Appendix A

Basin Conceptual Model

BASIN CONCEPTUAL MODEL

MOJAVE SOLAR PROJECT, Solar Thermal Energy Facility
Harper Dry Lake, California

Prepared for:

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Victorville, CA

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Project No. 27- 1643

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Table of Contents

1.0 List of Acronyms 9

2.0 Executive Summary 11

3.0 Introduction 16

3.1 Background 17

3.2 Purpose and Objective 18

3.3 Site Description, Demographics and Land Use 20

3.4 Domain 21

3.5 Photographs 22

4.0 Geologic and Hydrologic Setting 22

4.1 Previous Studies 24

4.1.1 The Mark Group (April 1989) 25

4.1.2 The Mark Group (December 1989) 26

4.1.3 AST (2007) 27

4.1.4 CSU and MWA (2007) 28

4.1.5 US Geological Survey (2001) 30

4.1.6 Subsurface Surveys (May 1990) 33

4.2 Climate and Precipitation 33

4.3 Topographyand Boundaries 34

4.4 Regional Geology 34

4.4.1 Geologic History 35

4.4.2 Structure 37

4.5 Local Geology 38
4.5.1 Cross Sections 41
4.5.2 Cross Section A-A' 41
4.5.3 Cross Section B-B' 42
4.5.4 Cross Section C-C' 42
4.5.5 Hydro-Stratigraphic Cross Section D-D' 43
4.5.6 Hydro-Stratigraphic Cross Section E-E' 43
4.5.7 Hydro-Stratigraphic Cross Section F-F' 44
4.5.8 Cross Section G-G' 44
4.5.9 Cross Section H-H' 44
4.5.10 Idealized Cross Section R-R' 46
4.5.11 Black Mountain Basalt Discussion 46
4.5.12 Structure 47
4.5.13 Harper fault zone 48
4.5.14 Harper Valley Fault Zone 48
4.5.15 Harper Dry Lake Fault 49
4.5.16 Black Mountain Fault 49
4.5.17 Lockhart Fault Zone 49
4.5.18 Lockhart Fault 49
4.5.19 South and North Lockhart Fault 50
4.6 Hydrogeology 51
4.6.1 Groundwater Elevations 51
4.6.2 Groundwater Occurrence and Flow 53
4.6.3 Recharge to the Domain 55
4.6.4 Groundwater Sinks 58
4.7 Aquifer Properties 58
4.7.1 Aquifer Testing Program 58

4.7.2 Aquifer Thickness Discussion 68
4.8 Groundwater Geochemistry 68
4.8.1 Domain 69
4.8.2 Groundwater Quality Characterization 74
4.8.3 Hinkley 75
4.9 Groundwater Use 77
4.9.1 Historical 78
4.9.2 Current 79
4.9.3 Water Budget 82
4.9.4 Water Rights 85
5.0 Surface Water 85
6.0 Environmental Impacts 86
6.1 Construction 87
6.2 Operation 89
6.3 Distance-Drawdown Projections 92
7.0 Groundwater Model Development 94
8.0 Limitations 94
9.0 References 95

List of Tables

4-1 Summary of Water Quality Samples Collected from the Ryken and Wetlands Supply Wells
4-2 Well Completion Details within a ½-Mile Radius of the Mojave Solar Project Site
4-3a Pre MSP Water Budget
4-3b Post MSP Water Budget
6-1 Estimated Monthly Water Usage

Appendix C Tables

4-4 Harper Laboratory Report Ryken Well S-1
4-5 Laboratory Report Ryken Well S-2
4-6 Laboratory Report Ryken Well S-3
4-7 Laboratory Report Wetlands Supply Well
4-8 Silt Density Index test results: Ryken Well – Harper Lake
4-9 Field Parameters
4-10 Harper Lake area wells Location Coordinates and Elevations
4-11 Harper Lake area wells Potentiometric Surface
4-12 Lake area wells Potentiometric Surface During Pump Test

List of Figures

1-1 Nearby Population Centers
1-2 Domain
1-3 Topography
1-4 Topography
1-5 Groundwater Basins
1-6 General Geology
1-7 Potentiometric Surface (1930)
1-8 Potentiometric Surface (1958)
1-9 Potentiometric Surface (1998)
1-10 Potentiometric Surface (2004)
1-11 Potentiometric Surface (6/27/2008)
1-12 Aquifer Pumping Test Wells
1-13 Southern California Faults
1-14 Harper Lake Area Hydrographs
1-15 Hinkley Area Hydrographs
1-16 Iron Mountain to Hinkley Area Hydrographs
2-1 Depth to Bedrock
2-2 Maximum Historical Harper Lake Shoreline
2-3 Conceptual Basalt Layer Perimeter
2-4 Geologic Cross Section Locations
2-5 Geologic Cross Section A-A'
2-6 Geologic Cross Section B-B'
2-7 Geologic Cross Section C-C'
2-8 Hydro-Stratigraphic Cross Section D-D'
2-9 Hydro-Stratigraphic Cross Section E-E'
2-10 Hydro-Stratigraphic Cross Section F-F'
2-11 Geologic Cross Section G-G'
2-12 Geologic Cross Section H-H'
2-13 Depth to Bedrock Lynx Cat – Iron Mountain Gap Area
2-14 Idealized Geologic Cross Section R-R'
4-1 Wells Within ½ Mile Radius
6-1 Surface Geophysics Transect Lines
6-2 Nearby Residential & Production Wells
6-3 MSP Production Wells
6-4 MSP Predicted Hydraulic Interference – Construction Period (26 Months)
6-5 MSP Predicted Hydraulic Interference – Operation Period (30 Years)

List of Graphs

2-1 Average Monthly Maximum & Minimum Temperatures
2-2 Average Monthly Precipitation
2-3 Average Monthly Evapotranspiration
2-4 Well J Hydrograph
2-5 Well J Hydrograph
2-6 Well J Hydrograph
2-7 Well M Hydrograph
2-8 Well M Hydrograph
2-9 Myrob Well Hydrograph
2-10 Green House Well Hydrograph
2-11 Ryken Well Hydrograph
2-12 Weltand Supply Well Hydrograph
2-13 Hay Farm Well Hydrograph
2-14 Hay Farm Well Hydrograph
2-15 Time-Drawdown, Theis
2-16 Time-Drawdown, Cooper-Jacob
2-17 Time-Drawdown, Neuman
2-18 Time-Drawdown, Moench
2-19 Time-Drawdown, Tartakovsky Neuman
2-20 Distance-Drawdown
2-21 Stiff Diagrams, 1990
2-22 Stiff Diagrams, 1992
2-23 Stiff Diagrams, 2000
2-24 Stiff Diagrams, 2002
2-25 Stiff Diagrams, Hinkley Well
2-26 Stiff Diagrams, East of Harper Lake Well
2-27 Stiff Diagrams, Ryken Well
2-28 Stiff Diagrams, Ryken Well
2-29 Chloride vs. Sulfate

List of Appendices

A	Figures
B	Graphs
C	Tables
D	Pressure Transducer Data
E	Laboratory Reports
F	Photographs
G	Miscellaneous
H	Geophysical Investigations
I	Numerical Model

1.0 LIST OF ACRONYMS

AF	acre feet
AFC	Application for Certification
AFY	acre feet per year
amsl	above mean sea level
b	aquifer thickness
BCM	Basin Conceptual Model
bgs	below ground surface
BLM	United States Bureau of Land Management
BMPs	best management practices
CA DWR	CA Department of Water Resources
CEC	California Energy Commission
cm/sec	centimeters per second
DEM	digital elevation model
DESCP	Drainage, Erosion, and Sediment Control Plan
ds	drawdown per log cycle
ECSZ	Eastern California Shear Zone
ft/day	feet per day
ft^2/day	square feet per day
FPLE	Florida Power and Light Energy
GHBs	general head Boundaries
gpd/ft	gallons per day per foot
gpd/ft^2	gallons per day per square foot
gpm	gallons per minute
gpm/ft	gallons per minute per foot
HFB	horizontal flow barrier package
HLB	Harper Lake Groundwater Basin
HVB	Harper Valley Groundwater Basin
K	hydraulic conductivity
LGS	Layne GeoSciences
lQal	lower Quaternary Alluvium
mg/L	milligrams per liter

MRB	Mojave River Basin
MSP	Mojave Solar Project
MWA	Mojave Water Agency
PG&E	Pacific Gas & Electric
Q	flow rate
Qae	active eolian sand deposit of latest Holocene age
Qal	Quaternary alluvium
Qap	active playa deposit of Holocene age
Qb	Quaternary basalt
Qoa	old alluvial fan deposit of mid-early Pleistocene
Qra	Recent alluvium of Holocene age
QToa	Late Tertiary to early Quaternary deposits
QTof	older fan and stream deposits of Pleistocene-Pliocene
Qtu	undifferentiated alluvial deposits of Holocene to late Pliocene age
QTp	playa deposits
pTb	non-water bearing metamorphic and granitic rocks
Qya	younger alluvium of Holocene to Pleistocene age
Qyf	younger alluvial fan deposits of Holocene-Pleistocene age
Qoa	Mid-Pleistocene older alluvium deposits
S	storativity coefficient
SEGS	solar electric generating systems
SCE	Southern California Edison
T	transmissivity coefficient
t	time
t_0	time axis intercept
TDS	total dissolved solids
µg/L	micrograms per liter
USGS	United States Geological Survey
uQal	upper Quaternary alluvium
ZCTA	zip code tabulation area

2.0 EXECUTIVE SUMMARY

Mojave Solar LLC is proposing to construct, own and operate a concentrated solar electric generating facility involving use of groundwater as a cooling water supply as a project alternative on a site approximately 1,765 acres near Harper Dry Lake, northwestern San Bernardino County, California. To facilitate the required regulatory review and approval of this project, ***Layne GeoSciences (LGS)*** has prepared this Basin Conceptual Model (BCM) for the Mojave Solar Project (MSP) thermal energy project to support numerical modeling of groundwater flow in this portion of the basin. This report addresses the hydrogeological framework, domain boundaries, hydraulic properties, sources of water, groundwater sinks, water storage, and geochemistry. Potential impacts to adjacent users of groundwater from supply water pumping at the proposed MSP were assessed.

The proposed MSP is positioned within the Harper Valley Groundwater Basin (HVB) which is part of the Mojave River Basin (MRB). The study area identified as the Domain is part of the HVB and is about 411 square miles.

BCM conclusions include the following:

- The HVB itself is a significant structure, and basin geometry controls groundwater flow. As an example, the HVB perimeter coincides with a groundwater divide caused by a bedrock structure consistent with a conventional basin shape.
- The deepest part of the basin is north of the present Harper Lake playa. The location of Harper Dry Lake does not appear to be controlled by deeper bedrock structure.
- Primary depositional environments for water-producing sediments in the project area are fluvial deposits and reworked lacustrine sediment from the ancestral Mojave River. Lacustrine / pluvial deposits, potentially extending laterally to a maximum ground surface elevation of 2,160 above mean sea level (ft amsl) (on the basis of recorded historic shorelines) also produce water. Due to subsurface information limitations, elevations of

lacustrine / fluvial sediment contacts are undefined. These sediments are of Pleistocene-age.

- Depth to groundwater beneath the project area is about 125 to 145 ft below ground surface (ft bgs).
- The early Pleistocene-age Black Mountain Basalt flow is beneath portions of Harper Dry Lake and the project area. In the project area, the basalt layer is likely positioned within the aquifer at about 500 ft bgs, with variable thickness ranging from about 75 to 200 ft. Where it is free of fractures, the basalt layer functions as an aquitard. Due to limited subsurface information, the perimeter positions and continuity of the basalt layer are unknown.
- Pleistocene-age unconsolidated sediment from lacustrine / pluvial depositional processes along with sediment from fluvial / reworked lacustrine environments likely continues beneath the basalt layer to bedrock. In the project area, the depth to bedrock is at about 900 to 1,000 ft bgs. Because of compaction and potential cementation, hydraulic conductivity is estimated to be 75 percent reduced within the unconsolidated sediment below 1,100 ft amsl.
- Within the Domain, but outside of the depositional influence of ancestral Harper Dry Lake (i.e., ground surface elevation of 2,160 ft amsl), the primary depositional environment for water-producing sediment is alluvial fan and fluvial. These sediments extend to bedrock and likely become more compacted at an estimated 1,100 ft amsl or less.
- Layers and zones are the building blocks for numerical groundwater flow model construction. The potentiometric surface within simulated water wells is commonly used for model calibration to real water well data. In the model, minimum well screen lengths are limited to the thickness of one layer. Through the use of layers and zones, the model requires accommodation of the following subsurface features: uQal (unconsolidated sediment above the basalt layer); the subsurface basalt flow; lQal (unconsolidated sediment beneath the basalt layer); lQal at elevations of 1,100 ft amsl or less; Qal (sediment beyond the perimeter of ancestral Lake Harper); Qal sediment below 1,100 ft amsl; faults; and

limited flood plain sediment in the vicinity of the Domain's portion of the Mojave River.

- For unconsolidated aquifer sediment above 1,100 ft amsl, excluding flood plain sediment, LGS recommends application of hydraulic conductivity of 843 gallons per day per square foot (gpd/ft^2) or 0.039 centimeters per second (cm/sec), unless subsurface data or depositional environment interpretations indicate otherwise.
- For aquifer sediment below 1,100 ft amsl, excluding flood plain sediment, LGS recommends application of hydraulic conductivity of 210 gpd/ft^2 (0.00975 cm/sec), unless subsurface data indicate otherwise.
- In aquifer areas inside the ancestral Harper Dry Lake footprint, LGS recommends application of a Storativity coefficient value of 0.003, unless subsurface data or depositional interpretations indicate otherwise.
- In aquifer areas outside the ancestral Harper Dry Lake footprint (i.e., no clay layers present providing aquifer confinement), LGS recommends application of a Storativity coefficient value of 0.12, unless subsurface data or depositional interpretations indicate otherwise.

- Groundwater targeted as the make-up water for cooling electrical generation equipment at the proposed MSP is not potable and will require treatment prior to its use for drinking purposes. The eastern side of the HVB and including the project area is of a sulfate-chloride character with chloride ranging from about 500 mg/L to 2400 mg/L and sulfate ranging from 350 mg/L to about 600 mg/L; boron and iron concentrations also tend to be elevated; reports of TDS ranged from about 1600 mg/L to 5500 mg/L.
- To comply with CEC requirements to estimate impact to neighboring property due to MSP water production, pumping from two on-site wells was simulated using a 2D analytic element flow model. The predictive simulation lasted 30 years and assumed that each of two production wells was pumped continuously at a rate of 670 gpm. A flow rate of 670 gpm

from two wells, 24 hours per day for one year is equivalent to 2,163 AFY. As a result of this simulated MSP water production, hydraulic interference of 0.5 feet is shown (on Figure 6-5) as a contour polygon. Maximum estimated hydraulic interference at positions off the MSP footprint and at a radial distance of 0.5 miles from production wells PW-1a and PW-2b is 1.4 feet. This interference to potential offsite wells located as close as 0.5 miles from the MSP supply wells is insignificant. LGS does not expect groundwater production during MSP operation to significantly impact water levels at neighboring wells. Similar hydraulic interference simulation was conducted for water production required during the MSP construction period.

- Based on the most recent information available, and accounting for the availability of the 707 AFY of water from the Ryken Well, approximately 4,900 AFY of groundwater is available for the proposed MSP. The proposed MSP is expected to require 2,163 AFY.
- LGS agrees with specific conclusions in the V. Ebbs Masters Thesis, which focused on underflow from the Middle Mojave River Valley Groundwater Basin to the HVB (Ebbs 2007). The sum of underflow through the Hinkley gap (the Red Hill gap) and Lynx Cat-Iron Mountain gap was estimated as 2,100 AFY. LGS, on the basis of literature review, has been unable to confirm underflow through the Lynx Cat-Iron Mountain gap.
- Although additional gaps within the perimeter bedrock structure likely exist, information is currently not available to support underflow estimates within specific HVB perimeter areas other than the Hinkley gap. The CA DWR stated within their description of the adjacent Superior Valley groundwater basin that some groundwater may discharge to the HVB beneath Quaternary-age basalt flows present along the southwest margins of the Superior Valley groundwater basin (CA DWR 1975).

Data from gravity and magnetotellurics investigations (see Figure 6-1, Surface Geophysics Transect Lines) were processed and analyzed including verifying their consistency with earlier regional gravity surveys. The result was an improved understanding of depth to bedrock and an estimate of the configuration of the subsurface Black Mountain basalt layer.

Results of a numerical groundwater flow model based on BCM Report information is provided in Appendix I. A calibrated, numerical groundwater flow model allows for prediction of impacts from changes to hydrologic conditions on subsurface flow and assists with HVB water budget evaluation.

3.0 INTRODUCTION

Layne GeoSciences, a part of the *Layne Christensen Company*, presents this Basin Conceptual Model (BCM) report for the proposed Mojave Solar Project (MSP) project at Harper Dry Lake, California. Information presented in this report will support subsequent groundwater flow modeling and be summarized within the Application for Certification (AFC) submitted to the California Energy Commission (CEC) as part of the permit process required before construction of the MSP. Development of a long-term water supply for the Project is the overall primary objective for the investigations conducted.

Mojave Solar LLC is proposing to construct, own and operate a concentrated solar electric generating facility involving use of groundwater as a cooling water supply as a project alternative on a site approximately 1,765 acres near Harper Dry Lake, northwestern San Bernardino County, California. To facilitate the required regulatory review and approval of the project, ***LGS*** has prepared this BCM to support subsequent hydrogeological investigation including numerical modeling of groundwater flow in this portion of the basin. This report addresses the hydrogeological framework, domain boundaries, hydraulic properties, sources of water, groundwater sinks, water storage, and geochemistry of the project. Potential impact to adjacent users of groundwater from supply water pumping at the proposed MSP are addressed.

Significant information sources for this BCM include the United States Geological Survey (USGS), California Department of Water Resources (CA DWR), California Division of Mines and Geology, Mojave Water Agency (MWA), other agencies, public-source consulting reports, as well as recent data acquired by ***LGS***. Relevant technical reports prepared by the Mark Group (April and December, 1989) describing hydrogeological conditions of the area were used as source documents. Applicable hydrogeological data and conditions presented in the 1987 AFC prepared by ERT Inc. for the nearby, active Luz Solar-Power facility, now known as the Florida Power and Light Energy (FPLE) SEGS VIII and IX, were used as source information.

3.1 BACKGROUND

The proposed MSP is at approximately 35.03º N / 117.33º W and is located within the HVB, a part of the Centro Sub-Basin of the MRB. The MSP is near Harper Dry Lake, as shown in Figure 1-1. Figure 1-1 shows the modified Harper Valley Groundwater Basin (Domain). The Domain is positioned within the western part of the Mojave Desert in southern California, 100 miles northeast of Los Angeles. The HVB comprises 640 square miles (410,000 acres) and includes a small portion of Kern County, with most of the basin within San Bernardino County. The HVB is centered on Harper Lake, a dry lake bed with a surface elevation of about 2,025 ft amsl; Harper Dry Lake is about 10 miles northwest of Hinkley, San Bernardino County, California (Lockhart quadrangle).

As shown in Figure 1-1, the Domain is bordered on the northeast by Fremont Peak and the Gravel Hills, on the southeast by a series of northerly trending low hills and Iron Mountain, and on the west by a topographic divide that separates the basin from the adjacent Antelope Valley Groundwater Basin. Public Land Survey System sections are identified in Figure 1-2 (Domain). Topography is shown in Figures 1-3 and 1-4. Neighboring groundwater basins relative to the HVB are shown in Figure 1-5.

Water resources and their occurrence and use are complicated issues in the Mojave Desert. Groundwater within the desert provides an important resource for domestic, agriculture, commercial, and industrial use and often supplements imported water from the State Water Project or Colorado River. Groundwater is a primary source of domestic water within the HVB.

The MRB was adjudicated in 1996. The Watermaster, a subdivision of the Mojave Water Agency (MWA), was appointed by the court to implement the terms of the Judgment entered in the adjudication. Water issues within the basin involving surface water or groundwater are managed by the MWA. For management purposes, the MWA subdivided the Mojave River surface-water drainage basin into several subareas. HVB is located entirely within the Centro subarea. The Mojave River is the primary source of surface water in the basin but is not dependable for supply because significant flows occur only after intense storms. As a result, groundwater is used for agriculture and municipal needs.

The headwaters for the Mojave River lie about 40 to 50 miles south of the Harper Dry Lake area within the high mountains of the central Transverse Ranges that were uplifted along the San Andreas Fault during the past several million years. The Mojave River channel is about 11 miles southeast of Harper Dry Lake. Recharge from the Mojave River to the HVB aquifers may be minor, possibly occurring during episodic storm flows, usually in the winter. During the rest of the year, most of the river is usually dry.

As shown in Figure 1-3, the Domain is drained by numerous ephemeral steams sloping toward Harper Dry Lake. The HVB has no streams discharging water out of the basin; it is a closed basin. Annual precipitation ranges from about 3 to 7 inches with highland areas of the basin receiving more precipitation and basin areas with low topography receiving less.

Annual precipitation ranges from about 3 to 7 inches. Highland areas of the basin receive precipitation at the high end of the range. Basin areas with low topography receive precipitation at the low end of the range.

Quaternary lacustrine and alluvial deposits, including unconsolidated younger alluvial fan material and unconsolidated to semi-consolidated older alluvium, can be water bearing within the basin (see Figure 1-6). The younger alluvium generally lies above the groundwater surface, whereas the older alluvium transects the water table (DWR, 1971). The alluvial deposits gradually thin and become interbedded with layers of silty clay of lacustrine origin toward the middle of the basin (Bader, 1969; DWR, 1964). The older alluvium is the most important water-bearing stratum in the basin, with average well yields reported at about 725 gpm with a maximum of 3,000 gpm (DWR, 1975). Groundwater within the basin is generally unconfined, although confined conditions are found near Harper Dry Lake (DWR, 1971). Available potentiometric surface maps for the Harper Dry Lake area, based on a limited number of wells, indicate groundwater flow toward Harper Dry Lake (see Figures 1-7, 1-8, 1-9, 1-10, Potentiometric Surface Maps for 1958, 1998, 2004, and 2008). The total storage capacity of the HVB is estimated to be 6,975,000 acre-ft (DWR, 1975).

3.2 PURPOSE AND OBJECTIVE

This BCM is the qualitative framework upon which hydrogeological data related to the Domain can be considered. The basic components of a conceptual model

are the sources and sinks of water to the region, the physical boundaries of the domain, and the distribution of hydraulic properties within the region. Information provided within the BCM supports development of a more quantitative representation of the subsurface hydrology, such as subsequent numerical groundwater flow modeling. It will be used as part of the permit requirements to comply with the following CEC regulations:

- (g)(14)(B) Provide a detailed description of the hydrologic setting of the project. The information will include a narrative describing the chemical and physical characteristics of nearby water bodies that may be affected by the proposed project.
- (g)(14)(B)(i) Describe groundwater bodies and related geologic structures.
- (g)(14)(B)(v) Inventory groundwater wells within 0.5 mile of the project.
- (g)(14)(C) Describe the water to be used and discharged by the project.
- (g)(14)(C)(ii) Describe the expected physical and chemical characteristics of the source and discharge water(s), including identification of both organic and inorganic constituents before and after any project-related treatment.
- (g)(14)(E) An impact analysis of the proposed project on water resources and a discussion of conformance with water-related LORS and policy.
- (g)(14)(E)(ii) If the project will pump groundwater, an estimation of aquifer drawdown based on a computer modeling study shall be conducted by a professional geologist and include the estimated drawdown on neighboring wells within 0.5 mile of the proposed well(s), any effects on the migration of groundwater contaminants, and the likelihood of any changes in existing physical or chemical conditions of groundwater resources shall be provided.
- (h)(3)(B)(iii) Describe geologic and flood hazards, meteorologic conditions and climatic extremes, and cooling-water availability.

This BCM presents existing hydrologic information for the Domain and allows for general conclusions regarding impacts for aspects of the current hydrologic

conditions upon current groundwater flow directions. In comparison, a calibrated, numerical groundwater flow model allows for prediction of impacts from changes to hydrologic conditions upon subsurface flow. Additionally, the BCM identifies data gaps before groundwater flow model development.

3.3 SITE DESCRIPTION, DEMOGRAPHICS AND LAND USE

The proposed MSP is located in the HVB about 10 miles northeast of Hinkley, a Mojave Desert town of Southeastern California (see Figure 1-5, Groundwater Basins). The Mojave Desert is characterized by barren mountain ranges and isolated hills with broad alluvial-filled valleys. The site is relatively flat with a very gentle downward slope toward Harper Dry Lake to the north-northeast. Portions of the proposed MSP site have recently been used for agriculture purposes. Structures on the site generally consist of irrigation equipment and numerous active and out-of-use water wells. Ground surface elevations within the main MSP footprint range from about 2,030 ft amsl at the northeastern edge of the site near Harper Dry Lake to about 2,100 ft amsl at the southwestern corner of the site (see Figures 1-3 and 1-4). Vegetation generally consists of sparse to moderate growth of desert plants and shrubs.

Demographic information presented herein support estimates of groundwater pumping. The United States does not define a census-designated place called Hinkley, but it does define a Zip Code Tabulation Area (ZCTA), 92347. For the 2000 census, the ZCTA of 92347 (Hinkley area) had a population of 1,915 (U.S. Census Bureau American Fact Finder). Within the study area, Hinkley contains the largest concentration of people and accounts for the most domestic water use (see Figure 1-1). Kramer Junction and Lockhart are the next largest communities. The population within the agricultural community of Lockhart – Harper Dry Lake, located near the proposed MSP, has declined. The Lockhart – Harper Dry Lake vicinity has approximately five active residential properties, with some properties serving multiple purposes. One property is an inactive concrete batch plant, where a caretaker resided. The actual number of residents in Lockhart, Kramer Junction, and other unincorporated parts of the study area is unknown at this time.

At the time this document was written, on the south side of Harper Dry Lake, one alfalfa field, approximately 160 acres, remained active; the field is owned and

operated by the Desert View Dairy in Hinkley (see Figure 1-12). Irrigation for this crop field involves pumping groundwater at about 1,140 gpm and applying water to the field with use of a mechanical pivot system.

An active well, located on Mojave Solar LLC property, supplies water to the Harper Dry Lake wetlands on the central portion of the south shoreline. It is monitored and operated by the U.S. Bureau of Land Management (BLM).

Existing Solar Electric Generating Systems (SEGSs), operated by FPLE and known as SEGS VIII and IX, are located near the southwest portion of Harper Dry Lake and each have about a 400-acre footprint (see Figure 1-1). Electrical output for each FPLE SEGS is about 80 megawatts. Related facilities include a 16-inch 8-mile underground natural gas pipeline that extends from State Route 58 along Harper Dry Lake Road to the FPLE SEGS VIII and IX. A 12-mile 220-kV transmission line connects the FPLE SEGS VIII and IX to the Southern California Edison (SCE) electrical grid by a substation located in Kramer Junction to the west. Several production wells positioned on the FPLE site provide process water.

Groundwater in the Hinkley area has been affected by a historical release of hexavalent chromium. The extent and movement of the affected groundwater has been assessed, and remediation is ongoing.

Refer to Figure 1-1, Nearby Population Centers, showing nearby highways; the towns of Hinkley, Kramer Junction, Lockhart, Barstow, and Victorville; Edwards and George Air Force Bases; Harper Dry Lake and Cuddeback Lake; and the Mojave River.

3.4 DOMAIN

As shown in Figures 1-1 and 1-2, the Domain is about 411 square miles and includes part of the HVB, Harper Dry Lake, Kramer Junction, a southern extension to Hinkley, the Hinkley gap, and a portion of the Mojave River. For comparison, the CA DWR describes the HVB area as 640 square miles. In both area and shape, the Domain coincides approximately with potentiometric surface maps prepared with use of 1958, 1998, and 2004 source data (CSU and MWA, September 2007). See Figures 1-7 through 1-9.

3.5 PHOTOGRAPHS

Twelve photographs are included within Appendix F showing the Domain, Harper Lake, relevant water wells, and the HVB/Superior Basin contact area.

4.0 GEOLOGIC AND HYDROGEOLOGIC SETTING

The Mojave River does not typically flow; it is usually dry. In the vicinity of Hinkley, rare flow within the river channel is from west to east and occurs from infrequent rain events during high precipitation years. In historic high-precipitation years, most recently in early 2005, the river flowed into the Silver Lake playa, a northern sub- basin of Lake Mojave.

Harper Dry Lake, along with Lake Manix and Lake Mojave to the east, are part of a series of formerly interconnected basins. During much of the wetter Pleistocene epoch (approximately10,000 to 1.8 million years ago), these basins were connected by the ancestral Mojave River. In the late Pleistocene, after breaching Lake Manix basin, Lake Mojave episodically discharged northward into Death Valley (Reheis, et al, 2007). Today, the ground surface at Harper Dry Lake is about 2,025 ft amsl (see Figures 1-3 and 1-4). Thomas W. Dibblee recorded historic shorelines of Harper Lake at 2,160 ft amsl (Reynolds and Reynolds, 1994). Figure 2-2 shows the maximum historical Harper Lake Shoreline.

The combination of re-working of basin sediments by the Mojave River with active shedding of sediments from the alluvial fans coming off of the Rand Mountains, the Black Mountains and other basin perimeter highlands likely resulted in a complex distribution of well-sorted and poorly sorted deposits. Distribution of sediment grain sizes and degree of sorting also was affected by the continuing regional tectonic activity.

The Domain is within the Mojave Block, one of the most tectonically active regions of the United States (Reheis, et al, 2007). Figure 1-13 shows southern California faults.

Geologic cross sections originally presented in the Hydrogeologic Assessment Report associated with permit application for the nearby FPLE solar energy facilities (SEGSs VIII and IX) indicate a laterally extensive subsurface basalt flow positioned within the alluvium aquifer (The Mark Group, April 1989). Thickness

of the Black Mountain Basalt flow ranges from about 75 to 200 feet, and although its continuity is undetermined due to limited investigation, it is likely present beneath the Hinkley Gap, Harper Dry Lake, the FPLE solar energy facilities, and the proposed MSP. The impact of extensive volcanism within the Domain, especially in the vicinity of the HVB perimeter and including portions of the Hinkley Gap upon sediment distribution, groundwater quality, general groundwater flow patterns, groundwater inflow, and aquifer transmissivity, is not well understood.

The sum of underflow through Hinkley gap and Lynx Cat - Iron Mountain gap was estimated by Ebbs (2007) as 2,100 AFY, with 1,100 AFY flowing through the Hinkley Gap and 1,000 AFY flowing through the Lynx Cat Mountain – Iron Mountain gap (Figure 2-13). However, LGS has been unable to identify a hydraulic connection between the Mojave River channel and the HVB through the Lynx Cat – Iron Mountain gap.

As part of their Superior Valley Groundwater Basin description (Figure 1-5), the CA DWR stated that some groundwater may discharge to the HVB beneath Quaternary basalt flows along the southwest margins of the Superior Valley basin (CA DWR 1975). This possible flow has not been quantified. Based on surface observations of this area, LGS agrees that underflow from the Superior Basin to the HVB is possible through unconsolidated sediment in the notch area of Water Valley located northeast of Harper Dry Lake. Water Valley is a perimeter valley draining toward Harper Dry Lake. LGS recommends obtaining subsurface information from this area to assist with determining underflow.

The amount of underflow to the HVB from adjacent Cuddeback Basin (located northwest of Harper Dry Lake) has been estimated as negligible by the CA DWR (The Mark Group, April 1989). Investigation is needed regarding potential underflow from neighboring basins west of Harper Dry Lake (e.g., Antelope Valley).

According to CA DWR descriptions of the Antelope Valley Groundwater Basin (see Figure 1-5), the Antelope Valley basin is bounded on the east by ridges, buttes, and low hills that form a surface groundwater divide (CA DWR 1975). Underflow from the Antelope Valley into the HVB is therefore unlikely.

Floodwater from Grass Valley occasionally flows into the HVB through Black Canyon on the eastern side of the HVB (CA DWR 1975).

Although additional gaps within the perimeter bedrock structure likely exist, information is currently not available to support underflow estimates within HVB perimeter areas other than the Hinkley gap.

4.1 PREVIOUS STUDIES

Preparation of this BCM included review of published papers and unpublished data relevant to study-area geology. For over 60 years, portions of the HVB have been the subject of numerous geologic or hydrogeologic studies by the USGS, CA DWR, private consultants, MWA and university researchers. Six useful studies, as applicable to the BCM, are presented below in chronological order:

April 1989 – "Final Report, Hydrogeologic Assessment Report, Harper Dry Lake, California, for LUZ Development and Finance Corporation, 88-03219.18", by The Mark Group (The Mark Group, April 1989).

December 1989 – "Preliminary Report, Aquifer Analysis, LUZ Solar Energy Generating Station, Harper Valley, California, 89-03409.18", by The Mark Group (The Mark Group, December 1989).

May 2007 – "Report on the Geophysical Investigations for the Harper-Hinkley Gap Area near Hinkley, California, for the Mojave Water Agency" by Aquifer Science and Technology (AST, 2007).

September 2007 – "Harper Dry Lake Basin, San Bernardino County, California, Hydrogeologic Report", by California State University, Fullerton Department of Geologic Sciences and the Mojave Water Agency (CSU and MWA, 2007).

2001 – Stamos, Christina L; Martin, Peter; Nishikawa, Tracy; and Cox, Brett F; "Simulation of Ground-Water Flow in the Mojave River Basin" , US Geological Survey Water-Resources Investigations Report 01-4002, version 1.1, prepared in cooperation with the Mojave Water Agency (Stamos, et al, 2001).

May 1990 – Crosby, Gary W; "Inventory of Groundwater Stored in the Mojave River Basins" for the Mojave Water Agency, by Subsurface Surveys, Inc (Crosby, 1990).

Each report and their relevance to the BCM is discussed below.

4.1.1 THE MARK GROUP (APRIL 1989)

This document described annual alfalfa production (circa 1989) in the vicinity of SEGSs VIII and IX (includes the proposed MSP area) as 2,000 acres, with historic records indicating a maximum of 3,000 acres. About 5 AFY of water is needed per acre to support alfalfa production in the Harper Dry Lake area. Historic water-well pumping values could not be obtained from the DWR because no records were kept. The total estimated pumping from the historical Lockhart Ranch for 1953 to 1986 was 380,000 acre-ft. BLM records do not indicate the presence of Indian reservations, springs, or state historic areas that would be affected by pumping at the subject site. Regional and local scale geology, including regional faults, was discussed. The basalt flow from nearby Black Mountain was introduced. Three local geologic cross sections were presented. These cross sections show an approximate 75 foot thick basalt layer within the alluvium aquifer. Beneath the project site, the aquifer is about 300 to 400 feet thick. Below the basalt, additional alluvium provides a second water-bearing zone. The cross sections show the subsurface basalt layer present in the areas of the FPLE SEGS VIII and IX and the proposed MSP southwest of Harper Dry Lake. Apparently, the alluvial water-bearing zone below the basalt layer is not present at the east end of Harper Dry Lake, as indicated by well 11N4W23C1. The specific capacity for wells in the vicinity of the site is 37 gpm/ft, on average. Groundwater flow gradient is from the Middle Mojave Basin (near Barstow) into the HVB. Available subsurface records indicate that the thickness of the aquifer between the basins (i.e., the Hinkley Gap) is about 75 ft, allowing for underflow between the basins. Historical pumping at Hinkley (in the Middle Mojave Basin) does not appear to have influenced water levels in the HVB. Groundwater flow from the western portion of the HVB (near Kramer Junction) is toward Harper Dry Lake. Aquifer thickness in the Kramer Junction vicinity, from analysis of geologic maps and well logs, is about 400 to 500 ft. The amount of groundwater flow reduced by the Lockhart fault is unknown. For the 1953 to 1986 water balance, the following assumptions were made: once water is removed from the ground, 20 percent returns as recharge, with 80 percent used by agriculture, evaporation, or the wetlands area; basin recharge sources are limited to storm runoff, basin floor rainfall, bedrock percolation within surrounding mountains and underflow from the Middle Mojave Basin through the Hinkley Gap. Annual recharge to the HVB from these sources was estimated. Projections were made to estimate

impacts to the water balance by including future groundwater use. Expected recharge to the HVB varies from 2,300 to 6,500 AFY. However, an informed case can be made to increase the CA DWR's estimate of 1,000 AFY recharge from the Middle Mojave Basin to 2,700 AFY, thereby making total annual recharge to the HVB about 4,000 to 6,500 AFY. These recharge values result in a 40-year deficit of 0 to 60,000 acre-ft. This deficit is smaller than the 34-year, 1953 to 1986 deficit of 95,000 AFY. Water quality was described. Groundwater quality in the vicinity of the Harper Valley area indicates that the highest TDS concentrations are located in the area west of Harper Dry Lake; TDS concentrations will generally be below the 2,500 mg/L requirements for the project.

4.1.2 THE MARK GROUP (DECEMBER 1989)

The Mark Group presented new aquifer characterization data based on separate results of constant rate pumping and related recovery from two existing supply wells. Well No. 7 was pumped at 700 gpm for a 4-day period. Well No. 13 was pumped at 1,400 gpm for a 4-day period. Calculations involved use of the Theis non-equilibrium equation, Cooper-Jacob straight-line method, by use of a computer-simulated model (PLASM). The "bottom" of the main aquifer was conservatively interpreted at about 1,600 ft amsl, on average, for an aquifer thickness of about 300 ft, on average. This aquifer thickness estimate was considered conservative because the "deeper" aquifer (i.e., saturated alluvium beneath the Black Mountain basalt flow) was ignored. Water in storage and leakage from perched groundwater (known to exist at depths of 5 to 20 feet in the western Harper Dry Lake area) were also ignored. The PLASM-based model used "No-Flow" recharge conditions along the outer boundaries, thereby nullifying arguments concerning the currently unknown actual groundwater recharge conditions. The model used a constant initial potentiometric head, because of data and time constraints involved in setting up the model to represent actual dynamic equilibrium flow conditions at the start of projected pumping iterations. Groundwater storage was considered within the "main aquifer" only, estimated to lie between elevations of approximately 1,900 and 1,600 ft amsl. The Lockhart Fault Zone was considered a significant impedance to groundwater flow from higher elevations in the southern portion of the model, despite no evidence that the fault significantly impedes groundwater flow.

Results indicated a T value of 300,000 gpd/ft for the 300-ft-thick aquifer in the vicinity of the pumped well (SEGS VIII and IX). As a conservative average of pumping-test analysis results and geologic well logs, a T value of 100,000 gpd/ft was used for most of the remaining basin based on geologic logs and certain well yield data from Sections 2 and 4 of T.11N/R.4W. Other T values (including 2,500 gpd/ft in the Lockhart Fault Zone) were based on a combination of geologic interpretations from the present investigation, combined with transmissivity interpretations in the USGS Open File Report 72-157, "Hydrologic Analysis of Mojave River Basin," California (Hardt, 1971). A constant storativity coefficient (S) value of 0.10 was used at all nodes of the PLASM-based model. Use of Theis-based analytical methods and an annual discharge volume of 4,800 AFY, a storage coefficient of 0.10 and T values of 300,000 and 100,000 gpd/ft allowed for estimation of drawdown projections at a 4-mile radius from the center of pumping of 2.8 to 5.2 ft after 15 years of pumping and 3.6 to 7.1 ft after 30 years of pumping. A distance-drawdown graph was not provided, likely because of time constraints mentioned in the associated transmittal letter. The document concludes that on the basis of historic effects of decreased agricultural pumping over the past 3 years, with the deepest portion of the 1986 depression cone recovered approximately 30 feet, the projected water use for SEGs VIII and IX alone may not actually lower the water table any more than current conditions.

4.1.3 AST (2007)

Results of DC resistivity and seismic refraction geophysical surveys provided improved understanding of the width and saturated thickness of unconsolidated sediment within the Hinkley Gap, which supported a more accurate estimate of the groundwater flux into the HVB. As a result of these geophysical surveys, the former Mojave River channel appears to be limited to the area west of Red Hill. A fault near the center of the survey line appears to delineate a change in the depth and character of the local bedrock and a change from coarse-grained channel fill deposits west of the fault to finer grained and thinner clay or silt deposits above the bedrock east of the fault. From AST's geophysical surveys, groundwater flow into the HVB through the Hinkley Gap is estimated at 1,468 AFY on the basis of an assumed hydraulic conductivity value consistent with sand and gravel (100 ft/day).

The USGS estimated the volume of groundwater into the HVB through the Hinkley Gap to be 3,071 AFY on the basis of 1994 conditions and by use of a MODFLOW model of the entire Mojave River Basin (Stamos, et al, USGS 2001).

The MWA, in 1983, estimated the volume of groundwater into the HVB through the Hinkley Gap to be 22 AFY. This estimate was based on a smaller cross sectional area for the Hinkley Gap, a smaller hydraulic gradient, and a smaller assumed hydraulic conductivity value than with the USGS analysis.

The Mark Group (1989) estimated the flux into the HVB through the gap to be 2,700 AFY on the basis of well log interpretations. The Mark Group used a saturated thickness of 150 feet, which is more than twice the saturated thickness of channel deposits calculated from the geophysical data; a width of the channel deposits of 3 miles, which is more than 3 times the width measured by the geophysical data; and a gradient of 0.0038, which is similar to the value AST used. The Mark Group assumed a hydraulic conductivity value of 100 ft/day, which is the value AST used.

4.1.4 CSU AND MWA (2007)

Eight relevant, previous studies, dated 1929 to 2003, are cited. With regard to the HVB, Cuddeback Valley is northwest, Superior Valley northeast, the Lower Mojave River Valley east, the Middle Mojave River Valley south, and Antelope Valley west to southwest. Ephemeral streams drain the HVB toward Harper Dry Lake. No streams discharge water out of the basin. HVB is a closed basin. The estimated annual runoff into Harper Dry Lake Basin is approximately 550 AFY, and this constitutes about 5 percent of the total water supply into the basin (DWR, 1967). Although the Mojave River is directly adjacent to the HVB watershed divide, the modern Mojave River does not appear to drain into the HVB. However, ostracod assemblages and geomorphic data from the Pleistocene give evidence of several pluvial lake high stands (including Harper Dry Lake) (Reynolds and Reynolds, 1994; Enzel et. al., 2003).

The western expression of the ECSZ comprises the North and South Lockhart faults (surface rupture within the last 1,000 years), the Harper Dry Lake Basin fault zone, the Harper Dry Lake fault, the Blackwater fault, and smaller faults. The Lockhart fault zone is documented to impede and affect groundwater flow

(DWR 1967). Water level data for wells adjacent to the Lockhart fault are presented to support statements of groundwater flow restriction.

The principal aquifer of the HVB is composed of older alluvium, which underlies the Late Pleistocene lake sediments and surrounds the lake as alluvial fan deposits. Groundwater in the basin is generally unconfined, although confined conditions are found near Harper Dry Lake where the aquifer splits into two or more distinct aquifers (DWR 1971). Other aquifer units are composed of fanglomerates and sandstone and are separated by volcanic units in regions lying beneath Harper Dry Lake. Groundwater level trends within the HVB center region appear to respond differently to stresses within the system than do other hydrograph units. Most notably, large groundwater pumping rates in the HVB center region did not reach or affect levels in the HVB northeast wells; which suggests the presence of a hydrogeologic boundary. The report presents 3 potentiometric surface maps for the HVB on the basis of source data from 1958, 1998, and 2004. The total storage capacity of the HVB is estimated to be 6,975,000 acre ft with a storage coefficient of 0.12 (DWR 1967, 2003). For 1990, total groundwater in storage was estimated to be 101,500 acre ft (Bookman Edmonston 1994; DWR 2003).

Calculations for subsurface flow through the Hinkley Gap depend on varying aquifer characteristics, channel size, and methods that produced AFY results ranging from 22 to 3,071 AFY. Potential for subsurface flow through the gap between Lynx Cat and Iron Mountain is plausible and should be considered in future investigations.

Groundwater pumping from local residents was determined to be minimal, less than 10 AFY. The MWA Watermaster reported 5,100 acre ft of water consumed in the HVB by large producers in 2006. Alternatively, The Mark Group estimated HVB annual consumption to be 5,500 acre ft in 1989. The DWR estimated consumption at 26,800 acre ft in 2003. The total annual average water budget for the HVB was calculated at +1,000 acre ft by the Mark Group (1989). The total annual average water budget for the HVB was calculated at +11,370 acre ft by the DWR (2003).

Water quality data is limited within Harper Dry Lake. In general, wells located further from Harper Dry Lake exhibit better water quality than those directly adjacent to the lake. Reported TDS concentration ranges show a decrease in

the low values, from 1,000 mg/L in 1979 to 179 mg/L in 2003, whereas the higher TDS concentrations have remained high, at 2,300 mg/L, on average, over the same time.

Due to minimal surface water, evaporation is considered negligible within the HVB, although evaporation can occur with water ponds on dry lake surfaces or through bare-soil evaporation (Stamos et. al. 2001).

4.1.5 US GEOLOGICAL SURVEY (2001)

This report presents a MODFLOW-based 3-D numerical groundwater flow model for the MRB including the HVB. This model has 2 horizontal layers: the top layer (layer 1) corresponds to the floodplain aquifer and the bottom layer (layer 2) corresponds to the regional aquifer. There are 161 rows and 200 columns with a horizontal grid spacing of 2,000 × 2,000 ft.

Undifferentiated alluvial deposits of Holocene to late Pliocene age (Qtu) form the bulk of the regional aquifer, which underlies and surrounds the floodplain aquifer in an unconformed fashion throughout most of the MRB. These deposits consist of sand, gravel, and silt that accumulated in alluvial-fan, braided-stream, and playa or lacustrine environments. Most of the deposits formed in the Pleistocene and late Pliocene, during and before the development of the Mojave River surface-water drainage basin. Geological units comprising the regional aquifer are conspicuously faulted and tilted and typically are deeply eroded. Deposits exposed on hills and in ravines are as thick as 350 ft, and subsurface data suggest that the unit may be as thick as 1,000 to 2,000 ft in several deep structural depressions near Barstow, Harper Dry Lake, and Victorville. The permeability of the regional aquifer (i.e., alluvial deposits) is lower than that of the floodplain aquifer (i.e., fluvial sediments of the Mojave River) in part because of poor sorting on alluvial fans but also because of the widespread accumulation of secondary (pedogenic and diagenetic) clay and calcium-carbonate cement. Permeability generally decreases with depth. From field observations, the upper, more permeable, 300 to 800 ft of alluvial deposits constitute most of the regional aquifer. Although deposits of the lower regional aquifer contain a substantial amount of groundwater in storage, the low-permeability and fine-grained nature of the sediments result in low well yields, generally poor-quality water (i.e.,

elevated concentrations of dissolved solids), and large drawdown in wells. Estimated T values for the regional aquifer range from 1,000 to 13,000 ft^2/d.

The permeable recent river deposits from the Holocene and the younger river deposits from the Holocene to Pleistocene constitute the floodplain aquifer. The floodplain aquifer is more productive than the regional aquifer, yielding most of the groundwater pumped from the basin. These alluvial deposits are 100 to 200 ft thick and are within about one mile of the Mojave River. Wells completed in the river deposits typically yield between 100 and 2,000 gpm, with rates reported as high as 4,000 gpm. These deposits accept most, if not all, of the recharge from the river. Hardt (1971) estimated T values from specific capacity data at individual wells and reported values for the floodplain aquifer of between 13,000 to 27,000 ft^2/d. For this USGS groundwater flow model report, Hardt's T estimates were supplemented with recent specific-capacity data. Following the example of Driscoll (1986, p. 1021) for unconfined aquifers, T was estimated by multiplying specific capacity data (in gal/d/ft) by 200 to obtain T in ft^2/d.

Runoff that enters the river through ephemeral tributary streams contributes to the surface water in the river during flooding. The contribution of flow from these tributary streams has never been gauged or measured directly. Since determining when the runoff from ungauged tributaries occurred in the past is not possible, the runoff in the ephemeral tributary streams is assumed to occur at the same relative magnitude and during the same years that ephemeral runoff in the Mojave River occurred at the Barstow gauging station (10262500). The river flows as far as the Barstow gauge only during large storm flows and, therefore, periods of flow at this gauge were used as an indicator of periods of probable runoff from the tributary washes.

Faults and other geologic structures control groundwater flow in part in the MRB. The faults are barriers or partial barriers to groundwater flow in the regional aquifer and, in many places, the floodplain aquifer, which results in stair step-like drops in the water table across the fault zones. Between the fault zones, the water levels are relatively flat. Documented barriers to groundwater flow include the Helendale fault, the Lockhart fault, the Calico-Newberry fault, and the Camp Rock-Harper Dry Lake fault zone (i.e., the Waterman fault). The Camp Rock-Harper Dry Lake fault zone consists of five relatively young strike-slip faults and affects subsurface flow by causing abrupt, stair step–like changes in the water

table as groundwater flows eastward. The Lockhart fault cuts through the northern part of Iron Mountain and extends south of Harper Dry Lake through Hinkley Valley and into the unconsolidated rocks south of the Mojave River in the Centro subarea. The Lockhart fault appears to impede the movement of groundwater in the regional and the floodplain aquifers. This effect is not evident in the floodplain aquifer along the river.

Groundwater passing into the Centro subarea from the Transition Zone flows around Iron Mountain toward Harper Dry Lake through Hinkley Valley on the east side and through a narrow gap between the Helendale fault and Iron Mountain on the southwest side. However, steep water-level gradients between the Helendale fault and Iron Mountain on the southwest side shown by water-level declines of more than 150 feet within a distance of only about two miles indicate that subsurface faults or shallow geologic features probably impede subsurface flow to Harper Dry Lake.

The five dry lakes in the MRB area were simulated as drains by use of the MODFLOW Drain (DRN) package. The altitude of the Harper Dry Lake drain was set at 2,020 ft amsl. Flow out of the drain is controlled by the conductance between the aquifer and the drain and by the effects of the hydraulic head at each cell. The drain conductance value used at Harper Dry Lake was 1.0 ft^2/d. The conductance was determined by model calibration because groundwater discharge to the dry lakes is not measured directly.

A steady-state model provided initial conditions for the transient-state simulation.

Simulating stream flow in the Mojave River for steady-state conditions is not straightforward, because of a series of wet and dry periods. To simulate the measured steady-state groundwater levels, the Mojave River stream flow in the Alto, Centro, and Baja model subareas was distributed such that the simulated steady-state water levels in each model subarea matched the measured values.

The modeling process for the study involved defining the model grid, model boundaries, aquifer properties, stream-aquifer interaction, and recharge and discharge. The model was calibrated to transient-state conditions (1931-1994) by a trial-and-error approach. The transient-state simulation results are in good agreement with measured data.

4.1.6 SUBSURFACE SURVEYS (MAY 1990)

This document presents five MRB maps, including Bouguer Gravity Anomaly; Magnetic; Depth to Bedrock; Water Table; and Isopach (Water Table to Bedrock). The HVB is included within Subsurface Surveys investigation domain.

A prominent ridge revealed by the geophysical data, partially buried, is the Hinkley High. Gravity data show it to be a massive, structurally high block extending east to west for 23 miles from Iron Mountain, through Hinkley, to Lead Mountain north of Yermo. The feature is cut and displaced by strike-slip faults but remains a massive barrier to groundwater flow. The spillage of flood waters from the Mojave River into Harper Dry Lake is across the surface of this feature a couple of miles east of Hinkley (i.e., the Hinkley Gap). The drainage divide, about a mile west of Grandview, is only 7 ft higher than the river bed. Despite a subtle gravity saddle along the flow path over the buried ridge, the gravity data indicate no deeply carved, filled-in channel. A channel fill with maximum thickness of about 200 ft is possible and can be reconciled with the interpretation of a former alternate course of the Mojave River.

The report cites other examples of the bedrock remaining shallow for considerable distance away from exposure in hills, including on the west side of Harper Dry Lake. Information available to LGS indicates that the Subsurface Surveys-referenced shallow bedrock represents a basalt flow with variable thickness averaging about 75 ft, positioned about 500 ft bgs. Beneath the basalt is additional alluvium continuing to the true bedrock top surface. The Subsurface Surveys geophysical model appears not to resolve basalt layers sandwiched within alluvium from bedrock. The report presents geophysical evidence that older lake beds near Harper Dry Lake cause perched groundwater conditions, not a theorized fault.

More than 2800 gravity and magnetic stations were occupied; approximately 900 pre-existing gravity measurements were used. Magnetics provided some information on depth to magnetic basement rocks and helped in assigning rock densities.

4.2 CLIMATE AND PRECIPITATION

The HVB is located in the west central Mojave Desert in northwestern San Bernardino County. Average daily low and high temperatures are 34ºF and

61ºF, respectively, during January. In the summer months, however, the average diurnal average temperature range is 72ºF to 102ºF (see Graph 2-1).

Mean annual precipitation in the basin is about 5 inches at the basin floor and about 8 inches in the surrounding highlands. Rainfall occurs largely in the winter months, with summer rainfall being rare (see Graph 2-2).

Average pan evaporation rate for the basin is 90 inches annually, with a maximum monthly evaporation rate of approximately 12 inches in July and a minimum monthly evaporation rate of 2.5 inches in January (National Oceanic and Atmospheric Administration, 1974). See Graph 2-3 showing Barstow average monthly evapotranspiration. Barstow is about 18 miles southeast of the proposed MSP. According to one investigation, evaporation is negligible within the HVB, even though evaporation can occur with water ponds on dry lake surfaces or through bare-soil evaporation (Stamos et. al. 2001).

4.3 TOPOGRAPHYAND BOUNDARIES

The maximum topographic relief between the Harper Dry Lake ground surface and basin perimeter highlands is approximately 1,750 feet. The lowest topography within the Domain, about 2,016 ft amsl (nominal 2,025 ft amsl), is at Harper Dry Lake (see Figures 1-3 and 1-4). As shown in Figure 1-1, the HVB is bounded on the east by non water-bearing rocks of Fremont Peak, Black Mountain, the Gravel Hills, and the Mud Hills; and on the west by a combination of surface drainage divides, portions of the Harper, Kramer Hills and Lockhart faults, and non water-bearing rock of the Kramer Hills and other low-lying basement hills. The HVB is bounded on the south by non water-bearing rocks of Mount General, Iron Mountain, and the Waterman Hills, and by subsurface drainage patterns. To the north, the Basin is bound by non water-bearing rocks of the Rand Mountains (CA DWR 1975). See Figure 1-5 showing adjacent groundwater basins and HVB area landmarks.

4.4 REGIONAL GEOLOGY

The Domain is located within the western zone of the Mojave Desert Geologic Province of California. The enigmatic western zone is largely covered by alluvium with scattered exposures of Tertiary sediments offset by detachment faults (i.e., low angle normal faults) along with right-lateral, strike-slip faults

frequently described as nearly vertical. These faults show a northwest to southeast trend and are present throughout the region (see Figures 1-6 and 1-12). Ambiguous older rock also crop out. Extensive Tertiary volcanism is evident within the western zone. Landforms resulting from desert processes are pronounced and include sand-dune-covered regions, playa lake deposits, alluvial fans, and mass wasting in the form of debris flow deposits and landslides. Patterns of sediment deposition and erosion from the Mojave River and its larger ancestor significantly influence the presence and movement of groundwater within the MRB and the HVB (see Figure 1-6).

4.4.1 GEOLOGIC HISTORY

The Mojave Desert apparently drained to the Pacific Ocean about 18 to 10 million years ago, as indicated by southward–flowing paleocurrents in the Miocene stream deposits near the Cajon Pass (Woodburne and Golz, 1972; Foster, 1980; Meisling and Weldon, 1989). From 10 million years ago, north–south-directed tectonic compression progressively buckled the crust of the Mojave Desert and the surrounding areas, which resulted in trends of east-west ridges and basins that altered regional patterns of drainage and sedimentation (Cox 2003).

During the late Pliocene and early Pleistocene, (2.0 to 0.78 million years ago), the northern San Bernardino Mountains were warped and faulted up along the southern Mojave Desert, and the San Andreas Fault shifted high peaks of the central San Gabriel Mountains to a position directly west of the San Bernardino Mountains (Meisling and Weldon, 1989). These tectonic movements produced a lofty mountain belt that shed increased amounts of water and sediment northward into the adjacent basin at the southern edge of the Mojave Desert. The ancestral Mojave River transported much of the rock detritus that was eroded from the San Bernardino Mountains (Cox 2003). The regional arch in the southern Mojave Desert continued rising and became a significant drainage divide during this period. Detritus transported northward by the ancestral Mojave River and other streams was therefore barred from areas north of the arch, including the Domain. Drainage was associated with a low point on the crest of the regional arch positioned north of Adelanto. Also, during this period, local folding and faulting along or near the Helendale Fault created a closed depression within the Domain. This topographic depression was filled with the

fine-grained playa sediments of unit QTp (Cox 2003), thereby forming the early framework for Harper Dry Lake.

The basin near Hesperia had completely filled with alluvium by the middle Pleistocene about 0.5 million years ago. This occurred when the alluvium built up to a low point on the crest of the regional arch located due north of Adelanto. Thereafter, the ancestral Mojave River rapidly advanced northward beyond the arch and deposited sand and gravel, unit Qoa (Cox 2003). Deposition for these sand and gravel sediments include the Domain. Throughout the remainder of the Pleistocene, the terminus of the Mojave River alternated between Harper Dry Lake and basins east of Barstow.

The transition from the ancestral to the modern Mojave River occurred during the late Pleistocene, about 60,000 to 70,000 years ago, when the river began incising its present shallow canyon between the San Bernardino Mountains and Barstow (Cox 2003). Once incision began, the river was locked into its present northeastward course south of Iron Mountain, abandoning the alternate northward route west of Iron Mountain (see Figure 1-1, Nearby Population Centers). Down cutting probably was induced by the broad uplift of the southern Mojave Desert that occurred in response to renewed north-south tectonic compression. This inferred late-Pleistocene pulse of regional compression also may account for the latest growth of the monoclinal flexure east of Point of Rocks, which lifted the top of unit Qoa about 30 ft on the southwest side of the Helendale Fault.

The Mojave River initially cut down about 350 feet where it crosses the Helendale Fault. However, the river and local tributaries filled about half of this early valley's depth with sand and gravel of the younger Alluvium (unit Qya). Deposition of unit Qya was completed by early Holocene, before 6,000 to 7,000 years ago. By cutting a deep trough into the slightly permeable sediments of the older fan and stream deposits (QTof) and then partly filling the trough with more permeable sand and gravel, favorable conditions were established for containment of groundwater flow within the floodplain aquifer. Permeability of the floodplain aquifer may be lower than expected in some areas of the MRB, however, because large tributary ravines along the west side of the river deposited abundant layers of poorly sorted silty sand and gravel that are interstratified among the well-sorted, more permeable river deposits.

The Mojave River completed a second cycle of cutting and filling after 6,000 to 7,000 years ago. During this cycle, the river incised a channel about 100 feet deep within the younger Alluvium (Qya), then filled this channel about halfway with coarse sand and gravel of recent Alluvium (Qra). These recent river deposits are the most permeable strata of the floodplain aquifer.

The regional pattern of groundwater movement in the MRB is affected by right-lateral, strike-slip faults with a predominate northwest to southeast trend and often act as barriers or partial barriers to ground-water flow (Stamos and Predmore, 1995). The HVB contains several faults that may restrict groundwater flow. The historical record describes many places along the Mojave River, including the Domain, that had a shallow water table or perennially flowing surface water where active faults acted as leaky barriers to groundwater flow. Prior to the pumping of water wells, groundwater of the region may have discharged to the river.

4.4.2 STRUCTURE

The western Mojave Desert region is tectonically a great triangular fault block known as the Mojave block. This block is bounded by the left-lateral Garlock fault with a northeast trend through the upper portion of the Cuddeback Lake quadrangle and separates the Mojave block (to the south) from the Sierra Nevada to the north, and the Great Basin to the northeast. The Mojave block is bounded to the south by the right-lateral San Andreas fault zone that has a northwest trend. The Mojave block is subdivided by numerous, discontinuous late-Cenozoic strike-slip faults commonly identified as the Mojave strike-slip province. Figure 1-13 shows southern California faults. The Lockhart, Gravel Hills-Harper Dry Lake, and the Blackwater faults are in the western part of the Mojave strike-slip province. A smaller part of the Mojave block, which includes the domain, was termed the Eastern California Shear Zone (ECSZ) by Dokka and Travis (1990). The region shows increased seismic activity, which stretches from the San Andreas fault near Indio, north-northeast across the Mojave and northward into Owens Valley. With respect to the San Andreas fault, the ECSZ may accommodate as much as 10 to 25 percent of the relative motion between the North American and Pacific plates. ECSZ source structural deformation over the past 3 million years has significantly influenced Domain basin geometry (see Figure 2-1).

Significant Domain structural features are the HVB itself and the Hinkley High. The adjacent Middle Mojave River Valley Basin is structural in origin, as are the remaining adjacent basins. Figure 2-11 shows structural features on Geologic Cross Section G-G'.

4.5 LOCAL GEOLOGY

Geology of the HVB and Domain is characterized by a variable-depth buried basin, subsurface basalt flows, pluvial/lacustrine sediments, alluvial fans, fluvial deposits from the ancestral Mojave River, and structural faults. Geologic units within the Domain can be divided into two main groups, the consolidated rocks and the unconsolidated sediment. The formations within these groups have dissimilar water-bearing characteristics, but in general, the unconsolidated gravel, sand, and clay deposits of Quaternary age are more porous and permeable than the consolidated basalts, schists, sandstone and granites of the pre-Tertiary, Tertiary, and Quaternary. Consolidated rocks form the mountains and hills surrounding the valley. Consolidated rocks also underlie the sediments providing structural form to the "bottom" of the basin. The consolidated rocks generally have low primary permeability and unknown storage capacity in potentially broken areas with secondary permeability. In the HVB, consolidated rocks receive most of the precipitation where they are exposed within the drainage area surrounding the basin. Runoff from the HVB-perimeter hills and mountains, which consist of consolidated rock, contributes significant recharge to the unconsolidated deposits of the valleys where most of the groundwater occurs. In the Domain, unconsolidated deposits are generally interbedded layers of gravel, sand, silt, and clay, with sand being the most abundant constituent.

The oldest unit within the Domain is the basement complex, of pre-Tertiary age, which consists of undifferentiated igneous and metamorphic rocks. This unit is commonly referred to as basement complex, or bedrock, in the well logs, and is mainly composed of quartz monzonite and gneiss, although often incorrectly identified as granite. The basement complex, or bedrock, is generally low in permeability except in fractures and weathered zones that yield small quantities of water. Compared to the amount of water available in the unconsolidated formations, stored water available in the basement complex is small.

Sedimentary rocks, of Tertiary age, overlie the basement complex and consist of sandstone with shale beds. Occasional basalt flows also overlie the basement complex. These rocks are generally located in the northern part of the Domain. These sedimentary rocks and basalt layers store and transmit negligible water to wells and springs.

Basalt flows identified as the Black Mountain Basalt (early Pleistocene age), overlie the older unconsolidated alluvial deposits (Pleistocene) within parts of the Domain, and in other parts occur as a mostly horizontal layer within saturated portions of the alluvium; in other areas, the basalt is in contact with Tertiary sandstone or pre-tertiary bedrock units (see Figure 2-3). The basalt layer functions as an aquitard. Additional discussion regarding the presence, configuration and hydrogeologic role of this basalt flow is provided in Section 4.5.11 of this report.

Older alluvium, of Pleistocene age, underlies most of the valley-floor areas within the Domain and is commonly overlain by a layer of younger alluvium. The older alluvium was deposited above the igneous, metamorphic, and consolidated sedimentary rocks previously described but is transected in places by basalt flows. Older alluvium consists mostly of moderately sorted sand with gravel, silt, and clay.

Within the Harper Dry Lake area and other segments of the HVB, portions of alluvium column were influenced or resulted from fluvial sedimentary processes of the ancestral Mojave River. The present-day position of the Mojave River channel did not coincide with the Pleistocene ancestral Mojave River Channel. The ancestral Mojave River flowed through a deeper horizon of the present-day Harper Dry Lake area, thus altering sediment deposition, especially the pluvial depositional environment associated with historical Harper Dry Lake.

The older alluvium is generally unconsolidated, but in some places, especially at depth, it may be slightly cemented. This unit is porous and permeable, extends below the water table, yields water to wells, and is the principle aquifer material shown in the local geologic cross sections. In the proposed MSP area, subsurface Black Mountain Basalt formation transects water-saturated older alluvium. The subsurface basalt flow(s) perimeter is generally unmapped and fractures or lack of fractures are mostly undocumented.

LGS has subdivided the Regional Aquifer into the uQal (unconsolidated Quaternary alluvium above the basalt layer) and the lQal (alluvium below the basalt layer) within limited Domain areas where subsurface basalt flows are present. This nomenclature is helpful when describing hydrogeological units.

Older alluvial-fan deposits, of Pleistocene age, sometimes identified as fanglomerate are composed of gravel, boulders, and sand derived from the igneous and metamorphic rocks and, where saturated, yield water to wells. This formation is located principally near the mountain fronts and provides for recharge to the basin from percolation of runoff from the mountains.

Younger alluvium of Holocene age, deposited above the older alluvium consists of sand with small quantities of gravel, silt, and clay. This unit is permeable and, where saturated, will yield water to wells. It is generally thin and is not an important water-bearing unit, because it generally lies above the water table. However, it does transmit precipitation and water from the intermittent streams to the older alluvium aquifer.

Sediment of Harper Dry Lake from pluvial / lacustrine depositional processes are more extensive than the present-day foot print of the dry lake (see Figure 2-2, Maximum Historical Harper Lake Shoreline). Thomas W. Dibblee recorded historic shorelines of Harper Dry Lake at 2,160 ft amsl (Reynolds and Reynolds, 1994). The sequence of Harper Dry Lake area geologic features, including deposits derived from pluvial and fluvial depositional environments and the Black Mountain basalt flow(s), is poorly understood. Driller's logs of historical Harper Dry Lake area agriculture wells were based on visual description of drill cuttings, with downhole electric logs of Harper Dry Lake area wells not commonly performed or not available. Although lithologic detail is not present on the driller's logs to identify pluvial process deposition, stratification commonly associated with lake environments cannot be ruled out within the footprint of ancestral Harper Dry Lake (i.e., topography elevation 2,160 ft amsl or less). Stratification of this type would be expected to affect aquifer characteristics, including S values.

The windblown sand, of Holocene age, is composed of actively drifting, fine to medium sand, ranging from a few feet to more than 25 ft thick. In parts of the area, the sand may be saturated, but generally it is above the regional water table (see Figure 1-6).

4.5.1 CROSS SECTIONS

To improve understanding of the geology beneath the MSP, eight geologic and hydro-stratigraphic cross sections have been prepared. Attempts have been made to include subsurface information from the deepest available boreholes. LGS received limited and incomplete release and disclosure of driller's logs from non-Mojave Solar property owners. Subsurface information sources used to construct the cross sections include driller's logs from historical exploration gas wells, historical water-well drilling logs, and cross sections previously prepared by the Mark Group and from available interpreted geophysical surveys. Locations for these cross sections are shown in Figure 2-4. Geologic Cross Sections A-A', B-B', C-C', and R-R' were modified from the Mark Group, Final Report, Hydrogeologic Assessment Report, Harper Dry Lake, California, for the LUZ Development and Finance Corporation (The Mark Group, April 1989).

4.5.2 CROSS SECTION A-A'

Cross Section A-A' (Figure 2-5) extends southwest to northeast and shows the thickness of the upper older alluvium aquifer (i.e., portion above the basalt) labeled upper Quaternary alluvium (uQal) at about 300 feet. The potentiometric surface, represented as unconfined, is shown as being about 150 ft bgs (about 1,950 ft amsl elevation). The Black Mountain Basalt formation labeled Quaternary basalt (Qb) is shown sandwiched within the older alluvium aquifer. Subsurface information from one exploration gas well (10N5W2A1) shows the basalt as about 180 ft thick, with the top of the basalt logged as 630 ft bgs (about 1,575 ft amsl elevation). Subsurface information from another water well further east (11N4W32D2) shows the top of the basalt at about 450 ft bgs (about 1,675 ft amsl elevation). This view infers that the basalt layer is continuous and elevation variation likely caused by the topography of that time period. The Lockhart fault is shown with an interpretation of expected vertical offset to the basalt. Subsurface information regarding potential alteration of the older alluvium and changes to the hydraulic conductivity within the fault zone is unavailable. Water wells in this area of the Domain terminate above the top of the basalt. Below the basalt, additional alluvium provides a second water-bearing zone, labeled lQal. Subsurface information from one exploration gas well (10N5W11D1) indicates basement rock (i.e., granite) at 3,065 ft bgs.

4.5.3 CROSS SECTION B-B'

Cross Section B-B' (Figure 2-6) extends cross section A-A' across Harper Dry Lake further to the northeast and shows thickness of the upper older alluvium aquifer (i.e., portion above the basalt) labeled uQal as being about 400 feet. This cross section shows the older alluvium aquifer (lQal) absent beneath the Black Mountain Basalt formation, labeled Qb, in the vicinity of the east end of Harper Dry Lake. Subsurface information from well 11N4W23C1 (near the east end of Harper Dry Lake) indicates bedrock (gneiss) beneath the basalt. On the extreme northeast end of the cross section, at well 11N3W8N1, the presence of lQal is again indicated. Subsurface information from two wells (11N4W23C1 and 11N3W8N1) indicates that the basalt ranges from 145 to 185 ft thick. Continuity of the basalt between these two wells is inferred between wells 11N4W23C1 and 11N3W8N1, a horizontal distance of about 3 miles. On the extreme northeast end of the cross section, at well 11N3W8N1, the depth to basement rock is 1,225 ft bgs.

The water table is shown as sloping from the northeast to the southeast, which is consistent with historical potentiometric surface maps (Figures 1-7 through 1-9).

4.5.4 CROSS SECTION C-C'

Cross Section C-C' (Figure 2-7) extends northwest to southeast and contains relatively abundant elevation information for the top of the basalt. Because of elevation variation for the top of the basalt, the upper older alluvium aquifer, labeled uQal, is shown as ranging between about 235 to 485 ft thick. Thickness of the upper older alluvium aquifer is shown at a maximum beneath the FPLE SEGS VIII and IX. Beneath the proposed MSP, the uQal is about 285 ft thick. Construction of well 11N4W29G2, positioned in the middle of the cross section, revealed basalt between 465 to 590 ft bgs, at 125 ft thick. Beneath the basalt at well 11N4W29G2, the lQal, consisting of gravel and clay, was encountered at 590 ft bgs. Well 11N4W29G2 terminated at a depth of about 925 ft bgs within lQal sediment.

Depth to water beneath the proposed MSP is shown as about 145 ft bgs.

4.5.5 HYDRO-STRATIGRAPHIC CROSS SECTION D-D'

Hydro-Stratigraphic Cross Section D-D' (Figure 2-8) extends west to east through the southern portion of Harper Dry Lake. This cross section shows characteristics consistent with a lucustrine depositional environment or, more specifically, pluvial deposition associated with non-glacial Pleistocene sedimentation. Alternating and interbedded horizons of clay, sand and gravel are apparent. Grain size variation relates to depositional energy conditions. Horizons of fine-grained sediment indicate deposition conditions involving quiet water with minimal precipitation and associated run-on into the lake. Coarse sediment horizons display time periods with relatively high depositional energy. This cross section shows the stratigraphic effect from lake level variation over time resulting in bedding discontinuity. This depositional pattern indicates the opportunity for confined hydraulic conditions within water-bearing horizons beneath the lake.

Positions of the FPLE SEGS VIII and IX and Harper Dry Lake are shown on the cross section. The scarcity of lithologic information within the present-day dry lake perimeter is apparent on the cross section.

The potentiometric surface is shown at about 1,900 ft amsl. Elevation of the dry lake ground surface is about 2,025 ft amsl. Depth to groundwater beneath Lake Harper is about 125 ft bgs.

4.5.6 HYDRO-STRATIGRAPHIC CROSS SECTION E-E'

Hydro-Stratigraphic Cross Section E-E' (Figure 2-9) extends west to east, south of Cross Section D-D', south of the southern shoreline of the lake, and includes the general areas of the proposed MSP and the FPLE SEGS VIII and IX. Similar to Cross Section E-E', this section shows depositional patterns consistent with a lucustrine environment outside of the present-day dry lake perimeter. Lithology from well 11N03W34E02S located on the east end of the section shows an abundance of clay: about 365 ft out of a total depth of 450 feet.

The potentiometric surface is shown at about 1,900 ft amsl.

4.5.7 HYDRO-STRATIGRAPHIC CROSS SECTION F-F'

Hydro-Stratigraphic Cross Section F-F' (Figure 2-10) extends northwest to southeast across Harper Dry Lake and includes Hinkley Gap on the southeast end. This section shows depositional patterns consistent with a lucustrine environment (see Cross Section D-D' discussion). Positions of Harper Dry Lake and Hinkley Gap are shown on the cross section. At well 10N03W02J01S, in the Hinkley Gap area, total depth is about 120 feet, which is above the projected potentiometric surface of 1,900 ft amsl. Availability of driller's logs within the Hinkley Gap area limited subsurface information.

4.5.8 CROSS SECTION G-G'

Cross Section G-G' (Figure 2-11) extends south to north from the Mojave River and continues through the Hinkley gap area. It was prepared from various data sources, including driller's logs, interpretations of depth to bedrock based on gravity data, and geophysical interpretations based on resistivity data. This cross section features the structure of the bedrock through the Hinkley gap, an area many investigators believe provides underflow into the HVB from the adjacent Middle Mojave River Valley Groundwater Basin. Significant structural features shown include the bedrock depression associated with the Middle Mojave River Valley Groundwater Basin, the Hinkley high, and the bedrock depression associated with the HVB. Elevation relations of the ephemeral Mojave River, the Hinkley High, the HVB, and the potentiometric surface are shown. The potentiometric surface shown at resistivity line R1 is based on an interpretation of the resistivity data. From the cross section, a decline in the potentiometric surface of about 44 feet would be required to interrupt underflow to the HVB because of the Hinkley High. Decline of this magnitude due to seasonal variation of the potentiometric surface is unlikely. Hydraulic interference from unidentified water pumping within the Hinkley gap area could interrupt underflow to the HVB. Hydraulic interference of this magnitude within the Hinkley gap is not documented.

4.5.9 CROSS SECTION H-H'

Cross Section H-H' (Figure 2-11) extends southeast to northwest from the Mojave River west of Barstow, through the Lynx Cat – Iron Mountain gap area

and across the western region of Harper Dry Lake. This cross section was prepared using digital elevation model (DEM) data, depth to bedrock based on gravity geophysical data interpretations, groundwater head interpretations, and correlation between previously prepared cross sections. Depth and thickness of the Black Mountain Basalt (Qb) layer was obtained from deep drill holes identified on Geologic Cross Sections A-A', B-B' and C-C' (Figures 2-5, 2-6 and 2-7). Depth to bedrock was generally assessed by visualizing the Depth to Bedrock contour map (Figure 2-1) sans the Black Mountain Basalt flow by projecting depth to bedrock information onto the profile from areas outside of the basalt flow perimeter. The ground surface elevation at the proposed MSP site is shown at about 2,050 ft amsl and the potentiometric surface, at that location, is shown at about 1,950 ft amsl (depth of 130 ft bgs).

A basalt layer is shown beneath Harper Dry Lake with variable elevation and it transects the Regional Aquifer (Qal). Elevations for the top of the basalt layer range from 1,425 to 1,700 ft amsl. The variable elevation shown may be an artifact of the ground surface at the time this basalt flowed, but deformation from movement on an unmapped faults is also possible. In the vicinity of the proposed MSP site, the top of the basalt is approximately 500 ft bgs. Available subsurface information is limited and indicates thickness of the basalt layer varies from 75 to about 200 ft.

The Regional Aquifer is subdivided into the uQal and the lQal in limited areas where subsurface basalt flows are present. Relevant alluvium horizons are labeled using the uQal and lQal nomenclature. Primary hydraulic conductivity of basalt is low and it is considered an aquiclude. Potential exists for leakage through basalt where it is faulted and fractured. Fractures within this subsurface basalt layer are generally undocumented. Based on available information from deep drill holes and geophysical survey data, the conceptual basalt perimeter is shown on Figure 2-3. In the Harper Dry Lake area, occasional drill holes reached the top of the basalt, but the basalt thickness was not often documented.

The depth to bedrock is variable. A bedrock elevation high within the Lynx Cat – Iron Mountain gap near Highway 58 is shown on Figure 2-13, Depth to Bedrock Lynx Cat – Iron Mountain Gap Area (an interpretation of gravity data). If non permeable and free of fractures, bedrock extending to the ground surface may restrict or block underflow between the adjacent Middle Mojave River Groundwater Basin and the HVB. Faults shown on the cross section may have

fractured the bedrock causing a possible conduit for underflow. Access to existing lithologic data, acquisition of new lithologic information, and the reprocessing of historical gravity data will help to better understand subsurface characteristics and potential for underflow through the Lynx Cat – Iron Mountain gap.

4.5.10 IDEALIZED CROSS SECTION R-R'

Idealized Geologic Cross Section R-R' (Figure 2-14) extends southwest from the proposed MSP in a direction northeast, across Harper Dry Lake, toward Black Mountain. This idealized schematic features significant subsurface geologic contacts and relevant structures. Relatively shallow Tertiary-age sedimentary rocks above the basement complex consist of sandstone and shale beds with some intrusive basalt flows present. These sedimentary rock layers are not present in the proposed MSP area, but generally are located north of Harper Dry Lake. Depth and thickness of the Black Mountain Basalt (Qb) layer was obtained from deep drill holes identified on Geologic Cross Sections A-A', B-B' and C-C' (Figures 2-5, 2-6 and 2-7). Depth to bedrock was generally assessed by visualizing the Depth to Bedrock contour map (Figure 2-1) sans the Black Mountain Basalt flow by projecting depth to bedrock information onto the profile from areas outside of the basalt flow perimeter. Note that gravity interpretation techniques used to create Figure 2-1 did not differentiate between basalt flows and bedrock. Depth to groundwater near the proposed MSP is about 125 to 145 ft bgs.

4.5.11 BLACK MOUNTAIN BASALT DISCUSSION

In the vicinity of Harper Dry Lake and beneath the proposed MSP, the Black Mountain Basalt, is present within the playa / lacustrine deposits and the fluvial deposits from the ancestral Mojave River. In other areas, the basalt may rest directly on Tertiary sandstone or pre-Tertiary bedrock units. The Black Mountain Basalt has yielded dates of 2.55±0.58 Ma (Burke et al., 1982) and 3.77±0.11 Ma (Oskin and Iriondo, 2004), making its age early Pleistocene. Depth to the top of the basalt is variable. The Black Mountain fault displaces the Black Mountain Basalt. The Black Mountain Fault is part of the Harper Fault Zone. This zone is mapped and labeled on Figure 1-6, General Geology. Beneath the proposed MSP, the expected depth to it is about 500 ft bgs. The lateral extent of the basalt

layer is unknown; however, gravity and magnetotellurics investigations (see Figure 6-1 and Appendix G, Geophysical Investigations) improved our understanding of this unit. No deep drill holes, available geophysical survey data, or geologic cross sections positioned within the expected basalt perimeter explicitly reveal gaps within the basalt; however, it may not be continuous. This uncertainty is due to scarcity and uneven distribution of subsurface data. Where it is present, thickness of the subsurface basalt layer ranges from about 75 to 200 feet. Figure 2-3 shows the conceptual perimeter of the subsurface basalt layer. This map was based on interpretation of information from the following sources:

- Figure 2-1, Depth to Bedrock (based on historical gravity data).
- Figures 2-5, 2-6, 2-7 and 2-12, Geologic Cross Sections.
- Data from relevant driller's logs; specifically 11N04W29G02S, 11N04W29P02S, 11N04W32D02S, 11N04W10F02S, 11N04W30F01S, 11N04W18R01S, and 11N04W19J01aS.
- Processed data acquired from gravity and magnetotellurics investigations.

The basalt and the clay to which it weathers function as an aquitard. Where present, the basalt layer subdivides the Qal aquifer into the uQal and lQal. Most of the Domain is free of basalt.

4.5.12 STRUCTURE

The HVB itself is a significant structure and basin geometry controls groundwater flow. As an example, the HVB perimeter coincides with a groundwater divide caused by bedrock structure consistent with a conventional basin shape.

Three major northwest trending fault zones positioned within the HVB include the Blackwater-Mud Hills Fault Zone, the Harper Fault Zone, and the Lockhart Fault Zone. These faults control the surface exposures of the bedrock materials adjacent to the basin and contributed to the formation of Harper Dry Lake. They may restrict groundwater flow and create subsurface compartments with isolated or different hydraulic qualities than do adjacent areas. Major and minor fault zones within the HVB are described below. Figure 1-6 shows approximate fault zone locations.

LGS performed gravity and magnetotellurics surveys to delineate variations in density and electrical resistivity which may be indicative of structural changes in the bedrock underlying the HVB. Refer to Appendix G, Geophysical Investigations. Based upon these geophysical investigations, LGS concluded the following:

- The deepest part of the basin is north of the present Harper Lake playa. The location of Harper Lake does not appear to be controlled by deeper bedrock structure.
- Southeast of Harper Lake, Profile 2 indicates an abrupt vertical displacement of the top of the bedrock and termination of the basalt, suggesting the presence of a fault. Bedrock south of the purported fault is near the ground surface.
- Profile 1 (transecting Harper Dry Lake) included a significant east-west portion, perpendicular to the remainder of the profile. A bedrock ridge oriented sub-parallel to this portion of the profile and likely related to the vertical displacement of bedrock discussed for Profile 2 is the best interpretation of these data.

4.5.13 HARPER FAULT ZONE

The Harper fault zone is a zone of short, primarily right-lateral strike-slip faults, including, from northwest to southeast, the Cuddeback fault, Gravel Hills fault, Harper Valley fault, Harper Dry Lake fault, and the Black Mountain fault.

4.5.14 HARPER VALLEY FAULT ZONE

Harper Valley Fault Zone and the **Black Water Fault Zone** are located to the northeast of Harper Dry Lake – The Harper Valley fault, southwest of Black Mountain, is a northwest-striking fault with up-to-the-northeast vertical displacement (Dibblee, 1968). This fault offsets a range of geologic units, from Pliocene basalts to Holocene alluvium. Drainages show evidence of gradient changes where they cross the fault. No strike-slip sense of displacement was noted. The Harper Valley fault zone is located principally within the bedrock units of the valley and does not appear to influence groundwater flow in the site area. The Blackwater fault zone is also located too far from Harper Dry Lake to influence local groundwater flow (The Mark Group, April 1989).

4.5.15 HARPER DRY LAKE FAULT

The Harper Dry Lake fault is likely the continuation of the Black Mountain fault (Bryant, 1987). South of Black Mountain, several faults form a broad zone within which Pleistocene deposits are cut and early Holocene deposits are folded.

4.5.16 BLACK MOUNTAIN FAULT

The Black Mountain fault is an approximately 30-km-long northwest-trending zone of high-angle faults, with a right-lateral strike-slip component, mapped by Dibblee (1968). Dibblee (1968) estimated about 0.8-km of right-lateral offset based on displacement of the Black Mountain anticline and as much as 600 m of down-to-the-southwest vertical displacement. The Black Mountain fault displaces the Black Mountain Basalt, which has yielded dates of 2.55±0.58 Ma (Burke et al., 1982) and 3.77±0.11 Ma (Oskin and Iriondo, 2004). This fault contains little evidence of late Pleistocene activity; Bryant (1987) reported that an old, presumably late Pleistocene shoreline of Harper Dry Lake is not offset by the Black Mountain fault. The Black Mountain fault cuts Qoa and Qia deposits but does not appear to cut Holocene deposits.

4.5.17 LOCKHART FAULT ZONE

The Lockhart fault zone consists of the sub-parallel Lockhart, South Lockhart, and North Lockhart faults. Although surface traces are discontinuous (Dokka and Travis, 1990), map patterns and seismic evidence suggest that the Lockhart fault is a continuation of the Lenwood fault, and the South Lockhart fault is the northwestern extension of the Helendale fault (Dibblee, 1985; Louie and Qin, 1991; Page and Moyle, 1960; Schell, 1994).

4.5.18 LOCKHART FAULT

The Lockhart Fault is located about three miles south of the FPLE SEGS VIII and IX. This 40-km-long right-lateral strike-slip Lockhart fault extends from just west of Barstow to the southern flank of the Rand Mountains. The fault trace is not exposed and is difficult to recognize on the ground, but it appears prominently on aerial photographs as a straight line running N50ºW. Dibblee (1968) stated that the fault is right-lateral strike-slip but the amount of displacement is not known (Dokka and Travis, 1990). The fault has a component of down to the northeast

that is most apparent east of Highway 395. Northwest of Highway 395, the fault trace is manifested as a dissected scarp or is aligned with a broad erosional trough (Bryant, 1987). The fault displaces Quaternary alluvium and places Holocene against late Pleistocene deposits east of Highway 395 (Bryant, 1987). The creation of a small mid-to late Holocene playa due to an approximate 30 cm of uplift that dammed a small drainage is additional evidence that this fault was active during Holocene. The Lockhart Fault has been active in very late Quaternary because it breaks the older alluvium, which suggests that the aquifer in Harper Valley has been displaced by the fault, thus altering its water-bearing characteristics.

The Lockhart fault splays immediately west of Highway 395 and creates a small playa near the splay termination. The main fault shows a farther northwest trend, becomes discontinuous, and terminates in a broad splay of faults and lineaments near the Rand Mountains. During a paleoseismic trenching investigation, Schell (1994) observed that some north and north-northwest trending lineaments mapped on the Rand Mountains pediment appeared to be faults exhibiting evidence of Holocene rupture. The north-striking faults and small grabens in the western part of the Rand pediment may also be related to the Lockhart fault zone or may be the result of interaction between the Lockhart fault and normal faults that bound the northern part of the Rand Mountains.

4.5.19 SOUTH AND NORTH LOCKHART FAULT

The South Lockhart fault lies 2 to 3 miles southwest of the Lockhart fault. It is a 27-km-long fault striking north to northwest. Northwest of the lake, it approaches and probably joins the Lockhart fault. To the southeast, it diverges from it and dies out in older alluvium. The fault is within the older alluvium, and its position is marked by the surface expression of weak scarps that show on aerial photographs. The fault trace is discontinuous, and the vertical displacement sense varies from down to the south to down to the north. QToa gravel deposits, located 11 km northwest of the Boron Air Force Station, are found on either side of the fault. These deposits appear to have been offset by a minimum of 1 km since QToa time. There is no evidence of displaced streams along the South Lockhart fault.

North Lockhart fault – the 6-km-long North Lockhart fault was classified as right-lateral strike-slip by Dibblee (1968). This fault shows down-to-the-north vertical

displacement near its southeastern end. The fault offsets mid- to late-Pleistocene alluvium and places mid-Pleistocene against Holocene alluvium at the southeastern end of the fault.

4.6 HYDROGEOLOGY

Water needed for the proposed MSP will be extracted from the HVB or, more specifically, the uQal Aquifer of the Domain. The CA DWR defines the HVB as positioned within the Harper Hydrologic Subunit.

Groundwater hydraulic information for the HVB has been obtained from readily available literature sources, existing and historical water wells, historical gas exploratory wells, available geophysical surveys, historical and newly prepared geologic cross sections, and quantitative hydraulic values derived from historical and newly performed aquifer pumping tests. Hydrogeological information of interest includes groundwater elevations, groundwater flow patterns, recharge, sinks, aquifer thickness, identification of aquitards, T, and S.

4.6.1 GROUNDWATER ELEVATIONS

Water levels within the HVB vary from about ground surface near Harper Dry Lake (perched water) to nearly 300 ft bgs, 10 miles west of the proposed MSP near Kramer Junction.

Comparisons of groundwater elevations between wells are useful because flow is from areas of high groundwater elevation to areas of low groundwater elevation. Groundwater elevations representing the potentiometric surface vary from a high of approximately 2,500 ft amsl in the northwest for well 31S/42E-23L1 to approximately 1,850 ft amsl for well 11S/5W-24N2 at Harper Dry Lake. Three historical domain-scale potentiometric surface maps based on depth-to-water data collected in 1958, 1998, and 2004 are included as Figures 1-7 through 1-9. Additionally, a potentiometric surface map localized to the proposed MSP area and based on depth-to-water data collected in June 2008 is included as Figure 1-11. These potentiometric surface maps show that groundwater levels are consistently lowest at Harper Dry Lake, which allows for groundwater to move from the perimeters of the basin to the dry lake area in a manner similar to a drain.

Figure 1-7 based on 1930 data shows the earliest potentiometric surface available and represents, as close as possible, predevelopment conditions.

Selected portions of the potentiometric surface maps are labeled to show hydraulic gradient. From historical records, agricultural-related water pumping in the Harper Dry Lake area was near a maximum in 1958. Figure 1-8, based on 1958 data, shows the hydraulic gradient ranging from 0.003 to 0.008. Distortions in the potentiometric lines indicate possible recharge from the Mojave River in the area between Lynx Cat and Iron Mountain. However, depth to bedrock maps based on historical gravity geophysics data show the Lynx Cat Mountain – Iron Mountain gap as being an unlikely groundwater pathway due to depth to bedrock mapped at the ground surface (see Figure 2-1, 2-12, and Figure 2-13).

Figure 1-9, based on 1998 data, shows the hydraulic gradient from 0.013 to 0.003. No known sources of recharge account for the relatively steep hydraulic gradient of 1.3 percent shown northeast of Kramer Hills. Subsurface data in this area of the Domain is mostly unavailable. This elevated hydraulic gradient may be due to thinning of the aquifer (see Figure 2-1), undocumented grain size distribution change effecting hydraulic conductivity, or hydraulic effects due to faults (see Figure 1-6). Distortions to the potentiometric lines indicate possible recharge from the Mojave River in the area between Lynx Cat and Iron Mountain and also through the Hinkley Gap.

Figure 1-10, based on 2004 data, shows the hydraulic gradient to range from 0.01 to 0.008. Again the hydraulic gradient northeast of Kramer Hills is anomalously high at one percent. Distortions in the potential lines indicate possible recharge from the Mojave River in the area between Lynx Cat and Iron Mountain and also through the Hinkley Gap.

Figure 1-11, based on June 2008 data from 14 wells, shows the hydraulic gradient to range from 0.02 to 0.001. Known faults are shown. Distortions to the potentiometric surface are apparent due to the pumping of production water at FPLE wells located near the Myrob well and Well J. Additional distortion is caused by irrigation pumping at the Ryken well.

Shallow borings completed by Applied Geotechnical Engineering, Inc. (1987) to support construction of SEGS VIII, located west of Harper Dry Lake, now operated by FPLE indicated the presence of near-surface, perched groundwater. The potentiometric surface of SEGS VIII-area perched water from this late 1980s

period showed flow toward Harper Dry Lake. Groundwater flow direction from nearby irrigated farmland toward Harper Dry Lake indicates applied irrigation water was, and is, the source of perched water present beneath the FPLE SEGS VIII and IX and the proposed MSP.

Hydrographs provided by the USGS National Water Information System are presented adjacent to well locations shown on a aerial photograph base; see Figures 1-14 (Harper Lake Area Hydrographs), 1-15 (Hinkley Area Hydrographs), and 1-16 (Iron Mountain to Hinkley Area Hydrographs). These hydrographs show both groundwater level and groundwater elevation information for different ranges of time. Some data was collected as early as 1946. Many of the hydrographs appear to show influence from pumping concurrent or close in time to specific water level measurements.

In general, based on a variety of source data, it appears that groundwater levels within former agriculture areas within the Harper Dry Lake area are currently recovering from historical pumping to supply irrigation demand.

4.6.2 GROUNDWATER OCCURRENCE AND FLOW

Within the MRB, the HVB, and the Domain, two aquifers are recognized by the USGS and by the MWA; commonly identified as the Floodplain and Regional Aquifers. These aquifers are hydraulically connected. Since the Mojave River is a loosing stream, underflow is from the Floodplain Aquifer to the Regional Aquifer. As discussed previously, T is significantly larger within the Floodplain Aquifer as compared to the Regional Aquifer. Nonetheless, relatively large yields have been documented from water wells (≥ 1,000 gpm) completed within the Regional Aquifer near Harper Dry Lake. The proposed MSP construction area involves the Regional Aquifer.

The occurrence of groundwater within the Regional Aquifer is subdivided into the uQal and the lQal in limited areas where subsurface basalt flows are present. In areas where the basalt layer is not present, it is identified as the Qal aquifer. Primary hydraulic conductivity of basalt is low and is considered an aquiclude. Potential exists for leakage through basalt layers where it is faulted and fractured. Fractures within subsurface basalt layers are generally undocumented. Additionally, the perimeter of subsurface basalt flows is generally unmapped. In

the Harper Dry Lake area, occasional drill holes reached the top of the basalt; less often was the basalt layer thickness documented.

In the vicinity of the proposed MSP, the potentiometric surface for the uQal Aquifer is about 1,904 ft amsl (see Figure 1-11) and depth to groundwater about 143 ft bgs. Thickness of the uQal aquifer beneath the proposed MSP is about 300 to 400 ft. The potentiometric surface of the lQal aquifer is undocumented because of the lack of wells completed within the lQal. Thickness of the lQal is also undocumented. Groundwater flows from the Domain perimeter toward Harper Dry Lake, and flow rates vary as a function of time and position within the Domain.

Perched groundwater was documented west of Harper Dry Lake (The Mark Group, April 7, 1987). Depth to groundwater within shallow geotechnical soil borings was recorded as 9 to 26 ft bgs. Elevations showed groundwater flow toward the Harper Dry Lake wetlands from these soil-boring locations. The 1987 report concluded that applied irrigation water was the source of the observed perched water. Perched groundwater within the Harper Dry Lake area is not considered a significant influence to groundwater flow within the Domain. However it could influence uQal water quality if the perched water leaked downward through access provided by improperly abandoned wells.

Outcrops of igneous, metamorphic and sedimentary rock within the Domain (see Figure 1-6) are areas of no flow. Hydraulic conductivity within these rock ridges and hills is low, and they are considered an aquiclude.

The basement rock (Figure 2-1) is a no-flow boundary. Hydraulic conductivity within the basement rock is low and is considered an aquiclude.

Faults within the Domain (Figure 1-6) can affect groundwater flow. These faults control the surface exposures of the bedrock materials adjacent to the basin and contributed to the formation of Harper Dry Lake. They may restrict groundwater flow and create subsurface compartments with hydraulic qualities isolated or different from those of adjacent areas. Generally, quantitative hydraulic conductivity data within fault zones is unavailable.

According to one investigation, evaporation is considered negligible within the HVB. Evaporation can occur with water ponds on dry lake surfaces or through bare-soil evaporation (Stamos et. al. 2001). Depth to non-perched groundwater beneath Lake Harper is estimated at about 125 ft bgs. Moisture present within

sediment beneath the playa surface likely derives from infrequent precipitation events rather than a hypothetical 125-ft-thick capillary fringe. A dry, white-colored, mineral crust covers the Harper Dry Lake playa, thus decreasing evaporation of moisture within near-surface lacustrine sediment. This mineral crust dissolves during precipitation events and reforms as the temporary playa surface water rapidly evaporates.

4.6.3 RECHARGE TO THE DOMAIN

Within the MRB, the HVB, and the Domain, recharge to alluvial aquifers occurs by the following sources:

- Storm runoff from the highlands that enters ephemeral streams with eventual percolation to the underlying aquifer;
- Precipitation falling on the basin floor;
- Precipitation falling on the surrounding mountain areas that percolates into bedrock with eventual flow into the basin;
- Underflow from groundwater basins adjacent to the HVB.

Over the long term, recharge to alluvial aquifers due to precipitation within the HVB is approximately equal to precipitation source recharge to the Domain. Percolation of rainwater into the 100,800 acres of hills surrounding the HVB with eventual flow into the basin is about 300 AFY (The Mark Group, April 7, 1987). Stable isotope tests show that recharge in desert environments varies from 0.34 to 0.51 percent of precipitation (Stone, 1986). Rainwater falling onto the 297,200-acre HVB floor and providing aquifer recharge is estimated at 420 AFY. Precipitation falling on the surrounding mountain areas that percolates into bedrock with eventual flow into the basin is estimated by the CA DWR as 550 AFY or about 1 percent of annual precipitation falling on those highland areas (CA DWR, 1967).

Additionally, the CA DWR states, based on a MWA report (MWA 1999) that for 1997-98 water year, HVB replenishment included an estimated 487 AFY from the spreading of treated wastewater and 1,383 AFY from spreading of imported water (CA DWR 2003).

Underflow estimates into the HVB were summarized in Table 8 of the CSU and MWA Document (September 2007) and included the following: 1,000 AFY

(DWR, 1967), 22 AFY (MWA, 1983); 2,700 AFY (The Mark Group, 1989); 3,071 AFY (Stamos, et al, USGS 2001); and 1,468 AFY (AST, 2007) and 1,100 AFY (CSU and MWA, 2007). Most of these estimates specify the underflow location as the Red Hill gap (aka the Hinkley Gap) or the area surrounding Red Hill. Total underflow listed on Tables 4-3a and 4-3b, BCM Report section 4.9.3 is 2,100 AFY. The underflow recharge estimate is the average of four estimates of underflow through the gap on the west side of Red Hill (aka Hinkley Gap) (CSU/MWA, 2007). The 1967 CA DWR underflow estimate was omitted since the underflow location was not specified. The 1983 MWA underflow estimate was omitted since it was superseded by the 2007 CSU and MWA underflow estimate. Underflow from the Middle Mojave River Valley Groundwater Basin through the Hinkley gap is facilitated by the presence of 150- to 200-ft-thick permeable ancestral Mojave River sediment within the HVB perimeter.

The sum of underflow through Hinkley gap and Lynx Cat - Iron Mountain gap was estimated by Ebbs (2007) as 2,100 AFY, with 1,100 AFY flowing through the Red Hill (Hinkley) gap and 1,100 AFY flowing through the Lynx Cat Mountain – Iron Mountain gap (Figure 2-13). However, LGS has been unable to identify a hydraulic connection between the Mojave River channel and the HVB through the Lynx Cat – Iron Mountain gap. Refer to Depth to Bedrock (Figure 2-1); Geologic Cross Section H-H' (Figure 2-12); and Depth to Bedrock, Lynx Cat – Iron Mountain gap area (Figure 2-13).

Additionally, V. Ebbs describes production data compiled by the MWA Watermaster indicating that an average of 4,000 AFY of groundwater within the HVB is used for irrigation (MWA Watermaster, 2007). Return flow -- water not consumed during the process of irrigation -- could account for up to 50 percent reentering the alluvial aquifers. A 50-percent return flow would contribute 2,000 AFY as recharge (Ebbs 2007).

Using selected cross section schematics that show depth to bedrock across the HVB perimeter (refer to Figure 2-1) along with information from previous investigation, LGS has evaluated the potential for underflow to the HVB through the Lynx Cat – Iron Mountain gap, along other portions of the Middle Mojave River Valley Groundwater Basin, and from other adjacent groundwater basins. In general, the HVB perimeter coincides with a groundwater divide caused by a bedrock structure consistent with basin geometry. Gaps within the perimeter bedrock structure exist, as demonstrated by the results of multiple focused

investigations of the Hinkley Gap area. Hydrogeological investigation of other potential gaps within the HVB perimeter bedrock rim to understand flow from adjacent basins has not been done.

The CA DWR supports conjecture that the HVB receives some groundwater flow from the Cuddeback Valley Groundwater Basin (CA DWR 1975). However, The Mark Group indicates little to no groundwater flows into the HVB from the Cuddeback Basin (The Mark Group, April 1987).

As part of their Superior Valley Groundwater Basin description (Figure 1-5), the CA DWR stated that some groundwater may discharge to the HVB beneath Quaternary basalt flows along the southwest margins of the Superior Valley basin (CA DWR 1975). This possible flow has not been quantified. Based on surface observations of this area, LGS agrees that underflow from the Superior Basin to the HVB is possible through unconsolidated sediment in the notch area of Water Valley located northeast of Harper Dry Lake. Water Valley is a perimeter valley draining toward Harper Dry Lake. LGS recommends obtaining subsurface information from this area to assist with determining underflow.

According to CA DWR descriptions of the Antelope Valley Groundwater Basin (Figure 1-5), the Antelope Valley basin is bounded on the east by ridges, buttes, and low hills that form a surface groundwater divide (CA DWR 1975). Underflow from the Antelope Valley into the HVB is judged as unlikely.

Although additional gaps within the perimeter bedrock structure likely exist, information is currently not available to support underflow estimates within HVB perimeter areas other than Hinkley gap.

The following summarizes recharge estimates to HVB alluvial aquifers on the basis of the above sources and from the numerical model water balance (Appendix I):

- 420 AFY Precipitation falling on the basin floor;
- 300 AFY Precipitation falling on the surrounding mountain areas;
- 550 AFY Storm runoff from the highlands that enters ephemeral streams;
- 2,100 AFY Hinkley Gap underflow;
- 3,160 AFY Indeterminate recharge;

- 6,530 AFY Total Recharge

From the numerical groundwater model (Appendix I) water balance, indeterminate recharge is indicated. The model water balance is a result of the model calibration process. This category of recharge likely occurs as underflow through HVB perimeter gaps and it is indeterminate because location of this recharge is unknown.

4.6.4 GROUNDWATER SINKS

Groundwater flows within the HVB, because of gravity, toward Harper Dry Lake (Figures 1-7 through 1-10), which is the basin low for topography and may also be the maximum for depth to bedrock (Figures 1-3, 1-4 and 2-1,). Harper Dry Lake is the single natural groundwater sink within the HVB. According to one investigation, evaporation is considered negligible within the HVB, even though evaporation can occur with water ponds on dry lake surfaces or through bare-soil evaporation (Stamos et. al. 2001).

Groundwater production within the HVB mostly occurs due to pumping near Harper Dry Lake. Primary categories of groundwater production include the FPLE SEGS VIII and IX and the Ryken irrigation well (Desert Valley Dairy).

Since the adjudication, consumption of water within the HVB has dropped by nearly 50 percent (MWA 2007). The MWA Watermaster has tracked and estimated annual water production for the HVB. Verified water production for the water year 2005-06 was 3,429 AFY (MWA 2007).

4.7 AQUIFER PROPERTIES

Aquifer properties relevant to understanding groundwater flow to wells are T, aquifer thickness, and S. T and S values are obtained by processing aquifer pumping test data and when test data is not available, T and S values may be estimated from literature sources. Aquifer thickness is obtained from driller's logs or from surface geophysical data interpretations.

4.7.1 AQUIFER TESTING PROGRAM

This section presents results of the pumping tests conducted at the proposed MSP property between August 14 and August 25, 2008. This aquifer testing

provides hydraulic information needed to evaluate the feasibility of using groundwater pumped from the uQal as the MSP process water source. The primary objective for conducting the pumping test was to obtain T and S values for the pumped aquifer. T and S values are important parameters when evaluating groundwater flow, including how hydraulic drawdown of the potentiometric surface caused by pumping varies with distance from the production well.

The uQal aquifer pumping test involved pumping the Ryken irrigation well located at the Desert View alfalfa field, south of Harper Dry Lake and immediately south of Lockhart Road, east of Harper Dry Lake Road. Three pumping periods were monitored. Pumping period I began on August 14, 2008 (starting clock time of 9:29), at an approximate constant pumping rate of 1,145 gpm for 3,391 minutes (2.4 days). Pumping period I was terminated because of electrical wire failure. Pumping period II began on August 17, 2008 (starting clock time of 9:51), at an approximate constant pumping rate of 1,145 gpm for 1,516 minutes (1.0 days). Pumping period II was terminated by an unknown automatic irrigation pivot timer. Pumping period III began on August 18, 2008 (starting clock time of 14:49), at an approximate constant pumping rate of 1,145 gpm for 9,746 minutes (6.8 days). After continuous pumping for 7 days or about 10,000 minutes (4 logarithmic cycles), the Ryken Well pump was turned off, thereby ending period III. Aquifer recovery data was collected for an additional 1,455 minutes (1.0 days). Discharge water was directed to the nearby circular alfalfa field using the existing discharge piping and irrigation pivot apparatus. The Desert View alfalfa field is approximately ¼ section or 160 acres.

The Ryken well constructed in 1967 is 14 inches in diameter and has milled screen slots positioned between 58 and 425 ft bgs. Well construction included a 24-inch-diameter pea-size gravel pack. No electric log of the drill hole was made. The driller's log indicates that the bottom 15 feet of the drill hole is clay rich. LGS interprets the Ryken Well construction details, in the context of available subsurface information, as fully screening the saturated thickness of the uQal. Although the Ryken Well log does not indicate the presence of basalt, it is likely present deeper than drilled, at an expected depth from 430 to 500 ft bgs.

The Ryken Well is outfitted with a vertical turbine pump powered by a 100-horsepower electric motor. There are no discharge flow controls such as gate valves or rheostats; the pump is configured to be on or off. Although the

objective was to keep the discharge rate constant during periods of pumping, fluctuations within a range of one to four percent of nominal flow (i.e., 1,145 gpm) occurred because of discharge height change caused by a minor tilt, toward the northeast, of the alfalfa field. Because of an excessive radius in the water-level access tube, a pressure transducer could not be installed. Water levels within the Ryken Well were monitored manually by use of an airline installed to a depth of 193.4 ft bgs. Maximum drawdown observed in the Ryken well during pumping was 37.06 feet.

During the pumping test, water level measurements were obtained from three observation wells and from the pumped well (see Figure 1-12, Aquifer Pumping Test Wells). The closest observation well relative to the pumped well (i.e., the Ryken Well) is the Hay Farm Well; the distance is about 759 ft.

Topography in the MSP area is relatively flat. The nearest surface water-like feature to the pumped well is Harper Dry Lake at about 3,700 feet (0.7 mile). The minimum distance between the pumped well and the irrigated alfalfa field is 330 ft.

Based on the driller's log of the Ryken Well, the upper 172 feet of sediments beneath the project area seems to be unconsolidated fine sand and clay, likely deposited in a pluvial/lucustrine environment related to the historical stages of Harper Dry Lake. Stratification allowing confined aquifer conditions is especially likely within this horizon. At 172 to 410 ft bgs, the sediments are mostly unconsolidated sand and gravel showing characteristics or influence from a fluvial depositional environment. Immediately before the pumping test, the static water level in the Ryken Well was approximately 143 ft bgs. Subtracting out the 15 ft of clay logged at the bottom and assuming that subsurface basalt mapping of the project area is valid (i.e., basalt layer estimated at between 430 and 500 ft bgs at the Ryken Well), the saturated thickness of the uQal is about 267 feet. LGS's interpretation of limited subsurface information indicates the uQal is hydraulically separated from the lQal by an approximate 75-ft-thick basalt layer (Pleistocene). Figure 1-11 shows groundwater flow within the uQal to the northeast, toward Harper Dry Lake. The horizontal gradient is about 0.0014. Figure 1-11 shows the Hay Farm Well located about 2,375 ft southwest of Harper Dry Lake with a potentiometric surface of 1,900 ft amsl. The dry lake surface elevation is about 2,025 ft amsl. With use of a horizontal gradient of 0.0014, the estimated potentiometric surface beneath Harper Dry Lake, nearest the Hay

Farm well, is projected at about 1,897 ft amsl or about 128 ft below the dry lake surface.

Drawdown was measured during the pumping periods and during the recovery periods after the pump was turned off. Drawdown within the pumped well was measured manually by use of an airline and recorded at the time indicated on the Aquifer Test Data Forms (see Appendix G). Additionally, water levels or drawdown were measured manually in two observation wells (Green House Well and Wetlands Supply Well) by use of a water level meter and recorded at the time indicated on the Aquifer Test Data Forms (Appendix G). Water levels or drawdown values were recorded automatically by use of a Solinst pressure transducer positioned down-well within the Hay Farm observation well. Unprocessed pumping test data is included in Appendix G.

Before and during the pumping tests, hydraulic head data were recorded within six wells by use of pressure transducers. These wells are shown in Figure 1-11 and 1-12 and are identified as the Hay Farm Well, the Myrob Well, Well J, Well M, Uli A/Uli B wells (associated with the dormant concrete batch plant, Hinkley Lake Rd). Well J is located about 300 ft south of a water production well operated by FPLE. Well M is located about 0.7 mile southeast of the same referenced FPLE production well. The Myrob Well is located about 350 feet northwest of another FPLE production well. The Uli wells are about 1.5 miles from the Ryken Well. Several graphs based on transducer data compensated for barometric pressure change are included in Appendix B. These graphs show the magnitude of hydraulic interference from FPLE production wells, pre-pumping test conditions, and hydraulic effects from pumping at the Ryken Well.

Graph 2-4 shows maximum hydraulic interference at Well J of over 6 ft (of hydraulic head) from pumping at the nearby FPLE production well during June 10 through July 1 (prior to the Ryken Well pumping test).

Graph 2-5 shows hydraulic head change within Well J before and during the Ryken Well pumping test between July 28 and August 19. Maximum hydraulic head change shown at Well J for this period is about 0.3 ft. The nearby FPLE production well is likely not being pumped during this time. The hydraulic interference shown is likely due to more distant FPLE production wells turning on and off. Patterns of hydraulic interference related to Ryken Well pumping periods (labeled on the graph) are not apparent.

Graph 2-6 shows hydraulic head change within Well J during and after the Ryken Well pumping period (labeled on the graph) from August 19 to August 29. Maximum hydraulic head change shown at Well J for this period is about 3.7 feet, attributable to the nearby FPLE production well cycling on and off. Note the lack of hydraulic interference caused by pumping at the Ryken Well when the nearby FPLE production well is off (i.e., when the hydraulic head is greater than 44 feet).

Graph 2-7 shows maximum hydraulic head change at Well M of about one foot from pumping at the FPLE production well near Well J during June 10 to July 1 (prior to the Ryken Well pumping test). Although the magnitude of hydraulic interference from the FPLE production well pumping at Well M is less than Well J, the same interference pattern is apparent.

Graph 2-8 shows hydraulic head change within Well M before, during and after the Ryken Well pumping periods (labeled on the graph) for July 28 to August 29. Maximum hydraulic head change shown at Well M for this period is about 0.75 ft. Patterns of hydraulic interference related to Ryken well pumping periods (labeled on the graph) are not apparent.

Graph 2-9 shows hydraulic head change within the Myrob Well before, during, and after Ryken Well pumping periods (labeled on the graph) for July 28 to August 29. Maximum hydraulic head change shown at the Myrob Well for this time period is about 2.9 ft and is attributable to the nearby FPLE production well cycling on and off. Patterns of hydraulic interference related to Ryken Well pumping periods (labeled on the graph) are not apparent.

Graph 2-10 shows depth to water change (based on manual measurements) within the Green House Well (2,095 ft from the Ryken Well) before and during Ryken Well pumping periods (labeled on the graph) between August 13 and August 20. Maximum hydraulic head change shown at the Green House Well for this period is about 0.7 ft. For the pumping period Aug. 17 to August 18, hydraulic interference to the Green House Well attributable to pumping at the Ryken Well was about 0.55 ft.

Graph 2-11 shows depth to water change (based on manual measurements) within the Ryken Well before the pumping periods (July 8 to August 14). The graph shows pre-test static hydraulic conditions after July 28, when the Ryken Well pump was off. Significant hydraulic interference from distant FPLE production wells to static conditions at the Ryken Well is not apparent.

Graph 2-12 shows depth to water change (based on manual measurements) within the Wetland Supply Well (3,149 ft from the Ryken Well) before and during Ryken Well pumping periods (labeled on the graph) between August 11 and August 25. Maximum hydraulic head change shown at the Wetland Supply Well for this period is about 1.6 ft. For the pumping period Aug. 14 to August 16, hydraulic interference to the Wetlands Supply Well attributable to pumping at the Ryken Well was about 1.1 ft.

Graph 2-13 shows hydraulic head change within the Hay Farm Well before the Ryken Well pumping periods for June 30 to July 1. The graph shows about 1.5 feet of hydraulic interference due to Ryken Well pumping for a portion of June 30.

Graph 2-14 shows hydraulic change within the Hay Farm Well before, during, and after Ryken Well pumping periods (labeled on the graph) for August 7 to August 29. Maximum hydraulic head change shown at the Hay Farm Well for this time period is about 3.35 feet attributable to pumping periods at the Ryken Well. For the pumping period August 18 to August 25, hydraulic interference to the Hay Farm Well attributable to pumping at the Ryken Well was about 2.2 ft.

Three pumping tests were conducted. The pumping periods were as follows: 3,391 minutes for Test 1; 1,516 minutes for Test 2; and 9,746 minutes for Test 3. There are no discharge flow controls such as gate valves or variable frequency controls; the pump is configured to be on or off. Although the objective was to keep the discharge rate constant during periods of pumping, fluctuations within a range of 1 to 4 percent of nominal flow (i.e., 1,143 gpm) occurred due to discharge height change caused by minor tilt, toward the northeast, of the alfalfa field. Flow rate was monitored by use of an existing flow meter located on the irrigation pivot apparatus and a Dynasonics TFXP portable transit flow meter based on ultrasonic technology located on the discharge pipe near the wellhead. Discharge water was directed to the nearby circular alfalfa field with use of the existing discharge piping and irrigation pivot apparatus. The Desert View alfalfa field is approximately ¼ section or 160 acres.

During the pumping test periods, no precipitation occurred within the pumping test project area or within the domain.

Although driller's logs of Harper Dry Lake area wells do not provide the detail needed to identify stratification commonly associated with lake environments, groundwater within the uppermost uQal and beneath the MSP area is likely

confined by clay layers formed during quiet water periods associated with ancestral Harper Dry Lake. Review of the pumping test data indicates that Test 1 provided the most useful data plots from the nearest observation well (Hay Farm well), primarily due to a stable static water level at the beginning of the test. For this test, 3,391 minutes of pumping was sufficient to obtain a steady slope at the nearest observation well (Hay Farm well).

Review of pretest measurements (refer to Graphs 2-10 through 2-13) for wells Ryken, Green House, Hay Farm, and Wetlands Supply indicate relatively stable static water levels. No hydraulic interference from pumping at nearby residential wells or FPLE production wells is indicated.

Water level measurements (see Graphs 2-10 and 2-12) for the Green House well (about 2,030 ft northwest of the Ryken pumping well) and Wetlands Supply well (about 3,226 ft east of the Ryken pumping well) showed relatively minor hydraulic influence from pumping at the Ryken well during the pumping period. Observed drawdown at these two distant observation wells provide an empirical comparison when evaluating distance-drawdown relations, including those based on analytical methods.

To derive T and S values from the pumping test data, water level data obtained during pumping and recovery were down-loaded from the transducer into a computer. Alternatively, manual measurements were entered into the computer by keyboard entry. Water level or head data must be converted into units of drawdown by subtracting the static water level from each water-level reading recorded.

Corrections to the drawdown data due to excessive partial penetration effects or excessive unconfined aquifer-thickness dewatering decrease during pumping were unnecessary.

The computer software AQTESOLV© version 4.50.002, Professional (Duffield, 1996-2007) was used to analyze the pumping test data obtained from both the pressure transducer and from manual measurements.

The analytical methods used in AQTESOLV to derive T and S values from unconfined pumping test data include the curve matching method developed by C.V. Theis (1935); the “straight line” solution developed by Cooper-Jacob (1946); a method of unconfined aquifer analysis by S.P. Neuman (1975); the Moench

solution (1997) and the Tartakovsky-Neuman solution (2007). Each of these methods is based on several assumptions. Although not important issues with this pumping test, the Neuman, Tartakovsky-Neuman, and Moench solutions can account for delayed gravity response and partial penetration hydraulic effects.

The Theis and Cooper-Jacob solutions were developed for confined aquifers. Additionally, AQTESOLV includes Jacob's correction for excessive unconfined aquifer-thickness dewatering decrease during pumping, thus allowing use of the Theis and Cooper-Jacob solutions when pumping unconfined aquifers.

Significant assumptions (Kruseman and Ridder, 1970) required for the use of these methods (i.e., in addition to the specified confined or unconfined aquifer conditions) include the following:

- The aquifer has seemingly infinite areal extent;
- The aquifer is homogenous and of uniform thickness over the area influenced by the test;
- Prior to pumping, the water table is horizontal over the area that will be influenced by the test;
- The aquifer is pumped at a constant discharge rate;
- The well penetrates the entire aquifer and thus receives water from the entire saturated thickness of the aquifer.

The site conditions and construction of the Ryken well appear to meet these assumptions in general, although evaluating aquifer homogeneity on the basis of driller's logs is difficult when rotary drilling methods are used. One or more of the available solutions are expected to conform to site hydraulic conditions because of method assumption sensitivity. Therefore, to assist with interpretation, we conducted a comparison of T and S values derived from different evaluation methods.

To derive T and S values from the drawdown (pumping or recovery) data, AQTESOLV involves a nonlinear least-squares parameter estimation algorithm for internal analysis of the data. The AQTESOLV software package also allows for visual curve matching to "reposition" the various type curves or slope (i.e., Cooper-Jacob straight line) to better fit the data. The program then plots the drawdown versus time data on a semi-logarithmic graph (Cooper-Jacob,

Neuman, and Tartakovsky-Neuman solutions) or a full-logarithmic graph (Theis and Moench solutions; (see graphs 2-15 through 2-19). These five solution methods were applied to pumping test data recorded from the nearest observation well (Hay Farm well). Calculation of T values involving the five solution methods ranged from about 199,000 gallons per day per foot (gpd/ft) to about 225,000 gpd/ft, which is generally consistent with T values expected for the uQal sediments and their thickness. Calculation of S values with the five solution methods ranged from 0.1 to 0.3 percent. These S values are too small for unconfined, water-table conditions and therefore are indicative of confined conditions. In an unconfined aquifer, S values generally range from 1 to 30 percent. The CA DWR has estimated an S value of 0.12 for the HVB alluvial sediment (CA DWR 1979). LGS expects stratified lucustrine sediments within the ancestral Harper Dry Lake footprint to demonstrate smaller S values consistent with confined aquifer conditions. Consistent with Graph 2-16 (Cooper-Jacob solution), LGS recommends use of an S value of 0.003 for uQal aquifer areas present within the ancestral Harper Dry Lake footprint. Dibblee recorded historic shorelines of Harper Dry Lake at 2,160 ft amsl (Reynolds and Reynolds, 1994). In aquifer areas outside of the ancestral Harper Dry Lake footprint, LGS recommends use of an S value of 0.12, unless subsurface data or depositional environment interpretations indicate otherwise.

The most distant wells (Green House and Wetlands Supply) showed relatively minor hydraulic influence from pumping at the Ryken well. This pattern of minor gradual drawdown at these two distant observation wells is helpful when verifying calculations of distance-drawdown relationships.

The five T values derived from the valid data set discussed above (transducer data taken at the Hay Farm observation well, Test 1) were evaluated to obtain the final results of this pumping test. Consistent with Graph 2-16 (Cooper-Jacob solution), LGS recommends use of a T value of 225,000 gpd/ft. Evaluation of the August 2008 uQal aquifer pumping tests beneath the proposed MSP provides a T value of 225,000 gpd/ft and S values of 0.003 (Harper Dry Lake vicinity) and 0.12 (outside ancestral Harper Dry Lake footprint). T and S values of 225,000 gpd/ft and 0.003 for the proposed MSP area are within the expected range for a confined aquifer consisting of unconsolidated sand and gravel with a saturated thickness of 267 ft. Unless subsurface data or depositional

environment interpretations indicate otherwise, LGS recommends application of the T value of 225,000 gpd/ft Domain wide (with exceptions noted below).

Hydraulic conductivity can be calculated by use of the T value and saturated thickness of the aquifer by the following mathematical relation:

$K = T/b$,

where K is the hydraulic conductivity, T is the transmissivity, and b is the saturated thickness of the aquifer (Loman, 1979). A T value of 225,000 gpd/ft and a saturated thickness of 267 ft yields a hydraulic conductivity value of 843 gpd/ft^2 (0.039 cm/sec). This K value is within the expected range for unconsolidated sediments consisting of coarse sand and gravel (Driscoll, 1987).

T and S values are sensitive to changes in the saturated thickness of the aquifer. Pumping at locations other than the Ryken well, where the saturated thickness varies from 267 ft, especially where the basalt layer is missing, will result in changes to the T and S values. Additionally, previous investigation noted that large, historical groundwater pumping rates in the Harper Dry Lake Basin Center region did not reach or effect levels in the Harper Dry Lake Basin Northeast wells. This finding may suggest the presence of a groundwater barrier or an impediment to groundwater flow (impermeable material or hydrogeologic boundary) within this region of the Domain (MWA and CSU Fullerton, 2007).

Aquifer thickness and transmissivity within the Domain change, in part, as a function of depth to bedrock (see Figure 2-1, Depth to Bedrock). LGS recommends application of a hydraulic conductivity value of 843 gpd/ft^2 (0.039 cm/sec) Domain-wide, with the following exceptions:

- Those portions of the Domain where knowledge of the depositional environment and sediment support a different K value;
- Fault zones where knowledge of groundwater flow support a different K value;
- Elevation below 1,100 ft amsl hydraulic conductivity is estimated at 210 gpd/ft^2 (0.00975 cm/sec). Because of compaction and partial cementation, a 75 percent reduction of hydraulic conductivity is estimated within alluvial sediment below an elevation of 1,100 ft amsl.

4.7.2 AQUIFER THICKNESS DISCUSSION

From study of well logs positioned within the Domain, the “bottom” of the uQal aquifer within the MSP area is at a nominal elevation of about 1,600 ft amsl which indicates an average aquifer thickness of about 300 feet.

The uQal and lQal designations are applicable where basalt flows are present and subdivide the Qal aquifer (i.e., the Black Mountain basalt). As Figure 2-3 shows, most of the Domain is free of basalt flows. Figures 1-9 and 2-1 provide the basis for lQal and Qal aquifer thickness evaluation. lQal and Qal aquifer thickness varies throughout the Domain mostly because of variable depth to bedrock.

Additionally, because of increased compaction and theorized cementation, alluvium at depth likely has reduced hydraulic conductivity. HVB and Domain relevant information is not available from readily accessible literature sources to define depth for this expected hydraulic conductivity change. LGS estimates a 75 percent reduction of hydraulic conductivity values below an elevation of 1,100 ft amsl.

Perched and leaking groundwater, potentially present at 5 to 30 ft bgs in areas west to southwest of Harper Dry Lake is judged as insignificant to modeling groundwater flow.

4.8 GROUNDWATER GEOCHEMISTRY

Water quality, especially in the proposed MSP area affects projected groundwater use. The CEC encourages the use of lower quality make-up water for energy facility cooling functions. The chemical character of the groundwater available from wells on or near the site is of marginal quality for domestic and agricultural use. The TDS concentration range MSP area water classifies it as brackish. However, it can be treated by a reverse osmosis system economically enough for it to be feasible for the purposes of the project. Because of the high transmissivity of the uQal aquifer, prolonged extraction for MSP supply water should not cause further increases in total dissolved solids and deterioration in quality by drawing in water of higher salinity from an expanded pumping depression reaching below Harper Dry Lake. Similarly, the proposed pumping of groundwater to supply the MSP is not expected to induce additional migration of Mojave River underflow. About 6,500 to 18,000 AFY of groundwater has been

used for historical agriculture production in the vicinity of the existing FPLE SEGS VIII and IX and the proposed MSP as compared to the 2,163 AFY needed during operation of the MSP. Refer to Section 4.8.1 for additional groundwater quality discussion and an evaluation of groundwater quality stability after 7 days of pumping at the Ryken Well. LGS does not expect groundwater production during construction and operation to significantly impact groundwater quality.

Identifying underflow recharge to the HVB, a basin described as closed because of bedrock structure, is a parameter of interest. To date, contrary to the closed basin description, limited underflow recharge to the HVB from the Middle Mojave River Valley Groundwater Basin has been identified (refer to previous recharge discussion). Hydrogeological investigation of other potential gaps within the HVB perimeter bedrock rim to understand underflow from adjacent basins is lacking and largely unavailable. Geochemical analyses are often used to identify recharge and salinization mechanisms and may assist with prioritizing HVB underflow investigation.

4.8.1 DOMAIN

Concentration of dissolved salts from groundwater in a desert environment is usually higher than typically measured elsewhere. Most of the dissolved salts are composed of minerals in concentrations that are generally not hazardous but create poor taste and residue problems such as pipe scaling and sink staining. From cursory analysis, the irrigation wells in Harper Valley show values ranging from approximately 400 to 5500 mg/L TDS. Shallow perched water within about 20 ft bgs, especially near Harper Dry Lake, is very high in salts because of concentration by irrigation runoff surface evaporation. This horizon with perched groundwater is typically avoided and not screened during well construction but may be a source of poor quality recharge to the water table. Water quality appears to vary with depth in several water quality horizons found beneath the area.

Coincident with an aquifer pumping test at the Ryken Well (Figure 1-12), groundwater samples were collected and analyzed by Test America analytical laboratories for Title 22 parameters, in part, to evaluate potential water quality change due to length of pumping time. Sample S-1 was collected early in the pumping test period on August 14, 2008. Sample S-2 was collected about 1 hour before turning the pump off on August 25. Water pumping during this period was

continuous at an approximate rate of 1,143 gpm. Additionally, groundwater from the Ryken Well was sampled on November 26 and analyzed for supplemental parameters to assist with water treatment equipment design.

Groundwater from the Wetlands Supply well (Figure 1-12) was sampled and analyzed by Test America analytical laboratories for Title 22 parameters and supplemental parameters to assist with water treatment equipment design. This sample was collected on November 5, 2008. Sample collection occurred after pumping for a minimum of 20 minutes at a rate of about 1,150 gpm.

The laboratory reports are included in Appendix E. The entire laboratory data set was organized into tables (see Appendix C). Tests for Silt Density Index and free Chlorine are performed in the field at the wellhead.

Presented below is a summary of concentrations for selected parameters:

Table 4-1 Summary of Water Quality Samples from the Ryken and Wetlands Supply Wells

Parameter	Ryken Well S-1	Ryken Well S-2	Ryken Well S-3	Wetlands Supply Well	Units
Sample Date	8-14-08	8-25-08	11-26-08	11-5-08	
GENERAL:					
Conductivity	2,600	2,400	NA	8200	µmhos/cm
Total Dissolved Solids	1,700	1,500	NA	5500	mg/L
Hardness	320	310	NA	920	mg/L
Color	<1	< 1	< 1	< 1	PCU
Sulfate	330	260	NA	930	mg/L
Ammonium (NH_4)	NA	NA	< 0.6	< 0.6	mg/L
pH	7.35	7.35	7.30	7.27	

Parameter	Ryken Well S-1	Ryken Well S-2	Ryken Well S-3	Wetlands Supply Well	Units
Sample Date	8-14-08	8-25-08	11-26-08	11-5-08	
Field Temperature	24	24	25	23.5	°C
Turbidity	<0.10	<0.10	NA	<0.10	NTU
Silt Density Index (SDI)	NA	NA	-.07/-.03/-.04	NA	
Free Chlorine (Cl_2)	NA	NA	0.05	0.01	mg/L
Total Suspended Solids	NA	NA	< 10	< 10	mg/L
CATIONS/ANIONS:					
Potassium (K)	6.5	8.2	NA	7.9	mg/L
Iron (total)	<0.040	<0.040	NA	0.25	mg/L
Iron (Fe^{+2})	NA	NA	< 0.10	< 0.10	mg/L
Sodium (Na)	400	370	NA	1400	mg/L
Magnesium (Mg)	17	15	NA	59	mg/L
Calcium (Ca)	98	100	NA	270	mg/L
Chloride (Cl)	690	580	NA	2400	mg/L
Nitrate Nitrogen (N)	3.0	1.6	NA	11	mg/L
Phosphate (PO_4)	NA	NA	NA	0.15	mg/L
Bicarbonate(as $CaCO_3$)	140	120	NA	130	mg/L
Fluoride (F)	0.64	0.56	NA	0.98	mg/L
Alkalinity (as $CaCO_3$)	140	120	NA	130	mg/L
Sulfate (SO_4)	350	260	NA	930	mg/L
Silica (SiO_2) (by EPA 6010B)	NA	NA	20	NA	mg/L

Parameter	Ryken Well S-1	Ryken Well S-2	Ryken Well S-3	Wetlands Supply Well	Units
Sample Date	8-14-08	8-25-08	11-26-08	11-5-08	
Silica (SiO_2) (by EPA 200.7)	NA	NA	43	35	mg/L
Chromium VI	<0.0010	0.0047	NA	<0.0010	mg/L
METALS:					
Barium (Ba)	28	34	NA	37	µg/L
Strontium (Sr)	NA	NA	2.5	8.3	µg/L
Lead (Pb)	< 1.0	< 1.0	NA	3.4	µg/L
Arsenic (As)	9.1	9.7	NA	5.5	µg/L
Aluminum (Al)	< 10	< 10	NA	<20	µg/L
Chromium (Cr)	3.4	4.8	NA	<4.0	µg/L
Cadmium (Cd)	< 1.0	< 1.0	NA	<2.0	µg/L
Selenium (Se)	5.3	5.0	NA	13	µg/L
Zinc (Zn)	< 20	< 20	NA	<40	µg/L
Mercury (Hg)	< 0.00020	<0.00020	NA	<0.00020	µg/L
Manganese (Mn)	1.3	< 1.0	NA	2.5	µg/L
Copper (Cu)	7.1	2.2	NA	7.1	µg/L
Silver (Ag)	< 1.0	< 1.0	NA	<2.0	µg/L
Nickel (Ni)	< 2.0	< 2.0	NA	<4.0	µg/L
Uranium (U)	8.0	5.0	NA	15	pCi/L
ORGANICS/ DISSOLVED GASES:					
TOC	NA	NA	0.76	0.47	mg/L

Parameter	Ryken Well S-1	Ryken Well S-2	Ryken Well S-3	Wetlands Supply Well	Units
Sample Date	8-14-08	8-25-08	11-26-08	11-5-08	
BOD5	NA	NA	< 2.0	< 2.0	mg/L
CO_2	NA	NA	3.5	18	mg/L

NA = Not available

Within the HVB groundwater quality is variable. To evaluate variation, relative to location and time, a series of Stiff Diagrams have been prepared on the basis of laboratory data from three water wells. These wells are identified as the Ryken Well, Well East of Harper Dry Lake, and the Hinkley Well. Concentrations of major cations and anions were graphed from water samples collected in 1990, 1992, 2000, 2002, and 2008 (Ryken Well only). Water can be categorized according to their content of major cations and ions. Graphs 2-21 through 2-24 show, on maps, Stiff Diagrams posted adjacent to the sampled well by sample year and easily allow visual evaluation of water quality change. Graphs 2-25 through 2-28 show the same Stiff Diagrams organized by sample well and readily allow visual evaluation of water quality change by year. With regard to these well locations, concentrations of major cations and anions were greatest at the Ryken Well. Of the three wells, the Ryken Well is closest to Harper Dry Lake. A pattern of water quality improvement is indicated at the Hinkley Well and to a lesser degree at the East of Harper Dry Lake Well. Water quality at the Ryken Well appears to be relatively stable over time.

Geochemical analyses are commonly employed to assess recharge and salinization mechanisms. Chloride and sulfate are the primary anions contributing to salinity in HVB waters. For water sampled at the Hinkley and Ryken Wells, the ratio of Cl to SO_4 is about 2:1 with increased anion concentrations. At the East of Harper Dry Lake Well, the ratio of Cl to SO_4 is about 1:1 with decreased anion concentrations. Different ratios of Cl to SO_4 between the Hinkley and Ryken Wells as compared to the East of Harper Dry Lake Well suggest different recharge sources. Significantly decreased anion

concentrations at the East of Harper Dry Lake Well reinforce hypothetical recharge other than through Hinkley Gap. Recharge from adjacent Superior Valley beneath Quaternary basalt flows, as suggested by the CA DWR (CA DWR 1975), is a possibility. Although gypsum deposits often are the source of dissolved sulfate in groundwater, hypothetical gypsum deposit(s) have not been identified within the HVB or Domain. Concentration patterns discussed above are readily apparent on Graph 2-29 (chloride vs. sulfate).

4.8.2 GROUNDWATER QUALITY CHARACTERIZATION

Groundwater quality within the HVB is generally marginal to inferior for irrigation and domestic uses because concentrations of boron, fluoride, and sodium are elevated. General groundwater quality information for the HVB is summarized below (DWR 1964):

- Reports from the west side indicate uneven mixtures of sodium, chloride, bicarbonate, and sulfate, with TDS content as high as 2,390 mg/L; elevated concentrations of fluoride, boron and sulfate have been reported.
- The southern side is calcium-sodium sulfate character with high sulfate, boron, and TDS concentrations.
- The northern side is of sodium sulfate-bicarbonate character with relatively high concentrations of sodium, fluoride, and boron.
- The eastern side (including the proposed MSP) is of a sulfate-chloride character, with chloride ranging from about 500 mg/L to 2400 mg/L and sulfate ranging from 350 mg/L to about 600 mg/L; boron and iron concentrations also tend to be elevated; reports of TDS ranged from about 1600 mg/L to 5500 mg/L.
- Groundwater targeted as the make-up water for cooling electrical generation equipment at the proposed MSP is not potable and would require treatment prior to drinking.

Groundwater targeted as the make-up water for cooling electricity generation equipment at the proposed MSP is not potable and will require treatment prior to its use for cooling and drinking. Water from the eastern side of the HVB including the project area, is of a sulfate-chloride character with chloride concentrations ranging from about 500 mg/L to 2400 mg/L and sulfate

concentrations ranging from 350 mg/L to about 600 mg/L; boron and iron concentrations also tend to be elevated; reported TDS concentrations ranged from about 1600 mg/L to 5500 mg/L. This TDS concentration range places the source water into the brackish category.

Advisory information regarding general groundwater quality for the proposed MSP area is summarized below:

- Groundwater TDS concentrations appear to increase as distance from the well to the present day playa lake shoreline decreases;
- The presence of perched groundwater caused by historical and current agriculture irrigation may be common in the proposed MSP area. Agricultural source perched water often contains elevated TDS concentrations. Improperly designed / constructed wells, both abandoned and active provide a vertical conduit between perched groundwater and the uQal aquifer;
- Proper well design / construction eliminates vertical connections between perched groundwater and the uQal aquifer and thereby reduce the TDS concentration of produced groundwater;
- Destruction procedures are available to eliminate vertical hydraulic connections at abandoned wells and thereby reduce the TDS concentration of produced groundwater.

4.8.3 HINKLEY

Blowdown cooling water from a Pacific Gas & Electric Co. (PG&E) compressor station located at 35863 Fairview Road in Hinkley containing hexavalent chromium as a corrosion inhibitor was discharged to unlined ponds for a 13-year period from 1952 to 1965 (Ecology and the Environment, 1988). This discharge process resulted in release of hexavalent chromium to groundwater in the Hinkley Valley. The Hinkley Valley is a narrow northwest-trending alluvium-filled depression between uplifted ridges of Mesozoic or older igneous intrusive granitic rocks, Tertiary volcanics, and Precambrian sedimentary and metamorphic rocks located north of the Mojave River and west of Barstow, California (Dibblee, 1967). The valley is about 8 miles long and 4 miles wide, on average, and the axis of the valley is relatively flat, with a gentle slope toward the

northwest away from the river. The valley connects in the north to Harper Valley, the center of which is occupied by Harper Dry Lake, through a narrow break in the bedrock hills (MWA, 1983). This narrow break in the bedrock hills is known as the Hinkley Gap.

This historical release created a groundwater plume containing detectable hexavalent chromium concentrations exceeding the California Maximum Contaminant Level for drinking water of 50 µg/L. The affected groundwater extends about 2 miles to the north of the compressor station and is about 1.3 miles wide (CA RWQCB Lahontan Region, 2008). PG&E provides monitoring of groundwater quality across the affected site and off-site areas by use of a comprehensive groundwater monitoring well network on a bi-monthly, quarterly, and semi-annual basis depending on well locations (CA RWQCB Lahontan Region, 2008). Groundwater flow is to the north-northwest in the project area (CA RWQCB Lahontan Region, 2008). The site is subject to various RWQCB orders, including a Cleanup and Abatement Order requiring PG&E to conduct cleanup of chromium in groundwater in a manner that does not threaten to create nuisance conditions (CA RWQCB Lahontan Region, 2008). PG&E proposes to implement various remediation projects to reduce contamination in the groundwater and contain plume migration (CA RWQCB Lahontan Region, 2008).

Extraction and application of affected groundwater to alfalfa fields at a dairy farm near the PG&E compressor station, by use of a subsurface drip irrigation system has been conducted to control plume migration (CA RWQCB Lahontan Region, 2006). Recent monitoring data from the dairy farm shows that migration of the plume in a northerly direction has ceased, and levels of total chromium in groundwater at the treatment site have been reduced to below the drinking water standard. Other monitoring data, however, shows that the plume is now migrating in a northwest direction, outside the capture zone of extraction wells at the dairy farm (CA RWQCB Lahontan Region, 2006).

Historic groundwater flow in the Hinkley Valley was northward from the Mojave River toward Harper Dry Lake, and the depth to groundwater in much of the valley was less than 30 ft (Papadopoulos, 2003). The Mojave River is the main source of recharge to the Hinkley Valley groundwater system, but the river seldom flows (Hardt, 1971). Groundwater flow in the Hinkley Valley has been significantly influenced by groundwater withdrawals for irrigation (Durbin and Hardt, 1974). Irrigation peaked in the mid-1950s when about 278,000 AFY of

groundwater was extracted (Papadopoulos, 2003). Irrigation pumping significantly dewatered the shallow aquifer, and water-level declines from 1930 to 1970 were more than 70 ft in the center of the valley (CA DWR, 1967; MWA, 1983). As a result of over pumping, much of the irrigated lands were abandoned.

The total thickness of alluvial sediments along the axis of the valley is about 300 feet. The alluvium in the valley consists of three distinct lithologic units: a basal unit of alternating layers of coarse sand and silt, a middle unit of lucustrine clay, and an overlying unit consisting of primarily sand and gravel layers that have alternating thin silt and clay layers along the axis of the valley grading to finer-grained deposits along the valley margins. The lacustrine clay, which is about 40 ft thick, on average, in the center of the valley, represents deposits from a late Pleistocene Lake. Along the axis of the valley, the coarse deposits above the clay unit, referred to as the upper aquifer, represent recent alluvial deposits along an abandoned route of the Mojave River, which once flowed northward through the valley. These deposits along the valley axis range in thickness from 120 ft in the southeast to 90 ft in the northwest. The finer-grained deposits along the margin of the valley above the clay unit represent fan and alluvial deposits derived from the bedrock ridges. The thickness and continuity of the lacustrine clay is such that there is little hydraulic communication between the upper and lower aquifer.

LGS interpreted aquifer pumping test data collected from the MSP area near Harper Dry Lake. The distance from the proposed MSP water production wells to the northern, leading edge of the affected groundwater plume in the Hinkley Valley is about 10 miles. This distance is too large for future water production by the proposed MSP to influence affected groundwater in the Hinkley Valley.

4.9 GROUNDWATER USE

Available data indicate sufficient quantity of groundwater in storage exists within the Domain under current conditions to supply the water requirements needed by the proposed MSP for its anticipated 30-year life. Additionally, an evaluation of Domain groundwater inputs and outputs indicates MSP groundwater use will not exceed the water budget. Available aquifer testing data indicate water supply requirements can be met from two pairs of properly constructed wells within the MSP area; see Figure 6-3 for proposed locations.

Historical groundwater use in the Harper Dry Lake area has been for irrigated agriculture, primarily alfalfa and similar forage crops. This water has been withdrawn from the uQal aquifer. Irrigation return water escaping evapotranspiration and percolating to near surface sources, such as shallow perched zones, contribute moisture to the natural consumption required by native plants. Because of the relatively low density of native plants within the desert environment of the Domain, irrigation return water that percolates and recharges the uQal and Qal aquifers is estimated at 50 percent of the water pumped for irrigation.

The MSP through ownership or purchase options has rights to 10,478 AFY of groundwater in the HVB (i.e. Centro Basin). These water rights consist of 9,380 AFY owned by Abengoa Solar, Inc., 224 AFY transferred in December 2008 from Jennie Most, trustee of the Most Family Trust, and an option to purchase 874 AFY from the Desert View Dairy (aka the Ryken Well). Refer to BCM Tables 4-3a and 4-3b, Pre and Post MSP water budgets.

4.9.1 HISTORICAL

Historic water well pumping data could not be obtained from the CA DWR because no records were kept. Historic use can best be estimated by assuming that approximately 5 AF was applied for each agriculture production acre each year (MWA, 1983). According to research (Mark Group Report, April 1989), annual agricultural production in the Harper Valley area has varied from 1,800 acres in 1953 to 2,300 acres in 1955 and 2,500 acres during 1968. Annual production ranged from 2,000 to 2,500 acres from 1968 to 1983. Annual production from 1984 to 1988 was approximately 1,500 acres. On the basis of an average pumping value of 5 acre-ft/acre, about 6,500 to 18,000 AFY of groundwater has been used for historical agriculture production in the vicinity of the existing FPLE SEGS VIII and IX and the proposed MSP. An unknown portion of this water (drain waters) may have recharged the shallow, perched groundwater system near a wetlands area in the southwest part of Harper Dry Lake.

Water level decline due to agricultural pumping from 1953 to 1986 varied from 80 ft at the center of the former Lockhart Ranch to 20 ft in the area of Black's Ranch (The Mark Group, April 1989). The drop in water level of this magnitude without

recovery indicates that groundwater extraction in the Harper Dry Lake area has historically exceeded recharge.

The historic change in water levels show a hydraulic cone of depression centered at the agricultural activities immediately west and south of Harper Dry Lake. The volume of dewatered sediments within this historical cone of depression represented an approximate 94,300 acre-ft depletion of groundwater storage, by use of a storage coefficient of 0.12 (The Mark Group, April 1989).

4.9.2 CURRENT

Known sources of HVB groundwater output are listed below:

- Existing FPLE SEGS VIII and IX production water: 1,109 AFY[1].
- Desert View Dairy alfalfa field (the Ryken Well) off Lockhart Road: 707 AFY[1].
- Residential water use based on a population estimate of 1,915 with a consumption rate of 200 gallons per person per day (CA DWR, 1967) from homes in the Lockhart / Harper Lake community and from Domestic/Residential properties within the City of Hinkley and vicinity based on a population estimate of 1,915 with a consumption rate of 200: about 430 AFY.

The sum of estimated production from sources listed above is 2,246 AFY.

A total of 278 water supply wells shown in Figure 1-2 were field verified by LGS. Wells within the domain were identified from a search of DWR, MWA, and USGS database information. A field survey was conducted to identify their location, assess operational status, and evaluate their use. The field survey consisted of walking or driving county roads and conducting and interviewing property owners as access would allow. Many of the historic wells could not be located. If access or an interview could not be secured, well status was evaluated from the nearest road and/or remote imaging, including by use of GoogleEarth™. Many of these wells are nonfunctional but have not been abandoned or destroyed in accordance with county regulations. In some cases, although the well could be

[1] Highest usage on record in the last 5 years (Mojave Basin Area Watermaster, 2008)

identified, its operational status could not be determined because access to the land was not available.

A San Bernardino County parcels base map dated July 11, 2008, was obtained from the Assessor's office. Water well locations identified from the field survey were linked to property owners by use of the County parcels base map. CA DWR Well Completion Report Request Forms were mailed to 118 property owners. Permission to access Well Completion Reports was granted by current owners for 31 wells or 11 percent. Of these, the CA DWR found 9 Well Completion Reports, or 3 percent of all wells, in their files.

Available information for water supply wells located within ½-mile radius of the MSP is summarized in Table 2 and shown in Figure 4-1. Nearby residential and production wells are shown on Figure 6-2.

Table 4-2 Well Completion Details

Water Supply Wells within a ½ Mile Radius of the MSP Site

State Well Number	Common Name	T. of Well Measuring Pt. Elevation (ft amsl)	Well TD (ft bgs)	Screen Top (ft bgs)	Screen Bottom (ft bgs)	Specific Capacity (gpm/ft)
	Well "J"	2,060	NA	NA	NA	NA
11N04W28E01S	NA	2,030	NA	NA	NA	NA
11N04W28N01S	NA	2,040	350	NA	NA	NA
11N04W28N03S	NA	2,044	NA	NA	NA	NA
11N04W29J02S	NA	2,046	NA	NA	NA	NA
11N04W29N01S	NA	2,061	NA	NA	NA	NA
11N04W29P01S	33544	2,056	410	180	410	36.5
11N04W29Q01S	NA	2,055	NA	NA	NA	NA
11N04W29Q02S	NA	2,046	NA	NA	NA	NA

State Well Number	Common Name	T. of Well Measuring Pt. Elevation (ft amsl)	Well TD (ft bgs)	Screen Top (ft bgs)	Screen Bottom (ft bgs)	Specific Capacity (gpm/ft)
11N04W29R01S	NA	2,045	303	NA	NA	NA
11N04W29R02S	E0001406	2,046	NA	NA	NA	NA
11N04W32A01S	NA	2,044	NA	NA	NA	NA
11N04W32A02S	NA	2,060	NA	NA	NA	NA
11N04W32C02S	NA	2,069	NA	NA	NA	NA
11N04W32C05S	NA	2,069	NA	NA	NA	NA
11N04W32D01S	NA	2,075	500	NA	NA	NA
11N04W32F01S	NA	2,080	225	NA	NA	NA
11N04W32F02S	NA	2,081	NA	NA	NA	NA
11N04W32F03S	NA	2,081	NA	NA	NA	NA
11N04W32F06S	NA	2,081	NA	NA	NA	NA
11N04W32F07S	NA	2,082	NA	NA	NA	NA
11N04W33B01S	37009	2,050	435	154	435	37.6
11N04W33C01S	NA	2,051	NA	NA	NA	NA
11N04W33D01S	NA	2,050	NA	NA	NA	NA
11N04W33F01S	37794	2,055	448	220	445	NA
11N04W33G01S	NA	2,059	310	NA	NA	NA
11N04W33G02S	37799	2,050	460	170	457	25.5
11N04W33G03S	37796	2,050	446	160	425	33.8

Key:

ft amsl – feet above mean sea level

ft bgs – feet below ground surface

gpm/ft – gallons per minute per foot of drawdown

NA – data not provided or available in either the CA DWR or USGS database

4.9.3 WATER BUDGET

HVB groundwater inputs and outputs, calculated by several investigators, were summarized previously in a 2007 document (CSU Fullerton and MWA, 2007). Based on LGS review of available relevant information, the most reliable output data is from the MWA Watermaster (see BCM Report section 4.9.2). From the numerical groundwater model's water balance (Appendix I), recharge of indeterminate origin is indicated. The model's water balance is a result of the model calibration process. This category of recharge likely occurs as underflow through HVB perimeter gaps and it is indeterminate because location of this recharge is unknown. Tables 4-3a and 4-3b show water budget information before and after the MSP start-up.

Table 4-3a Pre MSP Water Budget

HVB Inputs	AFY
Precipitation falling on the basin floor	420 (1)
Precipitation falling on the surrounding highlands	300 (1)
Runoff from the highlands that enters ephemeral streams	550 (1)
Hinkley Gap underflow	2,100 (2)
Recharge of indeterminate origin	3,160 (3)
Subtotal	6,530
HVB Outputs	
Evaporation	0
Surface Outflow	0
Subsurface Outflow	0
Consumptive Use	2,246 (4)
Subtotal	2,246
Net (Input-Output)	4,284

(1) Refer to BCM Report Section 4.6.3, Recharge to the Domain. Sources include The Mark Group, April 7, 1987;CA DWR, 1967

(2) Underflow through gap on west side of Red Hill (aka Hinkley Gap). Refer to Table 8, CSU and MWA, September 2007; average of four underflow estimates; excludes the two lowest estimates (basis: MWA 1983 estimate superseded in 2007 report and DWR 1967 no underflow location specified)

(3) Derived from numerical model water balance, BCM Report (Appendix I)

(4) Refer to BCM Report Section 4.9.2, Current

Table 4-3b Post MSP Water Budget

HVB Inputs	AFY
Precipitation falling on the basin floor	420 (1)
Precipitation falling on the surrounding highlands	300 (1)
Runoff from the highlands that enters ephemeral streams	550 (1)
Hinkley Gap underflow	2,100 (2)
Recharge of indeterminate origin	3,160 (3)
Subtotal	6,530
HVB Outputs	
Evaporation	0
Surface Outflow	0
Subsurface Outflow	0
Consumptive Use	3,702 (4)
Subtotal	3,702
Net (Input-Output)	2,828

(1) Refer to BCM Report Section 4.6.3, Recharge to the Domain. Sources include The Mark Group, April 7, 1987; CA DWR, 1967

(2) Underflow through gap on west side of Red Hill (aka Hinkley Gap). Refer to Table 8, CSU and MWA, September 2007; average of four underflow estimates; excludes the two lowest estimates (basis: MWA 1983 estimate superseded in 2007 report and DWR 1967 no underflow location specified)

(3) Derived from numerical model water balance, BCM Report (Appendix I)

(4) 2,163 (MSP) + 1,109 (SEGS VIII and IX) + 430 (HVB residential wells) = 3,702 AFY

Based on the most recent information available, and accounting for the availability of the 707 AFY of water from the Ryken Well (i.e., purchase option), approximately 4,900 AFY (4,284 AFY + 707 AFY) of groundwater is available for the proposed MSP. The proposed MSP is expected to require 2,163 AFY.

4.9.4 WATER RIGHTS

The MRB was adjudicated in 1996. The HVB is located entirely within the Centro subarea. The MSP through ownership or purchase options has rights to10,478 AFY of groundwater (i.e. HVB / Centro Basin). These water rights consist of 9,380 AFY owned by Abengoa Solar, Inc., 224 AFY transferred in December 2008 from Jennie Most, trustee of the Most Family Trust, and an option to purchase 874 AFY from the Desert View Dairy (the Ryken Well).

5.0 SURFACE WATER

The major surface water feature in the project area is a lacustrine marsh located at the southwestern edge of Harper Dry Lake less than 1 mile north of the proposed MSP. This semi-perennial marsh has had maximum dimensions of about 2 miles long and 0.25 miles wide. In the past, the area received its water supply from surface water and agricultural runoff. With significant decline in Harper Dry Lake area agriculture, the marsh has been maintained with groundwater pumped from a former irrigation well now owned by Mojave Solar LLC.

The ephemeral Mojave River, shown in Figure 1-1, is the southeast boundary of the Domain. Infrequent storms with significant precipitation result in Mojave River flow.

The ephemeral drainages within the HVB flow from adjacent mountain highlands to the central part of the basin at Harper Dry Lake. The watershed above Harper Dry Lake is approximately 235 square miles. Recharge to alluvial aquifers due to storm flow within the ephemeral streams has been discussed previously (see Recharge to Domain).

According to the San Bernardino County Flood Control District, the 100-year floodplain has not been established for the Harper Dry Lake area.

6.0 ENVIRONMENTAL IMPACTS

Environmental impacts due to use of groundwater pumped from the uQal aquifer as the MSP water supply source would be considered significant if the following impacts resulted:

- Substantial depletion of groundwater resources and interference with local wells (Figures 6-2 and 6-3);
- Substantial interference with groundwater recharge; or
- Use of water in a wasteful manner.

Project water quality or erosion/flooding-related impacts would be considered significant if the MSP resulted in the following:

- Degradation of groundwater quality;
- Discharge into surface waters resulting in alteration of surface water quality; or
- Substantial erosion or flooding off the site.

The direct effects of the MSP on local water resources will be those associated with using groundwater for construction, specifically for demands during site grading, and with the plant's operational water needs. No surface water will be used. Since the 100-year floodplain has not been established for the Harper Dry Lake area, construction and operation of the MSP does not trigger floodplain concerns.

Because of the high transmissivity of the uQal aquifer, prolonged extraction for MSP supply water should not cause further increases in total dissolved solids and deterioration in quality by drawing in water of higher salinity from an expanded pumping depression reaching below Harper Dry Lake. Similarly, the proposed pumping of groundwater to supply the MSP is not expected to induce additional migration of Mojave River underflow. About 6,500 to 18,000 AFY of groundwater has been used for historical agriculture production in the vicinity of the existing FPLE SEGS VIII and IX and the proposed MSP as compared to the 2,163 AFY needed during operation of the MSP. Refer to Section 4.8, Groundwater Geochemistry, for additional groundwater quality discussion and an evaluation of groundwater quality stability from seven days of pumping at the

Ryken Well. LGS does not expect groundwater production during MSP construction and operation to significantly impact groundwater quality.

Surface water within the Domain is limited to a small wetlands area in the south portion of Harper Dry Lake (north of the Wetlands Well). Refer to Section 5.0, Surface Water, for additional surface water discussion. The MSP will not discharge water or wastewater to the wetlands. LGS does not expect surface water to be significantly altered due to the MSP's construction or operation.

Since the 100-year floodplain has not been established for the Harper Dry Lake area, construction and operation of the MSP do not trigger floodplain concerns.

6.1 CONSTRUCTION

Currently, construction plans are to clear and grade the site with heavy equipment to provide a terraced site with gentle northerly and easterly sloping grades on each terrace. The preliminary cut and fill volume is estimated to be 4.2 million cubic yards. The cut and fill will be balanced; as such, there are no plans to import fill material during general grading operations. Because of the amount of soil and vegetation affected by grading activities, substantial water erosion control and dust control measures will be required to minimize offsite impacts. Overall, the will result in disturbance of approximately 1,765 acres. A construction phase SWPPP and DESCP to meet CEC requirements will include a series of management controls and BMPs to minimize erosion and impacts to drainage.

Construction of the MSP is expected to require 26 months. During MSP construction, water production is needed for potable water use and non-potable water use, including mass grading, dust suppression, sewage, and fire protection. Construction phase water usage is estimated to be between 59,800 and 1,766,050 gallons per day.

During MSP construction, plans are to produce water from three wells, including one well at each of the power blocks and from the Ryken Well.

Impact to neighboring property (Figure 6-2) due to construction phase water production from three on-site wells has been simulated using WinFlow, v. 3, developed by Environmental Simulations, Inc. The predictive simulation lasted 26 months and assumed that each of the three production wells was pumped

continuously at 410 gpm. A flow rate of 410 gpm from three wells, 24 hours per day is equivalent to 1,766,050 gallons per day. Simulations based on this rate will result in maximum hydraulic interference estimates. Predicted hydraulic interference is shown on Figure 6-4.

Hydraulic Interference resulting from 26 months of continuous pumping at 410 gpm from each of the three production wells is shown on Figure 6-4. Maximum estimated hydraulic interference at positions off the MSP footprint and at a radial distance of 0.5 miles from production wells PW-1a, PW-2b and the Ryken Well is five feet. This interference to potential offsite wells located as close as 0.5 miles from the MSP supply wells is not significant. LGS does not expect groundwater production during MSP construction to significantly impact water levels at neighboring wells. Based on interpretations of 2D modeling simulations, the uQal Aquifer shows minimal sensitivity (with regard to hydraulic head) to relatively small changes in the discharge rate (+- 20 AFY).

Maximum estimated on-site drawdown during construction is about nine feet, as shown on Figure 6-4. Pumping levels (or maximum on-site drawdown) are under estimated by WinFlow simulations, since well losses are not considered. Therefore, predictions of maximum onsite drawdown should be increased to account for well losses. A doubling of the maximum onsite drawdown predicted by the WinFlow simulations should be sufficient.

Water quality impacts could result from releases of chemicals used during construction, such as motor oil, fuel, and solvents. These chemicals can potentially contaminate surface waters during heavy storm events, or affect groundwater through infiltration. Mitigation measures are in place to prevent spills of chemicals, as well as to respond to spills should they occur. The SWPPP and DESCP will require storm water BMPs and temporary erosion control measures, including revegetation, dust suppression, and construction of beams and ditches, which will prevent accelerated soil erosion or dust generation. Adhering to proper material handling procedures and complying with the SWPPP will ensure that construction-related water quality impacts are not significant.

Because of the high transmissivity of the uQal aquifer, prolonged extraction for MSP supply water should not cause an increase in TDS concentration or deterioration in quality by drawing in water of higher salinity from an expanded

pumping depression reaching below Harper Dry Lake. Similarly, the proposed pumping of groundwater to supply the MSP during construction is not expected to induce additional migration of Mojave River underflow. About 6,500 to 18,000 AFY of groundwater have been used for historical agriculture production in the vicinity of the existing FPLE SEGS VIII and IX and the proposed MSP as compared to the 2,163 AFY needed during operation of the MSP. Refer to Section 4-8, Groundwater Geochemistry, for additional groundwater quality discussion and an evaluation of groundwater quality stability from seven days of pumping at the Ryken Well. LGS does not expect groundwater production during MSP construction to significantly impact groundwater quality.

Surface water within the Domain is limited to a small wetlands area in the south portion of Harper Dry Lake (north of the Wetlands Well). Refer to Section 5.0, Surface Water, for additional surface water discussion. The MSP will not discharge water or wastewater to the wetlands. LGS does not expect surface water to be significantly altered due to the MSP construction.

The direct effects of the MSP on local water resources will be those associated with using groundwater for construction, specifically for demands during site grading, and with the plant's process water needs. No surface water will be used. Since the 100-year floodplain has not been established for the Harper Dry Lake area, construction and operation of the MSP do not trigger floodplain concerns.

No significant changes to groundwater quality beneath the site are foreseen as a result of limited hydraulic interference caused by groundwater pumping during the construction period (Figure 6-4). Additionally, LGS does not expect groundwater production during MSP construction to significantly impact water levels at neighboring wells.

6.2 OPERATION

The Project proposes to use a wet cooling tower for power plant cooling. Water for cooling tower makeup, process water makeup, and other industrial uses such as mirror washing will be supplied from selected onsite groundwater wells. Water from the onsite wells also will be used to supply potable water for employees (e.g., drinking, showers, sinks, toilets). Operation of the 250 MW MSP is expected to require 2,163 AFY of water (includes 10 AFY for potable water) for

an anticipated 30 years. Figure 6-3 shows two wells, a production well and a backup well, located on the north ends of each of the two MSP power blocks. Supply water between power blocks will not be interconnected and each power block will have dedicated water treatment equipment. To meet the production demand, each well will be designed for a peak capacity of 1,172 gpm. The required annual water production (i.e., to support 2,163 AFY) has been normalized to a constant flow rate of 670 gpm from each of the two power blocks based on water production 24 hours per day and seven days per week.

Impact to neighboring property due to water production from two on-site wells has been simulated using WinFlow, v. 3, developed by Environmental Simulations, Inc. The predictive simulation lasted 30 years and assumed that each of two production wells was pumped continuously at 670 gpm. A flow rate of 670 gpm from two wells, 24 hours per day for one year is equivalent to 2,163 AFY. Predicted hydraulic interference (drawdown) is shown in Figure 6-5. This interference to potential offsite wells located as close as 0.5 miles from the MSP supply wells is insignificant. LGS does not expect groundwater production during MSP operation to significantly impact water levels at neighboring wells. Based on interpretations of 2D modeling simulations, the uQal aquifer shows minimal sensitivity (with regard to hydraulic head) to relatively small change in the discharge rate (+- 20 AFY).

Hydraulic interference resulting from 30 years of continuous pumping from two production wells at a rate of 670 gpm at each well is shown on Figure 6-5. Maximum estimated hydraulic interference at positions off the MSP footprint and at a radial distance of 0.5 miles from production wells PW-1a and PW-2b is 5.2 feet.

Maximum estimated on-site drawdown during MSP operations is 11.3 ft as shown on Figure 6-5. Pumping levels (or maximum on-site drawdown) are under estimated by WinFlow simulations since well losses are not considered. Therefore, predictions of maximum onsite drawdown predictions should be increased to account for well losses. A doubling of the maximum onsite drawdown predicted by the WinFlow simulations should be sufficient.

Water quality impacts could result from releases of chemicals used during MSP operation, such as motor oil, fuel, and solvents. These chemicals can potentially contaminate surface waters during heavy storm events, or affect groundwater

through infiltration. Mitigation measures are in place to prevent spills of chemicals, as well as to respond to spills should they occur. The SWPPP and DESCP will require storm water BMPs and temporary erosion control measures, including revegetation, dust suppression, and construction of beams and ditches, which will prevent accelerated soil erosion or dust generation. Adhering to proper material handling procedures and complying with the SWPPP will ensure that construction-related water quality impacts are not significant.

Because of the high transmissivity of the uQal aquifer, prolonged extraction for MSP supply water should not cause an increase in TDS concentration and deterioration in quality by drawing in water of higher salinity from an expanded pumping depression reaching below Harper Dry Lake. Similarly, the proposed pumping of groundwater to supply the MSP during operation is not expected to induce additional migration of Mojave River underflow. About 6,500 to 18,000 AFY of groundwater have been used for historical agriculture production in the vicinity of the existing FPLE SEGS VIII and IX and the proposed MSP as compared to the 2,163 AFY needed during operation of the MSP. Refer to Section 4.8, Groundwater Geochemistry, for additional groundwater quality discussion and an evaluation of groundwater quality stability from seven days of pumping at the Ryken Well. LGS does not expect groundwater production during MSP construction to significantly impact groundwater quality.

Surface water within the Domain is limited to a small wetlands area in the south portion of Harper Dry Lake (north of the Wetlands Well). Refer to Section 5.0, Surface Water, for additional surface water discussion. The MSP will not discharge water or wastewater to the wetlands. LGS does not expect surface water to be significantly altered due to operation of the MSP.

The direct effects of the MSP on local water resources during its operation will be those associated with the plant's process water and potable water needs. No surface water will be used. Since the 100-year floodplain has not been established for the Harper Dry Lake area, construction and operation of the MSP does not trigger floodplain concerns.

No significant changes to groundwater quality beneath the site are foreseen as a result of limited hydraulic interference caused by groundwater pumping during the operation period (Figure 6-5). Additionally, LGS does not expect groundwater

production during MSP operation to significantly impact water levels at neighboring wells.

Based on the estimated solar energy and plant operating profile, approximately 2,163 AFY of water will be used by the MSP (includes 10 AFY for potable water). Monthly water usage is projected to follow the monthly schedule shown in Table 6-1.

Table 6-1 Estimated Monthly Water Usage

Month	Approximate Water Usage Acre-Feet (gpm)[1]	Month	Approximate Water Usage Acre-Feet (gpm)[1]
January	55.27 (404)	July	291.66 (2,129)
February	78.35 (633)	August	272.81 (1,992)
March	150.99 (1,102)	September	240.65 (1,815)
April	230.28 (1,737)	October	135.35 (988)
May	278.72 (2,035)	November	80.10 (604)
June	289.16 (2,181)	December	59.66 (436)

[1]The estimated groundwater usage in gallons per minute (gpm) is based on average daily consumption. The maximum groundwater production rate for which the wells will be designed to pump is approximately 1,099 gpm (or 2,198 gpm for two production wells).

The water use schedule estimates water usage during the months of April through September to average between 1,737 and 2,181 gpm. During the winter months of October through March, the flow rate is significantly reduced, to between 404 gpm (January) and 988 gpm (October). The maximum groundwater production rate for which each well will be designed to pump is approximately 1,172 gpm (or 2,344 gpm for two production wells). The average flow rate normalized for the entire year is about 670 gpm for each well (or 1,340 gpm from two production wells). These flow rate estimates are conservative since they do not take into account MSP water storage capacity.

6.3 DISTANCE-DRAWDOWN PROJECTIONS

Distance-drawdown projections supplemental to the WinFlow simulations have been made using graphical methods. To calculate distance-drawdown graphs, the T and S coefficients must be known, or estimated, and pumping duration/pumping rates must be specified. For this task, T and S values were obtained from an aquifer pumping test: T = 225,000 gpd/ft and S = 0.003. The Jacob straight-line method was used to generate two families of graphs for two

pumping duration periods, t, of 2.35 days (matches the aquifer pumping test) and 30 years. A range of discharge rates were selected, including 1,143 gpm, which matches the pumping rate from the aquifer pumping test. See Graph 2-20, Distance-Drawdown. The equations used to create Graph 2-20 are as follows: $T = 528Q/ds$ and $S = Tt/4790r^2_0$; units are as follows:

T	gallons per day/foot
S	unit less
t	minutes
ds	feet per log cycle
Q	gallons per minute
r_0	feet

Selecting the Q = 1,143 gpm curve from the family of curves (Graph 2-20) based on a pumping duration of t = 2.35 days and an r value of 759 ft (the distance between the Hay Farm Well and the Ryken Well) shows a drawdown of 2.6 ft, which matches the observed drawdown during the pumping test. This indicates that T and S values calculated using the Cooper–Jacob solution are reasonable for aquifer conditions between these two wells.

Selecting the Q = 1,143 gpm curve from the family of curves (Graph 2-20) based on a pumping duration of t = 30 years and a drawdown value of 5 ft shows a distance from the pumped well of 7,100 ft. Therefore, after 30 years of continuous pumping at a rate of 1,143 gpm, 5 ft of hydraulic interference is estimated at a radial distance of 1.34 miles from the pumped well.

Selecting the Q = 1,143 gpm curve from the family of curves (Graph 2-20) based on a pumping duration of t = 30 years and an r value of ½ mile (2,640 ft) shows a drawdown of 5.9 ft.

Observed drawdown at the two distant observation wells was as follows: 1) the Wetlands Supply Well (r = 3,149 ft) and 2) the Green House Well (r = 2,095 ft) at 1.15 ft and 0.38 ft, respectively. Selecting the Q = 1,143 gpm curve from the family of curves (Graph 2-20) based on a pumping duration of t = 2.35 days and r values of 2,095 ft and 3,149 ft shows a drawdown of 1.4 ft and 1 ft, respectively. Comparison of observed drawdown with predicted drawdown at the Wetlands

Supply Well shows good agreement. At the Green House Well, poor agreement between observed and predicted suggests anisotropic lithologic conditions and/or well construction/condition issues.

7.0 GROUNDWATER MODEL DEVELOPMENT

A calibrated numerical groundwater flow model utilizing MODFLOW within Groundwater Vistas software has been constructed for the Domain. The model was constructed based on information presented in the BCM Report. Examples include recently acquired geophysical data pertaining to the Black Mountain basalt layer geometry, recently acquired aquifer parameters obtained from pumping-test data, and historical gravity-based mapping for the top of the basement elevation within the Domain. Additional information related to basin geometry and described within the BCM Report (Appendix A1) was incorporated into the model and improved its function.

Model calibration using a steady-state process focused on matching pre-development potentiometric surface data sets available from the 1920s and 1930s. This is similar to the approach adopted by the USGS in calibrating their Mojave River Basin Model (Stamos et al., 2001).

Nearly all HVB recharge is from underflow within the Floodplain Aquifer associated with the Mojave River. Sufficient recharge to the HVB appears to be available for the MSP. Due to a surplus water balance predicted by the model, aquifer recovery (see Figure 1-14) during MSP operation is expected to continue. LGS does not expect groundwater production for MSP operation to increase underflow from adjacent groundwater basins. Simulation results of the pumping test (i.e., the Ryken Well) and groundwater pumping required for the MSP construction/operation periods using MODFLOW and WinFlow (2D model) are consistent.

8.0 LIMITATIONS

This investigation was performed with the degree of care and skill ordinarily exercised under similar circumstances by experienced hydrogeologists practicing in this or similar locations. It is understood that inherent risks are associated with evaluating subsurface hydrogeological conditions. Additional investigation methods are available to evaluate subsurface hydrogeological conditions,

including subsurface drilling and surface geophysical surveys. If reduction of risk regarding investigation conclusions and recommendations are desired, then LGS should be contacted regarding the application of additional investigation methods. No warranty, expressed or implied, is made as to the conclusions and professional advice included within this investigation report.

The findings of this report are valid as of the present date. However, changes in the conditions of a property can and do occur with the passage of time, whether they are due to natural processes or the work of people on this or adjacent properties. Accordingly, the findings of this report may be invalidated wholly or partially by changes outside of our control. Therefore, this report is subject to review and revision as changed conditions are identified.

9.0 REFERENCES

Ahlfeld, D. P., Mulligan, A. E., 2000, *Optimal Management of Flow in Groundwater Systems*, Academic Press, Inc., San Diego, California.

Amoroso, Lee and Miller, David M, 2006, *Surficial Geologic Map and Geodatabase of the Cuddeback Lake 30' x 60' Quadrangle, San Bernardino and Kern Counties, California* and Pamphlet, U.S. Geological Survey, Open-file Report 2006-1276.

Anderson, M.P., and W.W. Woessner, 2002. *Applied Groundwater Modeling Simulation of Flow and Advective Transport*, Academic Press, Inc., San Diego, California.

Applied Geotechnical Engineering, Inc. 1987, *Geotechnical Engineering Study, Proposed Solar Electrical Generating Systems (SEGS), Harper Dry Lake, San Bernardino County, California.*

Aquifer Science and Technology, May 2007 – "*Report on the Geophysical Investigations for the Harper-Hinkley Gap Area near Hinkley, California*, for the Mojave Water Agency"

Bader, J.S., 1969, *Ground-Water Data as of 1967 South Lahontan Subregion California*: U.S. Geological Survey Water Resources Division Open File Report, 25 p.

Barlow, P.M., and A.F. Moench, 1999. WTAQ - *A computer program for calculating drawdowns and estimating hydraulic properties for confined and*

water-table aquifers, U.S. Geol. Survey Water-Resources Investigations Report 99-4225, 74p.

Bookman-Edmonston Engineering Inc., 1994, Ground Water Occurrence and Quality Lahontan Region, p. 264-357.

Bryant, W.A., 1987, Recently active traces of the Blackwater, Harper, Lockhart and related faults near Barstow, San Bernardino County, California Division of Mines and Geology, 7 Plates at various scales.

Burke, D.B., Hillhouse, J.W., McKee, E.H., Miller, S.T., and Morton, J.L., 1982 Cenozoic rocks of the Barstow Basin Area of Southern California – Stratigraphic relations, radiometric dates, and paleomagnetism: U.S. Geological Survey, Bulletin 1529-E, p. 16.

California Department of Water Resources (DWR), 1964, *Ground Water Occurrence and Quality, Lahontan Region.*

California DWR, 1967, Mojave River Ground Water Basins Investigation, Bulletin 84.

California DWR, 1971, *Water Wells in the Harper, Superior, and Cuddeback Valley areas, San Bernardino County, California*: Bulletin 91-19, 99 p.

California DWR, 1975, *California's Ground Water*: Bulletin 118, 135 p.

California DWR, 2003, California's Water, Bulletin 118 Update. South Lahontan Hydrologic Region, Harper Valley Groundwater Basin, p. 5.

California Regional Water Quality Control Board (CA RWQCB) Lahontan Region, 2008, *Resolution No. R6V-2008-0013*.

CA RWQCB Lahontan Region, April 2006, *Executive Officer's Report*.

California State University, Fullerton Department of Geologic Sciences (CSU) and the Mojave Water Agency (MWA) September 2007 – "*Harper Dry Lake Basin, San Bernardino County, California, Hydrogeologic Report*"

Cooper, H. H., Jr. and Jacob, C.E., 1946, *A Generalized Graphical Method for Evaluation of Formation Constants and Summarizing Well-Field History*, American Geophysical Union Transactions, v. 27, No. 4, p. 526-534.

Cox, B. F., 2003, Pliocene and Pleistocene evolution of the Mojave River, and associated tectonic development of the Traverse Ranges and Mojave Desert,

based on borehole stratigraphy studies and mapping of landforms and sediments near Victorville, California, Geological Society of America.

Crosby, Gary W, May 1990, *Inventory of Groundwater Stored in the Mojave River Basins,* Subsurface Surveys, Inc., prepared for the Mojave Water Agency.

Dibblee, T.W., Jr., 1967, *Areal Geology of the Western Mojave Desert, California*, U.S. Geological Survey Professional Paper 522.

Dibblee, T.W., Jr., 1968, Geology of the Fremont Peak and Opal Mountain quadrangles, California: Sacramento, CA, California Division of Mines and Geology, Bulletin 188, four plates.

Dibblee, T.W., Jr., 1985, Analysis of potential fault and seismic hazards to proposed Superconductor Supercollider Site in vicinity of Edwards AFB, Western Mojave Desert, CA, unpublished report for University of California at Davis.

Driscoll, Fletcher G., 1986, Groundwater and Wells, Johnson Division.

Dokka, R.K., 1989. *The Mojave extensional belt of southern California*: Tectonics, v. 8, no 2, p. 363-390.

Dokka, R.K., and Travis, C.J., 1990a. *Late Cenozoic strike-slip faulting in the Mojave Deser*t, California: Tectonics 9, no. 2. p311-340.

Dokka, R.K., and Travis, C.J., 1990b. *Role of the Eastern California shear zone in accommodating Pacific-North American plate motion*: Geophysical Research Letters 17, no. 9. p. 1323-1326.

Driscoll, F. G., 1987, *Groundwater and Wells*, Johnson Division, St. Paul, Minnesota, p. 75, Appendix 9.C.

Duffield, Glenn M., 1996-2007, *AQTESOLV® for Windows®*, version 4.50.002, Professional, Documentation, Geraghty and Miller Modeling Group, Reston, Virginia.

Ebbs, Veva, 2007, *Quantification of Sub-Surface Groundwater Flow from Middle Mojave River Valley Basin into the Harper Dry Lake Basin*, Masters Thesis, California State University, Fullerton.

Foster, J. H., 1980, Late Cenozoic tectonic evolution of Cajon Valley, Southern California: PhD thesis, Riverside, University of California, 236 p.

Glazner, A.F., Bartley, J.M., and Walker, J.D., 1989. Magnitude and significance of Miocene crustal extension in the central Mojave Desert, California: Geology, v. 17, p. 50-53.

Hantush, M.S., 1961a. *Drawdown around a partially penetrating well*, Jour. of the Hyd. Div., Proc. of the Am. Soc. of Civil Eng., vol. 87, no. HY4, pp. 83-98.

Hantush, M.S., 1961b. *Aquifer tests on partially penetrating wells*, Jour. of the Hyd. Div., Proc. of the Am. Soc. of Civil Eng., vol. 87, no. HY5, pp. 171-194.

Izbicki, John A, 2004, *Source and Movement of Ground Water in the Western Part of the Mojave Desert, Southern California*, U.S. Geological Survey, Water-Resources Investigations Report 03-4313, prepared in cooperation with the Mojave Water Agency.

Kruseman, G.P. and de Ridder N.D., 1970, *Analysis and Evaluation of Pumping Test Data*, Bulletin 11, International Institute for Land Reclamation and Improvement, p. 101.

Lohman, S.W., 1979, *Groundwater Hydraulics*, Geological Survey Professional Paper 708, p. 6.

Louie, J.N. and Qin, J., 1991, Subsurface imaging of the Garlock fault, Cantil Valley, CA: Journal of Geophysical Research, v. 96.

The Mark Group, April 1989 – "*Final Report, Hydrogeologic Assessment Report, Harper Dry Lake, California, for LUZ Development and Finance Corporation,* 88-03219.18".

The Mark Group, December 1989 – "*Preliminary Report, Aquifer Analysis, LUZ Solar Energy Generating Station, Harper Valley, California*, 89-03409.18".

McDonald, M.G., and A.W. Harbaugh, 1988, *A Modular Three-Dimensional Finite-Difference Groundwater Flow Model*: Techniques of Water-Resources Investigations of the U.S. Geological Survey, Book 6.

Meek, Norman, 1990, *Late Quaternary geochronology and geomorphology of the Manix Basin, San Bernardino County, California*, PhD. Dissertation., Department of Geography, University of California Los Angeles.

Meisling, Kristian E. and Weldon, Ray J., January 1989, Late Cenozoic tectonics of the northwestern San Bernardino Mountains, Southern California, Geological Society of America, v. 101; p 106-128.

Moench, A.F., 1993. *Computation of type curves for flow to partially penetrating wells in water-table aquifers*, Ground Water, vol. 31, no. 6, pp. 966-971.

Moench, A.F., 1996. *Flow to a well in a water-table aquifer: an improved Laplace transform solution*, Ground Water, vol. 34, no. 4, pp. 593-596.

Moench, A.F., 1997. *Flow to a well of finite diameter in a homogeneous, anisotropic water table aquifer*, Water Resources Research, vol. 33, no. 6, pp. 1397-1407.

Mojave Basin Area Watermaster, May 1, 2009. *Fifteenth Annual Report of the Mojave Basin Area Watermaster, Water Year 2007-08*.

Mojave Basin Area Watermaster, April 1, 2008. *Fourteenth Annual Report of the Mojave Basin Area Watermaster, Water Year 2006-07*.

Mojave Water Agency (MWA). 1999. Fourth Annual Engineer's Report on Water Supply for Water Year 1997-1998. Apple Valley, California. 77p.

Neuman, S.P., 1974. *Effect of partial penetration on flow in unconfined aquifers considering delayed gravity response*, Water Resources Research, vol. 10, no. 2, pp. 303-312.

Neuman, S.P., 1975, *Analysis of Pumping Test Data from Anisotropic Unconfined Aquifers Considering Delayed Yield*, Water Resources Research, v. 11, No. 2, p. 329-342.

Oskin, M. and Iriondo, A., 2004, Large-magnitude transient strain accumulation on the Blackwater fault, Eastern California Shear Zone: Geology, v. 32, p. 313-316.

Page, P.W., and Moyle, J., W.R., 1960, Data on water wells in the eastern part of the middle Mojave Valley area, San Bernardino County, CA, CA DWR, Bulletin No. 91-19.

Pollock, D.W. 1989, *Documentation of Computer Programs to Compute and Display Pathlines Using Results from the U.S. Geological Survey Modular Three-Dimensional, Finite-Difference Groundwater Flow Model*: USGS Open File Report.

Reheis, M, Miller, M, Oviatt, C., 2007, Pluvial Lake Manix, Mojave Desert: Effects of Subbasin Integration on Sedimentary Record, Presentation at XVII INQUA Congress 2007, U. S. Geological Survey.

Reynolds, Robert E and Reynolds, Richard L, 1994, *The Isolation of Harper Dry Lake Basin*, Special Publication 94-1, Department of Earth Sciences, San Bernardino County Museum, Redlands, California.

Rumbaugh, J.O., 2007, *Guide to Using Groundwater Vistas*, version 5: Environmental Simulations, Inc.

Stamos, Christina L. and S. K. Predmore, 1995, Data and Water-Table Map of the Mojave River Ground-Water Basin, San Bernardino County, California, November 1992, US Geological Survey Water-Resources Investigations Report 95-4148.

Stamos, Christina L; Martin, Peter; Nishikawa, Tracy; and Cox, Brett F, 2001, *Simulation of Ground-Water Flow in the Mojave River Basin*, U.S. Geological Survey, Water-Resources Investigations Report 01-4002, Version 1.1, prepared in cooperation with the Mojave Water Agency.

Stone, W.J., 1986, Natural Recharge in Southwestern Landscapes, Examples from New Mexico, Proceedings of the Conference on Southwestern Groundwater Issues, National Water Well Association, October 1986.

Tartakovsky, G.D. and S.P. Neuman, 2007. *Three-dimensional saturated-unsaturated flow with axial symmetry to a partially penetrating well in a compressible unconfined aquifer,* Water Resources Research, W01410, doi:1029/2006WR005153.

United States Geological Survey. National Water Information System. http://waterdata.usgs.gov/nwis

Woessner, W.W. and M.P. Anderson, 1992. Selecting calibration values and formulating calibration targets for groundwater flow simulations, Proceedings of the NWWA Conference on Solving Ground-Water Problems with Models.

Woodburne, M. O., and Golz, D.J., 1972, Stratigraphy of the Punchbowl Formation, Cajon Valley, Southern California: Berkeley, University of California Publications in Geological Sciences, v. 92, 73 p.