally, one or more of these new wells will reach the basement of the basin. This will provide essential data on the depth of the El Paso area along with the different geological that are present.
- Seismic surveys in the El Paso area - existing legacy oil and gas well surveys could be obtained and evaluated. This will provide better information on the depth and structures within the areas, including faults which could influence groundwater flow.
- Identify more wells in the northern part of the China Lake area from which TDS measurements can be collected. If possible, conducting additional SkyTEM resistivity surveys would greatly aid the assessment of groundwater salinity in this area.
- Identify any additional wells in the El Paso area from which TDS samples could be collected from. Secure TDS samples from any new wells drilled in the area. This additional information will greatly aid in the interpretation of the SkyTEM data and provide a better assessment of the overall groundwater salinity in the El Paso area.
- Continue with the collection and updating of the well construction data and linking the different data sources with their respective wells and well coordinates. The improved data should be updated in the Indian Wells Valley groundwater database.

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APPENDIX 1

HYDROGEOLOGIC CROSS SECTIONS ALONG THE SKYTEM FLIGHT LINES

See separate PDF file

APPENDIX 2

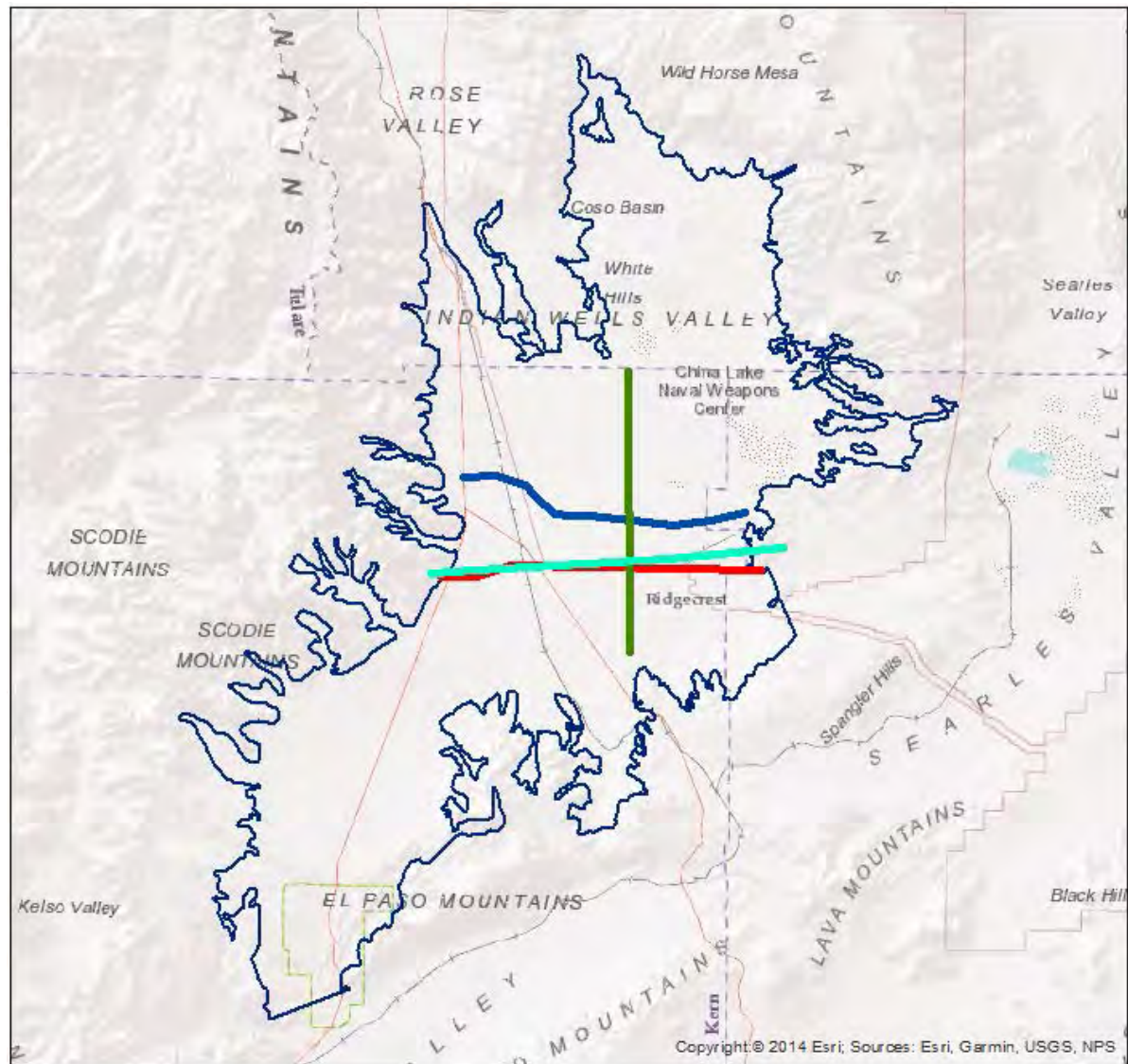
CROSS SECTIONS COMPARED WITH SECTIONS FROM EXISTING REPORTS

Appendix 2 provides a comparison of the HCM developed in this study with previously developed HCMs for the Indian Wells Valley. For the comparison, sections from different reports were scanned and added to the GeoScene 3D modeling software. The boundaries for the mapped hydrogeologic zones and the top of the basement were subsequently superimposed over the figures to provide a general comparison. In addition, wells and results from the SkyTEM survey were also included in the figures. It should, however, be noted that the location of the figures were estimated based upon the maps presented in the reports – exact tie points for the cross-sections were not available. There is a potential for error with regard to the precision of the placement of the report cross-sections within the GeoScene 3D software which needs to be considered when comparing the results.

Figure A2.1 shows the location for all the cross-sections used in the comparison. In order, the comparison includes the following reports:

- Naval Weapons Center, China Lake report NWC TP 6404 (Saint-Amand, 1986)
- USGS Water-Resources Investigations Report 89-4191 (Barenbrock and Martin, 1989).
- Navy DRI report
- TriECO Tetra Tech technical report from 2012 (Trieco, TT, 2012)

On the cross-sections, the thick yellow line represents the bottom of HGZ 1, the thick brown line represents the bottom of HGZ 2, the thick pink line represents the bottom of HGZ 3 and the thick purple line represents the top of the basement (granite). Areas where the brown line (bottom of HGZ 2) is not present shows where there is direct hydraulic contact between HGZ 1 and HGZ 3. The key to the well lithology is shown on Table 4.1 and the key to the colors for the SkyTEM resistivity is shown on Figure 4.4 in the main report.



Report Cross-section

- Navy 1986
- A-A' USGS
- B-B' Navy DRI
- E-E' TriECO TT
- Groundwater Basin

0 4 8 16
Kilometers

Figure A2.1 Location of the four cross-sections shown in Appendix 2 figures.

Figure A2.2 shows a comparison with the results from the Navy water supply report from 1986, where there was presented a hydrostratigraphic conceptual model of the main Indian Wells Valley basin.

A comparison of the two HCMs shows an overall good agreement, though this project has mapped the bedrock (granite) significantly lower, as it is seen in the SNORT 1 and SNORT 2 wells and interpreted from the seismic lines through the valley. The clay plug that was mapped out in the eastern portion of the basin was also not mapped in this study, though it is likely represented by the thicker HGZ 2 seen in the wells and SkyTEM data.

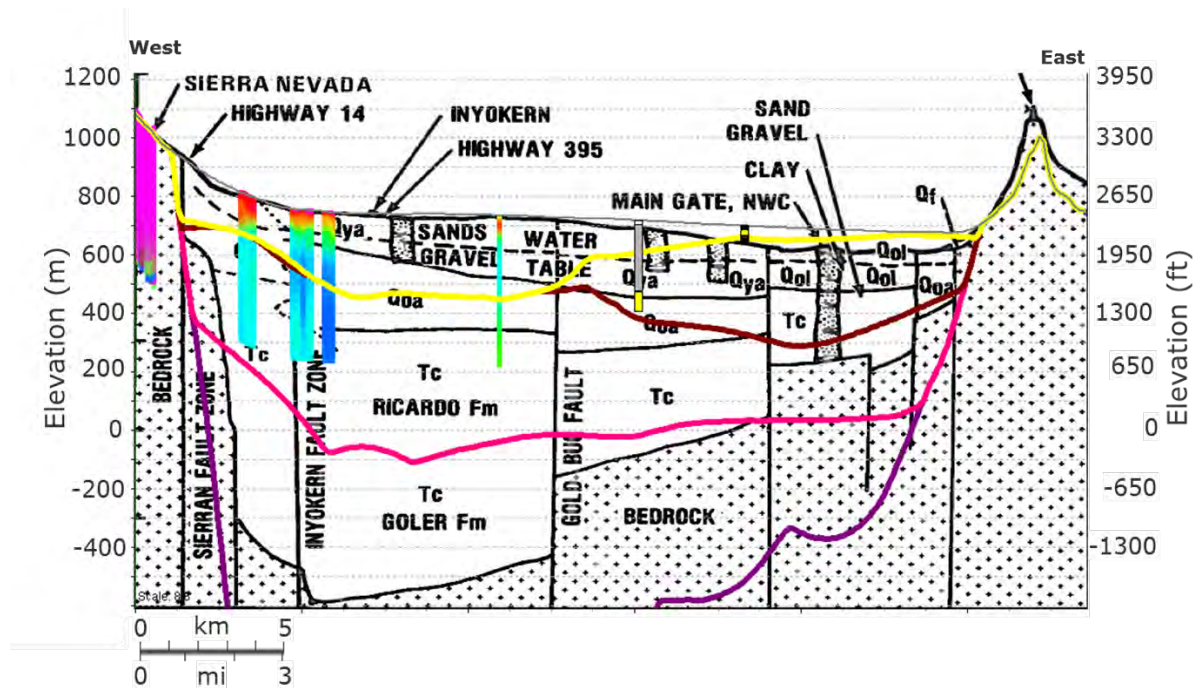


Figure A2.2 Cross-section in Figure 2 from NWC report Water Supply of Indian Wells Valley, California, from 1986.

Figure A2.3 shows a comparison with the results from the USGS Water-Resources Investigations Report from 1989.

A comparison of the two HCMs shows very good agreement between the models. Both models show direct hydraulic contact between the shallow aquifer (HGZ 1) and the deep aquifer (HGZ 3) in the western part of the basin, with the finer sediments (HGZ 2) becoming more prevalent towards the east. The USGS mapped the older alluvium (Qoa) deeper than in the 1986 Navy report, which is in better agreement with this model. The transition between the older alluvium and the Ricardo Formation is higher in the USGS report than in this model, however, there is little data available defining this boundary. This model also has the finer sediments in HGZ 2 extending deeper than they are presented in the USGS report, in the eastern half of the basin.

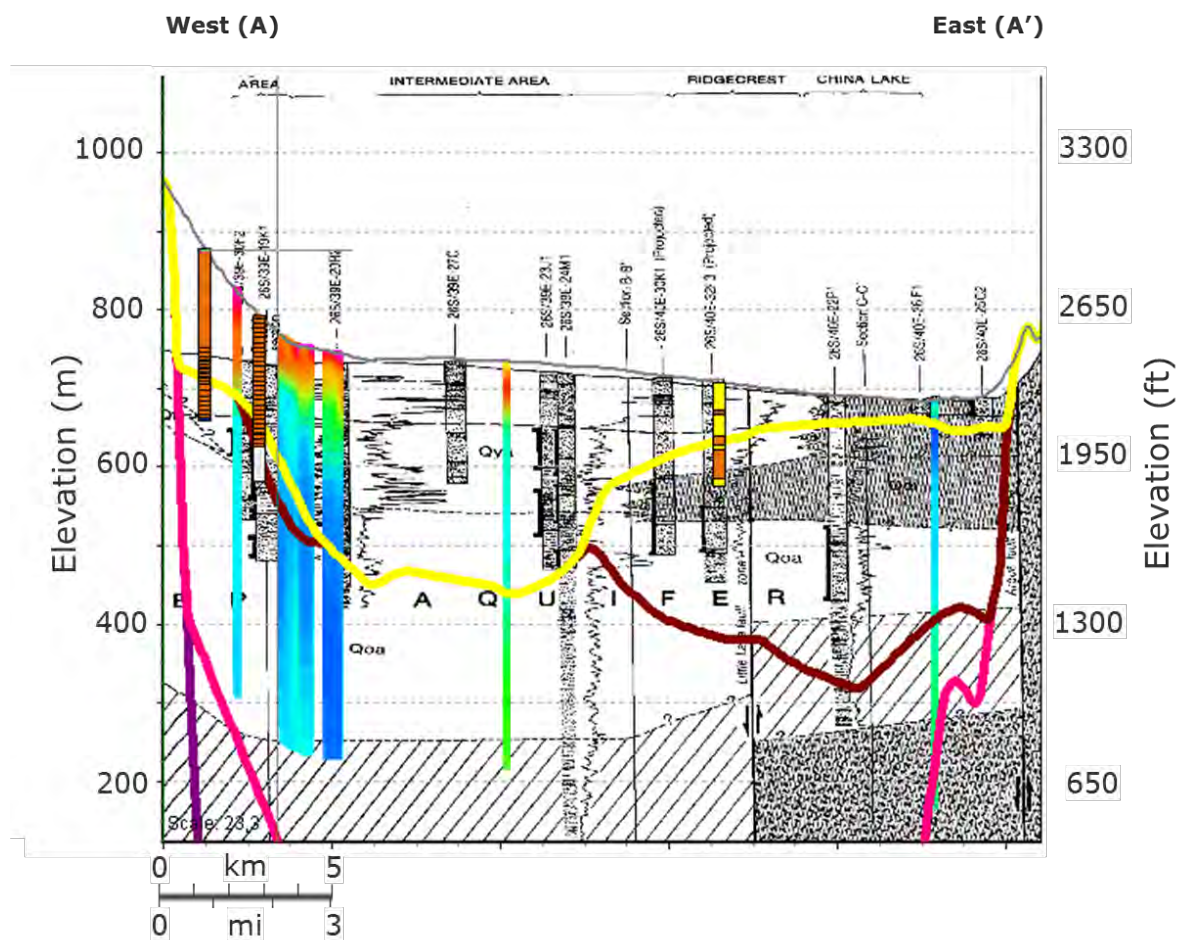


Figure A2.3 Cross-section A-A' from the USGS Water-Resources Investigations Report 89-4191, from 1989 (Brenbrock and Martin, 1989).

Figure A2.4 shows a comparison with the HCM presented in the Navy DRI report.

There are observed significant differences between these models. Specifically, in the southern part of the basin, the Navy DRI does not differentiate between the relatively coarse and the relatively finer alluvium sediments that are observed in the wells and SkyTEM data in the area. In addition, the wells and SkyTEM data shows that the coarser deposits in HGZ 1 are actually thicker than the Navy DRI model suggests.

A direct comparison of the models is, however, problematic, as the Navy DRI model focuses more on the depositional environment and does not necessarily differentiate between the coarser and finer sediments. In this study, the hydrogeologic zones were divided up primarily based upon the sediment size as observed in the SkyTEM and the boreholes. When this is taken into consideration, the differences between the models may not be as significant as to what is shown in Figure A2.4.

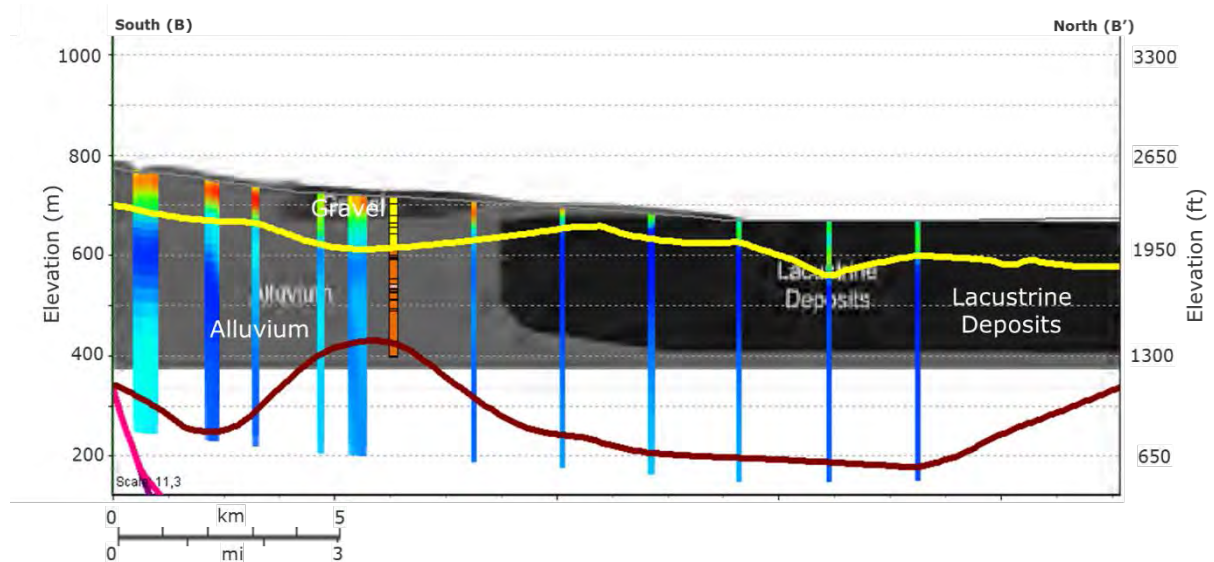


Figure A2.4 Cross-section B-B' from the USGS Water-Resources Investigations Report 89-4191, from 1989.

Figure A2.5 shows a comparison with the HCM presented in the TriECO Tetra Tech report from 2013.

In general, there is a very good agreement between the two models. This study identified three general hydrostratigraphic zones which are the equivalent to HGZ 1, HGZ 2 and HGZ 3 in this study. The main difference is that this study divided the deeper aquifer to include HGZ 4 which represents the lower part of the Ricardo Formation and the Goler Formation. The boundaries between the different zones fit very well, where both studies show direct hydraulic contact between the shallow aquifer (HGZ 1) and the deep aquifer (HGZ 3) in the western part of the basin.

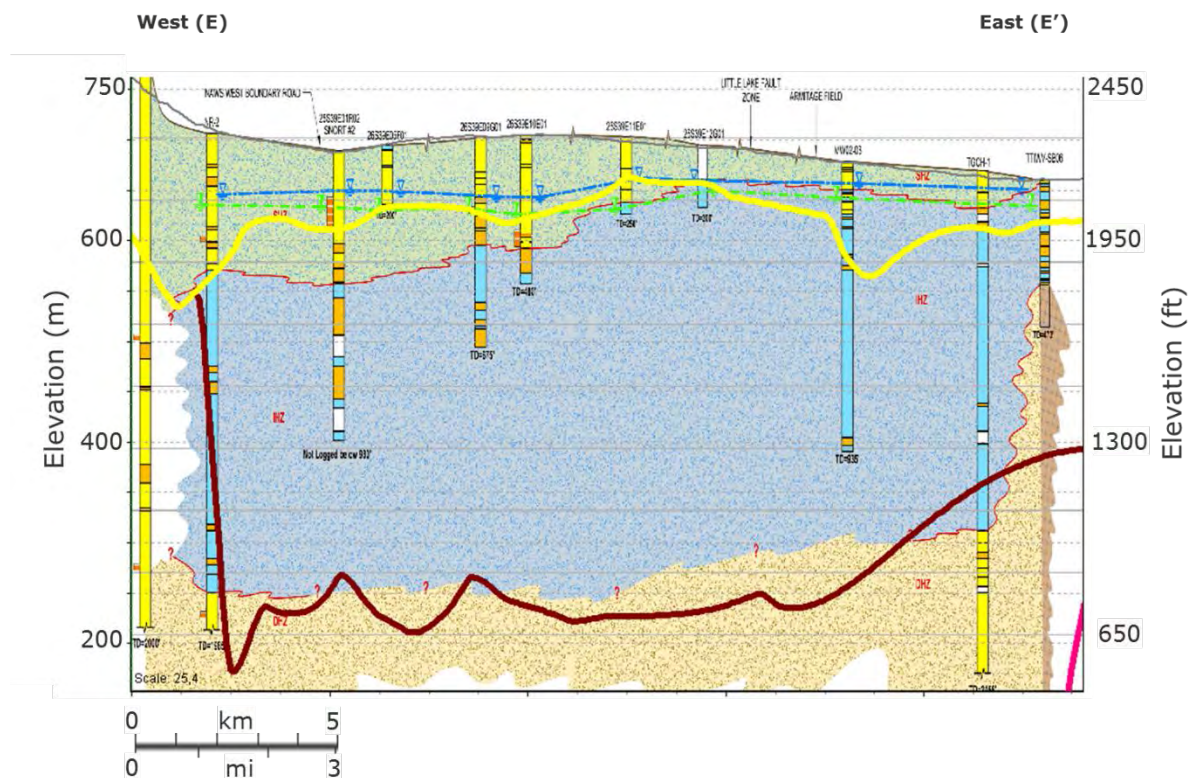


Figure A2.5 Cross-section B-B' from TriECO Tetra Tech report from 2012. Wells and SkyTEM data in the GeoScene3D model are not shown on this cross-section.

APPENDIX 2 REFERENCES

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