aquilogic, Inc.
environment • water • strategy

245 Fischer Avenue, Suite D-2
Costa Mesa, CA 92626
Tel. +1.714.770.8040
Web: www.aquilogic.com

February 5, 2019

Matthew H. Litchfield, P.E.
Assistant General Manager
Three Valleys Municipal Water District
1021 E. Miramar Avenue
Claremont, CA 91711-2052

sent via email to:
mlitchfield@tvmwd.com

Re.: Report of the Independent Peer Review Panel for the Groundwater Monitoring, Management, and Mitigation Plan (GMMMP) for the Cadiz Project

Dear Mr. Litchfield:

The report of the Independent Peer Review Panel ("the Panel") for the Groundwater Monitoring, Management, and Mitigation Plan (GMMMP) for the Cadiz Project accompanies this letter.

The Panel appreciates the opportunity to submit this report to Three Valleys Municipal Water District (TVMWD) and Jurupa Community Services District (JCSD). Should you have any questions, please do not hesitate to contact me at (949) 939-7160.

Sincerely,

aquilogic, Inc.

Anthony Brown
CEO and Principal Hydrologist

Wildermuth Environmental, Inc.

Mark J. Wildermuth

Mark Wildermuth, P.E.
President

Balleau Groundwater, Inc.

Dave Romero
President

Parker Groundwater

Timothy K. Parker

Tim Parker, PG, CHg
President and Principal Hydrogeologist

cc. Eldon Horst, JCSD

aquilogic, Inc.
environment ● water ● strategy

245 Fischer Avenue, Suite D-2
Costa Mesa, CA 92626
Tel. +1.714.770.8040
Web: www.aquilogic.com

REPORT OF THE INDEPENDENT PEER REVIEW PANEL FOR THE GROUNDWATER MANAGEMENT, MONITORING, AND MITIGATION PLAN (GMMMP) FOR THE CADIZ VALLEY GROUNDWATER CONSERVATION, RECOVERY AND STORAGE PROJECT

San Bernardino County, California

Prepared for:
Three Valleys Municipal Water District (TVMWD)
1021 E. Miramar Avenue
Claremont, CA 91711-2052

Prepared by:
Panel:
Anthony Brown, **aquilogic**
Mark Wildermuth, **Wildermuth Environmental**
Dave Romero, **Balleau Groundwater**
Tim Parker, **Parker Groundwater**

February 5, 2019

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

ACRONYMS AND ABBREVIATIONS

Note:	acronyms and abbreviations are spelled out in both the Executive Summary, which may be read independently, and the body of the report starting at Section 2.0: Introduction
A	cross-sectional area
ARZC	Arizona and California Railroad
AF	acre-feet
AFY	acre-feet per year
b	aquifer thickness
bgs	below ground surface
cm	centimeters
Cadiz	Cadiz, Inc.
Cadiz Project	Cadiz Valley Water Conservation, Recovery, and Storage Project
CEQA	California Environmental Quality Act
d	day
DRI	Desert Research Institute
E	modules of elasticity
Et	evapotranspiration
°F	degrees Fahrenheit
FEIR	Final Environmental Impact Report
ft	feet
gpm	gallons per minute
GMMMP	Groundwater Management, Monitoring, and Mitigation Plan
Panel	Panel
K	hydraulic conductivity
Km	kilometer
i	hydraulic gradient
L	liter
m	meter
MAF	million acre-feet
mg/L	milligrams per liter
mi	mile
MSL	mean sea level
N	porosity
n_e	effective porosity
Ppt	precipitation
Pi1	intergranular soil pressure prior to pumping
Pi2	intergranular soil pressure at maximum drawdown
ppb	parts per billion
Q	flow rate (quantity of water per time)
S	storativity
SMWD	Santa Margarita Water District
Su	compression of aquifer
SWP	State Water Project
T	transmissivity

TDS	total dissolved solids
USA	United States of America
USGS	United States Geological Survey
V	velocity (distance per time)
W	aquifer unit width
yr	year
Z	thickness of aquifer layer

1.0 EXECUTIVE SUMMARY

1.1 Introduction

An Independent Peer Review Panel ("Panel") was retained by Three Valleys Municipal Water District (TVMWD) and Jurupa Community Services District (JCSD) to conduct an impartial, objective, third-party review ("Review") of the Groundwater Management, Monitoring, and Mitigation Plan (GMMMP) for the Cadiz Valley Water Conservation, Recovery, and Storage Project (the Cadiz Project) and associated documentation. The Review was conducted in light of continuing study and reports that have been generated for, or pertinent to, the Cadiz Project after the certification of the Final Impact Report ("FEIR") for the Cadiz Project (ESA, 2012a) and the adoption of the GMMMP by the County of San Bernardino (ESA, 2012b).

The Panel consisted of the following groundwater professionals not previously employed by Cadiz: Anthony Brown of Aquilogic, Inc. (**aquilogic**), Tim Parker of Parker Groundwater - Technology, Innovation, Management, Inc. (**Parker Groundwater**), Mark Wildermuth of Wildermuth Environmental, Inc. (**WEI**), and Dave Romero of Balleau Groundwater Inc. (**BGW**) (see **Appendix A**).

1.1.1 Cadiz Project

The Cadiz Project is located at the confluence of the Fenner, Orange Blossom Wash, Bristol and Cadiz watersheds in eastern San Bernardino County (see **Figure 1** and **Appendix B**). Within this closed basin system, groundwater percolates and migrates downward from the higher elevations and eventually flows to Bristol and Cadiz dry lakes where it evaporates after mixing with the highly saline groundwater zone under the dry lakes. The portion that evaporates is lost from the groundwater basin and is unable to support beneficial uses. The fundamental purpose of the Cadiz Project is to conserve the substantial quantities of groundwater that are presently wasted and lost to evaporation to create a local water supply alternative for Southern California. Under the conservation and recovery component of the Cadiz Project, an average of 50,000 acre-feet per year (AFY) of groundwater would be pumped from the basin over a 50-year period.

1.1.2 Panel Objectives

The focus of the Review was to evaluate whether the GMMMP was sufficient to ensure that the proposed pumping at the Cadiz Project would not result in Potential Significant Adverse Impacts to Critical Resources ("Undesirable Results") that could not be effectively mitigated. The objectives of the Panel were to assess whether the GMMMP (ESA, 2012b):

- Provided sufficient management and monitoring to identify any Undesirable Results that could occur in response to proposed groundwater pumping as part of the Cadiz Project

- Provided effective Corrective Measures (i.e., mitigation) to address any Undesirable Results that do occur

In addition, where deemed necessary, the Panel has provided recommendations for management, monitoring, and mitigation procedures, and recommend additional work to improve the understanding of the hydrology of the Cadiz Project area. It should be noted that none of these recommendations are associated with a failure of the GMMMP to provide sufficient management, monitoring, and mitigation of Undesirable Results.

1.2 Groundwater Management, Monitoring, and Mitigation Plan

The GMMMP (ESA, 2012b) was developed to guide the long-term groundwater management of the groundwater basins tributary to the Cadiz Project. The GMMMP was a component of the FEIR for the Cadiz Project (ESA, 2012a), completed in accordance with the California Environmental Quality Act (CEQA) Guidelines Sections 15161 and 15378(a).

The success or failure of the GMMMP to manage and mitigate potential harm to Critical Resources will determine whether Undesirable Results actually occur. It should be noted that not all impacts from the proposed pumping at the Cadiz Project are deemed “significant and unreasonable”; that is, not all impacts are an Undesirable Result. Certain impacts may be less than significant but would still be monitored and managed in accordance with the GMMMP (ESA, 2012b). Other impacts may be deemed significant but the GMMMP provides Corrective Measures to reduce the impacts so they are no longer significant. The adaptive management approach within the GMMMP allows the plan to adapt to new data, new concerns, new technologies, etc. to ensure that either no Undesirable Results occur or, if they occur, they can be effectively mitigated. The following six Critical Resources were identified in the GMMMP (ESA, 2012b):

1. Basin Aquifers
2. Springs within the Fenner Watershed
3. Brine Resources at Bristol and Cadiz dry lakes
4. Air Quality
5. Project Area Vegetation
6. Colorado River and its Tributary Sources of Water

The GMMMP includes monitoring of spring flows, spring flow quality, vegetation, groundwater levels, groundwater quality, ground surface subsidence, migration of the saline-fresh water interface, brine resources, air quality, and soil conditions. In general, the monitoring in the GMMMP is appropriate to identify potential Undesirable Results. In addition, the monitoring thresholds that trigger mitigation are appropriate. Together, the monitoring and trigger thresholds are protective of Critical Resources.

The GMMMP (ESA, 2012b) also proposes Corrective Measures that have an effect throughout the watersheds (e.g., modification or cessation of pumping at the Cadiz Project well-field). Where such Corrective Measures will not prevent an ongoing impact, or will not alleviate an impact in a reasonable period of time, the GMMMP proposes resource-specific measures to address an Undesirable Result at a Critical Resource. In general, the mitigation in the GMMMP is practical and appropriate.

While the monitoring, management, and mitigation in the GMMMP is appropriate, the Panel has provided recommendations to supplement the GMMMP (see **Sections 1.3 and 7**).

1.2.1 Potential Impacts to Aquifers

The response of the aquifer system to the proposed pumping at the Cadiz Project was evaluated using numerical groundwater modeling (GSSI, 2011). In response to the cessation of pumping, an immediate aquifer water-level recovery is observed proximate to the Cadiz Project well-field. However, at some distance from the well-field, groundwater levels continued to decline. Under such circumstances, an Undesirable Result may occur many years after the implementation of a mitigation action (e.g., the cessation of pumping). Given the propagation of the cone of depression after pumping stops, continued monitoring of groundwater conditions proximate to Critical Resources will continue after mitigation is implemented, as proposed in the GMMMP (ESA, 2012b, Section 6.4.3).

It is noted that the GMMMP (ESA, 2012b) and FEIR (ESA, 2012a) considered the delay in the propagation of the cone of depression by evaluating potential Undesirable Results over a 100-year period. No Undesirable Results were identified in the FEIR that could not be mitigated, considering the drawdown that would result over 100 years using various recharge rates as low as 5,000 AFY.

Despite the fact that no un-mitigatable Undesirable Results were identified in the FEIR (ESA, 2012a), monitoring of overall groundwater conditions in the watersheds tributary to the Cadiz project was proposed in the GMMMP (ESA, 2012b). This monitoring is appropriate and protective of overall aquifer conditions.

A groundwater level drawdown threshold (80 feet) is proposed in the GMMMP (ESA, 2012b) for a distance of two miles from the center of the Cadiz Project well-field. This threshold is intended to provide a management “floor” below which mitigation actions would be triggered. Such a floor was selected as it lessens the need for resource-specific mitigation actions at individual Critical Resources, and it provides a proactive Corrective Measure that would prevent significant impact.

1.2.2 Potential Impacts to Springs within the Fenner Watershed

Opponents to the Cadiz Project have expressed concerns that the proposed pumping at the Cadiz Project might lower groundwater elevations in the fractured bedrock watershed that supports flow at Bonanza Spring. As the FEIR found (ESA, 2012a), and studies subsequent to the approval of the GMMMP (ESA, 2012b) conclude (Kenney and TLF, 2018), the weight of credible data obtained to date demonstrates there is no direct hydraulic connection between the springs and a regional groundwater table in the alluvial aquifer. However, the impact analysis in the FEIR (2012a), in an abundance of caution, assumed there was a direct hydraulic connection.

Assuming that a direct hydraulic connection between Bonanza Spring and the alluvial aquifer exists, the results of numerical groundwater modeling (GSSI, 2011; CH2M.Hill, 2012) suggested that a ten-foot decline in groundwater levels in the alluvial aquifer in the Fenner Valley below Bonanza Spring could result in a maximum drawdown at Bonanza Spring of about six to seven feet after hundreds of years. These drawdowns in groundwater elevation were deemed to be within the range of the historic groundwater level fluctuations resulting from natural climatic conditions (ESA, 2012a). Therefore, the impacts were considered to be, not only remote and unlikely, but also insignificant (ESA, 2012a).

In performing our Review, the Panel has considered the potential for an Undesirable Result assuming that a direct hydraulic connection exists, and the possible need for mitigation. With respect to potential impacts to springs, the GMMMP proposes spring flow and spring water quality monitoring, along with vegetation monitoring. This monitoring is appropriate and protective of this Critical Resource.

Aside from the management floor and modifications to pumping at the Cadiz Project well-field, resource-specific measures were considered for potential Undesirable Results at Bonanza Spring. These included the possible construction of a horizontal well to maintain spring flows. The proposed spring flow Corrective Measures in the GMMMP are practical and appropriate.

1.2.3 Potential Impacts to Brine Resources at Bristol and Cadiz Dry Lakes

The hyper-saline groundwater beneath the Bristol and Cadiz dry lakes supports two existing mineral strip-mining operations. Numerical groundwater modeling (GSSI, 2011) shows that between 30 and 65 feet of drawdown will occur beneath Bristol Dry Lake. Once groundwater levels beneath Bristol Dry Lake decline below 12 feet below ground surface (bgs), the trenches used to evaporate groundwater and recover precipitated salts will be dry, curtailing some mineral strip-mining operations.

With respect to potential impacts to Brine Resources, the GMMMP proposes groundwater level and groundwater quality monitoring at cluster wells at the dry lakes. This monitoring is appropriate, although groundwater level declines beneath the dry lakes are anticipated.

If numerical groundwater modeling predictions of groundwater levels beneath the dry lakes come to pass, it is likely that Corrective Measures will need to be implemented, as outlined in the GMMMP (Section 6.2.3, ESA, 2012b). These Corrective Measures include possible installation of injection and/or extraction well(s), a mitigation agreement, and/or modification of Cadiz Project operations to allow the strip-mining operations to continue. These Corrective Measures place the entire burden of the mitigation on the Cadiz Project and will not result in a disruption of the existing strip-mining operations. Thus, the mitigation actions proposed in the GMMMP are practical and appropriate.

1.2.4 Potential Impacts to the Saline-Fresh Water Interface

There is currently an established transitional interface between saline groundwater in the vicinity of Bristol and Cadiz dry lakes and freshwater moving towards the dry lakes from the Fenner Valley and other up-stream watersheds. The proposed pumping at the Cadiz Project will reverse groundwater flow between the Cadiz Project well-field and the dry lakes, causing the saline-fresh water interface to migrate towards the Cadiz Project well-field. However, some movement of the interface is an environmentally insignificant and reasonable consequence of the Cadiz Project's ability to conserve millions of gallons of fresh water (ESA, 2012a).

With respect to potential impacts to the saline-fresh water interface, the GMMMP proposes groundwater level and groundwater quality monitoring at cluster wells. This monitoring is appropriate, although some migration of the interface is anticipated.

A threshold perimeter distance of 6,000 feet for the potential movement of the saline-fresh water interface was specified by the County in the GMMMP (ESA, 2012b) and deemed insignificant in the FEIR (ESA, 2012a). If the interface migrates to the perimeter distance, Corrective Measures may be required to prevent further migration. These Corrective Measures include installing brackish water extraction or fresh water injection wells at the saline-fresh water interface. Such Corrective Measures are practical and appropriate.

1.2.5 Potential Impacts to Ground Surface Levels in the Watershed

The FEIR (ESA, 2012a) identified that aquifer and aquitard compaction could cause temporary and permanent subsidence at locations proximate to the Cadiz Project. However, significant subsidence across a wide area resulting from the proposed pumping at the Cadiz Project is not anticipated.

The GMMMP (ESA, 2012b; Section 6.3) proposes a monitoring program that includes land surveys, InSAR satellite data, and extensometers. This monitoring is appropriate.

In the event that significant subsidence is observed, the GMMMP (ESA, 2012b; Section 6.3.4) proposed Corrective Measures that include repairs to damaged structures, a potential mitigation agreement, and possible modification of Cadiz Project well-field operations to arrest subsidence. Such mitigation actions are practical and appropriate.

1.2.6 Other Potential Impacts

There are three other Critical Resources identified in the GMMMP: Air Quality, Project Area Vegetation, and the Colorado River and its Tributary Sources of Water. In general, the Panel concurs with the GMMMP proposed monitoring to evaluate whether any of these potential Undesirable Results occur. The Panel also concurs with the Corrective Measures, if required, proposed in the GMMMP (ESA, 2012b) and agrees that they are reasonably sufficient to avoid any Undesirable Results.

1.3 Recommendations

As noted, the monitoring, management, and mitigation approach proposed in the GMMMP (ESA, 2012b) is appropriate, as was previously determined by the Groundwater Stewardship Committee (2011). After careful review and consideration of the FEIR, GMMMP, and more recent technical reports, this Panel has recommended a number of complementary additions that could be made to the GMMMP, if feasible. Collectively these recommendations are intended to allay any concerns that opponents to the Cadiz Project may still have, improve public confidence in the Cadiz Project, and are provided in an abundance of caution. The recommendations are not intended to alter the analyses or findings regarding the environmental impacts of the Cadiz Project described in the FEIR (ESA, 2012a), or contain any significant new information. In addition, none of the recommendations are associated with a failure of the GMMMP to provide sufficient management, monitoring, and mitigation of Undesirable Results. However, the Panel strongly believes that the recommendations provide helpful direction in the ongoing monitoring, mitigation and management of the Cadiz Project. The recommended supplemental monitoring will produce additional information to assist with the following:

- Identifying and quantifying any Undesirable Results
- Further assessing the degree of hydraulic connection, if any, between Bonanza Spring and the alluvial aquifer in Fenner Valley below
- Monitoring brine water conditions beneath Bristol and Cadiz dry lakes
- Mapping the migration of the saline-fresh water interface over time
- Identifying changes in vegetation in riparian habitats below springs
- Evaluating the cause of any impacts (e.g., the proposed pumping at the Cadiz Project, climatic conditions, other factors)
- Determining the type, nature, magnitude, and duration of Corrective Measures that could be implemented
- Assessing the effects of any implemented mitigation

1.3.1 Detailed Plans

It is recommended that, at least one year prior to the commencement of the proposed pumping at the Cadiz Project, a more detail monitoring plan be prepared to document all aspects of data collection related to the Cadiz Project. A detailed Quality Assurance Project Plan (QAPP) should also be prepared. In addition, a formal data management system (DMS) should be developed for the Cadiz Project. Finally, an online repository should be developed to host all technical reports as they are finalized and delivered to the County as required by the GMMMP.

1.3.2 Geological Understanding

To provide additional information on the geologic structure and hydrogeology in the vicinity of Bonanza Spring, it is recommended that geophysical mapping be conducted in the area immediately above and for some distance below the spring. The objectives of the geophysical surveys would be to delineate structural features (i.e., faults) and other structural deformation, identify potential fracture lineaments with increased facture aperture and density (i.e., groundwater bearing potential), map the bedrock surface below the unconsolidated deposits south of the spring, and map the groundwater surface above and below the spring.

To provide additional information on the geologic structure and hydrogeology in the Fenner Gap, it is recommended that geophysical mapping be conducted in this area. The objectives of the geophysical surveys would be to delineate structural features (i.e., faults) and other structural deformation, identify the location and thickness of carbonate formations, identify potential karstic features (e.g., caves) and fracture lineaments with increased facture aperture and density (i.e., groundwater bearing potential), and map the groundwater surface.

1.3.3 Hydrogeologic Understanding

To provide additional information on hydrogeologic conditions between Bonanza Spring and the alluvial aquifer in the Fenner Valley below, it is recommended that additional monitoring wells be installed: (1) immediately below the spring (i.e., within 100 yards) with casings discretely screened in unconsolidated deposits beneath and adjacent to the stream fed by the spring, if they contain groundwater, and in the fractured bedrock beneath these deposits; and (2) at the limits of the alluvial aquifer (e.g., one mile southeast of Bonanza Spring).

1.3.4 Weather Conditions

It is recommended that a weather station, or at least a rain gauge, be installed in the bedrock watershed that supports flow at Bonanza Spring. This will assist in evaluating the relationship between precipitation, recharge, and spring flow.

1.3.5 Spring Monitoring

The potential for Undesirable Results to springs, notably Bonanza Spring, appears to be the most contentious issue related to the Cadiz Project. It is recommended that more frequent monitoring be conducted at the Bonanza, Whiskey, and Vontrigger springs using transducers and dataloggers. In addition, it is recommended that the exact geographic location and elevation of the spring emergence be mapped using a global positioning system (GPS) annually or after a change in location is observed during other monitoring activities.

1.3.6 Vegetation Monitoring

It is recommended that a terrestrial ecologist be retained to develop a scientifically appropriate, standardized methodology to monitor vegetation below the springs. Such a standardized methodology will allow changes in vegetation to be tracked over time.

1.3.7 Groundwater Monitoring

In general, the number and location of wells used to monitor regional groundwater conditions appear adequate. However, the Panel recommends that, in some cases, the frequency of groundwater monitoring be modified slightly (see **Section 7.10**). Monitoring groundwater levels at a higher frequency will better establish baseline conditions. It will also allow the response of the hydrologic system to increased pumping to be evaluated, including information on hydrogeologic structure within the watersheds, an improved understanding of hydraulic parameters (e.g., hydraulic conductivity and storativity), and identification of possible data gaps that may need to be filled. In addition, the increased monitoring frequency will assist in the assessment of potential Undesirable Results from the proposed pumping at the Cadiz Project. In doing so, it will also allow pumping operations to be optimized (e.g., well cycling, pumping rates) to maintain production while preventing Undesirable Results.

1.3.8 Third-Party Wells in Fenner Valley

There are no potable third party wells in the Cadiz Project area. However, it is recommended that transducers be installed during the pre-operational period in any third-party well that could be materially impacted by the proposed pumping at the Cadiz Project. This data will establish baseline groundwater conditions at the third-party wells, and allow for groundwater level and quality changes to be monitored during the proposed pumping at the Cadiz Project. Higher frequency data will assist in determining whether any observed impact results from the proposed pumping at the Cadiz Project or other factors, such as climatic variability.

1.3.9 Saline Migration

There is currently an established transitional interface between saline groundwater in the vicinity of Bristol and Cadiz dry lakes and freshwater moving towards the dry lakes from the

Fenner Valley and other up-stream watersheds. The saline–fresh water interface will migrate along areas of preferentially higher hydraulic conductivity. Such irregular migration may not be detected by just four well clusters (three at Bristol Dry Lake and one at Cadiz Dry Lake). Therefore, it is recommended that the location of the interface be mapped spatially and at depth using geophysical techniques prior to the commencement of pumping at the Cadiz Project. The results of this geophysical mapping can be used to locate the proposed cluster wells, and select the screened depths at each cluster. It is further recommended that the geophysical mapping be repeated every five years after the proposed pumping at the Cadiz Project is initiated. This will allow the migration of the saline-fresh water interface to be mapped in three-dimensions over time.

1.3.10 Subsidence

In the current GMMMP, the proposed land surface monitoring consists of conducting ground-level surveys, acquiring InSAR imagery, installing extensometers, and reviewing this information at various frequencies during pre-operational, operational, and post-operational periods. The Panel recommends that the InSAR data analysis be increased (see **Section 7.13**).

In the GMMMP (ESA, 2012b), it is proposed that three extensometers be placed in strategic locations with the highest probability of land subsidence proximate to the Cadiz Project well-field (ESA, 2012b). It is recommended that only one extensometer be installed during the pre-operational period. The installation of the two additional extensometers could be deferred until a temporal and more spatially extensive dataset on land subsidence is available (i.e., InSAR data and lithology data obtained from new production and monitor wells).

1.3.11 Groundwater Modeling

Numerical groundwater flow models have already been developed for the Cadiz Project (GSSI, 2011; CH2M.Hill, 2011). These numerical models present a reasonable representation of groundwater conditions for most areas of the watersheds tributary to the Cadiz project; however, they were based on a limited data-set and include significant assumptions and hydrogeologic judgement. The Panel recommends that numerical groundwater modeling be updated on a periodic basis (see **Section 7.14**) and, as part of defined updates, the model should also be recalibrated.

After the updates and recalibration, the numerical groundwater modeling can then be used to further evaluate potential Undesirable Results that may be caused by the proposed pumping at the Cadiz Project. The modeling should also be used to assess the effectiveness of the mitigation actions proposed in the GMMMP (ESA, 2012b).

1.3.12 Mitigation Actions

The County of San Bernardino imposed a requirement under the GMMMP that limited the aquifer drawdown to 80 feet within two miles of the center of the Cadiz Project well-field in the first 15 years of operation and 100 feet over the life of the Cadiz Project. The most common Corrective Measure in the GMMMP (ESA, 2012b) to prevent or alleviate Undesirable Results is to reduce or modify pumping at the Cadiz Project well-field (e.g., well cycling, individual pump rate adjustments). Such an action, as a stand-alone Corrective Measure, will likely be effective in the long-term; however, it may not alleviate certain impacts in a reasonable timeframe due to the response lag in the hydrologic system (e.g., groundwater levels would continue to decline at locations distant from the well-field for decades after pumping ceased). Therefore, the GMMMP included the following resource-specific measures that would either prevent ongoing impact or alleviate impact in a reasonable time frame:

- Bonanza Spring – the installation of a possible horizontal well immediately above Bonanza Spring, as provided in the FEIR (ESA, 2012a)
- Brine Resources – the installation of one or more brine extraction wells at the dry lakes to maintain mineral strip-mining operations, as proposed in the GMMMP (ESA, 2012b)
- Saline Intrusion – the extraction of brackish groundwater or injection of fresh water along the saline-fresh water interface, as proposed in the GMMMP (ESA, 2012b)

More details regarding these resource-specific measures needs to be developed. In addition, additional evaluation of these potential resource-specific measures is recommended, including analysis using an updated numerical groundwater flow model.

In addition to these resource-specific measures, it is recommended that the following additional Corrective Measures be evaluated:

- Bonanza Spring – The injection of water at the edge of the alluvial aquifer in Fenner Valley below Bonanza Spring to “cut-off” the propagation of the cone of depression at the edge of the alluvial aquifer in Fenner Valley below Bonanza Spring
- Bonanza Spring – The injection of water into water-bearing fractures immediately above Bonanza Spring to maintain groundwater levels in the watershed that support spring flow
- Bonanza Spring – the temporary provision of water for flow and habitat maintenance (e.g., a water tank and pipe to the spring head)
- Brine Resources – the injection of water at the saline-fresh water interface to “cut-off” the propagation of the cone of depression beyond the injection area (this injection could also halt the migration of the saline-fresh water interface)
- Air quality – the spraying of water on areas prone to dust generation

More details regarding these potential alternative mitigation measures need to be developed. Their feasibility (effectiveness, implementability, and cost) should be evaluated, including analysis using numerical groundwater modeling. Their effectiveness should examine both short-term effectiveness in preventing continued adverse impacts, and their long-term effectiveness at alleviating impacts in a reasonable period of time.

1.4 Conclusions

The GMMMP provides appropriate and sufficient management and monitoring to identify Undesirable Results that could occur in response to proposed pumping as part of the Cadiz Project. The Panel has recommended a number of complementary additions that could be made to the GMMMP, where such additions are feasible.

The GMMMP provides effective Corrective Measures to address any Undesirable Results in the long-term. Due to the response lag time in the hydrologic system, the modification or cessation of pumping at the Cadiz Project may not prevent ongoing impacts to certain Critical Resources. In addition, for the same reason, in some instances, the mitigation may not alleviate certain impacts in a reasonable period of time. Where the cessation or reduction of pumping at the Cadiz Project will not prevent or alleviate impacts, alternate resource-specific measures have been proposed in the GMMMP and/or FEIR to mitigate impacts. The Panel has also identified some additional measures that should be considered.

2.0 INTRODUCTION

An Independent Peer Review Panel ("Panel") was retained by Three Valleys Municipal Water District (TVMWD) and Jurupa Community Services District (JCSD) to conduct an impartial, objective, third-party review ("Review") of the Groundwater Management, Monitoring, and Mitigation Plan (GMMMP) for the Cadiz Valley Water Conservation, Recovery, and Storage Project (the Cadiz Project) and associated documentation. The Review was conducted in light of continuing study and reports that have been generated for, or pertinent to, the Cadiz Project after the certification of the Final Impact Report ("FEIR") for the Cadiz Project (ESA, 2012a) and the adoption of the GMMMP by the County of San Bernardino (ESA, 2012b). TVMWD and JCSD hold options to acquire water from the Cadiz Project and requested this Review of the GMMMP.

The focus of the Review was to evaluate whether the GMMMP was sufficient to ensure that the proposed pumping at the Cadiz Project would not result in Potential Significant Adverse Impacts to Critical Resources ("Undesirable Results") that could not be effectively mitigated (see **Section 2.1**).

The Panel consisted of the following groundwater professionals not previously employed by Cadiz:

- Anthony Brown of Aquilogic, Inc. (**aquilogic**)
- Tim Parker of Parker Groundwater - Technology, Innovation, Management, Inc. (**Parker Groundwater**)
- Mark Wildermuth of Wildermuth Environmental, Inc. (**WEI**)
- Dave Romero of Balleau Groundwater Inc. (**BGW**)

Biographical sketches for each member of the Independent Review Panel are provided in **Appendix A**.

Each of the above parties, except **aquilogic**, prepared an independent technical memorandum documenting their own review. During the Review process, the Panel met on five occasions via tele-conference to discuss aspects of the Review. In addition, the Panel had one lengthy tele-conference meeting with Geoscience Support Services, Inc. (GSSI) to discuss the numerical groundwater flow model developed for the Cadiz Project (GSSI, 2011).

Aquilogic was tasked with incorporating key elements of the memoranda prepared by individual members of the Panel, the discussions during tele-conferences, and their own review in this "Consensus Report". The Consensus Report has been reviewed by all members of the Panel, and all agree with the content herein.

As part of this work, the Panel was given unrestricted access to the Cadiz Project area, existing hydrogeologic and engineering consultants working on the Cadiz Project, and any documentation generated as part of, or pertinent to, the Cadiz Project. All members of the Panel have visited the Cadiz Project location, including Bonanza Spring, which has been the subject of recent studies.

2.1 Project Understanding

For readers unfamiliar with the Cadiz Project, a project overview is provided in **Appendix B**. Information in the overview and this sub-section is taken directly from aquilogic (2013) and the FEIR (ESA, 2012a) for the Cadiz Project. More detailed information about the project can be found within the FEIR. The following sections of the FEIR are particularly pertinent to the groundwater hydrology:

- Section 2: Project Background
- Section 3: Project Description
- Section 4.6: Geology and Soils
- Section 4.9: Hydrology and Water Quality
- Section 5.3.6: Geology and Soils (under Cumulative Impacts)
- Section 5.3.9: Hydrology and Water Quality
- Appendix B: GMMMP (ESA, 2012b), as further modified and adopted by the County of San Bernardino on October 1, 2012.
- Appendix H: Hydrology Reports

2.1.1 Background

Cadiz Inc. (Cadiz) is a private corporation that owns approximately 34,000 mostly contiguous acres in the Cadiz and Fenner Valleys (Cadiz Property), which are located in the Mojave Desert portion of eastern San Bernardino County, California (see **Figure 1**).

Cadiz, in collaboration with Santa Margarita Water District (SMWD) and other water providers participating in the Cadiz Project (Project Participants), developed the Cadiz Project to implement a comprehensive, long-term groundwater management program for the closed groundwater basin underlying its property. The program would allow for both the beneficial use of some of the groundwater, and future storage of imported surface water in the groundwater basin (**Figure 2**).

Underlying the Cadiz, Fenner, and Bristol Valleys is a vast groundwater basin that holds an estimated 17 to 34 million acre-feet (MAF) of fresh groundwater. The Cadiz Project, which would be sited on Cadiz Property, is located at the confluence of the Fenner, Orange Blossom Wash, Bristol and Cadiz Watersheds (watersheds), which span over 2,700 square miles.

Within this closed basin system, groundwater percolates and migrates downward from the higher elevations in the watersheds and eventually flows to Bristol and Cadiz dry lakes. The dry lakes represent the low point in this closed hydrologic system, meaning that all surface and groundwater within the surrounding watersheds eventually flows down-gradient to these dry lakes and not beyond. Once the fresh groundwater reaches the dry lakes, it evaporates, first mixing with the highly saline groundwater zone under the dry lakes and getting trapped in the salt sink, no longer fresh, suitable, or available to support freshwater beneficial uses. The portion that evaporates is lost from the groundwater basin and is not available for beneficial uses.

2.1.2 Project Purpose

Under Article X, Section 2 of the California Constitution, waters of the State must be put to maximum reasonable and beneficial use and should not be wasted. The fundamental purpose of the Cadiz Project is to save substantial quantities of groundwater that are presently wasted and lost to evaporation by natural processes. In the absence of the Cadiz Project, approximately three million acre-feet (MAF) of groundwater presently held in storage between the proposed wellfield and the dry lakes would become saline and evaporate over the next 100 years. By strategically managing groundwater levels, the Cadiz Project would conserve up to 2 MAF of this water, retrieving it from storage before it is lost to evaporation. The conservation opportunity is unique and garners special emphasis. The proposed conservation is not dependent upon future rainfall, snow pack or the needs and demands of others: the groundwater is already in storage. Moreover, the conservation and resulting water supply augmentation can be achieved independently from the environmental and regulatory conditions that generally constrain the importation of water to Southern California. The geographic isolation of the groundwater makes it non-tributary to the Colorado River system, and therefore eligible for distinctive treatment under federal regulations that may unlock additional complementary storage opportunities, both within the Basin and in Lake Mead.

The Cadiz Project makes available a reliable water supply for Project Participants, to supplement or replace existing supplies and enhance dry-year supply reliability. Both the State Water Project (SWP) and Colorado River water supplies are experiencing reductions from historic deliveries. As a result, Southern California water providers are looking for new supplies to replace or augment current supplies and enhance dry-year supply reliability. The Cadiz Project would optimize the reasonable and beneficial use of water within the aquifer system in a sustainable fashion—conserving water that would otherwise be wasted—to create a local water supply alternative for Southern California water providers.

The objectives of the Cadiz Project are as follows:

- Maximize beneficial use of groundwater in the Bristol, Cadiz, and Fenner Valleys by conserving and using water that would otherwise be lost to brine and evaporation

- Improve water supply reliability for Southern California water providers by developing a long term source of water that is not significantly affected by drought
- Reduce dependence on imported water by utilizing a source of water that is not dependent upon surface water resources from the Colorado River or the Sacramento-San Joaquin Delta
- Enhance dry-year water supply reliability within the service areas of SMWD and other Project Participants
- Enhance water supply opportunities and delivery flexibility for SMWD and other Project Participants through the provision of carry-over storage and, for Phase 2, imported water storage
- Support operational water needs of the Arizona and California Railroad (ARZC) in the Cadiz Project area
- Create additional water storage capacity in Southern California to enhance water supply reliability
- Locate, design, and operate the Cadiz Project in a manner that minimizes significant environmental effects and provides for long-term sustainable operations

2.1.3 Project Components

The Cadiz Project includes the following two distinct but related components:

- Groundwater Conservation and Recovery Component
- Imported Water Storage Component

Under the Groundwater Conservation and Recovery Component, an average of 50,000 acre-feet per year (AFY) of groundwater would be pumped from the basin over a 50-year period for delivery to Project Participants in accordance with agreements with Cadiz Inc. and the GMMMP. The GMMMP (ESA, 2012b) has been developed to guide the long-term groundwater management of the basin for the Cadiz Project. The level of groundwater pumping proposed under the Groundwater Conservation and Recovery Component is designed specifically to extract and conserve groundwater that would otherwise migrate to the dry lakes, enter the brine zone, and evaporate. The Groundwater Conservation and Recovery Component was analyzed at a project level in the FEIR (ESA, 2012a) in accordance with the California Environmental Quality Act (CEQA) Guidelines Sections 15161 and 15378(a).

Figure 1: Location of the Cadiz Project (aquilogic, 2013)

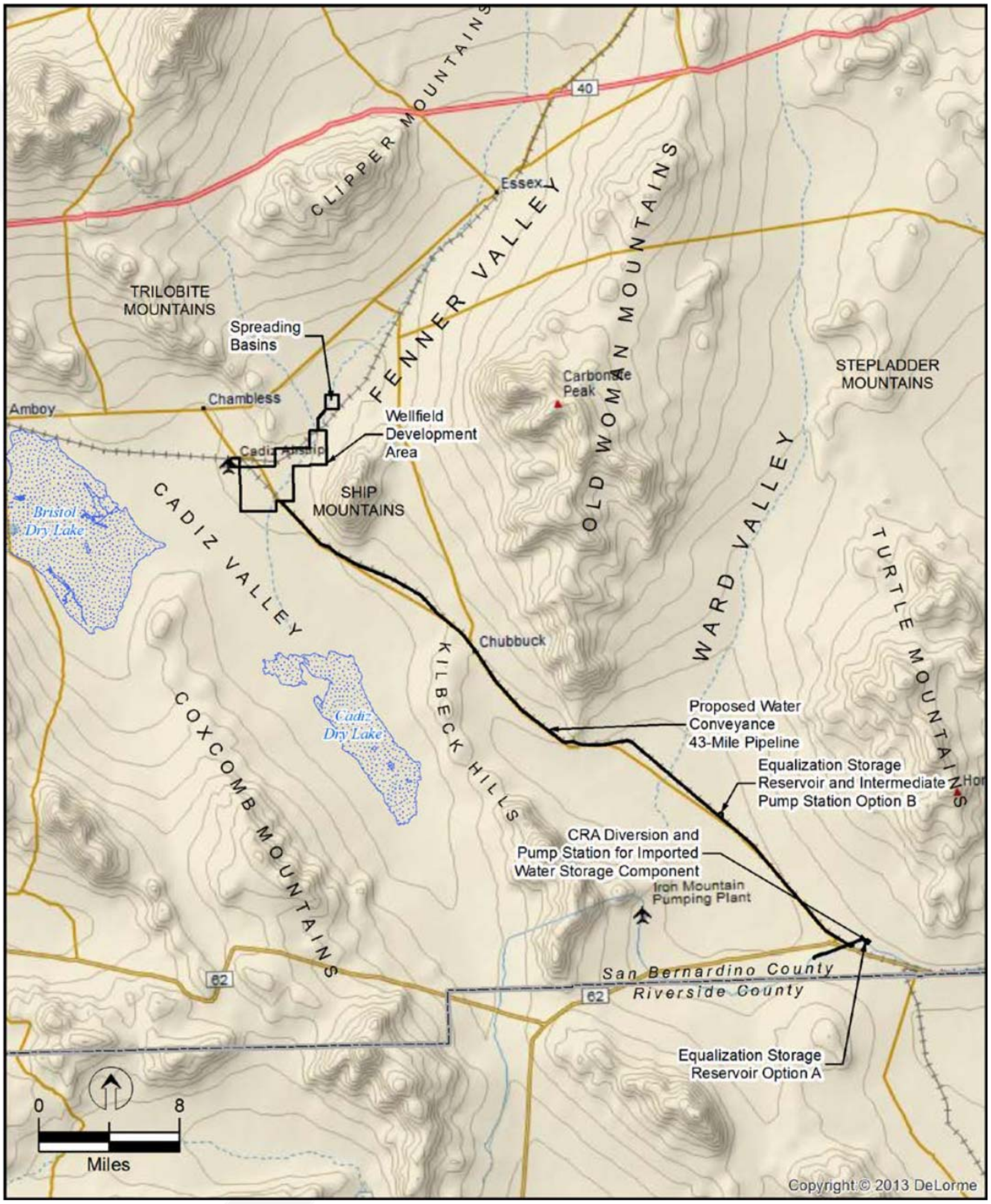


Figure 2: Cadiz Project Area Project (aquilogic, 2013)

2.2 Objectives

The objectives of the Panel were to assess whether the GMMMP (ESA, 2012b):

- Provided sufficient management and monitoring to identify any Undesirable Results that could occur in response to proposed groundwater pumping as part of the Cadiz Project
- Provided effective Corrective Measures (i.e., mitigation) to address any Undesirable Results that do occur

In addition, where deemed necessary, the Panel has provided recommendations for management, monitoring, and mitigation procedures, and recommend additional work to improve the understanding of the hydrology of the Cadiz Project. The recommendations are not intended to alter the analysis or findings regarding the environmental impacts of the Cadiz Project described in the FEIR (ESA, 2012a), or contain any significant new information. In addition, none of the recommendations are associated with a failure of the GMMMP to provide sufficient management, monitoring, and mitigation of Undesirable Results. Rather, the recommendations, if implemented, would provide the following:

- Improved overall hydrologic understanding of the Cadiz Project area
- Improved monitoring during the pre-operational (i.e., baseline), operational, and post-operational periods
- Further assurance that the Cadiz Project would not cause Undesirable Results
- Greater confidence that, if an Undesirable Result did occur, it could be mitigated effectively

2.3 Prior Reviews

The following independent technical peer reviews were previously conducted for the Cadiz Project:

1. Groundwater Stewardship Committee. October 2011 Summary of Findings and Recommendations. Cadiz Groundwater Conservation, Recovery and Storage Project (Groundwater Stewardship Committee, 2011).
2. County of San Bernardino. October 2012 review, establishment and approval of the GMMMP (County, 2012).
3. Geology and Hydrology Experts Review - 2018 Bonanza Spring Assessment. January 2018 (Geology and Hydrology Experts Review, 2018).

In addition to these independent technical peer reviews, the FEIR (ESA, 2012a), and GMMMP (ESA, 2012b) as an appendix to the FEIR, were again independently evaluated by the judiciary as part of six separate legal actions brought by opponents to the Cadiz Project. In all six actions, the courts affirmed the FEIR and GMMMP, rejecting the position taken by project opponents that these reviews and approvals, including the GMMMP and the California Environmental

Quality Act (CEQA) Mitigation Monitoring and Report Plan for the Project, were deficient. In June 2016, the California Appeals Court upheld the six trial court rulings and completed a *de novo* EIR review to validate the FEIR and GMMMP.

Aquilogic previously conducted a "Review of The Groundwater Hydrology of the Cadiz Project, San Bernardino County, California" (aquilogic, 2013). This impartial, objective, third-party review was prepared for Laborers International Union of North America ("LIUNA") pursuant to a settlement of litigation pending in Orange County Superior Court entitled "Rodrigo Briones, Lonnie Passmore, Laborers' International Union of North America Local Union No. 783 v. Santa Margarita Water District et al., Orange County Superior Court Case No. 30-2012-00620636-CU-WM-CXC (LIUNA) (Action)", between Real Parties-in-Interest, Cadiz, Inc., and Fenner Valley Mutual Water Company (Fenner), (collectively, Cadiz Parties) and, Rodrigo Briones, an individual, Lonnie Passmore, an individual, and LIUNA Local Union No. 783. Anthony Brown also sat on the review panel for the Geology and Hydrology Experts Review (2018).

Parker Groundwater. Tim Parker was an integral member of the Groundwater Stewardship Committee (2011) review. He also sat on the review panel for the Geology and Hydrology Experts Review (2018).

WEI. Mark Wildermuth sat on the review panel for the Geology and Hydrology Experts Review (2018).

Balleau has never participated in any review of, or other technical work associated with, the Cadiz Project.

2.4 Document Review

As noted, the Panel was given unrestricted access to the Cadiz Project area, existing consultants working on the Cadiz Project, and any documentation generated as part of, or pertinent to, the Cadiz Project. The Cadiz Project has been the subject of extensive technical evaluation as part of overall project development, the rigorous environmental review process under CEQA, independent analysis by the County of San Bernardino, multiple legal challenges to the FEIR (ESA, 2012a), and the overall permitting process for the project. The courts have upheld the FEIR and the findings therein, and there appear to be no legal or technical justification to prevent the project from proceeding. However, we understand that there are regulatory and political hurdles that need to be overcome for the project to proceed, and there is still opposition to the project. The opposition is principally focused on concerns that the proposed pumping at the Cadiz Project may impact springs in the mountains surrounding and above the Fenner Valley.

Given the extensive technical evaluations conducted for the Cadiz Project, there is a significant volume of documentation associated with the project. Therefore, the Panel focused their

Review on the following documents and gave specific attention to the work generated *after* the certification of the FEIR (ESA, 2012a) and the GMMMP (ESA, 2012b), notably items 7-16 below:

1. GSSI. (1999). Cadiz Groundwater Storage and Dry-Year Supply Program. Environmental Planning Technical Report. Groundwater Resources. Volume 1 and Volume 2. Report 1163. November 1999.
2. GSSI. (2011). Cadiz Groundwater Modeling and Impact Analysis, Volume 1- Report. September 1, 2011.
3. CH2M.Hill. (2011). Assessment of effects of the Cadiz Groundwater Conservation Recovery and Storage Project operation on springs. EIR Appendix H3 (see next bullet point).
4. Environmental Science Associates (ESA). (2012a). Final Environmental Impact Report (FEIR) for the Cadiz Valley Water Conservation, Recovery, and Storage Project. SCH# 2011031002. July 2011.
5. ESA. (2012b). Groundwater Management, Monitoring, and Mitigation Plan (GMMMP) for The Cadiz Valley Groundwater Conservation, Recovery and Storage Project. September.
6. Aquilogic, Inc. (2013). Review of the Groundwater Hydrology of the Cadiz Project, San Bernardino County, California. October 2013.
7. Zdon. (2016). Mojave Desert Springs and Waterholes: Results of the 2015–16 Mojave Desert Spring Survey, Inyo, Kern, San Bernardino and Los Angeles Counties, California. Andy Zdon and Associates.
8. Rose. (2017). Data Measured on Water Collected from Eastern Mojave Desert, California. Lawrence Livermore National Laboratory, LLNL-TR-737159. T.P. Rose. August 18, 2017.
9. Kenney and TLF. (2018). Updated Assessment of Cadiz Water Project’s Potential Impacts to Bonanza Springs. Kenney and TLF Consulting, LLC. January 2018.
10. Love and Zdon. (2018). Use of Radiocarbon Ages to Narrow Groundwater Recharge Estimates in the Southeastern Mojave Desert, USA. A.H. Love and A. Zdon. USA Hydrology-05-00051.
11. Zdon et al. (2018). Understanding the source of water for selected springs within Mojave Trails National Monument, California. A. Zdon, M. L. Davidson, and A.H. Love. Vol. 19, No. 2, 99–111.
12. Kreamer. (2018). Evaluation of “Understanding the source of water for selected springs within Mojave Trails National Monument, California” (Zdon, 2018). Professor D. Kreamer. June 2018.
13. Schroth. (2018). Comments on “Understanding the source of water for selected springs within Mojave Trails National Monument, California” (Zdon et al, 2018). B. Schroth, Ph.D.
14. Geology and Hydrology Experts Review. (2018). Bonanza Spring Assessment. January 2018.
15. TLF. (2018). Twentieth Annual Groundwater Monitoring Report, January - December 2017. TLF Consulting LLC. December 2018.

16. Kreamer. (2019). Review of “Use of Radiocarbon Ages to Narrow Groundwater Recharge Estimates in the Southeastern Mojave Desert, USA” (Love and Zdon, 2018). Professor D. Kreamer. January 2019.

3.0 GROUNDWATER MANAGEMENT, MONITORING, AND MITIGATION PLAN

The GMMMP (ESA, 2012b) was written pursuant to an agreement between SMWD, Cadiz, and San Bernardino County, and made part of the FEIR (ESA, 2012a). The GMMMP was then independently amended by the government agency responsible for groundwater management in the project area (i.e., San Bernardino County) after the certification of the FEIR. The GMMMP provides the following:

- Description of the Cadiz Project location and objectives
- Description of physical characteristics of the groundwater basin
- Identification of the Critical Resources and assessment of potential impacts in and surrounding the Cadiz Project area due to groundwater pumping
- Description of the modeling tools that will be used to refine the monitoring network and that will be used in the future to refine impact assessments and action criteria
- Description of the monitoring network and identification of the locations of the features of the monitoring network
- Description of the monitoring, testing, and reporting procedures that will be used to collect and analyze data
- Description of the action criteria established to avoid Undesirable Results
- Description of the decision-making process to be used once the action criteria are met or when the County considers refinements to the GMMMP
- Description of “Corrective Measures” that may be implemented to minimize Undesirable Results
- Description of objectives and requirements for a Closure Plan
- Description of the TRP (Technical Review Panel) and its responsibilities and procedures

The success or failure of the GMMMP to manage and mitigate potential harm to Critical Resources will determine whether Undesirable Results actually occur. It should be noted that not all impacts from the proposed pumping at the Cadiz Project are deemed “significant and unreasonable”; that is, an impact may not be an Undesirable Result. Certain impacts may be less than significant but would still be monitored and managed in accordance with the GMMMP (ESA, 2012b). Other impacts may be deemed significant but the GMMMP provides Corrective Measures (i.e., mitigation) to reduce the impacts so they are no longer significant. It is recognized that certain impacts that are considered insignificant under CEQA may still cause concern among some constituencies. The adaptive management approach within the GMMMP allows the plan to adapt to new data, new concerns, new technologies, etc. to ensure that either no Undesirable Results occur or, if they occur, they can be effectively mitigated.

The following six Critical Resources were identified in the GMMMP (ESA, 2012b):

1. Basin Aquifers
2. Springs within the Fenner Watershed
3. Brine Resources at Bristol and Cadiz dry lakes
4. Air Quality
5. Project Area Vegetation
6. Colorado River and its Tributary Sources of Water

The first item, Potential Significant Adverse Impact to Basin Aquifers, drives the risk to the remaining potential receptors of harm. Given ongoing opposition to the Cadiz Project and concerns expressed by certain environmental groups and the ongoing brine strip-mining operations at the dry lakes, the two receptors that have been associated with most controversy are potential Undesirable Results at the springs and to Brine Resources. These, and other potential impacts, are discussed in further detail below.

3.1 Potential Impacts to Aquifers

The response of the aquifer system to the proposed pumping at the Cadiz Project was evaluated using numerical groundwater modeling (GSSI, 2011). In response to the cessation of pumping, an immediate aquifer water-level recovery is observed proximate to the Cadiz Project well-field. However, at some distance from the well-field, groundwater levels continued to decline. This results from the continued movement of groundwater toward the well-field to infill the deepest parts of the cone of depression around the well-field. Under such circumstances, an Undesirable Result may occur at a Critical Resource even many years after the implementation of a mitigation action (e.g., the cessation of pumping). Given the propagation of the cone of depression after pumping stops, continued monitoring of groundwater conditions proximate to Critical Resources will continue after mitigation is implemented, as proposed in the GMMMP (ESA, 2012b, Section 6.4.3).

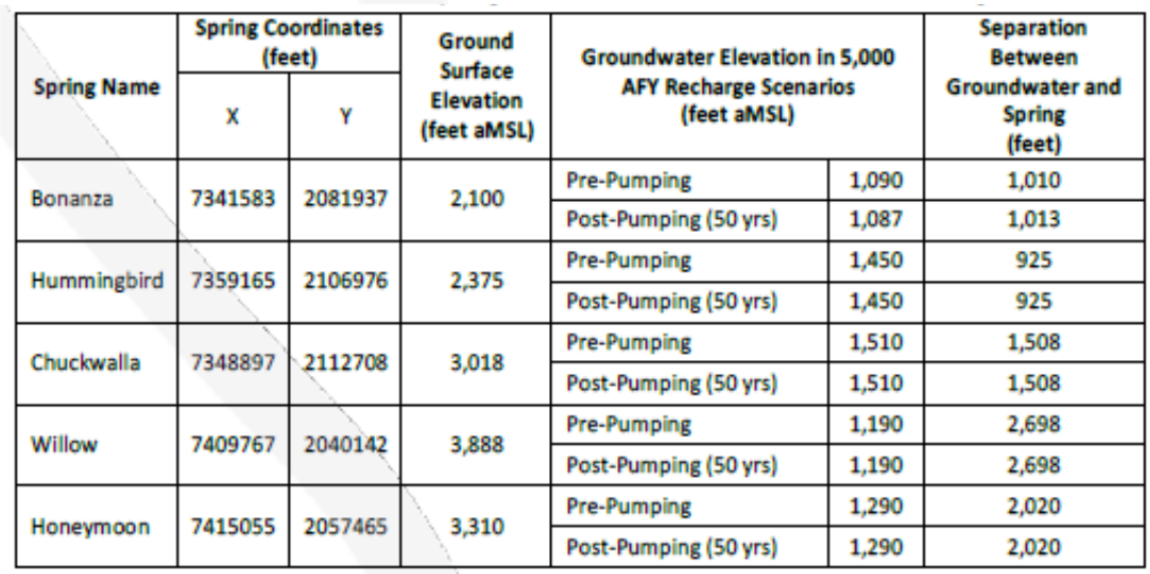
It is noted that the GMMMP (ESA, 2012b) and FEIR (ESA, 2012a) considered the delay in the propagation of the cone of depression by evaluating potential Undesirable Results over a 100-year period. No Undesirable Results were identified in the FEIR that could not be mitigated, considering the drawdown that would result over 100 years using various recharge rates as low as 5,000 AFY.

Despite the fact that no un-mitigatable Undesirable Results were identified in the FEIR (ESA, 2012a), monitoring of overall groundwater conditions in the watersheds tributary to the Cadiz project was proposed in the GMMMP (ESA, 2012b).

A groundwater level drawdown threshold (80 feet) is proposed in the GMMMP (ESA, 2012b) for a distance of two miles from the center of the Cadiz Project well-field. This threshold is intended to provide a management "floor" below which mitigation actions would be triggered. Such a floor was selected as it lessens the need for resource-specific mitigation actions at individual Critical Resources, as it is believed to provide a proactive Corrective Measure that would prevent significant impact.

3.2 Potential Impacts to Springs Within the Fenner Watershed

The spring closest to the proposed Cadiz Project extraction well-field is Bonanza Spring located in the Clipper Mountains (see **Figure 3**). The Bonanza Spring is approximately 11 miles from the center of the Fenner Gap. All Fenner Watershed springs, including Bonanza Spring, are located in crystalline bedrock formations and outcrop at much higher elevations than groundwater within the "alluvial aquifer" of the Fenner Valley. **Table 1** indicates the difference in elevation between various springs and the alluvial aquifer. Bonanza Spring is located over 1000 feet above the groundwater level in the alluvial aquifer under "worst case" recharge conditions.



Spring Name	Spring Coordinates (feet)		Ground Surface Elevation (feet aMSL)	Groundwater Elevation in 5,000 AFY Recharge Scenarios (feet aMSL)		Separation Between Groundwater and Spring (feet)
	X	Y				
Bonanza	7341583	2081937	2,100	Pre-Pumping	1,090	1,010
				Post-Pumping (50 yrs)	1,087	1,013
Hummingbird	7359165	2106976	2,375	Pre-Pumping	1,450	925
				Post-Pumping (50 yrs)	1,450	925
Chuckwalla	7348897	2112708	3,018	Pre-Pumping	1,510	1,508
				Post-Pumping (50 yrs)	1,510	1,508
Willow	7409767	2040142	3,888	Pre-Pumping	1,190	2,698
				Post-Pumping (50 yrs)	1,190	2,698
Honeymoon	7415055	2057465	3,310	Pre-Pumping	1,290	2,020
				Post-Pumping (50 yrs)	1,290	2,020

Table 1. Spring Elevations Under Worst Case Recharge Scenario (i.e., 5,000 AFY) (aquilogic, 2013)

Opponents to the Cadiz Project have expressed concerns that the proposed pumping at the Cadiz Project might lower groundwater elevations in the bedrock aquifer in the watershed that supports flow at Bonanza Spring. The GMMMP presents the results of an analysis by CH2M.Hill (2011) where two conceptual models of Bonanza Spring were developed. Bonanza Spring was chosen as an appropriate indicator spring for all springs in the Fenner Watershed because it is the closest spring to the proposed Cadiz Project well-field. Therefore, this would be the most likely spring to experience any Undesirable Results from the proposed pumping at the Cadiz

Project. The Panel agrees with the selection of Bonanza Spring as an indicator spring for potential Undesirable Results.

As the FEIR found (ESA, 2012a), and studies subsequent to the approval of the GMMMP (ESA, 2012b) conclude, the weight of credible evidence obtained to date demonstrates that there is no direct hydraulic connection between Bonanza Spring and a regional groundwater table in the alluvial aquifer in Fenner Valley below. In fact, the detailed geological mapping conducted after approval of the FEIR and GMMP by Kenney and TLF (2018) provides further evidence that Bonanza Spring is not hydraulically connected to the alluvial aquifer in the Fenner Valley below (see **Figures 4 and 5**). Thus, hypothetical conceptual model #1 ("Concept-1") reasonably assumed that no hydraulic connection existed between Bonanza Spring and the groundwater flow regime in the alluvial aquifer in Fenner Valley below. In Concept 1, the spring is supported by a watershed and groundwater system in fractured bedrock above a no-flow or low-flow boundary (e.g., fault or stratigraphic "perching" layer), as described in Scenarios 2 and 3 in aquilogic (2013), Section 6.1 (see **Figures 6 and 7**).

Recent GPS tracking of Bighorn Sheep reportedly shows that they frequent Bonanza Spring (CADFW, 2018). Anecdotal information suggests that hunters also take the view that it is important to maintain flow at Bonanza Spring. Comments received during the public review period for the FIER suggested the potential for a direct hydraulic link between Bonanza Spring and the alluvial aquifer in Fenner Valley below. Therefore, in order to address the possibility of a hydraulic connection between Bonanza Spring and the alluvial aquifer, hypothetical conceptual model #2 ("Concept-2") assumed that a direct hydraulic connection existed between Bonanza Spring and the groundwater flow regime in the alluvial aquifer in Fenner Valley below. In Concept 2, the spring is supported by a watershed and groundwater system in fractured bedrock with no geologic boundary to flow between the fractured rock system and the adjacent alluvial aquifer, as described in Scenario 1 in aquilogic (2013), Section 6.1 (see **Figure 8**).

Some researchers (Zdon, 2016; Zdon et al., 2018; Rose, 2017) continue to assert the hypothesis of a direct hydraulic connection between Bonanza Spring and the alluvial aquifer. Their assertions are principally based on their conclusions regarding groundwater geochemistry. However, these conclusions are disputed by other researchers (Kreamer, 2018; Schroth, 2018; Kreamer, 2019). For the purposes of this Review, we have not attempted to resolve the dispute over geochemical interpretation. This was unnecessary as the impact analysis in the FEIR (2012a), in an abundance of caution, assumed there was a direct hydraulic connection.

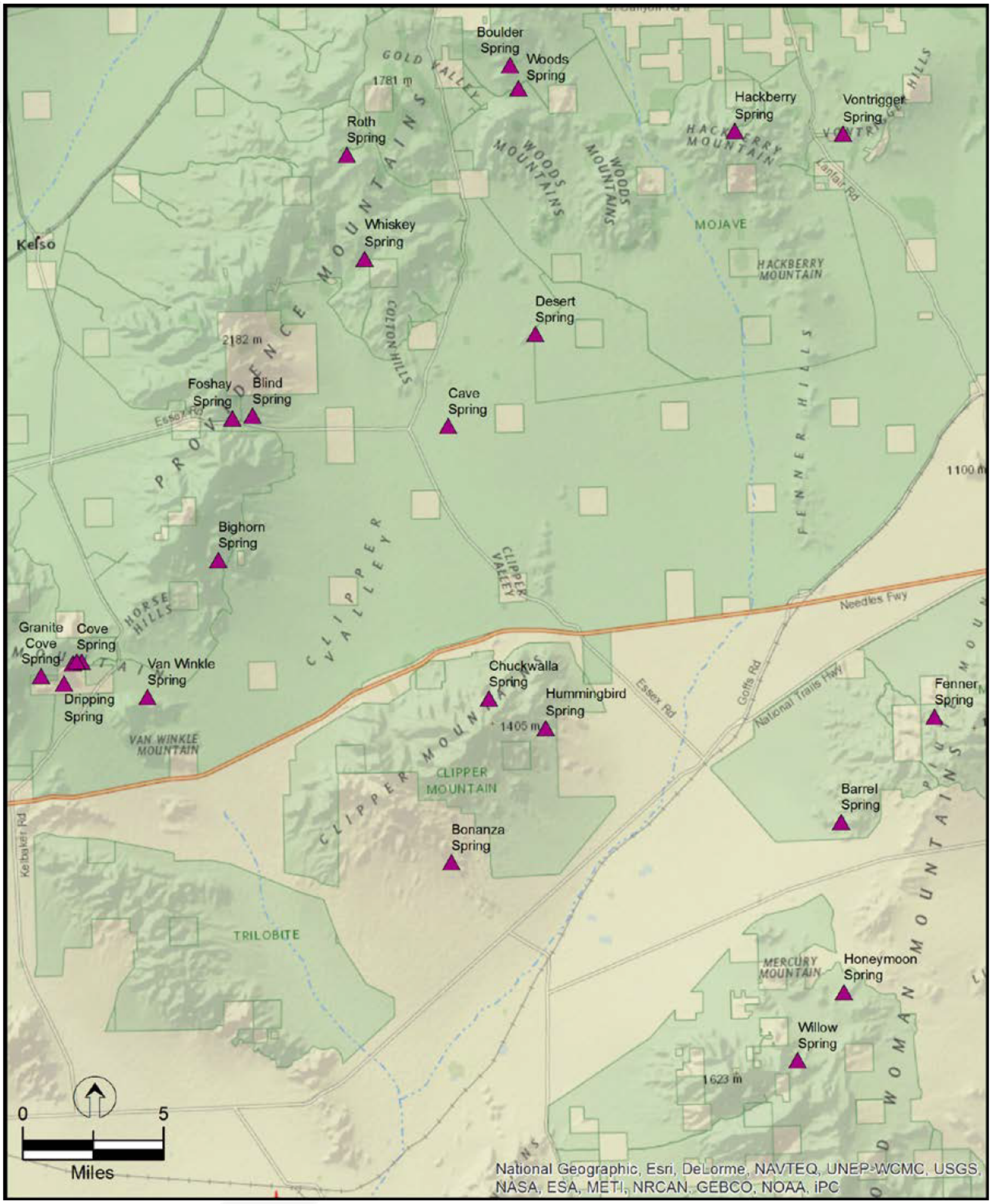


Figure 3: Springs within the Project Area (aquilogic, 2013)

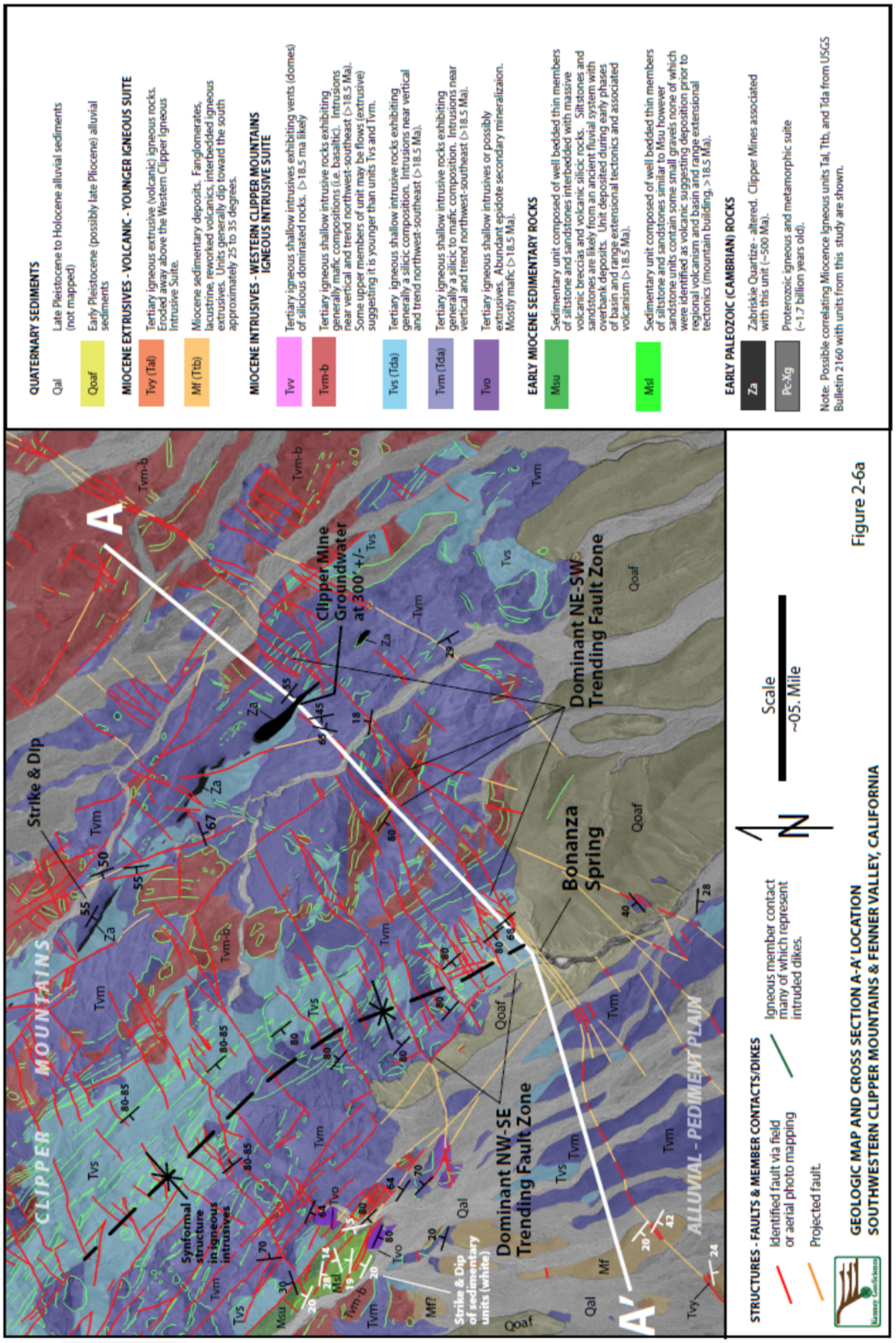


Figure 4: Geologic Map and Cross Section A-A' Location Southwestern Clipper Mountains and Fenner Valley (Kenney and TLF, 2018)

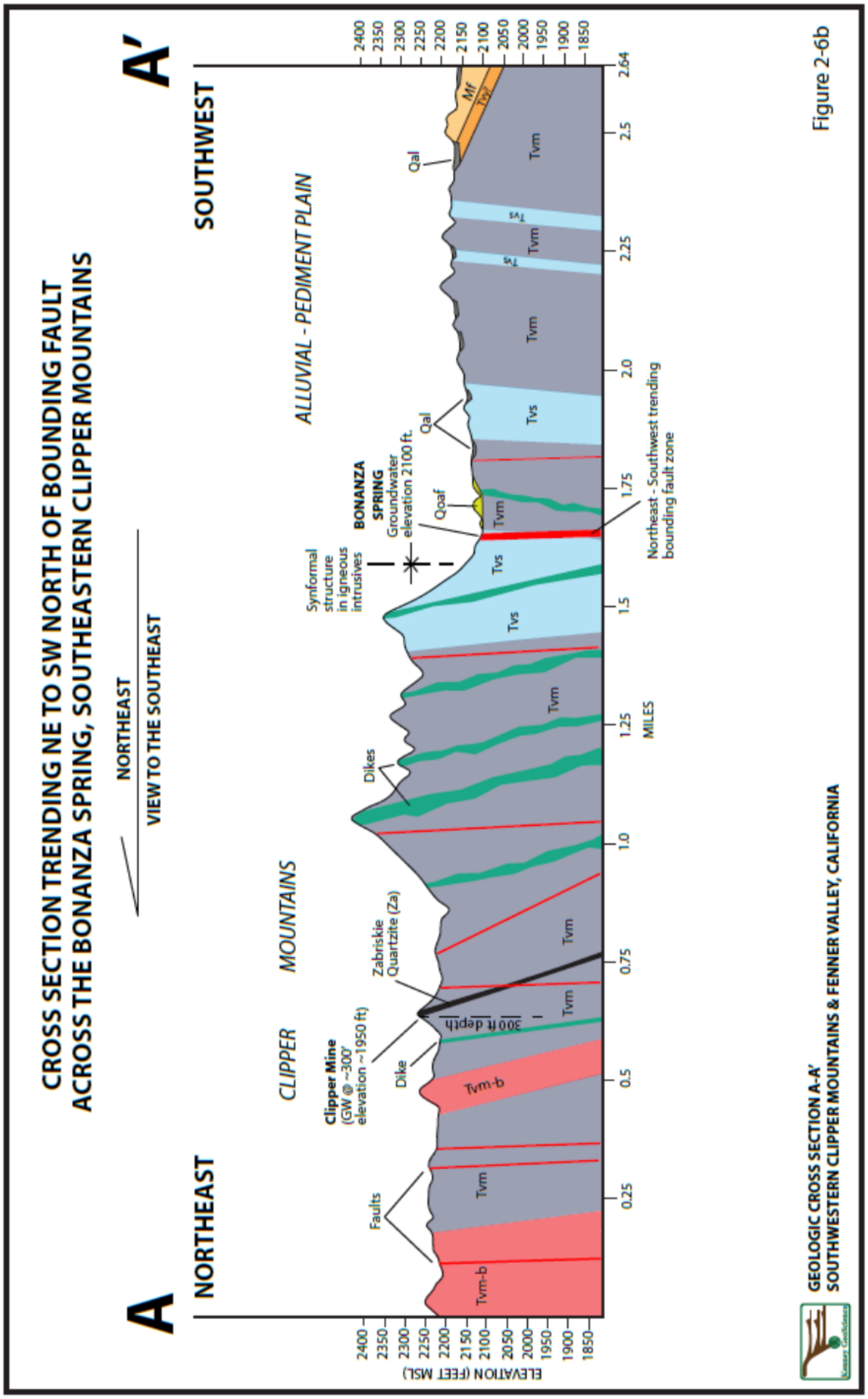


Figure 5: Geologic Cross Section A-A' Southwestern Clipper Mountains and Fenner Valley (Kenney and TLF, 2018)

Given the geological mapping of Kenney and TLF (2018), the hydrologic assessment in aquilogic (2013), and fundamental hydrogeologic concepts, the Panel has concluded that the weight of credible evidence suggests that no direct hydraulic connection exists between Bonanza Spring and the alluvial aquifer in Fenner Valley below. The evidence includes, but is not limited to, the following:

- The 11 mile distance between the proposed pumping at the Cadiz Project well-field and Bonanza Spring
- The over 1,000-foot change in elevation between groundwater in Fenner Valley and Bonanza Spring
- The hydrologic nature of the fractured bedrock watershed supporting Bonanza Spring and the alluvial deposits in Fenner Valley
- The identification of faults in the vicinity of Bonanza Spring that control spring location by Kenner and TLF (2018)
- The evaluation of groundwater geochemistry at Bonanza Spring by Kreamer (2019), notably lower water temperatures and spring flow variation
- The infiltration of stream flow supported by Bonanza Spring immediately down-stream of the spring (i.e., the presence of a vadose zone down-stream of Bonanza Spring)

Despite the weight of evidence, in performing our Review, the Panel has considered the potential for an Undesirable Result assuming that a direct hydraulic connection exists, and the possible need for mitigation.

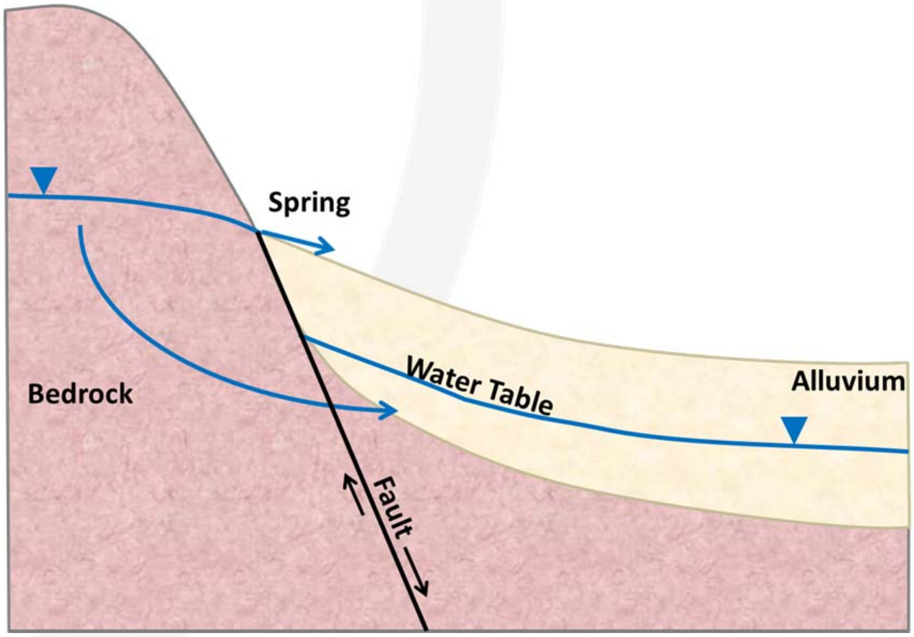


Figure 6: Scenario 2 – Fault Acts as a Partial Groundwater Flow Barrier (Groundwater in Alluvium NOT in Direct Hydraulic Communication with Spring) (aquilogic, 2013)

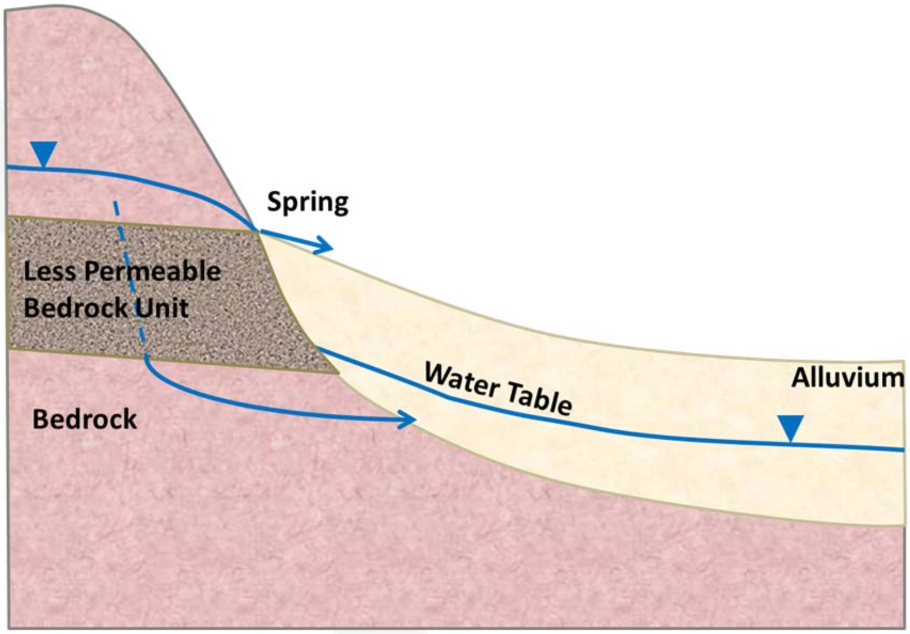


Figure 7: Scenario 3 – Stratigraphic Unit (i.e. Aquitard) Acts as a Partial Groundwater Flow Barrier (Groundwater in Alluvium NOT in Direct Hydraulic Communication with Spring) (aquilogic, 2013)

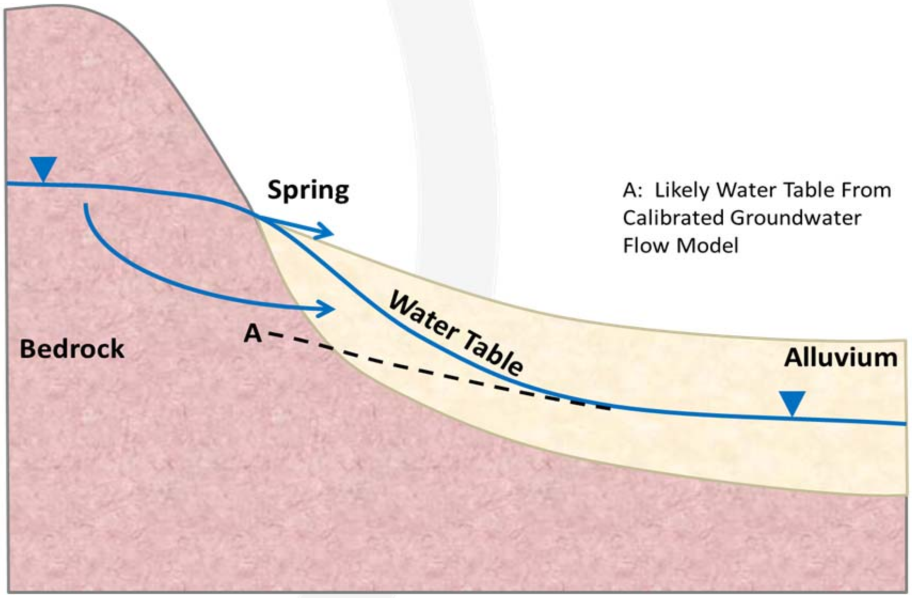


Figure 8: Scenario 1 – Groundwater in Alluvium in Direct Hydraulic Communication with (and Sustaining) Spring (aquilogic, 2013)

It has been noted in studies conducted after approval of the FEIR (ESA, 2012a) and GMMMP (ESA, 2012b) by Kenney and TLF (2018) that spring level and flow has fallen in recent years as a result of climatic conditions, and this may continue:

> *"Field mapping within the Bonanza Spring "watershed" area identified areas of very strong secondary mineralization and weathering. This was observed as chemical*

> *weathering of plagioclase phenocrysts in the igneous rocks, veins of quartz and iron minerals, abundant colorful (reds, orange, purple color) secondary minerals along fractures and penetrative to the rocks, and abundant liesegang banding rings. However, along the outer limits of the Bonanza Spring "watershed" area, the degree of secondary chemical weathering and mineralization dramatically decreased (Figure 2-5). Strongly altered rocks in the vicinity of the Bonanza Spring occur from the spring area to nearly the top of the local ridges toward the north, and slightly below the mountain ridges to the northeast. These observations suggest that fluids once flowed at higher elevations in the past and that the fluids preferentially may have primarily flowed from the north.*
>
> *It is interesting to point out that the Tunnel Well was likely excavated not for minerals, but instead to obtain groundwater. A metal pipe is observed to have been installed into the tunnel where a mound of earth at the entrance of the tunnel allowed for ponding water to occur inside the tunnel. It can be observed today in the tunnel that the fault zone is a groundwater barrier, with rocks northeast of the fault zone that are moist and rocks with the fault gouge zone that are dry. Groundwater may have historically been higher here (a spring?) than in other locations in the Bonanza Spring cuspate valley due to the intersection of the Southwestern Boundary Fault Zone and a northeast-southwest trending smaller scale fault extending across the valley to the northeast (Figure 2-5). These data suggest that the Tunnel Well "spring" exhibits a small-scale version in terms of fault structure as that proposed for the Bonanza Spring – due to the intersection of two fault zones at high angles to one another.*
>
> *An ancient abandoned channel of likely late Pleistocene age was identified less than 200 feet west of the Bonanza Spring (Figure 2-5). The abandoned channel is approximately 10 to 15 feet above the current Bonanza Spring Wash elevation and once flowed essentially due south. The significance of the abandoned wash with the Bonanza Spring is that abundant travertine deposits occur in the sediments at the base of the wash and adjacent bar deposits. The carbonate travertine deposits are over 8 feet thick and due to their elevation above the current Bonanza Spring suggest that during the Pleistocene, groundwater levels in the Bonanza cuspate valley area were higher by over 10 to 15 feet minimum. This observation is consistent with the observation of pronounced secondary weathering and mineralization of rocks at higher elevations within the Bonanza Spring cuspate valley.'*

Furthermore, variation in flow at Bonanza Spring is noted by other researchers, including those that postulate a direct hydraulic connection between the spring and groundwater in the alluvial aquifer (Zdon, 2016; Zdon et al, 2018; Rose, 2017).

Concept 2 is a simple representation of a generic mountain system with similar characteristics to the Clipper Mountains and was intended to evaluate the general response of a water table in fractured bedrock of mountains under various assumptions that are specific to hydrogeologic conditions at Bonanza Spring. The results of the Concept-2 model suggested that a ten-foot decline in groundwater levels in the alluvial aquifer in the Fenner Valley below Bonanza Spring could result in about one foot of drawdown at the springs after 50 years of pumping at the Cadiz Project and six to seven feet of drawdown at Bonanza Spring after hundreds of years, assuming that the decline in the alluvial aquifer was maintained at ten feet of drawdown indefinitely. These drawdowns in groundwater elevation attributed to the proposed pumping at the Cadiz Project were deemed to be within the range of the historic groundwater level fluctuations resulting from natural climatic conditions (ESA, 2012a). Therefore, the impacts were considered to be, not only remote and unlikely, but also insignificant (ESA, 2012a).

3.3 Potential Impacts to Brine Resources at Bristol and Cadiz Dry Lakes

The hyper-saline groundwater beneath the Bristol and Cadiz dry lakes supports two existing mineral strip-mining operations. These operations evaporate the hyper-saline groundwater from beneath the dry lakes to recover the precipitated salts. The Undesirable Results to Brine Resources on Bristol and Cadiz dry lakes that could result from proposed pumping at the Cadiz Project include the following: (1) lowering of hyper-saline groundwater levels in brine recovery wells and brine supply trenches used by the mineral strip-mining operations; and (2) impacts to the geochemistry of the hyper-saline groundwater (e.g., reduced calcium chloride or sodium chloride within the brine) that impact precipitate recovery.

Numerical groundwater modeling performed by GSSI (2011) shows that, depending on the recharge amount used in the modeling, between 30 and 65 feet of drawdown will occur beneath Bristol Lake. In general, the trenches used to expose saline groundwater to evaporation and precipitate salts for mineral strip-mining operations at Bristol Dry Lake are about 12 feet deep. Therefore, once groundwater levels beneath Bristol Dry Lake decline below 12 feet below ground surface (bgs), the trenches will be dry, curtailing current mineral strip-mining operations. As noted in the FEIR (ESA, 2012a), under natural climatic conditions, groundwater levels beneath the dry lakes have declined at times and these trenches were dry.

If the groundwater level predictions from the modeling come to pass, it is likely that Corrective Measures will need to be implemented, as outlined in the GMMMP (Section 6.2.3, ESA, 2012b), to allow the strip-mining operations to continue during the proposed pumping at the Cadiz Project. These resource-specific measures include the following:

- Provision of substitute supplies, deepening of wells
- Blending well water with another source
- Constructing replacement wells
- Paying the third-party owner for any increased pumping costs, and
- Entering into a mitigation agreement with the impacted third party well owner

These Corrective Measures place the entire burden of the mitigation on the Cadiz Project and will not result in a disruption of the existing strip-mining operations. On this basis, the FEIR and the GMMMP concluded any Undesirable Results were avoidable (ESA, 2012a). The modification, reduction, or cessation of pumping, if groundwater drawdowns exceeded the 80-foot “floor” within two miles of the center of the Cadiz Project well-field (see **Section 5.1**), were not the primary mitigation measures to avoid Undesirable Results to Brine Resources.

3.4 Potential Impacts to the Saline-Fresh Water Interface

There is currently an established transitional interface between saline groundwater in the vicinity of Bristol and Cadiz dry lakes and freshwater moving towards the dry lakes from the Fenner Valley and other up-stream watersheds. The interface is maintained in place by the movement of groundwater to the dry lakes and subsequent evaporation at the dry lakes. The proposed pumping at the Cadiz Project is intended to meet the conservation objective and capture most of the groundwater flowing toward the dry lakes that would otherwise be lost to evaporation and wasted. Thus, the proposed pumping will likely reverse groundwater flow between the Cadiz Project well-field and the dry lakes; that is, flow would be from the dry lakes to the well-field. This change in groundwater flow direction is expected to cause the saline-fresh water interface to migrate away from the dry lakes towards the Cadiz Project well-field.

Once saline groundwater has migrated into what was the fresh water part of the aquifer it will be difficult to reverse the effects. Therefore, some movement of the interface has been accepted as an environmentally insignificant and reasonable consequence of the Cadiz Project’s ability to conserve millions of gallons of fresh water (ESA, 2012a).

A threshold perimeter distance of 6,000 feet for the potential movement of the saline-fresh water interface was specified by the County in the GMMMP (ESA, 2012b) and deemed insignificant in the FEIR (ESA, 2012a). The GMMMP proposes the installation of cluster wells 6,000 feet from the currently mapped location of the interface. These cluster wells will monitor groundwater geochemical conditions, notably total dissolved solids (TDS) concentrations, to identify if the interface is approaching or has reached the threshold distance. If the interface reaches the cluster wells at the perimeter distance, Corrective Measures may be required to prevent further migration of the saline-fresh water interface. These resource-specific measures include installing brackish water extraction or fresh water injection wells at the saline-fresh water interface. It should be noted that there are no known existing wells used for potable supply within the 6,000-foot perimeter of the saline-fresh water interface that could be impacted.

Results of the analysis of saline water movement using the numerical groundwater model (GSSI, 2011; ESA, 2012b) indicate that migration of the saline-fresh water interface induced by the proposed pumping at the Cadiz Project ranges from 6,300 to 10,400 feet, depending on the recharge value used in the numerical groundwater model. These distances exceed the 6,000-foot perimeter distance specified in the GMMMP (see above). Consequently, the saline-fresh water interface will likely need to be actively managed when the Cadiz Project is operating. This adaptive management includes monitoring and mitigation (see above). The GMMMP (ESA, 2012b) provides that migration will be limited to 6,000 feet northeast of the dry lakes through physical measures (e.g., injection or extraction wells) or pumping restrictions if physical measures prove ineffective. Such Corrective Measures appear reasonable and should be effective, if implemented appropriately. The monitoring and mitigation proposed in the GMMMP (ESA, 2012b), complemented by additional monitoring and modeling improvements recommended herein, will ensure this potential impact remains insignificant once the Cadiz Project is operational and through the project's life.

3.5 Potential Impacts to Ground Surface Levels in the Watershed

The FEIR (ESA, 2012a) identified that aquifer and aquitard compaction (both elastic and inelastic) could cause temporary and permanent subsidence at locations proximate to the Cadiz Project – a potential Undesirable Result. The Fenner and other watersheds from which the Cadiz Project draws water have large volumes of groundwater in storage (between 17 and 34 million acre-feet [MAF]) (ESA, 2012a). These volumes greatly exceed the volumes that will be removed by the proposed pumping at the Cadiz Project after recharge has been considered: 50,000 AFY pumped for 50 years (2.5 MAF) minus 5,000 to 32,000 AFY of recharge for 50 years (0.25 to 1.6 MAF) resulting in a net loss from storage of 0.9 to 2.25 MAF. Therefore, significant subsidence across a wide area resulting from the proposed pumping at the Cadiz Project is not anticipated. However, localized subsidence may occur in areas proximate to the Cadiz Project well-field with geologic conditions that foster subsidence (e.g., areas underlain by inelastic clay layers).

The current agricultural pumping conditions (1,223 AFY in 2017) do not appear to induce subsidence and are not sufficient to allow for the identification of areas prone to localized subsidence. Such areas will only become apparent, if they exist, once the proposed pumping at the Cadiz Project has been sustained at higher volumes for an extended period. Thus, subsidence will need to be monitored during project operations.

Section 6 of aquilogic (2013) previously summarized the potential impacts to ground levels. Because no extensive building structures are proposed as part of the Cadiz Project, the region is largely undeveloped, and the Project area is underlain by predominantly coarser-grained sediments (sands and gravels), simple load compaction subsidence should not occur. It should be noted that, during the compilation of comments to the FEIR, there were no objections to the Cadiz Project raised by the two nearby railroads or the natural gas companies that have pipelines in the area. In fact, the projected subsidence impacts were determined to be within the range of published subsidence criteria.

With respect to potential carbonate cavern collapse and the railroad, the maximum allowable subsidence is 1-inch per 62-foot string of track. The example on p.57 aquilogic (2013) would result in 2.12 inches of deformation over 520 feet, or ¼ inch per 62-foot string; that is, well within the railroad tolerances. **Aquilogic** concurred with the estimates of groundwater pumping subsidence generated from the GSSI (2011) modeling. That is, maximum subsidence (2.5 to 3.13 feet) would occur beneath Bristol Dry Lake, where clay content is highest. The next highest area of subsidence (2.0 to 2.5 feet) would occur in an area within the Bristol Watershed, where clay is still present, close to the proposed Cadiz project well-field (where drawdown is greatest); that is, on Cadiz owned land. These levels of subsidence over the areas predicted are well within the railroad tolerances.

The GMMMP (ESA, 2012b; Section 6.3) proposes a monitoring program that includes land surveys, InSAR satellite data, and extensometers. In the event that significant subsidence is observed, the GMMMP (ESA, 2012b; Section 6.3.4) proposed Corrective Measures that include repairs to damaged structures, a potential mitigation agreement, and possible modification of Cadiz Project well-field operations to arrest subsidence. The GMMMP presents a reasonable approach to the monitoring and mitigation of potential subsidence. The monitoring and mitigation proposed in the GMMMP (ESA, 2012b), complemented by some slight modifications to the monitoring recommended herein, should ensure this Undesirable Result does not occur or, if it does occur, can be mitigated effectively during and after the Cadiz Project operational period.

3.6 Other Potential Impacts

There are three other potential Critical Resources identified in the GMMMP: Air Quality, Project Area Vegetation, and the Colorado River and its Tributary Sources of Water. Table 6-1 and Table 5-2 of the GMMMP (ESA, 2012b) summarize these potential impacts and the monitoring proposed to assess them:

- Air Quality Potential Impacts: Changes in air quality that exceed baseline conditions by 5 percent (%) and changes in soil conditions showing degradation of soil structure. Assessed using nephelometers.
- Project Area Vegetation. Reduction in the extent or character of Project area baseline vegetation. Assessed using vegetation monitoring.
- Colorado River and its Tributary Sources of Water. Removal of water from the Colorado watershed. The assumption that groundwater pumped at the Cadiz Project is non-tributary to the Colorado River is supported by substantial physical evidence (e.g., bedrock and groundwater divides). However, two monitoring wells (one existing and another to be installed) on property owned by Cadiz within the adjacent Piute Watershed that is tributary to the Colorado River will be monitored to assess the current interpretation.

The Panel has made some recommendations with respect to the Vegetation Monitoring at the Springs (see **Section 7.9**). However, in general, the Panel concurs with the GMMMP proposed monitoring to evaluate whether any of these potential Undesirable Results occur, and if they are caused by the proposed pumping at the Cadiz Project. The Panel also concurs with the Corrective Measures, if required, proposed in the GMMMP (ESA, 2012b) and agrees that they are reasonably sufficient to avoid any of these potential Undesirable Results.

4.0 GENERAL ASSESSMENT OF THE GMMMP

Table 6-1 in the GMMMP (ESA, 2012b) summarizes the monitoring and mitigation program for each potential Undesirable Result. For each of the Critical Resource categories, comments identified by the Panel are provided in **Table 2** below. The comments are based on whether the monitoring: (1) will identify an Undesirable Result; (2) has appropriate trigger thresholds; and (3) will be protective of Critical Resources. That is, collectively, do they avoid Undesirable Results? The Panel has concluded that, in general, the monitoring proposed in the GMMMP (ESA, 2012b) is sufficient for this purpose.

Nevertheless, some parties continue to express concerns about the Cadiz Project. Given these concerns, and the opportunity to improve the long-term efficacy of the monitoring and mitigation, the Panel has recommended the consideration and inclusion of additional monitoring, management and mitigation measures. If administratively feasible (e.g., permits and approvals to conduct certain monitoring can be obtained), these measures can be added to the GMMMP. These additional measures will provide greater assurances and greater confidence that the Cadiz Project will meet its water conservation objectives, can be implemented without causing Undesirable Results or, if they occur, any Undesirable Result can be mitigated.

The recommendations are not intended to alter the analysis or findings regarding the environmental impacts of the Cadiz Project described in the FEIR (ESA, 2012a), or contain any significant new information. Rather, the recommendations presented below are designed to:

- Improve the robustness of the GMMMP
- Broaden hydrogeologic knowledge of the Cadiz Project area
- Increase public confidence by providing additional monitoring, management and mitigation measures to further reduce the unlikely risk of Undesirable Results and are presented in an abundance of caution

Table 2. Monitoring and Trigger Threshold Summary with Panel Comments

Potential Impact	Monitoring Summary	Trigger Summary	Review Panel Comment
Springs	Visual observation and flow measurements at three springs (Bonanza, Whiskey, and Vontrigger) in accordance with the guidance document prepared by Desert Research Institute (DRI)	Reduction in average annual or seasonal flow or degradation in characteristics as correlated to precipitation	1. The GMMMP monitoring is appropriate to identify impacts. The understanding of the localized groundwater system proximate to Bonanza Spring could be improved with additional monitoring (i.e., additional monitoring wells, higher frequency monitoring). In addition, more defined vegetation monitoring is recommended (see below). 2. The proposed trigger thresholds are appropriate. For the avoidance of doubt, the GMMMP should evaluate threshold groundwater level declines in nearby wells (existing and recommended) that could be used as an early-warning of possible impacts to spring flow. Monitoring of these groundwater levels once the Project has commenced would be helpful and add to overall knowledge of the aquifer system. 3. The GMMMP monitoring and thresholds are protective of this Critical Resource. However, for the avoidance of doubt, and to address lingering concerns about impacts on the springs post-FEIR, we recommend that the GMMMP incorporate: (a) higher frequency spring flow monitoring; (b) additional localized groundwater monitoring; (c) more defined vegetation monitoring; (d) monitoring and other investigations (e.g., geophysical surveys) to confirm the conceptual model of spring flow; and e) considering new data collected before and after the initiation of pumping at the Cadiz Project, the hydrologic system at Bonanza Spring should be evaluated further with numerical groundwater modeling. The GMMMP contemplates a reassessment of monitoring every five years and this recommendation is not inconsistent with that requirement. Note: Cadiz has previously initiated monitoring of Bonanza and Vontrigger Springs; however, it has been denied access to Whiskey Spring.

Land Subsidence	Benchmark stations; InSAR; extensometers	Land surface decline of > 0.3 ft. A declining trend that would impact infrastructure	1. The GMMMP monitoring is appropriate to identify impacts. Although there have been no objections raised to this methodology, additional monitoring may be helpful. For the avoidance of doubt, we recommend: (a) additional InSAR analyses be performed; (b) only one initial extensometer be installed; and (c) the location and design of the additional extensometers be based on the InSAR data analyses. 2. The GMMMP trigger thresholds are appropriate. 3. The GMMMP monitoring and thresholds are protective of this Critical Resource. For the avoidance of doubt, we recommend: (a) more frequent InSAR data are analyzed; and (b) considering new data collected before and after the initiation of pumping at the Cadiz Project, the potential land subsidence should be evaluated using numerical groundwater modeling. The GMMMP contemplates a reassessment of monitoring every five years and this recommendation is not inconsistent with that requirement.
Saline Migration	Cluster wells between the dry lakes and Cadiz Project well-field	Total dissolved solids (TDS) concentrations increase >600 milligrams per liter (mg/L or ppm) at cluster wells ~6,000 feet from the current saline-fresh water interface.	1. The GMMMP monitoring is appropriate to identify impacts. Additional complementary measures could be considered by the Technical Review Panel, including conducting Electro-magnetic (EM) mapping of the saline-fresh water interface prior to pumping at the Cadiz Project during project operation, and post-operation. 2. The GMMMP trigger threshold is appropriate. 3. The GMMMP monitoring and thresholds are protective of this Critical Resource. For the avoidance of doubt, we recommend: (a) monitoring be supplemented with geophysics, and (b) considering new data collected before and after the initiation of pumping at the Cadiz Project, the migration of the interface should be evaluated using numerical groundwater modeling. The GMMMP contemplates a reassessment of monitoring every five years and this recommendation is not inconsistent with that requirement.

Brine Resources at Bristol and Cadiz dry lakes	Observation and cluster wells at dry lakes	Changes in brine water levels of >50% in the water column above of the mineral strip-mining company's pump intake	1. The GMMMP monitoring is appropriate to identify impacts. 2. The GMMMP trigger threshold is appropriate. 3. The GMMMP monitoring and thresholds are protective of this Critical Resource. For the avoidance of doubt, considering new data collected before and after the initiation of pumping at the Cadiz Project, brine water levels beneath the dry lakes should be evaluated further using numerical groundwater modeling. The GMMMP contemplates a reassessment of monitoring every five years and this recommendation is not inconsistent with that requirement.
Management of Overall Groundwater Drawdown	Monitoring within a 2-mile radius of the center of the Cadiz Project well-field	Groundwater decline of >80 feet at this distance (a groundwater management "floor")	1. The GMMMP monitoring is appropriate to identify impacts. However, for the avoidance of doubt, it is recommended that: (a) additional monitoring wells be installed proximate to Bonanza Spring; and (b) the frequency of monitoring be increased. 2. The proposed trigger threshold is appropriate. 3. The proposed monitoring and thresholds are protective of this Critical Resource. For the avoidance of doubt, we recommend: (a) additional groundwater monitoring be conducted; and (b) considering new data collected before and after the initiation of pumping at the Cadiz Project, the overall hydrologic conditions in the watersheds tributary to the Cadiz Project should be evaluated further with numerical groundwater modeling. The GMMMP contemplates a reassessment of monitoring every five years and this recommendation is not inconsistent with that requirement.

Third Party Wells	Groundwater observation wells	More than twenty (20) feet decline in static water levels	1. The proposed monitoring is appropriate to identify impacts. There is no evidence of wells withdrawing potable water within the Cadiz Project area. However, to improve understanding of the extent of potential drawdown (with the consent of the non-potable water users), it is recommended that transducers and data-loggers be installed at third-party wells where potential impacts appear most likely (i.e., third-party wells closest to the Cadiz Project well-field). The transducers should be maintained in these third-party wells for the pre-operational period and first five years of operations. 2. The proposed trigger threshold is appropriate. 3. The proposed monitoring and trigger threshold are protective of this Critical Resource. For the avoidance of doubt, we recommend: (a) increased frequency of monitoring at select third-party wells, and (b) considering new data collected before and after the initiation of pumping at the Cadiz Project, groundwater levels at third-party wells should be evaluated further using numerical groundwater modeling. The GMMMP contemplates a reassessment of monitoring every five years and this recommendation is not inconsistent with that requirement.
Adjacent Groundwater Basins	Groundwater observation wells	No action criteria necessary	1. The GMMMP is appropriate to identify impacts. 2. Trigger thresholds might be established in the unlikely event that adverse impacts from proposed pumping at the Cadiz Project are observed. 3. The GMMMP monitoring is protective of this Critical Resource.
Air Quality	Nephelometers, Soil testing	Changes in air quality that exceed baseline conditions by 5% and changes in soil conditions showing a degradation of soil structure	1. The GMMMP monitoring is appropriate to identify impacts. 2. The GMMMP trigger thresholds are appropriate. 3. The GMMMP monitoring and thresholds are protective of this Critical Resource.

Vegetation	Visual observation and correlation with groundwater levels	Reduction in the extent or character of Project area baseline vegetation	1. The GMMMP monitoring is appropriate to identify impacts. Aside from areas proximate to the springs, no groundwater dependent flora or fauna were identified in the FEIR. The weight of credible evidence indicates there is no direct hydraulic connection between Bonanza Spring and the alluvial aquifer in Fenner Valley below. Nevertheless, to address ongoing concern regarding the Bonanza Spring, and for the avoidance of doubt, it is recommended that further details and definition on vegetation mapping of Bonanza, Vontrigger, and Whiskey springs be provided. 2. The GMMMP proposed trigger thresholds can be refined in a more detailed vegetation monitoring plan. 3. The GMMMP monitoring and thresholds are protective of this Critical Resource. Nevertheless, for the avoidance of doubt, greater detail on the vegetation monitoring at springs should be provided, including more defined trigger thresholds. The GMMMP contemplates a reassessment of monitoring every five years and this recommendation is not inconsistent with that requirement.

The Corrective Measures for each Undesirable Result are presented in Table 6-1 in the GMMMP (ESA, 2012b, p. 120) and summarized in **Table 3** below, along with comments from the Panel. These comments are discussed further in later sections of this Consensus Report. The comments are provided in the context of whether the mitigation: (1) is practical (feasible and implementable) and appropriate; (2) will prevent an Undesirable Result; and/or (3) will alleviate an Undesirable Result, if it occurs, in a reasonable period of time.

Table 3. Mitigation Summary with Panel Comments

Potential Impact	**Corrective Measures**	**Comment**
Springs	Modification of Project operations to re-establish baseline flow and spring characteristics.	1. The GMMMP mitigation is practical and appropriate. 2. Based upon current evidence and analyses presented in this report, it is unlikely that there is a direct hydraulic connection between Bonanza Spring and the alluvial aquifer. To the extent there is a direct hydraulic connection, the FEIR concluded that the impact was not significant as the expected change, even after 100 years, was within the natural historic variation in water levels at Bonanza Spring. However, given the elevated concerns that continue to surround this specific resource, and for the avoidance of doubt, we recommend that additional mitigation measures be evaluated to prevent adverse impact (e.g.,

		aquifer recharge, temporary replacement water). A commitment to provide water for aquifer recharge or temporary replacement water appears feasible and sufficient to offset any observed impact at Bonanza Spring. The FEIR did propose the construction of a horizontal well to fulfill the same purpose. However, implementing this alternative mitigation may be difficult due to permitting issues. 3. Even if a direct hydraulic connection is assumed, the proposed mitigation will alleviate adverse impact. Alternative mitigation measures noted above should be evaluated to alleviate any impact in a more expeditious period of time.
Land Subsidence	Repair damaged structures. Enter into a mitigation agreement. Modification of Project well-field operations to arrest subsidence	1. The GMMMP mitigation is practical and appropriate. 2. The GMMMP mitigation may not prevent impact; however, the impacts may not be significant, and the potential impacts are not considered a threat to railroad and pipeline infrastructure. For the avoidance of doubt, the proposed monitoring program and thresholds (see **Table 2**) should be sufficient to trigger mitigation before an Undesirable Results occurs. 3. The proposed mitigation will alleviate impact in a reasonable period of time.
Saline Migration	Compensation. Installation of injection and/or extraction well(s) to maintain interface within its 6,000-foot limit. Modification of Project well-field operations	1. The GMMMP mitigation is practical and appropriate; 2. The GMMMP mitigation, notably injection/extraction wells, should prevent further migration of the interface. The recommended geophysical mapping (see **Table 2**) will allow for the pro-active design and installation of such wells, and earlier adjustments to Cadiz Project well-field operations. 3. The proposed mitigation will alleviate the migration in a reasonable period of time. It is unlikely that they will restore groundwater between the current interface and the 6,000-foot limit to its pre-impact condition. However, no potable water supplies will be impacted and restoration of the current interface does not appear to have any beneficial purpose.
Brine Resources at Bristol and Cadiz dry lakes	Compensation. Installation of injection and/or extraction well(s). Enter into a mitigation agreement. Modification of Project operations to maintain beneficial use	1. The GMMMP mitigation is practical and appropriate. 2. The proposed mitigation may prevent further impact to brine resources. The cost of installing and operating extraction wells will be borne by the Cadiz Project. While the impact may continue after mitigation due to the response lag time in the hydrologic system, the installation of injection wells is unlikely to prevent further impact. A mitigation agreement that includes the installation of brine extraction wells will allow mineral strip-mining operations to continue.

		3. The GMMMP mitigation can alleviate the impact to brine resources but it is unlikely that brine resources will be restored to their condition prior to pumping at the Cadiz Project for many decades, irrespective of the mitigation. Consequently, the mitigation agreement provides for the installation of brine extraction wells to allow mineral strip-mining operations to continue with no additional expense to the strip-miners.
Management of Overall Groundwater Drawdown	Modification of Project operations to avoid impact	1. The GMMMP mitigation is practical and appropriate. 2. The GMMMP mitigation may not prevent further impact due to the response lag time in the hydrologic system. However, the proposed monitoring program (see **Table 2**) can be used to trigger mitigation before Undesirable Results occur. 3. The GMMMP mitigation will alleviate impact in reasonable period of time proximate to the Cadiz Project well-field. The restoration of groundwater conditions further from the well-field will take many decades due to the response lag time. However, the lag-time response was analyzed under the FEIR over a 50-year post-pumping period, and Corrective Measures reflect this analysis.
Third Party Wells	Continued provision of substitute water supplies. Deepen or otherwise improve efficiency of impacted well(s). Blend impacted well water with another source. Construct replacement well(s). Compensation. Enter into a mitigation agreement. Modification of Project well-field operations	1. The GMMMP mitigation is practical and appropriate. 2. There are no third-party potable wells within the Cadiz Project area. The GMMMP mitigation will not prevent further impact to groundwater levels at non-potable third-party wells. However, it will provide a non-potable supply of water to impacted parties. 3. While the proposed mitigation will not alleviate the impact to groundwater levels at third party wells in a reasonable period of time, it will alleviate the impact to those third-party wells by providing an alternate water supply.
Adjacent Groundwater Basins	None	There are no anticipated impacts in adjacent basins. If information is developed to suggest there are impacts, the GMMMP monitoring program (see **Table 2**) should identify whether mitigation actions are needed.
Air Quality	Modification of Project operations to re-establish baseline air quality levels	1. The GMMMP mitigation is practical and appropriate. 2. The Cadiz and Bristol dry-lakes were identified as potential sources of air-quality impacts. However, due to the soil composition (high concentration of Calcium Chloride) at the dry-lakes, it is unlikely that air quality impacts will occur as a result of a reduction of moisture. In the unlikely event that significant air quality impacts are observed, the proposed mitigation may not

		prevent further impact due to the response time in the hydrologic system. Even with changes in Cadiz Project operations, brine water levels may not recover for many years. Therefore, in the unlikely event that significant air quality impacts occur, alternative mitigation measures should be evaluated (e.g., surface spraying in areas prone to dust generation). 3. The proposed mitigation will alleviate impact, but not in a reasonable period of time due to the response time in the hydrologic system. Therefore, in the unlikely event that significant air quality impacts occur, alternative mitigation measures should be evaluated.
Vegetation	Modification of Project operations to re-establish baseline vegetation	1. The GMMMP mitigation is practical and appropriate. 2. Aside from areas proximate to the springs, no groundwater dependent flora or fauna were identified in the FEIR. However, there is no credible evidence of a direct hydraulic connection between Bonanza Spring and the alluvial aquifer in Fenner Valley below. Nevertheless, for the avoidance of doubt, if it is assumed that a direct hydraulic connection exists and a significant impact is observed, the proposed mitigation may not prevent further impact due to the response lag time in the hydrologic system. Therefore, in the unlikely event that a significant impact to vegetation at springs associated with Cadiz Project operations occurs, alternative mitigation measures should be evaluated (e.g., temporary watering of vegetation). The FEIR did propose the construction of a horizontal well to fulfill the same purpose; however, trucking water may be easier, more practical, and more expeditious to implement. 3. The proposed mitigation will alleviate impact, but not in a reasonable period of time (see comment above). Therefore, in the unlikely event that a significant impact to vegetation at springs associated with Cadiz Project operations occurs, alternative mitigation measures should be evaluated.

5.0 ANALYSIS OF MONITORING AND MITIGATION

The GMMMP (ESA, 2012b) includes an assessment of Undesirable Results using numerical groundwater modeling to understand the potential hydrologic effects of the proposed pumping at the Cadiz Project. The Panel was provided access to the numerical model (GSSI, 2011) and reviewed various model simulations to gain perspectives on the potential hydrologic effects of the Cadiz Project.

The Cadiz Project will conserve water by capturing groundwater that would otherwise be wasted through evaporation from Bristol and Cadiz dry lakes. To achieve this, groundwater pumping will lower groundwater levels within the Fenner, Bristol Dry-Lake, Cadiz Dry-lake, and Orange Blossom Wash watersheds. For a project that involves the drawdown of aquifer water levels across a wide geographic area, the dynamics of groundwater storage changes related to the propagation of the cone of depression may be an important management factor. In particular, the lag time between groundwater level response distant from the pumping and the actual pumping activities (i.e., starting, continued pumping, modified pumping, and cessation) should be understood and considered).

For example, if an Undesirable Result is observed (e.g., reduced spring flows related to the proposed pumping at the Cadiz Project), then mitigation may include reduction or cessation of pumping at the Cadiz Project. However, even after the cessation of pumping, groundwater levels distant from the pumping may continue to decline for some period of time in response to prior pumping as a result of the response lag time. To provide context, a preliminary analysis using the numerical groundwater model for this example (i.e., potential hydrologic effects associated with the cessation of pumping at the Cadiz Project) is presented below

5.1 Aquifer Response to Pumping at the Cadiz Project

As an example[1], a scenario of pumping at the Cadiz Project using the GSSI (2011) model was run for 25 years. It was assumed that, in year 25, a threshold for an Undesirable Result was "triggered" at a monitoring point. This indicates that an impact may occur (e.g., reduced spring flow related to pumping at the Cadiz Project). It was then assumed that, as mitigation for this potential impact, pumping was terminated at the beginning of year 26. The continued aquifer response for several years after the cessation of pumping was analyzed using numerical groundwater model simulations with a recharge rate of 16,000 AFY.

---

[1] GSSI ran three model versions with different natural recharge rates to characterize a range of possible basin natural recharge (Project Scenario: 32,000 AF/Y, Sensitivity 1: 16,000 AF/Y and Sensitivity 2: 5,000 AF/Y). The example described herein is with the mid-range 16,000 AF/Y natural recharge version.

For this model simulation, in response to the cessation of pumping, an immediate aquifer water-level recovery is observed proximate to the Cadiz Project well-field (i.e., groundwater levels rise as groundwater infills the cone of depression around the well-field). However, at some distance from the well-field, groundwater levels continued to decline. This results from the continued movement of groundwater toward the well-field to infill the deepest parts of the cone of depression around the well-field. These distant locations could be coincident with a monitoring point being used to assess the effect of the proposed pumping at the Cadiz Project on a Critical Resource.

An illustration of the drawdown response in this model simulation is shown on **Figure 9**. The red dashed line (contour) indicates the location of 10 feet of drawdown after 25 years of pumping at the Cadiz Project. At the beginning of the 26th year when pumping stops, the blue lines illustrate the expansion of the 10-foot drawdown contour outward for the next 10, 20 and 30 years after pumping stops. That is, drawdown exceeds 10 feet for many years after that mitigation has been implemented – the cessation of pumping. Under such circumstances, an Undesirable Result may occur at a Critical Resource even many years after the implementation of the mitigation action (i.e., the cessation of pumping).

Given the propagation of the cone of depression after pumping stops, continued monitoring of groundwater conditions proximate to Critical Resources should continue after mitigation is implemented, as proposed in the GMMMP (ESA, 2012b, Section 6.4.3).

It is noted that the FEIR (ESA, 2012a) considered the delay in the propagation of the cone of depression by evaluating potential Undesirable Results over a 100-year period - 50 years of pumping 50,000 AFY and 50 years after pumping. No Undesirable Results were identified in the FEIR that could not be mitigated, considering the drawdown that would result over 100 years using various recharge rates as low as 5,000 AFY.

This model simulation is presented for illustrative purposes and further model simulations could be run to assess groundwater level responses to the mitigation actions proposed in the GMMMP once the Cadiz Project becomes operational, new data are collected, and the groundwater model is updated. In particular, simulations should examine whether a trigger threshold should be adjusted to account for the time lag between an action and the response at a monitoring point being used to assess Undesirable Results. Trigger thresholds for drawdown tied to several defined periods of time for a particular Critical Resource should also be evaluated. In addition, alternative mitigation actions that do not have time lag response issues (e.g., recharging the aquifer proximate to the Critical Resource) should be evaluated.

A groundwater level drawdown threshold (80 feet) is proposed in the GMMMP for a distance of two miles from the center of the Cadiz Project well-field. This threshold is intended to provide a management "floor" below which mitigation actions would be triggered. Such a floor was selected as it lessens the need for resource-specific mitigation actions at individual Critical Resources, as it is believed to provide a proactive Corrective Measure that would prevent significant impact.

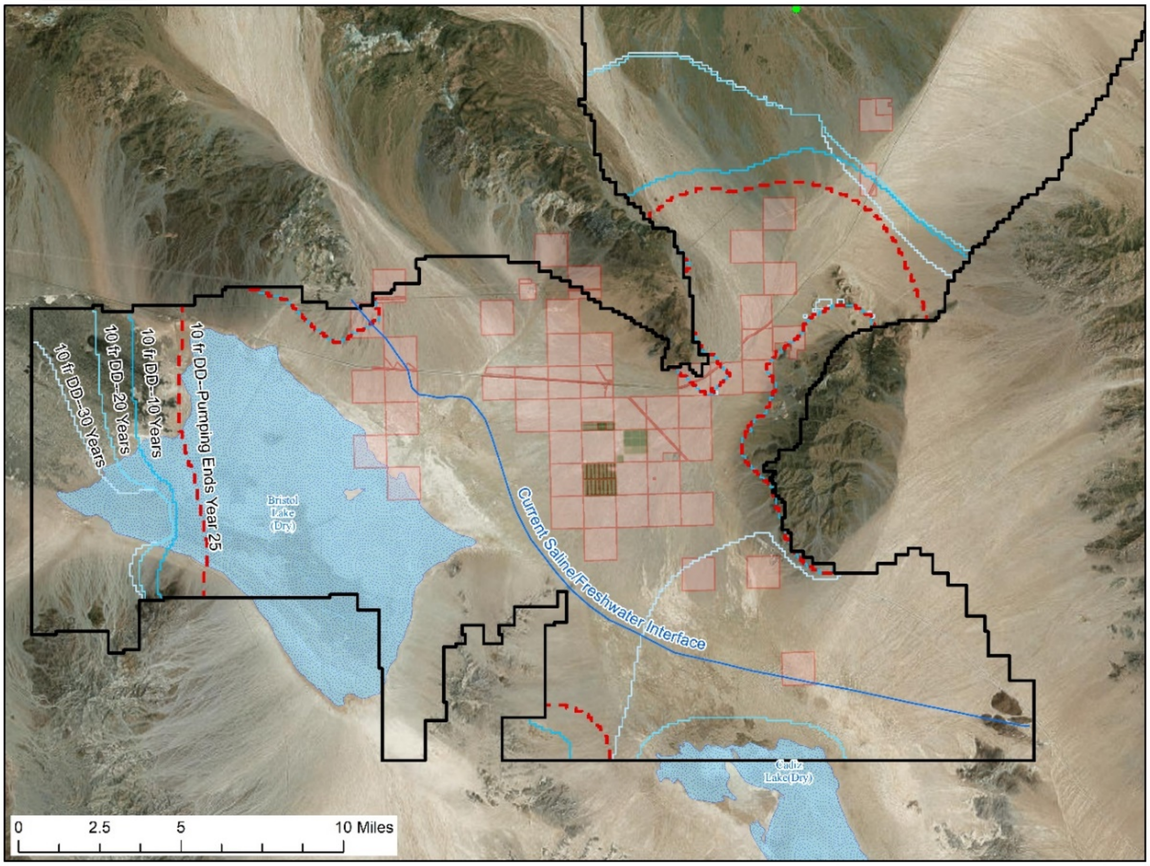


Figure 9: Lag in drawdown response related to the cessation of pumping at the Cadiz Project

It should be noted that the drawdown threshold two miles from the center of the Cadiz Project well-field may trigger mitigation when none is actually required. For example, if the 80-foot threshold is triggered, but unacceptable groundwater level declines are not observed closer to the springs (e.g., at monitoring well 6N15E1) or brine resources, no mitigation should be required. Conversely, if the 80-foot drawdown threshold is not triggered, but groundwater level declines observed closer to Critical Resources suggest an Undesirable Result could occur, then mitigation may be required. For these reasons, adequate monitoring is needed as close as reasonably possible to the Critical Resources. If monitoring closer to the Critical Resources indicates that an Undesirable Result could occur, then mitigation can be implemented.

The GMMMP (ESA, 2012b) discusses updating the numerical groundwater model(s) as information is collected during project operations. It is anticipated that subsequent modeling analysis will provide information that guides the “Decision-Making Process” (ESA, 2012b) associated with potential Corrective Measures for each identified Critical Resource. It is recommended that the numerical groundwater model be recalibrated after the installation and testing of new pumping wells at the Cadiz Project well-field, and this recalibration completed within a year. The model should then be recalibrated again after one year of pumping at higher flow rates (i.e., up to 50,000 AFY), and this recalibration completed within the second year of pumping. The recalibrated numerical groundwater model would then be used for the additional analyses recommended in this Consensus Report. The model should then be recalibrated again after five years of pumping and the collection of additional monitoring data for groundwater levels, groundwater geochemistry, spring flows, and land subsidence, etc. Again, this recalibration should be completed within a year.

5.2 Springs within Fenner Watershed

The FEIR (ESA, 2012a) and GMMMP (ESA, 2012b) concluded that it was very unlikely that a direct hydraulic connection existed between Bonanza Springs and the alluvial aquifer in Fenner Valley below. It further concluded that, even if there was a direct hydraulic connection, any impact would be within the natural historical variations in spring flow. Nevertheless, certain opponents to the Cadiz Project continue to express concerns about possible impact to the springs.

Subsequent to the finalization of the FEIR, detailed geologic mapping and hydrogeologic analyses conducted at Bonanza Spring (Kenney and TLF, 2018) conclude that there is no direct hydraulic connection between Bonanza Spring and the alluvial aquifer. However, some researchers (Zdon, 2016; Zdon et al., 2018; Rose, 2017) assert the hypothesis of a direct hydraulic connection between Bonanza Spring and the alluvial aquifer. Their assertions are principally based on their findings regarding groundwater geochemistry. These findings are disputed by other researchers (Kreamer, 2018; Schroth, 2018; Kreamer, 2019).

Irrespective of the dispute over groundwater geochemistry, given the geological mapping of Kenney and TLF (2018), the hydrologic assessment in aquilogic (2013), and fundamental hydrogeologic concepts, the Panel has concluded that the weight of credible evidence suggests that there is no direct hydraulic connection between Bonanza Spring and the alluvial aquifer in Fenner Valley below. The evidence includes, but is not limited to, the following:

- The 11 mile distance between the proposed pumping at the Cadiz Project well-field and Bonanza Spring
- The over 1,000-foot change in elevation between groundwater in Fenner Valley and Bonanza Spring

- The hydrologic nature of the fractured bedrock watershed supporting Bonanza Spring and the alluvial deposits in Fenner Valley
- The identification of faults in the vicinity of Bonanza Spring that control spring location by Kenner and TLF (2018)
- The evaluation of groundwater geochemistry at Bonanza Spring by Kreamer (2019), notably lower water temperatures and spring flow variation
- The infiltration of stream flow supported by Bonanza Spring immediately down-stream of the spring (i.e., the presence of a vadose zone down-stream of Bonanza Spring)

Despite the weight of evidence, for the purposes of this Review, we have not attempted to resolve the dispute over geochemical interpretation. The impact analysis in the FEIR (2012a), in an abundance of caution, assumed there was a direct hydraulic connection. Further, in performing our Review, the Panel has considered the potential for an Undesirable Result assuming, in an abundance of caution, that a direct hydraulic connection exists.

5.2.1 Geophysical Mapping

As noted, the Panel has concluded that the weight of credible evidence suggests that there is no direct hydraulic connection between Bonanza Spring and the alluvial aquifer in Fenner Valley below. However, in order to provide additional information on the geologic structure and hydrogeology in the vicinity of Bonanza Spring, it is recommended that geophysical mapping be conducted in the area immediately above, and for some distance below, the spring. The objectives of the geophysical surveys would be to delineate structural features (i.e., faults) and other structural deformation, identify potential fracture lineaments with increased facture aperture and density (i.e., groundwater bearing potential), map the bedrock surface below the unconsolidated deposits south of the spring, and map the groundwater surface above and below the spring. A geophysical contractor should be retained to plan and implement the geophysical mapping. If feasible, the mapping may include shallow seismic surveys, surface electro-magnetics (EM), time-domain EM (TDEM), and electrical resistance tomography (ERT).

5.2.2 Spring Flow Monitoring

The GMMMP provides for quarterly monitoring of flow at the Bonanza Spring. The Whiskey and Vontrigger springs will also be monitored quarterly, even though these springs are located beyond the projected drawdown in groundwater levels in the alluvial aquifers that results from the proposed pumping at the Cadiz Project. As such, the monitoring at Whiskey and Vontrigger springs will serve as background monitoring. This will allow any significant variations in flow at Bonanza Spring that result from pumping at the Cadiz Project to be isolated from variations that result from other factors (e.g., drought) that are observed at Whiskey and Vontrigger springs.

Given the smaller scale of the bedrock watershed that supports Bonanza Spring (Kenney and TLF, 2018), a change in recharge should have a rapid effect on hydraulic head within the groundwater in the bedrock watershed. Bonanza Spring would respond much more rapidly to this change in hydraulic head. That is, for example, with declining recharge, hydraulic heads within the watershed that supports Bonanza Spring will decline and flows at Bonanza Spring (and possibly its elevation) may also decline. As noted, in the past it appears that Bonanza Spring itself has moved downslope in response to the historic lowering of the groundwater elevations in the watershed that supports the spring (Kenney, 2018; Zdon et al., 2018). This lowering may occur in the future should current drought conditions persist or reoccur.

If it is assumed that there is a hydraulic connection between Bonanza Spring and the groundwater in the alluvial aquifer, the temporal response at Bonanza Spring to the proposed pumping at the Cadiz Project must be considered. The proposed pumping will occur 11 miles away from Bonanza Spring and at an elevation more than 1000 feet lower. Therefore, it will take many years for the cone of depression caused by the proposed pumping to propagate out to the edge of the alluvium within the Fenner Valley below Bonanza Spring (GSSI, 2011; CH2M.Hill, 2011). Thus, any Undesirable Results from the proposed pumping at the Cadiz Project may take many years to appear at Bonanza Spring, in the unlikely event they do ever occur. In addition, if the proposed pumping were to be lowered or stopped (e.g., as a mitigation measure), groundwater levels proximate to the pumping would rebound. Given this, should pumping be reduced or ceased, monitoring of the springs and groundwater levels would need to continue for some period until stable or recovering hydrologic conditions were observed.

In the current GMMMP (ESA, 2012b) no new monitoring facilities will be constructed. *In-situ* measurements will be made at the Bonanza, Whiskey and Vontrigger springs. The general assumption made in the GMMMP is that the nearest spring, Bonanza Spring, would be impacted by the proposed pumping at the Cadiz Project before any more distant spring, if such impact were to occur. That is, Bonanza Spring should be monitored and, if no adverse impact is observed, the other springs should not be impacted. As noted, background monitoring would be conducted at Whiskey and Vontrigger springs. The following measurements will be made at Bonanza, Whiskey, and Vontrigger springs: depth of ponded water, flow rates, electrical conductivity (EC), pH, temperature, any colorations of water, and general type and extent of adjacent vegetation. These measurements will be made quarterly prior to the proposed pumping at the Cadiz Project and during project operations, and annually in the post-operational period. The GMMMP (ESA, 2012b) proposes quarterly monitoring of three springs. However, the responses at these springs to individual hydrologic events (e.g., precipitation) are generally observed over time frames much shorter than three months. For example, one large storm in such an arid setting may only elicit a response at the springs that lasts a few days or weeks, and the nature of the response (e.g., increase and subsequent declines in flows over time) may only be evident with high-frequency data. These short-term responses are also valuable in assessing responses to longer-term hydrologic events (e.g., seasonal precipitation, climatic changes, sustained pumping), and the impact these can have on future spring flows.

Therefore, it is recommended that more frequent monitoring be conducted at the Bonanza, Whiskey, and Vontrigger springs. Ideally, this should include transducers and a data-logger to monitor ponded water depth at reasonable, higher-frequency intervals. A multi-parameter probe could be used to monitor depth/flow, EC, and temperature at the same frequency. Alternatively, EC and temperature could be manually monitored on a monthly basis for at least one year prior to the proposed pumping at the Cadiz Project, and during the first year of project operations. After that, manual monitoring could be conducted quarterly. Data-loggers would be downloaded during manual monitoring events. Other parameters, such as pH, water coloration, and observations of riparian vegetation, could be conducted quarterly. In addition, it is recommended that the exact geographic location and elevation of the spring emergence be mapped using a global positioning system (GPS) annually or after a change in location is observed during other monitoring activities.

It should be noted that additional monitoring recommended in this Consensus Report (e.g., spring flow monitoring, monitoring wells below Bonanza Spring) will require approvals from government agencies. The monitoring proposed in the GMMMP (ESA, 2012b) is sufficient to ensure that no Undesirable Results will occur, or can be mitigated. However, the additional monitoring recommended herein will assist in the overall understanding of the hydrology of the Cadiz Project area, notably at Bonanza Spring, and improved monitoring of possible Undesirable Results at Critical Resources. Therefore, given the value of such monitoring, it is hoped that such approvals will be forthcoming. If permission to install the transducers and data-loggers is not given, then ponded water depth and spring flow should be monitored on the same frequency as manual monitoring of EC and temperature.

Prior to any monitoring of spring flows, including manual monitoring, a correlation between ponded water depth and flow will need to be developed. This is normally done for a location immediately downstream of the spring where the stream profile is defined and constrained (e.g., where it crosses bedrock) or where the profile can be artificially constrained (e.g., construction of a v-notch weir). A location with a naturally confined profile should be identified. Ponded water depth and flow measurements should be taken at that location on several occasions during different flow conditions (e.g., low-flow, regular flow, storm-flow) to develop the correlation. The transducer or multi-probe would then be installed at that location.

The exact scientific method as to how the “general type and extent of adjacent vegetation” will be monitored was not specifically described in the GMMMP. It is recommended that a terrestrial ecologist be retained to develop a scientifically appropriate methodology to monitor vegetation at the three springs at least one year prior to the commencement of the proposed pumping at the Cadiz Project, during the operational period, and for some period after pumping has ceased. This might include defined transects across the stream below the springs, and identification and quantification of species at points along the transects over time. Such a standardized methodology will allow changes in vegetation to be tracked over time.

It is important that at least one year of higher-frequency data on spring conditions be obtained prior to the proposed pumping at the Cadiz Project. In particular, this monitoring will provide a baseline for Bonanza Spring that can compared to data collected after the pumping at the Cadiz Project is initiated. This baseline comparison will supplement and/or complement the comparison of data for Bonanza Spring to the time-contemporaneous data collected at the Whiskey and Vontrigger springs. That is, how does any change in conditions at Bonanza Soring compare to other springs, based on time-contemporaneous data, and how does it compare to conditions at Bonanza Spring prior to the proposed pumping at the Cadiz Project. Such comparisons will assist in evaluating whether any change at Bonanza Spring is the result of the proposed pumping at the Cadiz Project, climatic variability, and/or other factors.

Finally, we recommend that more detailed quality assurance and quality control (QA/QC) procedures be developed, described, implemented, and documented for the collection and analysis of all data pertinent to the springs. A detailed quality assurance project plan (QAPP) should be prepared to describe the QA/QC procedures. In fact, the QAPP should describe QA/QC procedures for the collection and analysis of all data pertinent to the Cadiz Project.

Although it appears unlikely that a direct hydraulic connection exists between Bonanza Spring and the alluvial aquifer in Fenner Valley below, the additional monitoring recommended herein will produce scientifically defensible information to assist with the following:

- Characterizing the degree, if any, of hydraulic communication between Bonanza Spring and the alluvial aquifer in the Fenner Valley
- Identifying and quantifying any Undesirable Results at Bonanza Spring
- Evaluating the cause of any such impacts (e.g., the proposed pumping at the Cadiz Project, climatic conditions, other factors)
- Determining the type, nature, magnitude, and duration of mitigation actions that could be implemented

5.2.3 Spring Flow Mitigation

As noted, the analyses presented in the FEIR (ESA, 2012a), aquilogic (2013), and Kenney and TLF (2018), indicates that there is likely no direct hydraulic connection between Bonanza Spring and the alluvial aquifer in Fenner Valley below. Therefore, without such a connection, the proposed pumping at the Cadiz Project will have no impact on Bonanza Spring (or other springs for that matter), and there would be no need for Corrective Measures. Even if there is a direct hydraulic connection, the FEIR concluded that the proposed pumping at the Cadiz Project would have no significant impact on Bonanza Spring, as any impact would be within historical variations observed at the spring. Therefore, given the lack of an Undesirable Result, there would be no need for mitigation.

The GMMMP still proposes potential Corrective Measures in the unlikely event that an Undesirable Result occurs at the springs (ESA, 2012a, Section 6.4.3). These measures include modification or cessation of pumping at the Cadiz Project well-field. However, as noted (See **Section 5.1**), due to the response lag time in the hydrologic system, such measures are reactive and would not prevent impact or alleviate impact in a reasonable period of time. The FEIR did assess the construction of a horizontal well just above Bonanza Spring to maintain spring flow (ESA, 2012a, Section 6.4.3). Such a Corrective Measure would prevent further impact and alleviate impact in a reasonable period of time. However, implementing such mitigation would require approvals from government agencies. Alternatively, an injection well could be installed either at the edge of the alluvial aquifer in Fenner Valley or above Bonanza Spring.

Injection of water at the edge of the alluvial aquifer would “cut-off” the propagation of the cone of depression caused by the proposed pumping at the Cadiz Project. Injection of water above Bonanza Spring would maintain groundwater levels in the fractured bedrock watershed that supports spring flow. Given the very low effective fracture porosity, only small volumes of water are anticipated to be needed for injection into water-bearing fractures. Such injection programs, if implemented proactively, could actually prevent impact to Bonanza Spring and, even if implemented reactively, would prevent further impact and alleviate the impact in a reasonable period of time. Like the horizontal well proposed in the FEIR (ESA, 2012a), implementing such injection would require approvals from government agencies.

Finally, flow at Bonanza Spring has been estimated to be about 10 gallons per minute (gpm) (Thompson, 1929). Even in the unlikely event that the proposed pumping at the Cadiz Project reduced flows at Bonanza Spring, water could be delivered to a temporary storage tank above the spring. Water from this tank could then be discharged to Bonanza Spring to maintain spring flows. The provision of supplemental water, if implemented reactively, would prevent further impact and alleviate the impact in a reasonable period of time. Like the horizontal well proposed in the FEIR (ESA, 2012a), implementing such a mitigation action would require approvals from government agencies.

5.3 Groundwater Monitoring

The GMMMP (ESA, 2012b) includes groundwater monitoring requirements, such as monitoring locations, monitoring type, monitoring frequency, monitoring parameters. The locations of monitoring points pertinent to Bonanza Spring and the Brine Resources are presented in **Figure 10** (an excerpt from Figure 5-1: Monitoring Features of the GMMMP [ESA, 2012b]).

The perimeter of the green area on **Figure 10** indicates the maximum extent of 20 feet of drawdown in the alluvial aquifer resulting from the proposed pumping at the Cadiz Project, with the numerical groundwater model calibrated to recharge of 32,000 AFY. The maximum extent of 20 feet of drawdown extends to the contact between the alluvium and the bedrock of the Clipper Mountains south of Bonanza Spring. It also extends beyond the mineral strip-mining operations at Bristol Dry Lake.

In the GMMMP (ESA, 2012b), it is proposed that groundwater conditions be monitored at wells 6N15E1 and 6N15E29 (see **Figure 10**) to observe the propagation of the cone of depression outward from the proposed pumping at the Cadiz Project toward Bonanza Spring. These wells would serve as sentry wells – providing an early indication of potential Undesirable Results at Bonanza Spring, assuming there is a direct hydraulic connection between the spring and the alluvial aquifer.

In the GMMMP, there is no threshold groundwater level decline at monitoring well 6N15E1 that would trigger mitigation. This is because no actual link, as opposed to a hypothetical link, between the alluvial aquifer and Bonanza Spring has been established. The credible evidence (Kenney and TLF, 2018) indicates that there is no hydraulic connection, and the analyses presented in the FEIR (ESA, 2012a) indicates that, even with an assumed hydraulic connection, the proposed pumping at the Cadiz Project would have a negligible impact on spring flows. Therefore, no such threshold at monitoring well 6N15E1 is warranted.

Despite the credible evidence, to assuage concerns and improve public confidence that the Cadiz Project can be operated without causing Undesirable Results, the Panel recommends that additional groundwater monitoring be conducted proximate to Bonanza Spring.

Monitoring well 6N15E1 is screened within the alluvial sediments of the Fenner Valley (Kenney, 2018, Figure 17 and Figure2-7b). The well is located approximately 1.5 miles southeast of the contact between alluvial deposits (Qoaf) and the Clipper Mountains. This well will be useful in identifying the propagation of potential drawdown in the alluvial aquifer of the Fenner Valley resulting from the proposed pumping at the Cadiz Project.

Monitoring well 6N15E1 is located approximately 3.5 miles southeast of Bonanza Spring. Ideally, a monitoring well should be placed closer to Bonanza Spring to monitor groundwater level conditions at the contact between the alluvial deposits and the Clipper Mountains (e.g., one mile southeast of Bonanza Spring). In addition, the well will not provide data on groundwater conditions within the fanglomerates and other unconsolidated deposits on the side slopes of the Clipper Mountains (if they contain groundwater). It will also not provide data on groundwater conditions in the fractured bedrock either below Bonanza Spring or in the watershed above Bonanza Spring that supports spring flow. Ideally, to more effectively monitor potential Undesirable Results at Bonanza Spring and evaluate the possible cause of the impact, monitoring wells could be placed in the following locations:

- Immediately below the spring (i.e., within 100 yards) with separate casings discretely screened in unconsolidated deposits beneath and adjacent to the stream fed by the spring, if they contain groundwater, and in the fractured bedrock beneath these deposits
- Below Bonanza Spring at the limits of the alluvial aquifer (e.g., one mile southeast)
- Immediately above the spring (i.e., within 50 yards) in the fractured bedrock watershed that supports spring flow

The monitoring of spring flow itself (see **Section 5.2.2**) negates the need for the latter monitoring well. That is, the spring itself serves as a groundwater monitoring point for the bedrock watershed that supports spring flow. The second monitoring well would provide a second, but not duplicative, groundwater data point within the alluvial aquifer in Fenner Valley. The first set of monitoring wells in the unconsolidated deposits and fractured bedrock below Bonanza Spring would provide data that could not be obtained from any currently existing monitoring wells. Therefore, this set of wells is the most important additional monitoring wells needed to evaluate groundwater conditions in relation to potential Undesirable Results at Bonanza Spring. These monitoring wells (outlined in Recommendations, Section 7) would provide a more definitive data set to monitor and evaluate potential Undesirable Results at Bonanza Spring. For example, if groundwater levels decline in 6N15E1, but not in the additional monitoring wells installed between Bonanza Spring and well 6N15E1, then it is unlikely that an Undesirable Result will occur at Bonanza Spring. As another example, if groundwater levels are stable at a new monitoring well one mile southeast of Bonanza Spring but declining in a monitoring well within the fractured bedrock, and flows at Bonanza Spring are impacted, the impact cannot be from the proposed pumping at the Cadiz Project, but rather a climatic or other effect within the watershed above the spring. As a third example, if groundwater levels are declining in all monitoring wells, and flows at Bonanza Spring are impacted, then the impact could be from the proposed pumping at the Cadiz Project, and Corrective Measures would need to be taken.

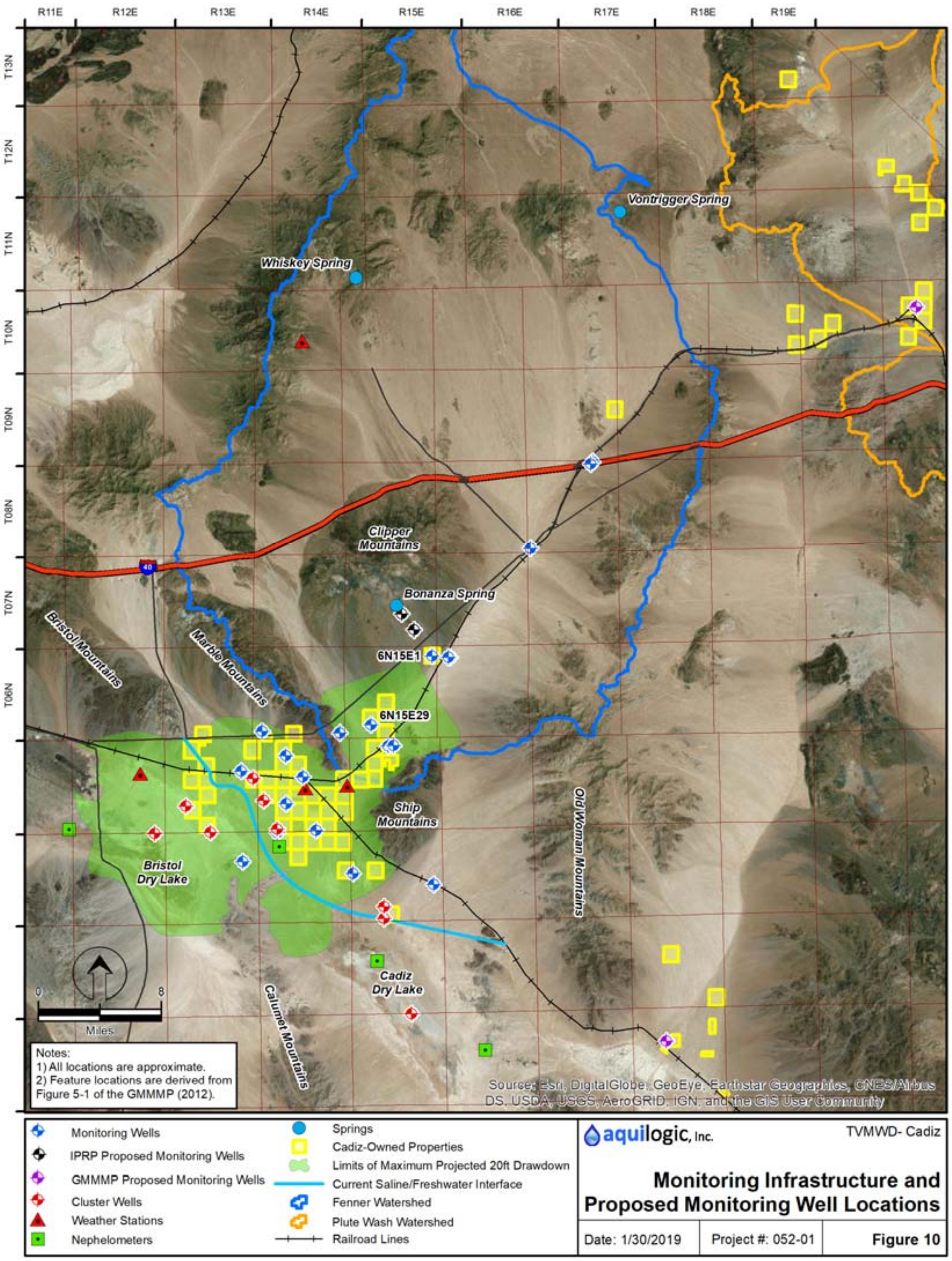


Figure 10: Excerpt of Monitoring Features from Figure 5-1 of the GMMMP (ESA, 2012b)

In the current GMMMP (ESA, 2012b, see Figure 5-1, p. 64), groundwater levels and water quality will be monitored in the Fenner Valley at 14 existing monitoring wells plus two proposed monitoring wells (Danby-1 located between Chubbuck and Rice; and Piute-1 located east of Goffs). It is proposed in Appendix B of the GMMMP (ESA, 2012b, p. 122) that groundwater level measurements be taken at various frequencies depending on well and operating period. In the pre-operational period, transducers will be used to collect high frequency groundwater level measurements at six existing monitoring wells (5N14E5F1, 6N15E01H, 6N15E29P1, 4N14E13J1, 5N14E24D2, 5N14E16H1); whereas, groundwater levels at the other ten wells will be measured manually on a monthly basis. In the GMMMP, it is proposed that groundwater level measurements be taken semi-annually during the operation period and annually during the post-operational period. During the pre-operational period, groundwater quality samples will be collected quarterly at five monitoring wells and annually at nine wells. During the operational and post-operational periods, groundwater will be sampled annually at the five wells previously sampled quarterly.

In general, the number and location of wells used to monitor regional groundwater conditions appear appropriate. Cadiz has prepared Annual Agricultural Monitoring Reports (CH2M.Hill, 2018) for two decades, as required under its permitted agricultural use. The data in these reports indicates that groundwater levels have not materially changed over the last twenty year period. However, when the Cadiz Project begins operation, the hydrologic system will be subject to annual pumping much higher than previously seen. This pumping will be maintained for up to 50 years. Given the increased pumping and concerns expressed by some project opponents, the Panel recommends that the frequency of groundwater monitoring be modified slightly.

The groundwater monitoring program proposed in the GMMMP (ESA, 2012b) may not provide the temporal resolution needed to establish baseline conditions immediately prior to the proposed pumping at the Cadiz Project or to evaluate the hydrologic response to the pumping of 50,000 AFY during the first few years of operation. Monitoring groundwater levels at a higher frequency will better establish baseline conditions. It will also allow the response of the hydrologic system to increased pumping to be evaluated, including information on hydrogeologic structure within the watersheds, an improved understanding of hydraulic parameters (e.g., hydraulic conductivity and storativity), and identification of possible data gaps that may need to be filled. In addition, the increased monitoring frequency will assist in the assessment of Undesirable Results (e.g., Bonanza Spring, Brine Resources) from the proposed pumping at the Cadiz Project. In doing so, it will also allow pumping operations to be optimized (e.g., well cycling, pumping rates) to maintain production while preventing Undesirable Results. Therefore, it is recommended that the following modified groundwater monitoring and sampling program be implemented concurrent with commencement of the Cadiz Project:

- Pre-operational (for at least one year) – transducers be placed in all 16 monitoring wells, plus the proposed monitoring wells adjacent to Bonanza Spring and brine migration cluster wells, to collect groundwater level readings (perhaps hourly basis), and the data-loggers downloaded quarterly.

- The groundwater quality sampling program proposed in the GMMMP (ESA, 2012b) is acceptable. The new monitoring wells proximate to Bonanza Spring proposed herein and any new brine migration cluster wells should be sampled quarterly.
- First year of operation – the pre-operational monitoring and sampling program recommended above should be maintained.
- Years 2-5 of operation – transducers should be maintained in the monitoring wells, and the data-loggers downloaded annually. Groundwater quality samples should be collected at all monitoring wells, including any newly installed monitoring wells, annually.
- Years 6-50 of operation – the groundwater monitoring and sampling program proposed in the GMMMP (ESA, 2012b) is acceptable. For any newly installed monitoring wells, groundwater levels should be monitored semi-annually and sampled annually for groundwater quality analyses. It should be noted that, under the adaptive management approach in the GMMMP, analysis of the data collected may require that the proposed monitoring program be modified for these later year of operation and the post-operational period.
- First post-operations year – the pre-operational monitoring and sampling program recommended above should be implemented during this period of rapid groundwater recovery.
- Years 2-5 post-operations – the monitoring and sampling program implemented in years 2-5 of operations should be implemented during this period of rapid groundwater recovery.
- Subsequent post-operations years - the groundwater monitoring and sampling program proposed in the GMMMP (ESA, 2012b) is acceptable.

5.4 Brine Resources Underlying Bristol and Cadiz Dry Lakes

The hydrograph below in **Figure 11** (GSSI, 2011) shows the projected drawdown of groundwater levels beneath the Bristol Dry Lake during the proposed pumping at the Cadiz Project. The hydrograph was produced from numerical groundwater modeling performed by GSSI (2011). It shows that, depending on the recharge amount used in the modeling, between 30 and 65 feet of drawdown will occur beneath Bristol Dry Lake. In general, the trenches used to expose saline groundwater to evaporation and precipitate salts for mineral strip-mining operations at Bristol Dry Lake are about 12 feet deep, and the two existing strip-mining operators utilize approximately 750 AFY of brine water. Therefore, once groundwater levels beneath Bristol Dry Lake decline below 12 feet bgs, the trenches will be dry, curtailing some strip-mining operations and processes. However, it is understood that the strip-mining operations already pump groundwater from existing wells into the trenches. In addition, under natural climatic conditions, groundwater levels beneath the dry lakes decline at times, and the trenches are then dry.

Viewed strictly from the standpoint of whether the project is causing a physical change in the environment, and if there were a need for a "physical solution" if the groundwater level predictions from the modeling come to pass, it is likely that Corrective Measures will need to be implemented as outlined in the GMMMP (ESA, 2012b) to mitigate impacts on the strip-mining businesses. These Corrective Measures include operational modifications and/or negotiation of a compensation or mitigation agreement with mineral strip-mining operator(s). Such an agreement would require that Cadiz bear all of the costs of drilling wells to pump the brine, as the strip-mining operators do presently in some locations, rather than rely on the high groundwater table to fill evaporation/precipitation trenches. For example, brine extraction wells deeper than 70 feet bgs could be installed to maintain mineral strip-mining at Bristol Dry Lake.

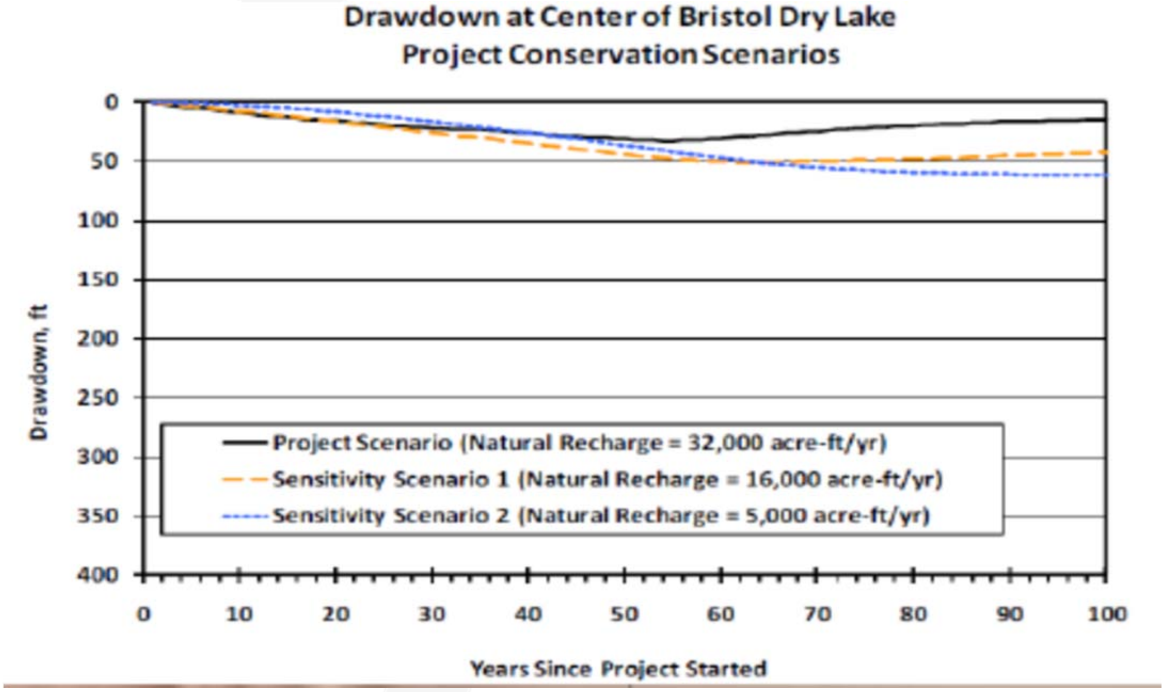


Figure 11: Drawdown Beneath Bristol Lake Under Three Recharge Scenarios (GSSI, 2011)

In Section 5.8 (p. 63) of the GMMMP (ESA, 2012b) it states that "*An additional well cluster will be installed on the Bristol Dry Lake playa to monitor brine levels and chemistry at different depths beneath the Dry Lake surface. This well cluster will be positioned in relation to the well clusters at the margin of the Dry Lake so as to provide optimum data for the variable density transport model*" (ESA, 2012b). The well clusters on Figure 5-1 (p.64) of the GMMMP are not labeled. However, there appears to be only one cluster in the middle of the Bristol Dry Lake (see **Figure 10**). It is also proposed in the GMMMP that a well cluster be installed at the middle of Cadiz Dry Lake (see **Figure 10**). It is recommended that these well clusters be added to the groundwater monitoring and sampling program after installation (see **Section 5.3**). In addition, it is recommended that groundwater samples collected at the well clusters be analyzed for lithium concentrations. This data may assist in the design and construction of any brine extraction wells that have to be installed to maintain mineral strip-mining operations.

GSSI (2011) analyzed hydrologic effects at the dry lakes using a numerical groundwater flow and transport model. The numerical model represents evapotranspiration (Et) from the dry lakes using a technique that involves specification of surficial elevations based on USGS 15-minute topographic quadrangles (Cadiz, Danby, Bristol Lake and Cadiz Lake) and an Et extinction depth below that surface reasonably assumed to be 15 feet bgs (GSSI, 2011, p. 36 - 37). The numerical model simulates direct Et from the saturated groundwater regime (water table) beneath the Bristol and Cadiz dry lakes. As the groundwater levels decline below the dry lakes in response to pumping at the Cadiz Project, the Et rate decreases. Eventually, when groundwater levels decline below the extinction depth, simulated Et stops.

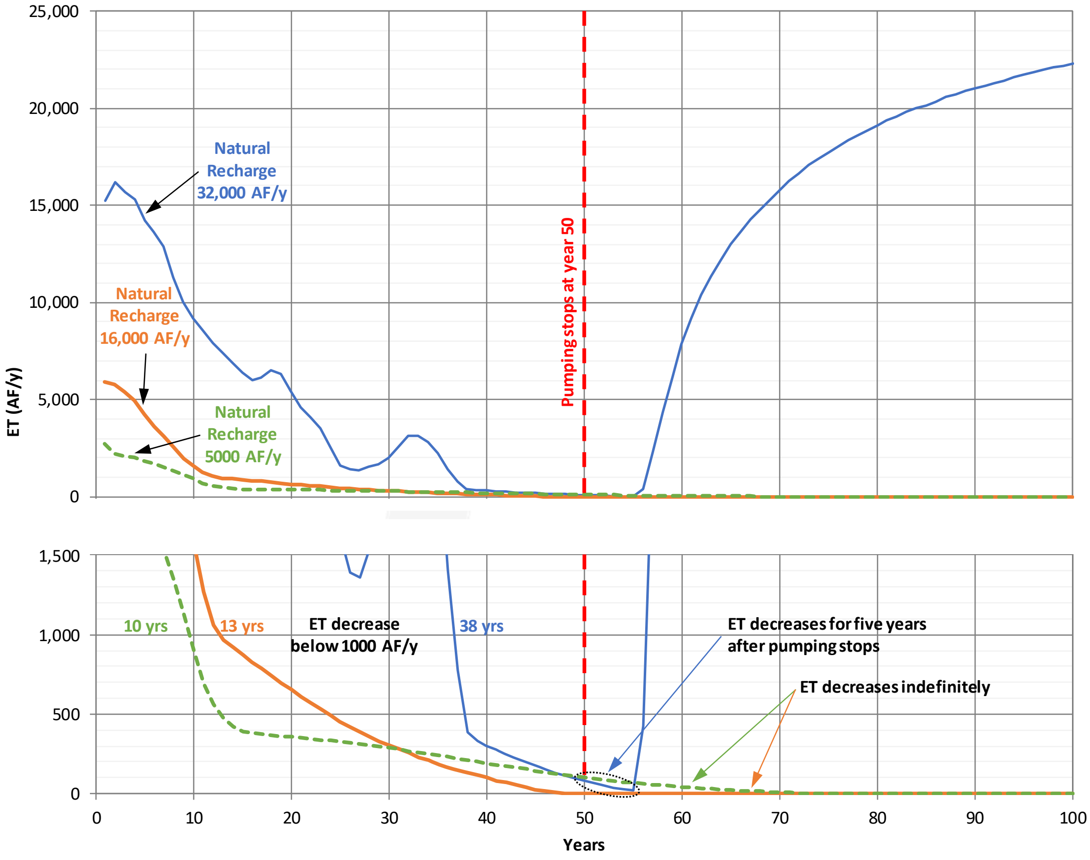


Figure 12: Simulated Et for Three Recharge Scenarios (lower chart is an expansion of the bottom 1,500 AFY of the upper chart)**.**

GSSI (2011, Tables 2, 3 and 4) ran three model simulations to provide water budget tables that include total Et for three project scenarios with different recharge rates (Project scenario: 32,000 AFY, Sensitivity 1: 16,000 AFY and Sensitivity 2: 5,000 AFY - GMMMP, p. 41 - 42). **Figure**

12 below shows the Et quantities reported from the GSSI (2011) water budget tables indicating the change in Et over time for each simulation.

Two important observations are apparent in **Figure 12:**

- First, with the proposed pumping at the Cadiz Project, Et lowers to small quantities (< 1,000 AFY) in each scenario (38 years in the Project Scenario, 13 years in Sensitivity 1, and 10 years in Sensitivity 2). This small volume of Et indicates that shallow groundwater levels below most of the dry lakes have been lowered below 15 feet bgs. With such groundwater level declines, the brine supply trenches would likely be dry and shallow brine recovery wells may have reduced yields.
- Second, Et continues to decrease after pumping at the Cadiz Project ceases in year 50. The continued decline in Et (and associated decline in groundwater levels) results from the time lag discussed previously in this Consensus Report (see **Section 5.1**). In the Project Scenario (32,000 AFY recharge), Et decreases for another five years after pumping at the Cadiz Project stops. In the Project Scenario, Et then recovers and exceeds 1,000 AFY seven years after pumping ceases. However, in Sensitivity Scenarios 1 and 2 (16,000 and 5,000 AFY, respectively), Et decreases indefinitely and shows no recovery for the 50-year period after pumping ceases. This indicates that shallow (high salt) groundwater levels at the dry lakes may not recover to within 15 feet of the land surface within the duration of this model simulation (i.e., 50 years after pumping ceases).

Lowering the groundwater table beneath Cadiz and Bristol dry lakes is a physical change necessary to achieve the conservation objectives of the Cadiz Project. Such a change is approved as part of the approach to optimally manage the basin under the GMMMP (ESA, 2012b). The above results indicate that simply stopping pumping at the Cadiz Project may not mitigate Undesirable Results to Brine Resources. However, such a cessation or modification of pumping was never intended to be the sole Corrective Measure for impacts to Brine Resources. As set forth in the GMMMP (ESA, 2012b, Section 6.2.3), alternative mitigation for loss of production at the mineral strip-mining operations will be needed (e.g., drilling new, deeper brine recovery wells). Careful logging and depth discreet sampling of any new brine recovery wells may allow the wells to be constructed to optimize recovery of select minerals (e.g., lithium).

5.5 Saline–Fresh Water Interface Migration

As noted in **Section 3.4** in this Consensus Report, there is currently an established transitional interface between saline groundwater in the vicinity of Bristol and Cadiz dry lakes and freshwater moving towards the dry lakes from the Fenner Valley and other up-stream watersheds. The proposed pumping will likely reverse groundwater flow between the Cadiz Project well-field and the dry lakes; that is, flow would be from the dry lakes to the well-field.

This change in groundwater flow direction will cause the saline-fresh water interface to migrate away from the dry lakes towards the Cadiz Project well-field. Results of the analysis of saline water movement using the numerical groundwater model (GSSI, 2011; ESA, 2012b, p. 52) indicate that migration of the saline-fresh water interface induced by the proposed pumping at the Cadiz Project ranges from 6,300 to 10,400 feet, depending on the recharge value used in the numerical groundwater model.

The GMMMP (ESA, 2012b) proposes the installation of nine cluster wells to monitor saline groundwater conditions and/or the potential migration of the saline–fresh water interface (see **Figure 10**) (ESA, 2012b). As noted above (**Section 5.4**), cluster wells will be installed in the middle of Bristol and Cadiz dry lakes. Two cluster wells will be installed between Bristol Dry Lake and the current location of the saline fresh water interface. Three cluster wells will be installed between the current location of the interface and the Cadiz Project well-field. One well will be installed at the interface to the north of Cadiz Dry Lake, and the final cluster will be installed between Cadiz Dry Lake and the Cadiz Project well-field, just north of the interface.

As per Page 68 of the GMMMP (ESA, 2012b), "*These new well clusters are set forth in Features 3, 8 and 9 and are depicted in Figures 5-1 and 5-2 as Proposed Induced Flow and Brine Migration Cluster Wells*." Unfortunately, the "features" are not numbered on Figures 5-1 or 5-2.

The installation of cluster wells proposed in the GMMMP is an appropriate approach to monitoring a saline–fresh water interface. Such wells have been used in other areas experiencing saline intrusion (e.g., West Basin of Los Angeles County, Orange County Groundwater Basin, Seaside Basin). However, the saline–fresh water interface will not migrate in a uniform regular fashion, either spatially or at depth. The migration will occur along areas of preferentially higher hydraulic conductivity, either spatially or vertically. That is, once the interface begins to migrate, it may do so in an irregular pattern of "saline fingers" as opposed to a uniform "saline front". These fingers will also vary with depth. Such irregular migration may not be detected by just four well clusters (three at Bristol Dry Lake and one at Cadiz Dry Lake).

Given the above, it is recommended that the location of the saline-fresh water interface be mapped spatially and at depth using geophysical techniques prior to the proposed pumping at the Cadiz Project. Given the relative homogeneity of the alluvial deposits and known groundwater depth, EM techniques will be effective at mapping the mineralization of groundwater (i.e., TDS content). Different EM tools can be used to spatially map groundwater mineralization at various depths. ERT can also be used to map vertical profiles of groundwater mineralization along cross-section lines. The outputs from the spatial EM mapping and ERT can be combined to create a three-dimensional visualization of the saline-fresh water interface. The results of this geophysical mapping can be used to locate the proposed cluster wells, and select the screened depths at each cluster. It is further recommended that the geophysical mapping be repeated every five years after the proposed pumping at the Cadiz Project is initiated. This will allow the migration of the saline-fresh water interface to be mapped in three-dimensions over time. An understanding of the migration of the saline-fresh water interface will allow any potential mitigation actions to be optimized (e.g., recharge of fresh water in areas and depths of preferential migration).

5.6 Potential Subsidence

In the current GMMMP (ESA, 2012b; Section 6.3, and Table 6-1), the proposed land surface monitoring consists of ground-level surveys, InSAR imagery, extensometers, and reviewing this information at various frequencies during pre-operational, operational, and post-operational periods. In the GMMMP, it is proposed that ground-level surveys be conducted on an annual basis for the pre-operational, operational and post operational periods. This methodology and frequency proposed in the GMMMP (ESA, 2012b) are appropriate.

The current GMMMP proposes to acquire InSAR imagery once during the pre-operational period, once every five years during the operational period, and twice at five-year intervals during the post operational period. InSAR is a powerful tool that cost-efficiently measures ground surface deformation throughout an area of interest. Thus, the Panel agrees with the selection of this technology in the GMMMP and recommends the following:

- The availability of historical InSAR imagery in the Project area should be investigated and, if available, acquired and processed to obtain a pre-operational assessments of land subsidence
- InSAR imagery should be acquired and processed every year during the first ten years of the operational period
- InSAR imagery should be acquired and processed every five years for years 11 through 50 of the operational period
- InSAR imagery should be acquired and processed every year for years 1 through 5 of the post-operational period
- InSAR imagery should be acquired and processed every five years thereafter during the post-operational period

In conjunction with groundwater monitoring data, InSAR analysis has the potential to indicate the presence and location of groundwater barriers. In addition, InSAR data in the early years of the proposed pumping at the Cadiz Project is especially important because most of the drawdown proximate to the Cadiz Project well-field (i.e., areas prone to land subsidence) will occur in these early years.

In the GMMMP (ESA, 2012b; Figure 5-2), it is proposed that three borehole extensometers be placed in strategic locations with the highest probability of land subsidence proximate to the Cadiz Project well-field. Borehole extensometers measure the continuous change in vertical distance between the land surface and a subsurface reference point in a borehole, where an anchor is placed. No information is provided on how the extensometers will be constructed (e.g., whether pipe, cable, rods, or how many anchor points will be constructed at each extensometer site). It is assumed that extensometers would be constructed during the pre-operational period. Deformation observations will be recorded daily during the operational period. The observational frequency is not stated for the post-operational period.

It is recommended that the expected number of anchor points at each extensometer site be defined. A general description of extensometer construction and instrumentation, and a recommended post-operational period measurement rate should also be specified. Data storage, QA/QC procedures, and the methods used to analyze data should be developed and documented prior to extensometer installation. Extensometer data can be compared to interferograms of two temporally-adjacent InSAR images to provide greater confidence in the regional estimates of ground level displacements from InSAR.

It is extremely costly to install extensometers and they only provide point source data. That is, only three measurements of land subsidence would be provided for the entire project area. Therefore, it is recommended that only one extensometer be installed during the pre-operational period. The installation of the two additional extensometers could be deferred until a temporal and more spatially extensive dataset on land subsidence is available (i.e., InSAR data). If the InSAR data indicates that land subsidence is an Undesirable Result, then the additional extensometers would be installed. The InSAR data coupled with the lithologic information from new production and monitoring wells would be used to help locate these extensometers.

6.0 GMMMP CLARIFICATION REQUESTS

The GMMMP (ESA, 2012b) was developed to describe how the Cadiz Project could be operated to avoid Undesirable Results through monitoring and adaptive management. Based on current knowledge, in general, the current GMMMP presents the following:

- A thorough description of the Undesirable Results
- A rigorous and appropriate monitoring program (that can be supplemented by recommendations presented herein)
- Practical, effective, and appropriate management and mitigation actions (which, can be supplemented, if feasible, by recommendations presented herein)

The monitoring program in the GMMMP will generate new information that, over time, will improve the understanding of the hydrologic system tributary to the Cadiz Project. This new data should be considered in the development of updated, calibrated, numerical groundwater modeling efforts. The GMMMP will need to be updated periodically in light of new data, modeling, and overall improved understanding. This may result in refinements to the monitoring, management and mitigation actions over time.

After reviewing the GMMMP, the Panel has presented certain recommendations (see **Sections 4 and 7**). In addition, the Panel has specific clarification requests with respect to certain statements or sections in the GMMMP.

6.1 Chapter 1

Comment 1. Section 1.1, Page 8. "*spreading basins*". **Comment:** Spreading basins may incur evaporative losses. It should be noted if injection wells have been considered.

Comment 2. Section 1.4.1, Page 14. "*SMWD will be the public agency carrying out the Project and will also be the public agency with the greatest responsibility for supervising the Project*." **Comment**: An organizational flow chart would help the reader to understand who is responsible for operational decisions, mitigation decisions, operational oversight, and overall control of the Cadiz Project.

Comment 3. Section 1.4.4, Page 16. "FVMWC will lease all Project facilities and control and operate the Project during its entire duration". **Comment**: Section 1.4.1 says SMWD will fulfill this role.

Comment 4. Section 1.5.1, Page 18. "*Extraction in any given year may range from 25,000 to 75,000 afy to accommodate carryover, but shall not exceed more than an average of 50,000 afy measured over a 10-year period, inclusive of agricultural production by Cadiz. Project participants can carry over their annual allocations by storing their water in the basin for later* *extraction and delivery during drought or emergency conditions within the 50-year operation period'*. **Comment:** Whether the second sentence carries precedence over the first requires clarification (e.g., if in the first ten years a participant builds up some carry over, can they cause the 50,000 AFY 10 year rolling average to be exceeded in any of the subsequent 10 years?). This requires clarification.

Comment 5. Section 1.6, Page 19. *"ARZC"*. **Comment:** This acronym should be spelled out as follows, Arizona and California Railroad.

Comment 6. Section 1.7, Page 20. *"Regardless of any phasing, the average annual extraction over the 50 years of Project operations will not exceed 50,000 afy from all combined Cadiz Agricultural Program and Project pumping"*. **Comment: The phrase** "measured over a 10 year averaging period" should be added.

6.2 Chapter 3

Comment 7. Footnote 8 Page, 34. "*The 100-year time frame assumes no Project pumping during years 51 through 10*". **Comment:** This explanation should be placed before the table as this is the first time this concept is introduced.

Comment 8. Chapter 3 Page 35. "*allow for the carryover of native water in storage*". **Comment:** This concept needs to be better explained.

6.3 Chapter 4

Comment 9. Table 4-2. Page 42. Column 3, Row 5 in the lowest recharge scenario "*0 – 80 Drawdown at Bristol Dry Lake (feet)*". **Comment:** The noting that the least drawdown at this receptor is associated with the lowest recharge is counter-intuitive. This could only be correct if the reader understands that, to calibrate the groundwater model with the lowest recharge (Scenario 2), the hydraulic conductivities used in this model were also the lowest.

Comment 10. Figure 4-7 Page 48. The 0-foot contour in Layer 2 is closer to the Cadiz Project well-field under low recharge conditions. This is counter-intuitive, unless the reader understands that to calibrate the groundwater model with the lowest recharge (Scenario 2), the hydraulic conductivities used in this model were also the lowest (Same as comment 9).

Comment 11. Section 4.2.1.5 Page 52. "*Results of the modeling indicate that the saline-freshwater interface in the Bristol Dry Lake area would move up to 10,400 feet northeast during Years 1 to 50 under the Project Scenario, up to 9,700 feet under Sensitivity Scenario 1, and up to 6,300 feet under Sensitivity Scenario 2*." The GMMMP needs to explain why the interface does not move as far under reduced recharge conditions because this concept is counter-intuitive. The reader needs to understand that to calibrate the groundwater model with the lowest recharge (Scenario 2), the hydraulic conductivities used in this model were also the lowest (Same as comment 9).

Comment 12. Section 4.2.1.5 Page 52. *"As a precautionary measure to limit the migration of hyper-saline groundwater and protect the health of the aquifer under the County Ordinance, the saline-freshwater boundary shall be monitored and its migration limited to 6,000 ft northeast of the dry lakes through physical measures (e.g., injection or extraction wells) or pumping restrictions if physical measures prove ineffective"*. **Comment:** Pumping restrictions may be a least preferred mitigation method in terms of the rapidity and targeted nature of a required response (see **Sections 4 and 7**).

6.4 Chapter 5

Comment 13. Chapter 5 Page 63. *"A total of thirteen different types of monitoring features have been identified for assessing potential impacts to critical resources during the term of the Project, as identified in Chapter 4. A summary of these thirteen types of monitoring features, as well as monitoring frequencies and parameters to be monitored, is provided in Tables 5-1 and 5-2. Locations are shown in Figures 5-1 and 5-2."* **Comment:** The "features" are not identifiable on Figures 5-1 or 5-2, and are not labeled with identifiers. Larger copies of Figures 5-1 and 5-2 should be provided.

Comment 14. Section 5.8 Page 73. *"A typical observation well cluster completion is illustrated on Figure 5-5."* **Comment:** It would be useful to know which Formations will be targeted – hydro-stratigraphic units (HSUs) in the upper alluvial and/or carbonate formations.

6.5 Chapter 6

Comment 15. Page 77. Section 6. Review of Monitoring and Mitigation of Significant Adverse Impacts to Critical Resources (Action Criteria, Decision-Making Process and Corrective Measures). The first paragraph of this section of the GMMMP contains a concise description of the process to identify the need for corrective action. It states:

> *"This Management Plan identifies specific quantitative criteria or trends (action criteria) that will "trigger" review and corrective actions where necessary to protect critical resources or otherwise avoid Undesirable Results. When action criterion are triggered, a review of the triggering event will be conducted to determine whether the event is attributable to or exacerbated by Project operations, and if so, which specific corrective measures should be implemented to avoid adverse impacts to critical resources or Undesirable Results. It is the intent of this Management Plan to identify deviations from baseline conditions, along with deviations from groundwater model Projections, at monitoring features as early as possible in order to identify and prevent the occurrence of adverse impacts to critical resources or Undesirable Results as a result of Project*

> *operations. Triggering events may, in some circumstances, necessitate immediate corrective actions and subsequent review to ensure that the triggering event resulted from Project operations."*

The decision-making process contained in the GMMMP describes the process to be followed in the event an action criterion is triggered, as well as changes to the GMMMP. The second sentence in the first full paragraph is presumptive and states:

> *"FVMWC may propose refinements to the action criteria and monitoring network after additional data has been accumulated which indicates that the monitoring is unnecessary."*

We recommend that the text be rewritten to state:

"FVMWC may propose refinements to the action criteria and monitoring network after additional data has been accumulated and thoroughly reviewed."

The decision process is described as follows:

- Initial notification – FVMWC will provide written notice of a triggering event with 10 days of its occurrence. To accomplish this within ten days assumes that the FVMWC can promptly review and assess the monitoring data, make technical findings, and issue notices. We recommend that the FVMWC refine this part of the process description to describe its internal review practices that will enable it to meet the ten-day notice requirement.

- Initial assessment and notification – Within 60 calendar days of issuing notice that an action criterion is triggered. The GMMMP states:

  "FVMWC will undertake a three-step assessment process. First, FVMWC will assess whether the triggering of any action criterion is attributable to Project operations. Second, for any triggering of an action criterion attributable to Project operations, FVMWC will assess whether the triggering of the action criterion constitutes a potential adverse impact. Third, for any triggering of an action criterion that is attributable to the Project and constitutes a potential adverse impact, FVMWC will assess, recommend, and implement corrective measure(s) (including refinements in monitoring or to this Management Plan) necessary to avoid or mitigate the potential adverse impact or Undesirable Result.

  FVMWC shall provide its written assessment and recommendation, along with supporting data, to SMWD, the County Representative, and the members of TRP within the sixty (60) day assessment period."

The 60-day period may not be long enough to determine attribution, the material significance of the triggering response, and to subsequently and thoughtfully "*assess, recommend, and* *implement corrective measure(s) (including refinements in monitoring or to this Management Plan) necessary to avoid or mitigate the potential adverse impact or Undesirable Result."* **Comment:** We recommend that the FVMWC refine this part of the process description to describe its internal review practices that will enable it to meet the 60-day reporting requirement, or extend the reporting requirement timeframe.

Comment 16. Technical Review Panel (TRP) Review and Recommendation – Within 90 days of receiving FVMWC written assessment. The GMMMP states:

> *"Upon receiving FVMWC's written assessment and recommendation, the TRP will have ninety (90) calendar days to determine whether it concurs with the assessment and recommendation (including but not limited to modifications to the monitoring network, corrective actions, etc.). During the TRP review period, the TRP may request additional data and analysis from FVMWC and will have access to all monitoring data. Within the ninety (90)-day TRP review period, the TRP will issue a written report of its review of FVMWC's assessment and recommendation, including whether it concurs with the assessment and recommendation, to the County Representative, FVMWC, and SMWD, and if it does not concur, the basis of its disagreement and any alternative recommended actions. The TRP's written report shall state whether or not the report reflects a consensus of the TRP members. If the TRP members cannot reach a consensus, the members' differing opinions and recommendations shall be set forth in the written report.'*

The proposed scope and schedule of the TRP effort is conditioned on the thoroughness and technical backup of the FVMWC assessment report. The cumulative review time, assuming the FVMWC and TRP stay within the time frames allocated in the GMMMP, could run up to 150 days or five months. This may be too long to determine a response to an Undesirable Result.

- County and SMWD Review and Documentation – no time schedule to complete. **Comment:** The decision-making process is adequate although the time frame is indefinite.

Comment 17. Page 86. There is an apparent inconsistency among the text on page 86 and Table 5-1: the text states that the groundwater levels *"will be monitored on a continuous basis throughout the operational and post-operational terms of the Project*." Table 5-1 states that groundwater levels will be monitored continuously during the pre-operational and operational periods, and perhaps continuously during the post-operational period. **Comment:** This apparent inconsistency should be cleared up. The Panel recommends that the observation well clusters be constructed, and monitoring initiated, in advance of the proposed pumping at the Cadiz Project . The relationship between groundwater levels at the observation well clusters and the mineral strip-mining operator wells and brine supply trenches should be determined prior to Cadiz Project startup.

Comment 18. Section 6.4.1 Page 87. *"Of the monitoring well network, SCE Well no. 5 and SCE Well no. 11, along with other newly installed well clusters located between the interface and the Project well-field will be located such that that they are appropriate to serve as "sentinel" wells to determine whether there is a progressive migration of the saline-freshwater interface."* **Comment:** It would be useful to know the well cluster locations beforehand and whether groundwater level drawdown is expected at these locations. This should ensure that there is sufficient time for mitigation to be in place before any adverse impact occurs should drawdown be greater than expected.

Comment 19. Section 6.4.3 Page 87. *"If the action criterion is triggered, the decision-making process will include: Assessment of whether the increased TDS concentration or migration of the saline-freshwater interface is attributable to Project operations*;". **Comment.** An additional, first bullet might be to increase monitoring frequency to determine any rate of change.

Comment 20. Section 6.4.4 Page 88. "*Installing one or more extraction well(s) or injection well(s) at the northeastern edge of Bristol Playa and/or north of Cadiz Playa where the salt mining source wells are located to maintain the saline freshwater interface within its 6,000-foot limit subject to the same mitigation measures imposed on the Project well-field as set forth in the SMWD Mitigation Monitoring and Reporting Program (see Figures 5-1 and 5-2)*'" **Comment:** Clarification is required as to why certain text was underlined and what the underlined text means.

Comment 21. Management of the groundwater floor. This feature of the GMMMP is described as follows:

> *"The Project may drawdown the aquifer in the center of the Project well-field area to a maximum drawdown level (the "floor") of elevation 530 feet (80 feet below baseline elevations). The floor will be calculated as an average groundwater elevation over a 2-mile radius from the center of the Project well-field area. Once the floor is reached, and absent approval of a new floor by the County, pumping must be reduced to a quantity at or below the amount that will maintain water levels at or above the 80-foot floor."*

This groundwater floor management scheme includes an adaptive management component to drop the floor from 80 to 100 feet provided that the change is supported by sufficient operational data, the change will increase conservation, and the change will not cause undesirable results. The action criterion proposed for the management of the groundwater floor is stated in the GMMMP as follows.

> *"The decision-making process will be initiated if the action criteria are triggered. The action criteria are trends in groundwater levels that demonstrate that the*

> *designated floor elevation will be exceeded within 10 years. If such changes are measured, the decision-making process will be initiated."*

Comment: The last sentence of the action criterion cited above should be clarified. We understand it to mean that if such trends in groundwater levels occur, the decision-making process will be initiated. Our monitoring recommendations should serve to address all remaining doubt and that the adaptive management plan will result in reasonable decision-making and mitigation approaches.

Comment 22. Section 6.5.3, Page 90. "*Installing one or more brine extraction well(s) and/or injection well(s) where the salt mining source wells are located <u>subject to the same mitigation measures imposed on the Project well-field as set forth in the SMWD Mitigation Monitoring and Reporting Program (see Figure 5-1)</u>.'*" **Comment:** Clarification is required as to why certain text was underlined and what the underlined text means.

6.6 Chapter 7

Comment 23. Section 7.2, Page 100. "*To ensure that the Closure Plan can be fully implemented, FVMWC will establish and maintain an escrow account or other equivalent financial assurances mechanism for post-closure operations*." **Comment:** When will the escrow account be set up - before 5 - 15 years of operation, before operation? Clarification on the timeframe is required.

Comment 24. Table 5-1 Page 112. Final row, 10th column "Bristol and Cadiz dry lakes" "Semi-annually". **Comment:** Depending on how far sentinel wells are from 6,000-foot perimeter, this frequency may be insufficient to be able to react to rapid changes in drawdown (see Recommendations in **Section 7**).

7.0 RECOMMENDATIONS

The monitoring, management, and mitigation approach proposed in the GMMMP (ESA, 2012b) is appropriate, as was previously determined by the Groundwater Stewardship Committee (2011). Such a determination was made prior to the imposition of the County's oversight and additional conditions imposed on the Cadiz Project. These conditions, among others, included the 80-foot floor on groundwater elevations two miles from the center of the Cadiz Project well-field, and the ability to modify or curtail pumping if the proposed pumping at the Cadiz Project causes an Undesirable Result.

After careful review and consideration of the FEIR, GMMMP, and more recent technical reports, this Panel has recommended a number of complementary additions that could be made to the GMMMP, if feasible (ESA, 2012b). Collectively these recommendations are intended to allay any concerns that opponents to the Cadiz Project may still have, improve public confidence in the Cadiz Project, and are provided in an abundance of caution.

The recommendations are not intended to alter the analysis or findings regarding the environmental impacts of the Cadiz Project described in the FEIR (ESA, 2012a), or contain any significant new information. In addition, none of the recommendations are associated with a failure of the GMMMP to provide sufficient management, monitoring, and mitigation of Undesirable Results. However, the Panel strongly believes that the recommendations provide helpful direction in the ongoing monitoring, mitigation and management of the Cadiz Project. The recommended supplemental monitoring will produce additional information to assist with the following:

- Identifying and quantifying any Undesirable Results
- Further assessing the degree of hydraulic connection, if any, between Bonanza Spring and the alluvial aquifer in Fenner Valley below
- Monitoring brine water conditions beneath Bristol and Cadiz dry lakes
- Mapping the migration of the saline-fresh water interface over time
- Identifying changes in vegetation in riparian habitats below springs
- Evaluating the cause of any impacts (e.g., the proposed pumping at the Cadiz Project, climatic conditions, other factors)
- Determining the type, nature, magnitude, and duration of Corrective Measures that could be implemented
- Assessing the effects of any implemented mitigation

7.1 Detailed Monitoring Plan

It is recommended that, at least one year prior to the commencement of the proposed pumping at the Cadiz Project, a more detail monitoring plan be prepared to document all aspects of data collection related to the Cadiz Project. The plan should also address data management, analyses, and interpretation. If a dispute arises over Undesirable Results, it is critical that data collection, management, analyses, and interpretation have been conducted in general accordance with a detailed monitoring plan. The plan should cover the pre-operational, operational, and post-operational periods. The plan should be a "living document" and should be updated periodically (e.g., every five years) as data collection and analysis techniques improve, and data requirements for the Cadiz Project change.

7.2 Quality Assurance

It is recommended that, at least one year prior to the commencement of the proposed pumping at the Cadiz Project, more detailed QA/QC procedures be developed, described, implemented, and documented for the collection and analysis of all data pertinent to the Cadiz Project. A detailed QAPP should be prepared to describe the QA/QC procedures for the collection and analysis of all data pertinent to the Cadiz Project.

7.3 Data Management System

It is recommended that, at least one year prior to the commencement of the proposed pumping at the Cadiz Project, a formal data management system (DMS) be developed for the Cadiz Project. The DMS should contain all data collected as part of the Cadiz Project. The data should be categorized by type, location, and date, as well as other data-pertinent fields. While a project-specific DMS can be developed, it is recommended that off-the-self software be used as the platform for the DMS for the Cadiz Project. The DMS should have a graphical user interface (GUI) that operates within a geographic information system (GIS) platform (e.g., ArcGIS). This will facilitate data input, data mapping, and data interpretation (e.g., by SpatialAnalyst).

7.4 Document Repository

The Cadiz Project will be implemented in an area with a very limited human population. However, some opponents to the Cadiz Project continue to distrust the conclusions reached in the FEIR, the County's adoption of the GMMMP, and the Court's review of the Cadiz Project. It is important that stakeholders have access to all documents pertinent to the Cadiz Project, regardless of whether they support or oppose the project. Therefore, it is recommended that an online repository be developed to host all technical reports as they are finalized and delivered to the County as required by the GMMMP.

7.5 Geological Understanding

It is recommended that, within one year of the commencement of the proposed pumping at the Cadiz Project, geophysical surveys be completed in two areas to assist in assessing geologic conditions (areas 1 and 2 on **Figure 13**):

- At Bonanza Spring
- In the Fenner Gap

To provide additional information on the geologic structure and hydrogeology in the vicinity of Bonanza Spring, it is recommended that geophysical mapping be conducted in the area immediately above, and for some distance below, the spring. The objectives of the geophysical surveys would be to delineate structural features (i.e., faults) and other structural deformation, identify potential fracture lineaments with increased facture aperture and density (i.e., groundwater bearing potential), map the bedrock surface below the unconsolidated deposits south of the spring, and map the groundwater surface above and below the spring. A geophysical contractor should be retained to plan and implement the geophysical mapping. The mapping may include shallow seismic surveys, surface EM, TDEM, and ERT.

To provide additional information on the geologic structure and hydrogeology in the Fenner Gap, it is recommended that geophysical mapping be conducted in this area. The objectives of the geophysical survey would be to delineate structural features (i.e., faults) and other structural deformation, identify the location and thickness of carbonate formations, identify potential karstic features (e.g., caves) and fracture lineaments with increased facture aperture and density (i.e., groundwater bearing potential) in the carbonates, and map the groundwater surface. A geophysical contractor should be retained to plan and implement the geophysical mapping. The mapping may include shallow seismic surveys, TDEM, and ERT.

Whatever geophysical techniques are recommended by the contractor, it is important to have control points to help interpret the geophysical data. Borehole logs and down-hole geophysical logs (i.e., eLogs) for existing wells will provide this control. If wells proximate to the geophysical surveys do not have geophysical logs but have poly-vinyl chloride (PVC) casing, then they can be logged using EM, natural gamma, temperature, and EC down-hole tools. If these wells have steel casing, then down-hole logging will be limited to gamma, temperature, and EC. The existing geological mapping (Kenney and TLF, 2018) will also provide some control for the geophysical survey at Bonanza Spring.

To provide additional data on hydrogeologic conditions proximate to Bonanza Spring, it is recommended that the geophysical survey be conducted within one year of the commencement of pumping at the Cadiz Project.

As noted, the recommended geophysical surveys, like other recommendations presented herein (e.g., spring flow monitoring, new monitoring wells), are located on Federal lands. Thus, it may be difficult to obtain approvals from government agencies to install the wells. Given the value of such monitoring, it is hoped that such approvals will be forthcoming.

7.6 Hydrogeologic Understanding

To provide additional information on hydrogeologic conditions between Bonanza Spring and the alluvial aquifer in the Fenner Valley below, it is recommended that the following additional monitoring wells be installed (see **Figure 13**):

- Immediately below the spring (i.e., within 100 yards) with casings discretely screened in unconsolidated deposits beneath and adjacent to the stream fed by the spring, if they contain groundwater, and in the fractured bedrock beneath these deposits
- At the limits of the alluvial aquifer (e.g., one mile southeast of Bonanza Spring)

The first set of monitoring wells in the unconsolidated deposits and fractured bedrock below Bonanza Spring would provide data that could not be obtained from any currently existing monitoring wells. Therefore, this set of wells is the most important additional monitoring wells needed to evaluate groundwater conditions in relation to potential Undesirable Results at Bonanza Spring. In addition, in the unlikely event that a direct hydraulic connection between Bonanza Spring and the alluvial aquifer exists, groundwater declines at these new wells may provide an “early warning” of potential Undesirable Results at Bonanza Spring.

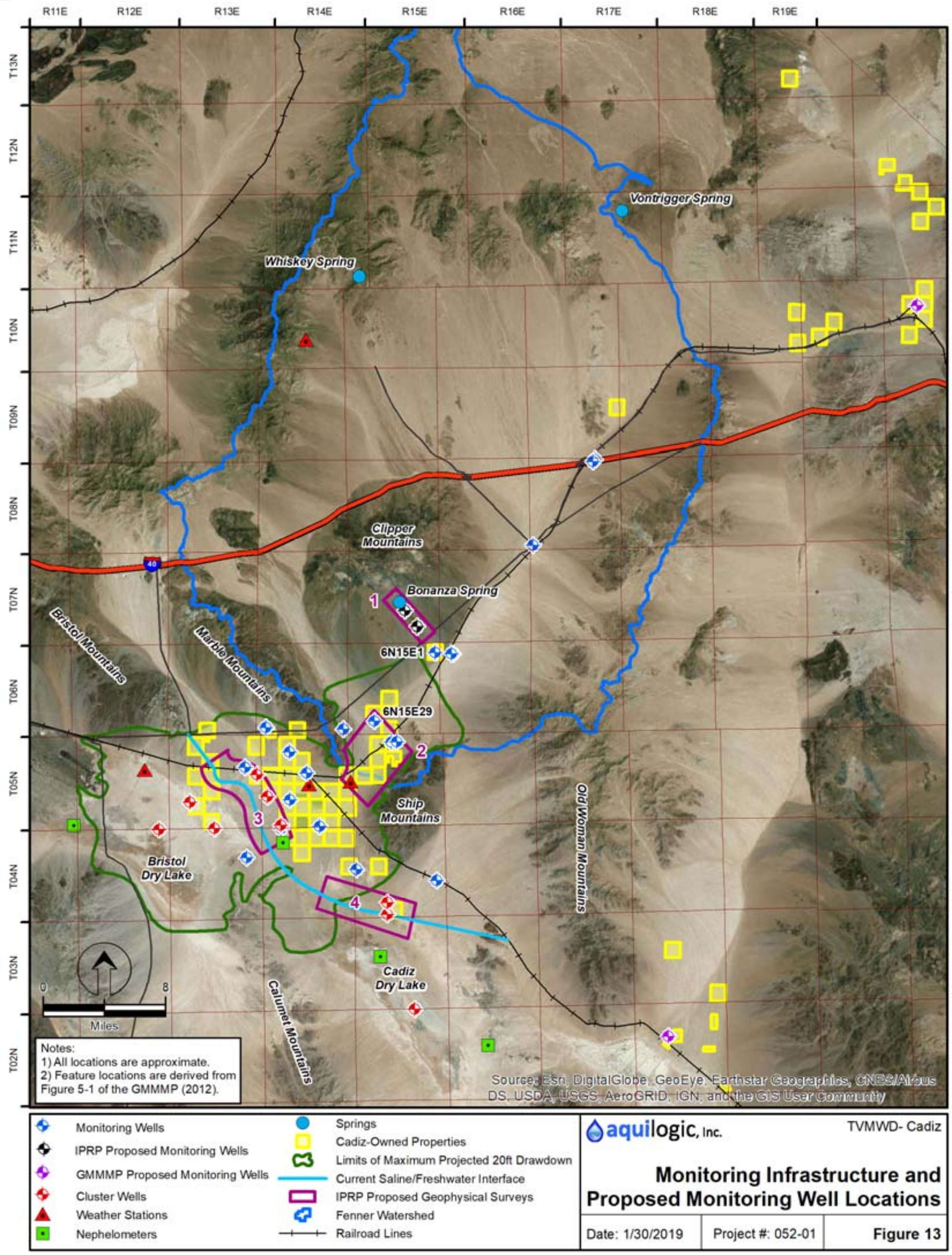
To provide baseline data on groundwater conditions proximate to Bonanza Spring, it is recommended that, if feasible, the new monitoring wells be installed at least one year prior to the initiation of pumping at the Cadiz Project.

7.7 Weather Conditions

It is recommended that a weather station, or at least a rain gauge, be installed in the bedrock watershed that supports flow at Bonanza Spring. This will assist in evaluating the relationship between precipitation, recharge, and spring flow. To provide baseline data on precipitation and its impact on flows at Bonanza Spring, if feasible, it is recommended that the weather station be installed as soon as possible.

7.8 Spring Monitoring

The potential for Undesirable Results to springs, notably Bonanza Spring, appears to be the most contentious issue related to the Cadiz Project. The GMMMP provides for quarterly monitoring of flow at the Bonanza, Whiskey and Vontrigger springs during the pre-operational and operations periods, and annually post-operations. The proposed monitoring of the Bonanza Spring and other springs is important to evaluate the effect of regional climatic trends. However, given the smaller scale of the bedrock watershed that supports Bonanza Spring (Kenney and TLF, 2018), the responses at these springs to individual hydrologic events (e.g., precipitation) are generally observed over time frames much shorter than three months. These short-term responses are also valuable in assessing responses to longer-term hydrologic events (e.g., seasonal precipitation, climatic changes, sustained pumping), and the impact these can have on future spring flows.



Notes:
1) All locations are approximate.
2) Feature locations are derived from Figure 5-1 of the GMMMP (2012).

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 13: Potential Geophysical Survey Areas

It is recommended that more frequent monitoring be conducted at the Bonanza, Whiskey, and Vontrigger springs to obtain a baseline. This should include transducers and a data-logger to monitor ponded water depth at frequent intervals. A multi-parameter probe could be used to monitor depth/flow, EC, and temperature at the same frequency. Alternatively, EC and temperature could be manually monitored on a monthly basis for at least one year prior to the proposed pumping at the Cadiz Project, and during the first year of project operations. After that, manual monitoring could be conducted quarterly. Data-loggers would be downloaded during manual monitoring events. Other parameters, such as pH, water coloration, and observations of riparian vegetation, could be conducted quarterly. In addition, it is recommended that the exact geographic location and elevation of the spring emergence be mapped using a GPS annually or after a change in location is observed during other monitoring activities.

Prior to any monitoring of spring flows, including manual monitoring, a correlation between ponded water depth and flow will need to be developed. This is normally done for a location immediately downstream of the spring where the stream profile is defined and constrained (e.g., where it crosses bedrock) or where the profile can be artificially constrained (e.g., construction of a v-notch weir). A location with a naturally confined profile should be identified. Ponded water depth and flow measurements should be taken at that location on several occasions during different flow conditions (e.g., low-flow, regular flow, storm-flow) to develop the correlation. The transducer or multi-probe would then be installed at that location.

To provide baseline data on spring flow conditions at springs, if feasible, it is recommended that the transducers be installed at least one year prior to the initiation of pumping at the Cadiz Project.

It is important that, if consent to conduct the monitoring can be secured, at least one year of high-frequency data on spring conditions be obtained prior to the proposed pumping at the Cadiz Project. In particular, this monitoring will provide a baseline for Bonanza Spring that can compared to data collected after the pumping at the Cadiz Project is initiated. This baseline comparison will supplement and/or complement the comparison of data for Bonanza Spring to the time-contemporaneous data collected at the Whiskey and Vontrigger springs. That is, how does any change in conditions at Bonanza Spring compare to other springs, based on time-contemporaneous data, and how does it compare to conditions at Bonanza Spring prior to the proposed pumping at the Cadiz Project. Such comparisons will assist in evaluating whether any change at Bonanza Spring is the result of the proposed pumping at the Cadiz Project, climatic variability, and/or other factors.

7.9 Vegetation Monitoring

The exact scientific method as to how the "general type and extent of adjacent vegetation" will be monitored at the springs and elsewhere in the watersheds was not described in the GMMMP. It is recommended that a terrestrial ecologist be retained to develop a scientifically appropriate, standardized methodology to monitor vegetation below the springs. This might include defined transects across the stream below the springs, and identification and quantification of species at points along the transects over time. Such a standardized methodology will allow changes in vegetation to be tracked over time.

To provide baseline data on vegetation conditions within the watersheds tributary to the Cadiz Project, it is recommended that vegetation mapping be initiated at least one year prior to the initiation of pumping at the Cadiz Project.

7.10 Groundwater Monitoring

The GMMMP includes groundwater monitoring requirements, such as monitoring locations, monitoring type, monitoring frequency, monitoring parameters. The locations of monitoring points are presented in **Figure 10** (an excerpt from Figure 5-1: Monitoring Features of the GMMMP [ESA, 2012b]). It is proposed in Appendix B of the GMMMP (ESA, 2012b) that groundwater level measurements be taken at various frequencies depending on well and operating period. In the pre-operational period, transducers will be used to collect high frequency groundwater level measurements at six existing monitoring wells (5N14E5F1, 6N15E01H, 6N15E29P1, 4N14E13J1, 5N14E24D2, 5N14E16H1); whereas, groundwater levels at the other ten wells will be measured manually on a monthly basis. In the GMMMP, it is proposed that groundwater level measurements be taken semi-annually during the operation period and annually during the post-operational period. During the pre-operational period, groundwater quality samples will be collected quarterly at five monitoring wells and annually at nine wells. During the operational and post-operational periods, groundwater samples will be sampled annually at the five wells previously sampled quarterly.

In general, the number and location of wells used to monitor regional groundwater conditions appear adequate. However, the Panel recommends that, in some cases, the frequency of groundwater monitoring be modified slightly. When the Cadiz Project begins operation, the hydrologic system will be subject to annual pumping higher than previously seen. This pumping will be maintained for up to 50 years.

The groundwater monitoring program proposed in the GMMMP (ESA, 2012b) will establish baseline conditions immediately prior to the proposed pumping at the Cadiz Project. However, to better evaluate the hydrologic response to the pumping of 50,000 AFY during the first few years of operation, monitoring groundwater levels at a higher frequency is recommended to provide an improved understanding of baseline conditions. Higher frequency monitoring when pumping is initiated at the Cadiz Project will also allow the response of the hydrologic system to increased pumping to be evaluated, including information on hydrogeologic structure within the watersheds, an improved understanding of hydraulic parameters (e.g., hydraulic conductivity and storativity), and identification of possible data gaps that may need to be filled. In addition, the increased monitoring frequency will assist in the assessment of potential Undesirable Results from the proposed pumping at the Cadiz Project. In doing so, it will also allow pumping operations to be optimized (e.g., well cycling, pumping rates) to maintain production while preventing Undesirable Results. Therefore, it is recommended that the following groundwater monitoring and sampling program be initiated at least one year prior to the commencement of pumping at the Cadiz Project:

- Pre-operational – transducers be placed in all 16 monitoring wells, plus the proposed monitoring wells adjacent to Bonanza Spring and brine migration cluster wells, to collect groundwater level readings on an hourly basis, and the data-loggers downloaded quarterly.
- The groundwater quality sampling program proposed in the GMMMP (ESA, 2012b) is acceptable. The new monitoring wells proximate to Bonanza Spring proposed herein and any new brine migration cluster wells should be sampled quarterly.
- First year of operation – the pre-operational monitoring and sampling program recommended above should be maintained.
- Years 2-5 of operation – transducers should be maintained in the monitoring wells, and the data-loggers downloaded annually. Groundwater quality samples should be collected at all monitoring wells, including any newly installed monitoring wells, annually.
- Years 6-50 of operation – the groundwater monitoring and sampling program proposed in the GMMMP (ESA, 2012b) is acceptable. For any newly installed monitoring wells, groundwater levels should be monitored semi-annually and sampled annually for groundwater quality analyses. It should be noted that, under the adaptive management approach in the GMMMP, analysis of the data collected may require that the proposed monitoring program be modified for these later year of operation and the post-operational period.
- First post-operations year – the pre-operational monitoring and sampling program recommended above should be implemented during this period of rapid groundwater recovery.
- Years 2-5 post-operations – the monitoring and sampling program implemented in years 2-5 of operations should be implemented during this period of rapid groundwater recovery.
- Subsequent post-operations years - the groundwater monitoring and sampling program proposed in the GMMMP (ESA, 2012b) is acceptable.

To provide baseline data on groundwater conditions throughout the watersheds tributary to the Cadiz Project, it is recommended that the updated monitoring program be initiated at least one year prior to the initiation of pumping at the Cadiz Project.

7.11 Third-Party Wells in Fenner Valley

No potable third party wells have been identified in the Cadiz Project area. However, it is recommended that transducers be installed during the pre-operational period in any third-party non-potable well that could be materially impacted by the proposed pumping at the Cadiz Project (i.e., third-party wells closest to the Cadiz project well-field). The transducers should be maintained in these third-party wells during the first five years of pumping at the Cadiz Project. After this initial operating period, groundwater levels should be measured quarterly at third-party wells during the remainder of the operations period, and annually in the post-operational period. Field water quality parameters should also be monitored at third-party wells on an annual basis during the pre-operational period, operational period, and for five years during the post-operational period.

This data will establish baseline groundwater conditions at the third-party wells, and allow for groundwater level and quality changes to be monitored during the proposed pumping at the Cadiz Project. Higher frequency data will assist in determining whether any observed impact results from the proposed pumping at the Cadiz Project, or other factors such as climatic variability.

To provide baseline data on groundwater conditions at third-party wells, it is recommended that the transducers be installed at least one year prior to the initiation of pumping at the Cadiz Project. It is recognized that consent of the third party is required and this is implicit in the recommendation.

7.12 Saline Migration

There is currently an established transitional interface between saline groundwater in the vicinity of Bristol and Cadiz dry lakes and freshwater moving towards the dry lakes from the Fenner Valley and other up-stream watersheds. The proposed pumping at the Cadiz Project will cause the saline-fresh water interface to migrate away from the dry lakes towards the Cadiz Project well-field. Results of the analysis of saline water movement using the numerical groundwater model (GSSI, 2011; ESA, 2012b) indicate that migration of the saline-fresh water interface induced by the proposed pumping at the Cadiz Project ranges from 6,300 to 10,400 feet.

The GMMMP (ESA, 2012b) proposes the installation of nine cluster wells to monitor saline groundwater conditions and/or the potential migration of the saline–fresh water interface (see **Figure 10**) (ESA, 2012b). The installation of cluster wells proposed in the GMMMP is an appropriate approach to monitoring a saline–fresh water interface. Such wells have been used in other areas experiencing saline intrusion. However, the saline–fresh water interface will not migrate in a uniform regular fashion, either spatially or at depth. The migration will occur along areas of preferentially higher hydraulic conductivity, either spatially or vertically. That is, once the interface begins to migrate, it may do so in an irregular pattern of "saline fingers" as opposed to a uniform "saline front". These fingers will also vary with depth. Such irregular migration may not be detected by just four well clusters (three at Bristol Dry Lake and one at Cadiz Dry Lake).

Given the above, it is recommended that the location of the interface be mapped spatially and at depth using geophysical techniques (areas 3 and 4 on **Figure 13**) prior to the commencement of pumping at the Cadiz Project. Given the relative homogeneity of the alluvial deposits and known groundwater depth, EM techniques will be effective at mapping the mineralization of groundwater (i.e., TDS content). Different EM tools can be used to spatially map groundwater mineralization at various depths. ERT can also be used to map vertical profiles of groundwater mineralization along cross-section lines. The outputs from the spatial EM mapping and ERT can be combined to create a three-dimensional visualization of the saline-fresh water interface. The results of this geophysical mapping can be used to locate the proposed cluster wells, and select the screened depths at each cluster. It is further recommended that the geophysical mapping be repeated every five years after the proposed pumping at the Cadiz Project is initiated. This will allow the migration of the saline-fresh water interface to be mapped in three-dimensions over time. An understanding of the migration of the saline-fresh water interface will allow any potential mitigation actions to be optimized (e.g., recharge of fresh water in areas and depths of preferential migration).

7.13 Subsidence

In the current GMMMP (ESA, 2012b; Section 6.3 and Table 6-1), the proposed land surface monitoring consists of ground-level surveys, InSAR imagery, extensometers, and reviewing this information at various frequencies during pre-operational, operational, and post-operational periods.

The current GMMMP proposes to acquire InSAR imagery once during the pre-operational period, once every five years during the operational period, and twice at five-year intervals during the post operational period. InSAR is a powerful tool that cost-efficiently measures ground surface deformation throughout an area of interest. Therefore, the Panel recommends the following:

- The availability of historical InSAR imagery in the Project area should be investigated and, if available, acquired and processed to obtain a pre-operational assessments of land subsidence

- InSAR imagery should be acquired and processed every year during the first ten years of the operational period
- InSAR imagery should be acquired and processed every five years for years 11 through 50 of the operational period
- InSAR imagery should be acquired and processed every year for years 1 through 5 of the post-operational period
- InSAR imagery should be acquired and processed every five years thereafter during the post-operational period

In the GMMMP (ESA, 2012b), it is proposed that three extensometers be placed in strategic locations with the highest probability of land subsidence proximate to the Cadiz Project well-field (ESA, 2012b). No information is provided on how the extensometers will be constructed (e.g., whether pipe, cable, rods, or how many anchor points will be constructed at each extensometer site). It is recommended that the expected number of anchor points at each extensometer site be defined. A general description of extensometer construction and instrumentation, and a recommended post-operational period measurement rate should also be specified.

It is extremely costly to install extensometers and they only provide point source data. That is, only three measurements of land subsidence would be provided for the entire project area. Therefore, it is recommended that only one extensometer be installed during the pre-operational period. The installation of the two additional extensometers could be deferred until a temporal and more spatially extensive dataset on land subsidence is available (i.e., InSAR data). If the InSAR data indicates that land subsidence is an Undesirable Result, then the additional extensometers would be installed. The InSAR data and lithologic data collected at new production and monitoring wells would be used to help locate these extensometers.

7.14 Groundwater Modeling

Numerical groundwater flow models have already been developed for the Cadiz project (GSSI, 2011; CH2M.Hill, 2011). These numerical models present a reasonable representation of groundwater conditions for most areas of the watersheds tributary to the Cadiz project; however, they were based on a limited data-set and include significant assumptions and hydrogeologic judgement.

In the GMMMP (ESA, 2012b), Annual Monitoring Reports will be prepared and these reports will contain “Updated groundwater flow, transport and variable density model results.” However, it is unclear when, how often, and how these updates will be accomplished. The existing numerical groundwater modeling was a key tool used to evaluate potential Undesirable Results in the GMMMP (ESA, 2012b). It is also anticipated that the Decision-Making Process outlined in the GMMMP (ESA, 2012b) will use any updated numerical modeling to perform ongoing evaluations of Undesirable Results, as well as design and assess the effects of any possible mitigation actions. Therefore, it would be reasonable to better define the scope of model updates.

The Panel recommends that numerical groundwater modeling be updated as follows:

- At least one year prior to the commencement of pumping at the Cadiz Project, an initial update to incorporate recent data and other recommendations by the Panel
- Once new water supply wells have been drilled, installed and tested at the Cadiz Project well-field, an update to incorporate recent data, and a recalibration of the model
- After one year of pumping at the Cadiz Project, an update to incorporate recent data, and a recalibration of the model
- An update to incorporate recent data, and a recalibration of the model, after five years of pumping at the Cadiz Project (this would include data collected on overall groundwater response to pumping, observations of spring flows, brine water conditions beneath the dry lakes, saline-fresh water interface migration, and land subsidence)
- Updates to incorporate recent data every five years thereafter during the operational period

It is recommended that the initial update include the following:

- An expansion of the model domain to include all of Cadiz Dry Lake - this will allow more detailed analysis of the possible Undesirable Results at Cadiz Dry Lake, and will eliminate concerns about drawdown intercepting a current boundary condition at Cadiz Dry Lake
- An expansion of the model domain to include the Clipper Mountains as active cells - this will allow for further analysis of flows at Bonanza Spring
- Update the water budget in consideration of data collected since the prior update.

After this initial update, the numerical groundwater modeling can then be used to further evaluate potential Undesirable Results that may be caused by the proposed pumping at the Cadiz Project. The modeling should also be used to assess the effectiveness of the mitigation actions proposed in the GMMMP (ESA, 2012b). In particular, simulations should examine whether a trigger threshold should be adjusted to account for the time lag between an action and the response at a monitoring point being used to assess Undesirable Results. In addition, the modeling should be used to assess alternative mitigation measures suggested in this report.

It is recommended that the first model recalibration include the following:

- Update the hydraulic property values (i.e., hydraulic conductivity and storativity) based on the aquifer tests and specific capacity tests conducted at the new water supply wells at the Cadiz Project well-field

- Update the discretization of hydraulic properties based on other new hydrogeologic information (e.g., new monitoring well data, geophysical surveys, down-hole geophysical logging, etc.)
- Update the project recharge and discharge terms, and update the recharge sensitivity analysis, based on data collected since the FEIR (ESA, 2012a) was completed
- Use land surveys, geophysical surveys, inter-ferograms created from InSAR imagery, and water quality data to identify groundwater barriers and, if present, incorporate them into the model domain.
- Use the geophysical surveys at the saline-fresh water interface to adjust the TDS baseline condition in the model
- Develop time-series groundwater level hydrographs, land surface deformation graphs, and water quality chemographs to facilitate the calibration
- Recalibrate the model to match the time series data for groundwater levels, land subsidence, and water quality

It is recommended that subsequent updates include data collected since the prior update, and subsequent recalibration follow the steps above in consideration of new data collected prior to the last calibration.

7.15 Mitigation Actions

The County of San Bernardino imposed a requirement under the GMMMP that limited the aquifer drawdown to 80 feet within two miles of the center of the Cadiz Project well-field in the first 15 years of operation and 100 feet over the life of the Project. The most common Corrective Measure in the GMMMP (ESA, 2012b) to prevent or alleviate Undesirable Results is to reduce or modify pumping at the Cadiz Project well-field (e.g., well cycling, individual pump rate adjustments). Such an action, as a stand-alone Corrective Measure, will likely be effective in the long-term; however, it may not alleviate certain impacts in a reasonable timeframe due to the response lag in the hydrologic system (e.g., groundwater levels would continue to decline at locations distant from the well-field for decades after pumping ceased). Therefore, the GMMMP included some Corrective Measures for specific Critical Resources. The following resource-specific measures would either prevent ongoing impact or alleviate impact in a reasonable time frame:

- Bonanza Spring – the installation of a possible horizontal well immediately above Bonanza Spring, as provided in the FEIR (ESA, 2012a)
- Brine Resources – the installation of deeper brine recovery wells at the dry lakes to maintain mineral strip-mining operations, as proposed in the GMMMP (ESA, 2012b)
- Saline Intrusion – the extraction of brackish groundwater or injection of fresh water along the saline-fresh water interface, as proposed in the GMMMP (ESA, 2012b)

More details regarding these resource-specific measures needs to be developed. In addition, additional evaluation of these potential resource-specific measures is recommended, including analysis using an updated numerical groundwater flow model.

In addition to these resource-specific measures, it is recommended that the following additional Corrective Measures be evaluated:

- Bonanza Spring – The injection of water at the edge of the alluvial aquifer in Fenner Valley below Bonanza Spring to "cut-off" the propagation of the cone of depression beyond the injection area
- Bonanza Spring – The injection of water into water-bearing fractures immediately above Bonanza Spring to maintain groundwater levels in the watershed that supports flow at the spring
- Bonanza Spring – the temporary provision of water for flow and habitat maintenance (e.g., a water tank and pipe to the spring head)
- Brine Resources – the injection of water at the saline-fresh water interface to "cut-off" the propagation of the cone of depression beyond the injection area (this could be combined with injection to halt the migration of the saline-fresh water interface – see above)
- Air quality – the spraying of water on areas prone to dust generation

More details regarding these potential alternative mitigation measures needs to be developed. Their feasibility (effectiveness, implementability, and cost) should be evaluated, including analysis using numerical groundwater modeling. Their effectiveness should examine both short-term effectiveness in preventing continued adverse impact, and their long-term effectiveness at alleviating impacts in a reasonable period of time.

It is understood that saline intrusion and mitigation scenarios have been modeled (teleconference with GSSI on December 17, 2018). The results of this modeling should be included in the GMMMP to provide confidence in the positioning of well clusters and the effectiveness of potential saline intrusion mitigation measures.

8.0 CONCLUSIONS

8.1 General

The GMMMP provides appropriate and sufficient management and monitoring to identify Undesirable Results that could occur in response to proposed pumping as part of the Cadiz Project. After careful review and consideration of the FEIR, GMMMP, and more recent technical reports, the Panel has recommended a number of complementary additions that could be made to the GMMMP, where such additions are feasible (ESA, 2012b) (see **Sections 7.5 through 7.13**). Collectively these recommendations are intended to allay any concerns that opponents to the Cadiz Project may still have, improve public confidence in the Cadiz Project, and are provided in an abundance of caution.

The recommendations are not intended to alter the analysis or findings regarding the environmental impacts of the Cadiz Project described in the FEIR (ESA, 2012a), or contain any significant new information. In addition, none of the recommendations are associated with a failure of the GMMMP to provide sufficient management, monitoring, and mitigation of Undesirable Results; that is, the Panel finds the GMMMP adequate. However, the Panel strongly believes that the recommendations provide helpful direction in the ongoing monitoring, mitigation and management of the Cadiz Project.

The GMMMP provides effective Corrective Measures to address any Undesirable Results in the long-term, although no un-mitigatable Undesirable Results were identified in the FEIR over a 100-year period (ESA, 2012a). For the avoidance of doubt, where the cessation or reduction of pumping at the Cadiz Project will not prevent or alleviate impacts in a reasonable period of time, alternate resource-specific measures have been proposed in the GMMMP and/or FEIR to mitigate impact (see **Section 7.15**). The Panel has also identified some additional measures that should be considered (see **Section 7.15**).

To provide greater confidence in the data collected as part of the Cadiz Project, and provide greater transparency to project stakeholders – including project opponents, the Panel has recommended the development and/or implementation of certain plans and actions (see **Sections 7.1 through 7.4**).

8.2 Aquifer Management

The numerical groundwater modeling performed to date (GSSI, 2011), considering three different recharge scenarios, is a useful tool to evaluate hydrologic conditions in the Cadiz Project area. The numerical groundwater modeling is also a valuable tool for the analysis of potential Undesirable Results and the evaluation of potential Corrective Measures. The numerical groundwater modeling performed to date was appropriate to support the development of the FEIR (ESA, 2012a) and GMMMP (ESA, 2012b).

The FEIR (ESA, 2012a) concluded that there were no Undesirable Results, or Undesirable Results that could not be mitigated, caused by the proposed pumping at the Cadiz Project, regardless of the recharge scenario. However, the GMMMP (ESA, 2012b) proposed monitoring, management actions, and Corrective Measures to identify, evaluate, and mitigate any Undesirable Results, and additional conditions were imposed by the County of San Bernardino.

Given the reliance on numerical groundwater modeling to support the FEIR and GMMMP, the model should be updated and recalibrated in accordance with the recommendations presented in **Section 7.14**.

8.3 Springs

The FEIR concluded (ESA, 2012a), and subsequent analyses concluded (Kenney and TLF, 2018), that no direct hydraulic connection exists between Bonanza Spring and the alluvial aquifer in Fenner Valley below. Kenney and TLF concluded the following, based on field evidence and other supporting data:

- The bedrock watershed that supports Bonanza Spring is fault bounded, which creates a barrier to groundwater outflow and an up-gradient capture zone for recharge from precipitation
- The volume of groundwater in storage in the bedrock watershed is sufficient to maintain the spring through substantial periods, potentially even droughts lasting several decades, but at reduced flows
- The long-term sustainability of Bonanza Spring is dependent on long-term average precipitation, which provides recharge to the watershed that supports Bonanza Spring
- The location of Bonanza Spring has changed over time in response to climatic variability, and such changes may occur in the future
- Bonanza Spring will not be affected by down-gradient conditions in the alluvial aquifer in the Fenner Valley below, including the proposed pumping at the Cadiz Project

Nevertheless, opponents to the Cadiz Project continue to assert that the proposed pumping at the Cadiz Project will impact the springs, and this appears to be their primary reason for why the project should not move forward. This Panel was not tasked specifically with determining whether a hydraulic connection exists between Bonanza Spring and the alluvial aquifer. However, based on our analysis of the GMMMP and other documentation, including the reports cited herein (Zdon, 2016; Zdon et al, 2018; Rose, 2017; Kenney and TLF, 2018; Experts Review, 2018; Kreamer, 2018; Schroth, 2018; Kreamer, 2019), the weight of credible evidence suggests that no direct hydraulic connection exists. Even if such a connection existed, the FEIR concluded

(ESA, 2012a) that the proposed pumping at the Cadiz Project would still have no significant impact at Bonanza Spring.

Irrespective of whether there is a hydraulic connection between Bonanza Spring and the alluvial aquifer, and what numerical modeling predicts the impacts will be even if such a connection exists, for the avoidance of any doubt, the GMMMP proposes a monitoring program to evaluate potential Undesirable Results at Bonanza Spring (ESA, 2012b). The Panel has recommended this program be supplemented as follows (see **Sections 7.5 through 7.10**):

- Geophysical mapping of in the area of Bonanza Spring (**Section 7.5**)
- Additional monitoring wells proximate to Bonanza Spring (**Section 7.6**)
- A weather station (or a rain gauge at a minimum) proximate to Bonanza Spring (**Section 7.7**)
- Higher frequency monitoring of spring flows and spring geochemistry at Bonanza Spring and other background springs (Whiskey and Vontrigger) (**Section 7.8**)
- More defined vegetation monitoring of the riparian habitat immediately down-stream of Bonanza Spring and other springs (Whiskey and Vontrigger) (**Section 7.9**)
- Higher frequency monitoring of groundwater conditions proximate to Bonanza Spring and in other parts of the watersheds tributary to the Cadiz Project (**Section 7.10**)

This enhanced monitoring program will improve the understanding of hydrologic conditions at Bonanza Spring, allow for improved monitoring and evaluation of potential Undesirable Results, and assist in the design and implementation of improved Corrective Measures, if significant impacts are observed.

If Undesirable Results at Bonanza Spring are observed, resource-specific measures are proposed in the GMMMP (ESA, 2012b). The Panel has recommended alternative mitigation actions that should be evaluated to prevent or alleviate the impacts (e.g., injection of water at the edge of the alluvial aquifer immediately below Bonanza Spring) (**Section 7.15**).

8.4 Brine Resources

The results of analyses using numerical groundwater modeling indicate that brine levels beneath the dry lakes will decline in response to the proposed pumping at the Cadiz Project. With such declines, the evaporation and precipitate recovery trenches used by two mineral strip-mining operations could dry out, and brine recovery wells may experience reduced yields. The cessation of pumping at the Cadiz Project is not expected to prevent further impact or alleviate impact in a reasonable time frame, given the response lag time in the hydrologic system.

To effectively mitigate the likely impact to Brine Resources, a mitigation agreement that includes the installation of deeper brine recovery wells could be implemented as provided in the FEIR (ESA, 2012a). Alternatively, as provided in the GMMMP (GMMMP, Section 6.4 and 6.4.4), water could be injected or spread at the saline-fresh water interface to cut-off the propagation of the pumping cone of depression before it causes significant impact to Brine Resources. This alternative mitigation program requires more detailed evaluation (**Section 7.15**).

8.5 Saline Migration

Existing analyses (GSSI, 2011) indicates that the saline-fresh water interface may migrate from 6,300 to 10,400 feet toward the Cadiz Project well-field. The installation of cluster wells to monitor the migration of the interface, as proposed in the GMMMP (ESA, 2012b), is reasonable and appropriate. However, the interface will preferentially migrate along areas and at depths with higher permeability, and the migration will occur along saline fingers rather than along a uniform saline front. The Panel recommends that a geophysical survey be conducted to establish baseline conditions for the saline-fresh water interface (**Section 7.12**) prior to the proposed pumping at the Cadiz project. The survey should also be used to select the locations and screened intervals for the proposed cluster wells. Subsequent surveys in the exact same areas should be conducted every five years to monitor the migration of the interface.

The cessation of pumping at the Cadiz Project will not alleviate significant impacts associated with saline migration in a reasonable period of time. However, resource-specific measures proposed in the FEIR (**Section 7.15**), such as injection of fresh water at the saline-fresh water interface to prevent further migration, should be effective.

8.6 Land Subsidence

The FEIR concluded (ESA, 2012a) that the proposed pumping at the Cadiz Project would not cause Undesirable Results related to land subsidence. However, a detailed subsidence monitoring program was proposed in the GMMMP (ESA, 2012b) to address any uncertainty as to whether significant land subsidence will result from the proposed pumping at the Cadiz Project. The Panel has recommended modifications to this program to improve its scope and efficacy, including the increased use of InSAR data (**Section 7.13**).

8.7 The GMMMP Document

The GMMMP (ESA, 2012b) meets the objectives set out for this Review (see **Sections 1.1 and 8.1**). However, the Panel has made recommendations that will improve the monitoring, management and mitigation programs (**Section 7**). There are also areas of the GMMMP that would benefit from clarification. These have been noted within **Section 6** of this Consensus Report.

9.0 REFERENCES

Aquilogic, Inc. (2013). Review of The Groundwater Hydrology of the Cadiz Project, San Bernardino County, California. October.

Belcher, W.R., Elliott, P.E. and Geldon, A.L. (2001). Hydraulic-Property Estimates for Use With a Transient Ground-Water Flow Model of the Death Valley Regional Ground-Water Flow System, Nevada and California: Water-Resources Investigations Report 01-4120.

CADFW. 2018. Letter to Cadiz, Inc. California Department of Fish and Wildlife. December 2018.

CH2M.Hill. (2011). Assessment of effects of the Cadiz Groundwater Conservation Recovery and Storage Project operation on springs.

Environmental Science Associates (ESA). (2012a). Final Environmental Impact Report (FEIR) for the Cadiz Valley Water Conservation, Recovery, and Storage Project. SCH# 2011031002. July.

Environmental Science Associates (ESA). (2012b). Groundwater Management, Monitoring, and Mitigation Plan (GMMMP) for The Cadiz Valley Groundwater Conservation, Recovery and Storage Project. September.

Fetter, C.W. (2001). Applied Hydrogeology Fourth Edition: Earlier editions copyright 1988, 1980 by Merrill Publishing Company, ISBN: 0-13-088239-9.

Groundwater Stewardship Committee. (2011). Summary of Findings and Recommendations. Cadiz Groundwater Conservation, Recovery and Storage Project (Stewardship Committee, 2011). October.

Geology and Hydrology Experts Review. (2018). 2018 Bonanza Spring Assessment. January.

GSSI. (1999). Cadiz Groundwater Storage and Dry-Year Supply Program. Environmental Planning Technical Report. Groundwater Resources. Volume 1 and Volume 2. Report 1163. November.

GSSI. (2011). Cadiz Groundwater Modeling and Impact Analysis, Volume 1- Report. September 1.

Kenney and TLF Consulting, LLC (TLF). (2018). Updated Assessment of Cadiz Water Project’s Potential Impacts to Bonanza Springs. January.

Krásný, J. & Sharp, J. (2007). Groundwater in Fractured Rocks: IAH Selected Paper Series, volume 9 1st Edition. ISBN 9780415414425.

Kreamer D. (2019). Evaluation of “Understanding the source of water for selected springs within Mojave Trails National Monument, California” (Zdon, 2018). June.

Kreamer D. (2019). Draft Review of “Use of Radiocarbon Ages to Narrow Groundwater Recharge Estimates in the Southeastern Mojave Desert, USA” (Love and Zdon, 2018). January.

Lohman, S.W. (1979). Ground-Water Hydraulics: U.S. Geological Survey Professional Paper 708.

Love A.H. and A. Zdon. (2018). Use of Radiocarbon Ages to Narrow Groundwater Recharge Estimates in the Southeastern Mojave Desert, USA. USA Hydrology-05-00051.

Rose, T. P. (2017). Data Measured on Water Collected from Eastern Mojave Desert, California. Lawrence Livermore National Laboratory, LLNL-TR-737159. August 18

Schroth B. (2018). Comments on “Understanding the source of water for selected springs within Mojave Trails National Monument, California” (Zdon et al, 2018).

Thompson, D.G. (1929). The Mohave Desert Region California, A Geographic, Geologic, and Hydrologic Reconnaissance: U.S. Geological Survey Water-Supply Pater 578.

TLF Consulting, LLC (TLF). (2018). Twentieth Annual Groundwater Monitoring Report, January - December 2017. December.

Zdon, A. and Associates, Inc. (2016). Mojave Desert Springs and Waterholes: Results of the 2015–16 Mojave Desert Spring Survey, Inyo, Kern, San Bernardino and Los Angeles Counties, California.

Zdon et al. (2018). Understanding the source of water for selected springs within Mojave Trails National Monument, California. Vol. 19, No. 2, 99–111.

APPENDICES

APPENDIX A BIOGRAPHICAL SKETCHES OF PANEL MEMBERS

Anthony Brown

CEO and Principal Hydrologist

Anthony is the founder, Chief Executive Officer (CEO) and Principal Hydrologist at **aquilogic**. Prior to **aquilogic**, he was the Chief Business Development Officer at exp, Senior Vice-President of Strategy & Development at WorleyParsons, and the global sector leader for their Environment business. He was previously the CEO and one of the founding principals at Komex Environmental, a global environmental consulting company. In December 2005, WorleyParsons acquired Komex.

Anthony received his Master of Science degree in Engineering Hydrology from Imperial College London in 1988.

Anthony has over 25 years of experience in many aspects of infrastructure engineering and environmental consulting, with a focus on hydrologic science, water resources, environmental engineering, and water treatment & supply. He has provided expert testimony in numerous "high-profile" cases involving emerging and recalcitrant chemicals in groundwater. He has also briefed the following on the impact of industrial chemicals on water resources:

- United States Environmental Protection Agency (US EPA) and State regulators;
- White House Officials;
- US, State, and local elected officials; and
- Professional bodies and academic institutions.

Anthony also has extensive experience in strategic development, mergers & acquisitions (M&A), marketing and business development (BD):

- Evaluating the markets, clients, competition, drivers and the company's position in the market;
- Developing a strategic direction and plan for the company;
- Implementing the strategic plan alongside operations;
- Leading all M&A, Joint Venture (JV) and alliance development activity; and
- Leading all BD activity for major clients/projects and emerging markets.

Mark Wildermuth, PE

President, Principal Engineer

Expertise:	Mr. Wildermuth has 42 years of experience in water resources engineering and planning, including: surface and groundwater hydrology; hydraulics and water quality; surface and ground water modeling; groundwater management, including recharge master plans; water resources systems planning, operation, and optimization; water rights; evaluation of receiving water impacts; and flood control facility design. Mr. Wildermuth has extensive expertise in the development of water resource management plans for groundwater basins and watersheds in Southern California, and he has provided expert witness testimony and opinions for litigation support and mediation in several important cases—the most recent being the recalculation of the Chino Basin safe yield and Phase 3 trial in the Antelope Valley groundwater adjudication. Mr. Wildermuth is a recognized expert in the hydrology of the Santa Ana Watershed, having developed groundwater models at some time in his career for all of the groundwater basins in the upper watershed and highly integrated surface and groundwater models for the Santa Ana River and its tributaries and underlying basins. These models are in active use to manage the Chino, Cucamonga, Six Basins, Temescal, and Mammoth Basins. Most notably, his work forms the basis for the estimation of sustainable yield and the development of groundwater storage and recovery programs. Mr. Wildermuth developed the recharge master plan concept, utilizing detailed surface water models and statistical techniques to identify new recharge projects and to determine expected new recharge and cost. Mr. Wildermuth designed and subsequently led the process to develop the salt and nutrient management plans for the Santa Ana River Watershed and subsequent updates. His work has withstood peer review and has been relied on in adjudicated basins, regulatory processes, and project financing. Mr. Wildermuth directs WEI's technology program, which conducts research and development of models, database/visualization tools, methodologies to estimate the sustainable yields of groundwater systems, and methodologies to evaluate the impacts of climate change on surface and ground water resources.
Education:	M.S., Engineering, University of California, Los Angeles, 1976 B.S., Engineering, University of California, Los Angeles, 1975
Licenses:	Professional Engineer, California, No. 32331
Professional History:	WEI – 1990 to Present James M. Montgomery, Consulting Engineers [JMM] (now called MWH) – 1987 to 1990 Camp Dresser & McKee, Inc. (now called CDM/SMITH) – 1980 to 1987 TetraTech – 1976 to 1980

BALLEAU GROUNDWATER, INC.
901 RIO GRANDE BLVD. NW, SUITE F-242
ALBUQUERQUE, NEW MEXICO 87104

Dave Romero is President of the firm of Balleau Groundwater, Inc. Dave received his Master's Degree in Hydrology from the University of Arizona with a focus on model analysis of groundwater interaction with surface water. He is a Certified Professional Hydrologist (#1817) by the American Institute of Hydrology (2008) with over 20 years of experience consulting in the hydrologic industry. He specializes in analysis of water budgets for both natural hydrologic conditions and changes induced to the natural system from development of surface water and groundwater. He has advised cities and peer reviewed hydrogeologic analyses for municipal water districts regarding water resources in settings that involve groundwater pumping, artificial aquifer recharge, aquifer recharge from flooding and remediation of groundwater contamination. He has also advised industrial water users, irrigation and conservancy districts, state and federal agencies, Indian tribes, water associations and private water users with matters involving water planning and source water availability. Dave has presented at conferences involving groundwater hydrology and has been invited to publish in a Theme Issue of the peer-reviewed journal *Groundwater* on research related to analysis of groundwater flow.

CV

Timothy K. Parker, PG, CEG, CHG
Principal Hydrogeologist

Tim Parker is an independent technical consultant working as Principal Hydrogeologist, Parker Groundwater, located in Sacramento California, specializing in integrated water resources and groundwater management, and serving public and private sector water industry clients. He has conducted hydrogeologic evaluations in the Basin Ranges, Central Valley, Coast Ranges, Los Angeles Coastal Plain, Mojave Desert, Modoc Plateau, Sierra Nevada, and Southern Cascades geomorphic regions of California. His current work largely focuses on assisting clients in understanding and meeting the new California Sustainable Groundwater Management Act requirements, while his experience includes water policy analysis, strategic water resources planning, groundwater management plan development and program implementation, regional and project scale groundwater monitoring for quantity and quality, groundwater recharge & storage projects, and litigation support. He formerly worked for Schlumberger Water and Carbon Services bringing sophisticated oil and gas industry geophysical tools and technologies to water industry clients, and prior to that he was with the California Department of Water Services Conjunctive Water Management Program. Tim is a California licensed professional geologist (#5594), certified engineering geologist (#1926), and certified hydrogeologist (#0012).

Tim currently serves the Groundwater Resources Association of California as Director and Legislative Committee Chairman; California Groundwater Coalition as Director; National Ground Water Association as Scientist and Engineer Section Director and NGWA Board Member; and International Association of Hydrogeologists as U.S. National Chapter Director. He has provided technical analysis and testimony to the California State Legislature in the development of groundwater management and recharge policy, was involved in SGMA development and initial roll out, and is involved with federal groundwater policy development through NGWA. Tim is also actively involved with the Association of California Water Agencies Groundwater Committee, SGMA Implementation Subcommittee, and has served on the Public Advisory Committee and co-chaired the Groundwater Caucus for preparation of the California State Water Plan. He is principal author of *Sustainable Groundwater Management Policy Directives,* prepared for the Mexican National Water Commission as an outcome of the 9th International Symposium on Managed Aquifer Recharge (IAH 2016); *Sustainability from the Ground Up, Groundwater Management in California, a Framework* (ACWA 2011); and co-authored the books *Potential Groundwater Quality Impacts Resulting from Geologic Carbon Sequestration* (WRF 2009), and *California Groundwater Management* (GRA 2005).

APPENDIX B CADIZ PROJECT OVERVIEW

aquilogic, Inc.
environment • water • strategy

245 Fischer Avenue, Suite D-2
Costa Mesa, CA 92626
Tel. +1.714.770.8040
Web: www.aquilogic.com

APPENDIX B:
CADIZ PROJECT OVERVIEW
San Bernardino County, California

Prepared for:

Three Valleys Municipal Water District
1021 E. Miramar Avenue
Claremont, CA 91711-2052

Project No.: 052-01

January 2019

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACRONYMS AND ABBREVIATIONS

>	less than
%	percent
°F	degrees Fahrenheit
AF	acre-feet
AFY	acre-feet per year
ARZC	Arizona and California Railroad
bgs	below ground surface
CEQA	California Environmental Quality Act
cm/d	centimeters per day
DRI	Desert Research Institute
ESA	Environmental Science Associates
feet/day	feet per day
feet/year	feet per year
FEIR	Final Environmental Impact Report
ft^2	square feet
GMMMP	Groundwater Management, Monitoring, and Mitigation Plan
gpm	gallons per minute
LLNL	Lawrence Livermore National Laboratory
MAF	million acre-feet
mg/L	milligrams per liter
mi2	square miles
MSL	mean sea level
OBW	Orange Blossom Wash
SMWD	Santa Margarita Water District
SWP	State Water Project
TDS	total dissolved solids
USGS	United States Geological Survey

1.0 INTRODUCTION

Cadiz Inc. (Cadiz) is a private corporation that owns approximately 34,000 mostly contiguous acres in the Cadiz and Fenner Valleys (Cadiz Property), which are located in the Mojave Desert portion of eastern San Bernardino County, California (see **Figure 1**).

Cadiz, in collaboration with the Santa Margarita Water District (SMWD) and other water providers participating in the Cadiz Project (Project Participants), has developed the Cadiz Project to implement a comprehensive, long-term groundwater management program for the closed groundwater basin underlying its property that would allow for both the beneficial use of some of the groundwater and storage of imported surface water in the groundwater basin (**Figure 2**).

Underlying the Cadiz and Fenner Valleys, and the adjacent Bristol Valley, is a vast groundwater basin that holds an estimated 17 to 34 million acre-feet (MAF) of fresh groundwater. The Cadiz Project area, which would be sited on Cadiz Property, is located at the confluence of the Fenner, Orange Blossom Wash (OBW), Bristol, and Cadiz Watersheds (Watersheds), which span over 2,700 square miles (**Figure 3**).

Within this closed basin system, groundwater percolates and migrates downward from the higher elevations in the Watersheds and eventually flows to Bristol and Cadiz dry lakes (**Figure 4**). The dry lakes represent the low point in the closed watershed basin, meaning that all surface and groundwater within the surrounding Watersheds eventually flows down-gradient to these dry lake areas and not beyond. Once the fresh groundwater reaches the dry lake areas, it evaporates; first mixing with the highly saline groundwater zone under the dry lakes and getting trapped in the salt sink, no longer fresh, suitable, or available to support freshwater beneficial uses. The portion that evaporates is lost from the groundwater basin and is therefore also unable to support beneficial uses.

Figure 1: Location of the Cadiz Project[1]

---

[1] Aquilogic, Inc. (2013). Review of The Groundwater Hydrology of the Cadiz Project, San Bernardino County, California.

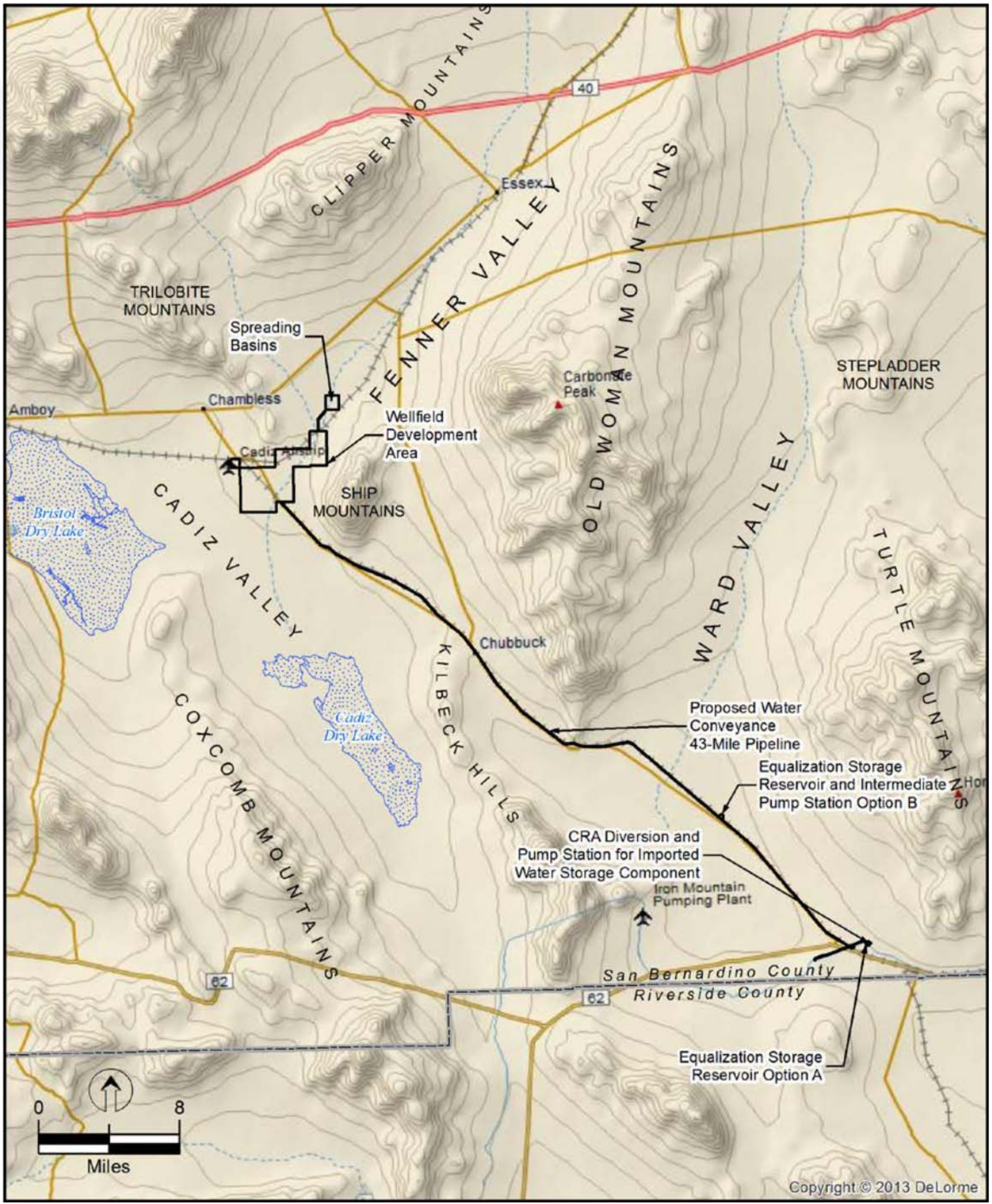
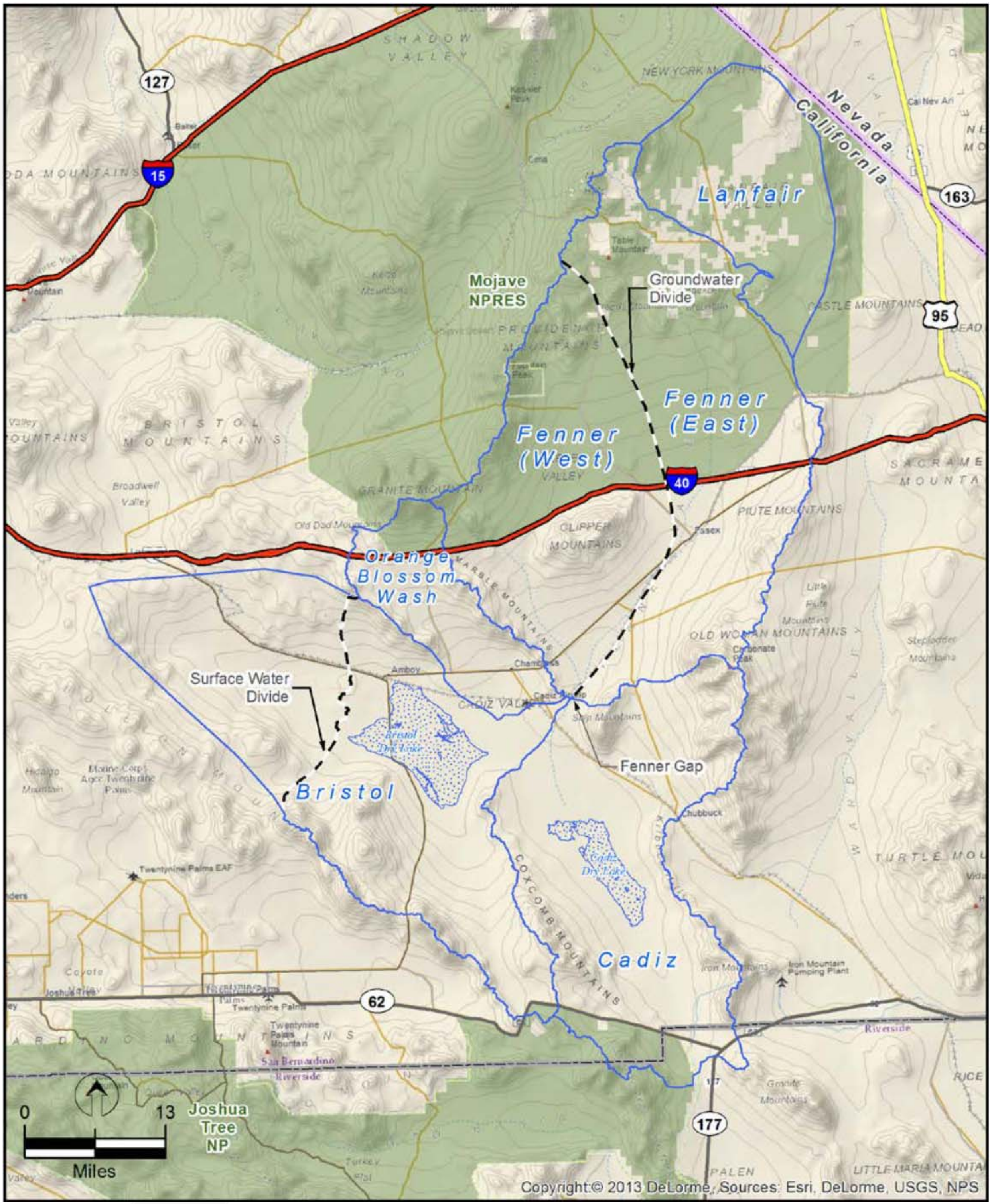


Figure 2: Cadiz Project Area[2]

---

[2] Aquilogic, Inc. (2013). Review of The Groundwater Hydrology of the Cadiz Project, San Bernardino County, California.



Copyright:© 2013 DeLorme, Sources: Esri, DeLorme, USGS, NPS

Figure 3: Watersheds in the Cadiz Project Area[3]

---

[3] Aquilogic, Inc. (2013). Review of The Groundwater Hydrology of the Cadiz Project, San Bernardino County, California.

1.1 Project Purpose

Under Article X, Section 2 of the California Constitution, waters of the state must be put to maximum reasonable and beneficial use and should not be wasted. The fundamental purpose of the Cadiz Project is to save substantial quantities of groundwater that are presently wasted and lost to evaporation by natural processes. In the absence of the Cadiz Project, approximately 3 MAF of groundwater, presently held in storage between the proposed wellfield and the dry lakes, would become saline and evaporate over the next 100 years. By strategically managing groundwater levels, the Cadiz Project would conserve up to 2 MAF of this water, retrieving it from storage before it is lost to evaporation. The conservation opportunity is unique and garners special emphasis. The proposed conservation is not dependent upon future rainfall, snow pack, or the needs and demands of others: the groundwater is already in storage. Moreover, the conservation and resulting water supply augmentation can be achieved independently from the environmental and regulatory conditions that generally constrain the importation of water to Southern California. The geographic isolation of the groundwater makes it non-tributary to the Colorado River system, and therefore eligible for distinctive treatment under federal regulations that may unlock additional complementary storage opportunities, both within the basin and in Lake Mead.

The Cadiz Project makes a reliable water supply available for Project Participants, to supplement or replace existing supplies and enhance dry-year supply reliability. Both the State Water Project (SWP) and Colorado River water supplies are experiencing reductions from historic deliveries. As a result, Southern California water providers are looking for affordable new supplies to replace or augment current supplies and enhance dry-year supply reliability. The Cadiz Project would optimize the reasonable and beneficial use of water within the aquifer system in a sustainable fashion—conserving water that would otherwise be wasted—to create a local water supply alternative for Southern California water providers.

The objectives of the Cadiz Project are as follows:

- Maximize beneficial use of groundwater in the Bristol, Cadiz, and Fenner Valleys by conserving and using water that would otherwise be lost to brine and evaporation.
- Improve water supply reliability for Southern California water providers by developing a long-term source of water that is not significantly affected by drought.
- Reduce dependence on imported water by utilizing a source of water that is not dependent upon surface water resources from the Colorado River or the Sacramento-San Joaquin Delta.
- Enhance dry-year water supply reliability within the service areas of the SMWD and other Southern California water provider Project Participants.
- Enhance water supply opportunities and delivery flexibility for the SMWD and other participating water providers through the provision of carry-over storage and, for Phase 2, imported water storage.

- Support operational water needs of the Arizona and California Railroad (ARZC) in the Project area.
- Create additional water storage capacity in Southern California to enhance water supply reliability.
- Locate, design, and operate the Project in a manner that minimizes significant environmental effects and provides for long-term sustainable operations.

1.2 Project Components

The Cadiz Project includes the following two distinct but related components:

- Groundwater Conservation and Recovery Component
- Imported Water Storage Component

Under the Groundwater Conservation and Recovery Component, an annual average of 50,000 acre-feet (AF) of groundwater would be pumped from the basin over a 50-year period for delivery to Project Participants in accordance with agreements with Cadiz and the Groundwater Management, Monitoring, and Mitigation Plan (GMMMP). The GMMMP has been developed to guide the long-term groundwater management of the basin for the Cadiz Project (ESA, 2012b). The level of groundwater pumping proposed under the Groundwater Conservation and Recovery Component is designed specifically to extract and conserve groundwater that would otherwise migrate to the dry lakes, enter the brine zone, and evaporate. The Groundwater Conservation and Recovery Component is analyzed at a project level in the Final Environmental Impact Report (FEIR) in accordance with California Environmental Quality Act (CEQA) Guidelines' Sections 15161 and 15378(a) (ESA, 2012a).

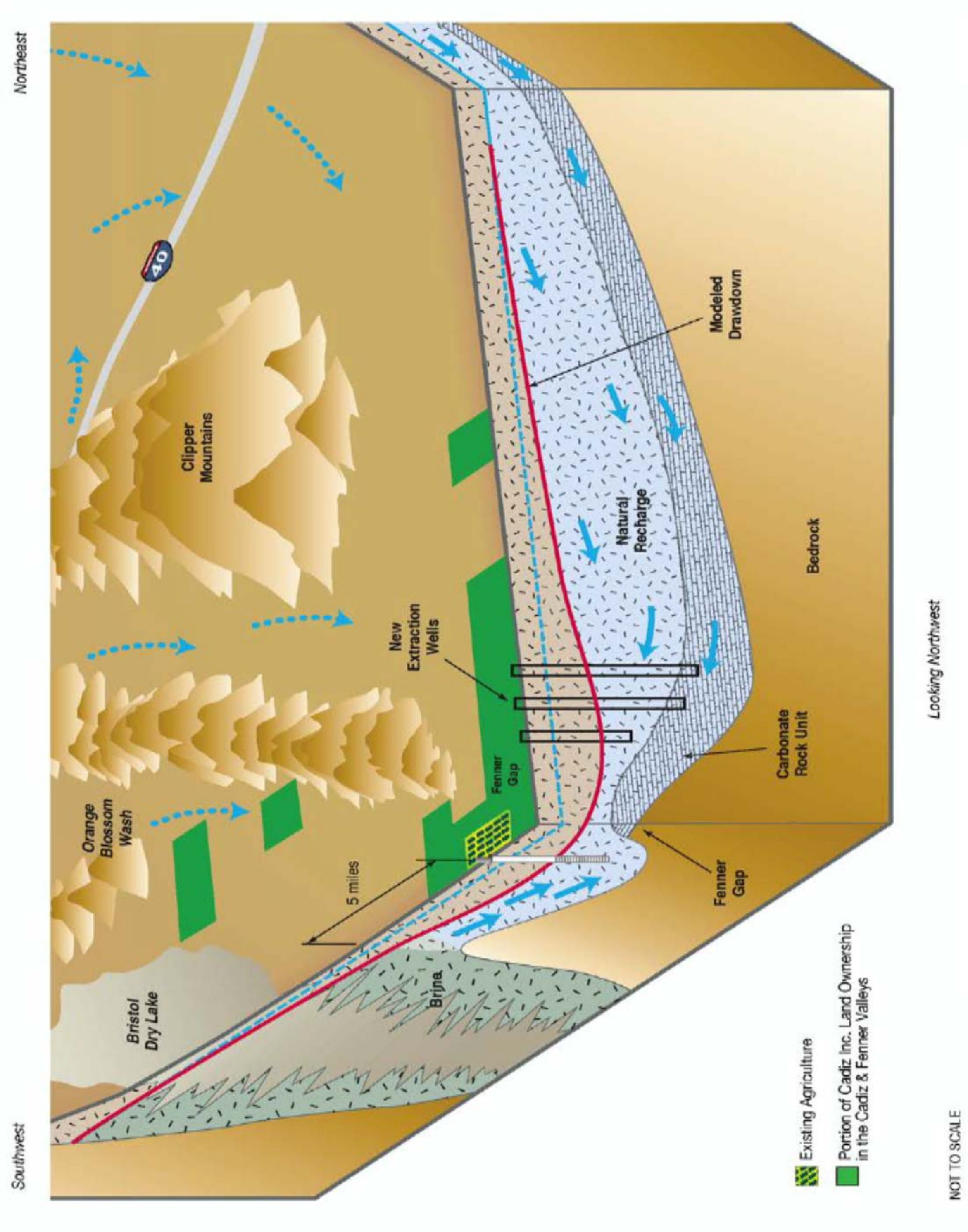


Figure 4: Conceptual Surface and Groundwater Flow. Source: ESA, 2012[4], Figure 3-3a

---

[4] Environmental Science Associates (ESA). (2012a). Final Environmental Impact Report (FEIR) for the Cadiz Valley Water Conservation, Recovery, and Storage Project, Prepared for Santa Margarita Water District (SMWD). SCH# 2011031002. July.

2.0 SITE SETTING

The following section provides a description of the area that surrounds the Cadiz Project including the Fenner, Lanfair, Bristol, Cadiz, and OBW Watersheds. The following discussions include an overview of the location, topography, surficial geology, structural geology, geologic development, stratigraphy, climate, surface water, land use, and groundwater production. The information is taken directly from **aquilogic** (2013).

2.1 Location

The Cadiz Project is located at the confluence of the Fenner, OBW, Cadiz, and Bristol Watersheds (see **Figure 2**). The Cadiz Project is approximately 17 miles east of Amboy in San Bernardino County, California (see **Figures 1 and 2**).

The watersheds that surround the Cadiz Project are located in the Eastern Mojave Desert, which is a part of the Basin and Range Geomorphic Province of the western United States (see **Figure 3**). Of these watersheds, the Fenner Watershed has the highest mountain elevations and largest surface area. This watershed encompasses approximately 1,100 square miles (mi^2) and is bounded by the Granite, Providence, and New York Mountains on the west and north and the Piute, Ship, and Marble Mountains on the east and south (ESA, 2012a).

The Fenner Gap occurs between the Marble and Ship Mountains near the location of the Cadiz Project. The Fenner Gap is the location of the groundwater outflow of the Fenner Watershed into the Bristol and Cadiz Watersheds. The Clipper Mountains rise from the southern portion of the Fenner watershed, just northwest of Fenner Gap (CH2M Hill, 2010).

2.2 Topography

The Basin and Range Geomorphic Province is characterized by a series of northwest/southeast trending mountain and valleys formed largely by faulting. One of the prominent features of the area is the Bristol Trough, a major structural depression caused by faulting (i.e., a graben). The Bristol Trough encompasses the Bristol and Cadiz Watersheds that together form a relatively low land area that extends from just south of Ludlow, California, on the northwest, to a topographic and surface drainage divide between the Coxcomb and Iron Mountains on the southwest (see **Figure 5**). The Bristol and Cadiz Valleys are bounded on the southwest by the Bullion, Sheep Hole, Calumet, and Coxcomb Mountains and on the northeast by the Bristol, Marble, Ship, Old Woman, and Iron Mountains.

The Cadiz and Bristol Dry Lakes are separated by a low topographic and surface drainage divide (CH2M Hill, 2010). Volcanic eruptions and resultant lava flows from the Amboy cinder cone have created a low topographic ridge that divides the Bristol Watershed into two surface water catchments. Surface water west of the divide does not flow to Bristol Dry Lake, but rather evaporates at a topographic low west of the lava flows; whereas, surface water east of the divide does flow to Bristol Dry Lake.

The New York Mountains, at the northern extent of the Project area, rise to elevations of approximately 7,532 feet above mean sea level (MSL). The Granite and Providence Mountains, to the west and northwest, range from 6,786 feet to 7,178 feet above MSL, respectively. The Piute Mountains located to the northeast, range up to 4,165 feet above MSL. The Clipper Mountains in the center of the Project area rise to an elevation of more than 4,600 feet above MSL. Finally, the Marble and Ship Mountains, located to the southwest and south of the Clipper Mountains in the center of the Project area, range up to 3,842 feet and 3,239 feet above MSL, respectively. Generally, the Fenner Valley slopes southward toward the Fenner Gap, which is the groundwater outlet from the valley, at an elevation of about 900 feet above MSL (CH2M Hill, 2010).

The mountain ranges surrounding the Bristol and Cadiz Watersheds are lower in elevation than those mountain ranges surrounding the Fenner Watershed. Peak elevations for these mountains include the following: Bristol at 3,422 feet above MSL; Iron at 3,296 feet above MSL; Bullion at 4,187 feet above MSL; Sheep Hole at 4,685 feet above MSL; Calumet at 1,751 feet above MSL; and Coxcomb at 4,416 feet above MSL.

The alluvial basins surrounded by these mountain ranges form gently sloping topographic valleys. In the Lanfair Valley, the alluvial surface slopes to the southeast and ranges in elevation from approximately 4,500 to 3,500 feet above MSL. In the Fenner Valley, the alluvial surface slopes generally to the south and ranges in elevation from 3,500 to 1,000 feet above MSL. In the OBW, the alluvial surface slopes to the southeast and ranges in elevation from 2,500 to 100 feet above MSL. In the Bristol and Cadiz Valleys, the alluvial surface slopes radially toward the dry lakes, and ranges in elevation from 1,000 to 600 feet above MSL.

The Bristol and Cadiz Dry Lakes represent the lowest elevations within the watersheds at 595 and 545 feet above MSL, respectively.

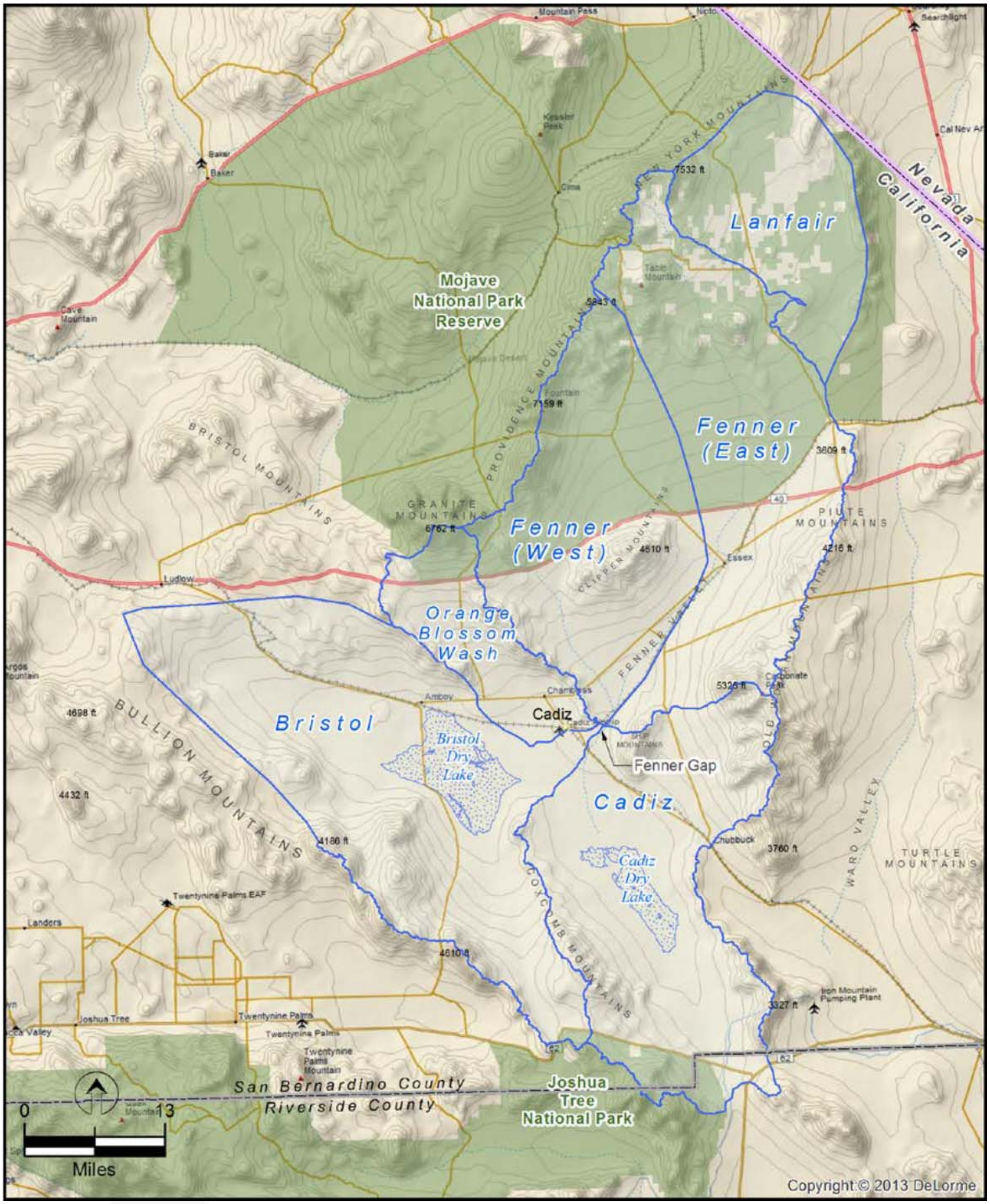


Figure 5: Project Area Topography[5]

---

[5] Aquilogic, Inc. (2013). Review of The Groundwater Hydrology of the Cadiz Project, San Bernardino County, California.

2.3 Surficial Geology

The surficial geology in the vicinity of the Cadiz Project can be classified into the following three types of cover (see **Figure 6**):

- Bedrock outcrops and mountain exposures
- Hillslope erosional deposits
- Alluvial basins

In general, the bedrock outcrops and exposures in the mountains are either Archean granite, Cambrian shale, dolomitic limestone and quartzite, Permian carbonate limestone, and Jurassic granite, with some Tertiary volcanics. The hillslope deposits are either exposed Miocene fanglomerates or Quaternary colluvium, talus, and landslide deposits, with disaggregated cover over the mountain bedrock. The surficial materials in the alluvial basins are generally coarse-grained Quaternary sediments ranging from fine-sand to cobbles, with some finer-grained Holocene sediment in ephemeral stream channels.

Cadiz and Bristol Dry Lakes are locally bordered by active dunes formed by fine to medium-grained windblown sand. These Holocene deposits overlie older playa deposits of differentiated Quaternary age (CH2M Hill, 2010).

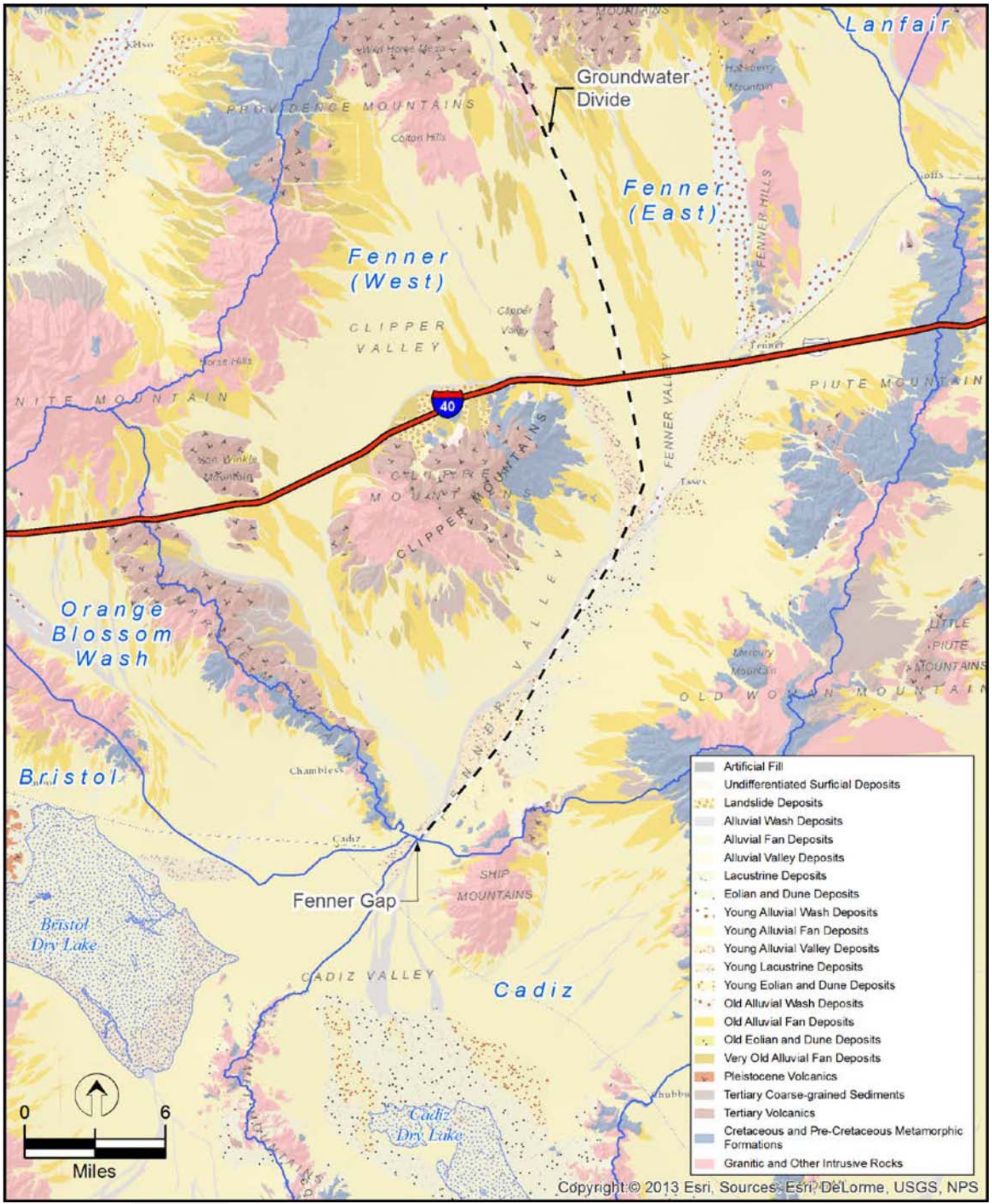
Amboy Crater, located near the western margin of Bristol Dry Lake, is a basaltic cinder cone and lava field believed to be as young as 6,000 years.

2.4 Structural Geology

The larger area of study is located at the eastern margin of the eastern California shear zone, a broad seismically active region dominated by northwest-trending right-lateral strike-slip faulting. Roughly a dozen fault zones showing evidence of Quarternary movement (during the last 1.6 million years) have been identified in, and adjacent to, Bristol, Cadiz, and Fenner Valleys (CH2M Hill, 2010).

Cadiz Valley is underlain by two major northwest-trending faults, inferred on the basis of gravity and magnetic data. These fault zones have strike lengths of at least 25 miles and may merge to the north and northwest with extensions of the Bristol-Granite Mountains and South Bristol Mountains fault zones (CH2M Hill, 2010).

Right-lateral slip of as much as 16 miles along the Cadiz Valley fault zone has been postulated on the basis of correlation of a distinctive Precambrian gneiss unit across the zone. Slickenside surfaces produced by fault movement and steeply dipping sediments recovered from cored drill holes beneath Cadiz Dry Lake suggest the fault zone displaces sediments of Pleistocene age (CH2M Hill, 2010).



Copyright:© 2013 Esri, Sources: Esri, DeLorme, USGS, NPS

Figure 6: Regional Surficial Geology[6]

---

[6] Aquilogic, Inc. (2013). Review of The Groundwater Hydrology of the Cadiz Project, San Bernardino County, California.

Bristol Dry Lake is bordered by probable extensions of the Cadiz Valley and South Bristol Mountain fault zones to the east, and by probable extensions of the Broadwell Lake and Dry Lake fault zones to the west. Geophysical data indicate this structural depression (or graben) may exceed 6,000 feet in depth. Geologic cores recovered from drilling at depths of more than 1,000 feet beneath Bristol Dry Lake suggest that subsidence of this basin began by Pliocene time and continues to the present, and therefore may be tectonically active (CH2M Hill, 2010).

Fenner Gap appears to be a structural sub-graben, formed by a system of northeast-trending, northwest-dipping normal faults, some of which are exposed in outcrops of the bedrock that flank the gap. The presence of these northeast-trending faults beneath the alluvial deposits that underlay the gap can be inferred from surface geology mapping, gravity surveys, a seismic reflection survey conducted across the gap, and recent test wells drilled in the Fenner Gap (CH2M Hill, 2010).

The system of normal faults that formed the sub-graben of Fenner Gap displace and tilt volcanic rocks of mid- to late- Tertiary age. However, these faults do not displace Quarternary sediments and are, therefore, not considered to be either active or potentially active (CH2M Hill, 2010).

The mountains that flank the Bristol-Cadiz graben are essentially block mountains (i.e., horsts) that have been uplifted relative to the adjacent graben and sub-grabens.

In addition to tectonic movement, Jurassic plutonic intrusions have affected the structural evolution of the regional geology. In many areas, including the Fenner Watershed, the intrusions created broad anticlinal structures. Subsequently, these structures were partially eroded-away and in-filled with fanglomerates and alluvium.

2.5 Geologic Development of the Cadiz Project Area

The oldest rocks underlying the project area are Archean granites. During the Archean or Cambrian periods, a series of major northwest-southeast fault zones developed. These fault zones include the South Bristol Mountains – Cadiz Valley fault zone, the Broadwell Lake – Calumet – Dry Lake fault zone, and the Ludlow – Sheep Hole fault zone. Over time, the area between these fault zones subsided creating a deep (>6,000 feet) graben structure. During the Cambrian and Permian periods, the Archean granites were overlain by sedimentary units, predominantly dolomite limestone, shale, and carbonate limestone (karst), likely deposited during periods of shallow marine inundation (limestone) and deltaic or continental settings (shales).

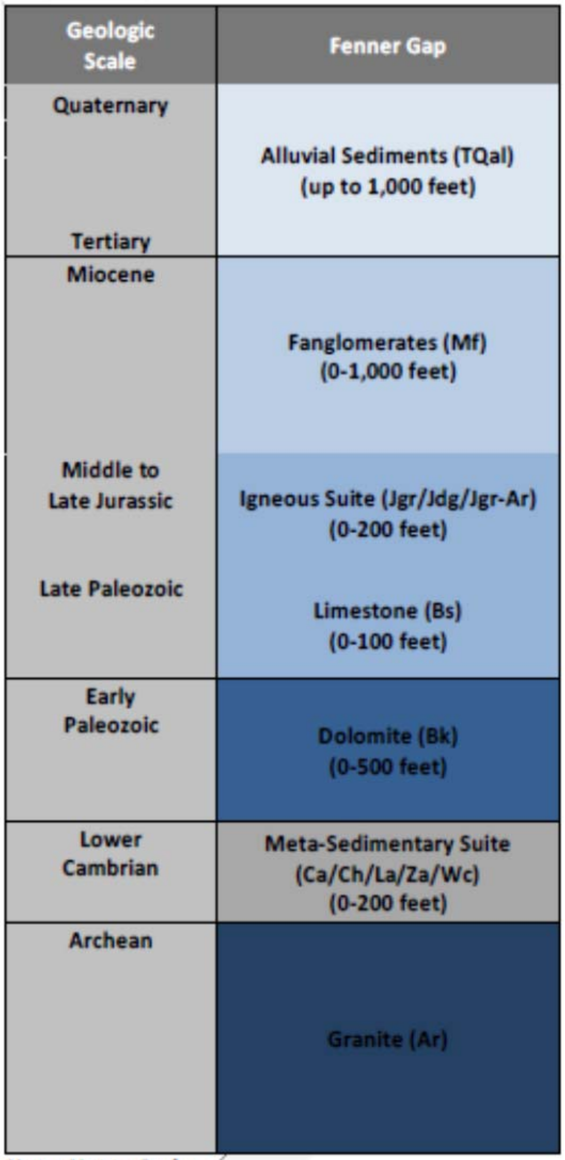
During the Jurassic period, plutonic intrusions (likely coupled with movement along the fault zones) uplifted the Cambrian and Permian sediments to the northeast of the Cadiz Valley fault zone into a broad anticline. In addition, ancillary, unnamed faults (mapped by Kenney GeoScience [Kenney], 2012), perpendicular to the main fault zone created “sub-grabens” (e.g., the Fenner Gap, and sub-basins within the Fenner Watershed) and a series of horsts (e.g., Marble Mountains, Ship Mountains). Subsequent to the Jurassic intrusions, the sediments of the anticline were partially eroded away. In the higher-energy mountain environments, only isolated areas of Cambrian and Permian rocks remain on the flanks of the mountains and uplift, and erosion exposed the Jurassic granite plutons at these horsts. Within the sub-grabens, erosion created an unconformity at the top of Cambrian and Permian units formerly folded in a broad anticline. During the Miocene, portions of the sub-grabens were in-filled with fanglomerates, and during the Quaternary period, substantial thicknesses of alluvium accumulated in the sub-grabens and basins. The Quaternary alluvium is present at the surface across most of the basins. However, in areas with ephemeral streams flow, a thin veneer of Holocene alluvium is present. In addition, late Quaternary and Holocene volcanic deposits are present associated with eruptions from the Amboy cinder cone, northwest of the Bristol Dry Lake.

This geological development has resulted in a deep graben (rift-valley) underlying the Bristol and Cadiz Dry Lakes, flanked by a series of horsts (block mountains). Ancillary faults, perpendicular to the main fault zones, have created sub-grabens and broad basins between the horsts. The horsts are primarily Jurassic granite plutons with isolated areas of Cambrian sediments on their flanks, notably dolomites and carbonate limestone (karsts). Within the basins, a thick sequence of quaternary alluvium covers an erosional unconformity (an eroded anticline created by Jurassic plutonic intrusion), and localized dolomite, carbonate, and shale are found beneath the alluvium.

The geologic development has, over time, created a closed hydrologic system. The alluvial basins are flanked by mountains on most sides. Given the arid climate, only brief ephemeral surface water flows occur during major storm events. Surface waters flow down the channels in the alluvium and discharge to the dry lakes, the lowest points in the closed hydrologic system. However, most water enters the system as infiltration in the surrounding mountains (both from rainfall and snow-melt) and, to a much lesser degree, infiltration across the alluvium. This infiltration recharges the groundwater within the basins, and groundwater flows toward the deep graben. Both surface water and groundwater exit the hydrologic system as evaporation at the dry lakes. Over geologic time, this has resulted in a deep saline water body beneath the dry lakes. Given the flow of groundwater into the graben from the surrounding basins, and the density of the saline water, the zone of saline water has been restricted to the graben (i.e., directly beneath the dry lakes), but likely extends to a depth of many thousands of feet.

2.6 Stratigraphy

The stratigraphy and structures observed in the Fenner Gap and adjacent mountains are typical of the geologic history of the Basin and Range Province. The region exhibits Paleozoic sedimentary craton platform deposits overlying pre-Cambrian igneous and metamorphic cratonal rocks. These rocks were then intruded by Mesozoic age igneous plutonic rocks, and then extended in the Miocene during regional extension. Since the Miocene, the region has been relatively tectonically inactive with the exception of relatively minor right-lateral strike-slip faulting due to the San Andreas Fault System. For the most part, since the Miocene, the dominating geologic processes have involved erosion of the local mountains and sediment infilling of the adjacent basins (Geoscience Support Services, Inc. [Geoscience], 2011a).



Geologic Scale	Fenner Gap
Quaternary Tertiary	Alluvial Sediments (TQal) (up to 1,000 feet)
Miocene	Fanglomerates (Mf) (0-1,000 feet)
Middle to Late Jurassic	Igneous Suite (Jgr/Jdg/Jgr-Ar) (0-200 feet)
Late Paleozoic	Limestone (Bs) (0-100 feet)
Early Paleozoic	Dolomite (Bk) (0-500 feet)
Lower Cambrian	Meta-Sedimentary Suite (Ca/Ch/La/Za/Wc) (0-200 feet)
Archean	Granite (Ar)

Note: Not to Scale

Figure 7: Generalized Stratigraphic Column of the Fenner Gap[7]

---

[7] Aquilogic, Inc. (2013). Review of The Groundwater Hydrology of the Cadiz Project, San Bernardino County, California.

The lithology within the Fenner Gap is complex due to historic tectonic activity and varies with distance away from the mountains towards the center of the gap. A generalized lithologic column can be seen in **Figure 7** and is based on the geologic interpretation presented by Kenney (2011). Generally, there is up to 1,000 feet of Tertiary to Quaternary alluvial deposits overlying Archean granitic bedrock. However, depending on the location within the Fenner Gap, there may be up to 1,000 feet of Miocene fanglomerates underlying the alluvial sediments. Underlying the fanglomerates, there may be up to 200 feet of a Jurassic igneous suite, including granite and gneiss. Underlying the Jurassic igneous suite, there may be up to 100 feet of limestone (Late Paleozoic), and up to 500 feet of Dolomite (Early Paleozoic). Underlying the dolomite, and overlying the Archean granite, may be up to 200 feet of Lower Cambrian-aged meta-sedimentary deposits, including limestone, shale, siltstone, and quartzite.

2.7 Climate

The eastern Mojave Desert is characterized as an arid desert climate with low annual precipitation, low humidity, and relatively high temperatures. Winters are mild, and summers are hot, with a relatively large range in daily temperatures. Temperature and precipitation vary greatly with altitude, with higher temperatures and lower precipitation at low altitudes, and lower temperatures and higher precipitation at higher altitudes (CH2M Hill, 2010).

2.7.1 Precipitation

Annual average precipitation at Mitchell Caverns, located at an altitude of 4,350 feet above MSL, is 10.47 inches. Amboy is represented by two stations: Amboy – Saltus Number 1, with an elevation of 624 feet above MSL and a long-term annual average precipitation of 3.28 inches (from 1967 through 1988); and, Amboy – Saltus Number 2, with an elevation of 595 feet above MSL and long-term annual average precipitation of 2.71 inches (1972 through 1992) (CH2M Hill, 2010).

Isohyet maps prepared using the PRISM model for the period 1971 through 2000 shows average annual precipitation that varies from about 4 inches in Bristol Valley to more than 12 inches in the New York Mountains. Relatively dry conditions prior to the mid-1970s (overall declining trend in the cumulative departure curve), and relatively wet conditions (overall rising trend in the cumulative departure curve) since the mid-1970s, is typical of much of Southern California (CH2M Hill, 2010).

2.7.2 Temperature

Air temperature in the eastern Mojave Desert reaches highs in the summer and lows in the winter. The average winter temperature is between 50 degrees Fahrenheit (°F) and 55 °F, with average daily maximum near 65 °F and average daily minimum near 40 °F. Average daily temperature in the summer months is over 85 °F, with maximum temperatures near 100 °F and occasionally exceeding 120 °F. Average daily minimum temperatures in the summer are around 70 °F, so the range of daily temperatures may exceed 20 °F to 30 °F (CH2M Hill, 2010).

The two weather stations in the area, Amboy and Mitchell Caverns, record air temperature. The minimum monthly temperature at Amboy is reported to be 50.7 °F in December and the maximum monthly temperature is 94.7 °F in July. The minimum monthly temperature at Mitchell Caverns is reported to be 46.3 °F in January and the maximum monthly temperature is 82.1 °F in July. The average annual temperatures at Amboy and Mitchell Caverns are 71.8 °F and 62.6 °F, respectively (CH2M Hill, 2010).

2.8 Surface Water

2.8.1 Intermittent Streams

The Watersheds form a closed drainage system with no surface outflow; all surface water in the Project area drains to Bristol and Cadiz Dry Lakes. The only outlets for surface water are direct evaporation of surface water, uptake, and transpiration by vegetation, infiltration, and then evaporation of soil moisture from the unsaturated zone, and direct evaporation from the dry lake surfaces (ESA, 2012a).

There are no perennial (year-round) streams in the Watersheds. Intermittent streams are distributed throughout the Watersheds. Ephemeral runoff within the Fenner Watershed flows into the Schulyer Wash, the principal drainage in the Fenner Valley Watershed, and then flows through Fenner Gap to either Bristol or Cadiz Dry Lakes. Ephemeral runoff within the OBW flows into Bristol Dry Lake. Ephemeral flow in the Bristol and Cadiz Watersheds flows into the Bristol or Cadiz Dry Lakes, respectively (ESA, 2012a).

It should be noted that the surface water catchments within the watersheds may not map directly to the underlying groundwater basins. As noted, the Bristol Watershed can be divided into two surface water catchments separated by a low topographic ridge associated with the Amboy volcanics. However, it is likely that all groundwater in the Bristol Watershed flows to the Bristol Dry Lake. The Lanfair Valley is located to the northwest of the Fenner Watershed. Surface water in the Lanfair Valley appears to flow to the southeast, enters the Ward Valley, and eventually drains to the Danby Dry Lake. However, groundwater in the Lanfair Basin likely flows directly south into the eastern portion of the Fenner Watershed, and thence through the Fenner Gap to Cadiz Dry Lake.

2.8.2 Springs

Some naturally-occurring springs and wet-ground that support denser vegetation are present at higher elevations within the mountain ranges that surround the watersheds (see **Figure 8**). No springs, wetlands, or phreatophyte vegetation are present in the lower elevations within the intervening basins and washes because the depth to groundwater in the alluvium is too great.

Many of the "springs" are supported by pipes or tunnels that have been driven into the subsurface to intercept groundwater and create "guzzlers". Many of these guzzlers are used by bunters to lure Big Horn Sheep or were used historically for railroad operations.

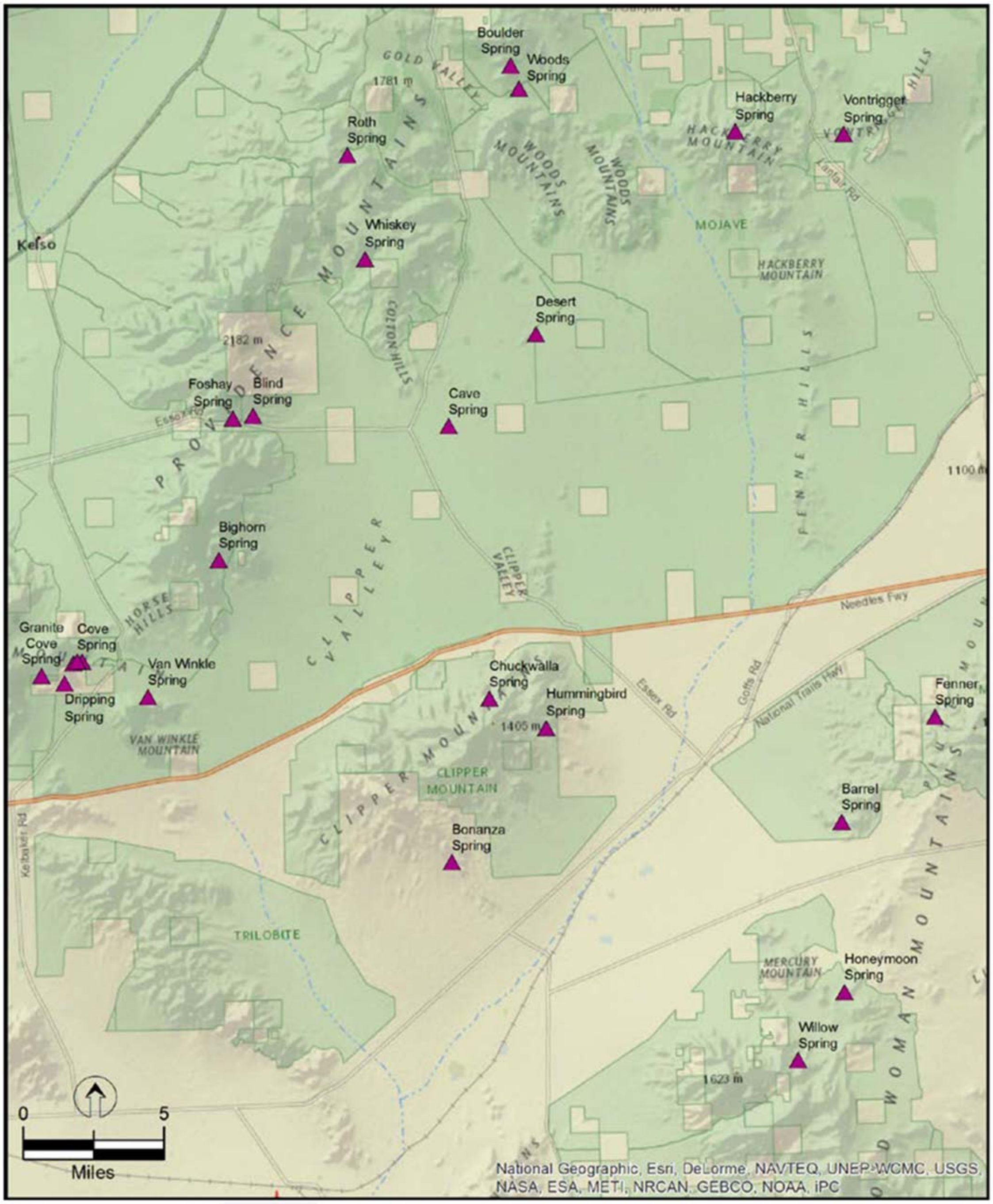


Figure 8: Springs within the Project Area[8]

---

[8] Aquilogic, Inc. (2013). Review of The Groundwater Hydrology of the Cadiz Project, San Bernardino County, California.

The closest naturally occurring spring to the project area is the Bonanza Spring located more than 11 miles north of Fenner Gap in the Clipper Mountains. Bonanza Spring is at an elevation of about 2,100 feet, substantially above the adjacent Fenner Valley floor at about 1,350 feet. More distant springs are found in the upper elevations of the Granite, Marble, Clipper, and Old Woman Mountains. Recent field mapping of the Marble Mountains has revealed numerous ephemeral pools or tinajas fed exclusively by surface run-off and guzzlers (ESA, 2012a).

It should be noted that these springs are found at elevations well above groundwater in nearby alluvial sediments. Therefore, they are likely sustained by localized, perched groundwater that mounds behind fault scarps or lower-permeability strata. As such, the springs are not in direct hydraulic communication with groundwater in the alluvium.

2.9 Land Use

Land use in the area consists primarily of desert conservation open space. There are isolated areas of agriculture, limited chloride mining of the brine from the dry lakes, and localized mining, military use, recreation, railroad, and electrical, gas, and oil utility corridors (ESA, 2012a).

2.10 Groundwater Production

Cadiz used, on average, 5,000 to 6,000 acre-feet per year (AFY) of groundwater between 1994 and 2007, for its agricultural operations. This annual usage was reduced beginning in 2007 in connection with the removal of approximately 500 acres of vineyard. Based on the current crop mix, the agricultural operations are using approximately 1,800 to 1,900 AFY (ESA, 2012a).

Two existing salt mining operations at the Bristol and Cadiz Dry Lakes involve evaporation of the hyper-saline groundwater from the dry lakes to obtain the remaining salts. One operation uses approximately 500 AFY of the hyper-saline groundwater based upon recorded water extractions, while the other operation uses approximately 250 AFY, for a total of 750 AFY (ESA, 2012a).

Average annual groundwater production for the Cadiz Valley Agricultural Development from 1998 to 2002 was approximately 5,600 AFY; and from 2003 to 2007 approximately 4,390 AFY. Annual average production from 2008 through 2013 was approximately 2,160 AFY. Total production during 2017 decreased slightly to 1,222.82 AF, compared to 1,857.99 AF in 2016 (TLF Consulting, LLC [TLF], 2018). This decrease in extraction is likely associated with increases in irrigation efficiency practices.

3.0 HYDROGEOLOGY OF THE PROJECT AREA

3.1 Hydrologic Inputs

3.1.1 Precipitation

Most of the precipitation in the Eastern Mojave Desert occurs between November and March. In general, the amount of precipitation increases with increasing elevation, and snow can accumulate at higher elevations (greater than 5,000 feet above MSL). Average annual precipitation ranges from approximately three inches on the Cadiz and Bristol Dry Lakes (elevations of 545 to 595 feet above MSL) to over 12 inches in the Providence and New York Mountains (elevations over 7,000 feet above MSL). The table below provides the total volume of precipitation that falls on each of the watersheds:

Table 1: Total Volume of Precipitation by Watershed

Watershed	Area (ft^2)	Precipitation Volume (AFY)
Bristol	22,141,717,000	170,541
OBW	4,736,693,394	46,232
Fenner (West)	13,700,280,036	173,716
Fenner (East)	16,625,535,879	234,753
Lanfair	7,831,938,617	123,806
Cadiz	16,482,012,982	131,042
Total	**81,518,177,907**	**880,090**

Note:
ft^2: square feet

3.1.2 Infiltration

Nearly all of the rainfall that falls on the alluvium enters shallow soil moisture storage or flows as run-off in ephemeral rills and streams, only to infiltrate downstream into unsaturated soils. After the rainfall events, most of this water is lost to the system as evapotranspiration and never recharges groundwater. Most of the recharge into the groundwater basins comes from water that has infiltrated in the surrounding mountains, and thence recharges groundwater as fracture-baseflow from bedrock to alluvium, or infiltration of surface water flows at the mountain bedrock-alluvium contact. Thus, the source of most of the groundwater recharge within the regional watershed occurs in the higher elevations since they receive higher volumes of precipitation.

It should be noted that no direct measurements of infiltration have been made at any locations within the watersheds. Estimates of infiltration, and resulting groundwater recharge, have been based on calculations using other parameter inputs (e.g., rainfall and surface cover).

3.1.3 Recharge

Several estimates of groundwater recharge have been completed for the Cadiz Project area since 1984. More recently, recharge estimates have been presented by Geoscience (1999), United States Geological Survey (USGS) (2000), and Lawrence Livermore National Laboratory (LLNL) (2000).

Geoscience (1999) estimated groundwater recharge based on a watershed model that included variables that affect the daily water balance of the watershed, including precipitation, runoff, vegetation interception, infiltration, evapotranspiration, soil moisture, and percolation. Geoscience estimated the total recoverable groundwater for the entire Project area (Bristol, Cadiz, and Fenner Watersheds) to range between 19,886 and 58,268 AFY. The recharge estimates for the Fenner and OBW Watersheds range from 14,646 to 37,254 AFY and 1,193 to 4,285 AFY, respectively. This provides an estimate for the combined total recoverable groundwater (Fenner and OBW) of 15,839 to 41,539 AFY (CH2M Hill, 2010).

The USGS (2000) estimated groundwater recharge based on a modified Maxey-Eakin model of the Project area (Bristol, Cadiz, and Fenner Watersheds), which was used to estimate groundwater recharge as a percentage of the average annual precipitation within discrete elevation-precipitation-recharge zones. The model estimated a median groundwater recharge rate of 2,550 to 11,800 AFY, of which 2,070 to 10,343 AFY was estimated for the Fenner Watershed alone (CH2M Hill, 2010).

LLNL (2000) reviewed the USGS (2000) Maxey-Eakin groundwater recharge estimates and concluded that they underestimated recharge to the Fenner Watershed. LLNL (2000) developed a separate Maxey-Eakin model of the Fenner Watershed, which estimated a recharge rate between 7,864 and 29,815 AFY, based on local precipitation (CH2M Hill, 2010).

Additionally, an estimated groundwater recharge value of approximately 32,000 AFY was generated by CH2M Hill (2010) using the model INFIL 3.0 for the model period of 1958 to 2007. The average annual groundwater recharge quantities for the Fenner Watershed, OBW Watershed, and in total, were estimated using the INFIL 3.0 model at 30,191 AFY, 2,256 AFY, and 32,447 AFY, respectively (CH2M Hill, 2010).

3.2 Groundwater Flow

In the Bristol and Cadiz Watersheds, groundwater flows radially toward the dry lakes from the surrounding hills and mountains. In the OBW, groundwater flows to the southeast from the Granite Mountains through the wash, and then to the southwest into Bristol Dry Lake. In the Fenner Watershed, groundwater generally flows radially from the surrounding mountains to the center of the valley and thence southward. A groundwater divide exists within the watershed. Recharge from the Providence, Granite, Clipper, and Marble Mountains (the western portion of the watershed) eventually discharges through the Fenner Gap to the Bristol Dry Lake. Recharge from the New York, Old Women, and Ship Mountains (eastern portion) eventually discharges through the Fenner Gap to the Cadiz Dry Lake.

As noted, it is likely that groundwater from the Lanfair Valley flows into the eastern portion of the Fenner Watershed, and eventually discharges to Cadiz Dry Lake.

3.3 Hydrologic Outflow

3.3.1 Groundwater Pumping

Cadiz currently owns and operates seven full-scale irrigation wells in the Cadiz Valley, including Wells 21 South, 21 North, 22, 27 South, 27 North, 28, and 33. During the period from 1986 to 2009, the total annual amount of groundwater pumped by Cadiz ranged from approximately 1,882 AF in 2009 to 6,689 AF in 1990 with an annual average of 4,602 AFY. In addition, a total of 1,118 AF of groundwater was pumped from Well PW-1 to provide a source of water for the pilot infiltration test conducted during the period between March and September 1999 (Geoscience, 1999). Since 2007, with changes in agricultural operations, the pumping rate has been reduced to between 1,800 and 1,900 AFY.

3.3.2 Dry Lakes

The Bristol and Cadiz Dry Lake playas are located at the lowest elevations in the watersheds that surround the Cadiz Project. All of the watersheds in the Cadiz Project area (including the Bristol and Cadiz Watersheds) are closed; that is, neither surface water nor groundwater discharge to adjacent watersheds. Therefore, the only natural outlet for surface and groundwater is evaporation from the dry lakes.

During sudden spring snow thaws and/or late summer thunderstorms of high intensity, surface water flows to the dry lakes and standing water can occur (CH2M Hill, 2010); however, the standing water rapidly evaporates immediately after such flash flooding events.

The dry lake playas consist of a variety of surface types, including salt crust and soft puffy porous surfaces which are largely devoid of vegetation. Clay and silts are the predominant soil types beneath the surface. Puffy surfaces are believed to be formed from upward groundwater movement in the capillary zone causing salts to precipitate and clays to swell on the surface, resulting in a network of polygons and hummocky relief. This puffy surface is reported to cover more than 60 percent (%) of Bristol Dry Lake (CH2M Hill, 2010).

3.3.3 Evapotranspiration

Geoscience (2000) developed a range of estimates of evapotranspiration from Bristol and Cadiz Dry Lakes, using three different methods, which ranged from 11,665 to 105,436 AFY. The upper range of values was based on evapotranspiration estimates at Franklin Dry Lake playa by Czarnecki (1997). An energy-balance, eddy-correlation technique was used to estimate evapotranspiration from the playa lake surface, which resulted in evapotranspiration rates of 0.1 to 0.3 centimeters per day (cm/d) (approximately 1.2 to 3.6 feet per year [feet/yr]) (CH2M Hill, 2010).

The USGS (2001) estimated evapotranspiration for a number of areas in the Death Valley regional flow system, which included estimates for open playas similar to the Bristol and Cadiz Dry Lakes. The USGS estimated evapotranspiration rates from 0.1 to 0.7 feet/year. They adjusted these evapotranspiration rates by the estimated long-term average annual precipitation rate (by subtracting the precipitation rate) to get evapotranspiration rates ranging from 0.15 to 0.21 feet/year. However, the USGS (2001) stated that the contribution of precipitation to evapotranspiration is uncertain. Given the high rate of evaporation in these arid environments, precipitation may not affect the evapotranspiration rates as estimated from micro-meteorological measurements. Using a range of 0.1 to 0.7 feet/year gives a range of evapotranspiration rates of 5,965 to 41,755 AFY for the Bristol and Cadiz Dry Lakes (CH2M Hill, 2010).

Between May and November 2011, Desert Research Institute (DRI) (2012), conducted an investigation on Bristol and Cadiz Dry Lakes to determine project-specific evaporation rates during the dry months when precipitation is absent. The investigation estimated an evaporation rate from Bristol Dry Lake of 7,860 AFY and from Cadiz Dry Lake of 23,730 AFY, for a total evaporation rate of 31,590 AFY (CH2M Hill, 2012). According to CH2M Hill (2012), the evaporation rate estimates were determined by extrapolating the measured data to an area over which evaporation was expected to occur, and for a full year based on expected monthly variations, as observed from pan and measured evaporation rates from Franklin Dry Lake. The estimated annual evaporation rates calculated by DRI (2012), are considered conservative, as they do not consider the additional groundwater losses due to agricultural pumping by Cadiz (4,600 AFY average production) or to the salt-mining operations on the dry lakes (approximately 750 AFY) (CH2M Hill, 2012). It should be noted that the extrapolated evaporation rates are for dry-weather evaporation; that is, groundwater-supported evaporation. They do not include direct evaporation of ponded rainfall or surface water inflows, or evaporation from the resultant shallow soil moisture, immediately after a rainfall event.

3.4 Storage Volume

The volume of groundwater in storage in the alluvium of the Fenner Valley and OBW has been estimated to be between 17 and 34 MAF. However, this storage estimate does not include water contained within the carbonate and fractured portion of the bedrock beneath the alluvium. Recent investigations have determined that these units may also store and conduct large volumes of groundwater. In addition, this storage estimate does not include groundwater within the Lanfair Valley, probably between 3 and 6 MAF that is likely tributary to the Fenner Basin. As such, the estimated volume of groundwater in storage is a conservative estimate, and the actual volume is most likely greater (CH2M Hill, 2010).

3.5 Aquifers

In the Cadiz Project area, the majority of the geologic deposits that store and transmit groundwater (i.e., aquifers) can be divided into the following four units:

- Upper alluvial aquifer
- Lower alluvial aquifer
- Tertiary fanglomerates
- Carbonate bedrock aquifer (consists primarily of Paleozoic limestone)

The alluvial aquifer units and the carbonate bedrock aquifer are in hydraulic continuity with each other. The differentiation is primarily due to stratigraphic differences and the extent of interconnecting secondary porosity with the carbonate unit (Geoscience, 2011a).

3.5.1 Alluvial Aquifer

The alluvial aquifer system is comprised mainly of Quaternary alluvial sediments consisting of stream-deposited sand and gravel with lesser amounts of silt. The thickness of this aquifer in the Project area has been interpreted to range from approximately 200 feet towards the flanks of Fenner Gap, to as much as 800 feet, as depicted Kenney (2011). To the west of Fenner Gap, the upper alluvium aquifer is separated from the lower alluvium aquifer system by discontinuous layers of silt and clay. The upper alluvial aquifer is very permeable in places and can yield 3,000 gallons per minute (gpm) or more with less than 20 feet of drawdown.

The lower alluvial aquifer consists of older sediments, including inter-bedded sand, gravel, silt, and clay of late Tertiary to early Quaternary age. The Cadiz agricultural wells are screened primarily in the lower alluvial aquifer and typically yield 1,000 to 2,000 gpm (Geoscience, 2011a).

3.5.2 Carbonate Aquifer

Carbonate bedrock of Paleozoic age, located beneath the lower alluvial aquifer, contains groundwater and is considered a second main aquifer unit. Groundwater movement and storage in the carbonate bedrock aquifer primarily occurs in secondary porosity. Recent studies performed by CH2M Hill, have shown that portions of the carbonate aquifer, are highly transmissive (e.g., contain karst features). It is also likely that other carbonate units may also exhibit localized areas of highly-transmissive secondary porosity features (Geoscience, 2011a).

3.5.3 Granitic Aquifer

Granitic and metamorphic rock forms the subsurface margins of the aquifer system. These basement rocks are generally impermeable but can have significantly increased permeability along fracture zones which are associated with the numerous faults that cross beneath Fenner Gap. Fracture zones in the hanging wall of the fault zones and along the detachment fault, range in thickness from 150 to 400 feet, and occupy a significant portion of the cross-sectional area in the Fenner Gap (Kenney, 2011).

3.6 Hydraulic Properties

The hydraulic properties of the aquifers obtained from recent pumping tests (Geoscience, 2011b) at the Cadiz property indicate that the aquifers are highly transmissive in the vicinity of the test wells (TW-1 and TW-2).

Hydraulic conductivities for the alluvial aquifer in the vicinity of pumping well TW-2, located in the center of the Fenner Gap, ranged from approximately 37 to 150 feet per day (feet per day). Hydraulic conductivity of the alluvial aquifer system in the vicinity of pumping well PW-1, located in an older alluvial fan northwest of Schulyer Wash was 158 feet/day. Storativities average approximately 0.002, reflecting semi-confined conditions in the alluvial aquifer system (Geoscience, 2011b).

Hydraulic conductivities for the carbonate aquifer in the vicinity of the Project area (TW-1), ranged from 602 to 1,023 feet/day. Storativities were representative of semi-confined (i.e., leaky) aquifer systems. The alluvial aquifer in the vicinity of TW-1 exhibited leakage effects during the pumping tests, suggesting that there may be a hydraulic connection with the overlying alluvial sediments (Geoscience, 2011b).

Hydraulic conductivity of the fractured granite may range from approximately 5 to 20 feet/day at depth in TW-2. Published values for hydraulic conductivity in fractured granitic rock range from 0.1 to 40 feet/day (Geoscience, 2011b).

The hydraulic properties obtained from aquifer testing and used for groundwater modeling are further summarized in **Table 2**.

Table 2: Hydraulic Conductivity Values Used in Groundwater Modeling and Obtained from Pumping Tests

Model Layer	Lithology	Location Relative to Fenner Gap	Modeled Recharge Rate Hydraulic Conductivity (feet/day)			Aquifer Test Hydraulic Conductivity (feet/day)
			32,000 AFY	16,000 AFY	5,000 AFY	
1	Alluvium	Inside and Outside	0.02 - 543	0.1 – 267	0.02 – 84	37 - 150
2	Alluvium	Inside and Outside	0.02 - 543	0.1 – 267	0.02 – 84	37 - 150
3	Alluvium	Inside and Outside	0.7 – 406	0.1 – 200	0.02 - 128	37 - 150
4	Carbonate	Inside and Outside	500 – 1,500	500 – 1,500	150 - 450	602 – 1,023
	Fanglomerate	Inside	60	25	9	0.0031
	Fanglomerate	Outside	2	1	0.3	0.0031
5	Carbonate	Inside and Outside	500 – 1,500	500 – 1,500	150 - 450	602 – 1,023
	Fanglomerate	Inside	60	25	9	0.0031
	Fanglomerate	Outside	2	1	0.3	0.0031
6	Weathered Granitic	Inside	75	50	15	4.6 – 19.7
	Weathered Granitic	Outside	2	1	0.3	4.6 – 19.7

3.7 Geochemistry

The quality of the groundwater in the Cadiz Project area is relatively good, with total dissolved solids (TDS) concentrations typically in the range of 300 to 400 milligrams per liter (mg/L). At Bristol and Cadiz Dry Lakes, surface water and shallow groundwater evaporation concentrates dissolved salts in the water, resulting in TDS concentrations as high as 298,000 mg/L. The freshwater/saline water interface, as defined by TDS concentrations greater than 1,000 mg/L, is located near the margins of the dry lakes (Geoscience, 2011a).

A summary of geochemical data in alluvial and carbonate aquifer units in the project area are further summarized in **Table 3**.

Table 3: Summary of Water Quality Analyses in the Project Area

Parameter	Aquifer Material (mg/L)	
	Alluvium	Carbonate
TDS	260	220
Calcium	26	24
Magnesium	5.2	5.7
Sodium and Potassium	52.9	65.6
Chloride	34	38
Sulfate	11	32
Carbonate	100	130

3.8 Conceptual Hydrogeologic Model

The watersheds that surround the Cadiz Project form a closed hydrologic system, both for surface water and groundwater. The complete watersheds include broad and deep alluvial basins surrounded by predominantly faulted and fractured, granitic bedrock mountains.

The thick sequence of alluvium (greater than 500 feet in many places) is underlain in localized areas by permeable fanglomerates, and highly-permeable carbonate (karts) and dolomitic limestone, overlying relatively impermeable granitic basement rocks. The fanglomerates, limestone, shale, and other rocks also outcrop within the surrounding mountains. The basins and mountains constitute a series of deep grabens, perpendicular sub-grabens, and horsts formed along major fault zones (**Figure 9**). Tectonic uplift and plutonic intrusion once created broad anticlinal structures within the basins; however, these have subsequently been partially eroded away and in-filled with the alluvium (**Figure 10**).

Alluvium, fanglomerates, and limestone make up the groundwater basins within the overall watersheds that surround the Cadiz Project. In addition, some areas outside the topographic surface-water catchments yield groundwater to the groundwater basins (e.g., west of the Amboy volcanics, and to the northwest from the Lanfair Valley). As such, groundwater basins do not exactly correlate with the overlying surface water catchments.

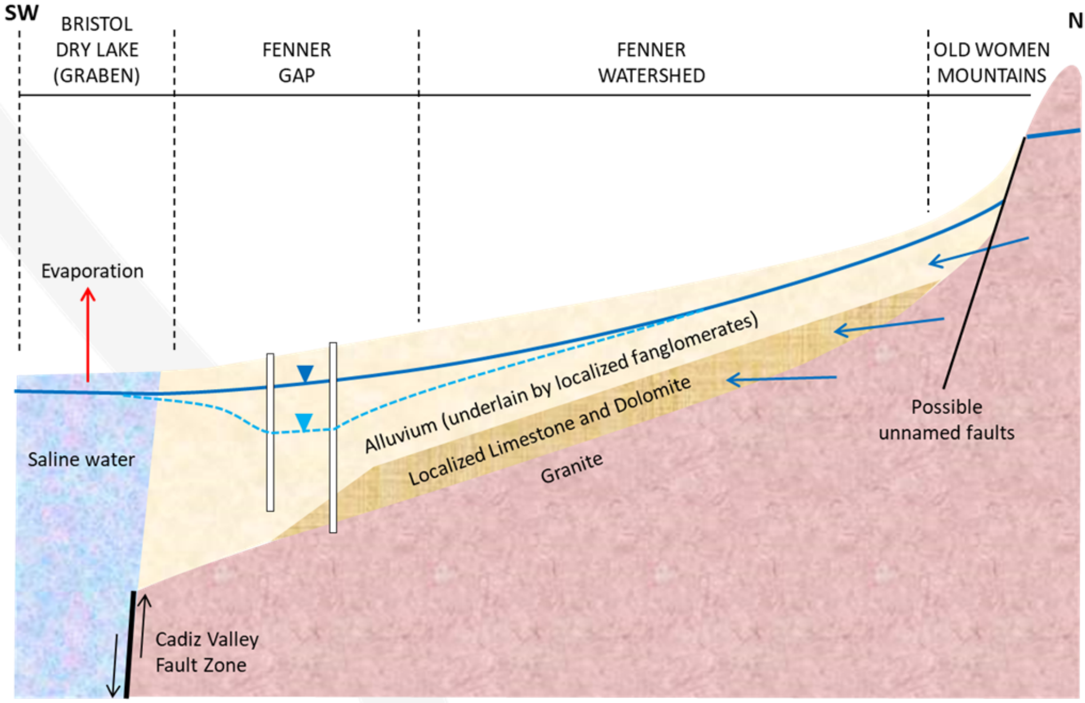


Figure 9: Simplified Hydrogeologic Section up Fenner Valley[9]

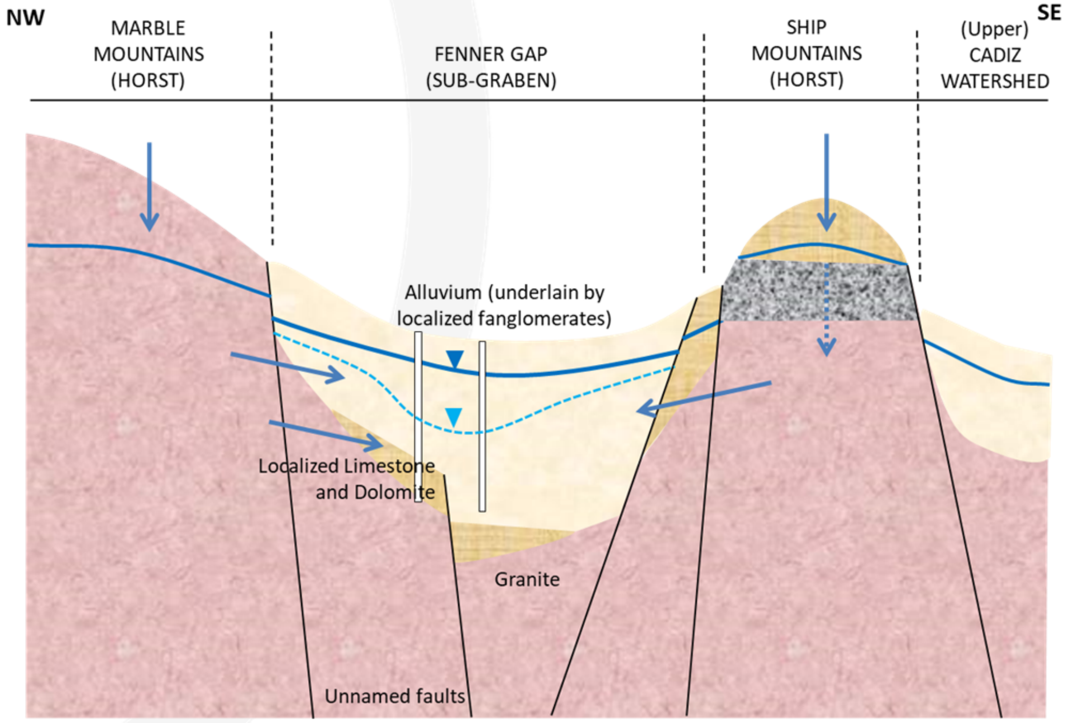


Figure 10: Simplified Hydrogeologic Section across Fenner Gap[9]

---

[9] Aquilogic, Inc. (2013). Review of The Groundwater Hydrology of the Cadiz Project, San Bernardino County, California.

Precipitation falls across the area, increasing with elevation, and can be present as snow-pack at higher elevations (approximately greater than 5,000 feet above MSL). Nearly all of the rainfall on the alluvium enters shallow soil moisture storage or flows as run-off in ephemeral rills and streams, only to infiltrate downstream into unsaturated soils. After the rainfall events, most of this water is lost to the system as evapotranspiration and never recharges groundwater. Most of the recharge into the groundwater basins comes from water that has infiltrated in the surrounding mountains, and thence recharges groundwater as fracture-baseflow from bedrock to alluvium, or infiltration of surface water flows at the mountain bedrock-alluvium contact.

Throughout most of the alluvial basins, groundwater is found at depths greater than 100 feet below ground surface (bgs). Only at the dry lakes is shallow groundwater encountered. However, at some locations, perched groundwater is present behind fault scarps and above low-permeability strata in the mountains. In these locations, springs can be found or created by drilling or tunneling into saturated rock/sediments. Given their elevation (i.e., more than 500 feet above groundwater in the nearby alluvium) and hydrologic origin, these springs do not appear to be in direct hydraulic communication with the groundwater in the alluvium.

In general, groundwater flows down the alluvial valleys toward the point of lowest hydraulic head within the system – the Bristol and Cadiz Dry Lakes. Groundwater within the Bristol, OBW (a sub-basin of the Bristol), and western portion of the Fenner Watersheds flows to Bristol Dry Lake. Groundwater within the eastern portion of the Fenner Watershed, tributary groundwater that enters the Fenner Valley from the Lanfair Valley, and groundwater in the Cadiz Watershed flows to the Cadiz Dry Lake. Given the storage volume of the alluvial basins and the distances between recharge in the mountains and evaporation in the dry lakes, infiltrating precipitation likely takes many hundreds of years to finally leave the system. No groundwater flows into adjacent basins or discharges to surface water that flows into adjacent watersheds, and all groundwater is eventually lost to the system as evaporation at the dry lakes.

Given the geochemical nature of the rocks within which infiltration and recharge occurs, and the filtering effect of the alluvial sediments through which groundwater flows, the groundwater is generally of high quality with low TDS concentrations. In addition, the permeability of the alluvial sediments and carbonates allows high yields at groundwater pumping wells.

Groundwater within the Fenner Valley, and tributary groundwater that enters the Fenner Valley from the Lanfair Valley, eventually flows through the Fenner Gap between the Marble and Ship Mountains. In addition, groundwater in the OBW flows to the south of the Fenner Gap before flowing to Bristol Dry Lake. All of this groundwater is tributary to the Cadiz Project. It has been estimated that between 17 and 34 MAF of groundwater storage, and between 5,000 and 32,000 AFY of annual recharge, is tributary to the Cadiz Project.

Cadiz plans to pump groundwater at proposed well locations within the Fenner Gap. These wells will essentially capture groundwater that currently flows through the Fenner Gap and OBW to the Bristol and Cadiz Dry Lakes and is lost as evaporation. The proposed pumping rate will exceed the annual groundwater recharge that is tributary to the Cadiz Project, and some water will be removed from long-term aquifer storage. After 50 years, pumping will cease and the aquifers will be allowed to recharge for at least 50 years. In addition, Cadiz has plans to import water for storage in the Fenner Watershed to supplement natural recharge.

4.0 REFERENCES

Aquilogic, Inc. (2013). Review of The Groundwater Hydrology of the Cadiz Project, San Bernardino County, California.

CH2M Hill. (2010). Cadiz Groundwater Conservation and Storage Project. July.

CH2M Hill. (2012). Technical Memorandum, Estimated Evaporation from Bristol and Cadiz Dry Lakes. May 8.

Czarnecki, J.B. (1997). Geohydrology and Evapo-transpiration at Franklin Lake Playa, Inyo County, California. U.S. Geological Survey Water-supply Paper 2377: 75 pp.

Desert Research Institute (DRI). (2012). Quantifying Evaporative Discharge from Bristol and Cadiz Dry Lakes. March 16.

Environmental Science Associates (ESA). (2012a). Final Environmental Impact Report (FEIR) for the Cadiz Valley Water Conservation, Recovery, and Storage Project, Prepared for Santa Margarita Water District (SMWD). SCH# 2011031002. July.

Environmental Science Associates (ESA). (2012b). Groundwater Management, Monitoring, and Mitigation Plan (GMMMP) for The Cadiz Valley Groundwater Conservation, Recovery and Storage Project. September.

Geoscience Support Services, Inc. (Geoscience). (1999). Cadiz Groundwater Storage and Dry-Year Supply Program, Environmental Planning Technical Report, Groundwater Resources, Volumes 1 and 2, Report 1163. November.

Geoscience Support Services, Inc. (Geoscience). (2011a). Cadiz Groundwater Modeling and Impact Analysis. September 1.

Geoscience Support Services, Inc. (Geoscience). (2011b). Technical Memorandum, Geohydrologic Assessment of the Fenner Gap Area. September 1.

Kenney GeoScience (Kenney). (2011). Geologic Structural Evaluation of the Fenner Gap Region Located Between the Southern Marble Mountains and Ship Mountains, San Bernardino County, California. August 31.

Lawrence Livermore National Laboratory (LLNL). (2000). A Calibrated Maxey-Eakin Curve for the Fenner Basin of the Eastern Mojave Desert, California. UCRL-ID-139030. May 15.

TLF Consulting, LLC (TLF). (2018). Twentieth Annual Groundwater Monitoring Report, January - December 2017, Prepared for Cadiz Valley Agricultural Development, Cadiz, Inc. December.

United States Geological Survey (USGS). (2000). Review of the Cadiz Groundwater Storage and Dry-Year Supply Program Draft Environmental Planning Technical Report, Groundwater Resources, Volumes I and II. Memorandum from James F. Devine to Molly S. Brady, Field Manager, Bureau of Land Management, Needles, California. February 23, 2000.

United States Geological Survey (USGS). (2001). Annual Ground-Water Discharge by Evapotranspiration from Areas of Spring-Fed Riparian Vegetation Along the Eastern Margin of Death Valley, 2000–02. Scientific Investigations Report 2006–5145.