EXHIBIT A

ASSESSMENT OF GROUNDWATER STORAGE FOR THE INDIAN WELLS VALLEY GROUNDWATER BASIN

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TECHNICAL WORKING GROUP:
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Acronyms, Abbreviations, and Initialisms

Abbreviation	Description
3D	3 dimensional
%	percent or percentage
<	less than
>	greater than
=	equal
AEM	airborne electro-magnetic
AF	acre-feet
amsl	above mean sea level
b	aquifer thickness
Basin	Indian Wells Valley Groundwater Basin
bgs	below ground surface
CASGEM	California Statewide Groundwater Elevation Monitoring
CHM	Conceptual Hydrogeologic Model
DHZ	Deep Hydrogeologic Zone
District	Indian Wells Valley Water District
DRI	Desert Research Institute
DTW	depth to water
DWR	California Department of Water Resources
Eqn	equation
ESRI	Environmental Systems Research Institute
ft	feet
ft^{-1}	per foot
ft/d	feet per day
GDE	groundwater dependent ecosystem(s)
Geoscience	Geoscience Support Services, Inc.
GIS	Geographic Information System(s)
GRD	Grid files
GSP	Groundwater Sustainability Plan
HCF	Hydrogeologic Conceptual Framework
HCM	Hydrogeologic Conceptual Model
HGZ	Hydrogeologic Zone
HGZ1	Hydrogeologic Zone 1
HGZ2	Hydrogeologic Zone 2
HGZ3	Hydrogeologic Zone 3
HGZ4	Hydrogeologic Zone 4

IHZ	Intermediate Hydrogeologic Zone
IWV	Indian Wells Valley
IWVGA	Indian Wells Valley Groundwater Authority
K	hydraulic conductivity
Kx	horizontal hydraulic conductivity
Kz	vertical hydraulic conductivity
KCWA	Kern County Water Agency
K&S	Krieger & Stewart Engineering Consultants
LSCE	Luhdorff & Scalmanini Consulting Engineers
mg/L	milligrams per liter
ohm-m	ohm-meter – unit of electrical resistivity
PEST	Parameter Estimation Software
S	storativity
SHZ	Shallow Hydrogeologic Zone
SNORT	Supersonic Naval Ordnance Research Track
Ss	specific storage
Surfer	Surfer 21.2.192 (Surfer™)
Sy	specific yield
TDS	total dissolved solids
TWG	Technical Working Group
U.S.	United States
USBR	United States Bureau of Reclamation
USGS	United States Geological Survey
USN	United States Navy
XYZ	coordinates in the X,Y,Z reference frame

TECHNICAL WORKING GROUP: ASSESSMENT OF GROUNDWATER STORAGE FOR THE INDIAN WELLS VALLEY GROUNDWATER BASIN

1.0 Executive Summary

A Technical Working Group (TWG) composed of qualified groundwater professionals designated by parties representing more than 80 percent of the total groundwater production from the Indian Wells Valley Groundwater Basin (Basin) was formed to assess groundwater storage in the Basin and evaluate other related technical questions. This paper was the subject of collaboration between these professionals applying scientific methods to estimate the total amount of groundwater and usable groundwater in storage in the Basin. This effort required defining the physical parameters of the Basin, including its geologic and hydrologic characteristics. Three separate methodologies were considered, and the average groundwater volumes estimated from those three approaches are as follows:

1. The total volume of groundwater in storage in the Basin is approximately 66.9 million acre-feet (AF); and
2. The amount of fresh groundwater in storage in the Basin is approximately 37.5 million AF.

2.0 Introduction

2.1 Background

Beneficial users of groundwater in the Basin have a common interest in understanding the amount of groundwater resources available. As such, a TWG has been formed to evaluate these issues and work collaboratively to estimate the total amount of groundwater and usable groundwater in storage. The TWG consists of technical representatives of beneficial users of groundwater that constitute over 80 percent of the pumping in the Basin. The TWG parties include the Indian Wells Valley Water District (District) represented by Krieger & Stewart Engineering Consultants (K&S), Parker Groundwater, and Ramboll, Meadowbrook Dairy represented by Luhdorff & Scalmanini Consulting Engineers (LSCE), Mojave Pistachios represented by aquilogic, Inc., and Searles Valley Minerals Inc. represented by Geoscience Support Services, Inc. (Geoscience).

This paper presents an overview of the collective work performed to date by members of the TWG related to the evaluation of groundwater storage volumes within the Basin (**Figure 1**).

2.2 Terms and Definitions

The following defined terms will be used throughout this paper:

- "Unconfined aquifer" (or water-table aquifer) is defined as "an aquifer in which the water table forms the upper boundary" (Freeze and Cherry, 1979, p. 48);
- "Confined aquifer" is defined as "an aquifer that is confined between two aquitards. In a confined aquifer, the water level in a well usually rises above the top of the aquifer" (Freeze and Cherry, 1979, p. 48); and
- "Aquitard" is defined as "the less-permeable beds in a stratigraphic sequence. These beds may be permeable enough to transmit water in quantities that are significant in the study of regional groundwater flow, but their permeability is not sufficient to allow the completion of production wells within them" (Freeze and Cherry, 1979, p. 47).

The following definitions are used throughout this paper to differentiate total groundwater storage from other subsets of groundwater in storage that are contained within that total volume:

- Total Storage – the total quantity of water in the zone of saturation within a groundwater basin;
- Total Fresh Water in Storage – the quantity of water in the zone of saturation with a total dissolved solids (TDS) concentration of less than 1,000 mg/L; and
- Total Brackish / Saline Water in Storage – the quantity of water in the zone of saturation with a TDS concentration of greater than or equal to 1,000 mg/L.

2.2.1 Definition of Storage

The California Department of Water Resources (DWR) defines "Groundwater in Storage" as "the quantity of water in the zone of saturation." (Bulletin 118 Definition as described in Best Management Practices – Water Budget [DWR, 2016]). Furthermore, DWR defines "Groundwater Storage Capacity" as "the volume of void space that can be occupied by water in a given volume of a formation, aquifer, or groundwater basin." (DWR, 2016).

Freeze and Cherry (1979), defined "storativity" (S) as "the volume of water that an aquifer releases from storage per unit surface area of the aquifer per unit decline in the component of hydraulic head normal to that surface" (p. 60). Storativity, also referred to as the older term "storage coefficient", describes the capacity of an aquifer to store or release water.

For an unconfined aquifer, the storativity (S) represents the total volume of water that drains by gravity-induced flow from the saturated aquifer. In this case, storativity (S) can be several orders of magnitude larger than for a confined aquifer. For unconfined aquifers, the amount of water stored due to the compressibility of water and the aquifer geologic matrix is negligible, and storativity (S) is called specific yield (Sy), which is expressed as a decimal fraction of 1 or a percentage (%).

Freeze and Cherry (1979), defined the "Specific Storage (Ss) of a saturated aquifer" as "the volume of water that a unit volume of aquifer releases from storage under a unit decline in hydraulic head" (p. 58).

For a confined aquifer, the storativity (S) is equal to the specific storage (Ss) times the aquifer thickness (b), and considers both the compressibility of the aquifer geologic matrix, and the compressibility of water. The storativity (S) can be determined from constant rate aquifer tests that include observation wells. In confined aquifers, storativities typically range from 0.005 to 0.00005 (Freeze and Cherry, 1979, p. 60).

For **unconfined aquifers**, the total volume of groundwater in storage is the total saturated volume multiplied by the Sy:

Storage = (total saturated volume) x (Sy)... (Eqn. 1)

Where:

Storage	=	Total volume of groundwater in storage [AF]
Total saturated volume	=	Volume of material saturated with groundwater [AF]
Sy	=	Specific Yield [unitless]

For **confined aquifers**, the total volume of groundwater in storage is the total volume of the confined aquifer multiplied by the storativity (S) plus the total saturated volume of the confined aquifer multiplied by the Sy:

Storage = [(total volume) x S] + [(total saturated volume) x Sy]................ (Eqn. 2)

Where:

Storage	=	Total volume of groundwater in storage [AF]
Total volume	=	Total volume of the confined aquifer [AF]
S	=	Storativity [unitless]
Total saturated volume	=	Volume of material saturated with groundwater [AF]
Sy	=	Specific Yield [unitless]

For confined aquifers, once the head in a confined aquifer is reduced below the top of the aquifer, unconfined conditions exist. In this case, to calculate the total groundwater in storage in a confined aquifer, both the volume of stored water under pressure, and the volume of unconfined water must be determined. The first part of the equation represents the total groundwater in storage while the aquifer is confined. The second part of the equation represents the storage when the aquifer becomes unconfined.

The ultimate development potential of a groundwater basin is constrained by several factors. Some of these factors, such as the economic and institutional ones, can change with time. Other factors, however, present significant physical and chemical constraints that will continue to limit the potential for groundwater development. Both types of factors can play a role. Some of these main factors include the following:

- **Physica**l. The basin recharge area may not be adequate to sustain development. The pumping could be too concentrated in a portion of basin. Well yields may be too low for the intended use, or the desired pumping rates;
- **Quality**. The water quality may not be suitable for the intended use without treatment. In coastal areas, there is an increased potential for seawater intrusion. Upwelling of poorer quality water in deeper parts of a basin can occur in some instances;
- **Economic**. There can be excessive costs associated with increased pump lifts, and the deepening of wells. There can be high costs associated with treating water if it does meet the requirements for its intended use;
- **Environmental**. Groundwater development may be constrained by the need to maintain groundwater levels for wetlands, stream baseflow, or other groundwater dependent ecosystems (GDE); and
- **Institutional**. Local groundwater management plans or ordinances may be in place that restrict use. Other factors include basin adjudication or impacts on surface water rights.

The volume estimates detailed below follow the three definitions described above for Total Storage, Total Fresh Water in Storage, and Total Brackish / Saline Water in Storage, which can be considered usable groundwater. However, the amount of recoverable groundwater in storage is limited by the factors listed above, including potential undesirable impacts. A determination of recoverable water was not made as part of this study.

2.3 Basin Setting

The Indian Wells Valley Basin (Basin) is a large, alluvium-filled groundwater basin in the Mojave Desert region of Southern California (**Figure 1**). According to DWR Bulletin 118: California's Groundwater (DWR, 2016), the Basin covers an area of 382,000 acres (597 square miles). The Basin lies with an active tectonic area of California and is bordered by and contains numerous active faults that have contributed to its geometry. The Basin consists of an asymmetric structural basin that is deeper on the west, with two areas (El Paso and China Lake) separated by a subsurface bedrock high, which has been filled with thousands of feet of alluvial sediments eroded from surrounding mountains consisting largely of igneous and metamorphic rocks. Interfingering with the alluvial deposits extending out from the mountains that rim the Basin are playa lake and lacustrine deposits found to be more than 1,000 feet thick in the China Lake

Area. Beneath the lacustrine deposits, several thousand feet of coarse-grained sediments that thicken to the west and thin to the east extend down to the bottom of the alluvial basin **(Figure 2**).

2.3.1 Hydrostratigraphy

The Berenbrock and Martin (1991) study, focused on the China Lake Area of the Basin, conceptualized this area of the Basin as a two-aquifer system **(Figure 3**). The shallow aquifer consists of a mixture of some older lacustrine deposits, shallow alluvium underlain by lacustrine deposits, younger lacustrine deposits, playa deposits, and sand dune deposits. The base of the shallow aquifer was poorly defined but assumed to slope from the west side of the China Lake Area, at an elevation of 1,950 feet above mean sea level (amsl), to the east and beneath China Lake, at an elevation of 1,850 feet amsl. The water-bearing deposits in the shallow aquifer primarily consist of fine sand, silt, and clay. In the eastern part of the Basin, lower permeability lacustrine and playa deposits confine, or partly confine, the underlying aquifer.

The deep aquifer includes the alluvium and lacustrine deposits in areas where the shallow aquifer is absent, and the alluvium and lacustrine deposits underlying the shallow aquifer in the eastern part of the Basin (**Figure 4**). The base of the deep aquifer is the bottom of the alluvium, and the saturated thickness of the deep aquifer was estimated to be at least 1,000 feet (Kunkel and Chase, 1969). The deep aquifer was assumed to be unconfined in most places, except the eastern part of the valley where it is confined by lacustrine and playa deposits consisting of silts and clays. The deep aquifer consists of medium to coarse sands with some gravels. The deep aquifer is the main water source for the Basin (Berenbrock and Martin, 1991).

The United States Bureau of Reclamation (USBR) (1993) identified an 800-foot- to 1,300-foot-thick clay layer extending over the majority of the China Lake Area of the Basin and underlying the shallow aquifer system. Sand and fine gravel valley fill the southwestern portion of the Basin and along the Sierra Nevada mountain front. The USBR (1993) showed that the lower permeability sediments extended further west toward the Sierra Nevada than previous conceptualizations had indicated (**Figure 5**), leading to a refinement of the two-aquifer system toward a more complex three-aquifer system.

TetraTech EMI (2003) reviewed data from nearly 300 wells in the China Lake Area of the Basin to create maps, cross-sections, and geochemical plots to identify three discrete hydrogeologic water-bearing zones. They designated these three zones as the Shallow Hydrogeologic Zone (SHZ), the Intermediate Hydrogeologic Zone (IHZ), and the Deep Hydrogeologic Zone (DHZ) (**Figure 6**). There is an extensive Pleistocene lake-deposited clay in the northern portion of the China Lake Area of the Basin that thins and tapers out to the south. This three-zone conceptualization continued in the later work of TriEco TetraTech (2012) (**Figures 7, 8,** and **9**).

In recent years as the Hydrogeological Conceptual Framework (HCF) has evolved, these three zones are now more commonly referred to as Hydrogeologic Zones, or HGZs. HGZ1 is the former SHZ. HGZ2 is the former IHZ, and HGZ3 is the former DHZ.

In consideration of the three water bearing zones, there are two groundwater production units in the China Lake Area of the Basin: the saturated portion of HGZ1, and the regional aquifer comprising the saturated portions of HGZ2 and HGZ3.

Groundwater within HGZ1 is generally limited to the eastern and northern portions of the China Lake Area of the Basin, where it occurs under unconfined or perched conditions on top of the low-permeability lacustrine clays of the upper portion of the HGZ2. Where present, these clays generally act as a barrier between HGZ1 and HGZ2/HGZ3. The depth to groundwater in HGZ1 is generally shallowest in the eastern portion of the China Lake Area of the Basin near the City of Ridgecrest sewage treatment ponds, ranging between 5 feet and 10 feet bgs.

The regional aquifer (saturated portion of HGZ2 and HGZ3) is primarily composed of fan deposits of sands and gravels with some interbedded lacustrine clays. Groundwater within the regional aquifer may occur under confined, semi-confined, or unconfined conditions. Where the lacustrine clays are present, groundwater is semi-confined to confined. Groundwater conditions become unconfined where these clays pinch out. In general, the regional aquifer is unconfined in the vicinity of Inyokern and in the western and southernmost portions of the City of Ridgecrest. In the eastern portion of the Basin, the regional aquifer is confined or semi-confined by lenses of the lacustrine and playa deposits.

Groundwater levels measured in wells screened in the regional aquifer are shallowest in the vicinity of the City of Ridgecrest sewage treatment ponds, where depths to water ranged from 22 feet to 34 feet bgs in two wells with screened intervals from 353 feet to 395 feet bgs. Groundwater levels are deepest south of Inyokern Road and east of Jacks Ranch Road, with depths to water ranging from 220 feet to over 350 feet bgs.

In developing a groundwater model for the Basin, Brown and Caldwell (2009) further refined the TetraTech EMI (2003) Conceptual Hydrologic Model (CHM), and included a large portion of the El Paso Area. Brown and Caldwell discarded the HGZ nomenclature, instead calling the hydrogeologic zones “layers”. Additionally, they parsed one of the HGZs to include an additional layer (**Figure 10**). Thus, the Brown and Caldwell groundwater model included the following four distinct layers:

- Layer 1 – Playa, lacustrine and eolian, alluvial silt and clay deposits as an unconfined aquifer;
- Layer 2 – Unconsolidated young alluvium, playa/lacustrine, and alluvial fan deposits as an unconfined / confined aquifer with variable transmissivity;
- Layer 3 – Older alluvium, more consolidated alluvial fan and basin fill deposits as an unconfined / confined aquifer with variable transmissivity; and
- Layer 4 – Older continental basin fill, heavily cemented, low permeability deposits of the Goler and Ricardo Formations as an unconfined / confined aquifer with variable transmissivity.

Additionally, within the Brown and Caldwell CHM, the following four distinct hydrostratigraphic features were identified (**Figure 10**):

- Fines plug – located in the western part of the Basin between Highway 395 and the Little Lake Fault;
- Gravel zone – located in the southwestern portion of the base between Highway 395 and the City of Ridgecrest;
- Playa – located on the eastern side of the Basin to the east of the Little Lake Fault; and
- High gradient zone – located to the southwest separating the El Paso Area from the China Lake Area of the Basin.

The Desert Research Institute (DRI) (McGraw et al., 2016), under contract to the United States Navy (USN), developed updates to the Brown and Caldwell (2009) model. Specifically, DRI incorporated revised estimates of playa evaporation rates and mountain front recharge while increasing the grid resolution of the model in both the vertical and horizontal directions. Additionally, DRI refined the model layering, by adding two additional layers, to better represent the aquifer units. This change increased the number of layers in the model from four to six (**Figure 11**). An additional layer was added to the unconsolidated, younger alluvium (Brown and Caldwell Layer 2), and one was added to the older basin fill (Brown and Caldwell Layer 4). The purpose of this refinement was to allow greater material property heterogeneity in the vertical direction because the simulated water levels were sensitive to how the clay lenses were vertically distributed. Additionally, the two new layers allowed for better estimates of average pore velocities (McGraw et al., 2016). **Figure 11** shows the general linkages between the various nomenclatures that have been used to describe the three-aquifer system. The DRI "Shallow" zone is effectively HGZ1, and is represented as DRI model layer 1. The DRI "Intermediate" zone is effectively HGZ2, and is represented as DRI model layers 2 and 3. The DRI "Deep" zone is effectively HGZ3, and is represented as DRI model layers 4, 5, and 6.

DRI updated its model in 2017 to incorporate regional faults as groundwater barriers in order to improve predictions of water levels in the El Paso Valley (DRI, 2017). Additional data processing was also incorporated into the updated model to remove duplicate and erroneous data.

Ramboll (2024), has reinterpreted the existing seismic survey data for the Basin, and the revised conceptualization of the Hydrogeologic Conceptual Model (HCM) includes a deeper, fourth HGZ as illustrated on **Figure 12**.

2.3.2 Basin Hydraulic Properties

Numerous investigators have estimated hydraulic parameters within the Basin, and generally nearly all of these are from the China Lake Area. Analysis methods used to estimate hydraulic properties have included reviewing geologic logs from various studies, drillers logs from water wells drilled throughout the Basin, aquifer tests, specific capacity tests, and literature values from studying Basin and Range lithologies (Kunkel and Chase, 1969; Dutcher and Moyle, 1973; USBR, 1993; Anderson et al., 1992; Schwartz and Zhang, 2003). Based on available historical information, Brown and Caldwell (2009) developed a range of hydraulic properties (hydraulic conductivity [K], horizontal to vertical hydraulic conductivity ratio [Kx/Kz], specific storage [Ss], and specific yield [Sy]) for the following four layers in its model, from shallowest to deepest:

- Playa and lacustrine deposits (Layer 1) – K values ranging from 0.1 feet per day (ft/d) to 100 ft/d, a Kx/Kz ratio of 10, and Sy values ranging from 0.05 to 0.15;
- Younger, unconsolidated alluvium (Layer 2) – K values ranging from 0.1 ft/d to 75 ft/d, a Kx/Kz ratio of 10, Ss values ranging from 0.00001 per foot (ft^{-1}) to 0.0001 ft^{-1}, and Sy values ranging from 0.05 to 0.12;
- Older alluvium (Layer 3) – K values ranging from 0.1 ft/d to 75 ft/d, a Kx/Kz ratio of 10, Ss values ranging from 0.00001 ft^{-1} to 0.0001 ft^{-1}, and Sy values ranging from 0.05 to 0.15; and
- Older basin fill (Layer 4) – K values ranging from 0.1 ft/d to 50 ft/d, a Kx/Kz ratio of 10, and Ss values ranging from 0.00001 ft^{-1} to 0.0001 ft^{-1}.

DRI subsequently utilized a pilot-point methodology (Doherty, 2003) within the Parameter Estimation (PEST) software module to automate the steady-state calibration process to develop a heterogenous hydraulic conductivity field for their model. Measured hydraulic conductivity values were used in the pilot-point schema as fixed values, while other hypothetical values were added in areas without measurements. Hydraulic conductivity values for all model cells were determined by interpolating between the measured and hypothetical values.

The DRI interpretation showed areas of higher hydraulic conductivity in the western central part of the China Lake Area of the Basin, with isolated pockets of lower conductivity zones to the northwest, east, southeast, and southwest. A zone of higher hydraulic conductivity is assumed in the western part of the Basin within the shallow layers of the model (Layers 1, 2, and 3), with hydraulic conductivities decreasing to the east. Layers 4 and 5 within the model have uniformly lower hydraulic conductivities extending west to east across the Basin. Layer 6 is limited to the western part of the Basin and has higher hydraulic conductivities.

Based on the interpretation of DRI, specific yields in the main groundwater production areas of the Basin (both the agricultural areas on the western part and the municipal production areas in the southern portion of the China Lake Area of the Basin) are approximately 0.15. The remaining areas of the Basin including the playa and regions to the northeast and southwest in the El Paso Area have specific yields that are approximately 0.25.

In the updated model (DRI, 2017), horizontal hydraulic conductivity distribution in the upper three layers of the model was further refined. Specific yield (Sy) and specific storage (Ss) were also refined but information on those resulting distributions was not provided by DRI in their 2017 technical memorandum (DRI, 2017).

In comparing the distribution of hydraulic conductivities from 2016 to 2017, the area of higher hydraulic conductivities now extends north to south throughout the central and northeastern parts of the China Lake Area of the Basin, while still extending toward the western boundary. The isolated pockets of lower hydraulic conductivity zones, while still located to the northwest, east, southeast, and southwest, have been reduced in size, and the resulting intermediate hydraulic conductivity zones have filled in the areas between the higher and lower hydraulic conductivity zones. Future refinements to the Basin model are expected to show additional changes in the distribution of hydraulic parameters.

3.0 Groundwater Storage Volume – Estimate 1

The TWG developed an estimate of the total volume of groundwater in the Basin utilizing data from the DRI groundwater model documentation (DRI, 2018; 2019a; 2019b; McGraw et al., 2016). The TWG relied on cross-sections and data extracts in published and generally available presentation documents provided by DRI at various times during the past several years. Using those documents from the DRI model documentation, the TWG "built" a three-dimensional Basin volumetric model with the following key features and assumptions:

1. DRI model boundary (lateral extent) (DRI, 2018; McGraw et al., 2016), although it should be noted that the DRI model boundary does not cover the entire Basin;
2. Kern County Water Agency (KCWA) groundwater levels from 2015 (the most recent data available at the time the model was built);
3. Five DRI vertical cross-sections to estimate the shape of the Basin and the DRI model layers (DRI, 2019b; McGraw et al., 2016);
4. DRI TDS concentration distributions in the shallow, intermediate, and deep layers of the DRI model (DRI, 2019a; McGraw et al., 2016); and
5. DRI Sy distributions within the lateral extent of the model boundary (DRI assumed no vertical variation) (DRI, 2019b; McGraw et al., 2016).

3.1 Methodology

Based upon the assumption made by DRI that Sy does not vary vertically and that, over most of the Basin, the Sy is nearly uniformly high at 0.225, it appears that DRI has assumed that the majority of the Basin within the modeling domain is an unconfined aquifer.

The calculation of the total storage of groundwater (volumetric model) in the Basin model area was accomplished using the general equation:

Storage = (total saturated volume) x (Sy) .... *(Eqn. 1)*

Where:

Storage	=	Total volume of groundwater in storage [AF]
Total saturated volume	=	Volume of material saturated with groundwater [AF]
Sy	=	Specific Yield [unitless]

Complexity in the DRI model resulted from the following:

1. Vertical variation in groundwater quality by partitioning of six stacked layers within the DRI model with disparate lateral variations, divided by hydrogeologic boundaries;
2. Spatial variation in Sy; and
3. Lateral variation in groundwater quality.

The primary software used for calculating the volume was Surfer 21.2.192 (Surfer^{TM}) (Surfer). Surfer is software primarily utilized for visualizing geological, hydrological, and environmental data. Surfaces were created as GRD (grid) files by calculating grids in Surfer using XYZ data and the default kriging gridding method with point kriging type. The grid consisted of 589 rows (399.66-foot node spacing) and 501 columns (400-foot node spacing). Lateral boundaries were defined using geographic information system (GIS) shapefiles, which were projected in State Plane California Zone V (U.S. feet). The unit of X, Y, and Z data was U.S. feet. The lateral grid extents were between 6500000 and 6700000 (X) and 2300000 and 2535000 (Y) (see **Figure 13**).

The total volume of groundwater in storage in the Basin was laterally constrained to the part of the Basin within the DRI groundwater model boundary (McGraw et al., 2016). This boundary was treated as vertical for the entire model. Three zones were evaluated within this boundary (see **Figure 11** for definitions of the zones and model layers).

The highest (shallowest) zone (HGZ1 consisting of DRI model layer 1) was vertically constrained by a top boundary surface defined by a spring 2015 water table surface (the most recent data available at the time the model was built) and a bottom boundary surface. The grid file for the spring 2015 groundwater surface elevation was calculated using XYZ data from KCWA (see **Figure 14**). The grid file for the bottom boundary surface of HGZ1 (consisting of DRI model layer 1) was calculated in Surfer by extrapolating elevation data measured from three vertical cross-sections from DRI (see **Figure 15** for overview, **Figure 16** for cross-section A-A’, **Figure 17** for cross-section B-B’, **Figure 18** for cross-section C-C’, and **Figure 19** for cross-sections D-D’ and E-E’).

The middle (intermediate) zone (HGZ2 consisting of DRI model layer 2-3) was vertically constrained in the transect locations by calculating grid file boundary surfaces on top and bottom using the same cross-sections and method for the bottom of DRI model layer 1. Grids were used to extrapolate the topography of the top and bottom of DRI model layers 2 and 3 in three dimensions.

The bottom (deep) zone (HGZ3 consisting of DRI model layers 4, 5, and 6) was vertically constrained by calculating grid file boundary surfaces on top and bottom using the same cross-sections and method for the bottom of DRI model layer 1, but additionally with the measured elevations of the bottom of the additional cross-sections (see **Figure 19**).

These topographic extrapolations produced several small areas wherein the underlying and overlying layers were overlapped (i.e., the underlying layer is above the overlying layer). This is an artifact of extrapolation where empirical data is lacking. In the model’s northwestern area, the bottom layer of the model protrudes through the extrapolated topographies of the otherwise overlying layers. To correct for this, pseudo-elevation data were incorporated into the XYZ data that were used to extrapolate the topography of the overlying layers, slightly lifting them up in these areas above the layers they overlie. This resulted in slight protrusion over the overlying layers through their overlying layers (layers 2 and 3), requiring pseudo data to slightly lift these layers in these small areas as well. Similarly, a small protrusion of the model base through layer 5 in the central northern area required a slight topographic raise of layer 5. Finally, in the central southern part of the model along the border, the extrapolated bottom of layer 1 is slightly above the 2015 groundwater surface, so a pseudo datum was added to the bottom of layer 1 to lower it. The locations of pseudo data are shown as black dots encircled in red in the bottom left of **Figure 20**.

The large apparent “peak” in **Figure 20** results from the increase in elevations of that layer in the cross-sections as shown on **Figure 17** for cross-section B-B’, and **Figure 18** for cross-section C-C’. The vertical to horizontal exaggeration for **Figure 19** is approximately 25 to 1, making the "peak" appear much larger than it is in reality.

Within each of the three zones, the volume calculations reflect variations in Sy. The spatial distribution of Sy values does not vary across zones vertically. The variation in Sy is presented with color gradients ranging from red (Sy < 0.09) to blue (Sy > 0.23) (see **Figure 21**). This variation was simplified in the volume model by partitioning the model into five Sy value zones represented by red (Sy = 0.09), yellow (Sy = 0.125), green (Sy = 0.16), aqua (Sy = 0.2), and blue (Sy = 0.225). The Sy figure from the DRI model (DRI, 2018; McGraw et al., 2016) was georeferenced in ESRI™ ArcMap and shapefiles for the Sy divisions were subsequently digitized. The boundaries between these five Sy categories were treated as sharp (non-gradational) vertical boundaries.

The spatial variation in water quality (TDS concentrations) In all three zones was derived from the DRI model documentation (see **Figure 22**) (DRI, 2019a; McGraw et al, 2016). The three DRI model zones have their own unique water quality distributions. Although the original water quality figures divided TDS concentrations into four categories (< 499 mg/L, 500 to 999 mg/L, 1,000 to 4,999 mg/L, and > 5,000 mg/L), in this volumetric model the layers were laterally partitioned between fresh groundwater (TDS < 1,000 mg/L) and brackish / saline water (TDS ≥ 1,000 mg/L). Within each layer, the fresh/saline groundwater boundaries were treated as vertical.

The overlap of Sy and TDS divisions creates multiple polygons (polygons AA through BS) within the model that represent unique combinations of the two parameters within each layer. Although there were multiple areas within the same zones with the same unique Sy – TDS combination (e.g., with Sy = 0.225 and fresh water), they were partitioned into separate polygons if they were not in contact. For each model layer, a "thickness" layer was calculated by subtracting the bottom elevation grid layer from the top elevation grid layer. The polygons with unique Sy and TDS combinations were then used to isolate the respective parts of the "thickness" layers by blanking data outside of each polygon for each respective part of the layer. Polygons AA through AS were used for layer 1, AT through BD for layers 2 and 3, and BJ through BS for layers 4, 5, and 6. The volume was then calculated in Surfer for each piece of each "thickness" layer. In total, DRI model layer 1 contained 19 unique polygons, DRI model layers 2 and 3 contained 15 separate polygons, and DRI model layers 4, 5, and 6 contained 10 separate polygons. The calculated volume results were in cubic feet and were converted to acre-feet (AF) using the equation [volume in AF] = [volume in cubic feet] x [2.29568×10^{-5} AF/cubic foot] (see **Figure 23** for example from Layer 1).

3.2 Results

Figure 23 summarizes the volumes of fresh and brackish / saline water in Layer 1 (DRI model layer 1, also referred to as the "shallow zone" or HGZ1). **Figures 24** and **25** summarize the volumes of fresh and brackish / saline water in Layers 2 and 3, respectively (DRI model layers 2 and 3, also referred to as the "intermediate zone" or HGZ2). **Figures 26, 27,** and **28** summarize the volumes of fresh and brackish / saline water in Layers 4, 5, and 6, respectively (DRI model layers 4, 5, and 6, also referred to as the "deep zone" or HGZ3). **Table 1**, shown below, summarizes the volumes of fresh water and brackish / saline water for each of the DRI model zones. The values in **Table 1** have been rounded to the nearest 10,000 AF.

Table 1. Estimates of Volumes of Fresh, Brackish / Saline, and Total Water in Storage within the DRI Model Domain

DRI Model Zone	DRI Model Layer	Volume of Fresh Water in Storage (AF)	Volume of Brackish / Saline Water in Storage (AF)	Total Volume of Water in Storage (AF)
Shallow (HGZ1)	**Layer 1**	**10,970,000**	**5,810,000**	**16,780,000**
Intermediate (HGZ2)	*Layer 2*	*3,170,000*	*5,080,000*	*8,250,000*
	Layer 3	*3,160,000*	*5,080,000*	*8,240,000*
	Layer 2 + 3	**6,330,000**	**10,160,000**	**16,490,000**
Deep (HGZ3)	*Layer 4*	*6,290,000*	*7,780,000*	*14,070,000*
	Layer 5	*6,320,000*	*7,720,000*	*14,040,000*
	Layer 6	*12,060,000*	*19,980,000*	*32,050,000*
	Layer 4 + 5 + 6	**24,670,000**	**35,480,000**	**60,160,000**
Total	**All 6 Layers**	**41,970,000**	**51,450,000**	**93,430,000**

3.3 Additional Considerations

This method incorporated lateral and vertical aquifer limits and Sy values from the DRI model. However, the lateral and vertical limits of the aquifers within the DRI model do not include all water-saturated sediments within the Basin. Thus, any calculation of total groundwater in storage using such DRI limits would be an under-estimate. In general, the Sy values in the DRI model are extremely high compared to prior estimates (e.g., Kunkel and Chase, 1969) and the groundwater flow model for the Basin developed by Brown and Caldwell (2009). That is, the Sy values in the DRI model are not entirely representative of actual hydrologic conditions in the Basin and might be overestimated by 30 percent, as discussed in later methodologies, and then compared below.

4.0 Groundwater Storage Volume – Estimate 2

The TWG developed a second estimate of the total volume of groundwater (including both fresh and saline / brackish) in the Basin utilizing data from the following sources:

1. Department of Water Resources (DWR, 2022a) Basin boundary (lateral extent);
2. Hydrogeologic unit lateral and vertical extents developed by Ramboll as part of the Hydrogeologic Conceptual Framework (HCF) for IWV (Ramboll, 2019);
3. Groundwater levels from spring 2017 California Statewide Groundwater Elevation Monitoring (CASGEM) Network (DWR, 2022b); and
4. Sy distributions from several published sources including:
   - Kunkel and Chase (1969);
   - Johnson (1967); and
   - Heath (1983).

4.1 Methodology

Figure 29 shows the lateral extent of the Basin with additional area polygons identifying the extent of what is described as the Meadowbrook Dairy, and the U.S. Navy's de-designated groundwater zone (an area within the Basin that does not qualify for municipal or domestic beneficial use [TriEco TetraTech, 2012, p. ES-3]).

Surface areas for each thickness interval were determined by georeferencing figures from Ramboll's HCF report (Ramboll, 2019), and then creating GIS shapefiles to calculate the area of each thickness interval. **Figure 30** shows the extent and thicknesses of the hydrogeologic units in Hydrogeological Zone 1 (HGZ1). HGZ1 would roughly be comparable to Layer 1 (shallow zone) in the DRI model. In this model, the HGZ1 area included the El Paso Area. **Figure 31** shows the extent and thicknesses of the hydrogeologic units in HGZ2. HGZ2 would roughly be comparable to Layers 2 and 3 (intermediate zone) in the DRI model. **Figure 32** shows the extent and thicknesses of the hydrogeologic units in HGZ3. HGZ3 would roughly be comparable to Layers 4, 5, and 6 (deep zone) in the DRI model.

For HGZ1, the average depth to water level within each of the thickness intervals was determined using the Spring 2017 CASGEM data. The average depth to water was subtracted from the high- and low-end thickness intervals. Sy values within this interval were estimated from Kunkel and Chase (1969) ranging from a low of 0.09 to a high of 0.13.

For HGZ2, the entire unit was assumed to be saturated. Sy values were determined based on the general lithologic descriptions included in Ramboll (2019). HGZ2 was described as finer lacustrine sediments, primarily clays and silts, with interbedded sands and gravels. Johnson (1967) reported average Sy values of 0.02 for clays, and 0.08 for silts.

For HGZ3, the entire unit was assumed to be saturated. Specific yield values were determined based on Heath (1983) which reported a Sy value of 0.22 for sand and 0.19 for gravel.

4.2 Results

On the basis of the unit thicknesses, their associated areas, and the range of Sy values for each HGZ, estimates for the volumes of water in each layer within each HGZ were prepared. **Tables 2, 3,** and **4** below summarize the estimated volumes of water within HGZ1, HGZ2, and HGZ3, respectively. The values in **Tables 2, 3,** and **4** have been rounded to the nearest 10,000 AF.

Table 2. Estimates of Volume of Water within HGZ1

HGZ1 Thickness Intervals (feet)			Saturated Thickness (feet)		Area (acres)	Specific Yield (Sy)		Storage (AF)	
Low	High	Average DTW (feet bgs)	Low	High	Area (acres)	Low	High	Low	High
328	500	224	104	276	100,000	0.09	0.13	940,000	3,590,000
164	328	143	21	185	100,000	0.09	0.13	190,000	2,410,000
82	164	93	0	71	66,000	0.09	0.13	0	610,000
0	82	122	0	0	17,000	0.09	0.13	0	0
Total					**283,000**			**1,130,000**	**6,610,000**

Notes: DTW – depth to water; bgs – below ground surface

Table 3. Estimates of Volume of Water within HGZ2

Aquifer Thickness (feet)	Area (acres)	Specific Yield (Low)	Specific Yield (High)	Storage–- Low (AF)	Storage–- High (AF)
>984	61,000	0.02	0.08	1,200,000	4,800,000
656 – 984	54,000	0.02	0.08	710,000	4,250,000
328 – 656	50,000	0.02	0.08	330,000	2,620,000
0 – 328	32,000	0.02	0.08	0	840,000
Total	**197,000**	**0.02**	**0.08**	**2,240,000**	**12,510,000**

Table 4. Estimates of Volume of Water within HGZ3

Aquifer Thickness (feet)	Area (acres)	Specific Yield (Low)	Specific Yield (High)	Storage – Low (AF)	Storage – High (AF)
>984	95,000	0.19	0.22	17,760,000	20,570,000
656 – 984	57,000	0.19	0.22	7,100,000	12,340,000
328 – 656	30,000	0.19	0.22	1,870,000	4,330,000
0 – 328	14,000	0.19	0.22	0	1,010,000
Total	**196,000**	**0.19**	**0.22**	**26,730,000**	**38,250,000**

Table 5 summarizes the estimated range of water volumes within each HGZ and the total volume within the Basin.

Table 5. Estimates of Volume of Water within Each HGZ and the Basin

HGZ	Area (acres)	Storage – Low (AF)	Storage – High (AF)
1	283,000	1,130,000	6,610,000
2	197,000	2,240,000	12,510,000
3	196,000	26,730,000	38,250,000
Total	**676,000**	**30,100,000**	**57,370,000**

4.3 Additional Considerations

The method described above only calculated groundwater in storage for the China Lake Area of the Basin and did not include estimates for the El Paso Area (except HGZ1). Thus, the actual total groundwater in storage in the entire Basin is greater than the figures shown in **Table 5**.

5.0 Groundwater Storage Volume – Estimate 3

The TWG developed a third estimate of the volumes of groundwater in storage (including fresh, brackish / saline, and total) using the updated Ramboll HCF (2024). The steps taken to develop the groundwater volume estimates using this methodology were as follows:

1. Update the HCF including depths and extents of each layer that formed a unique HGZ representing the lithologies in the Basin;
2. Estimate areas and volumes associated with each HGZ in the Basin;
3. Estimate the percentage net sand in each of the HGZs;
4. Estimate the total volume of material in each HGZ, including net sand volumes and mixed/fines volumes;
5. Tabulate a range of Sy values for clay, mixed sand and clay, fine sand, medium sand, and sand and gravel;
6. Estimate the total volume of groundwater in storage in each HGZ on the basis of the minimum and maximum values for the Sy ranges; and
7. Using existing water quality data for the Basin, estimate the volumes of groundwater in each HGZ that would be considered fresh, and brackish / saline.

5.1 Methodology

5.1.1 Updating the Hydrogeological Conceptual Framework (HCF)

The calculation of storage in the Basin for Estimate 3 is based upon the three-dimensional (3D) HCF model geometry and HGZs produced for the Brackish Groundwater Resources Feasibility Study (Ramboll, 2019), as modified based on the following discussion.

For the hydrogeological conceptual framework model (HCF), four different hydrogeologic zones (HGZs) were mapped. HGZ1 is predominantly unconsolidated sand and gravel with interbedded thinner clayey layers, and is considered to be unconfined. HGZ2, which lies below HGZ1, consists predominantly of unconsolidated clayey sediments, with interbedded productive sands and gravels, and is generally considered to be an aquitard. HGZ3 consists predominantly of unconsolidated sand and gravel, situated underneath HGZ2, though like HGZ1 can have clayey layers interbedded with the sand and gravel deposits as well as mixed lithology. This aquifer is confined where HGZ2 is present, but is unconfined where HGZ1 directly overlies HGZ3. HGZ4 consists of the semi-consolidated to consolidated fluvial, lacustrine, and volcanic rocks of the Ricardo Group, and predominantly alluvial gravel, sand, and clay of the Goler Formation.

Since the development of the hydrogeological conceptual framework (HCF) for the basin in 2019 (Ramboll, 2019), new data have become available. Specifically, parts or all of 12 seismic lines have been reprocessed by Collier Geophysics (Collier Geophysics, 2021 and 2023), transforming time to depth using sonic logs, identifying faults, the Basin bedrock bottom (Basement), and where possible, the surfaces of the HGZs. In addition, well completion reports and one newly installed monitoring well (EP-1) with lithology descriptions and a geophysical log have been added to the database.

The reprocessed seismic lines used in the update of the HCF are shown on **Figure 33**. These seismic lines provide more detailed information on the Basin Basement, as well as the top of HGZ3 and HGZ4. The interpretation of the seismic sections is based upon the few wells that extended into the Basement (Snort 1, Snort 2 and TGCH 1) and correlated between the lines. In addition, the results Monastero et al. (2002) were used in the interpretation of the top of HGZ4 and Basement.

The El Paso Area had the greatest amount of modification during the update. The reprocessed seismic sections showed that the basement in this part of the Basin was much deeper on the west side than previously modeled. A better constraint on the boundary between HGZ3 and HGZ4 was also obtained from the reprocessed seismic data interpretation.

Figure 34 shows the elevation of the bottom of the basement. **Figure 35** contains two cross-sections illustrating the updated HCF. Cross-section A-A’ crosses the entire basin from the southwest to the northeast. On this cross-section, the high basement separating the China Lake and the El Paso Areas is easily seen. In addition, A-A’ shows how HGZ2 thins and disappears to the northeast of the basement high, then thickening again towards the center of the basin around the playa lake. Cross-section B-B’ in **Figure 35** shows the HCF from west to east in the China Lake Area, where HGZ2 is not present in the western part of the basin, though quickly thickening towards the center of the basin. HGZ1 is relatively thin in the El Paso Area as well as in the playa lake portion in the center and eastern part of the China Lake Area. **Figure 36** shows the interpreted seismic section 92-02.

The total area and volume for each HGZ is presented in **Table 6**. The geometry and total varying thickness of the Basin is shown on **Figure 37**, and the thicknesses of each HGZ is shown on **Figure 38**. Note that a minimum thickness of 3 feet for each HGZ unit was used in the volume calculations. The 3-foot minimum was applied for both the distribution and volume of each HGZ, providing a more conservative estimate of the area and volume for each HGZ. This conservative approach takes into account the uncertainties associated with the interpolation of the HGZ surface boundaries in the model.

HGZ1 represents the unconfined aquifer in the Basin. To estimate the amount of groundwater storage capacity available, it is necessary to calculate the thickness of the unsaturated zone so that it can be removed from the total volume. This is done using water level measurements recorded in the wells. This data is supplemented with information on the water table as mapped out from the AEM data collected in 2017. The water level measurements from October 2017 were used to produce the water level map since these data correlate with the collection of the AEM data, providing the best geographic coverage across the basin. These two sources are combined and interpolated into a 100-meter square grid covering the entire Basin, providing an elevation for the water table. The unsaturated zone was thereafter removed from the total Basin volume calculations, resulting in calculations for the saturated sediments only, noting that water levels continued to decline resulting in a slight overestimate of total groundwater in storage.

The total area and volume for each HGZ is presented in **Table 6**.

Table 6. Total Area and Thickness of the HGZs

HGZ	Area (acres)	Area For Volume Calculation (acres)[1]	Total Volume (AF)[2]
HGZ1 total	294,000	279,000	89,200,000
HGZ1 saturated	*213,000*	*213,000*	*38,600,000*
HGZ2	350,000	293,000	172,500,000
HGZ3	352,000	282,000	332,300,000
HGZ4	383,000	268,000	460,800,000
Total Basin Volume			**1,054,800,000**
Total Saturated Basin Volume			***1,004,200,000***

Notes:
1. A minimum thickness of 3 feet for each HGZ unit was used in the volume calculations.
2. Area rounded to the nearest 1,000 acres and volume rounded to nearest 100,000 AF. HGZ1 is split up into total volume and saturated volume.

5.1.2 Determining the Percentage of Net Sand and Net Clay

Net sand and net clay for each hydrogeologic zone is calculated from available detailed well completion report lithologic descriptions and available geophysical logs for HGZ-1 and HGZ-2, and from the reprocessed seismic lines for HGZ-3 and HGZ-4. This information is used to qualitatively assess the appropriate specific yield range for each HGZ. To determine the percentage sand from the lithology logs, the lithologic descriptions are divided into three categories: coarse, mixed sediments, and fine. Coarse sediments include descriptions where sand, gravel or cobble is the descriptor in the lithology logs. Fine sediments include descriptions where clay and silt are the descriptors. Mixed lithology has both coarse and fine sediments in the descriptor. The well lithologic data are supplemented with interpretation of 61 geophysical logs, where the resistivity logs are used to determine where the layers consist of predominantly sand (resistivities over 30 ohm-m). In areas where total dissolved solids (TDS) are above 1,000 mg/L, the resistivity is too greatly influenced by the salinity and not included in the analysis. **Figure 39** shows an example of how the lithology and the resistivity logs are interpreted. In cases where there are different totals between the lithology and resistivity logs, an evaluation is made based upon the quality of the lithology descriptions. In the case shown on **Figure 39**, there is a highly detailed lithologic description from a cored hole which was used to record the total coarse materials in the hydrogeological zones.

For each well analyzed, the percentage net sand and net clay within the hydrogeologic zone is recorded. The net sand values presented include the percentage of the well lithology description that contain only sand and/or gravel. The net clay values include the percentage of the well lithology description that contain only clay and silt. Lithologies with sand or gravel as the primary and silt or clay as a secondary descriptor in the lithology log description are not included in net sand. The reverse is also true for mixed clay.

The percentage net sand and net clay within a hydrogeologic zone vary spatially. To illustrate this, the percentage net sand is interpolated to a one-mile square grid. From this, a map of the thickness of the net sand for each one-mile grid is created for HGZ1 and HGZ2, which most wells penetrate. Maps showing the net sand for HGZ1 and HGZ2 are shown on **Figure 40** and **Figure 41**. Data from HGZ3 and HGZ4 are sparse and insufficient to estimate net sand from the well information, and instead reprocessed seismic data were used.

Figure 40 shows the results of the calculated net sand for HGZ1, presented as an average distributed in a one-mile square grid. Areas without one-mile squares have no well data providing information on the net sand. Net sand in HGZ1 is generally over 40%, with a Basin-wide average of 52%. The observed net sand values vary significantly across the Basin, with a tendency of higher net sand values to the west, closer to the Sierra Nevada Frontal Fault and in the center of the Basin west of Ridgecrest. Note the sparse well data in the El Paso Area and in the northeastern part of the Basin.

Figure 41 shows the results of the calculated net sand for HGZ2. As expected, there is a lower percentage of net sand in HGZ2, with a Basin-wide average of 23%. However, values do vary significantly over short distances. This is illustrated in the area around Ridgecrest where there are adjacent one-mile squares with net sand varying from less than 20% to over 80%. This underscores the variability of the sand lenses within HGZ2 which are very difficult to model in the HCF. Like for HGZ1, there is sparse well data in the El Paso Area and in the northeastern part of the Basin.

Table 7 shows the average percent net sand, mixed lithology and net clay calculated for HGZ1 and HGZ2. These are based solely on the lithology descriptions and borehole logs. Note that for HGZ2, which is dominated by finer sediments, the net clay is lower than the net sand. However, HGZ2 is dominated by mixed lithology, comprising 62% of the total in the basin. Upon closer review of the lithological descriptions in the wells, most of the descriptions with mixed lithology have clay or silt as the primary descriptor (i.e. sandy clay), and thus there is observed a tendency towards finer sediments in mixed lithology.

Table 7. Calculation of the Percent Net Sand, Mixed Lithology and Net Clay for HGZ1 and HGZ2

HGZ	Net Sand (%)	Mixed (%)	Net Clay (%)
HGZ1	54.7	40.6	4.7
HGZ2	22.8	62.0	15.2

Note: There are not enough wells that penetrate HGZ3 and HGZ4 to calculate the volumes for these zones based upon well data

The net sand and net clay calculated from the reprocessed seismic sections (Collier Geophysics, 2021 and 2023) is used to assess the appropriate range of specific yield values for HGZ3 and HGZ4. The technique used in this study is commonly applied in the oil and gas industry to identify potential reservoirs. This analysis mapped the percentage of net sand units along the reinterpreted seismic lines. **Figure 42** provides shows an example from line 92-02, which shows the net sand along the seismic section. **Figure 43** illustrates the net clay along the same section. These results are presented in **Table 8**. The variability between the different seismic lines is not as great as what is observed in HGZ1 and HGZ2. However, it is noted that in HGZ3 where HGZ2 is not present, the net sand content increases. This can be seen in the averages for lines 92-02 and 00-07, which are higher than the other lines, and cross this zone. It needs to be noted that the seismic lines were collected to capture the deeper sediment, and thus there is poor resolution above approximately 100 mS (the upper 100-150 meters; Collier Geophysics, 2023). Thus, the net sand and net clay for HGZ1 and HGZ2 was not estimated from the seismic sections.

Table 8. Calculated Net Sand in HGZ3 and HGZ4, Averaged for Each Seismic Line (Collier Geophysics, 2021 and 2023)

Line	Net Sand in HGZ3 (%)	Net Sand in HGZ4 (%)	Net Clay in HGZ3 (%)	Net Clay in HGZ4 (%)
82-01	7.3	10.1	52.6	53.1
88-02	9.3	8.6	46.8	49.0
88-08	12.6	9.3	53.6	59.3
88-01	9.9	13.8	63.6	58.2
88-07	14.3	9.5	45.5	52.7
88-05	13.4	15.8	56.5	54.7
88-04	15.1	17.9	56.4	48.4
82-03	11.7	10.6	46.1	45.8
92-01	13.2	13.9	48.4	49.4
00-07	23.3	15.7	26.3	33.7
92-02	18.9	11.1	34.6	37.7
00-06	16.6	4.1	44.5	66.4
Average	**13.8**	**11.7**	**47.9**	**50.7**

Note: The location of the seismic lines is shown on **Figure 19**.

Table 9 shows the saturated volumes for each HGZ, divided into calculated net sand, calculated mixed, and fines.

Table 9. Calculation of the Total Volume, Net Sand Volume and Mixed/Fines (Lithology with Mixed with or Only Containing Silt and/or Clay) for Each HGZ

HGZ	Total Volume (AF)	Net Sand Volume (AF)	Mixed Volume (AF)	Net Clay Volume (AF)
HGZ1	38,600,000	21,100,000	15,700,000	1,800,000
HGZ2	172,500,000	39,300,000	107,000,000	26,200,000
HGZ3	332,300,000	45,800,000	127,300,000	159,200,000
HGZ4	460,800,000	53,900,000	173,300,000	233,600,000

Note: The volumes for HGZ1 are saturated volumes only.

5.1.3 Specific Yield and Storativity

There is limited direct empirical data on Sy obtained from previous studies on the Basin, although previous studies do make Sy assumptions based on observations. Thus, there is uncertainty with regards to the Sy that should be used to calculate groundwater in storage. However, there have been studies that have looked at Sy for the different sediment types, where ranges of Sy have been compiled. The United States Geological Survey (USGS) conducted a thorough study of Sy from different sediment types at numerous locations in California (USGS, 1967). The study produced a range of values for the different sediment types, and are shown in **Table 10**. These values correspond well with the values reported from other general studies, including Heath (1983) and Robson (1993). The values also correspond with the values from the Basin, as reported by Kunkel and Chase (1969).

Table 10. Range of Specific Yield from USGS (1967)

Sediment	Sy Minimum	Sy Maximum
Clay	0.01	0.10
Mixed Sand and Clay	0.04	0.12
Fine Sand	0.10	0.32
Medium Sand	0.15	0.32
Sand and Gravel	0.15	0.25

To accommodate for a range in Sy, total groundwater in storage was calculated using a maximum and minimum value. The percentage net sand for each HGZ has been calculated. For the portion of the HGZ that is net sand, the value for Sy used corresponds to sand and gravel. For the portion of the HGZ that is mixed and fines, the values for mixed sand and clay is used. Thus, the Sy used for each HGZ is simply:

[(% net sand) x (Sy sand and gravel)] + [(% mixed and fines) x (Sy mixed sand and clay)] *(Eqn. 3)*

Where:

% net sand	=	percentage of sand in HGZ unit being considered [%]
Sy sand and gravel	=	specific yield of sand and gravel of HGZ unit [unitless]
% mixed and fines	=	percentage of mixed sand and clay in HGZ unit being considered [%]
Sy mixed sand and clay	=	specific yield of mixed sand and clay of HGZ unit [unitless]

These values for HGZ1 and HGZ2 have been placed into the one-mile square grid based upon the net sand calculations and averaged out for HGZ3 and HGZ4. The result is an average Sy that includes the ranges for both net sand and the mixed materials in the HGZs.

Storativity used to calculate the storage in the confined aquifers is calculated on the one-mile grid. A review of the resulting storage coefficient for the one-mile square grid shows a range of between 1×10^{-3} to 1×10^{-6}, which correspond well with the values estimated by Dutcher and Moyle (1973).

5.2 Results

For the calculations, the Basin has been divided up into one-mile square grids. This is done to provide a spatial distribution of storage volume throughout the Basin. For each one-mile square, there is an average thickness divided up into net sand thickness and mixed/fines thickness. The minimum and maximum values for Sy are based upon the range of Sy for sand and gravel, as presented in **Table 10**. For the mixed and fines, the Sy used was 0.08 for HGZ1 and HGZ3, as the non-net sand sediments in these zones is dominated by mixed lithologies. For HGZ2, the lithological logs indicate a greater predominance of clay, and thus an Sy of 0.06 is used to account for the higher content of clay in the zone. **Table 11** shows the range of Sy for HGZ1, HGZ2, and HGZ3. For HGZ4, the zone is semi-consolidated to consolidated; thus, Sy is set with a range of 0.06 to 0.10 to accommodate for the lower Sy observed in consolidated materials (Heath, 1983).

The totals for the minimum and maximum total groundwater in storage are shown in **Table 12**. Total groundwater in storage is greatest in HGZ1 and HGZ3, as HGZ1 is unconfined and HGZ3 is partially unconfined. HGZ2 and HGZ4 have lower storage volume estimates since both are confined aquifers. The values in **Tables 11,** and **12** have been rounded to the nearest 100,000 AF.

Table 11. Calculated Total Groundwater in Storage for Each HGZ

HGZ	Saturated Volume (AF)	SY Range	Minimum (AF)	Maximum (AF)
HGZ1	38,600,000	0.12 – 0.17	4,600,000	6,600,000
HGZ2	172,500,000	0.08 – 0.10	13,800,000	17,200,000
HGZ3	326,200,000	0.12 - 0.14	39,100,000	45,700,000
Subtotal	537,300,000	0.11 – 0.13	57,500,000	69,500,000
HGZ4	460,800,000	0.06 – 0.10	27,600,000	46,100,000
Total	**998,100,000**	**0.09 – 0.12**	**85,100,000**	**115,600,000**

The totals are also divided up for the China Lake Area and El Paso Area, shown in **Table 12**.

Table 12. Minimum and Maximum Total Groundwater in Storage Values Divided up by Basin Area

HGZ	Minimum (AF)		Maximum (AF)	
	China Lake	El Paso	China Lake	El Paso
HGZ1	4,300,000	300,000	6,200,000	400,000
HGZ2	10,400,000	3,400,000	13,100,000	4,100,000
HGZ3	32,700,000	6,400,000	38,100,000	7,600,000
Subtotal HGZ1-3	47,400,000	10,100,000	57,400,000	12,100,000
HGZ4	15,900,000	11,700,000	26,500,000	19,600,000
Total	**63,300,000**	**21,800,000**	**83,900,000**	**31,700,000**

Total groundwater in storage across the Basin is not evenly distributed. Thus, the distribution of the groundwater in storage for each HGZ represented in each one-mile square in the grid has been calculated.

Figure 44 shows the distribution of minimum storage for HGZ1. This shows that there is a larger volume of total groundwater in storage in the center of the Basin, just west of Ridgecrest, as well as an area with larger volume of total groundwater in storage adjacent to the Coso Range in the northern part of the basin. The area of larger groundwater storage volume in the northern part of the basin corresponds with what has been interpreted as a buried channel or delta observed in the AEM data, which appears to contain fresh water (Ramboll, 2019). In contrast, there is less groundwater in storage in the El Paso Area as well as the eastern portion of the China Lake Area. In both areas, HGZ1 is relatively thin, and particularly in the El Paso Area, nearly completely unsaturated.

Figure 45 shows the distribution of the minimum calculated total groundwater in storage for HGZ2. In the northwestern part of the basin continuing in a band towards Ridgecrest, HGZ2 is relatively thin to not present, and thus total groundwater storage in HGZ2 is limited there. Total groundwater storage in HGZ2 is greatest in the center of the basin.

Figure 46 shows the distribution of the minimum groundwater in storage for HGZ3 and **Figure 47** shows the distribution of the minimum groundwater in storage for HGZ4.

The totals for the median of the total groundwater in storage are also divided up with regards to water quality. The available TDS data was contoured, with the one-mile square grid for each HGZ divided up into the following water quality zones:

- TDS under 1,000 mg/L, representing fresh groundwater resources;
- TDS from 1,000 – 3,000 mg/L, representing transitional groundwater resources; and
- TDS over 3,000 mg/L, representing brackish and saline groundwater resources.

There is no available data for HGZ4 and thus the totals for HGZ3 were used for HGZ4. However, this indicates a high amount of uncertainty associated with the water quality in HGZ4 and the totals should be considered with caution. The groundwater in storage totals with respect to water quality are presented in **Table 13**. The volume of groundwater with TDS values of under 1,000 mg/L across the Basin is shown on **Figure 48**.

The volumes in **Table 13** should not be interpreted as available in their entirety to meet water-supply demands; complete dewatering of any aquifer is environmentally undesirable. The recoverable groundwater in storage is determined on the basis physical, water quality, economics, environmental, and institutional factors (DWR 2003), including the potential for undesirable impacts, and has not yet been determined.

Table 13. Minimum and Maximum Storage Value for Each HGZ, Divided Up Into Water Quality Zone, with Respect to Total Dissolved Solids (TDS) Concentrations

HGZ	Minimum Groundwater in Storage Considering Water Quality (AF)			Maximum Groundwater in Storage Considering Water Quality (AF)		
	Under 1,000 mg/L	1,000-3,000 mg/L	Over 3,000 mg/L	Under 1,000 mg/L	1,000-3,000 mg/L	Over 3,000 mg/L
HGZ1	3,500,000	400,000	700,000	5,000,000	600,000	1,000,000
HGZ2	6,700,000	300,000	6,800,000	8,400,000	300,000	8,500,000
HGZ3	19,700,000	800,000	18,600,000	22,900,000	900,000	21,900,000
Subtotal HGZ1-3	*29,900,000*	*1,500,000*	*26,100,000*	*36,300,000*	*1,800,000*	*31,400,000*
HGZ4	15,200,000	900,000	11,500,000	25,500,000	1,300,000	19,300,000
Total	**45,100,000**	**2,400,000**	**37,600,000**	**61,800,000**	**3,100,000**	**50,700,000**

5.3 Additional Considerations

The storage calculations conducted in Estimate 3 are based upon the revised HCF model, which has been developed using the best available science and most recent data, including the AEM data collected in 2017 and the recently reprocessed seismic lines. Net sand has been calculated from the wells and seismic sections, providing the best available total and net sand volume calculations in the basin, which helped in selecting the range of specific yield values to use for the total groundwater in storage calculations. That said, there is still a significant amount of uncertainty associated with the groundwater storage calculations.

A large amount of the uncertainty in the groundwater storage calculations lies with the limited availability of direct empirical data on specific yield for the sediments in the IWV Basin. There have been only a few specific yield values that have been determined directly through aquifer testing, with none calculated from wells in the El Paso Area of the basin. Because of this uncertainty, a range for specific yield based the UGSG report (USGS 1967) was used. This range is large and resulted in a difference of a factor of 2.4 between the minimum and maximum calculated total groundwater in storage. Empirical data on Sy for the different sediment types in the Basin, calculated from appropriately designed and executed aquifer tests would help refine the values for specific yield.

There is also high uncertainty associated with the water quality in the deeper zones, particularly HGZ4, as well as in the El Paso Area as a whole. Collecting more water quality samples from the deeper zones basin-wide and the central and southern portion of the El Paso Area would be useful to determine if the water quality in these zones is adequate for potable supply.

6.0 Discussion

Table 14 summarizes the key differences between the three groundwater storage estimates including differences in the following:

- Methodology Used;
- Areas Considered;
- Number of HGZs Considered; and
- Volumes Considered.

As a result of these key differences, a direct comparison between all three estimates is not possible. However, some notable and supportable conclusions can be reached regarding the volume estimates.

Table 14. Key Differences Between the Three Groundwater Storage Estimates

Key Difference	Estimate 1	Estimate 2	Estimate 3
Methodology	DRI Model Boundary KCWA 2015 Water Levels DRI Vertical Cross-Sections DRI TDS Concentrations DRI Sy Distributions	DWR Basin Boundary Ramboll HGZ CASGEM 2017 Water Levels Literature Sy	DWR Basin Boundary Revised HGZs (Added HGZ4) Net Sand / Mixed / Fines Literature Sy DRI TDS Concentrations
Areas Considered	China Lake & El Paso Areas	China Lake Area	China Lake & El Paso Areas
Number of HGZ	3	3	4
Volumes Considered	Total, Fresh, Brackish	Total	Total, Fresh, Transitional, Brackish

6.1 Total Groundwater in Storage

Table 15 compares the total volumes of groundwater in storage, noting that Estimate 2 did not consider the volume stored in the El Paso Area, and Estimate 3 included an additional deeper HGZ4 volume that was not included in the other estimates.

Average values can be calculated for the three methods used to estimate total groundwater in storage for HGZ1 through HGZ3, noting that Estimate 2 did not consider the groundwater in the El Paso Area. While there is uncertainty in each of the three groundwater volume estimates, and differences in volumes that resulted from the different methodologies utilized, averaging the three estimates provides a "middle" range that more likely represents actual groundwater volumes within the Basin. Differences between the volume estimates for each of the methodologies is discussed below in **Section 6.3**. The averages for the three methods indicate the following:

- The total groundwater in storage in HGZ1 and HGZ2 is approximately **21,870,000 AF**. This groundwater is readily accessible using existing wells or new wells screened within these zones.

Additional infrastructure (i.e., wells, pumps, pipelines) may be needed to access some of this groundwater; and

- The total groundwater in storage in HGZ1 through HGZ3 is approximately **66,890,000 AF**. This groundwater is accessible but additional infrastructure (i.e., wells, pumps, pipelines) would be needed to access some of this groundwater, notably in HGZ3.

Table 15. Total Groundwater Volumes in Storage by Estimate and HGZ

HGZ	Type	Estimate 1	Estimate 2		Estimate 3		Average of Methods
		Value [AF]	Low [AF]	High [AF]	Low [AF]	High [AF]	Value [AF]
HGZ1	Range	---	1,130,000	6,600,000	4,600,000	6,600,000	---
	Average	16,780,000	3,870,000		5,600,000		8,750,000
HGZ2	Range	---	2,240,000	12,520,000	13,800,000	17,200,000	---
	Average	16,490,000	7,380,000		15,500,000		13,120,000
HGZ3	Range	---	26,740,000	38,240,000	39,100,000	45,700,000	---
	Average	60,160,000	32,490,000		42,400,000		45,020,000
Sub-Total	**Range**	**---**	**30,110,000**	**57,370,000**	**57,500,000**	**69,500,000**	**---**
	Average	**93,430,000**	**43,740,000**		**63,500,000**		**66,890,000**
HGZ4	Range	---	---		27,600,000	46,100,000	---
	Average	---	---		**36,850,000**		**---**
Total	Range	---	---		**85,100,000**	**115,600,000**	---
	Average	---	---		**100,350,000**		**---**

Note: Estimate 2 only considered the volume stored in the Main Basin (China Lake) and excluded the El Paso Area.

6.2 Fresh and Brackish / Saline Groundwater in Storage

Table 16 compares the estimated volumes of groundwater in each HGZ that are considered “fresh”, with a TDS concentration of less than 1,000 mg/L, and “brackish / saline”, with a TDS concentration of greater than or equal to 1,000 mg/L.

Average values can be calculated for the two methods used to estimate fresh and brackish/saline water in storage for HGZ1 through HGZ3. The averages for the two methods indicate the following:

- The total fresh groundwater in storage in HGZ1 and HGZ2 is approximately **14,550,000 AF**. This groundwater is readily accessible using existing wells or new wells screened within these zones. Additional infrastructure (i.e., wells, pumps, pipelines) may be needed to access some of this groundwater.

- The total fresh groundwater in storage in HGZ1 through HGZ3 is approximately **37,530,000 AF**. This groundwater is accessible but additional infrastructure (i.e., wells, pumps, pipelines) would be needed to access some of this groundwater, notably in HGZ3.

Table 16. Total Fresh and Brackish / Saline Groundwater Volumes in Storage by Estimate and HGZ

HGZ	Type	Estimate 1		Estimate 3				Average of Methods	
		Fresh [AF]	Brackish [AF]	Fresh [AF]		Brackish [AF]		Fresh [AF]	Brackish [AF}
HGZ1	Range	---	---	3,500,000	5,000,000	1,100,000	1,600,000	---	---
	Average	10,970,000	5,810,000	4,250,000		1,350,000		7,610,00	3,580,000
HGZ2	Range	---	---	6,700,000	8,400,000	7,100,000	8,800,000	---	---
	Average	6,330,000	10,170,000	7,550,000		7,950,000		6,940,000	9,060,000
HGZ3	Range	---	---	19,700,000	22,900,000	19,400,000	22,800,000	---	---
	Average	24,670,000	35,480,000	21,300,000		21,100,000		22,990,000	28,290,000
Sub-Total	**Range**	**---**	**---**	**29,900,000**	**36,300,000**	**27,600,000**	**33,200,000**	**---**	**---**
	Average	**41,970,000**	**51,460,000**	**33,100,000**		**30,400,000**		**37,530,000**	**40,930,000**
HGZ4	Range	---	---	15,200,000	25,500,000	12,400,000	20,600,000	---	---
	Average	---	---	20,350,000		16,500,000		---	---
Total	Range	---	---	**45,100,000**	**61,800,000**	**40,000,000**	**53,800,000**	---	---
	Average	---	---	**53,450,000**		**46,900,000**		---	---

Note: Estimate 2 did not differentiate between fresh groundwater and brackish / saline groundwater. As a result, the average values in this table are based upon Estimate 1 and Estimate 3, and the sum of the fresh and brackish / saline averages do not equal the total averages shown in **Table 15** that are based upon all three estimates.

6.3 Groundwater Volume Differences Between the Various Methodologies

Specific yield (Sy) is one of the key drivers for differences between the various volume estimates. For Estimate 1, the assumed Sy in the DRI model is relatively high and likely unrepresentative. A value of approximately 0.225 was utilized across the majority of the model domain. This factor, coupled with vertical homogeneity across all model layers, suggests that Estimate 1 overestimates the volume of groundwater in storage within the Basin. The Sy for Estimate 2 varied from 0.02 to 0.19 in the "Low" scenario, and 0.08 to 0.22 in the "High" scenario. The Sy for Estimate 3 varied from 0.08 to 0.12 in the "Low" scenario, and 0.10 to 0.17 in the "High" scenario. Since Estimate 2 and Estimate 3 uses ranges of Sy values, volume of groundwater in storage is expected to fall somewhere near the middle of the ranges.

Table 17 summarizes the results for when the Estimate 1 methodology is reworked utilizing the Sy ranges from the Estimate 2 and Estimate 3 methodologies. Using the Estimate 2 Sy ranges, within the Estimate 1 model framework the total volume of groundwater ranges between a low of approximately 64,900,000 AF to a high of approximately 81,690,000 AF. This range is between 69 percent and 87 percent of the baseline Estimate 1 total volume of approximately 93,400,000 AF. Using the Estimate 3 Sy ranges, within the Estimate 1 model framework the total volume of groundwater ranges between a low of approximately 53,100,000 AF to a high of approximately 62,700,000 AF. This range is between 57 percent and 67 percent of the baseline Estimate 1 total volume of approximately 93,400,000 AF.

Table 17. Total Groundwater Storage Volumes Using Estimate 1 Methodology with Different Sy

HGZ	Estimate 1	Using Estimate 2 Sy Ranges		Using Estimate 3 Sy Ranges	
	[AF]	Low [AF]	High [AF]	Low [AF]	High [AF]
HGZ1	16,780,000	7,040,000	10,180,000	9,390,000	13,300,000
HGZ2	16,490,000	1,580,000	6,350,000	8,170,000	7,950,000
HGZ3	60,160,000	56,280,000	65,160,000	35,540,000	41,470,000
Total	**93,430,000**	**64,900,000**	**81,690,000**	**53,100,000**	**62,720,000**

A second key driver for differences between the various groundwater volume estimates is differences in lithological assumptions utilized in the three estimate models. **Figure 49** shows a comparison in lithologies for a similar cross-section between Estimate 1 and Estimate 3. While the HGZs in the Estimate 1 cross-section are, for the most part, of uniform thickness along the cross-section, there are significant changes in all three HGZ thicknesses along the cross-section in the Estimate 3 cross-section.

These lithological layer thickness and extent differences, coupled with the Sy differences described above, will result in groundwater volumes that vary (in some cases significantly) between the three methodologies utilized above.

6.4 Estimated Groundwater Volumes Compared To The GSP

The Groundwater Sustainability Plan (GSP) for the Basin (Indian Wells Valley Groundwater Authority [IWVGA], 2020, p. 3-26) refers to and utilizes the 1993 United Stated Bureau of Reclamation (USBR) estimated groundwater volume of 2,370,000 AF as "available groundwater in storage". The GSP then estimates the remaining groundwater in storage as of 2017 as 1,750,000 AF. This value is likely a gross underestimation of the remaining groundwater within the Basin for the reasons illustrated above.

Based on the three methodologies described in this paper, the total estimated average volumes of "fresh" groundwater remaining in the Basin are approximately 7,610,000 AF in HGZ1 and 6,940,000 AF in HGZ2, for a combined total of approximately 14,550,000 AF. These volume estimates are 4.3 times larger than the GSP value for HGZ1, 4.0 times larger for HGZ2, and 8.3 times larger for both HGZ1 and HGZ2 combined.

7.0 Conclusions

A TWG of qualified groundwater professionals representing parties that pump more than 80 percent of the groundwater in the Indian Wells Valley Groundwater Basin conducted a series of analyses to estimate the total amount of groundwater and usable groundwater in storage. This effort required defining the physical parameters of the Basin, including its geologic and hydrologic characteristics. Three separate methodologies were considered, and the following conclusions can be drawn from this work as further described below.

1. Regardless of which estimating methodology is used, given the size of the Basin (area and depth of lithologies), the volume of groundwater in storage is large, ranging from a low of approximately **30.1 million AF** (excluding the El Paso Area) to a high of **115.6 million AF** (including HGZ4) (see **Table 15**). Using the average of the three methods approximately **21.9 million AF** of total groundwater in storage is readily accessible in HGZ1 and HGZ2. Under the average of the three methodologies, an additional **45.0 million AF** of total groundwater in storage is available within HGZ3, for a total of **66.9 million AF** available in HGZ1 through HGZ3.
2. There is a substantial volume of fresh water within the Basin ranging from a low of approximately **42.0 million AF** to a high of **61.8 million AF** (see **Table 16**). Using the average of Estimates 1 and 2, approximately **14.5 million AF** of fresh groundwater in storage is readily accessible in HGZ1 and HGZ2 and an additional **23.0 million AF** of fresh groundwater in storage is available within HGZ3, for a total of **37.5 million AF** of fresh water available in HGZ1 through HGZ3.
3. There is a substantial volume of brackish / saline water within the Basin that has the potential to be utilized as a resource subject to treatment to reduce TDS concentrations. These volumes range from a low of approximately **40.0 million AF** to a high of **53.8 million AF** (see **Table 16**).
4. Specific yield (Sy) is one of the key drivers for differences between the various volume estimates. The assumed Sy in the DRI model is a relatively high and likely unrepresentative value of approximately 0.225 across the majority of the model domain. This factor, coupled with vertical homogeneity across all model layers, suggests that the DRI model overestimates the volume of groundwater in storage within the Basin. Accordingly, Estimate 1 using the DRI model assumptions likely overestimates the total groundwater in storage. Estimate 2 did not include groundwater in storage in the El Paso Area. The Estimate 3 methodology estimated groundwater in storage across the entire Basin and adopted a range of more realistic Sy values based on sediment types. Therefore, the estimates using the Estimate 3 methodology are likely most representative of reality and closely match the average values from the three approaches. Specifically, the estimate using the Estimate 3 methodology produced a range of **57.5 to 63.5 million AF** of groundwater in storage in HGZ1 through HGZ3, while the average of the three methods produced an estimate of approximately **66.9 million AF** of groundwater in storage in HGZ1 through HGZ3.

5. Aquifer pumping test data in several areas of the Basin, and conducted on wells screened within the various lithologies, would be the best way to reduce the uncertainty associated with the current variability in Sy.
6. A second key driver for differences between the various groundwater volume estimates is differences in lithological assumptions utilized in the three estimate models (see **Figure 49**). While the HGZs in the Estimate 1 cross-section are, for the most part, of uniform thickness along the cross-section, there are significant changes in all three HGZ thicknesses along the cross-section in the Estimate 3 cross-section.
7. The Estimate 3 methodology is notably rigorous because it involved the calculation of groundwater storage in the Basin based on a three-dimensional (3D) HCF model geometry and HGZs produced for the Brackish Groundwater Resources Feasibility Study. Significant insight was garnered as a result of the updated Ramboll HCF (specifically Basin and HGZ geometry) coupled with the data utilized in the net sand and mixed / fines analysis.
8. The estimates have identified the approximate volumes of groundwater in storage across HGZ1 through HGZ3 or HGZ1 through HGZ4, depending on the methodology. The recoverable groundwater in storage would be determined on the basis of physical, water quality, economic, environmental, and institutional factors including the potential for undesirable impacts.

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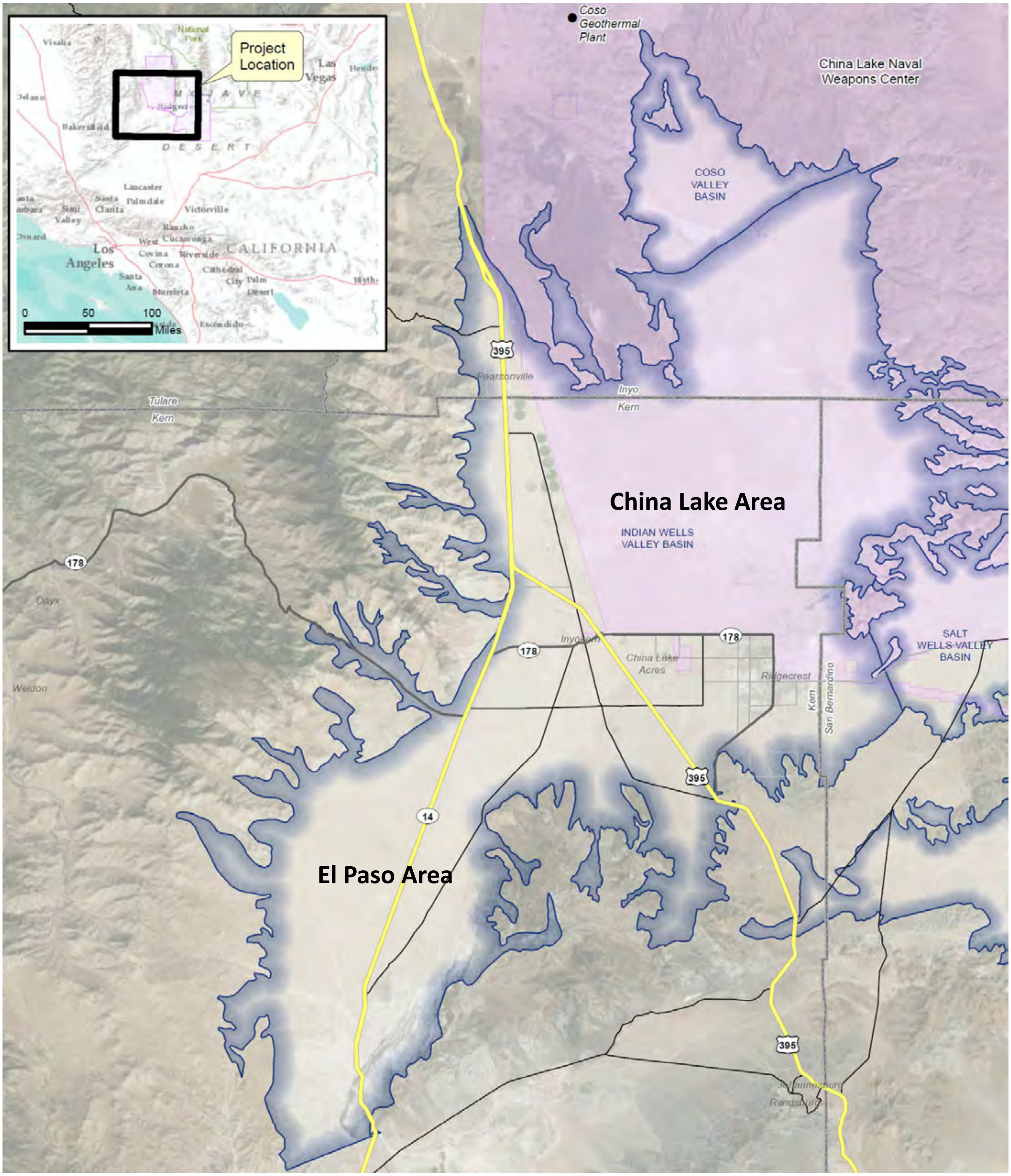
Figures



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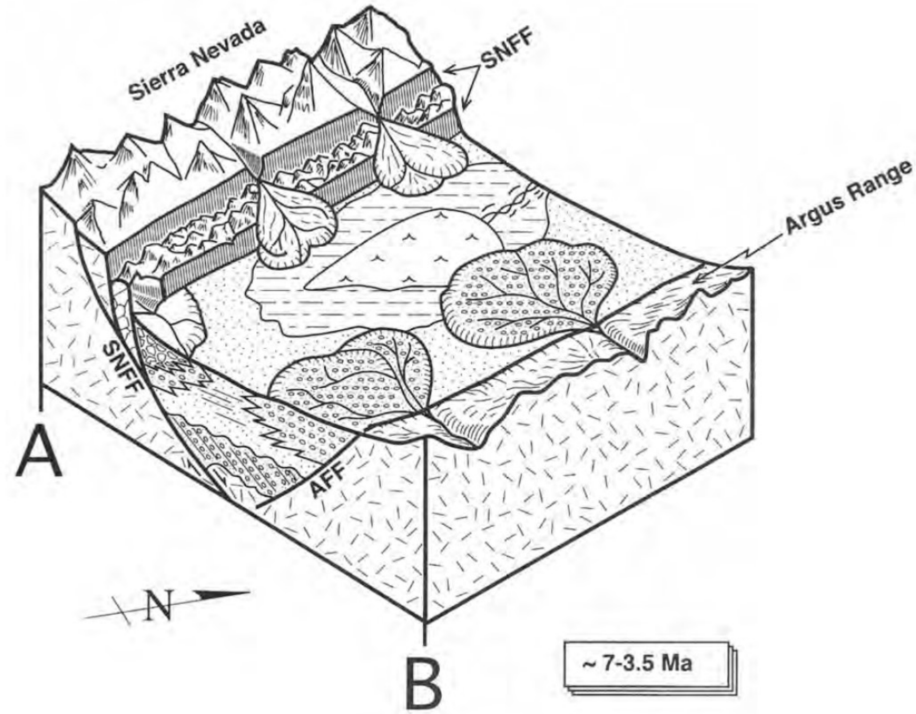
Indian Wells Valley
Area Map

Date: 9/18/2023		**Figure 1**



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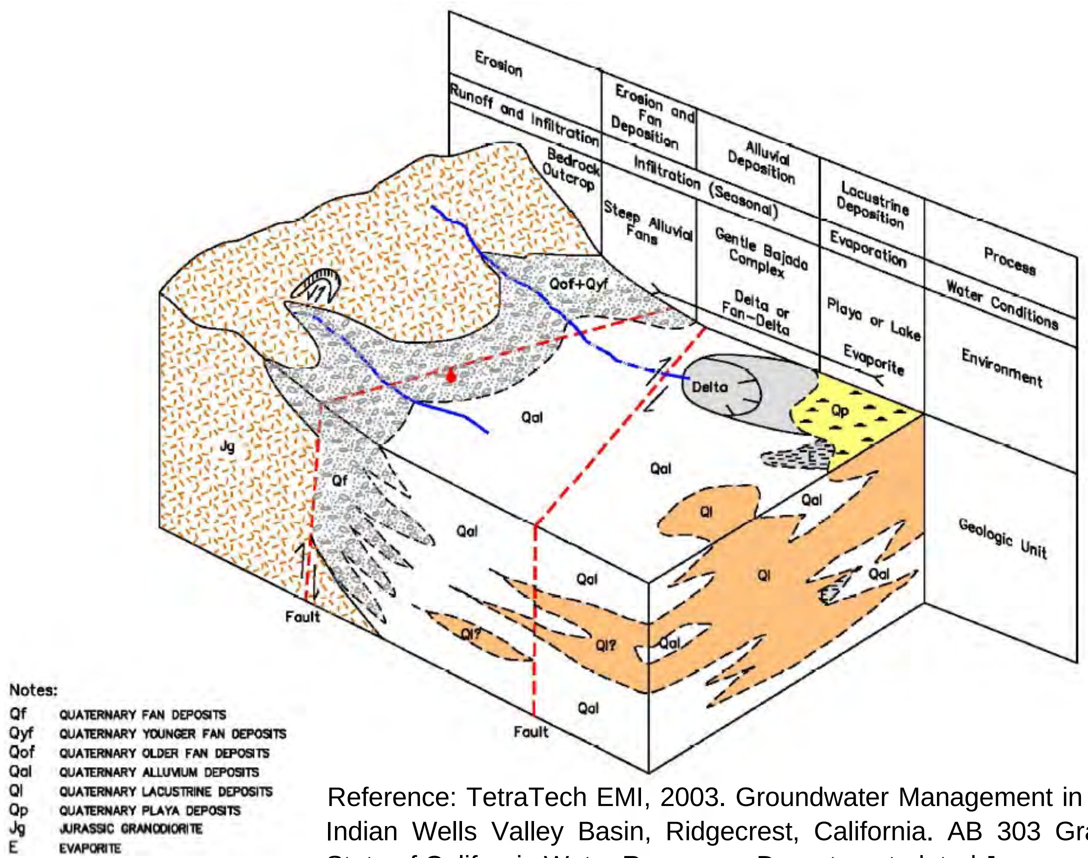

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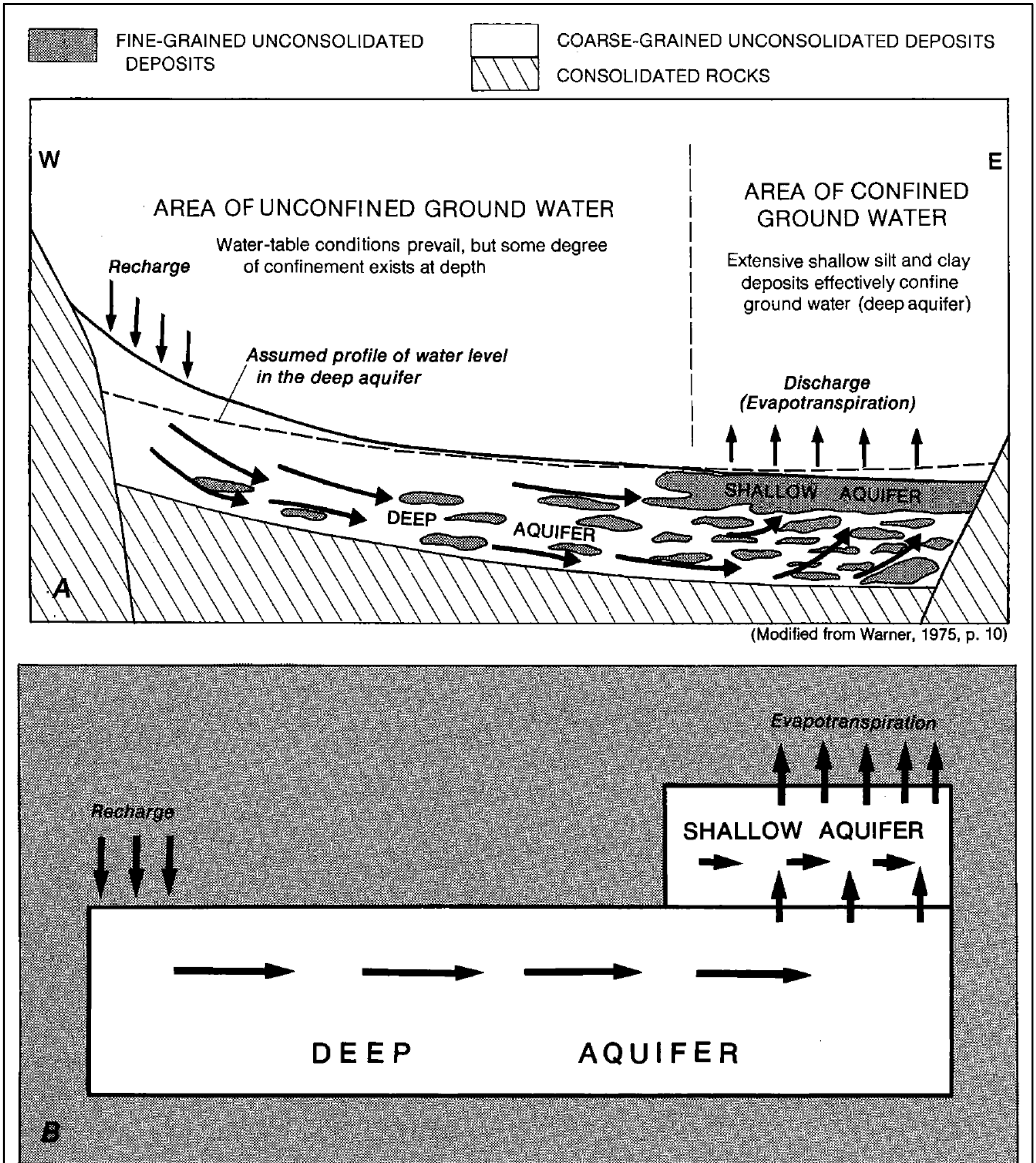
Indian Wells Valley
Basin Depositional Environment

Date: 9/18/2023		**Figure 2**



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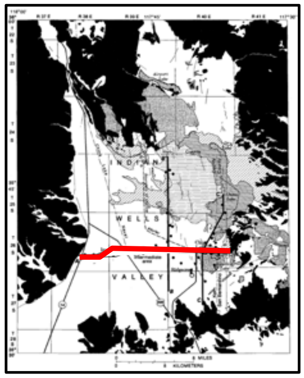
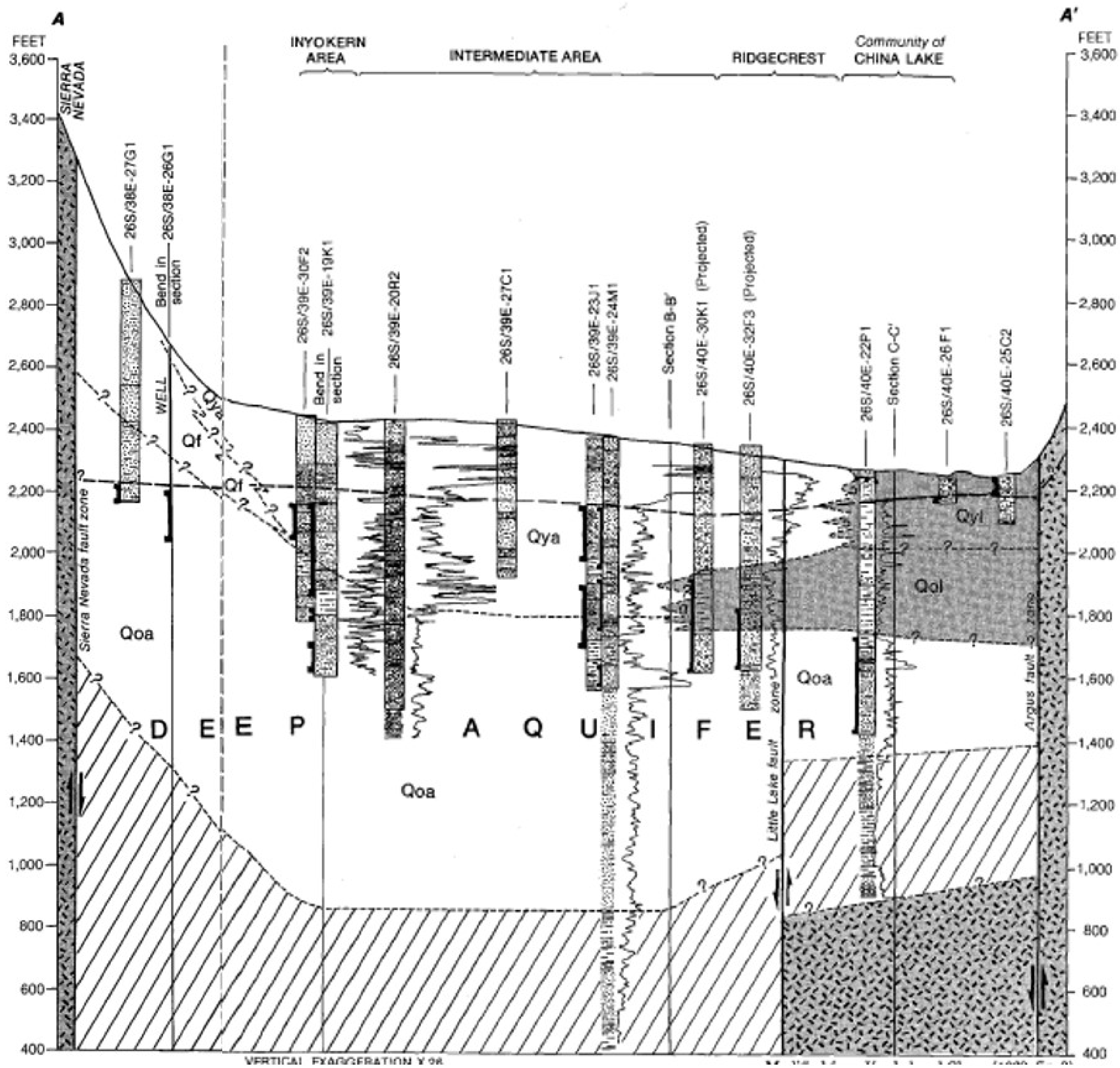
Date: 9/18/2023	**Figure 3**





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Indian Wells Valley
2-Aquifer West-East Cross-Section

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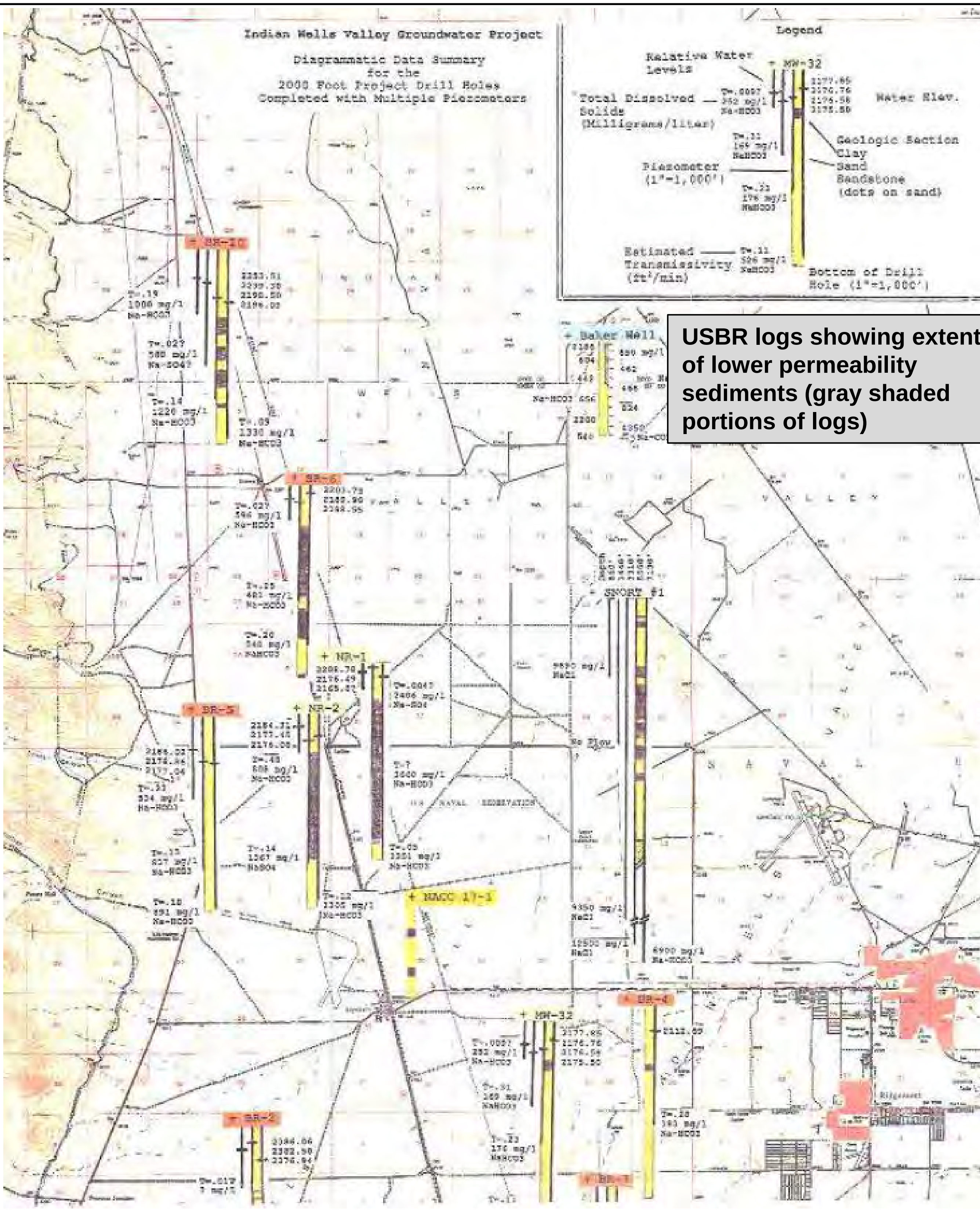
Figure 4



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USBR Logs Showing Lower Permeability Sediments

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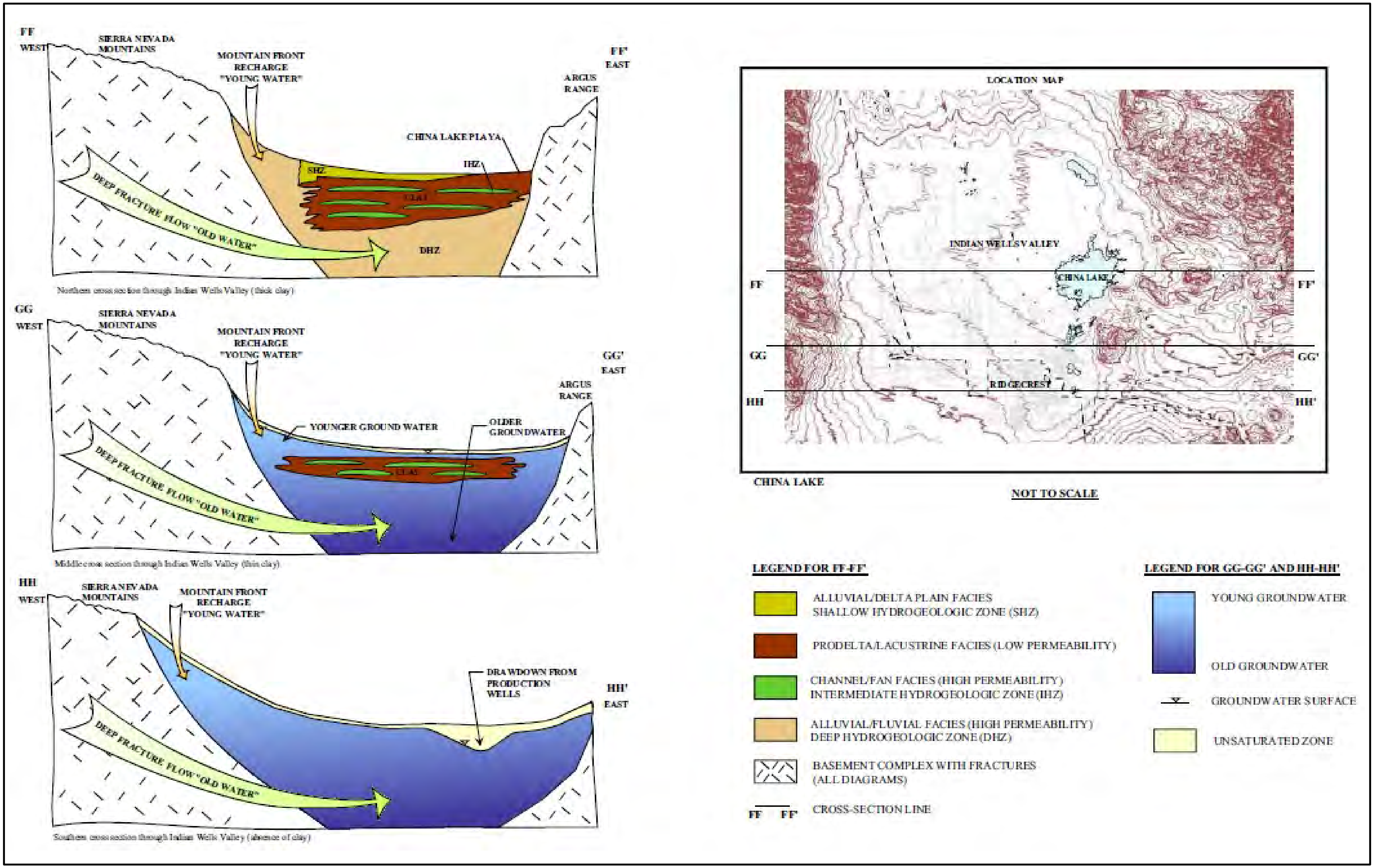
Figure 5



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Indian Wells Valley
3-Aquifer Conceptualization

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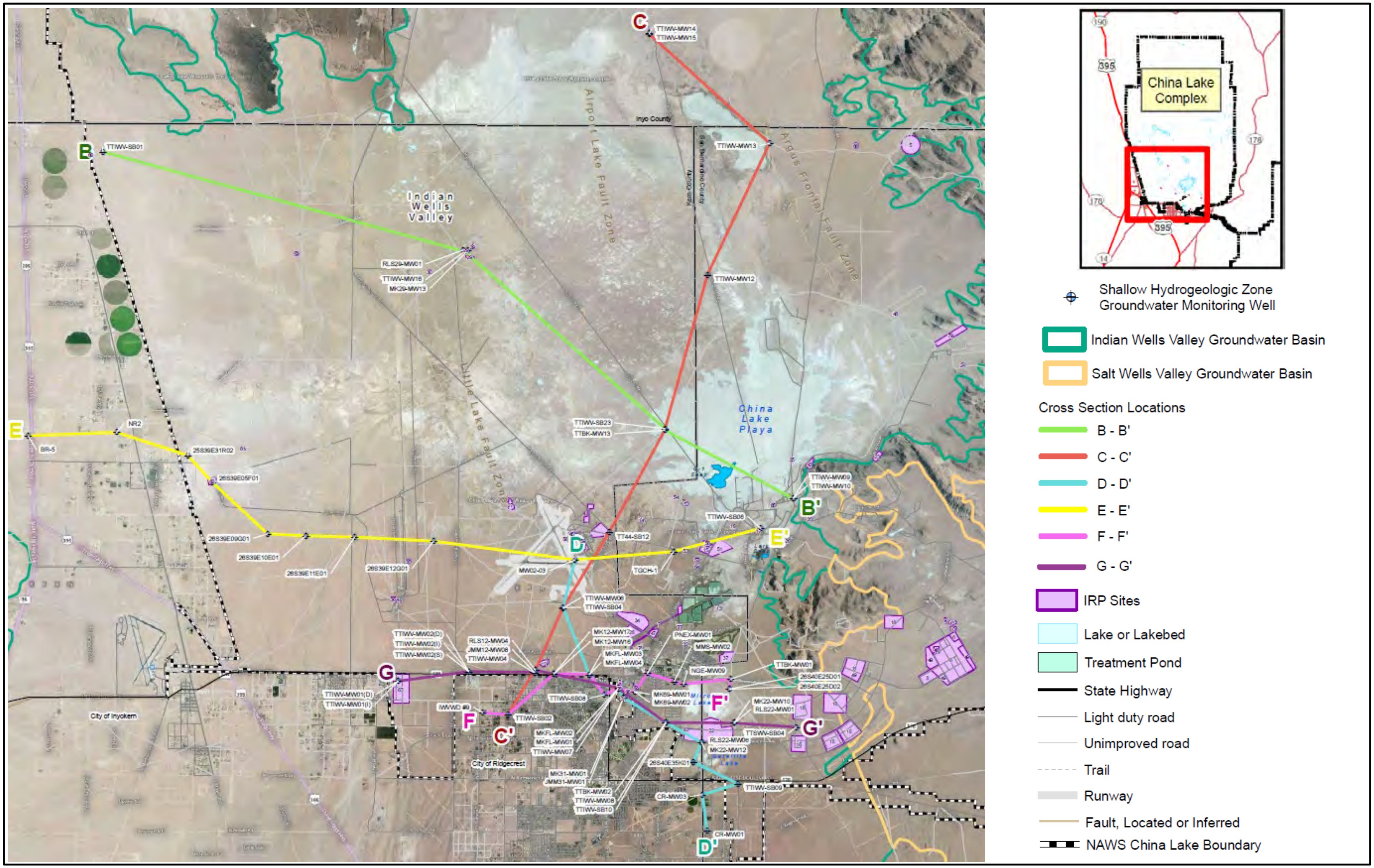
Figure 6



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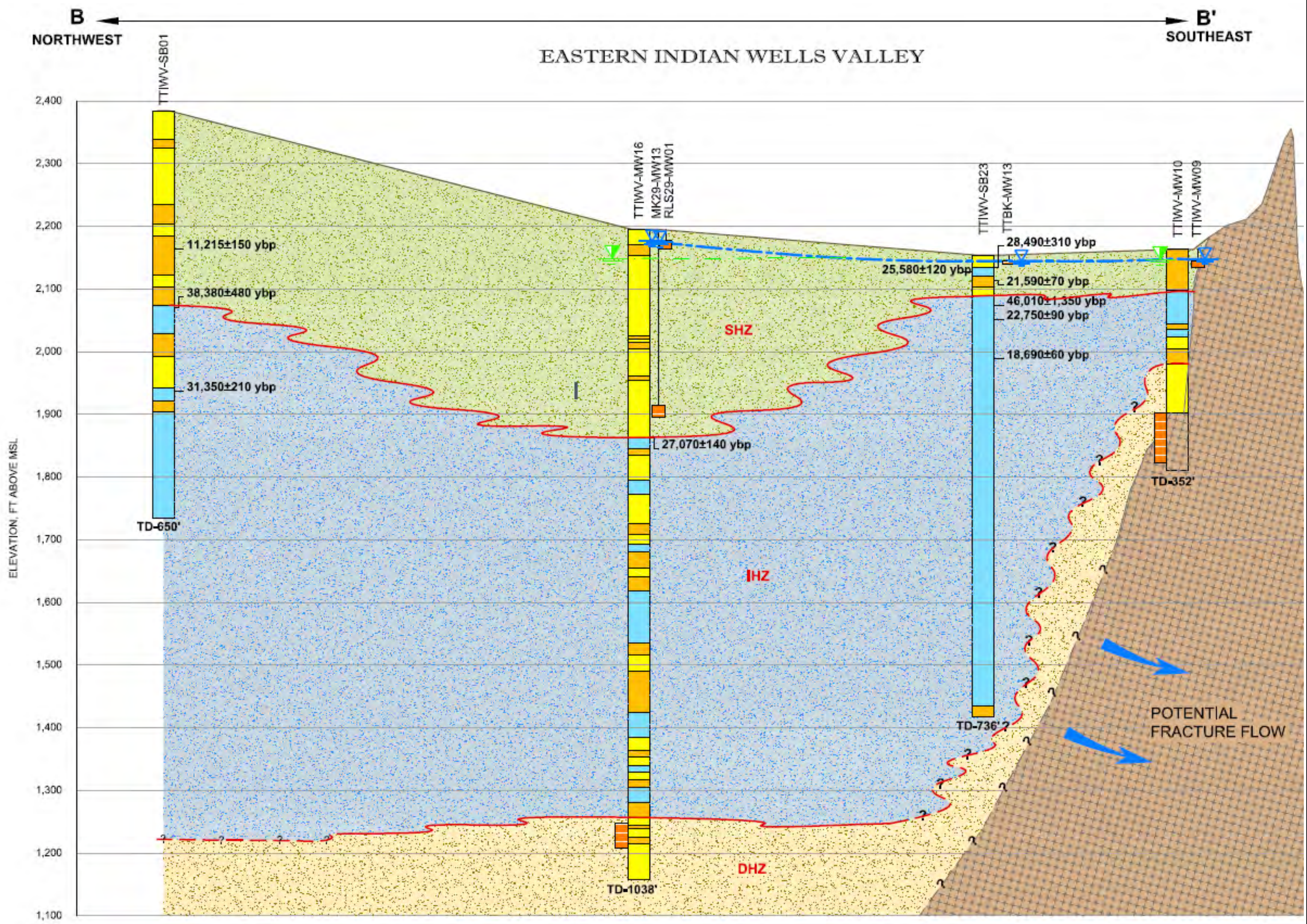
Indian Wells Valley
Recent Basin Cross-Sections

Date: 9/18/2023

Figure 7



LEGEND

	MORE PERMEABLE LITHOSTRATIGRAPHIC UNITS; USCS TYPES GW, GP, SW, SP, SP/SM, SW/GM, GW/CL		LOCATION AND LENGTH OF WELL SCREEN		STATIC WATER LEVEL, SHALLOW HYDROGEOLOGIC ZONE
	LESS PERMEABLE LITHOSTRATIGRAPHIC UNITS; USCS TYPES SC, SM, ML, OL, MH, GC, GM, SC/SP, SM/SP		SEQUENCE REPRESENTING LACUSTRINE DEPOSITION (CONCEPTUAL CONTACT)		POTENTIOMETRIC SURFACE, REGIONAL AQUIFER
	LOW PERMEABILITY LITHOSTRATIGRAPHIC UNITS; USCS TYPES CL, CH, CL/ML				STATIC WATER LEVEL, SALT WELLS VALLEY
	BEDROCK	FT =	FEET		WATER TABLE (SHZ)
SHZ	SHALLOW HYDROGEOLOGIC ZONE	IWV =	INDIAN WELLS VALLEY		POTENTIOMETRIC SURFACE, REGIONAL AQUIFER
IHZ	INTERMEDIATE HYDROGEOLOGIC ZONE	MSL =	MEAN SEA LEVEL		WATER TABLE (SWV)
DHZ	DEEP HYDROGEOLOGIC ZONE	TD =	TOTAL DEPTH		
	TOP OF LITHOLOGIC BORING/GROUND SURFACE	SWV =	SALT WELLS VALLEY		
		USCS =	UNIFIED SOIL CLASSIFICATION SYSTEM		
		ybp =	YEARS BEFORE PRESENT		

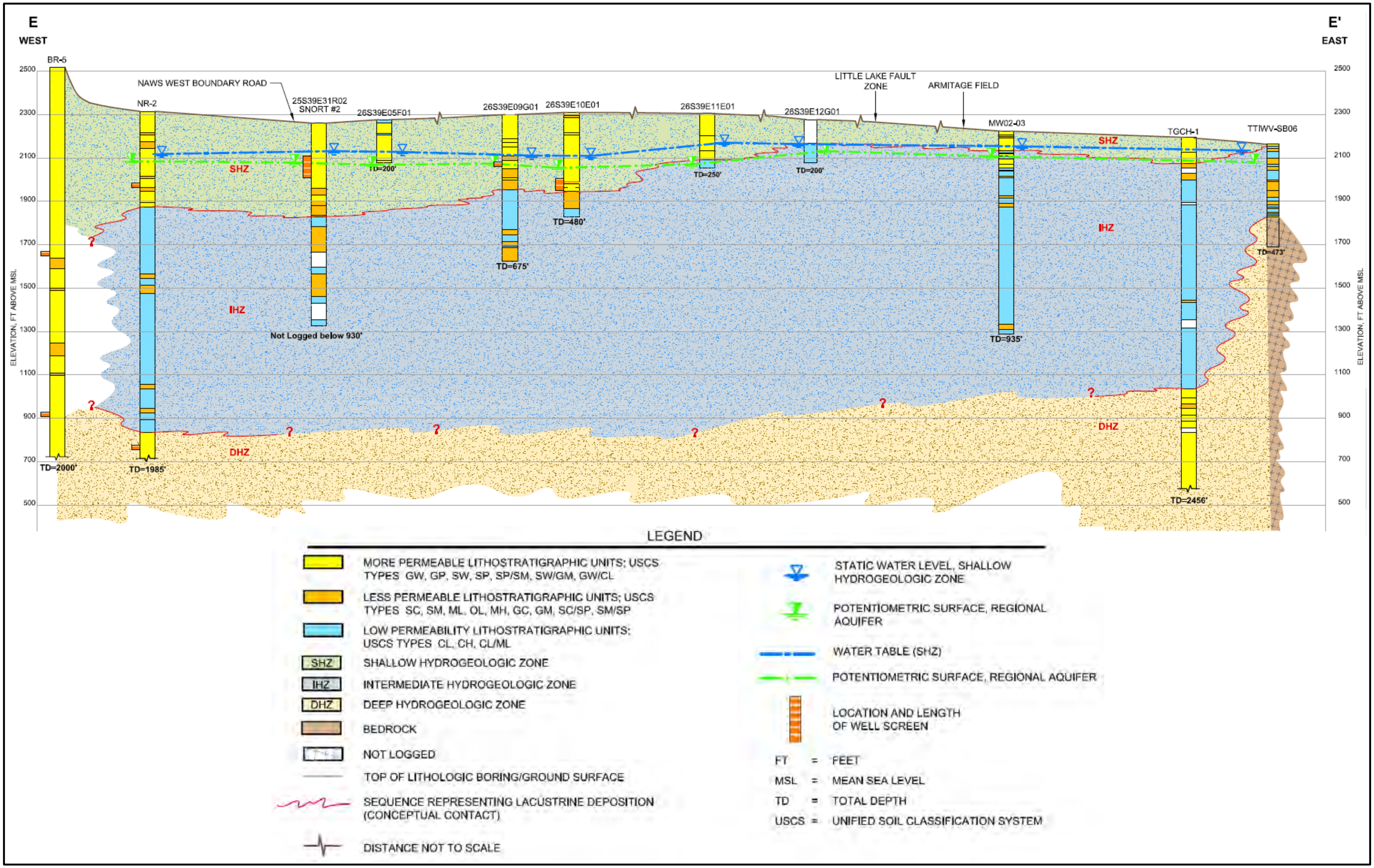
Reference: TriEco TetraTech, 2012. Technical Justification for Beneficial Use Changes for Groundwater in Salt Wells Valley and Shallow Groundwater in Eastern Indian Wells Valley. Naval Air Weapons Station China Lake, California. TRIE-2205-0004-0003, dated May 25.

Indian Wells Valley
Technical Working Group

Indian Wells Valley
Basin Cross-Section B-B'

Date: 9/18/2023

Figure 8



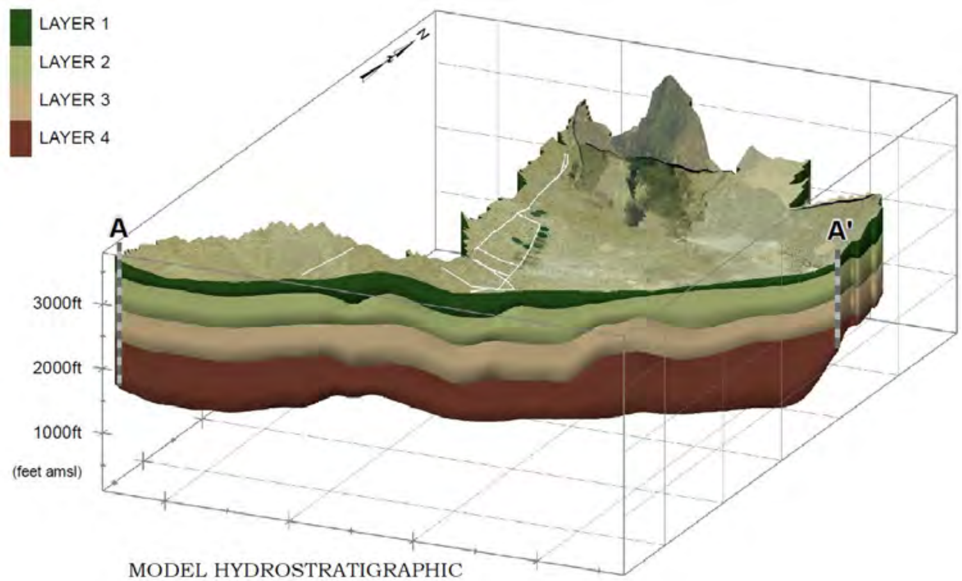
Reference: TriEco TetraTech, 2012. Technical Justification for Beneficial Use Changes for Groundwater in Salt Wells Valley and Shallow Groundwater in Eastern Indian Wells Valley. Naval Air Weapons Station China Lake, California. TRIE-2205-0004-0003, dated May 25.

Indian Wells Valley
Technical Working Group

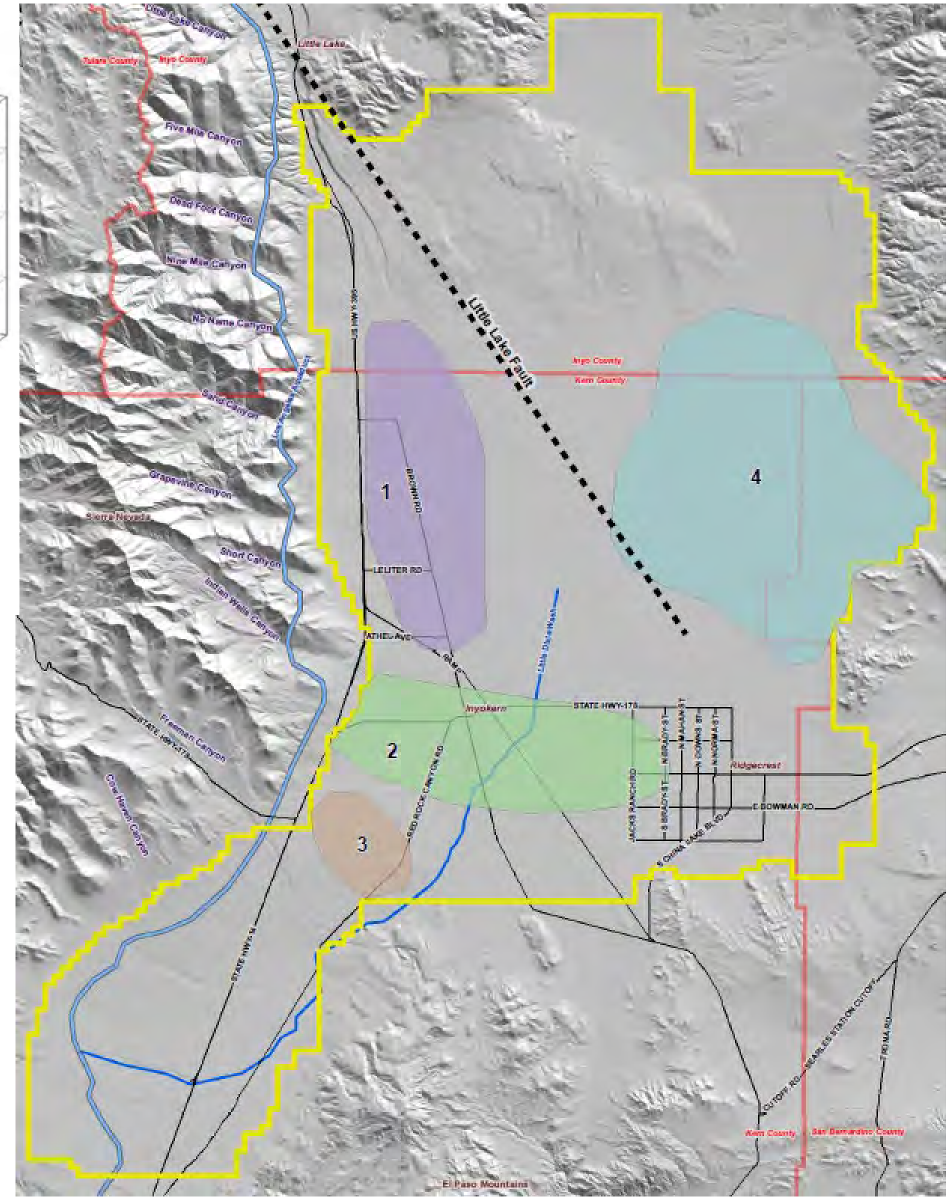
Indian Wells Valley
Basin Cross-Section E-E'

Date: 9/18/2023

Figure 9



MODEL HYDROSTRATIGRAPHIC
CROSS SECTION A-A'



EXPLANATION

HYDROSTRATIGRAPHIC FEATURES

- 1 - FINES PLUG
- 2 - GRAVEL ZONE
- 3 - HIGH GRADIENT
- 4 - PLAYA
- LITTLE LAKE FAULT
- ACTIVE MODEL DOMAIN

Reference: Brown and Caldwell, 2009. Final Report: Indian Wells Valley Basin Groundwater Flow Model and Hydrogeologic Study. Prepared for Indian Wells Valley Water District, dated March 27.

Indian Wells Valley
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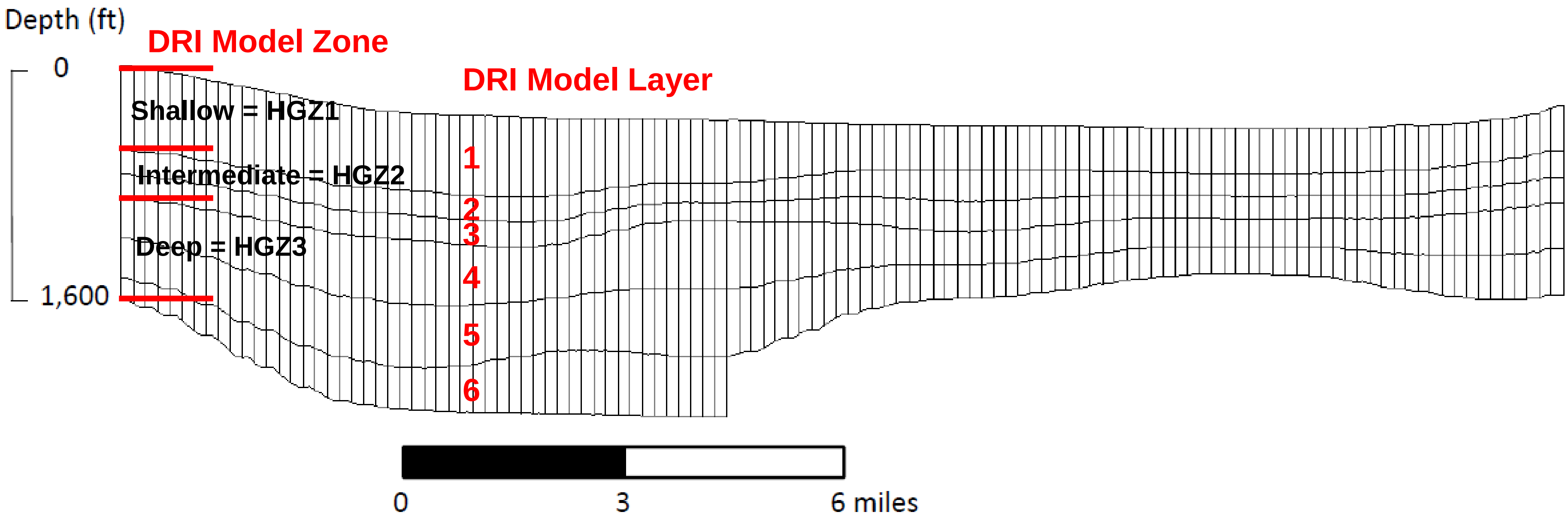
Indian Wells Valley
Brown & Caldwell CHM Geometry

Date: 9/18/2023 | **Figure 10**



vertical exaggeration = 10

Layer thickness 100 – 500 ft

DRI Model Zone	Hydrogeologic Zone	Model Layers
Shallow	HGZ1	1
Intermediate	HGZ2	2 and 3
Deep	HGZ3	4, 5, and 6

Reference: DRI, 2018. Indian Wells Valley Groundwater Model. Presentation to TAC. Slide 16 – Flow Model, dated October 4.

Modified to include explanatory labels.

Indian Wells Valley
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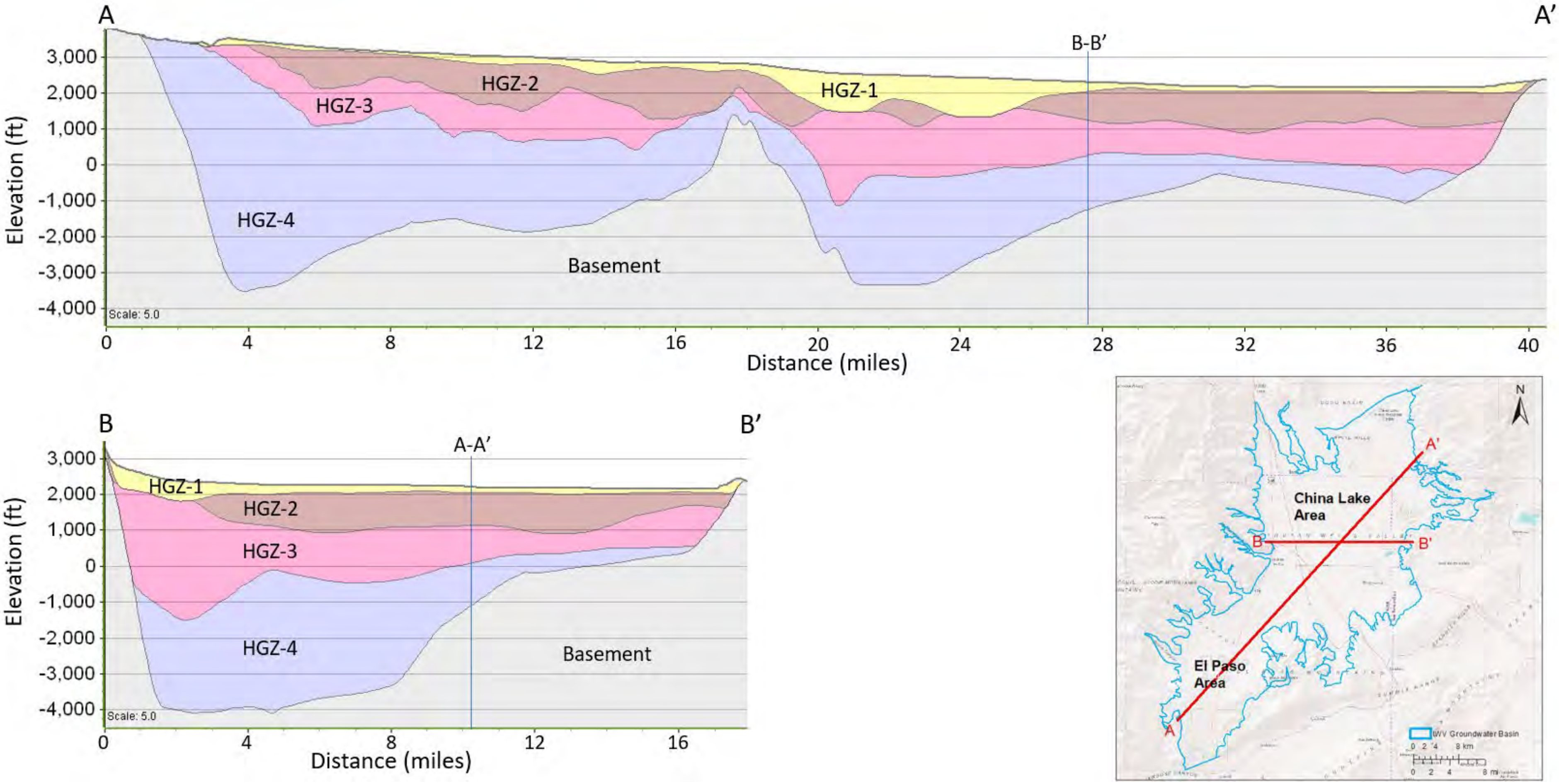
Indian Wells Valley
DRI Model Layers

Date: 9/18/2023

Figure 11



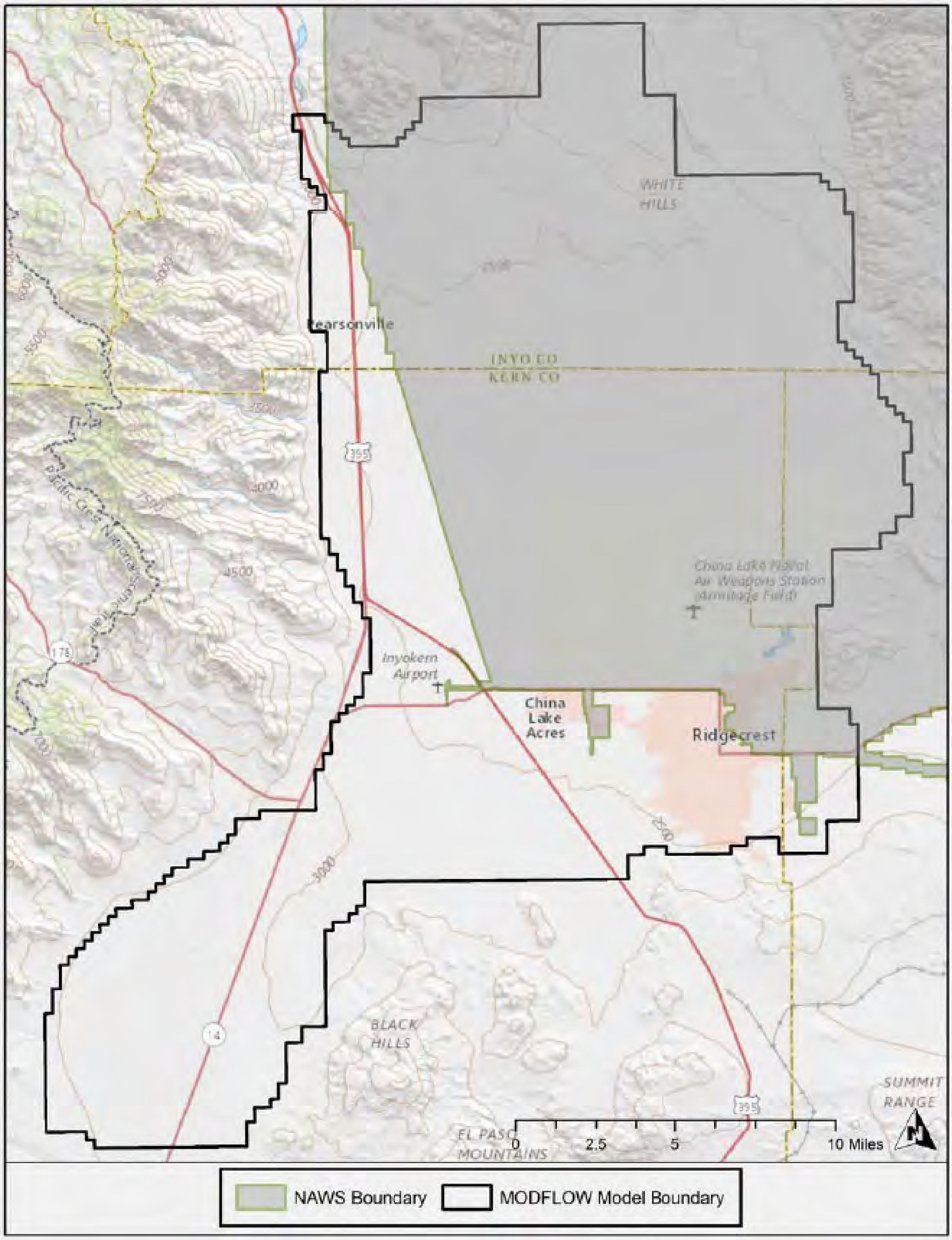
Reference: Ramboll, 2024. Storage Estimate – Indian Wells Valley. Prepared for Indian Wells Valley Water District. September 2022, Revised June 2023 and February 2024.

Indian Wells Valley
Technical Working Group

Indian Wells Valley
Ramboll 4-Zone HCM

Date: 9/18/2023

Figure 12



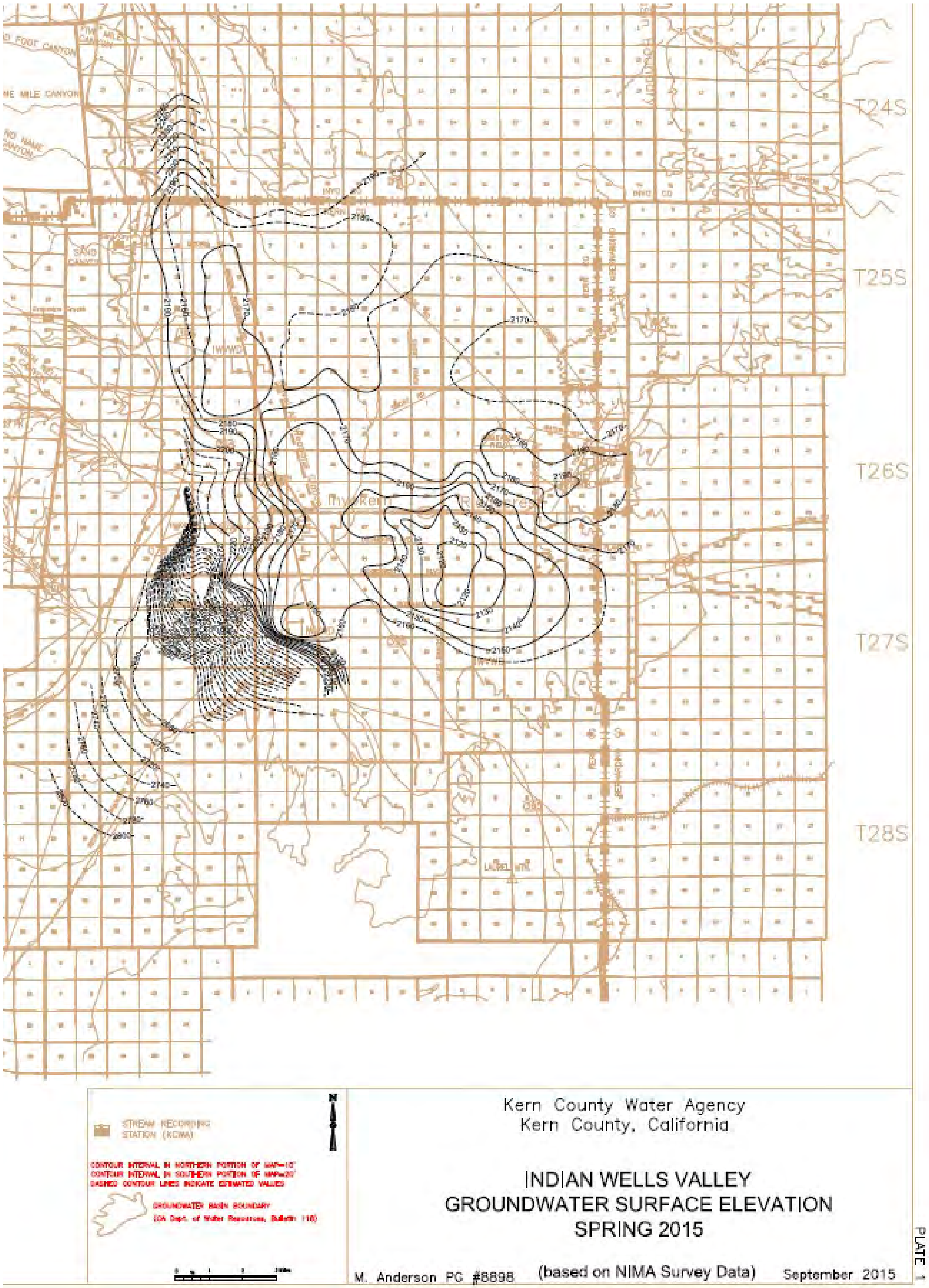
Reference: Stetson Engineers, 2017. Indian Wells Valley Model Review of DRI 2017 Model Update. Figure 1, dated December 7.

Indian Wells Valley
Technical Working Group

Indian Wells Valley
DRI Model Boundary

Date: 9/18/2023

Figure 13



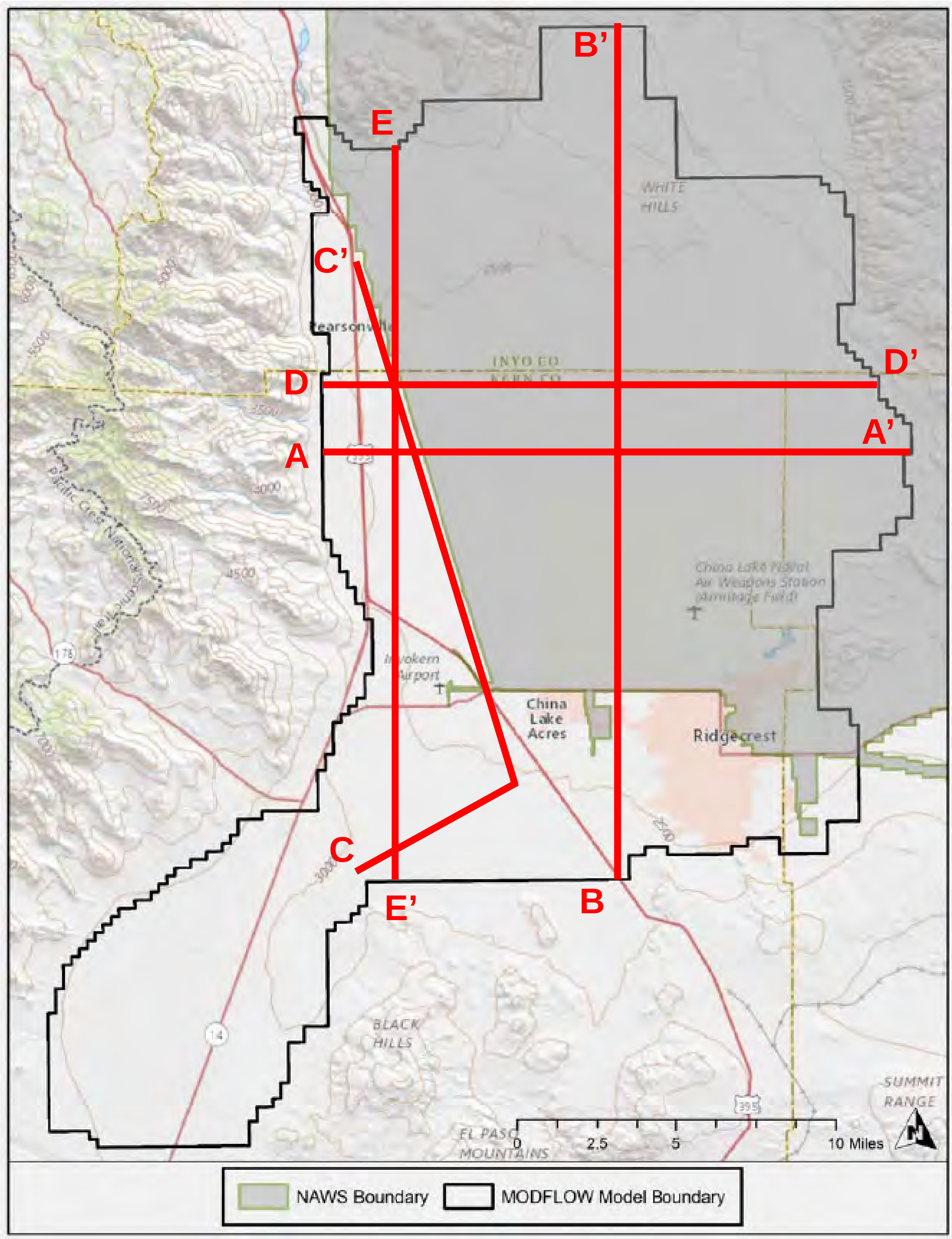
Reference: Kern County Water Agency, 2015. Indian Wells Valley Groundwater Surface Elevation Spring 2015. Plate 1, dated September.

Indian Wells Valley
Technical Working Group
Indian Wells Valley

Spring 2015 Groundwater Surface Elevation

Date: 9/18/2023

Figure 14



Reference: Stetson Engineers, 2017. Indian Wells Valley Model Review of DRI 2017 Model Update. Figure 1, dated December 7.

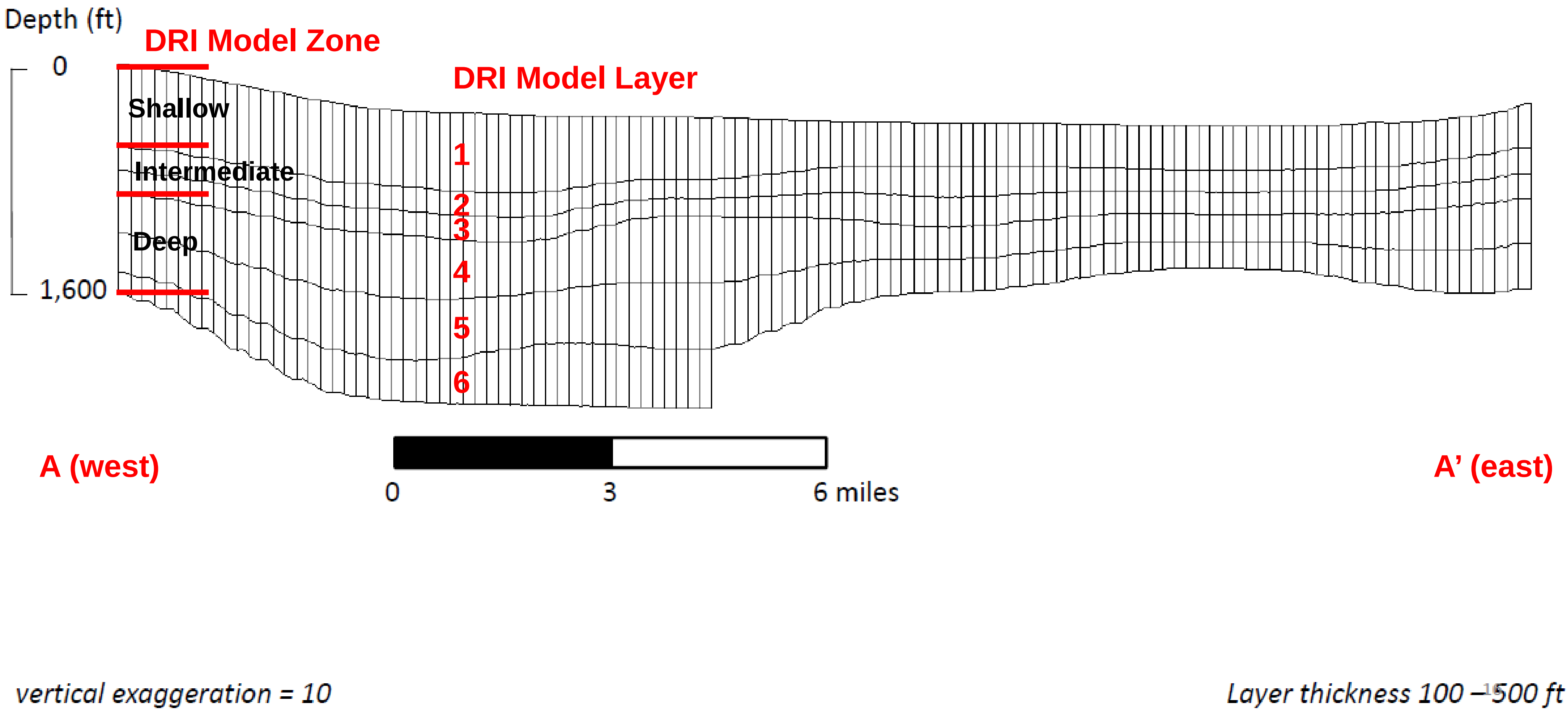
Modified to show cross-section locations.

Indian Wells Valley
Technical Working Group

Indian Wells Valley
Cross-Section Locations

Date: 9/18/2023

Figure 15



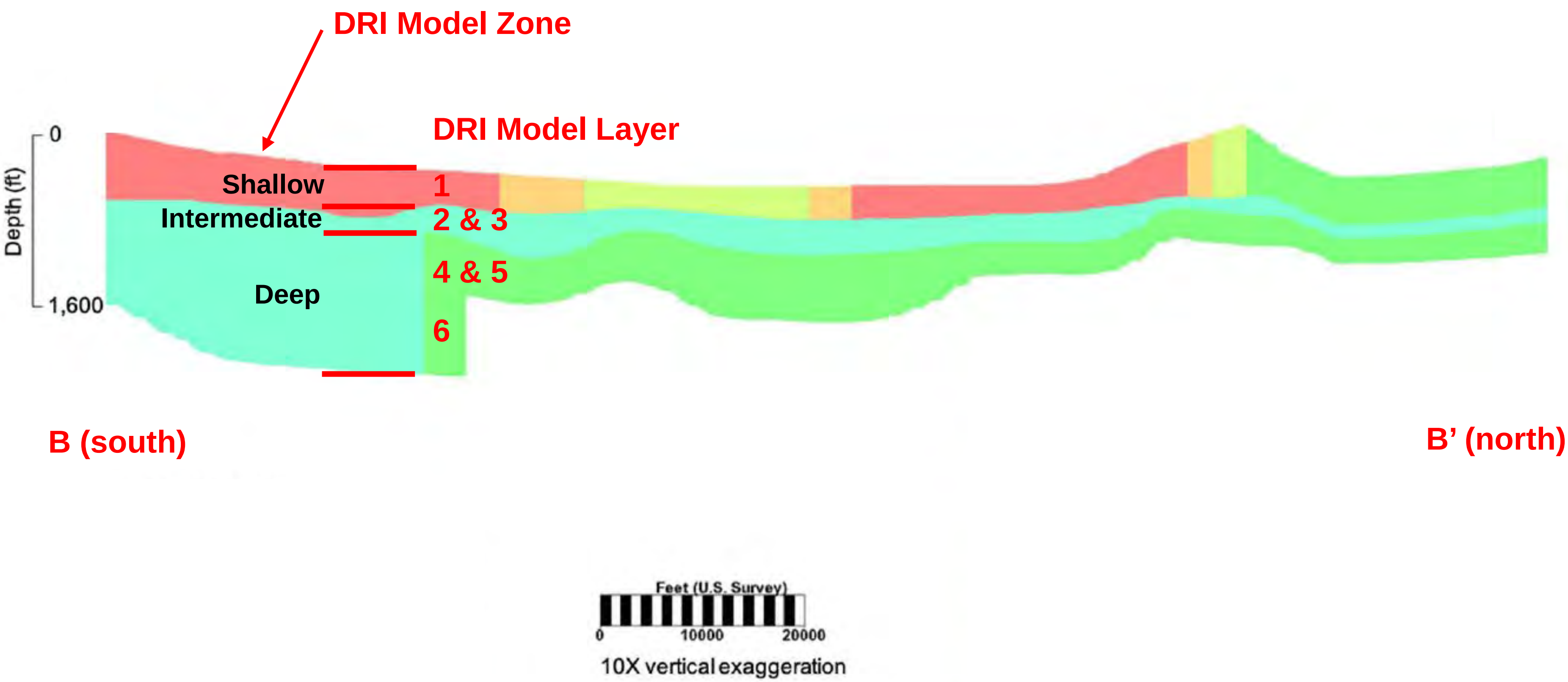
Reference: DRI, 2018. Indian Wells Valley Groundwater Model. Presentation to TAC. Slide 16 – Flow Model, dated October 4.

Modified to include explanatory labels.

Indian Wells Valley
Technical Working Group

Indian Wells Valley
DRI Model Cross-Section A-A'

Date: 9/18/2023		**Figure 16**



Note: The colors on the cross-section are the DRI-assumed hydraulic conductivities. This analysis only used the colors to define the shape of the boundaries between the various model layers.

Reference: Stetson Engineers, 2020. Groundwater Sustainability Plan for the Indian Wells Valley Groundwater Basin. Bulletin 118 Basin No. 6-054. Indian Wells Groundwater Authority. Appendix 3-H – Model Documentation. DRI Figure 15, dated January.

Modified to include explanatory labels.

Indian Wells Valley
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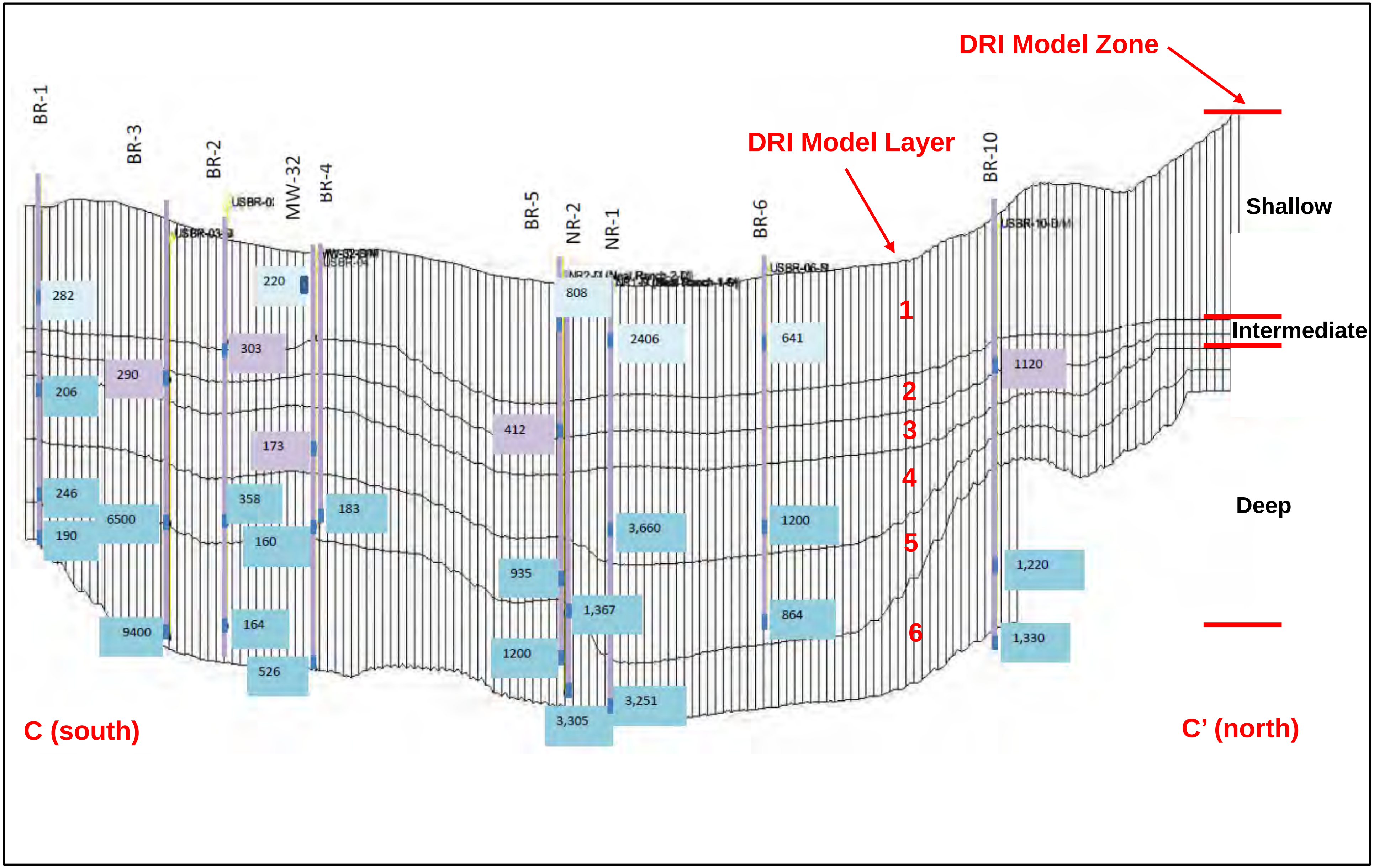
Indian Wells Valley
DRI Model Cross-Section B-B'

Date: 9/18/2023

Figure 17



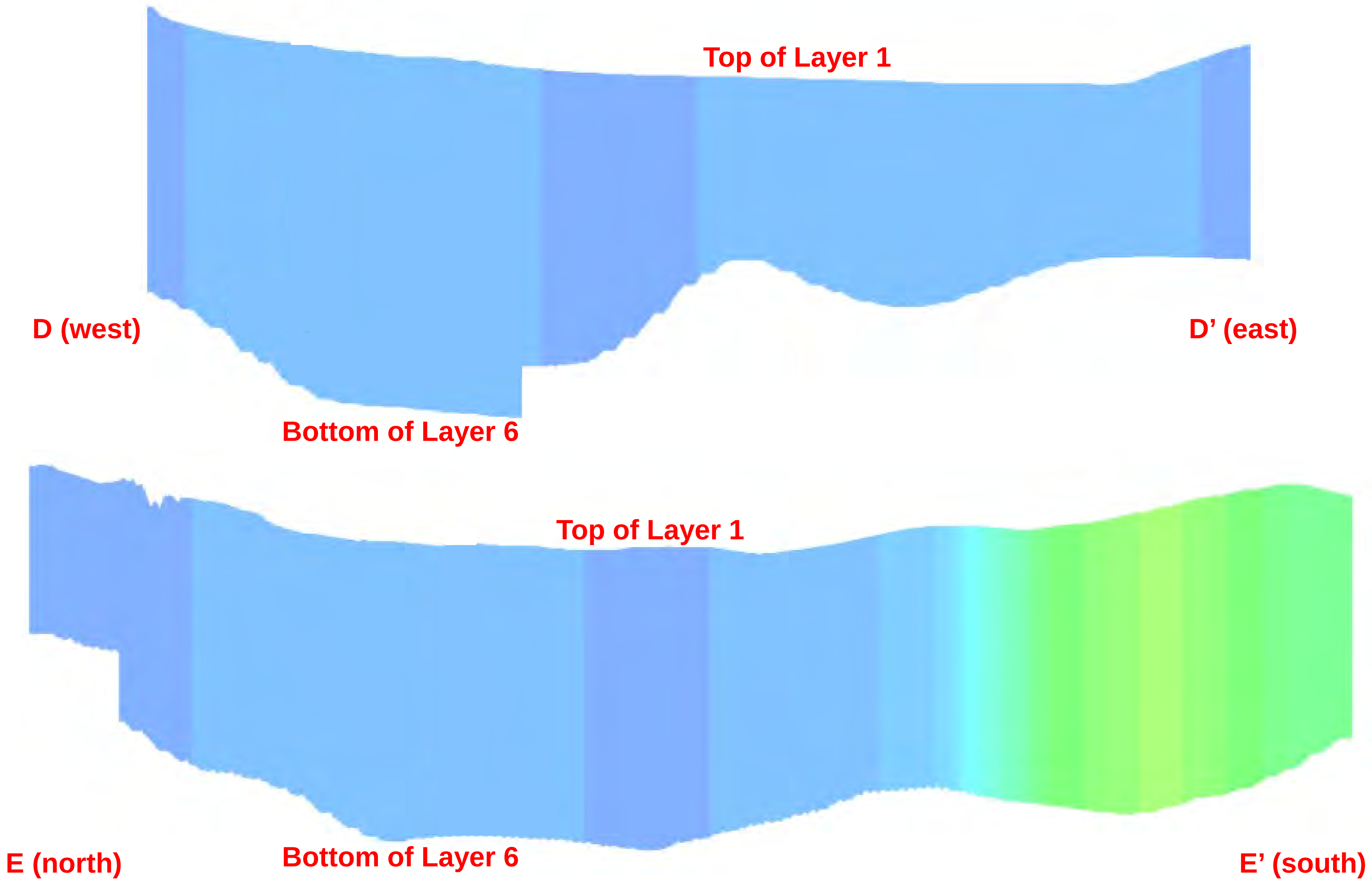
Reference: DRI, 2019. Indian Wells Valley Draft TDS Transport Model Baseline Pumping Conditions. Presentation to IWV TAC. Slide 7, dated February 7.

Modified to include explanatory labels.

Indian Wells Valley
Technical Working Group

Indian Wells Valley
DRI Model Cross-Section C-C'

Date: 9/18/2023		**Figure 18**



Reference: DRI, 2019. IWV Model Cross Sections – Hydraulic Conductivity and Specific Yield. Personal Communication. Mr. Christopher Garner. August 13.

Modified to include explanatory labels.

Note: The colors on the cross-sections are the DRI-assumed specific yield.

Indian Wells Valley
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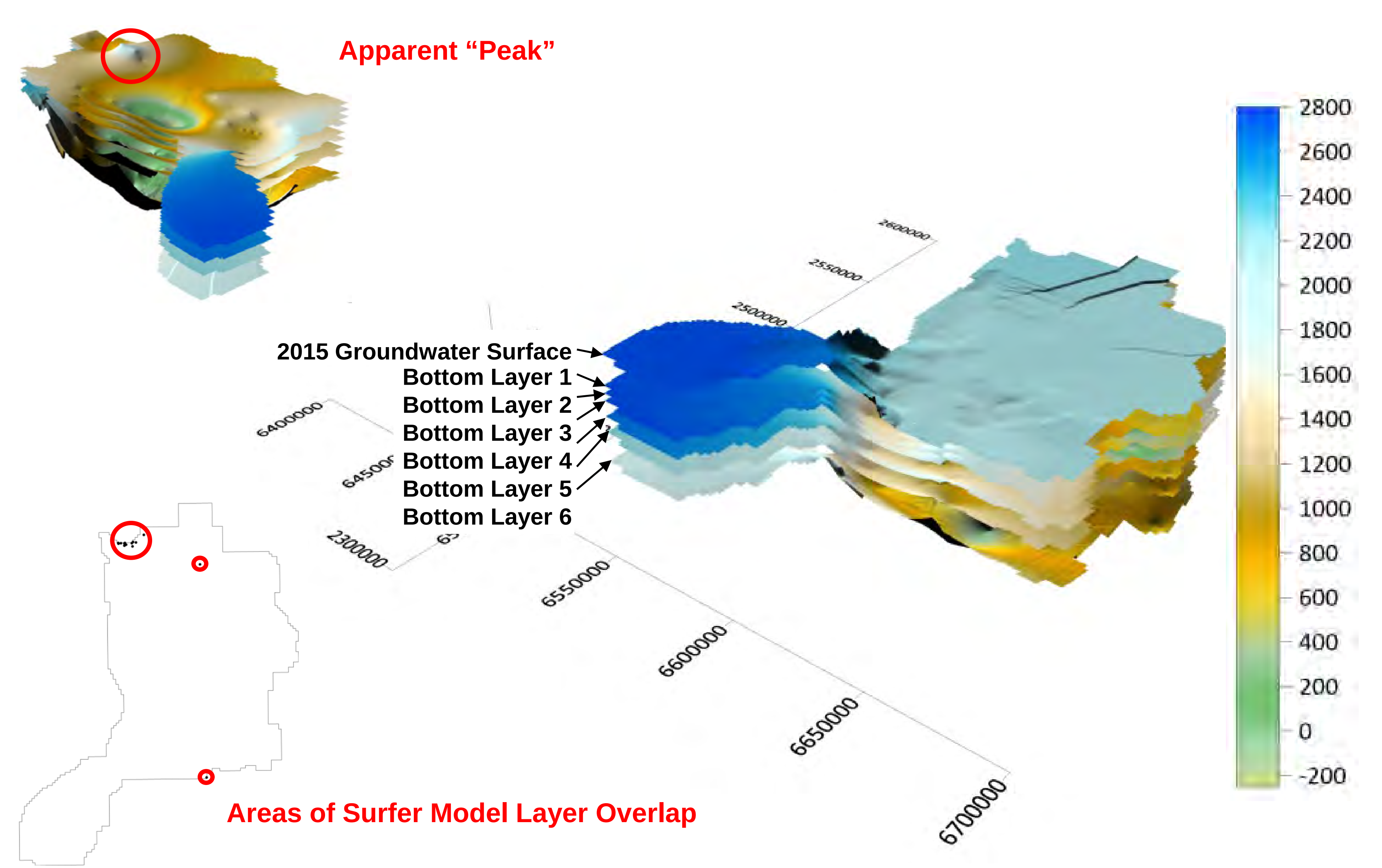
Indian Wells Valley

DRI Model
Cross-Sections D-D' & E-E'

Date: 9/18/2023

Figure 19



The large apparent "peak" in **Figure 20** results from the increase in elevations of that layer in the cross-sections as shown on **Figure 17** for cross-section B-B', and **Figure 18** for cross-section C-C'. The vertical to horizontal exaggeration for **Figure 20** is approximately 23 to 1, making the "peak" appear much larger than it is in reality.

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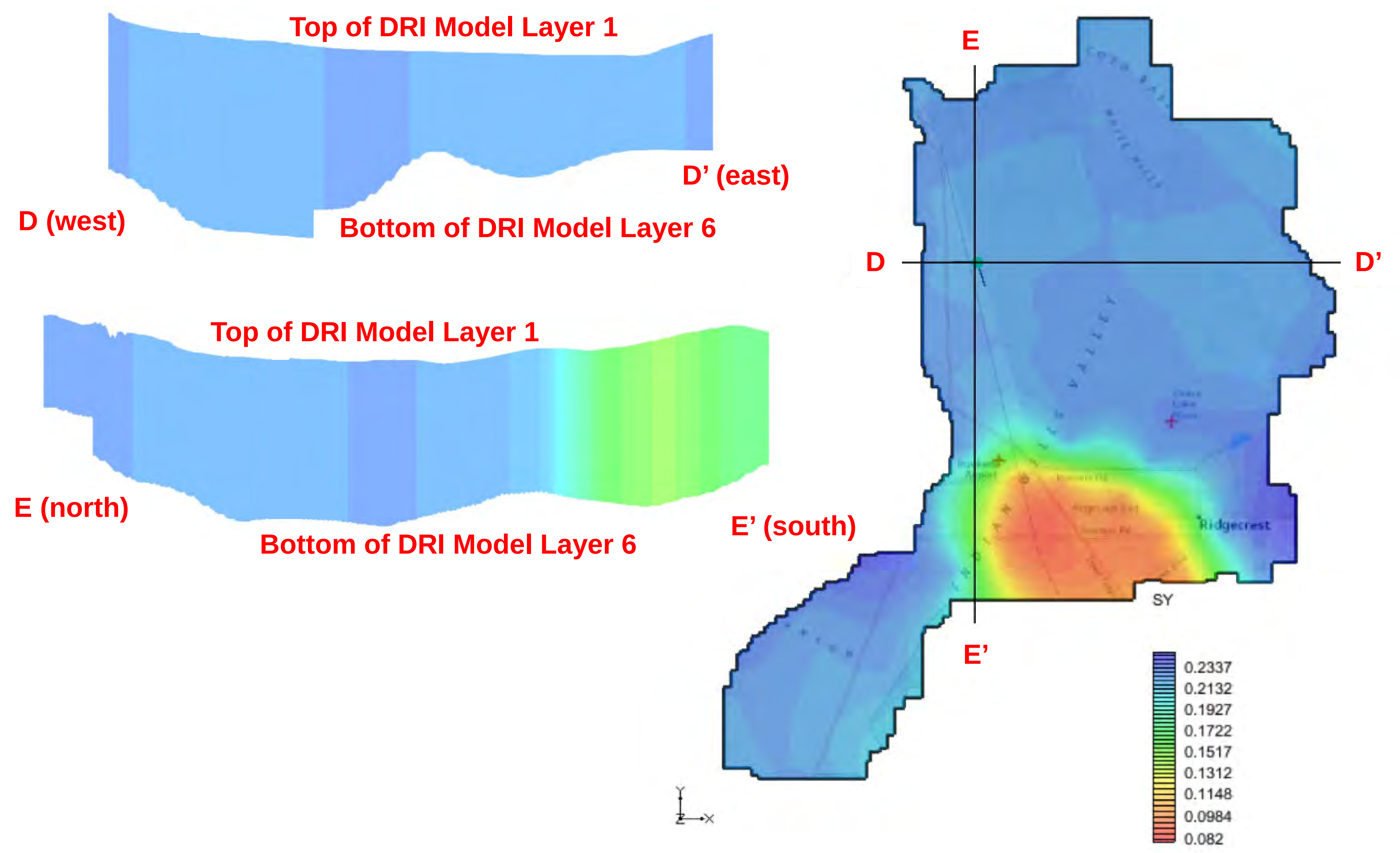
Indian Wells Valley
Overlap of Surfer Model Layers

Date: 9/18/2023

Figure 20



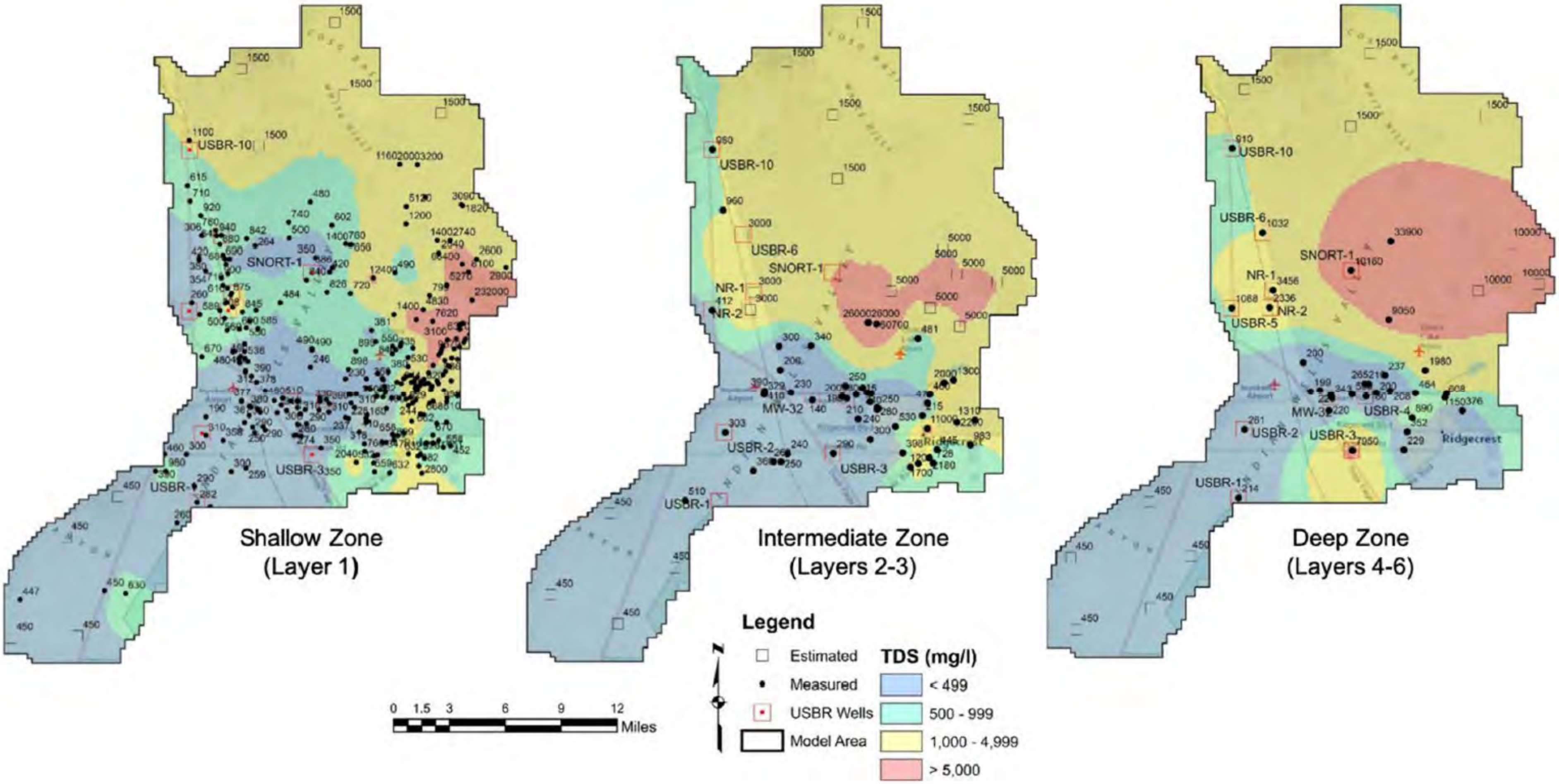
Reference: DRI, 2019. IWV Model Cross Sections – Hydraulic Conductivity and Specific Yield. Personal Communication. Mr. Christopher Garner. August 13.

Modified to include explanatory labels.

Indian Wells Valley
Technical Working Group
Indian Wells Valley

DRI Model
Specific Yield (Sy) Distribution

Date9/18/2023		**Figure 21**



Reference: Stetson Engineers, 2020. Groundwater Sustainability Plan for the Indian Wells Valley Groundwater Basin. Bulletin 118 Basin No. 6-054. Indian Wells Groundwater Authority. Appendix 3-H – Model Documentation. DRI Figure 40, dated January.

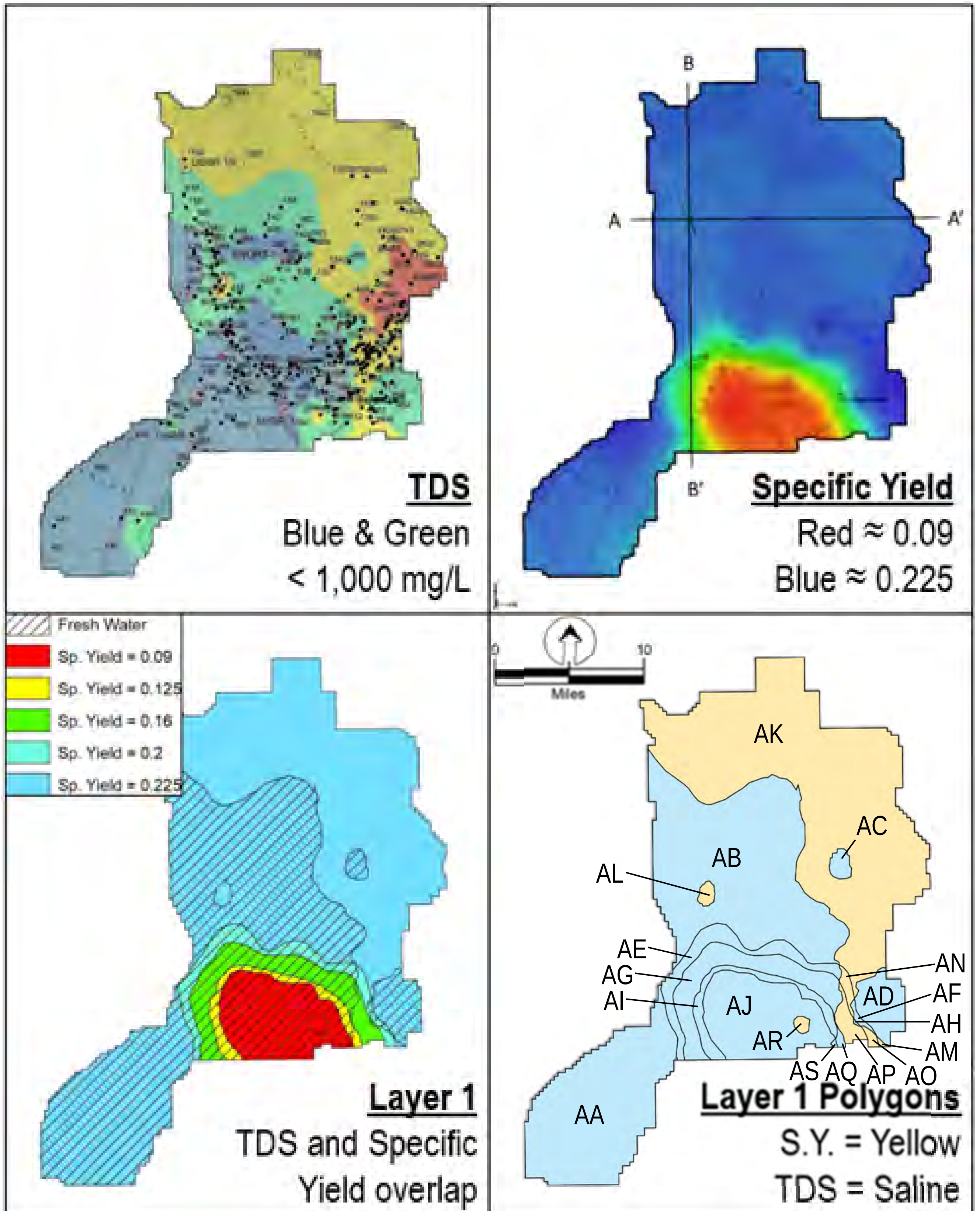
Modified to include explanatory labels.

Indian Wells Valley
Technical Working Group
Indian Wells Valley

DRI Model Distribution of Total Dissolved Solids (TDS)

Date: 9/18/2023

Figure 22



Layer 1 Volumes (Acre-Feet)

Fresh Water

AA = 4,865,950
AB = 4,437,468
AC = 92,625
AD = 212,728
AE = 465,102
AF = 8,103
AG = 447,124
AH = 683
AI = 125,721
AJ = 313,311

Brackish / Saline Water

AK = 5,664,417
AL = 80,352
AM = 2,620
AN = 24,825
AO = 7,616
AP = 24,633
AQ = 2,115
AR = 2,521
AS = 339

Fresh Water Total

10,968,815

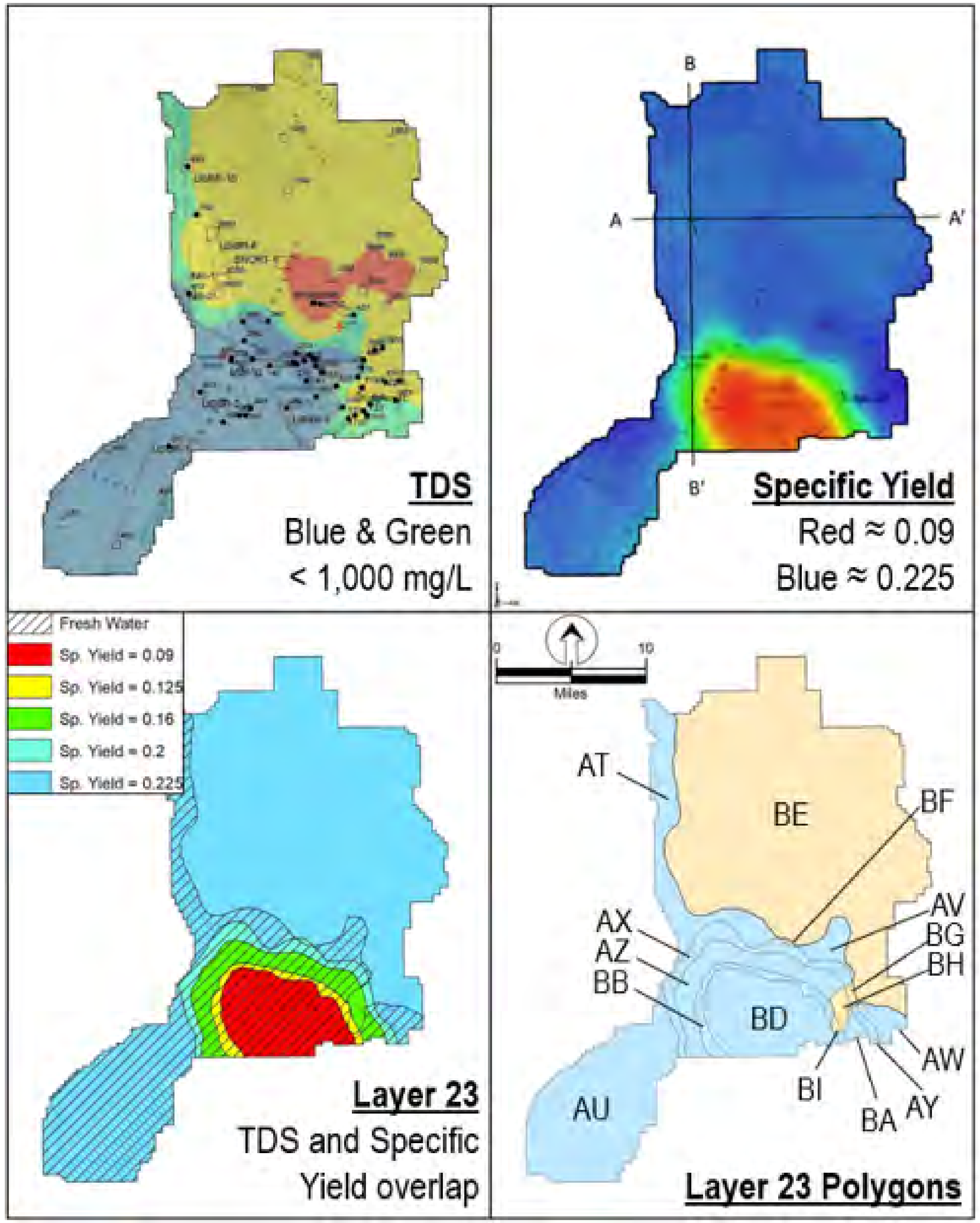
Brackish / Saline Water Total

5,809,437

Indian Wells Valley
Technical Working Group

Indian Wells Valley
Layer 1 Estimated Volumes

Date: 9/18/2023		**Figure 23**



Layer 2 Volumes (Acre-Feet)

Fresh Water

AT = 683,049
AU = 1,226,127
AV = 151,659
AW = 97,926
AX = 274,168
AY = 26,897
AZ = 308,253
BA = 26,416
BB = 89,236
BD = 287,588

Brackish / Saline Water

BE = 5,027,308
BF = 4,982
BG = 14,626
BH = 30,383
BI = 6,068

Fresh Water Total

3,171,319

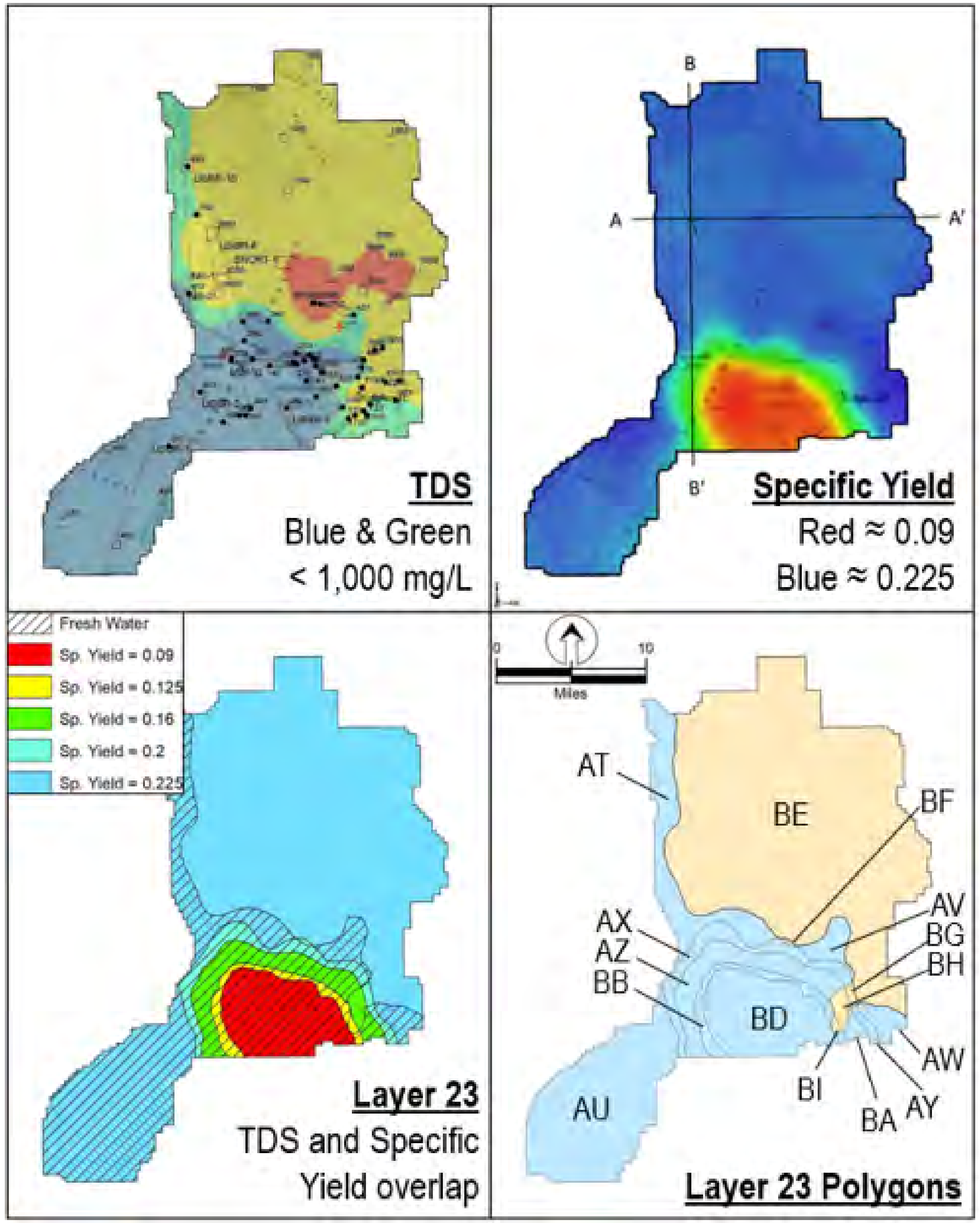
Brackish / Saline Water Total

5,083,366

Indian Wells Valley
Technical Working Group

Indian Wells Valley
Layer 2 Estimated Volumes

Date: 9/18/2023 | **Figure 24**



Layer 3 Volumes (Acre-Feet)

Fresh Water

AT = 678,865
AU = 1,215,841
AV = 152,112
AW = 99,246
AX = 273,675
AY = 27,302
AZ = 306,808
BA = 26,844
BB = 88,840
BD = 286,178

Brackish / Saline Water

BE = 5,026,083
BF = 4,981
BG = 14,773
BH = 30,743
BI = 6,163

Fresh Water Total

3,155,711

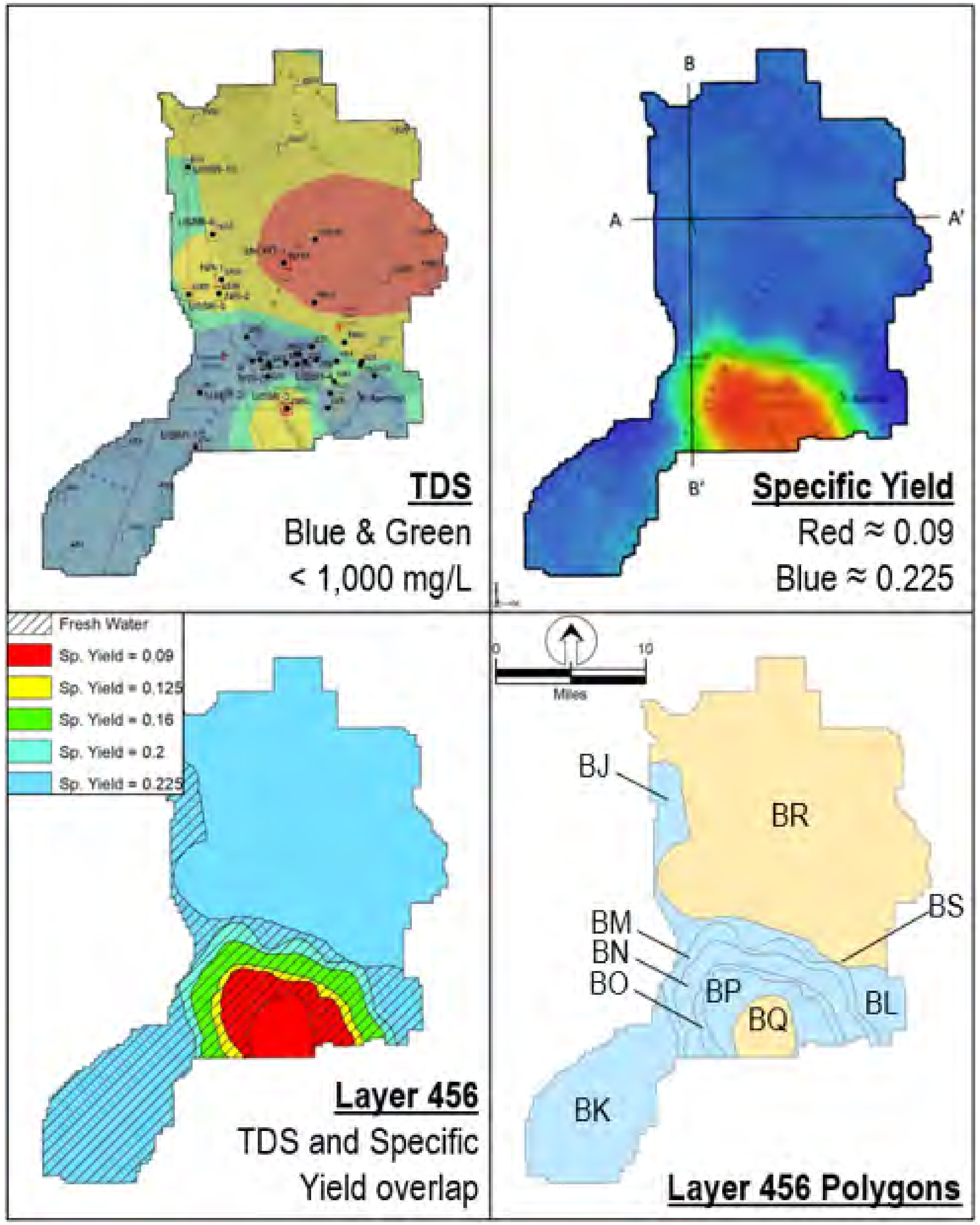
Brackish / Saline Water Total

5,082,742

Indian Wells Valley
Technical Working Group

Indian Wells Valley
Layer 3 Estimated Volumes

Date: 9/18/2023		**Figure 25**



Layer 4 Volumes (Acre-Feet)

Fresh Water

BJ = 993,158
BK = 2,681,842
BL = 586,544
BM = 582,818
BN = 782,364
BO = 230,331
BP = 431,998

Brackish / Saline Water

BQ = 260,235
BR = 7,520,117
BS = 3,588

Fresh Water Total

6,289,055

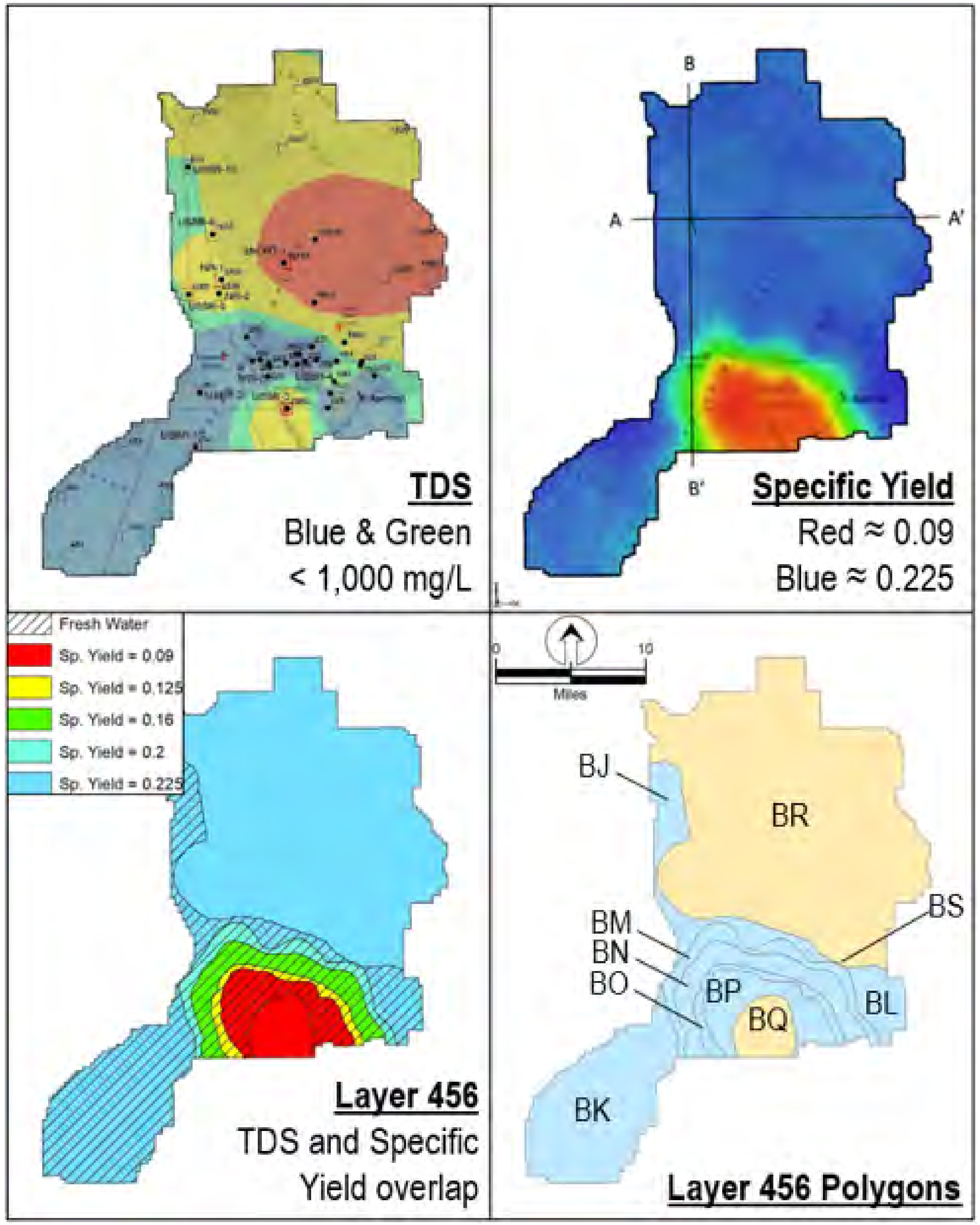
Brackish / Saline Water Total

7,783,940

Indian Wells Valley
Technical Working Group

Indian Wells Valley
Layer 4 Estimated Volumes

Date: 9/18/2023		**Figure 26**



Layer 5 Volumes (Acre-Feet)

Fresh Water

BJ = 995,203
BK = 2,709,589
BL = 587,228
BM = 581,564
BN = 781,455
BO = 230,276
BP = 432,361

Brackish / Saline Water

BQ = 259,625
BR = 7,455,428
BS = 3,593

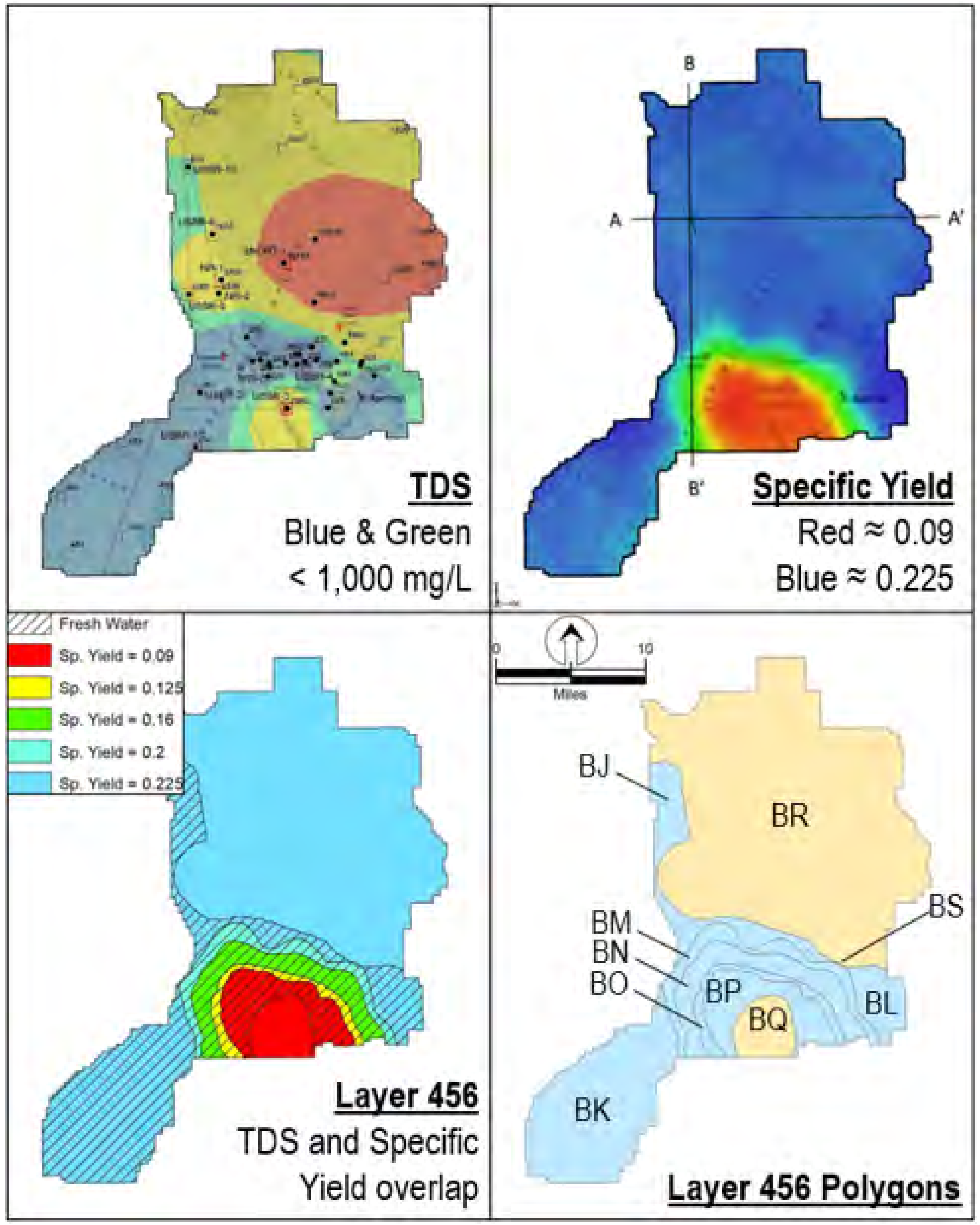
Fresh Water Total

6,317,676

Brackish / Saline Water Total

7,718,646

Indian Wells Valley Technical Working Group Indian Wells Valley **Layer 5 Estimated Volumes**		
Date: 9/18/2023		**Figure 27**



Layer 6 Volumes (Acre-Feet)

Fresh Water

BJ = 2,132,830
BK = 4,252,290
BL = 1,197,746
BM = 1,373,327
BN = 1,775,860
BO = 460,088
BP = 872,571

Brackish / Saline Water

BQ = 458,818
BR = 19,513,548
BS = 9,039

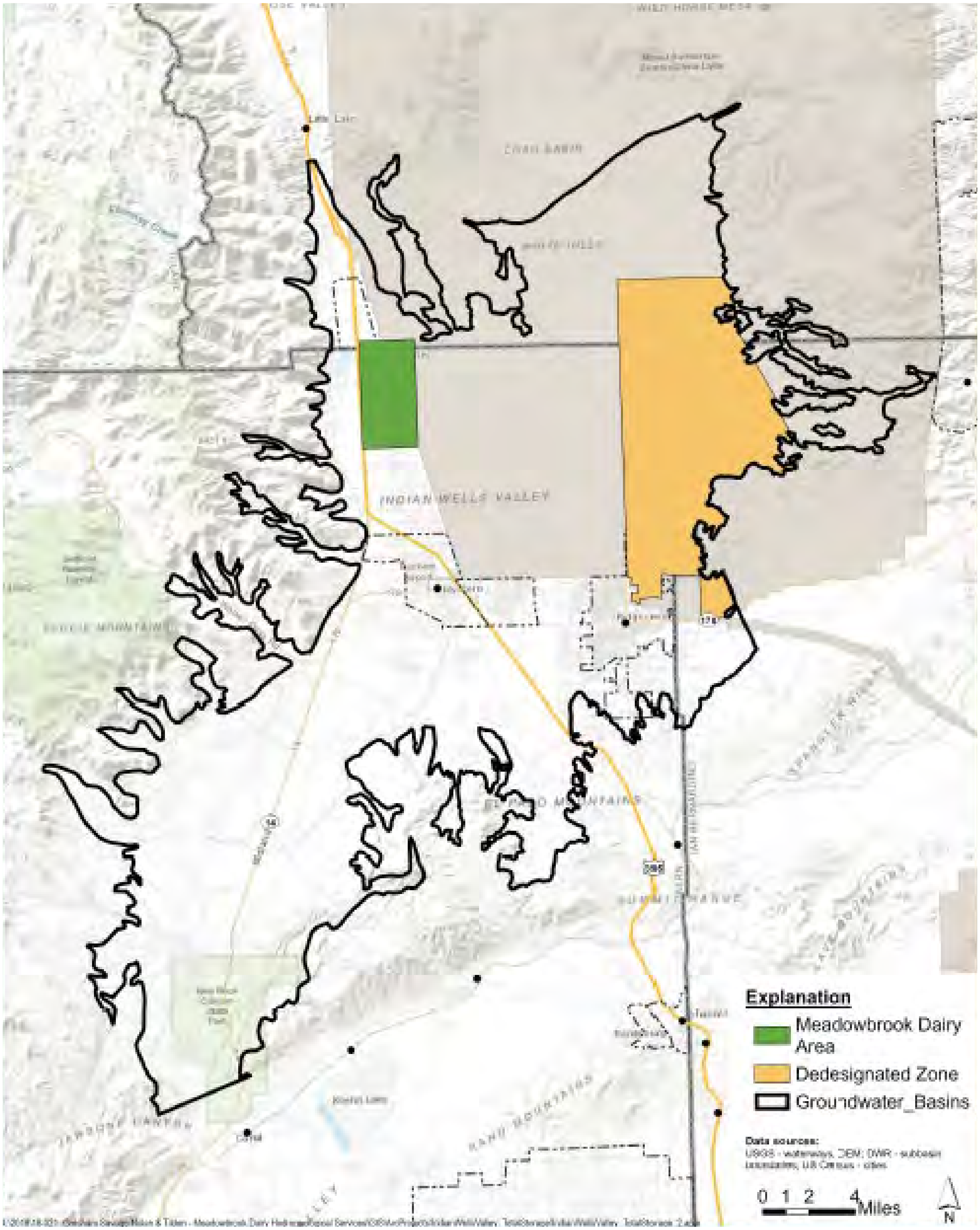
Fresh Water Total

12,064,712

Brackish / Saline Water Total

19,981,405

Indian Wells Valley Technical Working Group Indian Wells Valley **Layer 6 Estimated Volumes**		
Date: 9/18/2023		**Figure 28**

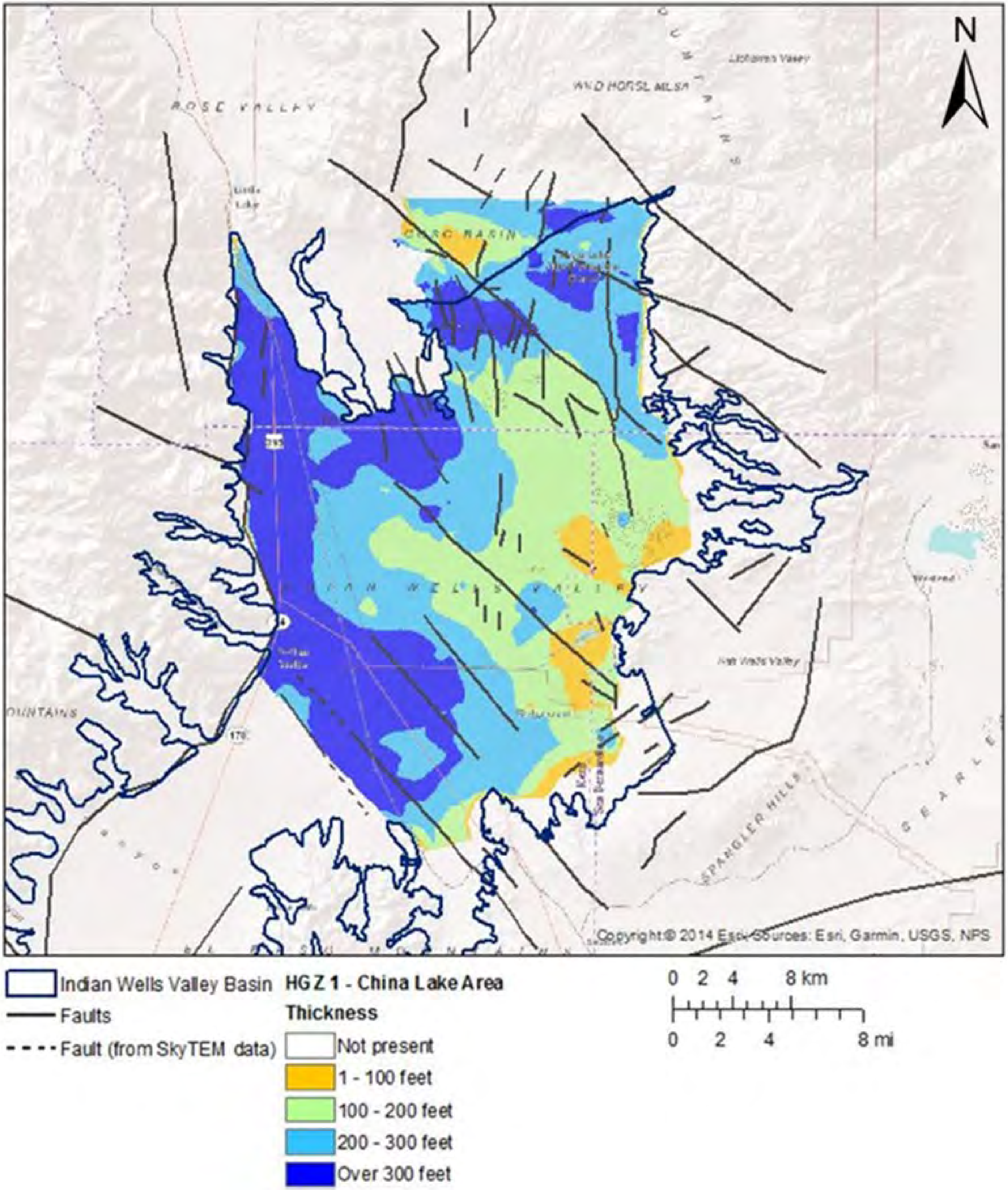


Indian Wells Valley
Technical Working Group
Indian Wells Valley

Groundwater Storage Calculation Areas

Date: 9/18/2023

Figure 29



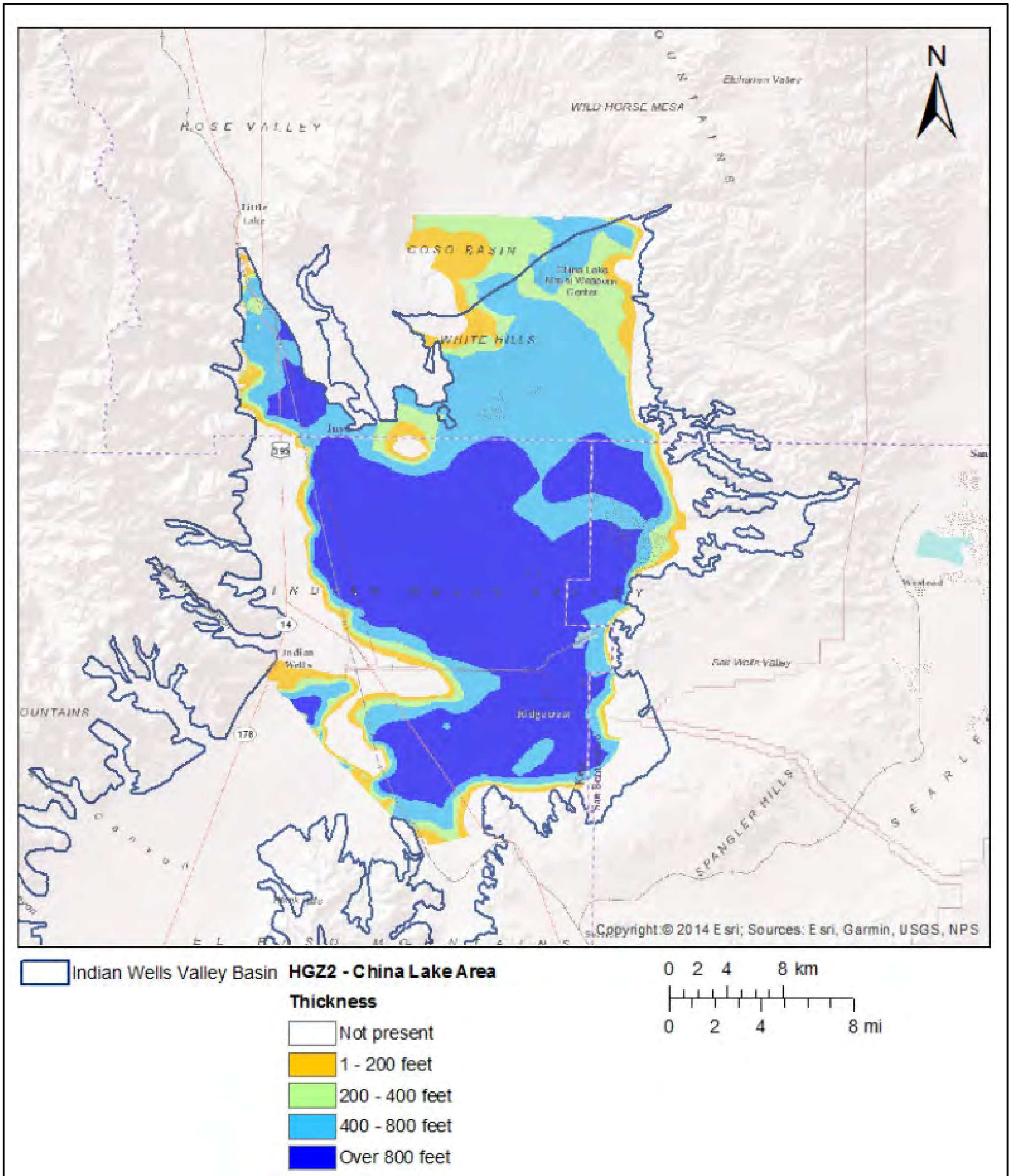
Reference: Ramboll, 2019. Hydrogeologic Conceptual Framework – Indian Wells Valley. Figure 6.5 – Thickness of the HGZ 1 in the China Lake area of the Indian Wells Valley Groundwater Basin, dated June.

Indian Wells Valley
Technical Working Group

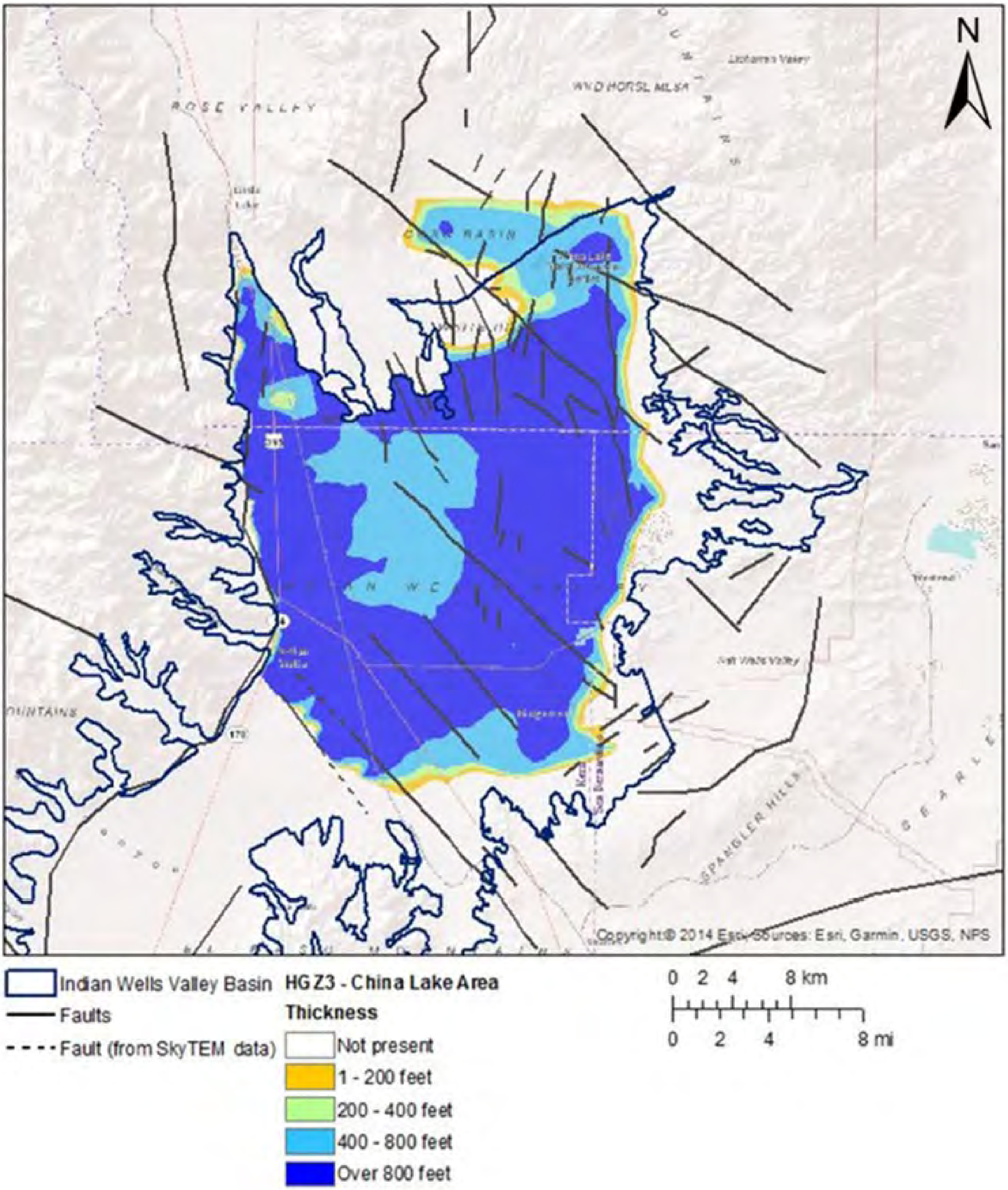
Indian Wells Valley
HGZ 1 Extent And Thickness

Date: 9/18/2023

Figure 30



Reference: Ramboll, 2019. Hydrogeologic Conceptual Framework – Indian Wells Valley. Figure 6.6 – Thickness of the HGZ 2 in the China Lake area of the Indian Wells Valley Groundwater Basin, dated June.	Indian Wells Valley Technical Working Group Indian Wells Valley **HGZ 2 Extent And Thickness** Date: 9/18/2023 — **Figure 31**



Reference: Ramboll, 2019. Hydrogeologic Conceptual Framework – Indian Wells Valley. Figure 6.7 – Thickness of the HGZ 3 in the China Lake area of the Indian Wells Valley Groundwater Basin, dated June.

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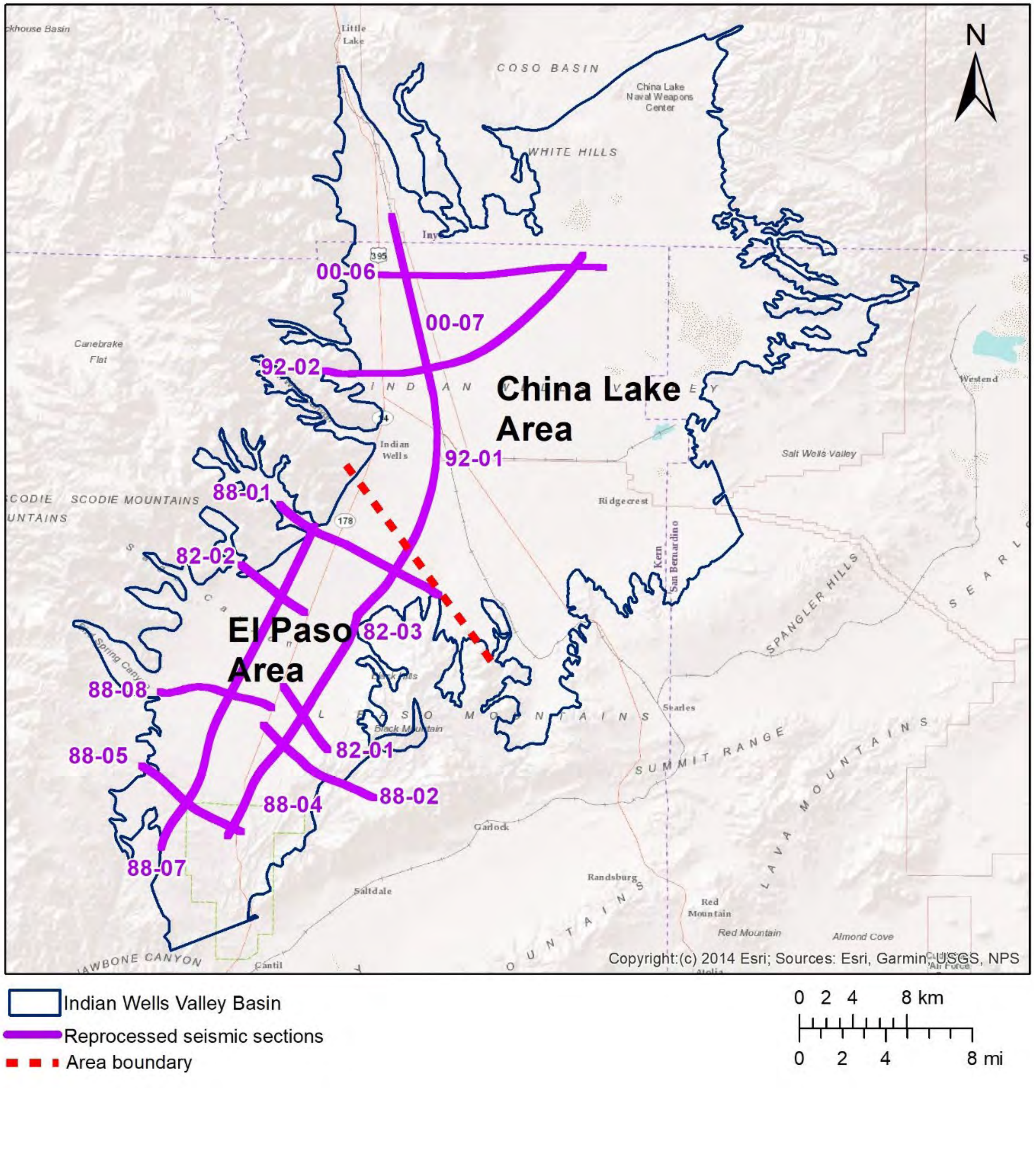
Technical Working Group

Indian Wells Valley
HGZ 3 Extent And Thickness

Date: 9/18/2023		**Figure 32**



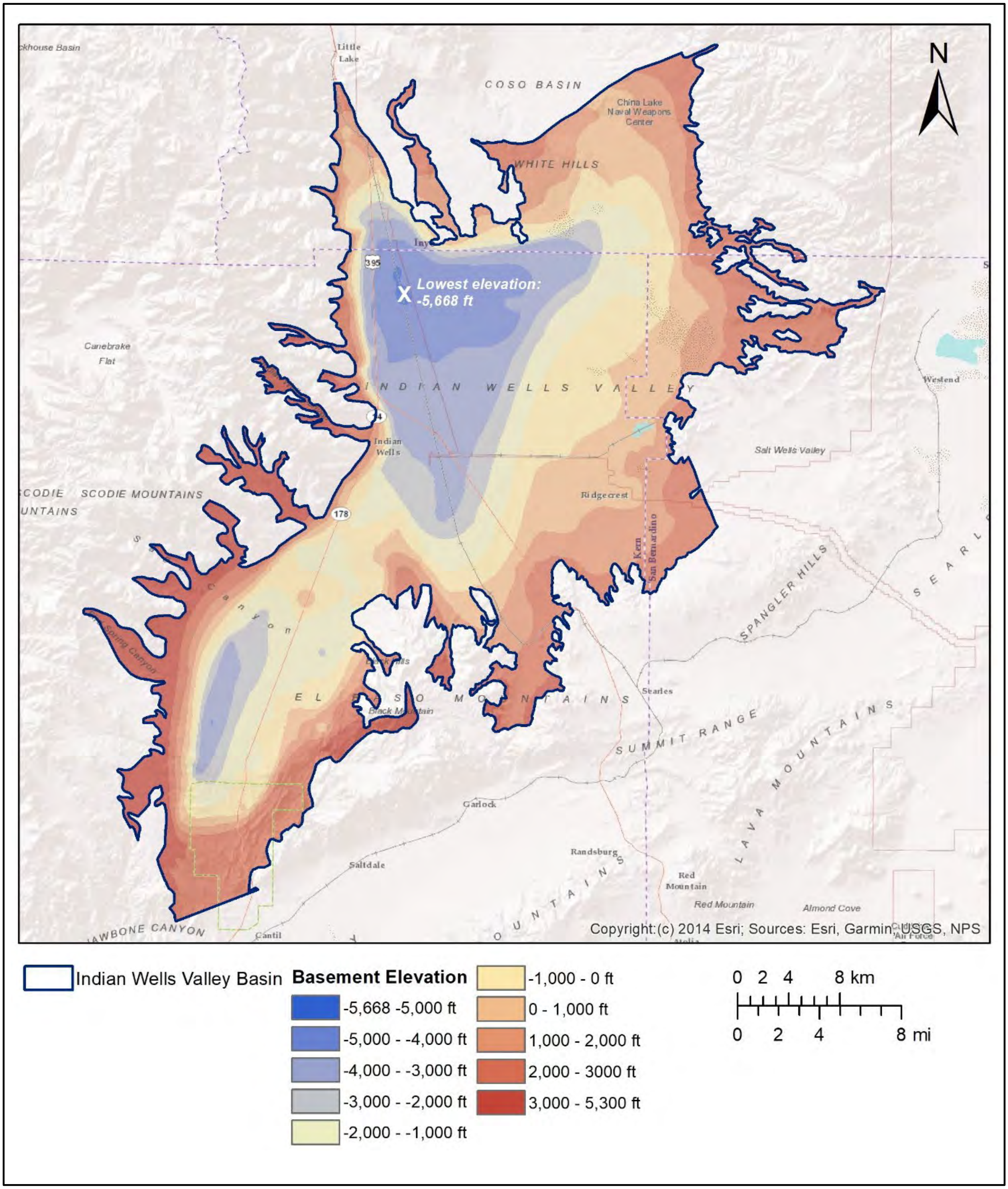
Reference: Ramboll, 2024. Storage Estimate – Indian Wells Valley. Prepared for Indian Wells Valley Water District. September 2022, Revised June 2023 and February 2024.

Indian Wells Valley
Technical Working Group
Indian Wells Valley

Location of the Reprocessed Seismic Lines in the Indian Wells Vally Basin

Date: 9/18/2023

Figure 33



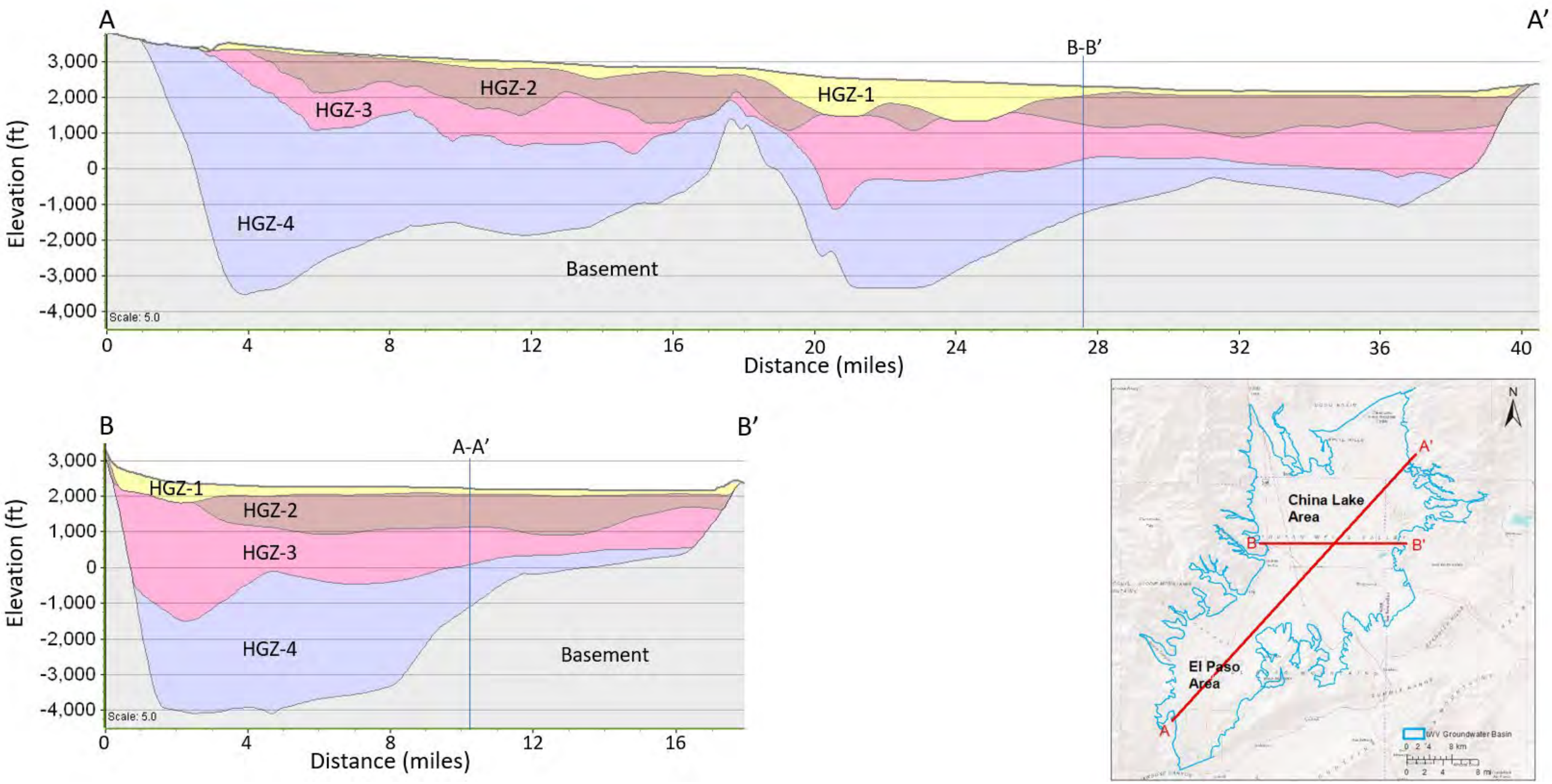
Reference: Ramboll, 2024. Storage Estimate – Indian Wells Valley. Prepared for Indian Wells Valley Water District. September 2022, Revised June 2023 and February 2024.

Indian Wells Valley
Technical Working Group
Indian Wells Valley

Elevation of the Basement in the Indian Wells Valley Basin

Date: 9/18/2023

Figure 34

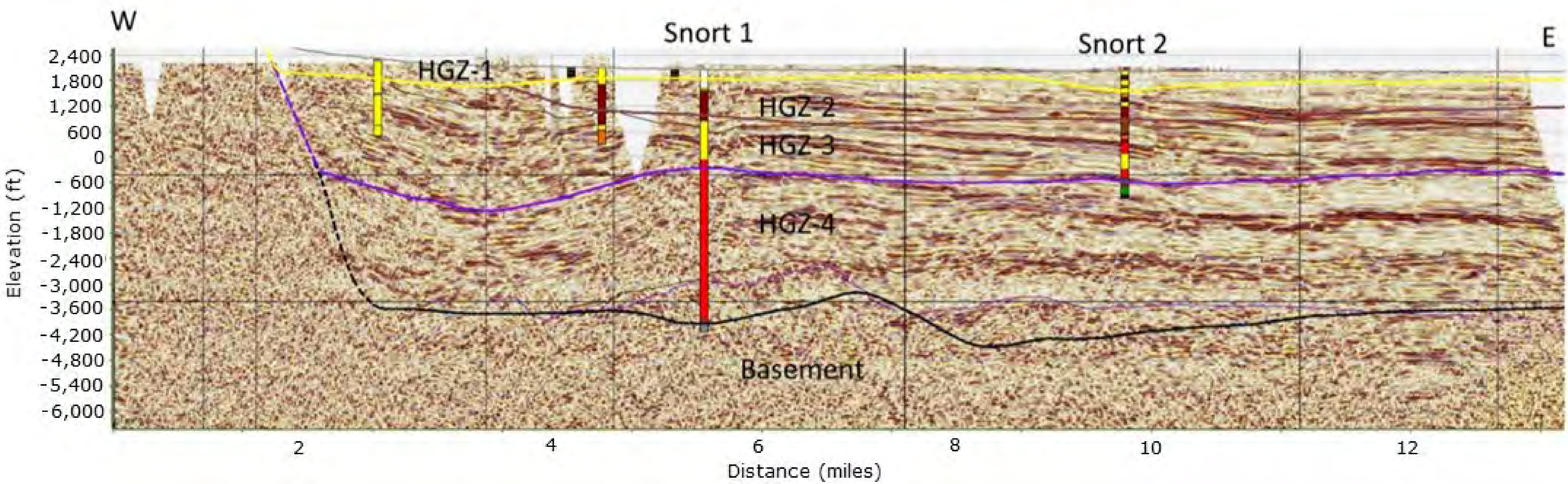


Reference: Ramboll, 2024. Storage Estimate – Indian Wells Valley. Prepared for Indian Wells Valley Water District. September 2022, Revised June 2023 and February 2024.

Indian Wells Valley
Technical Working Group
Indian Wells Valley

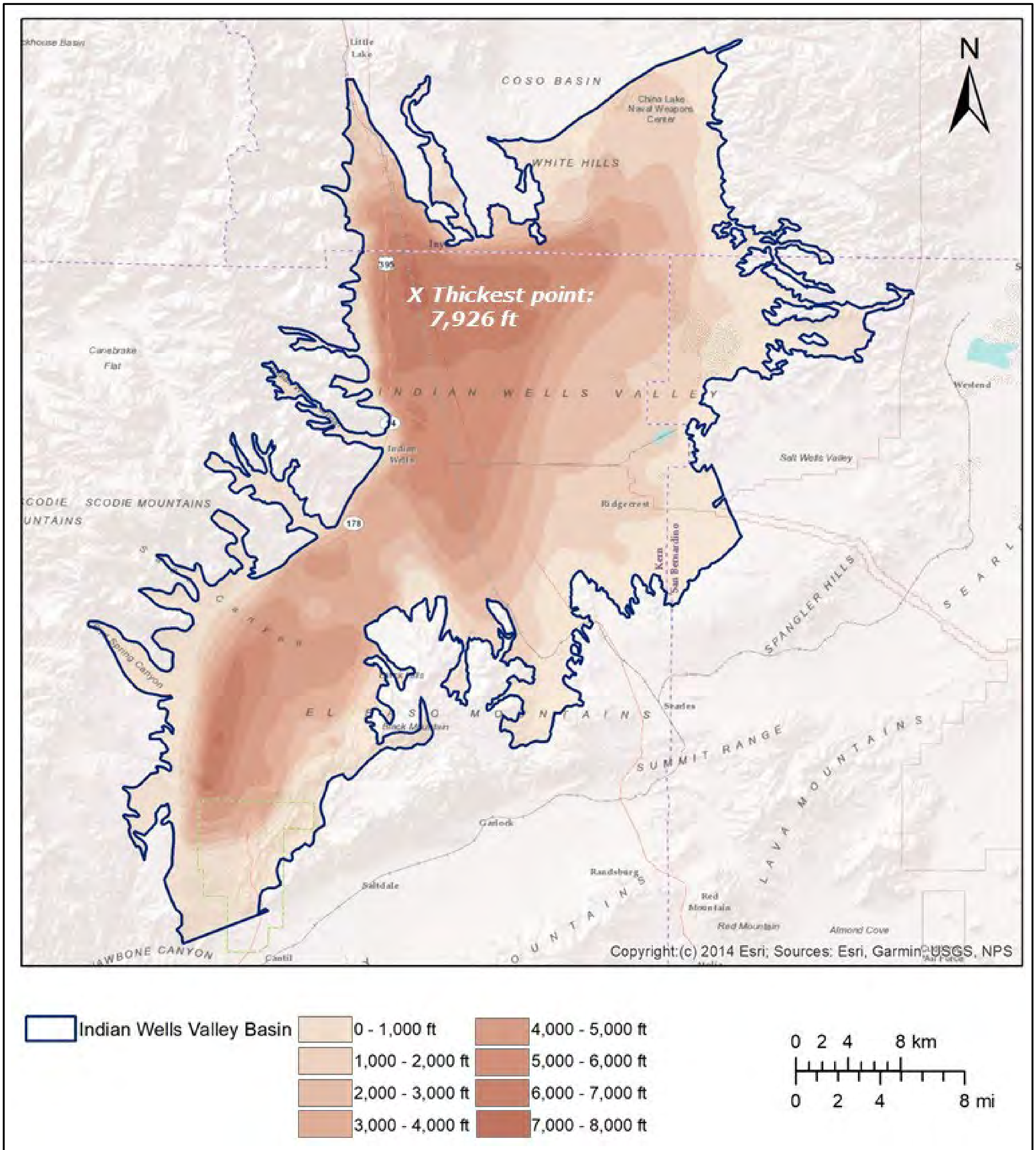
Cross-Sections Showing the Updated HCF, Including the Four HGZs, & Location Map

Date: 9/18/2023		**Figure 35**



Reference: Ramboll, 2024. Storage Estimate – Indian Wells Valley. Prepared for Indian Wells Valley Water District. September 2022, Revised June 2023 and February 2024.

Indian Wells Valley Technical Working Group Indian Wells Valley **Seismic Section 92-02, as Interpreted in the Updated HCF**		
Date: 9/18/2023		**Figure 36**



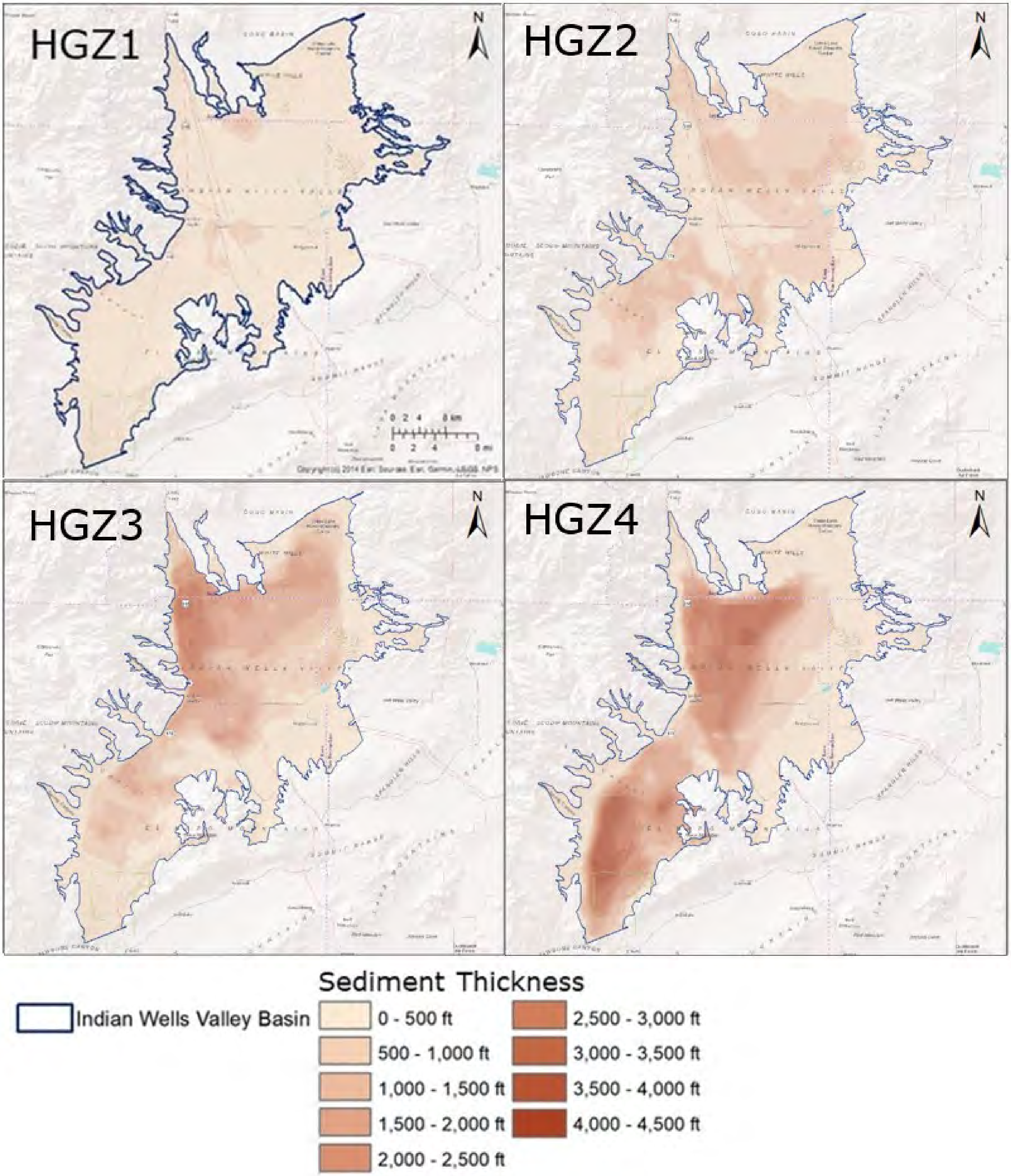
Reference: Ramboll, 2024. Storage Estimate – Indian Wells Valley. Prepared for Indian Wells Valley Water District. September 2022, Revised June 2023 and February 2024.

Indian Wells Valley
Technical Working Group
Indian Wells Valley

Total Thickness of the Sediments in the Indian Wells Valley Basin

Date: 9/18/2023

Figure 37



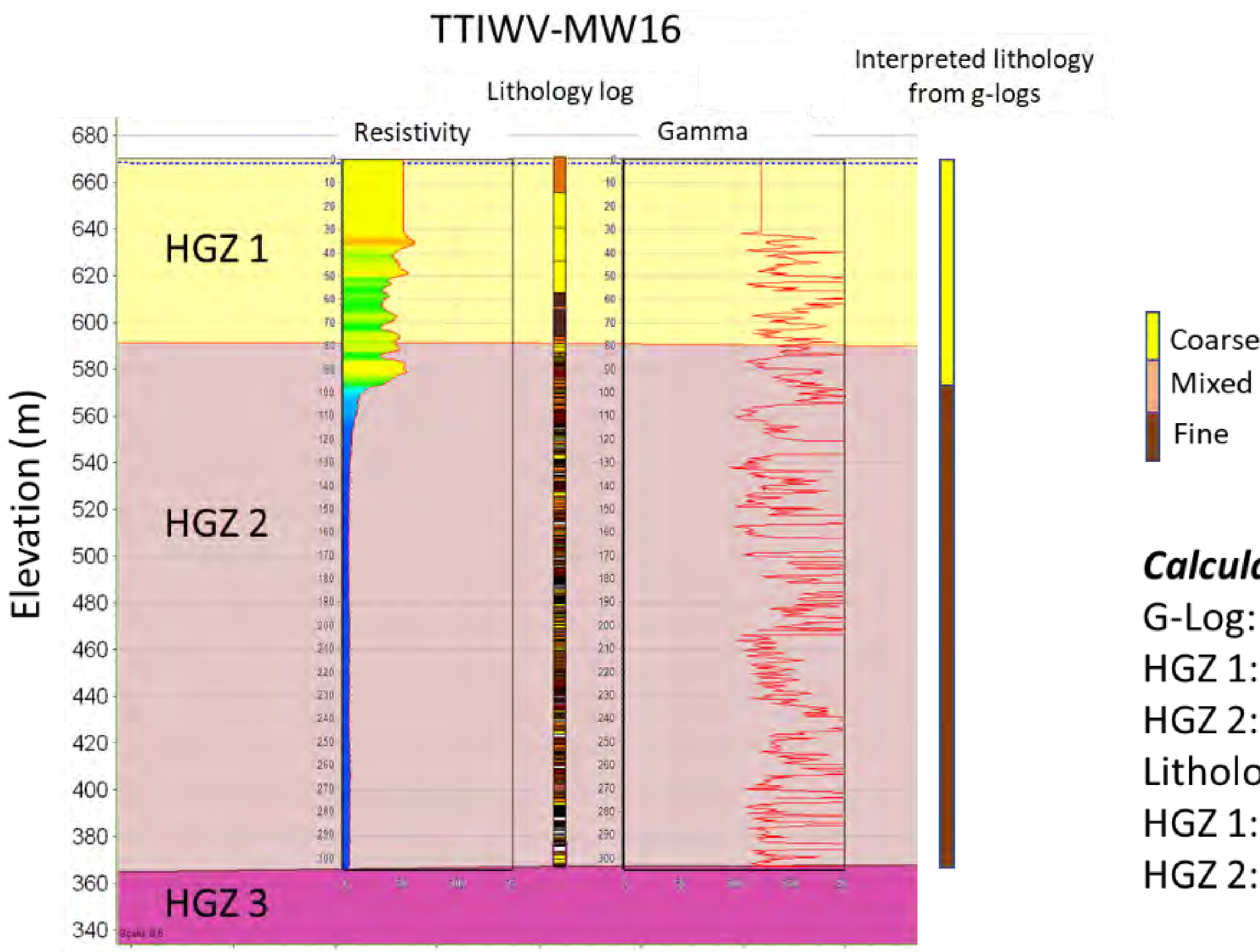
Reference: Ramboll, 2024. Storage Estimate – Indian Wells Valley. Prepared for Indian Wells Valley Water District. September 2022, Revised June 2023 and February 2024.

Indian Wells Valley
Technical Working Group
Indian Wells Valley

Thickness of Each HGZ in the Updated HCF

Date: 9/18/2023

Figure 38



Calculated percent coarse

G-Log:

HGZ 1: 100% Coarse

HGZ 2: 0% Coarse

Lithology Log:

HGZ 1: 70% Coarse

HGZ 2: 16% Coarse

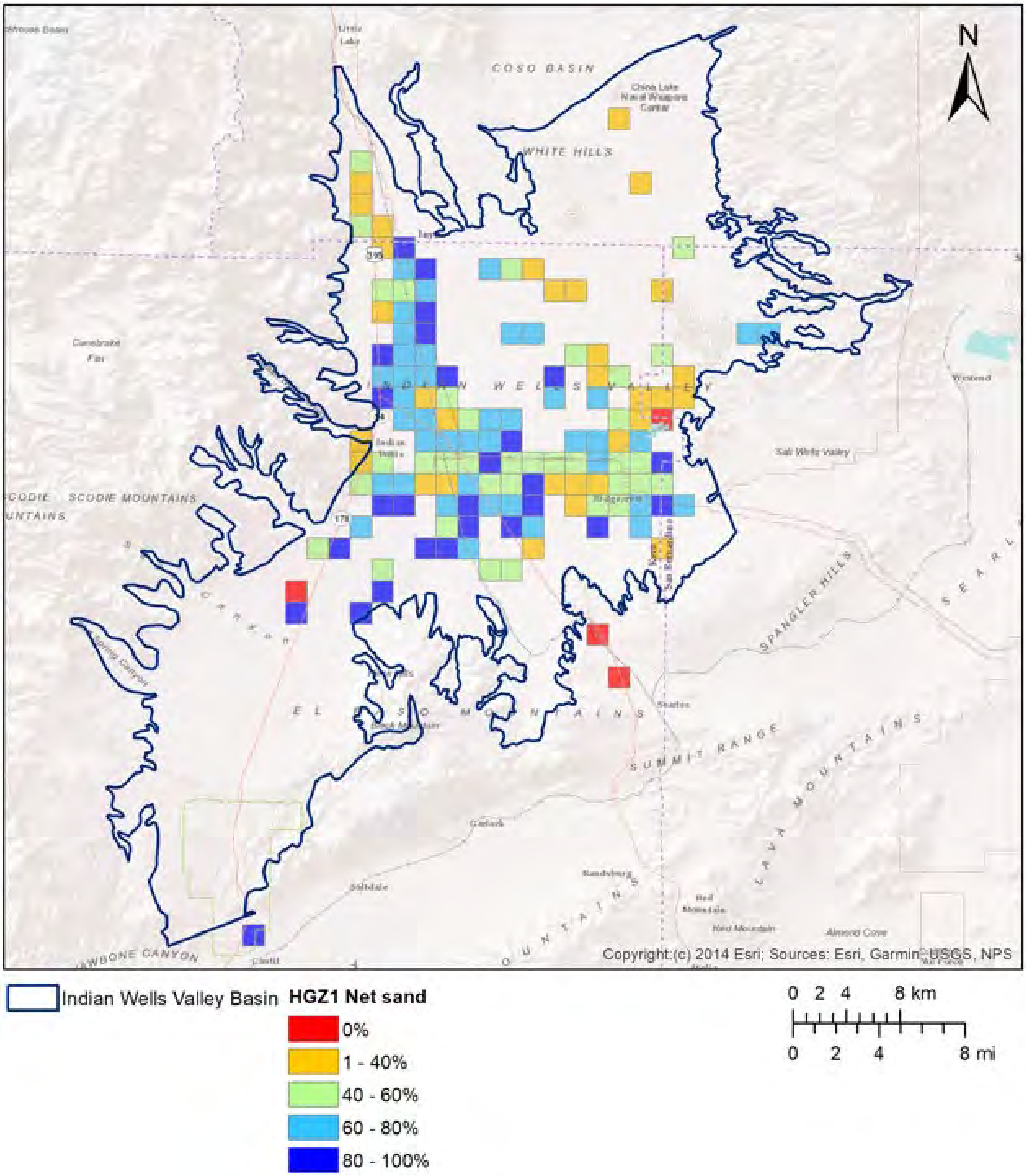
Note that the lithology log is more detailed and does not correspond fully with the resistivity and gamma log. Thus, the interpreted boundary between coarse and fine materials based on the geophysical log, shown on the right side of the figure, is lower than the interpretation from the lithology log.

Reference: Ramboll, 2024. Storage Estimate – Indian Wells Valley. Prepared for Indian Wells Valley Water District. September 2022, Revised June 2023 and February 2024.

Indian Wells Valley
Technical Working Group
Indian Wells Valley

Example Showing How the Net Sand (Coarse Materials) was Interpreted

Date: 9/18/2023		**Figure 39**



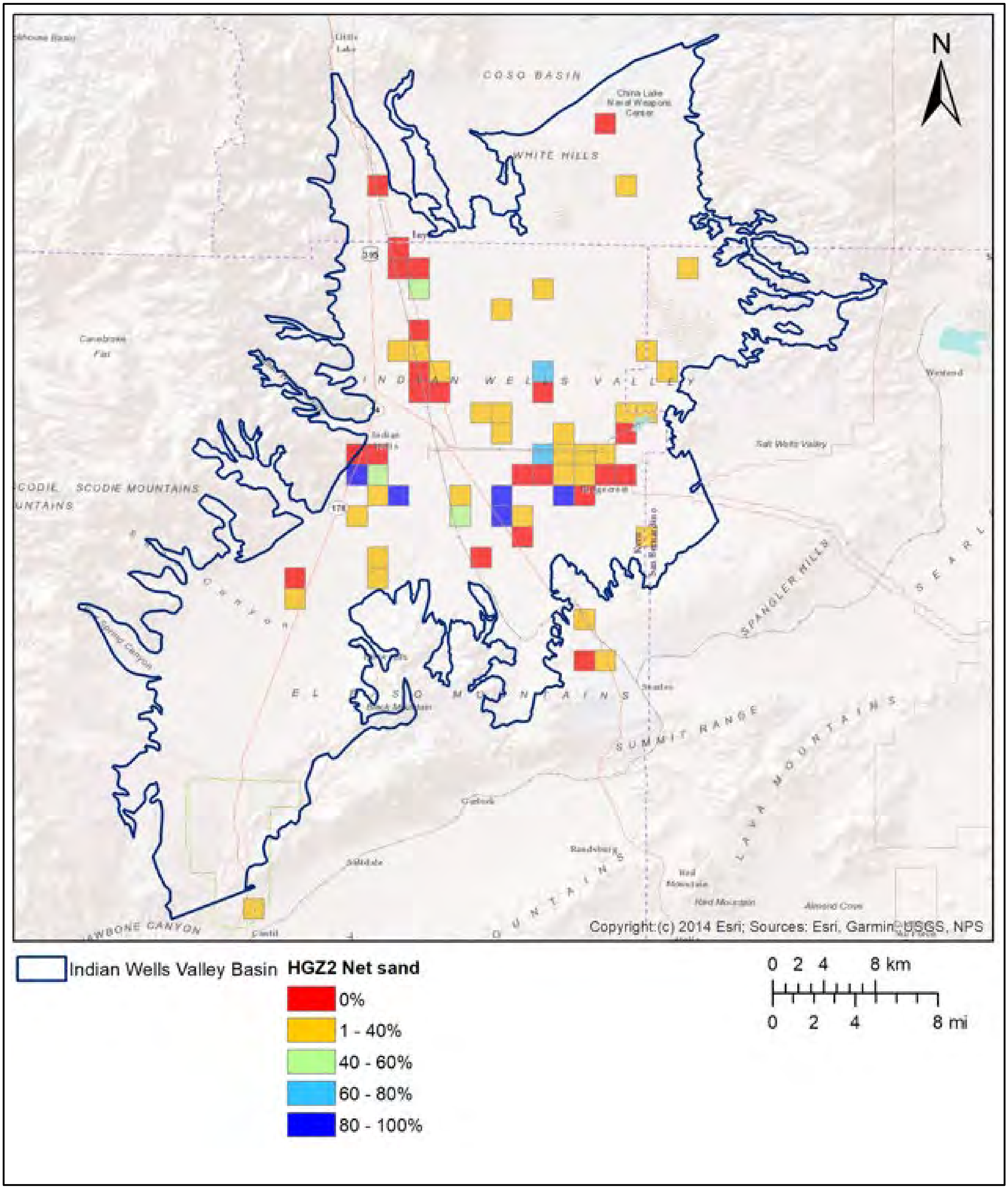
Reference: Ramboll, 2024. Storage Estimate – Indian Wells Valley. Prepared for Indian Wells Valley Water District. September 2022, Revised June 2023 and February 2024.

Indian Wells Valley
Technical Working Group
Indian Wells Valley

Net Sand for HGZ1, Represented in One-Mile Square Grids

Date: 9/18/2023

Figure 40



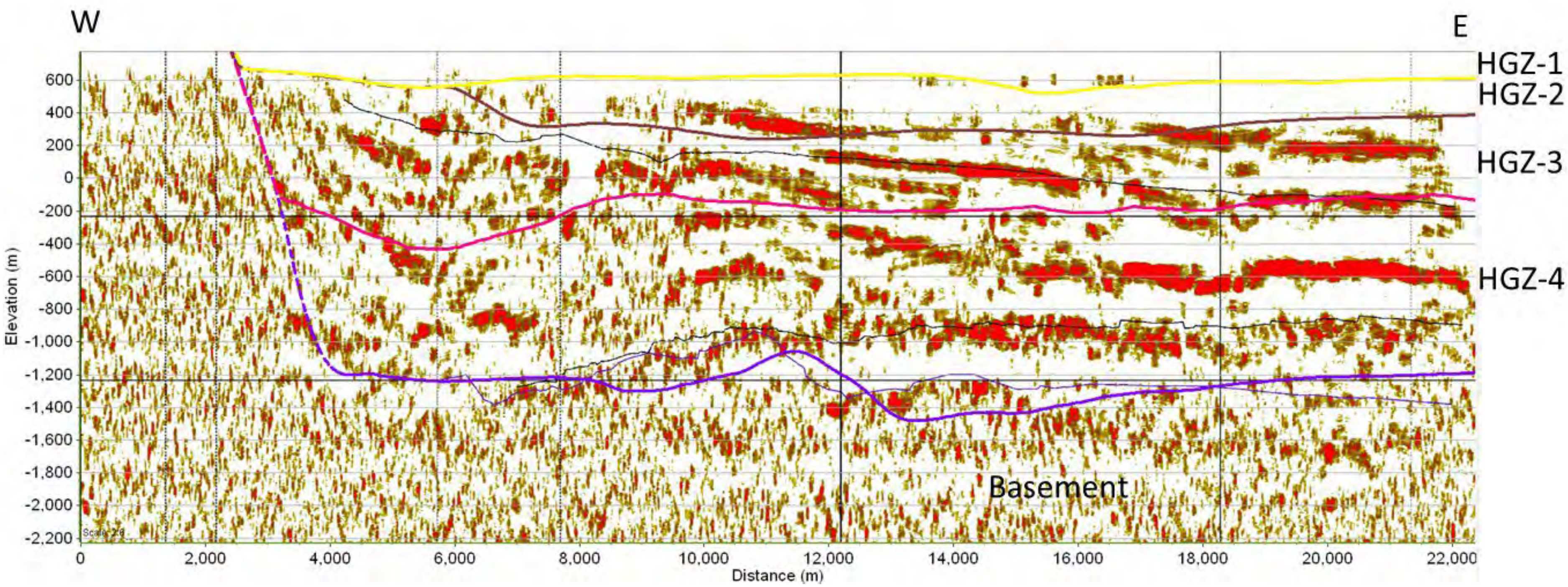
Reference: Ramboll, 2024. Storage Estimate – Indian Wells Valley. Prepared for Indian Wells Valley Water District. September 2022, Revised June 2023 and February 2024.

Indian Wells Valley
Technical Working Group
Indian Wells Valley

Net Sand for HGZ2, Represented in One-Mile Square Grids

Date: 9/18/2023

Figure 41



On this line, HGZ 3 contains of 19% net sand, and HGZ 4 contains 11% net sand.

Reference: Ramboll, 2024. Storage Estimate – Indian Wells Valley. Prepared for Indian Wells Valley Water District. September 2022, Revised June 2023 and February 2024.

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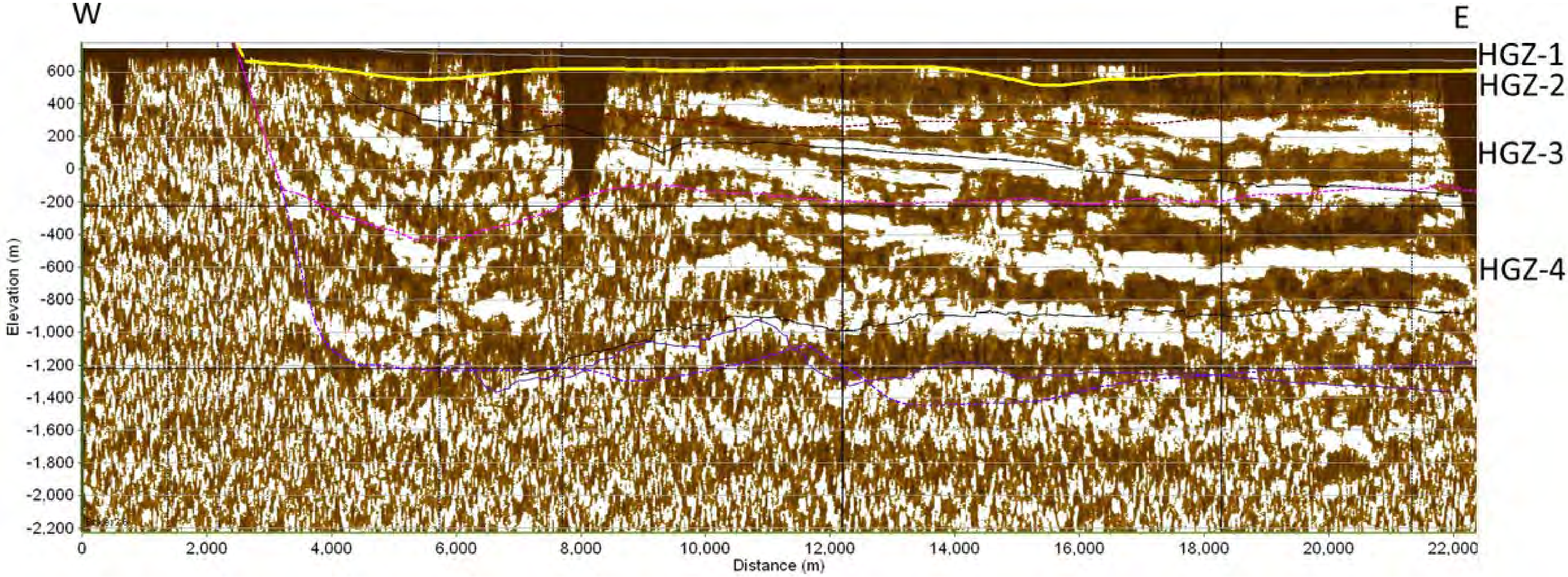
Seismic Line 92-02 Showing the Interpreted Net Sand (Dark Red Colors)

Date: 9/18/2023

Figure 42



Reference: Ramboll, 2024. Storage Estimate – Indian Wells Valley. Prepared for Indian Wells Valley Water District. September 2022, Revised June 2023 and February 2024.

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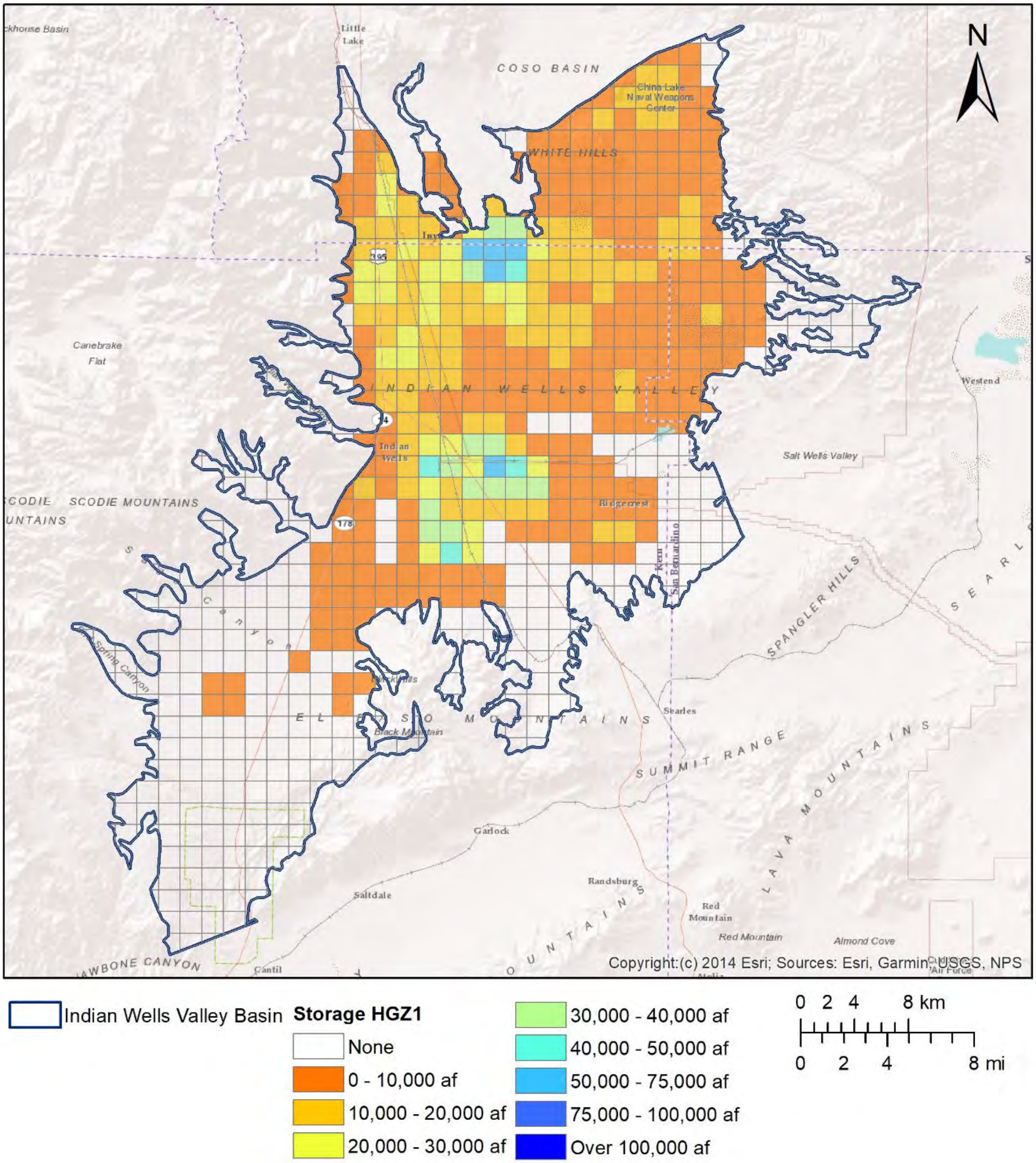
Seismic Line 92-02 Showing the Interpreted Net Clay (Dark Brown Colors)

Date: 9/18/2023		**Figure 43**



Reference: Ramboll, 2024. Storage Estimate – Indian Wells Valley. Prepared for Indian Wells Valley Water District. September 2022, Revised June 2023 and February 2024.

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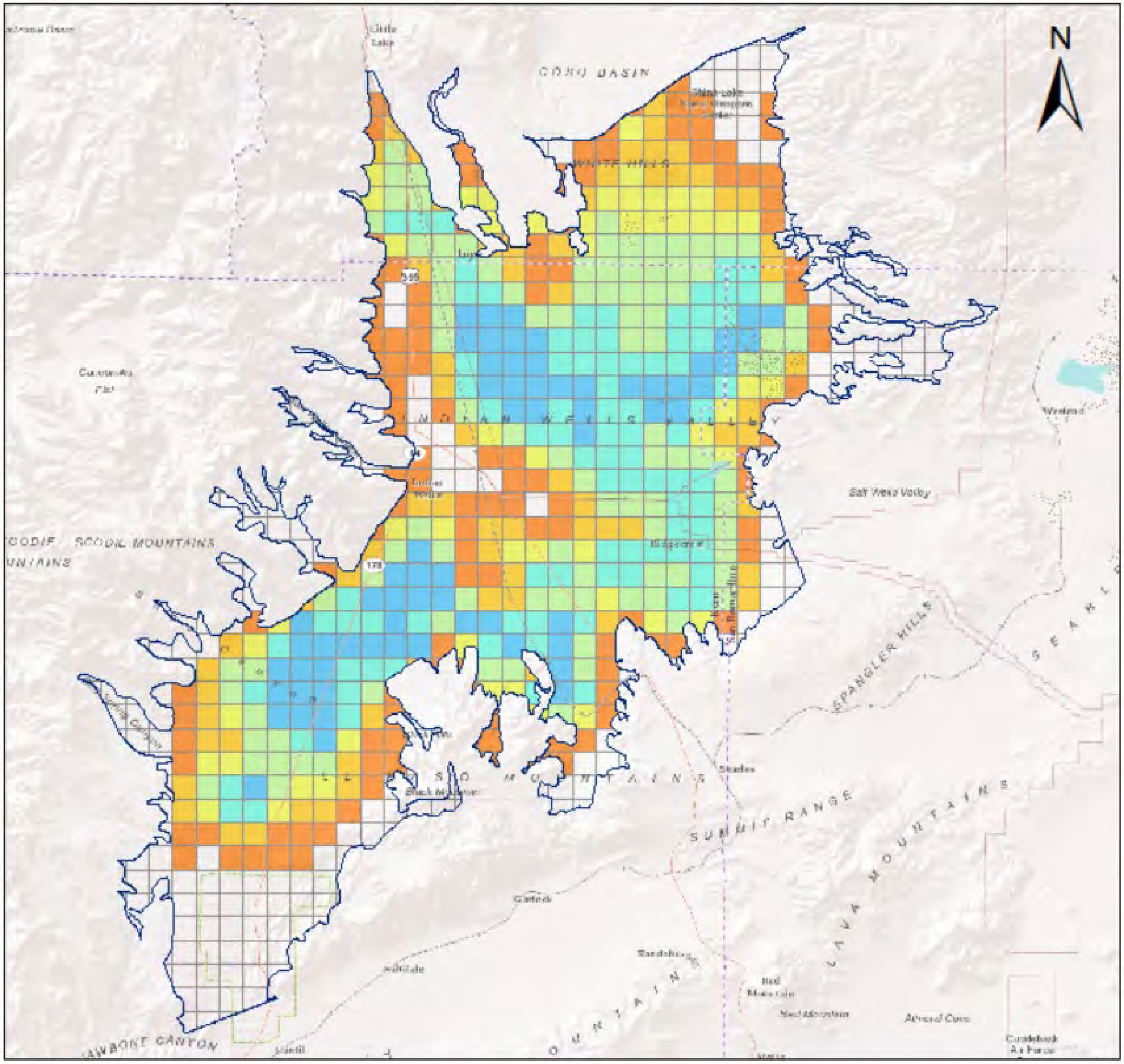
Distribution of Minimum Total Groundwater in Storage in HGZ1

Date: 9/18/2023

Figure 44



IWV Groundwater Basin

Storage HGZ2

- None
- 0 - 10,000 af
- 10,000 - 20,000 af
- 20,000 - 30,000 af
- 30,000 - 40,000 af
- 40,000 - 50,000 af
- 50,000 - 75,000 af
- 75,000 - 100,000 af
- Over 100,000 af

0 2 4 8 km

0 2 4 8 mi

Reference: Ramboll, 2024. Storage Estimate – Indian Wells Valley. Prepared for Indian Wells Valley Water District. September 2022, Revised June 2023 and February 2024.

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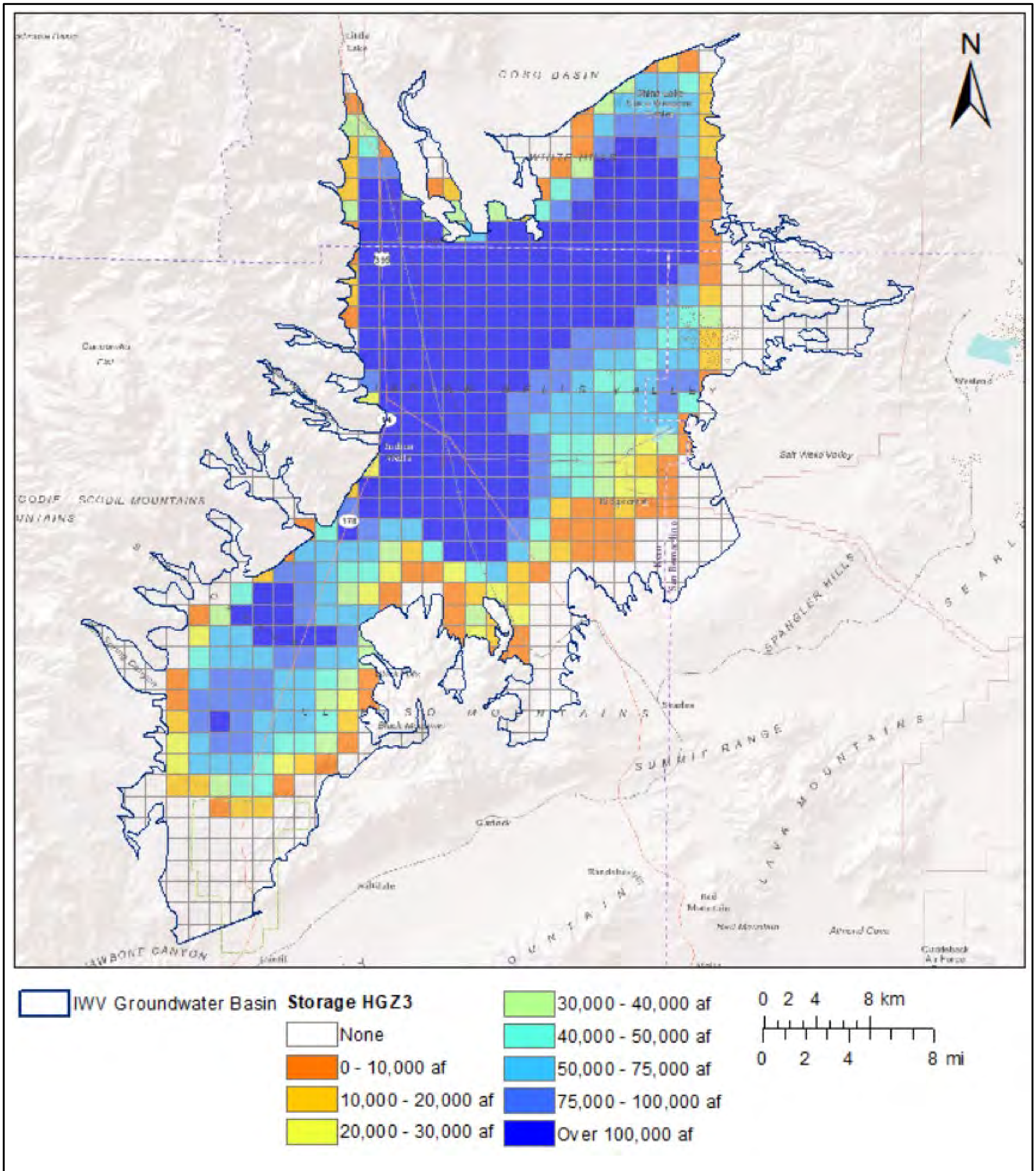
Distribution of Minimum Total Groundwater in Storage in HGZ2

Date: 9/18/2023 | **Figure 45**



Reference: Ramboll, 2024. Storage Estimate – Indian Wells Valley. Prepared for Indian Wells Valley Water District. September 2022, Revised June 2023 and February 2024.

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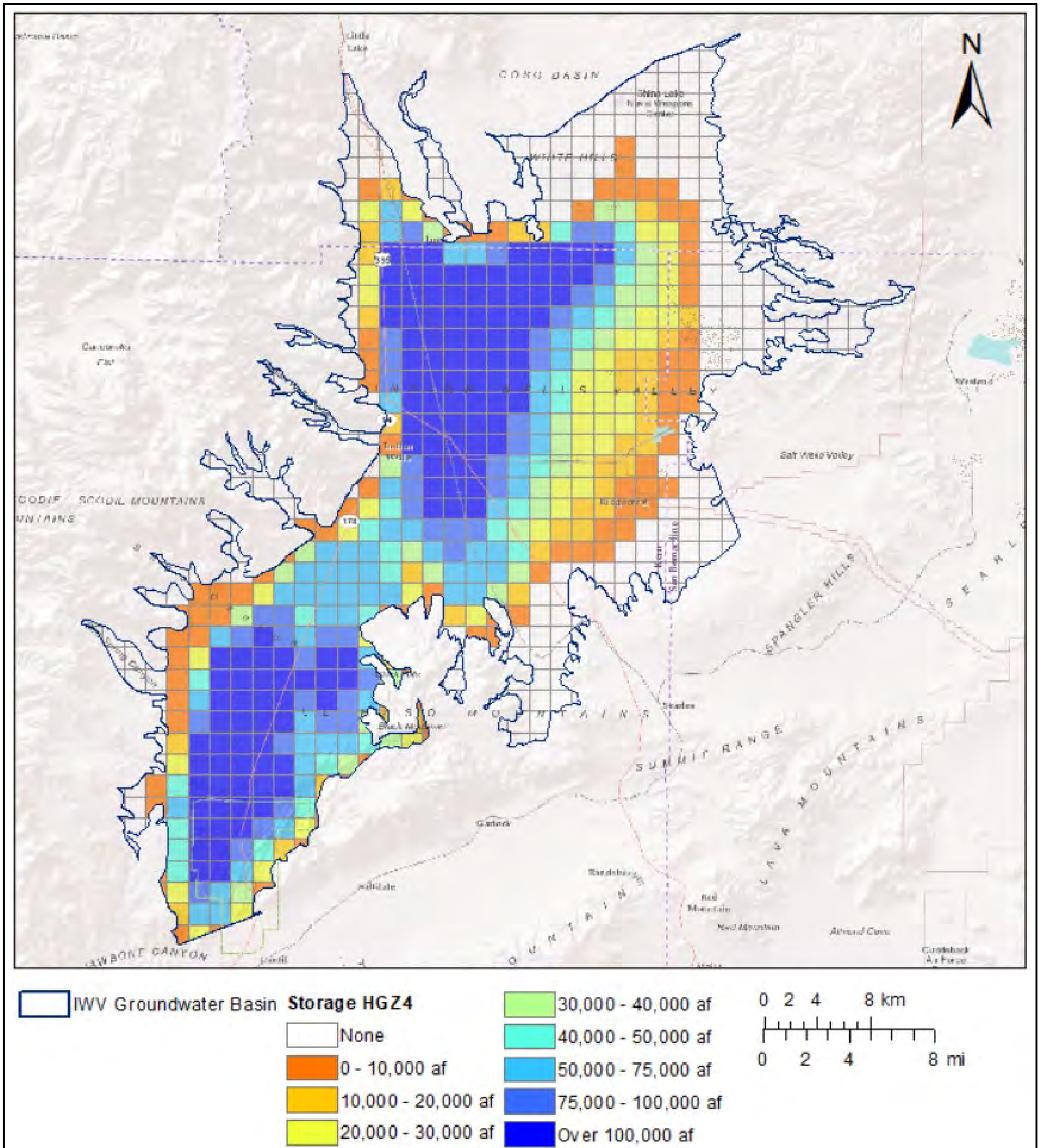
Distribution of Minimum Total Groundwater in Storage in HGZ3

Date: 9/18/2023		Figure 46



Reference: Ramboll, 2024. Storage Estimate – Indian Wells Valley. Prepared for Indian Wells Valley Water District. September 2022, Revised June 2023 and February 2024.

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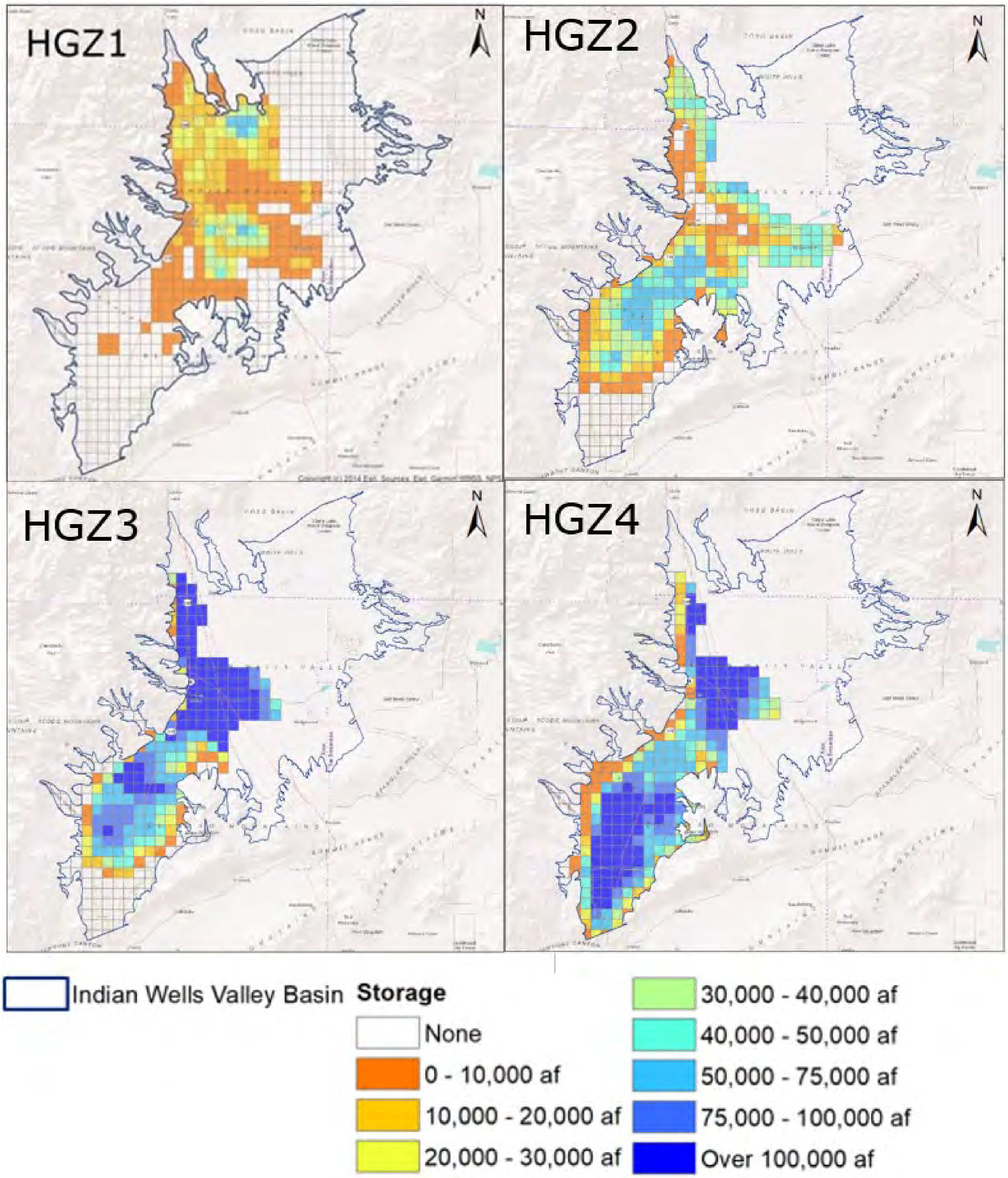
Distribution of Minimum Total Groundwater in Storage in HGZ4

Date: 9/18/2023

Figure 47



Reference: Ramboll, 2024. Storage Estimate – Indian Wells Valley. Prepared for Indian Wells Valley Water District. September 2022, Revised June 2023 and February 2024.

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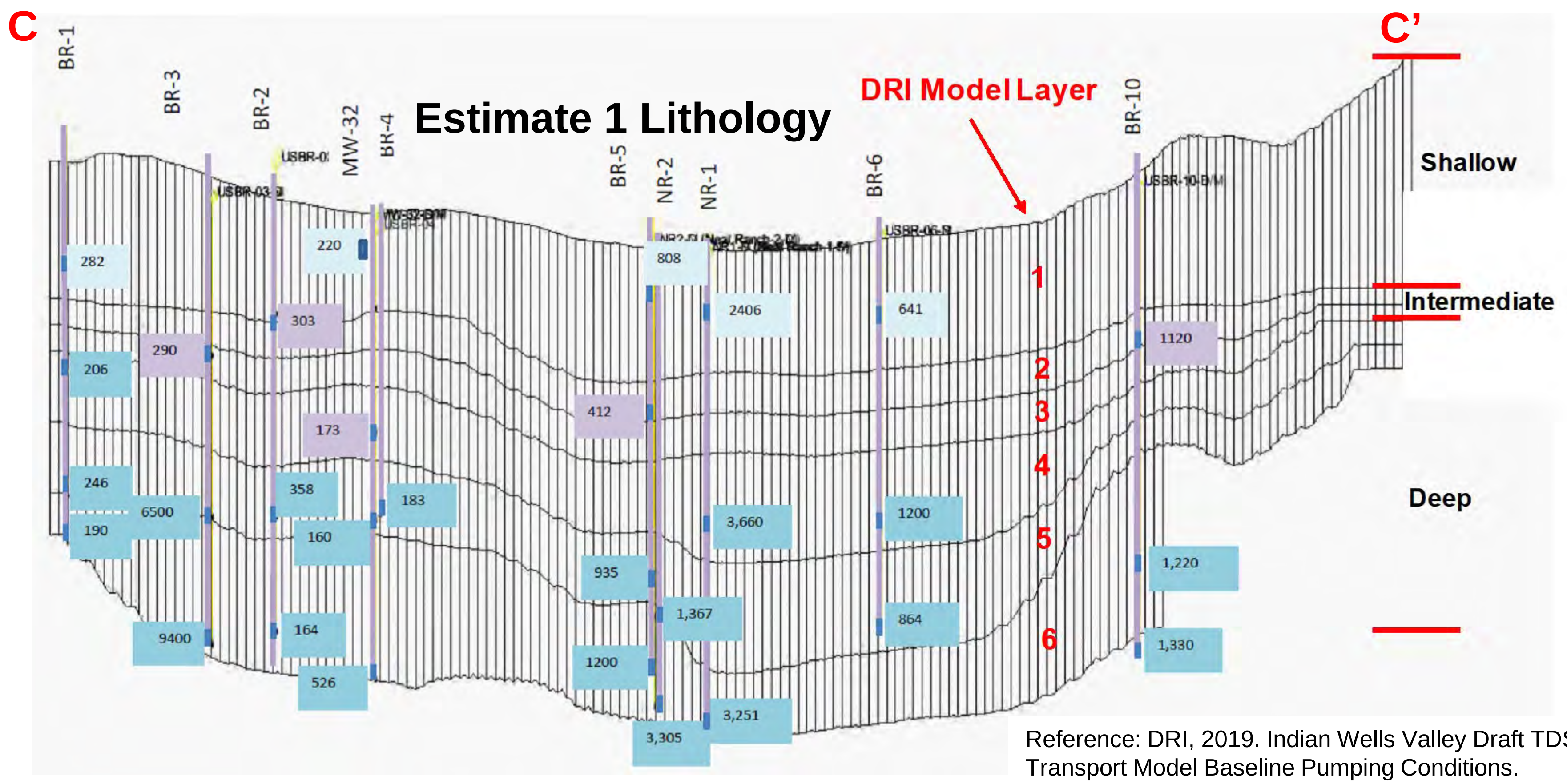
Distribution of Total Groundwater in Storage Under 1,000 mg/L TDS

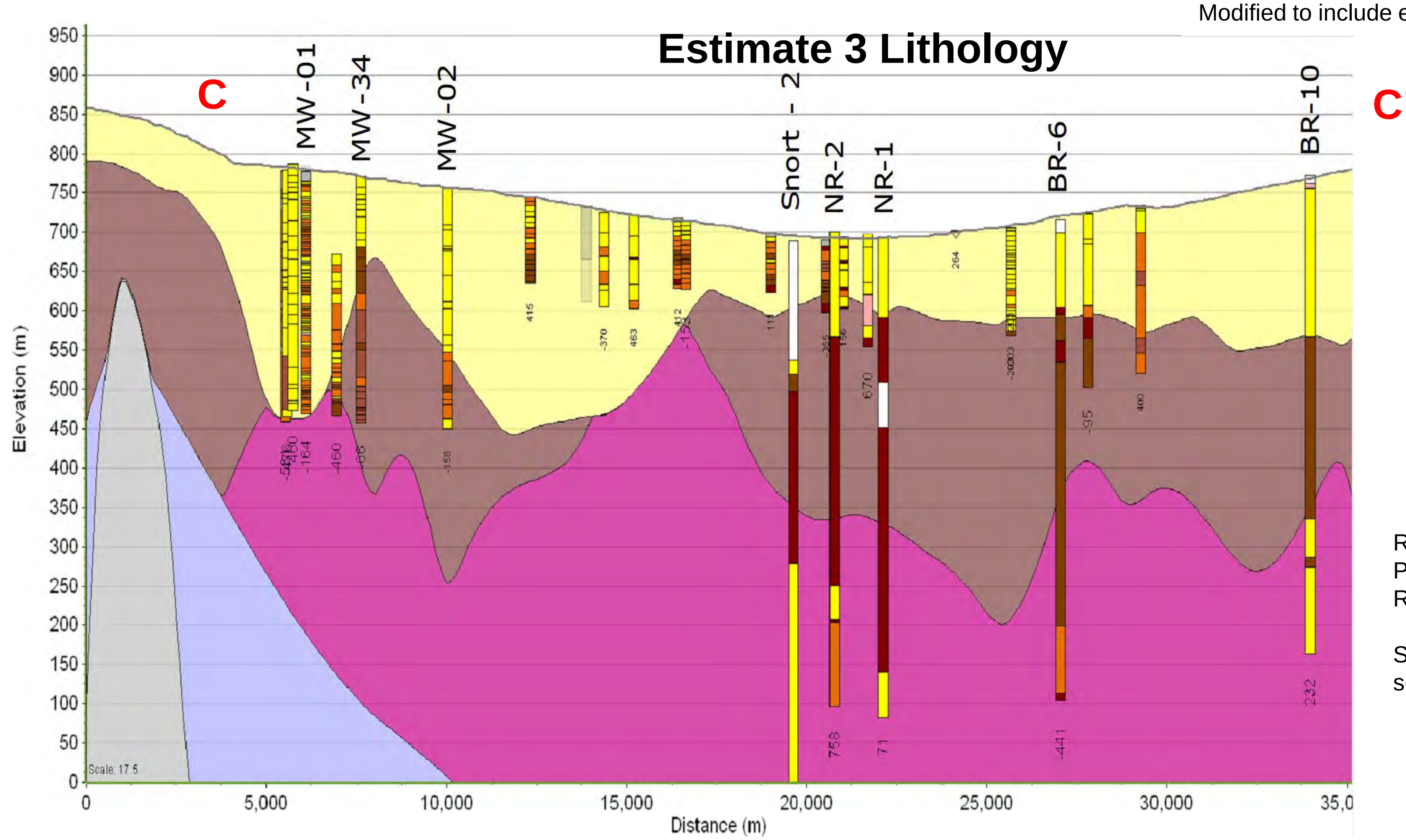
Date: 9/18/2023

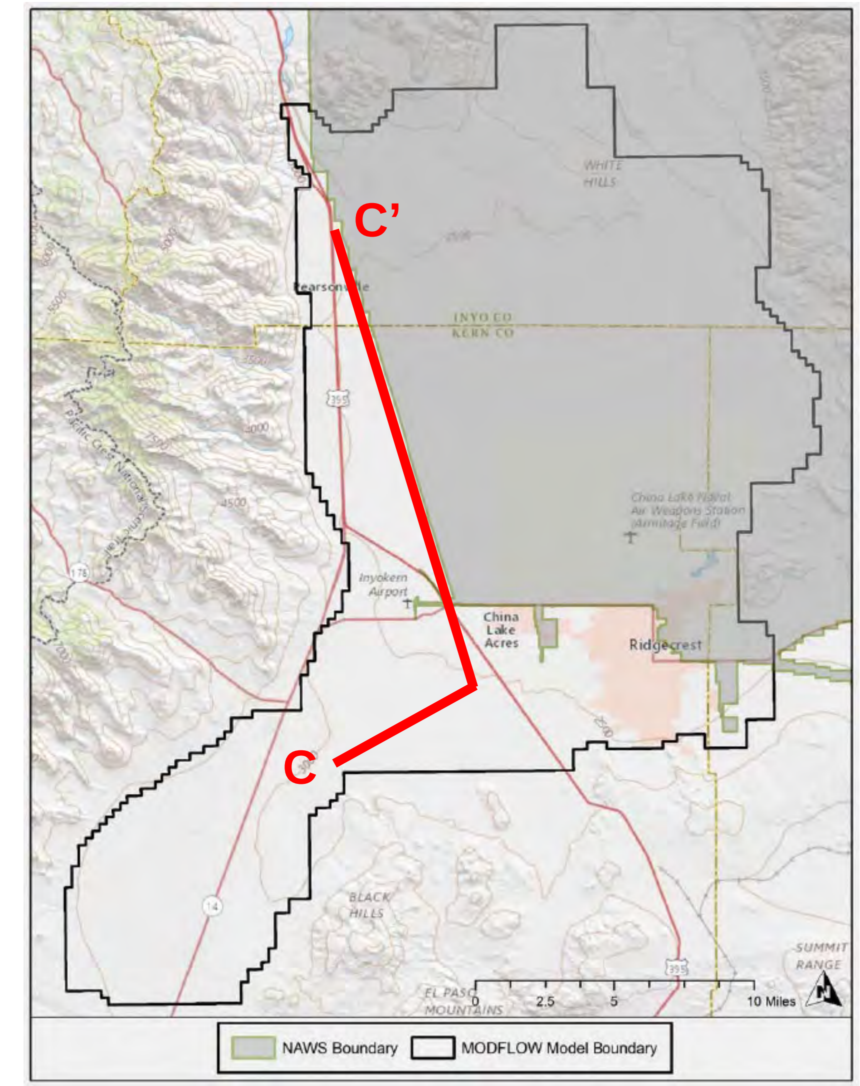
Figure 48



Reference: DRI, 2019. Indian Wells Valley Draft TDS Transport Model Baseline Pumping Conditions. Presentation to IWV TAC. Slide 7, dated February 7.

Modified to include explanatory labels.





Reference: Stetson Engineers. (2017). Indian Wells Valley Model Review of DRI 2017 Model Update. Figure 1. December 7.

Modified to show cross-section location.

Reference: Ramboll, 2024. Storage Estimate – Indian Wells Valley. Prepared for Indian Wells Valley Water District. September 2022, Revised June 2023 and February 2024.

Scales modified to approximately match horizontal and vertical scales of DRI cross-section C-C'.

Indian Wells Valley Technical Working Group Indian Wells Valley **Comparison of Estimate 1 Lithology To Estimate 3 Lithology**		
Date: 9/18/2023		**Figure 49**