United States Department of the Interior
NATIONAL PARK SERVICE
Mojave National Preserve
222 East Main Street, Suite 202
Barstow, California 92311

IN REPLY REFER TO:

28 February 2000

F2

Dirk Reed, Project Manager
Metropolitan Water District
P.O. Box 54153
Los Angeles, California 90054

Re: National Park Service Comments on *Cadiz Groundwater Storage and Dry-Year Supply Program Environmental Impact Statement* and Supporting Technical Documents

Dear Mr. Reed:

Below are comments from the National Park Service (NPS) on the *Cadiz Groundwater Storage and Dry-Year Supply Program Environmental Impact Statement* (EIS). As the *Cadiz Groundwater Resources* report is a technical appendix to the EIS, NPS also offers comments on that document.

NPS offers its comments on the EIS because of the geographical proximity of Mojave National Preserve to the Cadiz Groundwater Storage Project (Project) and because one or more key groundwater basins are shared by Mojave National Preserve and the Cadiz Project. Mojave National Preserve, a unit of the National Park System, is located approximately 15 miles north of the main Project area. Fenner Basin, which is expected to provide the primary source of natural recharge groundwater to the Cadiz Project, runs nearly 30 miles into the Mojave National Preserve, and is one of the park's major groundwater aquifers. The Cadiz Project has the potential to adversely affect the groundwater resources of Mojave National Preserve and air quality in the Preserve. F2-1

This letter addresses these potential adverse impacts in four sections: (1) adequacy of the EIS; (2) air quality; (3) adequacy of the monitoring and mitigation plan; and (4) proposed changes to the Project and environmental analysis.

1. Adequacy of the EIS

A. Adequacy of the Cadiz Groundwater Resources Report

F2-2

The most critical element of the EIS is the analysis of the impacts of the Cadiz Project on groundwater resources in the Project area and on groundwater resources of adjacent lands, including the Mojave National Preserve. The *Cadiz Groundwater Resources* report forms the underpinnings of the groundwater impacts analysis in the EIS. The groundwater impacts analysis of the EIS will be severely flawed, if not rendered totally invalid, by a groundwater resources study that is inadequate or technically unsound. Without a sound groundwater study it is not possible for NPS to rely on the EIS to properly assess the impacts of the Project on the Mojave National Preserve.

Recently, the *Cadiz Groundwater Resources* report was critically and objectively reviewed by the U.S. Dept. of Interior Geological Survey (USGS), NPS hydrologists and water rights specialists with our Washington Office, and experts with the County of San Bernardino. Each of these groups has independently drawn the conclusion that the groundwater study conducted in support of the Cadiz EIS is seriously flawed.

The most significant flaw that the reviewers found in the study is the estimated rate of natural groundwater recharge. The EIS suggests that the project will remove no more indigenous water from the basin than is naturally recharged. The watershed model and water-balance studies presented in the EIS and the underlying groundwater study, however, overestimate the natural recharge to the basin by 5 to 25 times the values estimated by USGS. Therefore, the proposed pumping rates in the EIS call for water extraction that is greatly in excess of the amount of water that is recharged.

The USGS and the other expert reviewers also found a number of other serious flaws in the groundwater study (see attachment 1). They report that the chloride mass balance approach was not properly applied in the study and greatly overestimated water availability in the basin. The reviewers found that the evaporation rates used in the groundwater flow model were not based on sound technical grounds. They found that the amount of water currently predicted by the study to discharge at Bristol and Cadiz Dry Lakes is incorrect. The *Cadiz Water Resources* report fails to account for soil water storage and subsequent withdrawals by desert plants. Estimates of groundwater storage in the Fenner aquifer are inaccurate and misleading. F2-2

These are but a few of the inaccuracies and errors found by USGS, NPS, and the County of San Bernardino in the EIS and supporting *Cadiz Water Resources* report. Such serious flaws and inaccuracies in the key component of the impact analysis invalidate the conclusions in the EIS. The EIS, therefore, does not portray an adequate description of potential impacts and must be revised. For example, the EIS does not address how water level declines will impact the dry lakes. The EIS overestimates the size of the groundwater basins. The EIS fails to point out that isotopic data indicate that the groundwater in the desert basins was recharged thousands of years ago during a much wetter climate.

There are major discrepancies between the existing groundwater study and what the USGS and other reviewers have found. NPS is concerned that the groundwater study supporting the EIS is so technically flawed that it is not possible for the EIS to adequately evaluate the impacts of the Project on the groundwater resources of Mojave National Preserve.

B. Specific Comments on the EIS

The following are specific comments from NPS concerning the EIS: F2-3

Public Meetings – The public meetings were held approximately two weeks after receipt of the EIS. There was not sufficient time to review the EIS before the meetings. F2-4

Index – 40 CFR 1502.10 states that EISs must have an index. The Cadiz EIS has no index. F2-5

Executive Summary

Page ES-32 - Add aesthetics as an impact. The scars from the construction activities, and the view of the well field and spreading basins would change the views of the desert. F2-6

Page ES-35, Cumulative Impacts – "There are no known closely related past, present, and reasonably foreseeable probable future projects in the Cadiz Project Area." This statement in the EIS is misleading. Please see NPS comments on Cumulative Impacts below. F2-7

Page ES-39, BLM Responsibilities – In addition to permitting the project, BLM also has the option of not permitting the project and not granting a right-of-way, especially since the CDCA plan does not have a utility corridor compatible with the Cadiz project. This portion of the EIS appears pre-decisional. F2-8

1.0 Introduction

Page 1-6, column 1, para. 5, last line – Same comment as above. BLM does not have to grant an amendment to the CDCA plan. F2-9

3.0 Formulation and Evaluation of Project Alternatives

Section 3, Formulation and Evaluation of Alternatives – Several alternatives that were eliminated from detailed consideration entail using lands either within or immediately adjacent to Joshua Tree National Park (see pages 3-6 – 3-8 and the Executive Summary). A project of this type within any unit of the National Park System is inconsistent with the land use of the area (as stated in the EIS) and would likely not be permitted. To include such areas in the EIS analysis seems a "red herring" attempt to make the project appear more environmentally sensitive. If there is a true concern for NPS resources, then the project should not be located 15 miles from the Mojave National Preserve, also a unit of the National Park System. NPS has concerns about the potential impacts of this project to Mojave National Preserve. Why was no mention made of the Preserve in the formulation and selection of alternatives? This seems to be an oversight. F2-10

Page 3-4 - Add that an existing land use is the Mojave National Preserve. F2-11

Page 3-12, Section 3.5.2 – This section states that, in the selection of alternatives, environmental issues were considered including "impacts to adjacent public uses of park lands." If so, why was no mention made or consideration given to the Mojave National Preserve? By the standards established in the EIS, the project should be located elsewhere. F2-12

Page 3-16, column 2, first para., line 12 – The EIS is inadequate with respect to water rights essential for the proposal to be viable. Evidence of Cadiz, Inc.'s legal rights to the entire amount of water proposed to be removed, under each alternative, should be provided. Further, the EIS needs a discussion of the status of water rights related to the Project and adjacent lands, including wilderness areas and Mojave National Preserve. F2-13

Page 3-20 - Please cite references to the theory of "mounding" and "lateral movement of water". Has this been observed in other locations? F2-14

Section 3, Alternatives, General Remarks – The alternatives to the project are nothing more than minor variations on the same theme except for the no-project alternative. All of the other alternatives contemplate the same water storage and retrieval plans with only the water conveyance route to the pumping plant being the variable. These are minor, project-level variations, not alternatives. A reasonable range of alternatives has not been evaluated as is required under the National Environmental Policy Act (NEPA) (40 C.F.R. 1502.14, 1505.1[e]). The current range of alternatives is far too narrow. F2-15

Please evaluate, in detail: 1) other locations for the project, 2) using the Fenner, Bristol, and Cadiz aquifers for storage of Colorado River water only (i.e., no take of indigenous water), and 3) taking a significantly reduced amount of indigenous water, with the amount reflecting USGS estimates for natural recharge to the area. The analysis of these new alternatives should be carried through Section 5 (Affected Environment, Impacts, and Mitigation). Please explicitly discuss a rationale should these alternatives be found rejected from detailed analysis. F2-16

The EIS should also include an alternative which limits or eliminates the amount of indigenous water that will be drawn from the basins and includes additional conservation measures to make up for any deficit in dry years. The EIS declines to consider water rationing, even on a limited basis, as a means for reducing water demand during dry years, except in situations where water shortages have reached critical levels. Public education, xeriscaping, lawn watering on every third day and other water conservation measures have allowed the City of Denver to reduce its average daily per capita water consumption by 11.8 percent in less than ten years. An 11.8 percent decrease in dry-year demand for water in the Metropolitan Water District (MWD) service area would translate into a savings of nearly 500,000 acre feet per year. While the BMP program for southern California is expected to reach a similar goal in 20 years without rationing, there is no consideration of the impact of xeriscaping, increasing water rates during dry years, and every-third-day lawn watering or other similar limited preemptive rationing measures. Adding these items to the list of BMPs could reduce consumption even further and, at very least, negate or reduce the need for the Cadiz project to pump indigenous water from the project area. Thus, the EIS has neglected a significant alternative means of addressing dry year shortfalls in lieu of pumping out indigenous water from groundwater basins that are not even located within MWD's service area. F2-17

Page 3-18, column 1, para. 2, line 2 – Based on reviews conducted by the NPS, USGS, and San Bernardino County, the NPS disagrees with the statement that "the aquifer system has an estimated annual recharge of approximately 30,000 acre-feet per year." USGS Maxey-Eakin Models suggest that the annual recharge for the area is approximately 2,500 acre-feet. This is an order of magnitude less than the EIS estimates. Since the Cadiz Project plans to take the amount of indigenous water that is equal to the annual recharge, these differences in recharge rates are a significant concern to the NPS. Please modify the EIS and the project proposal to reflect revised recharge rates. F2-18

Page 3-20, column 2, last para., lines 3-9: "Spreading basins in the *upper reaches of Fenner Valley* (emphasis added) were initially considered but were rejected because they would be constructed on relatively steep slopes, would require more grading and cause more habitat disturbance...". The upper reaches of Fenner Valley lie completely within the borders of the Mojave National Preserve, yet no mention is made of this unit of the National Park System in the decision to not locate facilities there. Not only would the project disrupt a protected ecosystem, it would be incompatible with the current land use. F2-19

Page 3-40, Section 3.8.4 - The selection of the preferred environmental alternative should be reexamined. The EIS cites that by selecting the no action alternative, environmental impacts would result from the potential lowering of the water table within MWD's service area. No mention is made, however, of the potential lowering of the project site's water table and its subsequent environmental impacts to the immediate area and the adjacent Mojave National Preserve. F2-20

4.0 Description of Project Alternatives

Page 4-63 – Since the EIS discounts the no action alternative based upon the impact to a groundwater basin, it should also discount the proposal for its potential impact to the Fenner Basin. F2-21

In the next paragraph (Conveyance and Storage Deficits), the no-action alternative will not *cause* an increase in the deficit. With the no-action alternative there is a projected deficit. The projected deficit is caused by increase water consumption without any conservation measures being imposed. The no-action alternative could not cause an impact because there would be no action. F2-22

Page 4-63 - Including the construction of a desalination plant should not be included with the no action alternative. It is a separate action and should be considered as a separate alternative. F2-23

5.0 Affected Environment, Impacts and Mitigation

Page 5-17, column 2, para. 2, line 4 – Since the Cadiz project is not in conformance with the CDCA plan, BLM also has the option of not permitting the project. F2-24

Page 5-16 – The EIS states that the project impact would be limited to small areas. Please quantify. F2-25

Page 5-44 - It is incorrect to say that a fault is considered to be not potentially active. Inactive faults can have the potential to become active. F2-26

Page 5-46 - "Future seismic activity in the Cadiz Project area would not be expected to have any impacts on the boundaries between individual groundwater basins or to create channels for movement of groundwater between basins". This statement should be clarified with a statement that major seismic activity could cause changes to groundwater basins and its channels. F2-27

Page 5-58 – The potential effects of subsidence need to be addressed in greater detail in this chapter. The EIS states that the topic is addressed more fully under mitigation measure WR-1, but nowhere in the EIS are the impacts fully described. F2-28

Page 5-65, Section 5.4.6, Level of Significance after Mitigation – Subsidence is not listed here as a significant impact after mitigation, yet on page 5-52 a project is said to have a "significant adverse impact" if it results in land subsidence. The EIS further states that mitigation measure WR-1 on page 5-105 will reduce the potential subsidence effects to below significant. However, WR-1 calls for monitoring and subsequent remedial actions if the monitoring shows subsidence of more than one foot per mile. Whatever corrective action is taken after this monitoring cannot prevent the problem because the subsidence would have already occurred. Therefore, the impact must be significant under the criteria established in the EIS. Remedial actions listed on F2-29 page 5-106 include repairing damaged structures and modifying the project storage and extraction schedules. How does repairing damaged structures prevent subsidence or mitigate this impact to below significance? How would the project storage and extraction schedules be modified? Would they be modified to prevent further subsidence? Why isn't cessation of extraction one of the remedial measures listed for mitigation of subsidence? Please modify sections 5.4 and 5.5 to indicate that impacts associated with subsidence are significant after mitigation. F2-29

Page 5-66, column 1 – There is little discussion of the Mojave National Preserve throughout the EIS, despite the fact that it is a 1.6 million-acre unit of the National Park System located just 15 miles north of the project area. The description of the physiography and topography here is one such place that the Preserve could be described. In addition, please include in the EIS a map similar to the one on page 5-67, but showing the southern boundary of the Preserve. F2-30

Page 5-80, Groundwater Recharge – The EIS states that groundwater recharge occurs at the upper elevations of the basin. Please state that this is within the Mojave National Preserve. F2-31

Page 5-80, column 2, para. 1, lines 9-11 – The EIS states that "the occurrence of active groundwater replenishment in the Bristol, Cadiz, and Fenner watersheds is supported by...isotopic evidence for a geologically recent age (Holocene) for the groundwater." The USGS, however, has determined that isotopic data from this EIS and other studies suggest that there is limited recharge to these basins under present day climatic conditions. Indeed, groundwater in these desert basins was recharged thousands of years ago. To say that isotopic data suggest there is "active groundwater replenishment" is a misrepresentation of the scientific evidence. F2-32

Page 5-80 – The EIS states that there was no significant decline in the groundwater table from 1983-1998. This implies that there was some decline. What was the decline? If the recharge is greater than the extraction, why is there a decline? Please explain. F2-33

Page 5-81, Groundwater Discharge - The EIS reports that current ground water withdrawal at the Cadiz site is 5,000 to 6,000 acre-feet per year and then reports that no significant declines have resulted. What is the extent of the monitoring network and data from which this conclusion was drawn? Also, what is considered a "significant" decline? F2-34

Page 5-83, Section 5.5.2 – The threshold of significance for depletion of groundwater contains too many conditions. It should not be tied to impacts on nearby well production and permits for existing or planned uses of the groundwater. Depletion of groundwater resources at rates in excess of natural recharge should be the threshold of significance. This threshold should be determined quantitatively after the natural recharge rate has been established accurately. If this is not possible, the threshold of significance should be based on monitoring results which indicate a defined lowering of elevation of the groundwater table that signifies that the depletion rate has exceeded the natural recharge rate. F2-35

Page 5-89 – The table depicting project operational scenarios raises questions. What agency is responsible for regulating "put" and "withdraw"? What assurances are there that water will be "put" for a number of years before it is withdrawn? The EIS states that water will be "put" in wet years and "withdrawn" in dry years. Who decides what constitutes a wet year vs. a dry year? What if there are no wet years? Will the project become merely a water mining/extraction operation if there are no wet years? There is confusion in describing the project as a "wet year F2-36 storage and dry year withdrawal" project. It is unreasonable to assume that, in every scenario, there will be at least 5 wet years with which to begin. The NPS assumes that this reflects surplus years on the Colorado River; not wet years on the Colorado River or in the Fenner Valley basin. Further, NPS assumes that "dry year" refers to dry years on the Colorado River. Please define these terms so the proposal is understandable. F2-36

Page 5-91, Potential Impacts to Nearby Communities - The only information presented in the EIS concerning Mojave National Preserve is that it is 15 miles north of, and up-gradient from the project spreading basins and well field. While these are important considerations, the EIS should include a description of the Preserve's water dependent resources. These include many springs and seeps that support the nationally important flora and fauna resources of the Preserve, including its designated Wilderness Areas. Even very small sources of water in a desert environment are critical to preserving these resources. These springs could be impacted by changes in the characteristics (e.g. water level or gradient) of the valley bottom aquifers. Additionally, there are designated Wilderness areas on BLM lands outside of the Mojave National Preserve that equally depend upon springs and seeps for their ecology. The EIS states that there is no potential for impact to groundwater underlying Mojave National Preserve. However, the ground-water model developed for this EIS shows predicted drawdown up to 25 miles away from the proposed pumping centers (Cadiz, Inc., attachment 2), well within the range of Mojave National Preserve. The EIS does not present any simulated drawdown contours so it is difficult for the reader to understand the extent of potential ground-water drawdown and therefore, the extent of potential impacts. It is important to note that even a very small drawdown can have a dramatic effect on spring flow. The limited information NPS has received on the model results suggest that there is potential for drawdown to occur upgradient and in areas well outside the Project area, possibly within the Mojave National Preserve. F2-37

Page 5-91, Impacts to Water Resources – The EIS must show a map of projected drawdown contours (i.e., the cone of depression), including the maximum drawdown, under various infiltration and extraction scenarios. Please identify on this map all springs, seeps, wells, riparian areas and other water sources, and superimpose on it the boundary of the Mojave National Preserve. Groundwater contour maps are a basic output component of three-layer groundwater models such as the one used in the Cadiz EIS. Such maps were presented to NPS by Cadiz, Inc. on 2 February 2000 (see attachment 2). The zero drawdown contour extends to the north, but is off the maps and outside the model boundary. How far north does the zero contour extend? The Old Woman Mountains Wilderness appears to be within this contour. Will there be impacts to springs in this wilderness as a result? Does the contour extend into the Mojave National Preserve, and will there be resultant impacts to NPS water resources? F2-38

Page 5-95 - Releasing "1,015,532 tons of salt" and "12.2 tons of perchlorate" into the groundwater table should be considered a significant impact. Please revise the EIS accordingly. F2-39

The State's provisional limit on perchlorate is 18.0 nanograms per liter. The EIS suggests that the Colorado River water is two orders of magnitude more polluted than what is considered safe for human consumption.

Page 5-103, Springs and Phreatophytes – The EIS states there would be no impact to springs in the Clipper Mountains. The concerns presented above leave NPS hesitant to agree that there would be no impact as stated. F2-40

Page 5-105 – What agency would be responsible for approving and enforcing the groundwater monitoring and mitigation plan? F2-41

Page 5-105 – NPS withholds detailed comment on the Mitigation Measures for water resources until a detailed monitoring and mitigation plan is prepared. F2-42

Page 5-107, column 1, para. 2 – The EIS states, "Potential impacts to water resources include adverse changes to the quality and quantity of surface water and groundwater," but concludes that these impacts will not be significant because of a forthcoming monitoring and mitigation plan. This is not a valid conclusion. Until a detailed monitoring and mitigation plan passes agency review and public scrutiny, the significance of the impacts cannot be adequately quantified. F2-43

Section 5.6, Air Quality – The EIS states that the Cadiz Project would be in a nonattainment area for ozone and particulate matter (PM10). Therefore, the project emissions would be subject to the General Conformity Rule found at 40 CFR 93.150. Under this rule, the BLM must determine whether the project emissions will be above the de minimus levels found in the Clean Air Act regulations. Was this determination made for ozone and PM10? There does not appear to be a conformity discussion in the EIS, so the NPS assumes that a conformity determination was not made. BLM must issue a draft conformity discussion to the public for a 30-day review per 40 CFR 93.156. NPS recommends that this public review run concurrent with a comment period for a supplemental draft EIS. F2-44

Page 5-113, Sensitive Receptors – The Mojave National Preserve is a sensitive receptor. F2-45

Page 5-116, Air Quality, Operations Impacts – As the project extracts water, Cadiz and Bristol Dry Lakes will become drier. Please provide an analysis of the air quality impacts associated with this effect. Impacts to the Mojave National Preserve should be included in the analysis. F2-46

Page 5-261 – NPS is concerned about impacts to the night sky. We request that any permanent night lighting associated with the project be shielded and controlled by a switch or motion sensor so that they do not remain lit continuously. F2-47

7.0 Cumulative Impacts

Section 7, Cumulative Impacts - The cumulative impacts analysis incorrectly assumes that only other MWD water projects (Hayfield Groundwater Storage Project) should be taken into consideration in the cumulative impacts analysis. This is a serious flaw in the analysis and may void the entire cumulative impacts analysis. The cumulative impacts analysis needs to take into consideration the impacts from other projects which affect the same resources. This would include, but not be limited to existing agricultural projects such as Cadiz, Inc.; other wells and water extraction facilities in the Bristol, Fenner, and Cadiz aquifers; playa mining operations; existing traffic; etc. F2-48

The definition of cumulative impacts on page 7-1 is inaccurate, and leads the reader to believe that a project must be "closely-related" to contribute to cumulative impacts. As stated above, however, a project need only have similar impacts or affect the same resources to contribute to cumulative impacts. Please revise the definition of cumulative impacts per 40 CFR 1508.7, and rewrite the cumulative impacts chapter in the EIS based on this corrected definition.

The cumulative impacts analysis fails to separately assess cumulative impacts from each alternative in conjunction with other projects. F2-49

The cumulative impacts analysis for Water Resources (7.5.5) does not take into account the past, present and reasonably foreseeable future impacts of the project on the volume of indigenous groundwater withdrawn from the project basins when combined with the groundwater pumping by Cadiz, Inc.'s agriculture operations and possibly other groundwater users which draw from the same aquifers. Significant cumulative effects include changing the elevation of the groundwater in the basin by decreasing it more than 150 feet. Other significant cumulative effects include drawing out up to two million acre-feet of indigenous groundwater over the life of the project, when combined with Cadiz Inc.'s additional 61,740 acre feet drawn from the project basins over the past 15 years plus their projected water use for the foreseeable future. F2-50

The cumulative impacts analysis does not take into consideration the impacts of the Rail Cycle project which, according to the EIS on page 5-11, "could result in potential impacts on groundwater which would affect the Cadiz Project." Not only could the Rail Cycle project impact the Cadiz Project, but the combined impacts of the Cadiz Project and Rail Cycle could have significant impacts on the groundwater, traffic, air quality and other aspects of the environment. Although the Rail Cycle project is currently tied up in litigation, it is a "reasonably foreseeable future action" which should be taken into consideration in a cumulative impacts analysis. F2-51

The cumulative impacts analysis does not take into consideration the cumulative impact of water conveyance structures and other linear structures which may prevent wildlife migration. In particular, there is no cumulative impacts analysis for the combined impact of the parallel alignment and potential barriers of the Eastern Canal (alternative), the Cadiz Rice Road and the Arizona California Railroad line on desert sheep, desert tortoise, and other wildlife migration patterns. F2-52

10.0 Irreversible and Irretrievable Commitment of Resources

Page 10-1, Irreversible and Irretrievable Commitment of Resources - Irreversible environmental changes caused by the project should include basin subsidence and reduced groundwater carrying and holding capacity of the groundwater basin as a result of the subsidence. Additionally, depletion or significant reduction of indigenous groundwater from the basin should be included if natural recharge will take many years to bring the basin back to existing groundwater levels prior to the project. The project itself may be an irreversible and irretrievable commitment of resources such that the projected 50-year project life will be lengthened indefinitely. As such, the impacts to the groundwater basin caused by the project will be lasting, indefinite, and, perhaps, irreversible. F2-53

15.0 Glossary of Terms, Acronyms and Units of Measure

Page 15-1, Glossary - Define "Cumulative Impacts" using the NEPA or CEQA definition. The current definition is neither a CEQA nor a NEPA definition. Define "Direct Effect" using the NEPA or CEQA definition. Define "Indirect Effect" using the NEPA or CEQA definition. There is no distinction under either NEPA or CEQA between "direct effects" or "indirect effects" and "direct impacts" or "indirect impacts" respectively. Both CEQA and NEPA regulations state that "impacts" and "effects" are synonymous. 40 CFR 1508.8, 14 CCR 15358. This distinction between "impacts" and "effects" should be eliminated from the glossary and anywhere it is used F2-54 in the EIS/EIR. Therefore, delete the definitions of "Direct Impact" and "Effect" from the glossary. F2-54

2. Air Quality

The wind rose on page 5-74 of the EIS shows that winds blow from the south through the project area 20% of the time during the period evaluated. Pumping plans in the EIS call for the project to pump more water than it recharges. This will create less groundwater discharge at Cadiz and Bristol Dry Lakes. Over the long term, water levels beneath the lakes would decline. Lower water levels would then cause the upper sediments of the lakes to dry out and result in a dust problem. As is evident from the figure on page 5-74, this dust could easily blow into the Mojave National Preserve. NPS considers this a significant impact and one that is unacceptable. Please provide an analysis of this issue and modify the water resources and air quality sections as appropriate. The project must be modified to prevent this potential effect, and monitoring and mitigation must be implemented to ensure that the Cadiz Project will have no long-term negative effects to air quality in the Preserve. F2-55

3. Adequacy of the Monitoring and Mitigation Plan

The EIS refers throughout the document to a "Groundwater Monitoring and Management Plan" F2-56 that will be prepared for the Cadiz project. This document is discussed briefly on page 5-105 of the EIS. Each impact to water resources that is listed as potentially significant in the EIS is supposedly mitigated by this plan. Specifically, see impacts associated with ground structure instability (subsidence, hydrocompaction, and liquefaction), water quality (changes in surface and groundwater quality, movement of the saline/freshwater interface), and water quantity (groundwater levels, groundwater supply to Bristol and Cadiz Dry Lakes) on pages 5-105 – 5-107. The details of the monitoring and mitigation plan are not outlined in the EIS, however, so the public has no basis for which to judge the effectiveness of this plan. Until the details of this plan are released, it is impossible to judge whether the monitoring and mitigation plan would truly reduce the level of impacts to below significance.

It is the understanding of the NPS that the monitoring and mitigation plan is currently in production. Nevertheless, the plan must pass public review and scrutiny in an appropriate NEPA forum, especially since it is being used to suggest that it will alleviate each significant impact to water resources. NPS requests that a monitoring and mitigation plan be prepared in advance of the final EIS with the advice and assistance of USGS and appropriate stakeholders including NPS and San Bernardino County. The monitoring must include measures that will provide an early warning of potential impacts to the Mojave National Preserve and to wilderness areas. The mitigation must have legally-enforceable, regulatory controls and triggers sufficient to modify or halt the project if necessary to control impacts. This plan would constitute "significant new information" as described by NEPA regulations, necessitating the preparation of a revised draft or a supplemental draft EIS. The monitoring and mitigation plan should serve as an attachment or appendix to the new EIS.

4. Modified Project Proposal and Environmental Analysis

A project that negatively impacts any springs, seeps, or riparian areas in any wilderness area or in the Mojave National Preserve is not acceptable. Water resources in wilderness and the Preserve are protected federal water rights and are a trust resource belonging to the American public. In the arid desert environment, the few surface water resources that do exist are critical to wildlife and the maintenance of a delicate ecosystem. If the project pumps out more indigenous water than is naturally recharged, there could be a significant negative effect to these resources. Based on the results of the independent review of the *Cadiz Water Resources* report, there is ample evidence that the existing groundwater study contains serious technical flaws. The study must be revised in order properly assess the impacts of the project on groundwater resources both within the project area and on adjacent lands, including the Mojave National Preserve. F2-57

If the revised groundwater study supports the findings of the USGS and the other reviewers, the project proposal must be modified so that the Cadiz Project and MWD take no more indigenous water than is naturally recharged on an annual basis, or will cause a change in any water source in a wilderness area or the Mojave National Preserve. Based on the results of the USGS and other reviewers, the natural groundwater recharge rate should be at least an order of magnitude less than that currently suggested in the EIS.

NPS requests that you prepare a new groundwater model that accurately reflects the groundwater hydrology of the desert basins in question. This document should be prepared with the advice and assistance of interested stakeholders including NPS and the County of San Bernardino. Further, the groundwater study should reflect the consensus view of all pertinent groundwater resources experts, including the USGS, NPS water resources experts, consultants for San Bernardino County, MWD, and specialists for other affected parties.

The implementing regulations for NEPA state that agencies shall prepare supplements to draft environmental impact statements if "there are significant new circumstances or information relevant to environmental concerns and bearing on the proposed action and its impacts." (40 CFR 1502.9). These regulations further state, "If a draft statement is so inadequate as to preclude meaningful analysis, the agency shall prepare and circulate a *revised* draft...". The Cadiz Project requires a new modeling effort and water analysis, and therefore necessitates preparation of a revised draft or supplemental draft EIS. A revised environmental analysis must allow the public adequate opportunity to comment on the potential environmental effects that are predicted by an accurate water resources study. Please prepare a new groundwater study and a revised draft or supplemental draft EIS and issue it to the public for review. F2-58

The revised or supplemental draft EIS also must undergo substantial revisions to address the concerns stated above, including but not limited to incorporation of a completed mitigation and monitoring plan, revised and expanded evaluation of air quality issues, and revised alternatives and cumulative impacts analyses.

It is my sincere hope that we can work together to resolve NPS concerns about the Cadiz EIS, and more importantly, the entire Cadiz project. As you know, Christopher J. Stubbs of my staff is the NPS coordinator for the review of this project. Feel free to contact Chris at (760) 255-8815 with questions about this letter or any other concerns you may have. F2-59

Sincerely,

Mary G. Martin, Superintendent

Attachment 1:
USGS Review

] F2-60

In Reply Refer To: Feb. 23, 2000
Mail Stop 423

MEMORANDUM

To: Molly S. Brady, Field Manager
Bureau of Land Management, Needles, California

From: James F. Devine /Signed/
Senior Advisor for Science Applications

Subject: Review of the Cadiz Groundwater Storage and Dry-Year Supply Program Draft Environmental Planning Technical Report, Groundwater Resources, Volumes I and II.

As requested by the U.S. Department of the Interior, Bureau of Land Management, the U.S. Geological Survey has reviewed the subject draft report. This draft report was written in support of the Cadiz Groundwater Storage and Dry-Year Supply Program Draft Environmental Impact Report/Draft Environmental Impact Statement/SCH. No. 99021039 (referred to as Draft Report in this review). This memorandum presents USGS comments.

GENERAL COMMENTS:

The Metropolitan Water District of Southern California has proposed a water storage project known as the Cadiz Groundwater Storage and Dry-Year Supply Program (Cadiz Project). The aim of the Cadiz Project is to ensure the reliability of Southern California's existing water supply via the Colorado River Aqueduct by storing Colorado River water in the Fenner, Bristol, and Cadiz watersheds during wet years and withdrawing stored water along with indigenous ground water during dry years. The proposed project would utilize the ground-water basin underlying the Cadiz and Fenner valleys for storage of part of Metropolitan's Colorado River supplies during wet years for later recovery and use during dry years. One of the stated project objectives is to provide up to 2.0 million acre-feet (maf) of indigenous ground water for transfer out of the watershed. In the Draft Report, indigenous ground water is defined as water that naturally recharges the ground-water system on a long-term average. A watershed model and water balance calculations, developed as part of the Draft Report, estimated that the quantity of indigenous water ranges from 20,000 to 71,000 acre-feet per year. A ground-water flow model was used to evaluate the impacts of the proposed project; the model assumed that the annual recharge to the Fenner, Bristol, and Cadiz watersheds was 50,000 acre-feet per year. The review of the Draft Report shows that the watershed model and water-balance studies presented in the Draft Report overestimate the natural recharge to the basin by 5 to 25 times the values estimated by this review team using similar methods. It is the opinion of the review team that the regional watershed model, water-balance studies, and ground-water flow and transport models were used without adequate data to support the results and the conclusions presented in the Draft Report. The assumptions and methods applied in the development and calibration of both the watershed and ground-water flow models, which are essential for predicting the environmental impacts of the proposed project, are not defensible. The ground-water flow model was developed using an overestimate of natural recharge. This calls into question the usefulness of using the results of the ground-water flow model for predicting the environmental impact of this project. Until more appropriate fluxes and boundary conditions are used, the environmental impact of this study is yet unknown. The following discussion highlights the analysis and rationale for the above statements.

A watershed model was used to calculate "recoverable water" in the basin. Recoverable water was defined in the Draft Report as the total amount of surface runoff and infiltrating water that reaches the regional water table (ground-water recharge or indigenous ground water). The Draft Report estimates that the total amount of recoverable water for the entire watershed ranges from 20,000 to 58,000 acre-feet per year, with a median value of 39,000 acre-feet per year. The watershed model is a detailed daily water budget model: daily precipitation, infiltration, runoff, vegetation interception, evapotranspiration, soil moisture, and percolation are addressed. However, the model does not address bedrock permeability, and this may become an important factor for upland areas, such as the Providence Mountains, where low permeability granitic and metamorphic rocks underlie shallow soils. The model simulates the greatest amount of percolation in these areas; however, the bedrock permeability may be less than the simulated percolation rates. If this is the case, the model should be simulating runoff instead of percolation. Another major problem is that the model does not incorporate any routines to route water through the surface drainage network and estimate downstream flows and subsequent percolation. The fact that runoff occurs does not imply that the water will percolate farther downstream in the basin and eventually become recharge. Vegetation in desert environments is very efficient at extracting soil water from great depths. For example, creosote has been reported to extract water from depths as great as 18 feet below land surface. The model will overestimate the recoverable water (annual recharge) to the watershed because the watershed model does not address bedrock permeability and assumes that all runoff from a soil area becomes recharge.

Two types of data were used in the Draft Report to support the watershed model results: chloride mass balance data and isotopic data. The chloride mass balance approach was not properly applied and greatly overestimates water availability in the basin. In the Draft Report, the total area of the Fenner watershed was assumed to contribute recharge; however, studies by Prudic (1994) and Izbicki et al. (1998) indicate that recharge has not occurred on the valley floors of the neighboring Ward Valley and Mojave River basin for thousands of years. Dettinger (1989) estimated that some recharge might occur in alluvial basins in Nevada as a result of precipitation, runoff, and infiltration at elevations in excess of 4,000 feet. If one assumes that recharge only occurs at elevations in excess of 4,000 feet in the Fenner watershed, this would reduce the area of potential recharge from 718,000 acres to 126,000 acres. Another problem with the chloride mass balance approach, as applied in the Draft Report, is that the assumed chloride concentration of precipitation (3.5 milligrams per liter) is much higher than the values used by other investigators (0.4 to 0.8 milligram per liter) (Dettinger, 1989; Prudic, 1994). If one assumes that only the area of the watershed with elevations in excess of 4,000 feet can contribute recharge and that the chloride concentration of precipitation is 0.8 milligram per liter (Prudic, 1994), then the estimated recharge for the Fenner watershed, using the chloride mass-balance approach, is 1,710 acre-feet per year. This value is more than 20 times less than the value of 40,000 acre-feet per year estimated in the Draft Report.

The occurrence of active ground–water recharge in the Fenner, Bristol, and Cadiz watersheds is reported in the Draft Report to be supported by isotopic evidence of geologically "recent" (Holocene) age of ground water. Carbon-14 data from observation wells in Fenner Gap range from 18 to 25 percent modern carbon and have apparent ages ranging from 11,500 to 14,000 years before present. The Draft Report suggests that water-rock reactions have occurred and ground-water ages are younger than the apparent ages indicate. On the basis of carbon-13 data provided as part of the Draft Report, it is apparent that reactions have occurred between ground water and aquifer materials; however, it is still possible to interpret the carbon-14 data. A complete interpretation of possible rock-water reactions and resulting corrections in carbon-14 data was beyond the scope of this review; however, an estimate of corrected carbon-14 ages for the Fenner Gap samples was made on the basis of data and rock-water reactions interpreted from other studies. As described in the review comments for section 9.3, the corrected carbon-14 ages range from 5,500 to 10,600 years before present. As a group, the isotopic data show that there is limited recharge under present-day climatic conditions and that ground water sampled at Fenner Gap was recharged thousands of years ago.

The USGS, as part of this review, estimated recharge in the Fenner, Bristol, and Cadiz watersheds using a modified Maxey-Eakin model (1949). The model assumptions and results are included as an attachment to this review. The USGS completed two models for the region. The first model used an elevation-precipitation correlation based on a network of 114 precipitation stations in the Great Basin and the Mojave Desert and represents the regional elevation-precipitation correlation. The second model used an elevation-precipitation correlation for four stations in or near the Cadiz watershed. This model provides unrealistically high estimates of precipitation for elevations of 5,000 feet and higher and does not correctly represent the relation of precipitation with elevation on a regional basis (see attachment). Recharge estimates obtained using the first model provided reasonable estimates of spatially distributed recharge based on a comparison of recharge estimates obtained for various locations throughout the southern Nevada and south-central Great Basin regions. The estimates obtained from the first model were consistent with previous estimates of recharge in the Mojave Desert region, and were more than one order of magnitude less than the recharge estimates obtained from the Draft Report for the three watersheds included in the Cadiz study area. For example, the Draft Report estimated median value of 39,077 acre-feet per year for the three Cadiz area watersheds is 15 times greater than the USGS model (model 1) estimate of 2,550 acre-feet per year. Recharge estimates obtained using the second model were based on unjustifiably high maximum precipitation rates of 500 to 750 millimeters per year for the higher elevations of approximately 6,500 to 7,500 feet. Although precipitation estimates obtained using the second model can be considered reasonable for elevations of approximately 4,000 feet and less, the relatively high precipitation estimates obtained for the summit areas of the Granite and New York Mountains are more representative of expected precipitation rates for elevations of 10,000 feet and higher in the southern Basin and Range Province. Even when using the very unrealistic precipitation rate for the Cadiz area, the total basin recharge estimated by the second model is still approximately 5 times less than the total basin recharge simulated in the ground-water flow model developed for this Draft Report. This result indicates that the modified Maxey-Eakin model cannot provide the recharge magnitudes indicated in the Draft Report, even when attempts are made to account for uncertainty in precipitation estimates (the original Maxey-Eakin model would estimate even less recharge). In summary, the median recharge rates estimated by the Draft Report watershed model are most likely 15 times higher than the values estimated by the preliminary Maxey-Eakin models developed by the USGS.

The water-balance studies in the Draft Report estimated long-term recharge by estimating discharge by soil evaporation on the Bristol and Cadiz dry lakes. Prior to ground-water development in the watershed, natural ground-water recharge was equal to natural ground-water discharge or, in this case, soil evaporation from Bristol and Cadiz dry lakes. The Report multiplied an assumed soil evaporation rate by the area of the dry lakes. This method assumes evaporation occurs over the entire area of the lakebed (41,600 acres for Bristol and 29,788 acres for Cadiz) and neglects any contribution by surface-water runoff on the lakebed. The total evaporation estimated in the report ranged from 20,000 to 71,000 acre-feet per year. The final value used in the ground-water model developed for the Draft Report was 50,000 acre-feet per year; therefore, the average evaporation rate used in the Draft Report was 0.7 foot per year. As part of this review, the USGS measured the area of the lakebeds to be 58,457 acres, about 13,000 acres less than the Draft Report value. Water-level data from wells constructed on the lakebed indicate that the depth to water exceeds 10 feet throughout most of Bristol dry lake (Moyle, 1967). Kunkel and Chase (1969) estimated that the annual rate of evaporation from bare soil on China Lake in Indian Wells Valley decreased to negligible amounts at water-level depths of more than 7 feet below land surface. An ongoing study by the USGS in Death Valley has measured rates of about 0.17 feet/year on a salt playa (salt crust) where the depth to water was less than 1 foot (Guy DeMeo, USGS, WRD, Las Vegas, Nevada, written communication, 2000). If one uses the Death Valley number for the evaporation rate (0.17 foot per year), and multiplies that by the area of dry lake playa surface digitized from the geologic map (58,457 acres), the estimated evaporation is 9,900 acre-feet per year. This value probably overestimates the evaporation, because it uses the total area of the lakebeds and ignores any contribution from surface runoff. The total evaporation used in the ground-water flow model (50,000 acre-feet per year) is unreasonable on the basis of depth to water and soil characteristics, and needs to be significantly reduced. Multiple depth monitoring wells are needed on the dry lakes to determine the depth to water. The evaporation from the lakebeds needs to be measured using energy-budget methods (Laczniak et al., 1999) or salt crust accumulation methods (Feth and Brown, 1962) to better quantify this water loss.

As has been stated above, the quantity of natural ground-water recharge to the Fenner, Bristol, and Cadiz watersheds and discharge (evapotranspiration) from Bristol and Cadiz dry lakes has been grossly overestimated. A direct result of these overestimates of recharge and discharge is that the ground-water flow model developed as part of the Draft Report is incorrect because it was calibrated using overestimated recharge and evapotranspiration values. Specifically, the aquifer parameters (e.g., hydraulic conductivity, transmissivity, and the extinction depth for soil evaporation from the dry lakebeds) are overestimated. In general, the consequences of an incorrect model are inaccurate simulations of steady-state and transient conditions (water levels and simulated fluxes) and unreasonable predictions of water levels and fluxes in response to the proposed put/take scenarios. The model needs to be recalibrated before it can be used to predict water-level changes, solute movement, and land subsidence resulting from the planned recharge/pumpage operation. The operating scenarios described for the Cadiz Project's 50-year term of operations indicate a transfer of 1.3 to 2.0 million acre-feet of indigenous ground water out of the watershed. The Draft Report assumes that 2.5 million acre-feet of natural ground water will recharge the watershed over the 50-year term of the project; therefore, the Draft Report predicts that there will be no long-term ground-water-level declines. However, if the natural recharge is less than the quantity of indigenous ground water transferred out of the watershed, water-level declines will be greater than currently simulated by the model. The ground-water flow model needs to be recalibrated with lower values of natural ground-water recharge. After the model has been recalibrated, the model needs to simulate the long-term effects (100 to1,000 years) of the proposed project on water levels and ground-water discharge to Bristol and Cadiz dry lakes. The model grid will need to be expanded to evaluate the long-term impact of ground-water withdrawls on spring discharge and water levels in Fenner Valley.

The brines present beneath the dry lakes have a greater density than freshwater. Consequently, a density-dependent solute transport model is needed to accurately simulate the movement of the brine. A nondensity-dependent model, MT3D, was used to simulate the brine movement for this Draft Report. This model cannot simulate a density-dependent solute transport problem and, therefore, any results and conclusions regarding the water levels and movement of brine near the dry lakes are questionable.

In summary, the results of the watershed model, chloride mass-balance studies, isotopic data, water balance (evaporation at the dry lakes), and ground-water flow and solute transport models presented in the Draft Report greatly overestimate natural ground-water recharge and discharge. Data presented in the Draft Report and all previous studies done in the area are consistent with small amounts of recharge to desert basins. The 50,000 acre-feet per year of natural ground-water recharge to the Fenner, Bristol, and Cadiz watersheds is 5 to 25 times the values estimated by the review team. Such a large error in such an important component of the model invalidates the flow and solute model results and predictions. No matter what the actual recharge value is, if the project pumps more water than it recharges, there will be less ground-water discharge at the dry lakes. Over the long-term, this will cause water levels beneath the dry lakes to decline. A density-dependent solute-transport model is needed to evaluate the long-term impacts of the project on the brine levels. The Draft Report does not address how water-level declines will impact the dry lakes. With a decrease in ground-water discharge, will the mining operation at the dry lakes be impacted? Will lower water levels cause the upper sediments to dry out and result in a dust problem? The failure of the model to simulate the water levels beneath dry lakes invalidates the model's ability to predict any impacts resulting from the recharge/pumping operation on water levels and solute transport beneath the dry lakes. With less recharge in the model, water-level declines resulting from the pumping phase of the project will be greater than currently estimated. This will undoubtedly cause the high salinity water beneath Bristol dry lake to move towards the pumping wells, assuming there does not exist a ground-water barrier between the well field and Bristol dry lake. If ground-water pumpage of indigenous ground water exceeds the natural recharge to the watershed, there will be long-term impacts on water levels and natural ground-water discharge (evaporation and spring discharge) from the watershed.

As part of this review, the U.S. Geological Survey was requested to recommend ground-water monitoring and management strategies for the Cadiz Project. Preliminary recommendations are included in this summary and throughout the review document. Following are some of the more significant recommendations. Prior to the initiation of this project, better estimates of natural recharge and discharge need to be made. Infiltration of precipitation and streamflow should be quantified by collecting soil-moisture, chemical, and isotopic data in areas of potential recharge. A long-term ground-water-level and quality monitoring network needs to be established to help determine the impacts from the project. The network should include multiple-well monitoring sites to monitor water levels and water quality with depth. Monitor wells will be needed on the dry lakes to determine if the lakes are hydraulically connected to the regional aquifer. Monitor wells will be needed above the current water table to sample the recharge water during the put phase of the project, when water levels will rise in response to the artificial recharge. Wells will also be needed about 100, 250, and 500 feet below the current water table to monitor the movement of the recharge water. Microgravity measurements could be collected to estimate water levels in areas where well data are sparse. A revised ground-water flow model could be used to optimally locate the monitor well sites. Springs within the predicted long-term (100-year) drawdown cone should be monitored for flow and water quality. Velocity logs and downhole sampling should be completed on the production wells to help determine the principal zones contributing water to the wells. This information will be important for recalibrating the ground-water flow model and designing the proposed well field. Soil evaporation from Bristol and Cadiz dry lakes should be measured using energy-budget or salt accumulation methods prior to and during the proposed project to help determine the impact of the project on the dry lakes. Interferometric synthetic aperture radar (INSAR) could be used to monitor land movement (inflation or subsidence) that may occur as a result of the proposed project (Galloway et al., 1998). The INSAR images could be used to help locate potential barriers or changes in aquifer properties.

<u>SPECIFIC COMMENTS:</u>

2.0--INTRODUCTION

Page 15, 2.2, Purpose and Scope. Is this the purpose and scope for the entire project or just for the pilot study? In this part of the report one would expect the purpose and scope for the entire project. Much of the material that follows has to do with determining the hydrogeology of the area. The pilot test study is a small part of Volumes I and II.

Page 16, 2.4, Previous Investigations. The authors list previous investigations but do not list the major findings of the reports. For example, Friewald (1984) estimated underflow through Fenner Gap to be 300 acre-feet per year, significantly less than the value of 30,000 acre-feet per year presented in the Draft Report. The report states that Prudic (1994) estimated percolation rates and ages of water in the unsaturated sediments in the Mojave Desert. The Draft Report neglects to report that Prudic (1994) estimated that the age of water at the depth of 10 meters is between 16,000 and 33,000 years. In addition, percolation rates below a depth of 10 meters at the Ward Valley site (the basin directly east of Fenner Valley) were on the order of 3 to 5 centimeters per 1,000 years. Prudic's results indicate that there is no recent recharge at the sites that he studied. The Draft Report presents a list of companies involved with investigations in the Bristol and Cadiz dry lake areas but does not discuss the findings of these studies. The reports by P.E. LaMoreaux & Associates, Inc. (1995) and Boyle Engineering Corporation (1996) question the quantity of ground-water underflow reported by Cadiz Land Company, Inc. (20,000 acre-feet per year) and suggest that the quantity of underflow is significantly less (3,000-4,000 acre-feet per year). The results of these studies need to be presented and evaluated.

Page 19, 2.5, Data Sources. The Draft Report states that it used data from Moyle (1967), but later in the Draft Report, Moyle's (1967) measurements of depth to water beneath the dry lakes were not used in the computation of evaporation from the dry lakes. The report utilizes data by Shafer (1964) later in the Draft Report to substantiate paleo river channels. This report is not readily available; therefore, it would be beneficial to reproduce some of the key elements of the Shafer (1964) report in this document.

3.0--DESCRIPTION OF AREA

Page 29, 3.2, Drainage Boundaries and Surface Stream System. The Draft Report considers Bristol, Cadiz, and Fenner one drainage system because all surface and ground water are reported to drain to a central location. However, it should be noted that the surface-water drainages of Bristol and Cadiz are separated by the coalesced alluvial fans of the Calumet Mountains to the south and the Marble Mountains to the north. Rosen (1992) reports that both basins have completely separate internal drainage. The ground-water basins are not well defined; however, northwest-southwest regional faulting may separate the Bristol and Cadiz ground-water systems. Sparse water-level data from Moyle (1967) suggest that there may be a barrier to ground-water flow on the eastern end of Bristol Dry Lake. Additional data are needed to better define the ground-water flow system. Data are not presented in the report to show that Bristol and Cadiz basins are closed ground-water basins.

The Draft Report includes the southern third of Lanfair Valley in the Fenner watershed. The southern third of Lanfair Valley is indeed part of the surface-water drainage system; however, it is probably not part of the Fenner ground-water basin. Friewald (1984) includes the southern third of the Lanfair Valley as part of the Lanfair ground-water basin. Ground water that recharges at the flanks of the New York Mountains moves to the east in Lanfair Valley and discharges at Piute Spring on the eastern part of the valley (Friewald, 1984). The Woods and Hackberry Mountains and the Vontrigger Hills form the southern boundary to the Lanfair ground-water basin. Surface-water drainage occurs along the Watson Wash; however, available data do not indicate that ground water follows the same drainage. Geophysical data or well data are needed to define the thickness of the basin-fill deposits beneath the Watson Wash to determine if ground water can move through the narrow gap between the Woods and Hackberry Mountains. The Draft Report references a study by Viceroy Gold Corporation (1990) as a basis for including the southern third of Lanfair Valley in the Fenner ground-water basin. Because this reference is not readily available, the data presented in the Viceroy (1990) study should be included in the Draft Report to substantiate including the southwestern third of Lanfair Valley in the Fenner ground-water basin. In any case, the quantity of ground-water discharge from Lanfair

Valley to Fenner Valley must be small because of the limited extent of the aquifer in the mountain gaps.

The Draft Report cites Izbicki et al. (1998) to imply that infiltration from washes during storm events is a source of recharge to Fenner basin. The work described in that paper was done in the western part of the Mojave Desert in washes that drain the Cajon Pass area. This area is far wetter than the Fenner watershed. In addition, the wash studied has some unique geologic features that may not be applicable to the washes draining the Fenner Basin. Furthermore, Izbicki et al. (1998) indicate that the quantity of flow and the amount of recharge from the wash are small and that travel times through the thick unsaturated zone are as long as several hundred years.

Page 30, 3.3, Climate.

Page 31, **3.3.2, Precipitation.**

Page 34, 3.3.6, Evaporation. Please show graph of monthly evaporation rates.

4.0--GEOLOGY

Page 35, 4.1, Regional Geologic Setting. The depression that forms the Bristol watershed is believed to be the result of regional movement along the fault (Rosen, 1989). What is the age of these faults and do they cut the water-bearing deposits?

Page 35, 4.2, Stratigraphy. Grouping the geologic formations into only three groups (bedrock, loose alluvial sediments, and fine-grained sediments underlying Bristol and Cadiz dry lakes) is an oversimplification. Inspection of the geologic and geophysical logs presented in the Draft Report indicates that the alluvial sediments become more fine-grained and indurated with depth. Most of the loose alluvial sediments as described in the Draft Report lie above the water table. The Draft Report presents figure 17 showing the estimated bedrock elevations of the Bristol, Cadiz, and Fenner watersheds and cites Maas (1994) as the source of the data. How were these bedrock elevations determined? What geophysical techniques were utilized? Borehole data, showing the elevation where bedrock was encountered, should be included on figure 17. Figure 19 in the Draft Report shows the estimated depth to bedrock in the Fenner Gap area. This map does not contour the depth to bedrock correctly in the areas where well data are available. For example wells MW-7 encountered bedrock at a depth of about 500 feet. Figure 19 has a contour of 1,500 feet passing near this well. Figure 19 overestimates the depth to bedrock in Fenner Gap and the map is incorrectly contoured. Well data need to be shown on the map. Symbols shown on the map need to be included in the explanation. The data used to construct the simplified seismic cross section (figure 20) should be included with the Draft Report.

The statement that most of the sediment is Holocene is questionable. Numerous studies have shown that Pleistocene soils are widespread and common at the surface in the Mojave Desert, and where they are not present at the surface they are commonly present just a few meters beneath Holocene alluvial fan sediment. See McDonald et al. (1995) for one of many nearby examples. Several photographs in Volume 1 nicely illustrate the argillic and calcic horizons in the area, and the section on paleontology describes calcic materials in the area of the well field. Unpublished geologic mapping by USGS identifies widespread Pleistocene soils in the area. For example, much of the valley between the Marble and Clipper Mountains is underlain by stage IV calcic horizons within one meter of the surface. Argillic horizons are important hydrologically, and their presence is hinted at by the non-linear rate of percolation in the percolation pond experiments.

Page 37, 4.3, Structure. The Draft Report states that more than a dozen faults (figure18) is evidence of Quaternary movement in the Fenner watershed. How do these faults affect the movement of ground water? Why weren't these faults considered in the development of the ground-water model described later in the Draft Report? Rosen (1989) is cited as saying that subsidence of the Bristol dry lake continues to the present. This would suggest that the faults cut the aquifer system, and are potential barriers to ground-water flow. These faults could have a major impact on the storage and recovery operation if they are barriers or partial barriers to ground-water flow.

Figure 18 does not include the Iron Mountains Fault, which may connect to the northwest with the Bristol-Granite Mountains Fault and thereby pass near the well field at Cadiz. In addition, this figure is incorrectly ascribed to the reference by Miller and Howard (1985); that paper included the Iron Mountains Fault and did not show many of the connections of faults across the Bristol-Danby trough. The faults shown in figure 18 must correctly reflect the cited source, which shows the Iron Mountains fault as Quaternary. The steep slope on the buried basement surface under the proposed well field could be support for a connection of the Iron Mountains and Bristol-Granite Mountains faults. The well field accordingly may straddle a buried fault only a few meters beneath the surface, which may have hydrologic implications and seismic hazard implications.

The Draft Report cites geothermal heating (up to 90^{o}F) in the Fenner Gap and suggests that the heating may be caused by convection of ground water with a zone of brecciated bedrock in the Fenner Gap. What is the flowpath for the ground water to move into the brecciated bedrock? The presence of the geothermal water would preclude a significant quantity of underflow of ground water through the alluvial deposits in Fenner Gap. If there were a significant quantity of underflow through the gap, one would expect cooler temperatures associated with winter recharge of precipitation and runoff (around 60^{o}F).

5.0--GEOHYDROLOGY

Page 39, 5.1, Groundwater Basins. The Draft Report assumes that Bristol, Cadiz, and Fenner basins are closed; however, hydrologic data are not presented in the report to substantiate this statement. Does ground water move from Dale dry lake to Cadiz or from Cadiz ground-water basin to the southern part of Ward Valley? Water-level and geologic data are needed to support the statement that the basins are closed.

The Draft Report assumes that the topographic divides form the margins of the ground-water basins. This assumption will result in the overestimation of the size of the ground-water basins, because most of the margins of the basin consist of nonwater-bearing consolidated rocks. The ground-water basins should be defined by the contact of the consolidated rocks and the saturated basin fill.

Page 39, 5.2, Aquifer Systems. Sediments in the basins may, and almost certatinly does, include the early Miocene volcanic rocks and associated sediments, which are shown on the geologic maps and described in the geologic history, but ignored in the treatment of materials in the basins. Volcanic rocks dip northeast from the Marble Mountains and roughly north from the Ship Mountains. It seems likely that some of this section is present in deeper parts of the ground-water basin.

The upper alluvial unit is unlikely to be just Quaternary sediments as defined. Quaternary sediments have accumulated at rates of a few meters per ten thousand years, and even in sites of rapid deposition are unlikely to be 800 feet thick, as described in the Draft Report. Regardless of their exact thickness, numerous buried soil horizons are to be expected within a thick Quaternary section.

The Draft Report divides the basin into an upper alluvial aquifer, lower alluvial aquifer, and a bedrock aquifer. It is unclear how the upper and lower alluvial aquifers were delineated. The report states that the average thickness of the upper aquifer is 500 feet. Does this thickness include the unsaturated alluvium? Inspection of the geophysical and lithologic logs presented in the Draft Report indicates that the deposits become poorly sorted with a higher percentage of fine grained deposits at about 300 to 400 feet below land surface in the Fenner Gap (MW-3, MW-6, and MW-7). Inspection of the short- and long-normal resistivity logs indicates that there is little separation between the logs. The lack of separation suggests that the sediments are fine-grained or indurated. The spontaneous potential log also shifts at this point in the borehole, indicating a change in water chemistry or sediments. This change in character on the logs is probably the contact between the upper alluvial sediments and the lower alluvial sediments. The long-normal resistivity averages about 40 ohm-m above the contact and less than 20 ohm-m below the contact. The water table is about 300 feet below land surface in the Fenner Gap; therefore, the saturated thickness of the upper alluvial aquifer is on the order of only 100 feet in the Fenner Gap. The lower aquifer would then extend from 400 feet below land surface to the top of the bedrock. As indicated on the lithologic logs and shown on plate 3 of Draft Report, these lower sediments contain high percentages of silt and clay and are less permeable than the overlying deposits.

The Draft Report states that the upper aquifer is very permeable. This statement is based on pumping well PW-1. Well PW-1 is located downgradient of the Fenner Gap, and is probably in the Bristol Trough as described by Jachens et al. (1992). Inspection of the lithologic and geophysical logs for PW-1 indicates that well encountered relatively permeable deposits to a depth of 650 feet. Inspection of the short and long normal resistivity logs shows significant separation to this depth, suggesting permeable deposits. Below 650 feet the logs merge together and decrease in resistivity, suggesting less permeable deposits. The long normal resistivity decreases from about 50 ohm-m above 650 feet below land surface to less than 30 ohm-m below 650 feet. The water table at PW-1 is about 275 feet below land surface. These interpretations indicate that the saturated thickness of the upper alluvial aquifer is about 375 feet at well PW-1 compared with 120 feet at well MW-3.

The lower alluvial aquifer is reported to yield water freely to wells. This statement is supported in the Draft Report by the statement that the "Cadiz agricultural wells are screened primarily in the lower alluvial aquifer and typically yield 1,000 to 2,000 gallons per minute." The Draft Report needs to present the lithologic and geophysical logs, well-construction information, and specific-capacity data to support this statement. As indicated later in the water-quality section of this review, the water chemistry of the Cadiz agricultural wells is significantly different than the chemistry in the Fenner Gap wells, suggesting that the Cadiz wells are pumping water from the upper alluvial aquifer.

The Draft Report indicates that the recent drilling in Fenner Gap indicates that the Paleozoic rocks that underlie the Fenner Gap comprise a third aquifer unit. The data that support this statement need to be presented in the Draft Report. Well CI-2 is perforated in the "bedrock aquifer." What is the specific capacity of this well?

5.3 Groundwater Recharge, Flow Direction, and Flow Rate

Page 40, 5.3.1, Groundwater Recharge. See comments regarding the infiltration from washes inferred from Izbicki et al. (1998) in the section 3.2 comments. The report cites several references as reporting that the principal recharge to Bristol and Cadiz dry lakes is seepage of ground water into the lakebed sediments from adjacent alluvial deposits. Did these references estimate the quantity of ground-water seepage?

The Draft Report states that the occurrence of active ground-water replenishment within the Bristol, Cadiz, and Fenner watersheds is supported by (1) the existence of a regionally consistent hydraulic gradient, (2) isotopic evidence for a geologically "recent" age of the ground water, and (3) stable ground-water elevation recorded in wells located between Fenner Gap and Bristol dry lake despite continuous ground-water pumping by Cadiz agricultural operations for more than 15 years. What does a regionally consistent hydraulic gradient indicate? The gradient is dependent on the aquifer hydraulic conductivity and the quantity of ground-water flow. If the hydraulic conductivity is poorly defined, then the gradient doesn't indicate the quantity of flow. Please refer to the comments about isotopic evidence for geologically "recent" (Holocene) age for ground water in comments for Section 9.33. It is stated that the ground-water elevations have been "stable"; however, data indicate predevelopment water-level elevations of about 600-625 feet while figs. X-4 to X-15 show current water-level elevations of about 580 feet or less. This indicates there has been drawdown in the area under relatively low pumping rates. The report by Boyle Engineering Corporation (1996) states that the measured drawdowns in the Cadiz wells indicate that the perennial yield of the basin is less than 4,000 acre-feet per year.

The estimated average amount of recoverable water (surface runoff and ground-water recharge) available to Project area is reported to range from 15,000 to 37,000 acre-feet per year. What is the breakdown of quantities of surface runoff and ground-water recharge? How was the surface water routed from Fenner Gap to Bristol and Cadiz dry lakes? Was the surface-water drainage divide between Bristol and Cadiz dry lakes considered? The validity of these numbers will be discussed in the review of Section 6.0. Based on model results presented in Section 8, the amount of ground water available to the Project area on an annual basis is estimated to be 30,000 acre-feet per year. The validity of this number will be discussed in the review of Section 8. These numbers should not be presented in this part of the Draft Report.

Page 41, 5.3.2, Groundwater Flow Direction. The data used to construct the water-level elevation map (figure 21) needs to be included in the Draft Report. The data points need to be presented on the map. Does the map represent water levels collected at the same time or is it a collection of different time periods? The map does not accurately represent the water levels measured in the Fenner Gap area. For example the water level reported for the Siam well 5N/15E-4X1 is 641 feet but the map indicates a water level of 670 feet. Well 6N/15E-29Q has a measured water level of about 690 feet; however, on the map the water level is about 750 feet. These are just two examples of many problems on the contour map. With the scarcity of data, many of the contour lines should be queried. What impacts do the faults have on the ground-water flow direction? One would think that the northwest/southeast trending faults might be barriers to flow. In addition, geothermal heating (presented in Section 4.3) indicates that the faults are impacting the flow system. The Draft Report states that ground water flows through Fenner Gap and then migrates to Bristol and Cadiz dry lakes. If the water levels for the Cadiz agricultural wells (presented in the Draft Report) are plotted on the map, there is a water-level depression related to the 15 years of agricultural pumping (water-level elevations range from 590 feet on the north end of the agricultural fields to 530 feet on the south end of the fields. How has this agricultural pumping changed the predevelopment movement of ground water? Water levels beneath the fields are currently lower than historical water-level measurements beneath Bristol dry lake (Moyle, 1967), indicating that ground water moving southward through Fenner Gap will be captured by the irrigation wells.

The Draft Report refers to a "paleowash" identified by a seismic survey in the vicinity of Danby (Shafer, 1964). The seismic data should be presented in the Draft Report. How deep was the "paleowash"? The Draft Report states that water levels support a "paleowash." The water-level data simply indicate the direction of ground-water movement. Fenner Gap is a discharge point from Fenner Valley, therefore, ground water is moving towards this discharge point. How was it determined that no ground water moves through Skeleton Pass? Are there any water-level or geologic data to support this statement? The water-level contour map (figure 21) indicates that ground water moves through Skeleton Pass.

Page 42, 5.3.3, Groundwater Flow Rate. How were the ground-water flow rates determined? Supporting data need to be presented. These data should be presented in chapter 9.

5.4 Groundwater Discharge

Page 42, 5.4.1, Evaporation. Ground-water levels along the east end of Bristol dry lake are as much as 50 feet below land surface (Moyle, 1967; and this Draft Report). Surface evaporation from these depths would be very small. This suggests that ground-water discharge from Fenner Valley also is small. The evaporation estimates are discussed in great detail in the review of s Section 6.6.2.

Page 43, 5.4.2, Ground-water Pumping in Area. The volume of water pumped by Cadiz agricultural operations cited in the second and third paragraphs appears to be contradictory.

Page 44, 5.5, Ground-water Storage. Ground-water storage values are presented here without supporting documentation. These values should not be presented until the method is discussed. These values will be discussed in the review of Section 6.4.

Page 44, 5.6, Ground-water Quality. The Draft Report states that the quality of fresh ground water varies only minimally throughout the Bristol, Cadiz, and Fenner watersheds. Inspection of data presented in the Draft Report and the USGS database indicate that there is more variation than is indicated in the Draft Report. For example, there is even a large variation in water chemistry of wells in Fenner Gap (table 20), ranging from a total dissolved solids (TDS) of 267 nilligrams per liter (mg/L) in well CI-1 to 1,040 mg/L in well MW-3. The total dissolved-solids map (figure 23) needs to have the data (well and TDS values) plotted on the map. The data as plotted on the map indicate that the TDS upgradient of Fenner Gap has a higher concentration (350-400 mg/L) than downgradient of the gap (300 mg/L). If underflow from Fenner Valley is the main source of recharge to the Cadiz agricultural wells, how can the TDS be higher in the recharge water than in the Cadiz wells (less than 300 mg/L in table 3)? The presence of the high TDS values at the dry lakes would indicate that there should be springs along the freshwater/saltwater interface. This conceptual model can be observed at Death Valley. Are springs present around the dry lakes?

Page 45, 5.7, Interrelationship of Bristol, Cadiz and Fenner Watersheds with Other Groundwater Basins. As stated previously in this review, water-level and geologic data are needed to support the statement in the Draft Report that the basins are closed.

6.0--EVALUATION OF WATER RESOURCES

Page 46, 6.1, Evaluation of Recoverable Water Using a Watershed Model. The watershed model is reviewed below by section. In addition, we have presented some recharge estimates for the watershed using alternative modeling approaches. A description of these alternative models and the model results are presented as an attachment to this review.

General comments on approach--A watershed model was used to calculate "recoverable water" in the basin. Recoverable water is defined in the Draft Report as the total amount of surface runoff and infiltrating water that reaches the ground-water surface. The two terms were not discussed separately in the text of the Draft Report; however, they were separated in model results presented in Appendix F.

The watershed model incorporates the Thornthwaite equation to estimate daily potential evapotranspiration and an additional routine to estimate soil infiltration. The Thornthwaite equations yields estimates of potential evapotranspiration that are smaller than estimates produced using other approaches (Dingman, 1994) and, as a result, this model will tend to overestimate infiltration and runoff when compared to other methods. The model then calculates infiltration by subtracting surface runoff and vegetation interception from daily precipitation. The model does not account for soil water storage and subsequent withdrawal by plants. Vegetation in desert environments is very efficient at extracting soil water from great depths. For example, creosote has been reported to extract water from depths as great as 6 meters below land surface. Numerous studies show that infiltration to depths below this thick root zone does not occur in desert basins--and soluble salts such as chloride accumulate just below the root zone (Phillips, 1994; Prudic, 1994; Izbicki et al., 1998). The amount of infiltrating water that reaches the water table approaches zero in most of the basin and water-potential data from other studies in desert basins suggest that water (in the form of vapor) may move upward from the water table to the root zone in many areas (Prudic, 1994). No field data or other evidence supporting infiltration to depths below the root zone for any of the soil groups is presented in the Draft Report. These issues are discussed in greater depth in the review of Section 6.7 --'"Estimates of ground-water recharge using a chloride mass balance approach."

A small amount of infiltration and subsequent recharge may occur in desert basins where water accumulates in topographic depressions. These areas include natural topographic depressions, such as certain playas (Osterkamp and Wood, 1987), man-made depressions, such as bomb-blast craters at the Nevada Test Site (Tyler et al., 1992; Pohl, 1996), and intermittent streams (Scanlon, 1994; Izbicki et al., 1998; Nimmo, 1999). As a group, these studies uniformly conclude that infiltration and subsequent ground-water recharge from these areas is small. The model does not incorporate any routines to route water through the surface drainage network and estimate downstream flows and subsequent infiltration. The existence of runoff does not imply that that water will infiltrate farther downstream in the basin. Although isotopic data are cited in the Draft Report as evidence of infiltration from washes, review of Section 9.3.3 "Evaluation of Groundwater Age Using Isotopes," suggests that the isotopic data presented in the Draft Report actually show that the amount of water from infiltration of surface flows is small. No other field data or evidence of infiltration from washes is presented in the Draft Report. An estimate of the "recoverable water" in the basin using data from the Draft Report and data from studies in similar areas is presented in the "Conclusion" section of this review.

The watershed model is a detailed daily water budget model: daily precipitation, infiltration, runoff, vegetation interception, evapotranspiration, soil moisture, and percolation are addressed. The model results provide an estimate of the recoverable water. It appears that the model does not account for bedrock permeability, and this may become an important factor for upland areas with shallow soils underlain by low permeability granites and metamorphics. For example, soil unit D defines an important watershed modeling unit that is used to subdivide the watershed model into areas of similar characteristics. For soil unit D, these are predominantly upland areas with shallow soils and thus the permeability of the underlying bedrock may have an important effect. It may be incorrect to assume that the hydrologic response for soil unit D will be similar for all locations covered by this soil type (even if the soil area is subdivided on the basis of the isohyets). There may be important differences in the hydrologic response of this model unit between areas underlain by low permeability bedrock and areas underlain by high permeability bedrock. It would be important to incorporate these differences into the watershed model, at least for soil unit D, because the model unit defined by this soil class on average has the highest computed recharge rates.

Page 47, 6.2, Description of the Bristol, Cadiz and Fenner Watershed Model. Each of the three basins is subdivided into hydrologic or modeling response units. For the Fenner watershed, five sub-areas are defined on the basis of soil types (A, B, C, and D) and an additional subdivision based on precipitation isohyets for subdivision for D. The long-term isohyetal map is based on precipitation records from Twentynine Palms, Amboy, Needles, Mitchell Caverns, Mountain Pass, Kelso, and Yucca Grove. There are additional stations in the region surrounding the Cadiz study area that could have been used in the watershed modeling to obtain a more accurate representation of daily precipitation (e.g., Iron Mountain, Searchlight, Joshua Tree, Baker, Eagle Mountaint, and Parker).

Page 49, 6.2.1, Delineation of Model Subareas. The Bristol, Cadiz, and Fenner watersheds define the total watershed model area. A total of 11 subareas are defined for the three watershed areas. How were topographic effects such as differences in slope, aspect, and drainage characteristics, taken into consideration in the subarea boundaries?

Most recharge is simulated in the watershed model as occurring in soil group D. These soils should have limited rates of percolation (recharge) and high rates of runoff because of the impervious bedrock that underlies this soil type. If these soils have high runoff potential and are underlain by low-permeability bedrock, why are the highest recharge rates occurring at these locations (according to the watershed model)? There is no justification in the report for all the recharge occurring in the bedrock areas.

6.3 Model Parameter Determination

Page 52, 6.3.2, Soil Curve Number and Surface Runoff. No comments.

Page 54, 6.3.3, Temperature and Evapotranspiration. Thornthwaite's formula is cited but no reference is given. There is no way to know if this equation considers the lack of vegetation. The alpha coefficient (ratio of soil moisture to field capacity) is not the appropriate function for soil evapotranspiration. The method selected comes from Thornthwaite and Mather (see Hanks and Ashcroft, 1980, fig 4.6, pg. 115). A more appropriate function for the Mojave region is the modified Priestley-Taylor function (Flint and Childs, 1990), but only when vegetative cover is accounted for (Stannard, 1993). The assumptions in the Draft Report would underestimate evapotranspiration and therefore overestimate recharge.

Page 56, 6.3.4, Infiltration, Vegetation Interception, Soil Moisture, and Percolation. The estimates of potential evapotranspiration, 0.12 to 0.434 inches per day, seem high. The assumption that if soil moisture exceeds field capacity precipitation will percolate downward to replenish ground-water storage is questionable without accounting for the bedrock permeability under shallow soils, which is where most of the model calculated recharge comes from. Low-permeability bedrock holds excess soil moisture in the root zone where it may be removed by evapotranspiration processes. The rate of recharge in these situations is limited to the permeability of the bedrock and must be accounted for. Also see the equation for percolation on p. 57, which needs to account for bedrock permeability.

Page 57, 6.3.5, Assumption for Soil Thickness, Initial Soil Moisture, Field Capacity, and Apparent Specific Gravity. The estimates of field capacity are below the range that would be calculated from the STATSGO database, 13 to 17% for soil type D in the Providence Mountains area. For the same general area as soil type D, estimates using the STATSGO database would be 17--24%. The soil thickness for the shallow soils seems reasonable, but the soil thickness for the deeper soils is in error. Although taxonomically the soils may be less than 2 meters (6 feet), the rooting depth, and therefore the evapotranspiration depth is much deeper, perhaps as much as 6 meters (20 feet). This is particularly important for channels.

6.4 Sensitivity and Uncertainty of Model Parameters. The model sensitivity analysis does not test the entire reasonable range of field capacity and soil thickness. These are two of the most sensitive parameters. If the true range of these two parameters were tested, the model would show a larger range and significantly less water would be simulated as being recharged.

6.5 Validation of Watershed Model Methodology. This section is much too brief. There needs to be more information provided on the Big Sandy Valley watershed so that basin characteristics can be compared. Western Arizona has a much different climate characteristic than southeastern California because of an increase in average elevations eastward towards Arizona and increased moisture input from the Gulf of Mexico, primarily during the Southwestern Summer Monsoon. In general, the climate is wetter and cooler, with more precipitation occurring as snow and a higher frequency of intense storms during the monsoon season. These differences in precipitation characteristics must be understood and accounted for before a model that is calibrated in Big Sandy Valley can be assumed to be a calibrated model in the Cadiz study area. In addition to differences in climate, differences in basin characteristics, such as topography, vegetation, soils, and geology, may cause non-transferability of a calibrated model. In general, there is an important transition from granitics and metamorphic rocks in southeastern California to sedimentary and volcanic rocks moving eastward onto the Colorado Plateau. Also, there is an increase in vegetation density with an increase in coniferous vegetation type and also in grasses moving eastward onto the Colorado Plateau.

The comparison of a recoverable water estimate between average simulated and measured watershed outflow is not very meaningful in terms of model calibration, especially when calibrating a model to be used in a different basin. The best way to determine if the hydrologic characteristics and processes in a watershed have been adequately represented by a model is to compare the hydrographs of simulated and measured daily watershed outflow because the timing, duration, and intensity of runoff events are much more indicative of watershed characteristics than mean outflow rates.

6.6 Water Balance for the Bristol, Cadiz, and Fenner Watersheds. How was it determined that the basins are closed basins? Show data that supports that there is no inflow or outflow from upgradient and downgradient basins.

Page 59, 6.6.1, Outflow Terms-Groundwater Pumping. Agricultural pumping is estimated at 5,026 acre-feet per year. Were return flows considered in the budget or are the fields drained?

Page 60, 6.6.2, Evaporation Loss from Dry Lakes. The Draft Report states that a wide range of methods are used for determining evapotranspiration rates in playa settings. Because of the importance of accurately determining this number, there should have been an effort to use an energy balance (Czarnecki, 1997; Laczniak and others, 1999) or salt scraping method (Lines, 1979, described below) to estimate the evaporation from the playa.

Page 60, 6.6.2.1, Determination of Evaporation Area. The Draft Report assumes that evaporation occurs over the entire surface area of Bristol and Cadiz dry lakes on the basis of the assumption of shallow depths to water. The report references Moyle (1967) as support for "shallow" depths to water. Plotting the water levels presented in Moyle (1967) indicates that the depth to water exceeds 10 feet throughout most of Bristol dry lake. Water levels beneath the eastern third of the dry lake range from 30 to 54 feet below land surface. Kunkel and Chase (1969) revised estimates of Lee (1913) for bare-soil evaporation from different depths to ground water in Indian Wells Valley, California. In their study they estimated that the annual rate of evaporation from bare soil decreased to negligible amounts at water-level depths of more than 7 feet below land surface. The Draft Report sites "puffy" soil as evidence of capillary movement of shallow water. How did this study differentiate between shallow perched water (remnant from local runoff--see Volume 1, figure 10--Photograph of Bristol Dry Lake during Flood Conditions) and regional ground-water evaporation? The total area of Bristol and Cadiz dry lakes is reported to be 41,600 and 29,788 acres, respectively (table 8, Volume1). However, the value calculated utilizing the geologic data presented by the Department of Defense (1998) and digitizing the geologic map of Kupfer and Bassett (1962) is 40,972 acres for Bristol and 17,485 acres for Cadiz. What is the reason for the large discrepancy in values for Cadiz dry lake? In any case, on the basis of the water-level data presented in Moyle (1967) the area used to calculate the evaporation is too large. Also it should be determined if there is a perched water body at the lakebed. If the water body is perched, then the evaporation from the lakebed can not be used to calculate discharge from the regional aquifer.

Page 60, 6.6.2.1, Estimated Evapotranspiration Loss. The Draft Report neglects to account for direct recharge of precipitation and runoff on the dry lakes, and assumes all the evaporation is from ground water that has originated north of Fenner Gap. As shown on figure 10 of Volume 1 (Photograph of Bristol Dry Lake During Flood Conditions), the dry lakebeds become lakes during rainfall events. In a study of the Bonneville Salt Flats, Turk (1973, p. 73) found that infiltration rates ranged from 2.5 to 4.0 feet per day on the salt crust and from 0.4 to 1.4 feet per day in areas of clay and silt. Clearly the infiltration of ponded water on the lakebeds needs to be addressed in the water balance. The Draft Report references Todd (1980) for the evapotranspiration rates used in table 8 to calculate total evapotranspiration. Todd (1980) states that for water tables within 1 meter of ground surface, evaporation is largely controlled by atmospheric conditions; but below this depth, soil properties become limiting and the rate decreases markedly with depth. Todd (1980) presents data only to about 7 feet below land surface (about 2% of pan evaporation). As stated above, Moyle's (1967) data indicate that the depth to water beneath most of Bristol dry lake exceeds 10 feet. Therefore, one should use values less than 2% (0.26 feet per year) to estimate the total evaporation. As stated in Todd (1980), evaporation is limited by soil properties at depths greater than 3 feet. The presence of a salt crust further limits the evaporation.

In a study of the Bonneville Salt Flats, Lines (1979) scraped halite (NaCl) that had accumulated on the surface of the dry lakebed sediments to determine the evaporation of ground water from the barren surface. Lines (1979, p. 86-89) estimated that the evaporation during May-December 1976 ranged from about 0.0025 to 0.00042 inch per day. The estimates were made using the weight of halite that had accumulated at land surface on 2 square-foot plots and the concentration of NaCl in the evaporating shallow brine, which averaged about 295 grams per liter. Ground-water levels at the study plots declined during the summer and fall, but ranged from 0.21 to 2.21 feet below land surface. Similarly, Feth and Brown (1962, p. 100-101) scraped salt from dry mudflats near the edge of the Great Salt Lake during the summer of 1954, and they determined that ground-water evaporation rates at land surface averaged about 0.003 inch per day. Assuming an average evaporation rate of 0.003 inch per day from the surface of Bristol and Cadiz dry lakes (total of 71,388 acres from table 8 or 58,457 acres from the Mojave Desert Ecosystem Program (1998)) and that evaporation is negligible during the winter (December through February), evaporation of ground water from the two dry lakes could be no more than about 6,500 to 5,300 acre-feet per year depending on what value is used for the lakebed area. An ongoing study by the USGS in Death Valley has measured rates of about 0.17 feet per year on a salt playa (salt crust) where the depth to water was less than 1 foot and 0.27 feet per year on a bare soil with some salt mix where the depth to water was 1 to 2 feet (Guy DeMeo, USGS, WRD, Las Vegas, Nevada, written communication, 2000).

Clearly the values for evaporation and areas of potential evaporation are too large as presented in table 8. If one uses the Death Valley number for the evaporation rate (0.17 feet per year) and multiplies that by the area of the dry lake playa surface digitized from the Kupfer and Basset (1962) geologic map (58,457 acres), the estimate evaporation is 9,900 acre-feet per year. The evaporation rate estimated in the report (20,000 to 71,000 acre-feet per year) is unreasonable on the basis of depth to water and soil characteristics, and needs to be significantly reduced. The area of potential evaporation also needs to be reduced significantly.

Page 61, 6.6.3, Total Outflow. The total outflow is stated to be 76,000 acre-feet per year. As stated above, the estimate of evaporation from the dry lakes is too high and needs to be recalculated using lower evaporation rates and smaller areas of potential evaporation. Therefore, this estimate for total outflow is too large. If there was in fact this much ground-water discharge at the dry lakes, one would expect to see springs and vegetation similar to Ash Meadows in Nevada (see Laczniak and others, 1999). To put things in perspective, the estimated evapotranspiration along the entire reach of the Mojave River (Victorville to Afton Canyon) is about 17,000 acre-feet per year (Lines and Bilhorn, 1996). The Mojave River area has areas of perennial flow and riparian habitat.

6.7 Estimates of Groundwater Recharge Using a Chloride Mass Balance Approach. The chloride mass balance approach and associated equations presented in this section are derived from regional recharge studies of the High Plains aquifer (Wood and Sanford, 1995). This is a much different environment than Bristol, Cadiz, or Fenner basins. Although semi-arid, the High Plains receive between 13 and 22 inches per year of precipitation, areal recharge occurs through the unsaturated zone. In contrast, precipitation in the study area is about 7 inches per year and the assumptions associated with the approach as described in the Draft Report are not valid (Wood, 1999). Violation of these assumptions is discussed in the Draft Report; however, this is not a matter of using an approach, violating a few assumptions and qualifying the results--it is a matter of using a completely wrong approach.

There is an alternative chloride mass-balance approach for arid regions where assumptions needed to use the Wood and Sanford (1995) approach are not valid. In contrast to estimates of recharge described in the Draft Report, when properly applied the chloride mass-balance approach is used to estimate the time since recharge has last occurred. Phillips (1994) described the use of the chloride mass balance approach for alluvial basins in the arid portions of the Southwestern United States. In the Mojave Desert, the approach has been applied near the study site at Ward Valley (Prudic, 1994; National Research Council, 1995), at the Nevada Test Site (Tyler et al., 1995), and in the western part of the Mojave Desert (Izbicki et al., 1998). Although the hydrology at specific sites differ, the general conclusions from these studies is that chloride has been accumulating in the unsaturated zones for 13,000 years in western part of the Mojave Desert (Izbicki et al., 1998) to as long as 58,000 years in Ward Valley adjacent to Fenner Valley. This is a different result than the 40,000 acre-feet of annual recharge estimated using the chloride mass-balance approach for Fenner Valley in this Draft Report.

Although the data needed to calculate the time since recharge were not collected as part of this study, the report indicates that chloride and other soluble salts have accumulated in the unsaturated zone beneath Fenner Valley. On the basis of increased dissolved solids and chloride concentrations as high as 933 mg/L measured in monitoring wells after water from the test recharge basins in Fenner Gap through the unsaturated zone to the water table, a large amount of chloride has accumulated in the unsaturated zone at the test site and it has been a long time since recharge has occurred through the unsaturated zone at this location. Data from this Draft Report, and from all other studies done in the Mojave Desert, are consistent and indicate that only negligible recharge occurs on the alluvial valley floors of desert basins. In addition, there is a large body of literature from other parts of the American Southwest, Australia, and arid zones throughout the world that supports this conclusion.

Dettinger (1989) estimated that some recharge may occur to alluvial basins in Nevada as a result of precipitation, runoff, and infiltration at higher altitudes. The chloride mass-balance approach described by Wood (1999) may (with great uncertainty) be applied to these areas to estimate an upper limit on recharge to Fenner basin. Assuming that recharge in the Fenner basin only occurs from precipitation at altitudes greater than 4,000 feet (Dettinger, 1989), recharge to Fenner basin is about 1,710 acre-feet per year. This value was estimated using the chloride mass balance approach as follows:

$$Q = [(P*Cl_p) / Cl_{gw}] A_{4000}$$

where P is average annual precipitation about 10 inches per year (0.83 feet per year) (this Draft Report);

Cl_p is the chloride concentration in precipitation from the Mojave Desert, about 0.8 mg/L;

Cl_{gw} is the chloride concentration in ground water from Fenner Gap monitoring wells, about 49 mg/L. This value excludes low chloride concentrations in water from agricultural wells operated by Cadiz Inc. (this Draft Report); and

A_{4000} is the area of the basin above 4,000 feet, about 126,000 acres.

The average chloride concentration used in this calculation is subject to uncertainty. The value used in these calculations is the value used for bulk precipitation in chloride mass-balance calculations for Ward Valley (Prudic, 1994). This value is higher than the volume-weighted mean chloride concentration measured in precipitation at National Atmospheric Deposition

Program (NADP) site at Red Rock, Nevada. This site has been operated for 14 years and is the best data for the region. However, data from the NADP sites are wet-fall only (rain, snow, etc.); these data do not include dry-fall (dust, particulates, ect.). This value also is higher than the chloride concentration for bulk precipitation of 0.4 mg/L measured for precipitation by Dettinger (1989) to estimate ground water recharge in 16 basins in Nevada. This value is lower than the chloride concentration of 3.5 mg/L used in this Draft Report to estimate recharge in Fenner Valley.

At best, recharge estimates calculated using the chloride mass balance approach described by Wood and Sanford (1995) provide an upper limit on ground-water recharge from higher altitudes in the Fenner basin. Dettinger's (1989) work was for basins farther north in Nevada and may not be directly transferable to Fenner Valley. For example, there may not be large quantities of recharge at altitudes greater than 4,000 feet in the southern California Desert and chloride may be accumulating in the unsaturated zone in that part of the basin. No data are provided in the Draft Report to demonstrate that infiltration to depths below the root zone and subsequent ground-water recharge occur in the study area at altitudes greater than 4,000 feet.

If the chloride mass-balance method is applied but the deposition rate is 0.8 mg/L, which is what has been recommended for Ward Valley, and if you assume that all the recharge comes from soil type D then the method alone would calculate a recharge of 3,000 acre-feet per yearr. Even if you use the entire Fenner watershed area, rather that soil type D, the recharge would be 9,000 acre-feet per year. The 3.5 mg/L accumulation number used is much higher than most other researchers would use.

6.8 Groundwater Storage Estimates

Page 64, 6.8.1, Groundwater Storage Estimates for the Fenner Watershed. Estimates of ground-water storage using this methodology are misleading. Although there are large amounts of ground water in storage, much of this water is difficult to extract owing to decreased permeability with depth. In addition, the water chemistry of the deeper sediments in most desert basins contains high concentrations of fluoride, arsenic, and other trace elements.

Page 64, 6.8.1.1, Procedure. As stated earlier in the review, there appears to be a problem with the depth to bedrock map. Where checked with borehole data presented in the Draft Report, the depth to bedrock map overestimated the depth to bedrock. The specific yield values will decrease with depth in the aquifer, because of cementation and compaction of the sediments.

Page 65, 6.8.1.2, Parameters Used for Storage Calculation. Same comments as above.

Page 66, 6.8.1.3, Results. Need a statement indicating that not all of this could be extracted economically and the water chemistry of this water may be greater than drinking-water standards for some constituents.

Page 67, 6.8.2, Groundwater Storage Estimates for the Project Area. The estimate is based on the depth to bedrock map presented in the Draft Report (figure 17). As stated above, this map appears to overestimate the depth to bedrock.

7.0--FENNER GAP PILOT INFILTRATION TEST

Overall the largest weakness with this section is the lack of a numerical model. A pre-experiment model, using the soil parameters estimated from field and laboratory analysis, should have been conducted. This step is a critical part to any large-scale field experiment. The results would demonstrate the adequacy (or inadequacy) of the estimated parameters. Modeling of the unsaturated zone is a much more difficult part of the study than modeling of the saturated zone. The non-linearity of the relation between water content and water potential is critical in understanding the response of the system to continual ponding. The hydrologic characterization of the unsaturated (vadose) zone is still a critical part of site characterization. The demonstration of adequate data and understanding are needed to show how the system will respond to long-term ponding (and infiltration) and pumping. Post-experiment modeling (history matching) would help to further develop the hydrologic properties of the unsaturated zone using standard inverse methods.

7.1 Pilot Spreading Basin. What is the rationale for requiring 200 feet of a saturated alluvial aquifer? Should not the requirement be for a specified unsaturated alluvial thickness because the artificial recharge and mounding will occur above the water table? Again a model would be helpful in defending, or providing rationale for assessing, the thickness required for the saturated or unsaturated zone.

7.3 Pilot Test Field Testing. Report should include plots of the pumping-test data. Show the type-curve matches for determining aquifer characteristics (Ttansmissivity and Storage). How were the gypsum blocks isolated in the boreholes? Were bentonite seals placed in the holes to prevent preferential flow through the borehole?

Page 76, 7.3.4.1, Principle of Operation. The resistance between the two probes is calculated from voltage measurements made in the gypsum blocks. The resistance is converted to water potential using a calibration equation. This section incorrectly states that the sensors measure water potential which is converted to Kohms (this appears to be just a misstatement). Heat dissipation probes, which are a much better measures of water potential, should have been used. They would provide data necessary for modeling.

Page 77, 7.4, Eight-Month Infiltration Test Monitoring. Was the model used to simulate the drawdown at the pumping well and the mounding beneath the ponds? This would be useful to help calibrate the model on a local scale. The model could then be used to predict water-level changes resulting from the larger scale project.

Page 77, 7.4.1, Climatological Data. What is the "evapotranspiration monitor" on the weatherstation and why were solar radiation measurements, the driving force for evapotranspiration, not measured during the study period?

Page 77, 7.4.4.2, Single-Ring Infiltrometer Field Tests. Is the reference to Bouwer (1998) the 1989 reference? The method employed is not as straight forward as other infiltrometer methods.

A long-term measurement (greater than 6 hours), where lateral flow is less important, would give a better measure of the expected conditions in the similar, but larger, ponded area.

7.5 Water Quality Monitoring

Page 83, 7.5.2, Sampling Procedure. Some wells may not have been completely purged prior to sample collection using the procedure described in the Draft Report. For example, monitoring well CI-1 is 420 feet deep and the depth to water is about 300 feet. Given a casing diameter of 2 inches, about 19 gallons of water are in the casing. According to procedures described in the Draft Report, only 6 liters of water (about 1.5 gallons) were removed from each well prior to sample collection. The sampling procedure increases uncertainty associated with the interpretation of chemical and isotopic data presented in the Draft Report.

Page 85, 7.5.3.2, Baseline Analyses-General Suite. Comments for this section also include comments on results of chemical analyses presented in table 12 and Appendix U.

Results of chemical analyses show that background water quality from the Fenner Gap monitoring wells has a relatively wide range in dissolved solids from 267 to 1,040 mg/L. On the basis of Stiff diagrams presented in Appendix U most water is sodium bicarbonate or sodium bicarbonate-sulfate in chemical composition. No baseline water-quality samples from monitoring wells in Fenner Gap had a calcium bicarbonate composition and high pH (greater than 9.0) that would be expected for water from Schuyler Wash that infiltrated through a thick unsaturated zone to recharge the underlying ground water. As a result, chemical data are not consistent with large amounts of infiltration from the wash as interpreted in the Draft Report. It is interesting to note that after water from the test recharge ponds infiltrated through the unsaturated zone to the water table, water from the monitoring wells became increasing calcium bicarbonate in chemical composition (table 22).

Page 85, 7.5.3.3, Baseline Analyses-Isotopes. Comments for this section are included in comments for section 9.3.3 “Evaluation of groundwater age using isotopes.”

8.0--CADIZ GROUNDWATER MODEL

8.1 Model Development. Please clearly explain for what purpose the models were developed.

Page 94, 8.1.1, Conceptual Model. The conceptualizations of model layers 2 and 3 are not clear. Semiconfined is insufficient information. In MODFLOW, are these layers confined or confined/unconfined (LAYCON=2 or 3)? On the basis of Plate 3, there may be continuous clay layers; you choose to assume them to be discontinuous.

Page 95, 8.1.2.1, MODFLOW Model. Please clearly explain and defend the nonuse of the fault (HFB) package given the high degree of faulting in the study area. The northwest/southeast trending faults may be barriers to ground-water flow and should be incorporated into the model.

Page 97, 8.1.2.2, MT3D Model. Please clearly explain and defend the use of MT3D, a nondensity-dependent transport model, to model brine transport. Water with high TDS concentrations (about 300,000 mg/L beneath Bristol dry lake) has a greater density than freshwater. This greater density will affect the physics of the flow system; therefore, in order to estimate the potential impact of the proposed project on the movement of the high-density brine one must use a density-dependent ground-water flow and transport model. To determine the potential impacts of the proposed project on the salt playas, a density-dependent transport model is needed.

Page 98, 8.1.2.3, Pre- and Post-Processors. No comments

Page 98, 8.1.3, Model Size, Grid Geometry and Boundary Conditions. Please show a typical model cross-section.

8.1.4 Flow Model Aquifer Parameters

Page 99, 8.1.4.1, General. Please use specific yield instead of effective porosity (effective porosity is used later in the report as a porosity). It is stated much later in the report that layer 2 is confined/unconfined; therefore, the top elevation of this layer is required. I assume that layer 3 is confined, although it is never stated. Define “mathematically superimposing” and “appropriate gridding algorithm.”

Page 100, 8.1.4.2, Elevations of Aquifer Boundaries. Move this section to Section 8.1.3. How were the elevations determined? As stated earlier in the review, the bottom elevation of the upper aquifer in Fenner Gap is too low.

Page 100, 8.1.4.4, Hydraulic Conductivity and Transmissivity. Note that Jacob’s method is valid only for confined aquifers; therefore, is not applicable to layer 1 data. The use of the screened interval to calculate K can overestimate the K value. The well efficiency is not normally used to estimate T from specific capacity data (see Driscoll, 1987) and will overestimate T. Please provide a reference for the E-log sequential method and show example calculations. How were K-values adjusted using clay percentages and what is the basis for this adjustment? Give specific clay percentages used in table 14. Show point estimates of hydraulic conductivity and transmissivity on contour maps (figures 61-64) for comparison. Overlaying figures 60, 62 and 63, the hydraulic conductivity and transmissivity contours do not appear to be consistent. A map with the model grid and associated parameter values for all layers needs to be presented in the Draft Report.

Data for the aquifer tests presented in table 14 need to be presented in the Draft Report or be in a published document. The USGS logged well 5N/14E-13 shown in the table 14. Inspection of the geologic log for this well indicated that the sediments were poorly sorted, gravelly sand and silt with increasing silt content with depth. On the basis of this lithologic description, it is difficult to justify an average hydraulic conductivity of 699 gallons per day per foot squared (gpd/$ft^{2)}$. An average value of 100 gpd/ft^2 would be the highest that one would expect for these materials. What was the pumping rate for this test? Also, why is this well assigned to layer 2 when the well is perforated at the water table? According to Plate 3, most of this well is perforated in layer 1. The upper estimate of the layer-2 transmissivity seems too high. From your description of the layer-2 materials, the hydraulic conductivity values may be in the range of 1 to 10 gpd/ft^2 (Freeze and Cherry, 1979). The layer-3 transmissivity values are too high. For sandstone the transmissivity values should range between 0.4-4000 gallons per day per foot (gpd/ft) and for carbonate rocks the transmissivity values should range between 4-4000 gpd/ft (Freeze and Cherry, 1979).

In general, the hydraulic conductivity and transmissivity values are too high, which allows the high flux rates that are assumed in the model. The pumping-test data presented in the Draft Report for well PW-1 (Appendix M) indicate a specific capacity of about 200 gpm/ft. The empirical equation used to estimate transmissivity from specific capacity in a unconfined aquifer is to multiply the specific capacity (gallons per minute per foot) by 1,500 to give transmissivity (gpd/ft) (Driscoll, 1987, p. 1021). Using this equation for the well PW-1 data indicates that the transmissivity of the aquifer near well PW-1 is 300,000 gpd/ft. Dividing this estimated transmissivity by the perforated interval of the well (500 feet) will give an estimate of the average hydraulic conductivity--in this case 600 gpd/ft^2. This value is about 70% of the value estimated on table 14 (851 gpd/ft^2). On table 14, it is assumed that well PW-1 is only perforated in 36 feet of layer 1. On plate 3 of the Draft Report it appears that layer has been placed at an elevation of 300 feet, which would indicate that well PW-1 is perforated in about 300 feet of layer 1. In table 14, the hydraulic conductivity of layer 1 is assumed to be 2.7 times the hydraulic conductivity of layer 2. Assuming this ratio is correct, the estimated hydraulic conductivity values at PW-1 are 800 and 300 gpd/ft^2 for layers 1 and 2; respectively. It is clear that the adjusted hydraulic conductivities estimated for this well in table 14 (1,835 gpd/ft^2 for layer 1 and 680 gpd/ft^2 for layer 2) are too large. Using lower values would decrease the allowable flux rate.

Page 103, 8.1.4.5, Vertical Leakance. Vertical leakance (VCONT) is calculated using vertical K values not horizontal K values. Assuming anisotropies of 1 to 2 orders of magnitude may greatly reduce the calculated VCONT values. Lower VCONT values can lead to greater stratified flow than is currently being modeled.

8.1.5 MT3D Model Aquifer Parameters

Page 104, 8.1.5.2, Aquifer Thickness. Thickness of aquifer units in the Fenner Gap needs to be reduced.

Page 105, 8.1.5.3, Longitudinal and Transverse Dispersivity. The longitudinal dispersivity value of 50 feet seems small. Gelhar et al. (1992) report that at the field scale (greater than 1,000 meters), longitudinal dispersivity values of about 100 meters (greater than 300 feet). Anecdotally, other researchers have used longitudinal dispersivity values on the order of their grid spacing. The use of small dispersivity values will sharpen the solute front and allow less spreading than would a larger value.

Page 105, 8.1.5.4, Total Dissolved Solids Concentrations. Review of the data in table 22 shows that prior to artificial recharge in the Fenner Gap area dissolved solids concentrations in some wells were as high as 1,040 mg/L. This is higher than the 300 to 400 mg/L reported in the Draft Report. It is not clear from the Draft Report why wells having high dissolved-solids water were sampled only one time or why this water was not analyzed for stable isotope or carbon-14 activity.

8.1.6 Recharge and Discharge

Page 106, 8.1.6.2, Subsurface Inflow. Show locations of injection wells on a figure. Into which layer was water injected?

Page 106, 8.1.6.3, Areal Recharge. Show recharge cells on a figure.

Page 106, 8.1.6.4, Ground-water Pumping. Pumping information does not match data presented on page 43.

Page 107, 8.1.6.5, Evapotranspiration. Show the ET cells on a figure. Justify the use of an extinction depth of 100 feet; this value seems to be much too large; it should be less than 10 feet for bare-soil evaporation. Using a too large extinction depth allows much more flux to leave the system than if a smaller value were used. State the values of the ET surface and the maximum ET used in the model.

8.2 Model Calibration

Page 107, 8.2.1, Selection of Calibration Period. The discussion of the calibration period makes no sense. Why is the precipitation record important? It seems that the pumping record would have a greater impact on the ground-water system. How is 1958-85 a steady-state condition? How is this implemented in the model? Compare the simulated steady-state water levels with measured, predevelopment water levels.

Page 108, 8.2.2, Discussion of Calibration Process. What do you mean by "Therefore, for the purposes of this model, the model-generated water levels beneath Bristol and Cadiz dry lakes were not used and were considered boundary conditions"? If the simulated water levels beneath the lakes are 40 to 80 feet below measured water levels, this indicates that the simulated initial conditions are much too low and the model should be recalibrated. Note that most of the calibrated water levels in the northern part of the model area (e.g., figures X-13 and X-15) are 20 to 40 feet higher than measured water levels. This information, coupled with the lower-than-measured lake water levels, indicates a simulated gradient greater than measured conditions. This implies that even though overestimated T values are used in the model, the model could not transmit the estimated inflows without increasing the simulated hydraulic gradient.

Page 109, 8.2.3, Discussion of Model Calculated Recharge and Discharge. The report states that the model simulated recharge term (50,000 acre-feet per year) is supported by the stable water level trends. As described below, the water levels were not stable. The model could not simulate 50,000 acre-feet per year discharge without having an unreasonable evaporation extinction depth (100 feet) and the resulting simulated water levels at the dry lakes were 50 feet too low. In addition, the simulated water-level gradient through the Fenner Gap was greater than the measured gradient, even using unreasonably high transmissivity values. The model results indicate that the conceptual model is incorrect.

Page 110, 8.2.4, Discussion of Model-Generated Water Levels. Show the simulated steady-state water levels. Published data indicate that steady-state water levels were about 600-625 feet around the project area; these data are 40 or more feet higher than the initial water levels shown in figures X-4 to X-15. This indicates that the steady-state water levels were underestimated throughout the model domain. Show measured water levels on simulated water-level contour figures. The model underestimates the water-level declines at the Cadiz agricultural well field. The model fit appears reasonable at the scale plotted; however, if the measured data ranges only on the order of 25 feet for the period of simulation, one should not plot it on a scale that has a range of 400 feet. The model results need to be replotted on a reasonable scale and consideration should be given to predevelopment water-level measurements in the area (Moyle, 1967). As stated previously, the model does a poor job of simulating the water-level gradient north of Fenner Gap.

The model needs to be recalibrated, starting with steady-state conditions. The model needs to be able to simulate the observed water levels and gradients. Matching the water levels at Cadiz and Bristol dry lakes will be an important element of the calibration process. Initial calibration might include using the MODFLOW drain function to simulate discharge at the dry lakes.

8.2.5 Discussion of Water Budget

Page 112, 8.2.5.1, Water Balance Analysis. The water budget is meaningless because the model does not correctly simulate the water levels beneath the dry lakes.

Page 113, 8.2.5.2, Natural Recharge to the Cadiz Project Wellfield. The value of 30,000 acre-feet per year of recharge is based on an invalid model. As stated above, the gradient simulated by the model is too high through the Fenner Gap, even using unreasonably high transmissivity values. Earlier in the report it is stated that all the recharge originates from the mountains in Fenner Valley. If 30,000 acre-feet per year is simulated as moving through Fenner Gap, where does the model simulate the remaining 20,000 acre-feet per year recharge to the system?

8.3 Evaluation of Project Operational Scenarios Using the Cadiz Groundwater Model. The following sections discussing the operational scenarios (Sections 8.3.1-8.3.6) were not reviewed, because the model needs to be recalibrated before using it to predict future scenarios.

8.4 Evaluation of Subsidence

Page 116, 8.4.2, Description of Subsidence Simulation Model. As most readers will not be familiar with Helm's model, please present the model with all assumptions.

Page 116, 8.4.3, Model Input Data Parameters. Were the proposed spreading basins included as one of the modeled sites? The overburden of the water may cause increased subsidence. Please show sites where model was applied on a figure.

Page 117, 8.4.3.1, Idealized Lithologic Log Development. What is an "idealized lithologic log"? Please show one.

Page 117, 8.4.3.2, Water levels. Where in the column are the boundary conditions defined?

Page 118, 8.4.3.5, Preconsolidation Stress. State the value of preconsolidation head used in the subsidence model. Compaction occurs after the head drops below the preconsolidation head; therefore, the timing of compaction is affected by the choice of this value.

Page 119, 8.4.4, Model Output. Please show the time varying subsidence for all 19 sites.

SECTION 9.0--RESULTS

9.1 Results of Evaluation of Water Resources

Page 120, 9.1.1, Results of Watershed Model. The Draft Report estimates that the total amount of recoverable water for the entire watershed ranges from 20,000 to 58,000 acre-feet per year, with a median value of 39,000 acre-feet per year. As discussed in great detail in the review of Section 6.0, there are major problems with the watershed model assumptions and results. The watershed model is a detailed daily water-budget model: daily precipitation, infiltration, runoff, vegetation interception, evapotranspiration, soil moisture, and percolation are addressed. However, the model does not address bedrock permeability, and this may become an important factor for upland areas with shallow soils underlain by low-permeability granites and metamorphics. For example, soil unit D defines an important watershed modeling unit that is used to subdivide the watershed model into areas of similar characteristics. For soil unit D, these are predominantly upland areas with shallow soils and thus the permeability of the underlying bedrock may have an important effect. The estimates of field capacity used in the model (13 to 17 %) are below the range that would be calculated from the STATSGO database for soil unit D in the Providence Mountains area. Estimates using the STATSGO database, for the same general area as soil unit D, would be 17 to 24 %. The soil thickness for the shallow soils seems reasonable, but the soil thickness for the deeper soils is in error. Although taxonomically the soils may be less than 2 meters, the rooting depth, and therefore the evapotranspiration depth, is much deeper. As shown in figure 26 of the Draft Report, field capacity and soil thickness are very sensitive parameters for the watershed model. Increasing the field capacity and/or the soil thickness will reduce the model-calculated recharge. Therefore, the range of recoverable water calculated by the watershed model used in the Draft Report would be larger (the low end would be lower and the high end would remain the same) and the resulting median value would be lower.

To test the reasonableness of the recharge values simulated by the Draft Report watershed model, the USGS developed two Maxey-Eakin water-balance models. The model development and model results are included as an attachment to this review. The median recharge rate estimated by the watershed model (39,077 acre-feet per year) is 3 to 15 times higher than the values estimated by the preliminary Maxey-Eakin models developed by the USGS (2,550 to 11,800 acre-feet per year). The quantity of recharge estimated with the watershed model appears to be an overestimate of the recharge and, therefore, the recharge rates should be reevaluated.

Page 121, 9.1.1.4, Groundwater Storage Capacity. This value is misleading in that it assumes that all of the water can be removed and that all of the water is of suitable quality. Table 10b of the Draft Report overestimates the thickness of layer 2 and overestimates the specific yield of the bedrock aquifer.

Page 121, 9.2, Geology of Fenner Gap. There are inconsistencies in the measured thickness of alluvium and the values and the depth to bedrock contour map presented in the Draft Report (figure 19). As indicated in the Draft Report, the difference in bedrock elevation between wells 5/14-13 and CI-2 suggest the presence of a fault. This fault and other faults in the area should be studied to determine if they are barriers or partial barriers to ground-water flow. These faults may compartmentalize the proposed recharge and change the proposed recharge/pumpage operation.

9.3 Geohydrology of Fenner Gap

Page 125, 9.3.1, Bedrock Aquifer. It is unclear from the data presented in the Draft Report that there is a bedrock aquifer in the study area. Additional geohydrologic and geochemical data need to be collected to determine the significance of the bedrock aquifer.

9.3.2 Alluvium

Page 129, 9.3.2.1, Geohydrologic Characteristics. The Draft Report presents results of a pumping test conducted for well PW-1. It is apparent from inspection of the data that water levels are being affected by leakage. Water levels made during the test indicate that actual drawdowns are less than those predicted by the Theis curve at larger values of time. This type of deviation generally reflects the presence of a lateral recharge boundary or a leaky aquifer. Because there are no apparent recharge boundaries, the departure from the curve probably is the result of leakage of ground water from overlying or underlying sediments. The transmissivity and storage coefficient of an aquifer affected by leakage may be solved by conventional methods of analysis on the basis of the Theis equation if the data are collected at or close to the pumped well. In general, drawdown data collected early in an aquifer test are affected by leakage to a lesser degree than data collected at a later time (Neuman and Witherspoon, 1972, p. 1291). Analysis of drawdown data collected from wells at a distance from the pumped well, and at later times tends to overestimate the transmissivity of the aquifer. Therefore, early time data (in this case 0.1 to 10 minutes after commencement of pumping) should be analyzed from the pumping well and close observation well. Data collected during the recovery phase will be affected by leakage and will overestimate the transmissivity.

Page 130, 9.3.2.2, Baseline Water Quality. Inspection of the trilinear diagram of water-quality samples for wells in the Fenner Gap indicate that there is a wide range of water quality in the gap. The Draft Report states that the difference is the result of development problems. However, when one inspects the data a definite pattern appears. Most of the wells in the gap are perforated only 100 feet below the water table. In general, these wells are sampling the upper alluvial aquifer. Wells in the southeastern part of the gap (wells MW-3, 5, and 6) have TDS values in excess of 500 mg/L and have high percentages of sodium. These wells may be influenced from poor quality water from the underlying and surrounding bedrock. The thermal water sampled in Fenner Gap indicates upward flow from the underlying bedrock, possibly along fault zones. The two deepest wells (5/14-13 and PW-1) have the lowest TDS values (328 to 294 mg/L) of the wells sampled. These wells also have similar water chemistry, having a higher percentage of sulfate and calcium then samples from the other wells. As stated in the Draft Report, these wells appear to be on the downthrown (southwestern) side of a northwest-southeast trending fault. Wells CI-3 and MW-2 are probably also on the southwestern side of the fault; however, they have similar chemistry to the wells on the upthrown (northeastern) side of the fault. In addition, these wells are screened only in the upper 100 to 200 feet of the aquifer. This suggests that wells PW-1 and 5/14-13, which are perforated 500 to 300 feet beneath the water table, yield a large percentage of their water from the water-bearing deposits that are more than 100 feet below the water table. A velocity log and downhole sampling should be completed in these wells to identify the major water-bearing zones. In Fenner Gap, apon the northeastern side of the fault, water-bearing deposits are not as prevalent at depths of more than 100 feet below the water table. As shown on plate 3 of the Draft Report, a silt and clay layer is present at about 150 feet below the water table at wells PW-1 and CI-3. This fine-grained layer must separate the two types of water. It is interesting to note that the hydraulic head in well PW-1 is about 5 feet higher than the head in the nearby CI-3 well. The land-surface elevations should be resurveyed to verify this difference.

The source of water to the upper aquifer on the downgradient side of the fault probably is underflow through the Fenner Gap in the permeable deposits directly beneath the water table because the TDS and water types are similar. However, the source of water to the lower aquifer on the downgradient side of the fault cannot be solely underflow from Fenner Gap. The lower aquifer downgradient of the fault contains lower TDS and has different chemistry compared with upgradient wells in the Fenner Gap (see figure 80 in the Draft Report). Recharge along the Orange Blossom Wash may be the source of this water. Additional geochemical and isotopic data are needed from the deep wells to help answer this complex hydrologic puzzle.

Page 133, 9.3.3, Evaluation of Groundwater Age Using Isotopes. Comments presented for this section also include comments for isotopic data and correspondence from M. Lee Davisson of Lawrence Livermore National Laboratory from Appendix T.

General Comments--A number of controversial land uses have been proposed for the study area and adjacent basins--including the Bolo Landfill (RailCycle) and the low-level radioactive waste disposal site at Ward Valley. Because of the high profile of these proposed sites, the region has been extensively studied and there are a large amount of isotopic data collected in the study area and adjacent basins. Much of this previous work concluded that recharge in the area is small. Although data from these studies are readily available, it does not appear in the Draft Report. These data are important and have been included as part of this review (figure 1).

Comments on interpretation of oxygen-18 and deuterium data--The ∂D and $\partial^{18}O$ isotopic compositions of precipitation collected by Friedman et al. (1992) at Mitchell Caverns and at Amboy (near Bristol dry lake and closer to the study site) are different. Data from Mitchell Caverns plots on the meteoric water line. Data from Amboy plot on a line parallel to, but below, the meteoric water line. The isotopic composition of precipitation data at Amboy relative to the meteoric water line is typical of precipitation in summer-dominated precipitation regimes of the Mojave Desert and across much of the arid southwestern United States. The isotopic composition of water from Mitchell Caverns is typical of water from cooler, higher altitude sites. The similarity in isotopic composition (both in absolute magnitude and position relative to the meteoric water line) of ground water sampled as part of the Draft Report in the Fenner Gap areas to precipitation at Mitchell Caverns suggests that the ground water originated as recharge from precipitation that fell at a higher altitude rather than from locally derived precipitation. This is consistent with the interpretation presented in the Draft Report and is not consistent with infiltration from Schulyer Wash. Mitchell Caverns and other higher altitude locations are many miles from the study site and ground-water flow paths through alluvial aquifers are long.

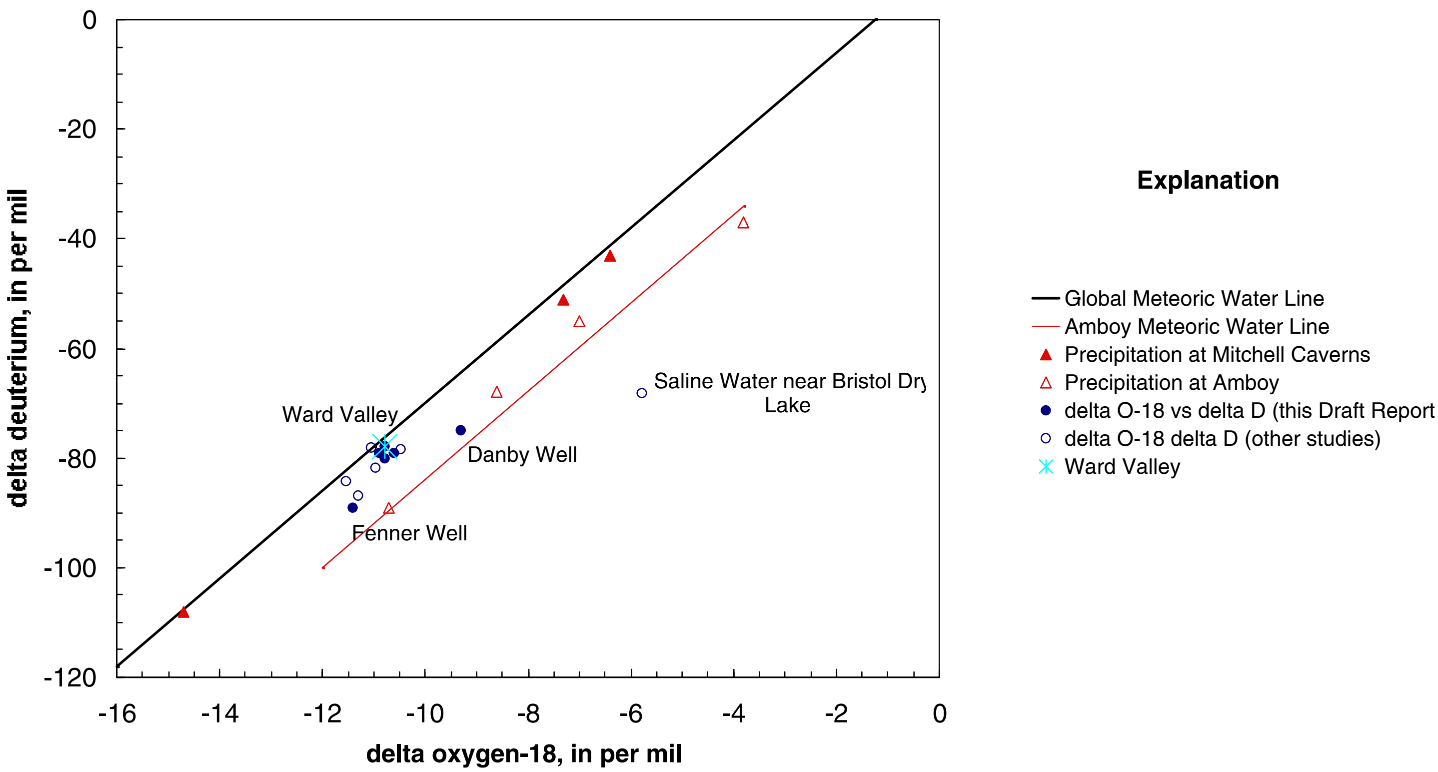

Figure 1.--Delta oxygen-18 and delta deuterium data from Fenner Valley and vicinity

Water from the Danby well (this Draft Report) plots below the meteoric water line along the local meteoric water line at Amboy. Its position along the Amboy meteoric water line suggests a locally derived origin for water from this well. This is consistent with the interpretation presented in the Draft Report and the ∂D and ∂^{18}O composition of water from the Danby well is cited as evidence of infiltration from washes that drain Fenner Valley. However, if infiltration is occurring along the wash, why is there no isotopic or chemical evidence of water from this source in the Fenner Gap wells? Similarly, data from an upgradient well along the wash at Essex (LaMoreaux & Associates, 1995) show no evidence of infiltration from the wash. Friewald

(1984) described several wells in Danby were that drilled for the railroad between 1901 and 1927. One the basis of water-level data collected by Friewald (1984), the depth to water at this site is about 250 below land surface. At that time, at least one of these wells yielded water from above the regional water table and could not be representative of water from the regional aquifer. It is possible that the Danby well sampled as part of this Draft Report is old, its casing has failed, and water from the well is not representative of the aquifer. Izbicki (1998) estimates that several hundred years are required for water from washes to infiltrate through thick unsaturated zones and reach the water table. Tritium would not be expected in ground water at this site regardless of its source. A failed casing and leakage of surface water into the well also would explain the presence of tritium in water from the Danby well sampled as part of this Draft Report. The Danby well may not be representative of water from the aquifer. Because of the uncertainty of the validity of this sample, the data should not be used as evidence of infiltration from the wash and should not be considered as part of the interpretations in this Draft Report. Proper identification of the well, inspection of the well, and inspection of the integrity of its casing are required to verify or reject this sample.

The Draft Report claims that the natural variability in the isotopic composition of water in the Fenner Gap area is small and consistent with one large source of ground-water recharge. However, on the basis of the large variability in chemical quality of water from wells, this variability has not been adequately addressed with samples collected as part of the Draft Report. Water-chemistry data indicate large differences in the chemical quality of water even in the small area near the recharge site. These large differences in chemistry would not be expected near a large source of ground-water recharge. They are in fact consistent with water from a number of smaller sources converging at a single location. It is not clear from the Draft Report why wells with high dissolved-solids water were sampled only one time or why this water was not analyzed for stable isotope or carbon-14 activity.

As a group the data from wells that were sampled in Fenner Gap are isotopically similar to data collected at the Ward Valley (National Research Council, 1995) and near the proposed Bolo Landfill (LaMoreaux & Associates, 1995). The most negative (lightest) samples are from a well along the eastern edge of Fenner Valley, sampled by Gleason et al. (1984). This sample plots along the local meteoric water line at Amboy and, on the basis of its location, would not be expected to receive recharge from the higher altitudes in the Providence Mountains near Mitchell Caverns. Saline water from a well near Bristol dry lake plots farthest from the meteoric water line as a result of evaporation. These data give an estimate of variations in the natural isotopic composition of water from wells in the study area--additional data are required for further interpretation.

The similarity of the ∂D and $\partial^{18}O$ isotopic compositions of water from wells to present-day precipitation is interpreted in the Draft Report as evidence of recharge during present-day climatic conditions. Given the wide range and seasonality in the ∂D and $\partial^{18}O$ composition of present-day precipitation measured by Friedman et al. (1992), care must be used when interpreting changes in ∂D and $\partial^{18}O$ isotopic compositions of water in terms of paleoclimatic signals. Unlike many other areas of the world, in the western part of the Mojave Desert (Izbicki et al., 1995) and in parts of coastal California (Izbicki et al., 1992), correlations between carbon-14 ages and the ∂D and $\partial^{18}O$ isotopic composition of ground water do not show a large shift toward more negative values (lighter) with increasing age. The reasons for this are unclear but may be related to the marine influence on climate and precipitation in southern California. Paleoclimatic studies have shown that, unlike most of the world, the temperature of the Pacific Ocean off the California coast during the Pleistocene (CLIMAP, 1976) was similar to present-day temperatures (Pisias, 1979).

Comments on the interpretation of tritium data--On the basis of data collected at Santa Maria and correlation with samples collected at Ottawa Canada (International Atomic Energy Agency, 1981), tritium in present-day precipitation in coastal California is expected to be about about 2 tritium units (TU) or about 6.4 picoCurries per liter (pCi/L) (Izbicki, 1992; Michel, 1989). Tritium in precipitation increases with increasing distance from the ocean; Michel (1989) estimated tritium concentrations in southern California to be about 3.3 TU in 1983. On the basis of samples of stormflow runoff collected at different sites in the Mojave Desert (U.S. Geological Survey, unpublished data), tritium in present-day precipitation in the Mojave Desert may be about 6 TU, slightly higher than Michel's estimate and slightly lower than the estimate in this Draft Report. Tritium in precipitation at Santa Maria reached a peak concentration of about 1,200 TU in 1962. Correcting for radioactive decay to the present time (about 3 half-lives) produces an estimate of about 150 TU. This is lower than the value reported in this Draft Report. The actual tritium concentrations in precipitation at the site probably are between the decay-corrected Santa Maria value and the value presented in the Draft Report. However, even after allowing for radioactive decay, tritium is readily measurable in environmental samples if the proper analytical techniques are used.

The tritium data for the Danby well (Stephens & Associates, 1992) has significant error associated with the measurement. The precision of the tritium analysis for this well is poor and the analytical techniques used were not intended for environmental studies of recharge processes. Analytical techniques that incorporate gas scintilation, electrolytic enrichment, or the recently developed helium-ingrowth procedures allow for detection limits of 0.2 TU or lower. The Draft Report interprets data from the Danby well as recently recharged water, and the ∂D and $\partial^{18}O$ isotope data suggest that the water is locally derived. Unfortunately, the well sampled is not identified by State well number. There are several old wells in the Danby area; water-level data (Friewald, 1984) suggest that at least some of the wells do not measure water representative of the aquifer. As previously discussed, Izbicki (1998) estimated that several hundred years are required for water from washes to infiltrate through thick unsaturated zones and reach the water table. Tritium would not be expected in ground water at the Danby well regardless of its source. Data from this well should not be considered as part of the interpretations in this Draft Report unless the sampled well is identified and the integrity of its casing verified.

Comments on the interpretation of carbon-14 data--Carbon-14 data from observation wells in Fenner Gap range from 18 to 25 percent modern carbon and have an apparent ages ranging from 11,500 to 14,000 years before present. In Appendix T, M. Lee Davisson suggests that water-rock reactions have occurred and that ground-water ages are younger than apparent ages indicate. However, he still believes that the ground-water age is early Holocene to late Pleistocene. The Draft Report dismissed the carbon-14 data and interpretations provided by M. Lee Davisson and suggested that carbon-14 data are not interpretable because reaction between ground water and aquifer materials (primarily dissolution of carbonate minerals) during recharge and subsequent movement through the aquifer have altered the carbon-14 activity of the ground water.

In areas where the recharge rate is small and infiltrating water passes through a thick unsaturated zone prior to ground-water recharge, the Draft Report is correct in stating that carbon-14 activities are altered and may not be interpretable. However, in areas where large amounts of recharge occurs, the unsaturated zone is leached of chloride and other soluble salts, and carbonate minerals have not accumulated. The estimates of recharge presented in the Draft Report are large and, if correct, would leach soluble salts and, therefore, extensive accumulations of carbonate minerals would not be present in the unsaturated zone in these area. These conditions allow interpretation of rock-water reactions and their effect on carbon-14 activities.

On the basis of carbon-13 data provided as part of the Draft Report, reactions have occurred between ground water and aquifer materials. However, it is possible to interpret carbon-14 data and correct ground-water ages to account for the dissolution of carbon from aquifer materials that do not contain carbon-14. Numerous studies in the literature demonstrate corrections for rock-water interactions and the application of carbon-14 data to ground-water recharge studies. A complete interpretation of possible rock-water reactions and resulting corrections in carbon-14 data is beyond the scope of this review. However, an estimate of corrected carbon-14 ages for water from wells sampled in Fenner Gap can be made on the basis of data and rock-water reactions interpreted from other studies. Given the following,

1. Organic carbon typically has $\partial^{13}C$ compositions ranging from -21 to -28 per mil, depending on the source. Ground water in most desert aquifers contains dissolved oxygen. As a result, sulfate reduction and oxidation of organic material to bicarbonate cannot occur and contributions from organic material in the aquifer are limited.

2. Inorganic carbon in carbonate minerals present as caleche or as cement in desert aquifers typically has a $\partial^{13}C$ of about -4 per mil in areas where marine limestones are present the $\partial^{13}C$ of inorganic carbon may be as low as 0 per mil (Izbicki et al., 1995). For the purposes of calculations presented in this review, dissolution or isotopic exchange between ground water and carbonate minerals is the primary source of carbon that does not contain carbon-14 to ground water in desert aquifers. This assumption is consistent with the geochemical framework presented in the Draft Report.

3. Detailed sample collection and geochemical modeling studies done along flowpaths in the western part of the Mojave Desert show that the $\partial^{13}C$ composition of infiltrating water in active recharge areas is close to equilibrium with atmospheric $\partial^{13}C$ and has a value near -13 per mil (Izbicki et al.,, 1995) at the time of recharge. For the purposes of calculations presented in this review, the carbon-14 value of infiltrating water at the time of recharge is assumed to be 100 percent modern carbon. Carbon-14 activities in surface runoff and recently recharge water in the Mojave Desert is actually between 95 and 90 percent modern carbon (La Mareaux & Associates, 1995; Izbicki et al., 1995). Lower initial carbon-14 activities will result in older corrected ground-water ages.

Assuming a closed system and conservation of mass, a calculation can be made to estimate the fraction of the dissolved inorganic carbon dissolved from aquifer materials using the following equation:

$$C_m f_m = C_r f_r + C_w f_w$$

where: C_m is the measured $\partial^{13}C$ composition of the ground water. When using this approach, the fraction carbon measured in the ground water, f_m, is 1;
C_r is the $\partial^{13}C$ composition of the rock--assumed to be -4 per mil;
f_r is the fraction of the dissolved inorganic carbon from the rock;
C_w is the initial $\partial^{13}C$ composition of ground water at the time of recharge--assumed to be -13 per mil;
f_w is the fraction of the dissolved inorganic carbon from the recharge water. (To solve the equation f_w is written as $f_w = f_r - 1$).

Once the fraction of carbon from the aquifer materials is known, the corrected carbon-14 activity can be calculated using the following equation:

$$^{14}C_m = {}^{14}C_r f_r + {}^{14}C_w f_w$$

where: $^{14}C_m$ is the measured carbon-14 activity of the water. The fraction of carbon measured in the water is 1.
$^{14}C_r$ is the carbon-14 activity of the rock--assumed to be 0 because the rock has great age.
$^{14}C_w$ is the carbon-14 activity of the water corrected for mineralogical reactions. The fraction of the carbon-14 from the recharge water was calculated from the previous equation.

Results of these calculations are summarized in table 1.

Although subject to considerable discussion and additional interpretation if more data were available, the fraction of dissolved inorganic carbon from rock dissolution and corrected carbon-14 numbers are consistent with interpretations presented in the Draft Report by M. Lee Davisson of Lawrence Livermore National Laboratory. Corrected carbon-14 ages presented in table 1 also are consistent with corrected carbon-14 ages between 9,300 and 12,700 years before present estimated for the proposed Bolo Station Landfill Site (La Moreaux & Associates, 1995) in Cadiz Valley to the south of the study area and with corrected carbon-14 ages between 4,500 and 22,000 years before present estimated for Ward Valley east of the study area (National Research Council, 1995). Younger water, recharged 2,300 years before present, was sampled in parts of Cadiz Valley upgradient from the proposed landfill near the mountain front.

Mixing of younger ground water infiltrated from washes with older ground water also is cited as a source of error associated with carbon-14 measurements. In the Draft Report, the $\partial^{18}O$ and ∂D composition of water infiltrated from washes is believed to be characterized by samples from the Danby well. Water from this well has a unique ∂D and $\partial^{18}O$ isotopic composition and plots along the local meteoric water line for Amboy. If the Draft Report is correct in its interpretation,

∂D and $\partial^{18}O$ data suggest that water infiltrated from wash must be only a small component of the water sampled from wells at Fenner Gap. If a mixture is present, the Draft Report is correct in stating that carbon-14 measurements in water from wells represent an average age of the water; therefore, if even a small amount of comparatively young water from the wash infiltrated to the water table it would mix with ground water that would have to be even older than the corrected ages shown in table 1.

Summary--As a group isotopic data from this Draft Report and from studies in adjacent areas are consistent and show there is limited recharge under present-day climatic conditions and that ground water in desert basins was recharged thousands of years ago.

Table 1--Carbon-14 activities and ages for ground water from wells in the Fenner Gap.

Well number	Measured carbon-14 activity (pmc)	Measured carbon-13 (per mil)	Uncorrected Carbon-14 age (years before present)	Fraction DIC from rock (f_r)	Corrected carbon-14 activity (pmc)	Corrected carbon-14 age (years before present)
Assuming a carbon-13 composition of -4 per mil for rock dissolution						
CI-1	19	-7.8	13,600	0.58	45	5,500
CI-2	18	-8.4	14,000	0.51	37	8,300
CI-3	24	-9.4	11,900	0.40	40	7,600
MW-7	25	-10	11,500	0.33	38	8,100
Assuming a carbon-13 composition of 0 per mil for rock dissolution						
CI-1	19	-7.8	13,600	0.40	32	9,500
CI-2	18	-8.4	14,000	0.35	28	10,600
CI-3	24	-9.4	11,900	0.28	33	9,100
MW-7	25	-10	11,500	0.23	32	9,200

9.5 Infiltration

Page 139, 9.5.3, Groundwater Mounding. Was the ground-water model described in Section 8.0 used to simulate the water-level drawdown resulting from the pumping during the test and water-level mounding resulting from the recharge operation? The measured results of this test (figures 103 and 108) would provide excellent data to calibrate the ground-water flow model on a local scale. How were the drawdown and recharge mound figures constructed in such detail (figures 103-108)? The measured data from the wells are too sparse to construct the figures. The symmetry of the drawdown and mounding could be useful for identifying changes in lithology and potential barriers to flow. As postulated in the Draft Report and in this review, a northwest-southeast trending fault lies almost directly beneath the recharge ponds. Since the production well is perforated in the upper and lower aquifers, and the extent of the lower aquifer is limited by the fault to the northeast, one would expect to see a barrier affect in the measured drawdown. Unfortunately, there are no wells perforated opposite the lower aquifer between the production well and the recharge ponds. A better monitoring network would be needed to define the drawdown and mounding. Microgravity would be a good technique to apply to fill in the gaps during a follow-up recharge activity. The calibrated model could then be used with more confidence, then the poorly calibrated regional model, to help manage the large-scale recharge operation. In addition, a two-dimensional unsaturated zone model could be calibrated with the measured data, to provide information on the unsaturated zone properties.

Page 140, 9.5.4, Water Quality Changes (Includes comments for 9.5.4.1 and 9.5.4.2). Water-quality changes observed in monitoring wells after water infiltrated through the thick unsaturated zone beneath the recharge basins are consistent with leaching of chloride and other soluble salts from the unsaturated zone. As described in previous comments from Section 6.7, accumulation of chloride and other soluble salts is consistent with the lack of recharge in desert basins. The relatively high chloride concentrations measured in observation wells suggest that the salt accumulation was large and that the length of time since recharge has occurred at that site must be long.

The Draft Report does not discuss what happens with this high TDS water. Was the solute-transport model described in Section 8 used to simulate the movement of this TDS plume? It is interesting to note that the TDS contours do not agree with the water-level contours. What are the implications of this high TDS water for the large-scale operation? What will be done with this high TDS during the pump-back operation? Wells CI-3 and MW-2 should have been sampled to determine the transport of the TDS plume.

9.9 Analysis of Project Impacts Using the Groundwater Model

Page 148, 9.9.1, Project Area Water Level Changes. As described in great detail in the review of the model in Section 8.0, the model does not accurately simulate current water levels. Water levels are too high in Area A and too low near the dry lakes. The simulated gradient through the Fenner Gap is higher than the gradient measured in the gap, even using unreasonably high hydraulic conductivity values (in excess on 1,000 gpd/ft^2). Too much recharge is being simulated in the model; therefore, the gradient is too high and an unreasonable evapotranspiration rate is being simulated in the model. The simulation of soil evaporation from the dry lakes using a 100-foot extinction depth is unreasonable. The model needs to be recalibrated before it can be used to predict water-level changes resulting from the planned recharge/pumpage operation.

Water-level contours and drawdown contours need to be presented for each scenario. These contours are needed to show the areal extent of mounding during recharge operations and drawdown during the pumping operation. In addition to simulating scenarios 5 and 6, please make two long-term simulations considering the recovery of the aquifers after the 50-year put/take operations cease. The length of these simulations should be long enough such that there is little change in head between subsequent stress periods. Note that steady-state simulations will not suffice because density-dependent flow and transport takes many years to equilibrate. These simulations are needed to show the long-term affects of the recharge and pumping operations. If more water is withdrawn than is recharged, it will take many years for the drawdown cone to stabilize, especially if realistic recharge rates are simulated in the model.

Page 148, 9.9.2, Groundwater Supply to Bristol and Cadiz Dry Lakes. Results of the watershed model, chloride mass balance studies, isotopic data, and water balance (evaporation at the dry lakes) presented in the Draft Report greatly overestimate natural ground-water recharge. Data presented in the Draft Report and all previous studies done in the area are consistent with small amounts of recharge to desert basins. The 1,150,000 acre-feet of ground water projected as discharge to Bristol dry lake, under existingl conditions, over a 50-year period is not correct. The actual number is much smaller. Such a large error in such an important component of the model almost certainly invalidates the flow and solute model results and predictions.

As a check on the simulated underflow through Fenner Gap, a simple Darcy's Law calculation was completed using the data presented in the Draft Report. Friewald (1984) and P.E. La Moreaux & Associates (1995) performed similar calculations. Darcy's Law states that Q = KIA where Q is equal to the rate of underflow; K is equal to the hydraulic conductivity, and A is equal to the cross-sectional area. The gradient (I) was determined by measuring the water-level distance between wells MW-7 and MW-1 (612.72-602.47=10.25 feet) and dividing by the measured distance between the wells (5,950 feet; measured on plate 3 of the Draft Report). The resulting gradient is 0.0017 feet per feet. The cross-sectional area was measured along the cross-section D-D' on plate 3. Two areas were measured: the first area (A1) is the area of the saturated unconsolidated deposits from the water table to 100 feet below the water table, and the second area (A2) is the area of the saturated unconsolidated deposits from 100 feet below the water table to the contact with the underlying bedrock. This was done because inspection of the geophysical and lithologic logs indicated that there was a change in the hydraulic properties of the unconsolidated deposits at about 100 feet below the water table. The resulting areas were approximately 486,000 ft^2 for A1 and 3,300,000 ft^2 for A2. If we assume the hydraulic conductivity values estimated for the upper and lower alluvial aquifers, presented earlier in this review (see review comments for Section 8.1.4.4), are representative of the two aquifers (800 gpd/ft^2 for the upper aquifer and 300 gpd/ft^2 for the lower aquifer), we can estimate the underflow through the Fenner Gap. Note that these hydraulic conductivity values were estimated from well PW-1 that is downgradient of a postulated fault, and this well penetrates deposits that are not present in the gap. The calculated underflows are about 740 acre-ft/yr and 1,887 acre-ft/yr for A1 and A2, respectively. Therefore, the combined estimated underflow through the Fenner Gap is about 2,627 acre-feet per year. If one assumes that the hydraulic conductivity estimated from the specific capacity data of well PW-1 is representative for the entire cross sectional area (600 gpd/ft^2; see review comments for Section 8.1.4.4), then the total estimated underflow would be about 4,330 acre-feet per year. These estimates are higher than the 270 acre-feet per year estimated by Friewald (1984) lower or slightly higher than the 3,720 acre-feet per year estimated by P.E La Moreaux & Associates (1995), and significantly less than the 30,0000 acre-feet per year estimated in the Draft Report. The Draft Report must reevaluate the recharge and hydraulic conductivity estimates used in the ground-water flow model.

Regardless of the recharge value, if the project pumps more water than is recharged, there will be less ground-water discharge at the dry lakes. Over the long term, this will cause water levels beneath the dry lakes to decline. A density-dependent solute-transport model is needed to evaluate the long-term impacts of the project on the brine levels. The Draft Report does not address how water-level declines will impact the dry lakes. With a decrease in ground-water discharge, will the mining operation at the dry lakes be impacted? Will lower water levels cause the upper sediments to dry out and result in a dust problem? As stated previously in this review, the failure of the model to simulate the water levels beneath the playas invalidates the models ability to predict any impacts resulting from the recharge/pumping operation on water levels and solute transport beneath the playas. With less recharge in the model, water-level declines resulting from the pumping phase of the project will be greater, which will undoubtedly cause the high salinity water to move from the Bristol dry lake area towards the pumping wells if there is not a ground-water barrier between the well field and Bristol dry lake.

Page 150, 9.10, Subsidence and Hydrocompaction. As stated previously in the review, the water-level changes predicted by the ground-water model are based on an incorrectly calibrated model; therefore, the predicted subsidence values will also be in error.

Page 151, 9.11, Project Spreading Basins. The entire project should be reevaluated after recalibrating the ground-water flow and solute-transport models.

REFERENCES

CLIMAP, 1976, The surface of the ice-age earth: Science, vol. 191, no. 4232, p. 1131-1137.

Czarnecki, J.B., 1997, Geohydrology and evapotranspiration at Franklin Lake Playa, Inyo County, California: U.S. Geological Survey Water-Supply Paper 2377, 75 p.

Department of Defense, 1998, Mojave Desert ecosystem program: 8 CD-ROM.

Dettinger, M.D., 1989, Reconnaissance estimates of natural recharge to desert basins in Nevada, U.S.A., by using chloride-balance calculations: Journal of Hydrology, vol. 106, p. 55-78.

Dingman, S.L., 1994, Physical hydrology: Prentice Hall, Upper Saddle River, New Jersey, 575 p.

Driscoll, F.G., 1987, Groundwater and wells (2nd ed.): Johnson Division, St. Paul, Minnesota, 1089 p.

Feth, J.H., and Brown, R.J., 1962, Method for measuring upward leakage from artesian aquifers using rate of salt-crust accumulation, *in*: Geological Survey Research 1963; U.S. Geol. Survey Prof. Paper 450-B, p. 100-101.

Flint, A.L., and Childs, S.W., 1991, Modification of the Priestley-Taylor equation for estimating evapotranspiration for soil water limited conditions: Journal of Agricultural and Forest Meteorology, vol. 56, p. 247-260.

Freeze, R.A., and Cherry, J.A., 1979, Groundwater: Prentice Hall, Englewood Cliffs, New Jersey, 604 p.

Friedman, Irving, Smith, G.I., Gleasom, J.D., Warden, Augusta, and Harris, J.M., 1992, Stable isotope composition of water in southeastern California--Modern precipitation: Journal of Geophysical Research, vol. 97, no. D5, p. 5795-5812.

Friewald, D. A., 1984, Ground-water resources of Lanfair and Fenner Valleys and vicinity, San Bernardino County, California: U.S. Geological Survey Water-Resources Investigations Report 83-4082, 60 p.

Galloway, D.L., Hudnut, K.W., Ingebritsen, S.E., Phillips, S.P., Peltzer, G., Rogez, F., and Rosen, P.A., 1998, Detection of aquifer system compaction and land subsidence using interferometric synthetic aperture radar, Antelope Valley, Mojave Desert, California: Water Resources Research, vol. 34, no. 10, p. 2573-2585.

Gleason, J.D., Veronda, Guida, Smith, G.I., Friedman, Irving, and Martin, Peter, 1994, Deuterium content of water from wells and perennial springs, southeastern California: U.S. Geological Survey Hydrologic Investigations Atlas HA-727, 1 map.

Hanks, R.J., and Ashcroft, G.L., 1980, Applied Soil Physics: Springer-Verlag, p. 159.

International Atomic Energy Agency, 1981, Statistical treatment of environmental isotope data in precipitation: Technical Report Series No. 206, 255 p.

Izbicki, J.A., in review, Testing alternative conceptual models of the movement of water through a thick, heterogeneous unsaturated zone underlying an intermittent stream in the western part of the Mojave Desert, USA.

Izbicki, J.A., Michel, R.L., and Martin, Peter, 1992, ^{3}H and ^{14}C as tracers of ground-water recharge. p. 122-127, *in:* Engman, T., Saving a threatened resource, Proceedings of the American Society of Civil Engineers, Baltimore, MD, August 2-6, 1992.

Izbicki, J.A., Michel, R.L., and Martin, Peter, 1995, Source, movement, and age of groundwater in the Mojave River basin, California. p. 43-56, *in:* Adar, E.M., and Leibundgut, Christian (eds.), Application of tracers in arid zone hydrology, International Association of Hydrological Sciences, Publication No. 232, Wallingford, U.K., 452 p.

Izbicki, J.A., Michel, R.L., and Martin, Peter, 1998, Chloride and tritium concentrations in a thick unsaturated zone underlying an intermittent stream in the Mojave Desert, southern California, USA, p. 81-88, *in*: Brahana, J.V. et al., (eds.), Gambling with groundwater, Proceedings of the International Association of Hydrogeologists, Las Vegas, Nevada, September 28 to October 2, 1998, American Institute of Hydrology, Saint Paul, MN, 753 p.

Izbicki, J.A., Radyk, John, and Michel, R.L., in review, Movement of water through the thick unsaturated zone underlying Oro Grande and Sheep Creek Washes in the Mojave Desert, USA.

Jachens, R.C., and Howard, K.A., 1992, Bristol lake basin—A deep sedimentary basin along the Bristol-Danby trough, Mojave Desert, p. 57-59, in: Reynolds, R.E., Old routes to the Colorado, San Bernadino County museums special publication 92-2, Redlands, CA, 106 p.

Kupfer, D.H., and Basett, A.M., 1962, Geologic reconnaissance map of the southeastern Mojave Desert, California: U.S. Geological Survey Investigations Field Studies Map MF-205.

Kunkel, Fred, and Chase, G.H., 1969, Geology and ground water in Indian Wells Valley, California: U.S. Geological Survey Open-File Report, 84 p.

Laczniak, R.J., DeMeo, G.A., Reiner, S.R., Smith, J.L., and Nylund, W.E., 1999, Estimates of ground-watrer discharge as determined from measurements of evapotranspiration, Ash Meadows are, Nye County, Nevada: U.S. Geological Survey Water-Resources Investigations Report 99-4070, 70 p.

LaMoreaux & Associates, 1995, Isotopic study of groundwater: proposed Bolo Station landfill site and adjacent areas, San Bernardino County, California: LaMoreaux & Associates, Tuscaloosa, AL, 25 p.

LaMoreaux & Associates, 1995, Technical comments on groundwater recharge and projected drawdown computations for Bristol-Cadiz Valley: LaMoreaux & Associates, Tuscaloosa, AL, 20 p.

Lee, C.H., 1913, Use and conservation of the underground reservoirs of California: Western Engineering, vol. 3, p. 189-194.

Lines, G.C., 1979, Hydrology and surface morphology of the Bonneville Salt Flats and Pilot Valley playa, Utah: U.S. Geological Survey Water-Supply Paper 2057, 107 p.

Lines, G.C., and Bilhorn, T.W., 1996, Riparian vegetation an its water use during 1995 along the Mojave River, Southern California: U.S. Geological Survey Water Resources Investigations Report 96-4241, 10 p., 1 oversize plate.

Maas, J., 1994, Depth to basement calculated from gravity data: Cadiz Land Co., Inc.

McDonald, E.V., McFadden, L.D., and Wells, S.G., 1995, The relative influences of climate change, desert dust, and lithologic control on soil-geomorphic processes on alluvial fans, Mojave Desert, California: Summary of results, *in* Reynolds, R.E., and Reynolds, J., eds. Ancient surfaces of the east Mojave Desert, San Bernardino County Museum Association, vol. 42, no. 3, p. 35-42.

Michel, R.L., 1989, Tritium deposition in the continental United States, 1953-83: U.S. Geological Survey Water-Resources Investigations Report 89-4072, 47 p.

Miller, D.M., and Howard, K.A., 1985, Bedrock geologic map of the Iron Mountains quadrangle, San Bernardino and Riverside Counties, California: U.S. Geological Survey Miscellaneous Field Investigations Map MF-1736, scale 1:62,500.

Moyle, W.R., Jr., 1967, Water wells and springs in Bristol, Broadwell, Cadiz, Danby, and Lavic Valleys and vicinity, San Bernardino and Riverside Counties, California: California Department of Water Resources Bulletin 91-14, 17 p., 5 appendixes.

National Research Council, 1995, Ward Valley--An examination of seven issues in earth sciences and ecology: National Academy Press, Washington D.C., 212 p.

Neuman, S.P., and Witherspoon, P.A., 1972, Field determination of hydrologic properties of leaky multiple aquifer systems: Water Resources Research, vol. 8, no. 5., p. 1284-1298.

Nimmo, J.R., 1999, The Darcian approach and practicality: determination of basin-scale recharge measurements from sparse point measurements (abs.): Geological Society of America, Proceedings of 1999 Annual Meeting, October 25-28, Denver, CO, p. 125.

Osterkamp, W.R., and Wood, W.W., 1987, Playa-lake basins on the southern high plains of Texas and New Mexico: Part 1--Hydrologic, geomorphic, and geologic evidence for their development. Geological Society of America Bulletin, vol. 99, p. 215-223.

Phillips, F.M., 1994, Environmental tracers for water movement in desert soils of the American Southwest: Soil Science of America Journal, vol. 58, p. 15-24.

Pisias, N.G., 1979, Model for paleoceanographic reconstructions of the California current during the last 8,000 years: Quaternary Research, vol. 11, p. 373-386.

Pohl, G.M., 1996, Development of a coupled surface/subsurface hydrologic model and stochastic analysis of a vadose zone and saturated zone numerical model: Unpublished Ph.D. Dissertation, University of Nevada, Reno.

Prudic, D.E., 1994, Estimates of percolation rates and ages of water in unsaturated sediments at two Mojave Desert sites, California-Nevada: U.S. Geological Survey Water-Resources Investigations Report 94-4160, 19 p.

Rosen, M.R., 1992, The depositional environment and evolution of Bristol lake basin, eastern Mojave Desert, California, p. 60-64: in: Reynolds, R.E., Old routes to the Colorado, San Bernadino County museums special publication 92-2, Redlands, CA, 106 p.

Scanlon, B.R., 1994, Water and heat fluxes in desert soils, 1--Field studies*:* Water Resources Research, vol. 30, no. 3, p. 709-719.

Shafer, R.A., 1964, Report on investigations of conditions which determines the potentials for development in the desert valleys of eastern San Bernadino County, California: Unpublished report, Engineering Dept., Southern California Edison Co., 172 p., 12 plates.

Stannard, D.I., 1993, Comparison of Penman-Monteith, Shttleworth-Wallace, and modified Priestley-Taylor evapotranspiration models for wildland vegetation in semiarid rangeland: Water Resources Research, vol. 29, no. 5, p. 1379-1392.

Stephens & Associates, 1992, Evaluation of regional recharge in Cadiz Valley Development Corporation project area, San Bernardino County, California, March 2, 1992.

Todd, D.K., 1980, Groundwater hydrology (2nd ed): John Wiley and Sons, New York, 535 p.

Turk, L.J., 1973, Evaporation of brine, A field study on the Bonneville Salt Flats, Utah: Water Resources Research, vol.6, no. 4, p. 1209-1215.

Tyler, S.W., McKay, W.A., Mihevc, T.M., 1992, Assessment of soil moisture movement in nuclear subsidence craters, Journal of Hydrology, vol. 139, p. 159-181.

Tyler, S.W., Chapman, J.B., Conrad, S.H., and Hammermeister, Dale, 1994, Paleoclimatic response of a deep vadose zone in southern Nevada, USA, as inferred from soil water tracers. p. 351-361, *in:* Adar, E.M. and Leibundgut, Christian, (eds.), Application of tracers in arid zone hydrology, International Association of Hydrological Sciences, Publication No. 232, Wallingford, U.K., 452 p.

Viceroy Gold Corporation, 1990, Castle Mountain Project, San Bernadino County, California, mine plan and reclamation plan.

Wood, W.W., and Sanford, W.E., 1995, Chemical and isotopic methods for quantifying ground-water recharge in a regional semiarid environment: Ground Water, vol. 33, no. 3, p. 458-468.

Wood, W.W., 1999, Use and misuse of the chloride-mass balance method in estimating ground water recharge. Ground Water, vol. 37, no. 1, p. 2-3.

Attachment

Copy To: **Willie Taylor, Director, Office of Environmental Policy and Compliance**
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USGS Preliminary Recharge Estimates for the Fenner, Bristol, and Cadiz Watersheds

The U.S. Geological Survey, as part of this review, estimated the recharge to the Fenner, Bristol, and Cadiz watersheds using a modified Maxey-Eakin (1949) model. The modified model is based on a continuous exponential curve fitted to the original Maxey-Eakin step function, which is used to estimate recharge as a percentage of average annual precipitation within discrete elevation-precipitation-recharge zones (Hevesi and Flint, 1998, Hevesi and Flint, in press). The modified Maxey-Eakin model was used in this review to provide a preliminary evaluation of the Cadiz project recharge estimates on the basis of an established approach of estimating recharge for basins in the southern Great Basin and the Mojave Desert regions.

Background

The watershed model recharge estimates presented in the Draft Report were compared with preliminary estimates obtained using a well-established and tested empirical method of estimating basinwide recharge in the southern Great Basin and the Mojave Desert regions. The method is based on basin-scale water-balance studies conducted by Maxey and Eakin (1949) throughout the central and southern Great Basin in Nevada. The studies indicated that a simple linear model for five elevation – precipitation – recharge zones could be used to estimate recharge. The linear model is a step function, which provides recharge estimates as a constant percentage of average annual precipitation within each of the five discrete zones. The percentage increases from a minimum of 3% for zone 1, with precipitation rates ranging from 203 to 305 millimeters per year (8 to 12 inches per year), to a maximum of 25% for zone 5 with precipitation rates of 508 millimeters per year (20 inches per year and greater). For precipitation rates less than 203 millimeters per year, recharge is estimated to be 0 by the Maxey-Eakin method. Dettinger (1989) indicated that the Maxey-Eakin model provided reasonable results on the basis of chloride-balance estimates of recharge for desert basins in Nevada. Rush (1970) applied the Maxey-Eakin method to estimate recharge for various basins throughout the Nevada Test Site in south-central Nevada, located in the transitional zone between the Great Basin and Mojave Desert regions. Results presented by Osterkamp and others (1994) using a combined watershed and channel-loss modeling approach provide a good basinwide comparison with Maxey-Eakin estimates for the Upper Amargosa River watershed. A three-dimensional regional ground-water flow model of the Death Valley ground-water basin indicated that spatially distributed recharge estimates using a modified Maxey Eakin model provided reasonable results on the basis of simulation results which were calibrated against regional discharge estimates, known ground water withdrawals, and measured water-table elevations (D'Agnese and others, 1997).

Hevesi and Flint (1998, in press) developed a modified Maxey-Eakin model on the basis of recharge estimates obtained from various studies in the central and southern Nevada region (Lichty and McKinley, 1995; Osterkamp and others, 1994; Winograd, 1981; Flint and Flint, 1994) (figure 1). The modified Maxey-Eakin model is applied to develop spatially distributed estimates of recharge using spatially distributed estimates of average annual precipitation. The average annual precipitation estimates are developed using available precipitation records from a network of regional monitoring sites and available digital elevation models (Hevesi and Flint, in press; Hevesi, Flint, and Istok, 1992; Hevesi, Istok, and Flint, 1992). The modified Maxey-Eakin model provides a continuous exponential curve for estimating recharge as a function of average annual precipitation and was developed on the basis of more recent studies, which indicate low recharge and net infiltration[1] rates for locations in the Great Basin with less than 203 millimeters per year precipitation (Nichols, 1987; Kwicklis, 1999; Flint and Flint, 1994, 1995) and recharge rates as high as approximately 50% of average annual precipitation for higher elevations with precipitation rates as high as 639 millimeters per year (25 inches per year) (Lichty and McKinley, 1995). Studies conducted by Nichols (1987) for a site in the northern Amargosa Desert and by Flint and Flint (1995) indicate negligible (less than 0.1 millimeter per year) recharge rates for inter-channel areas in thick alluvium. Studies conducted by Lichty and Mckinley (1995), using both the chloride balance and watershed modeling methods, indicate recharge rates of 11 to 33 millimeters per year (0.4 to 1.3 inches per year) for a small upland basin in the Kawich range of south-central Nevada, at elevations of 2,190 to 2,870 meters (7,185 to 9,416 feet). Lichty and McKinley measured an average precipitation rate of 336 millimeters per year (13.2 inches per year) for this study site during a six year study period. Results obtained by Lichty and McKinley for a higher elevation basin at 2,985 to 3,292 meters (9,498 to 10,801 feet) in the Toiyabe Range of central Nevada, with an average precipitation rate of 639 millimeters per year (25 inches per year), indicate much higher recharge rates of approximately 300 to 320 millimeters per year (11.8 to 12.6 inches per year). In the development and calibration of a regional ground water flow model for the Death Valley ground water basin, D'Agnese and others (1997) estimated that the percentage of precipitation occurring as recharge for zone 5 (average precipitation rates of 508 millimeters/year and higher) of the original Maxey-Eakin model is likely to be closer 30%, rather than 25% as indicated by Maxey and Eakin (1949). In general, the modified Maxey-Eakin model developed by Hevesi and Flint (1998, in press) provides higher estimates of basinwide recharge compared to the original Maxey-Eakin model, and is consistent with the recent studies indicating that recharge is likely to be higher on-average than 25% of the average precipitation rate for the wetter, higher elevation locations that apply to zone 5 (figure 1).

Development of the Maxey-Eakin Method for the Fenner, Bristol, and Cadiz Watersheds

To evaluate estimated recharge volumes provided in the Draft Report, the modified Maxey-Eakin method was applied to obtain preliminary estimates of spatially distributed recharge for the Fenner, Bristol, and Cadiz watersheds (figures 2 and 3). Precipitation was estimated using an available 30-meter digital elevation model for the area of the watersheds (figure 4) and two empirical elevation – precipitation correlation models

[1]Net infiltration is defined by Flint and Flint (1994) as the rate of water percolation below the zone of seasonal evapotranspiration, and represents a potential recharge rate through thick (> 100 meters) unsaturated zones.

(model 1 and model 2) (figure 5). Model 1 was developed by Hevesi and Flint (1998, in press) for the Death Valley region using a network of 114 precipitation stations for an area including most of the southern Great Basin and Mojave Desert regions. The model is a fitted regression curve and is similar to other empirical models representing the observed precipitation-elevation correlation in the southern Nevada and southeastern California region (French, 1983, 1986). Spatially distributed recharge estimates obtained using model 1 precipitation estimates and the modified Maxey-Eakin model for the Death Valley region were considered to be generally consistent with estimates of ground-water discharge and measured water-table elevations on the basis of the calibration of a three-dimensional ground water flow model which incorporates estimates of regional discharge, recharge, and a three-dimensional geologic framework model to match simulated with measured water-table elevations (D'Agnese and others, 1997).

A second model (model 2) was developed specifically for the review of the Draft Report by visually fitting a curve through the elevation-precipitation data from four stations (Mitchell Caverns, Amboy, Iron Mountain, and Twentynine Palms) in or adjacent to the three watersheds in the Cadiz study area (figure 5). The model provides an imposed extrapolation which estimates unrealistically high (relative to precipitation monitoring sites throughout the southern Great Basin and Mojave Desert regions) values of precipitation for elevations of 1,500 meters (4,921 feet) and higher. The estimates obtained using this model are considered to be unreasonably high on the basis of the observed orographic influences on precipitation in the Mojave Desert region. In addition, the average annual precipitation rate of 255 millimeters per year (10 inches per year) obtained using 37 complete years of daily precipitation records for the Mitchell Caverns site at an elevation of 1,326 meters (4,350 feet) is higher than the average annual precipitation rate obtained at other nearby locations in the Mojave Desert region with comparable elevations. For example, the elevation of the Mountain Pass site is 1,442 meters (4,730 feet), while average annual precipitation (based on 30 complete years of daily precipitation records) at this site is only 213 millimeters per year (8.4 inches per year).

Model 1-- Recharge estimates for the Fenner, Bristol, and Cadiz Watersheds

Figure 6 shows the spatial distribution of the preliminary USGS estimates of average annual precipitation using model 1 for the Fenner, Bristol, and Cadiz watersheds. Figure 7 shows the spatial distribution of the preliminary USGS estimates of average annual recharge for the watersheds obtained using the modified Maxey-Eakin model and the estimated average annual precipitation map. The spatial distribution of recharge rates as high as 10 to 20 millimeters per year for the higher elevation locations of the New York Mountains and the Providence Range within the Cadiz Project study area are considered reasonable in comparison to recharge estimates obtained throughout the Mojave Desert region in southeastern California and southern Nevada. For example, recharge has been estimated to be approximately 20 millimeters per year (0.79 inch per year) at elevations of approximately 2,200 meters (7,218 feet) in the northern part of the Nevada Test Site based on measurements of seepage in underground tunnels. The recharge rates of 10 to

20 millimeters per year (0.39 to 0.79 inch per year) also compare well with the recharge estimate of 13 to 33 millimeters per year obtained by Lichty and McKinley (1995) for the Kawich Range study basin at elevations of 2,190 to 2,870 meters (7,185 to 9,416 feet) in south-central Nevada. The spatial distribution of recharge obtained by model 1 is generally consistent with the watershed model results presented in the Draft Report indicating that most recharge occurs for soil type D which corresponds to the shallow soil areas of the more rugged upland locations in the Providence and New York Mountains (Figure 8).

Model 1-- Recharge estimates for the expanded study area

Preliminary recharge estimates were also obtained for an expanded study area including parts of basins adjacent to Fenner, Bristol, and Cadiz watersheds (figure 9). Although the assumption that surface-water and ground-water divides are equivalent is reasonable, a possibility exists that interbasin transfer of ground water through carbonate aquifers (or some other permeable structure or unit) provides inflow to the Cadiz Project watersheds. The total area contributed to ground-water recharge for the Cadiz project as represented by the expanded study area is considered to be highly unlikely as a true contributing area, especially since much of the area included in the northeastern part of the expanded area drains toward Ivanpah and Soda Lakes (dry). The intent of developing recharge estimates for the expanded area is to provide a comparison with the estimated recharge volumes presented in the Draft Report. The total estimated recharge volume for the expanded area is assumed to be greater than the actual recharge volumes available for the Cadiz project. The spatial distribution of the model 1 preliminary precipitation estimates for the expanded study area is provided in figure 10, and the recharge estimates for the expanded area is provided in figure 11. These results were considered reasonable in comparison to recharge studies conducted throughout the southern Great Basin.

Model 2--Recharge estimates for the Fenner, Bristol, and Cadiz Watersheds

Figure 12 shows the spatial distribution of the preliminary estimates of average annual precipitation using model 2 for the Fenner, Bristol, and Cadiz watersheds. Although this model provided a better fit to the precipitation records for the four Cadiz area precipitation stations, precipitation estimates of as high as 517 to 625 millimeters per year (2.3 to 24.6 inches per year) were obtained for elevations of approximately 1,800 meters (5,906 feet) and higher in the Providence and New York Mountains. These estimates are considered to be too high on the basis of a comparison with locations having similar amounts of precipitation but which are at much higher elevations, such as South Lake at an elevation of 2,920 meters (9,580 feet) in the southeastern Sierra Nevada and Lee Canyon at an elevation of approximately 2,800 meters (9,187 feet) in the Spring Mountains of southern Nevada. Model 2 recharge estimates are as high as 100 millimeters per year (3.9 inches per year) in the New York Mountains (figure 13), which is considered to be unreasonably high for this location on the basis of a comparison with estimated recharge rates of approximately 20 millimeters per year (0.79 inches per year) obtained for similar elevations on the Nevada Test Site and with recharge estimates of approximately 11 to 33 millimeters per year obtained by Lichty and McKinley (1995). It is unlikely that recharge rates in the Mojave Desert would be greater then recharge rates obtained for locations in the southern Great Basin Desert because potential evapotranspiration rates in the Mojave are higher because of higher air temperatures. In addition, the average permeability of the dominantly volcanic, sedimentary, and low grade metamorphic consolidated rock types for the Nevada Test Site and the Kawich Range study locations is likely to be higher than the average permeability of the dominantly granitic and metamorphic consolidated rock types for the watershed area.

Model 2-- Recharge estimates for the expanded study area

The model 2 preliminary precipitation estimates for the expanded region included maximum precipitation estimates of 500 to 750 millimeters per year (19.7 to 29.5 inches per year) for the higher elevations areas of the New York Mountains and the Clark Mountain Range (north of the Mountain Pass precipitation station), as indicated in figure 14. These estimates are considered to be unreasonably high on the basis of the characteristics of the vegetation found at these two locations. Locations with measured precipitation rates of approximately 450 to 500 millimeters per year (17.7 to 19.7 inches per year), including South Lake and Lake Sabrina along the southeastern Sierra Nevada and Lee Canyon in the Spring Mountains, are characterized by relatively dense coniferous forests. Juniper and Pinion Pine associations found at the higher elevations in the New York and Clark Mountain Ranges are more typical of precipitation rates of approximately 250 to 350 millimeters per year (9.8 to 13.8 inches per year). The model 2 estimates (figure 15) indicate recharge rates as high as 100 to 375 millimeters per year (3.9 to 14.8 inches per year) for these higher-elevation locations. In general, these recharge rates require relatively wet conditions and this is not consistent with the characteristics of the vegetation at these locations.

Comparison of Maxey-Eakin recharge results with recharge estimates obtained from the Draft Report

Table 1 provides a comparison of precipitation and recharge estimates obtained by the Draft Report with the preliminary estimates obtained using the modified Maxey-Eakin model 1. Table 2 provides a comparison of precipitation and recharge estimates obtained by the Draft Report with the preliminary estimates obtained using the modified Maxey-Eakin model 2. The preliminary estimates of average annual precipitation obtained using model 1 compare well with the estimates of basin precipitation provided by the Draft Report. Although the minimum precipitation rate of 96 millimeters per year (3.8 inches per year) estimated using model 1 is somewhat higher than the estimate of 76 millimeters per year (3.0 inches per year) obtained from the Draft Report, the model 1 basinwide average precipitation rate of 128 millimeters per year (5.0 inches per year) compares well with the average rate of 127 millimeters per year obtained from the Draft Report, and the model 1 maximum estimate of 301millimeters per year (11.8 inches per year) also compares well with the maximum of 305 millimeters per year (12.0 inches per year) provided in the Draft Report. Precipitation estimates for the expanded study region were on average higher than for the Fenner, Bristol, and Cadiz watershed area as indicated by the basin-wide average of 205 millimeters per year (8.1 inches per year) for the expanded region. Precipitation estimates obtained using model 2 were on average higher than the basinwide averages obtained from the Draft Report (table 2). The higher precipitation rates of 517 to 734 millimeters per year obtained for elevations greater than approximately 1,800 meters (5,906 feet) are considered unreasonable (excessively high) based on a comparison with records from equivalent elevations in the southern Basin and Range. Even with these unacceptably high precipitation rates, the recharge estimates obtained using model 2 were approximately 2.5 times lower than those obtained in the Draft Report for Fenner watershed (10,343 acre-feet per year predicted using model 2 versus 25,950 acre-feet per year predicted in the Draft Report), and approximately 3.3 times lower for the total area of the three watersheds (11,807 acre-feet per year versus 39,077 acre-feet per year). The estimated model 2 recharge volume of 50,643 acre-feet/year for the expanded area is only 1.3 times greater than the estimated recharge volume presented in the Draft Report for the three watersheds. This result indicates that the recharge estimates presented in the Draft Report requires a combination of unrealistically high estimates of precipitation and recharge in the New York, Providence, and Clark Mountains, and the highly unlikely scenario of an interbasin transfer of all recharge from the Mountain Pass area (including the Ivanpah and eastern Mojave watersheds) into the Fenner, Bristol, and Cadiz watersheds. This represents an approximate doubling of the total area contributing to recharge relative to the area defined by the surface water basin for the Fenner, Bristol, and Cadiz watersheds.

Table 1. Comparison of Precipitation and Recharge Estimates Presented in the Draft Report and Predicted by the Preliminary Maxey-Eakin Model 1 (Na = not available)

	Cadiz Report				USGS Preliminary Estimates: Model 1				
	Fenner	Bristol	Cadiz	Total	Fenner	Bristol	Cadiz	Total	Expanded Area
Watershed Area (square miles)	1,000[d]	1,170[d]	540[d]	2,710	1,100[e]	1,172[e]	581[e]	2,852	5,830
Average Precip. Rate (millimeters/year) (inches/year)	Na	Na	Na	127 5.0	147 5.8	119 4.7	111 4.4	128 5.0	205 8.1
Max. Precip Rate (millimeters/year) (inches/year)	Na	Na	Na	305 12.0	301 11.8	271 10.7	210 8.3	301 11.8	328 12.9
Min. Precip. Rate (millimeters/year) (inches/year)	Na	Na	Na	76 3.0	103 4.0	97 3.8	96 3.8	96 3.8	96 3.8
Average Recharge Volume[a] (acre-feet/year)	25,950	2,789[b]	10,338[c]	39,077	2,070	363	114	2,547	10,837
Average Recharge Rate[f] (millimeters/year) (inches/year)	12.36 0.49	1.13 0.045	9.12 0.36	6.87 0.27	0.90 0.035	0.15 0.006	0.09 0.0035	0.43 0.017	0.89 0.035
Max. Recharge Rate (millimeters/year) (inches/year)	Na	Na	Na	Na	20.0 0.79	13.3 0.52	4.3 0.17	20.0 0.79	27.8 1.09
Min. Recharge Rate (millimeters/year) (inches/year)	Na	Na	Na	Na	0.00 0.00	0.00 0.00	0.00 0.00	0.00 0.00	0.00 0.00

a—median values for the Cadiz reported values from table 16 in the Draft Report
b—median value for Orange Blossom Wash
c—median value for watershed excluding Fenner and Orange Blossom Wash
d—watershed areas provided in Draft Report
e—watershed areas calculated using digitized watershed boundaries
f—average recharge rates calculated using watershed areas

Table 2. Comparison of Precipitation and Recharge Estimates Presented in the Draft Report and Predicted by the Preliminary Maxey-Eakin Model 2 (Na = not available)

	Cadiz Report				USGS Preliminary Estimates: Model 2				
	Fenner	Bristol	Cadiz	Total	Fenner	Bristol	Cadiz	Total	Expanded Area
Watershed Area (square miles)	1,000[d]	1,170[d]	540[d]	2,710	1,100[e]	1,172[e]	581[e]	2,852	5,830
Average Precip. Rate (millimeters/year) (inches/year)	Na	Na	Na	127 5.0	174 6.8	117 4.6	104 4.1	137 5.4	228 9.0
Max. Precip Rate (millimeters/year) (inches/year)	Na	Na	Na	305 12.0	625 24.6	517 20.3	325 12.8	625 24.6	734 28.9
Min. Precip. Rate (millimeters/year) (inches/year)	Na	Na	Na	76 3.0	89 3.5	78 3.1	78 3.1	78 3.1	78 3.1
Average Recharge Volume[a] (acre-feet/year)	25,950	2,789[b]	10,338[c]	39,077	10,343	1,102	362	11,807	50,643
Average Recharge Rate[f] (millimeters/year) (inches/year)	12.36 0.49	1.13 0.045	9.12 0.36	6.87 0.27	4.48 0.18	0.45 0.018	0.30 0.012	1.97 0.077	4.14 0.16
Max. Recharge Rate (millimeters/year) (inches/year)	Na	Na	Na	Na	232 9.1	129 5.1	27 1.1	232 9.1	375 14.8
Min. Recharge Rate (millimeters/year) (inches/year)	Na	Na	Na	Na	0.00 0.00	0.00 0.00	0.00 0.00	0.00 0.00	0.00 0.00

a—median values for the Cadiz reported values from table 16 in the Draft Report
b—median value for Orange Blossom Wash
c—median value for watershed excluding Fenner and Orange Blossom Wash
d—watershed areas provided in Draft Report
e—watershed areas calculated using digitized watershed boundaries
f—average recharge rates calculated using watershed areas

Conclusions

Recharge estimates obtained using model 1 provided reasonable estimates of spatially distributed recharge on the basis of a comparison of recharge estimates obtained for various locations throughout the southern Nevada and south-central Great Basin regions. The model 1 recharge estimates were more than 1 order of magnitude less than the recharge estimated by the watershed model presented in the Draft Report for the Cadiz study region. The estimated median recharge of 25,950 acre-feet per year for the Fenner watershed presented in the Draft Report is 12.5 times greater than the model 1 estimate of 2,070 acre-feet per year for the Fenner watershed. For the Cadiz watershed, the estimated median recharge of 10,338 acre-feet per year presented in the Draft Report is 91 times higher than the model 1 recharge estimate of 114 acre-feet per year. The estimated median recharge value of 39,077 acre-feet per year presented in the Draft Report for the total area of the Fenner, Bristol, and Cadiz watersheds is 15.3 times greater than the model 1 estimate of 2,547 acre-feet per year. The Model 2 estimates of maximum precipitation rates are as high as 517 to 734 millimeters per year (which are unjustifiably high), yet the total basin recharge of 11,807 acre-feet per year is still 3.3 times less than the estimated median total basin recharge estimated by the watershed model presented in the Draft Report. This indicates that the modified Maxey-Eakin model cannot provide recharge estimates that are comparable with the results provided in the Draft Report, even when uncertainty in precipitation estimates are accounted for by assuming unreasonably high precipitation rates for the higher elevations. In summary, the median recharge rates estimated by the watershed model presented in the Draft Report are an order of magnitude higher than recharge estimated using a modified Maxey-Eakin model and the model 1 precipitation estimates that were found to be more consistent with measured precipitation rates in the Mojave Desert region.

References:

D'Agnese, F.A., Faunt, C.C, Turner, K.A., and Hill M.C., 1997, Hydrogeologic Evaluation and Numerical Simulation of the Death Valley Regional Ground-Water Flow System, Nevada and California: U.S. Geological Survey Water-Resources Investigations Report 96-4300, 124 p.

Dettinger, M.D., 1989, Reconnaissance estimates of natural recharge to desert basins in Nevada, U.S.A., by using chloride-balance calculations: Journal of Hydrology, v. 106, p. 55-78

Flint, A.L., and Flint, L.E., 1994, Spatial distribution of potential near surface moisture flux at Yucca Mountain, *in* High Level Radioactive Waste Management, Proceedings of the Fifth Annual International Conference, Las Vegas, Nev., May 22-26, 1994: LaGrange Park, Ill., American Nuclear Society, p. 2352-2358.

Flint, L.E., and Flint, A.L., 1995, Shallow infiltration processes at Yucca Mountain, Nevada- neutron logging data 1984-93: U.S. Geological Survey Water-Resources Investigations Report 95-4035, 46 p.

French, R.H., 1983, Precipitation in southern Nevada: Journal of Hydraulic Engineering, v. 109, no. 7, p. 1023-1036.

French, R.H., 1986, Daily, seasonal, and annual precipitation at the Nevada Test Site, Nevada: Las Vegas, Water Resources Center, Desert Research Institute, DOE/NV/10384-01, 40 p.

Hevesi, J.A., and Flint, A.L., in press, Geostatistical Model for Estimating Precipitation and Recharge in the Yucca Mountain Region, Nevada-California, U.S. Geological Survey Water-Resources Investigations Report #96-4123, 102 p.

Hevesi, J.A., and Flint, A.L., 1998, Geostatistical estimates of future recharge for the Death Valley Region, *in* High Level Radioactive Waste Management, Proceedings of the Ninth Annual International Conference, Las Vegas, Nev., May 11-15, 1998: LaGrange Park, Ill., American Nuclear Society, p. 173-177.

Hevesi, J.A., Flint, A.L., and Istok, J.D., 1992, Precipitation estimation in mountainous terrain using multi variate geostatistics--part II, Isohyetal maps: Journal of Applied Meteorology, v. 31, no. 7, p. 677-688.

________ , Istok, J.D. and Flint, A.L., 1992, Precipitation estimation in mountainous terrain using multi variate geostatistics--part I, Structural analysis: Journal of Applied Meteorology, v. 31, no. 7, p. 661-676.

Kwicklis, E.M., and Rousseau, J.P., 1999, Analysis of percolation flux based on heat flow estimated in boreholes, *in* Rousseau, J.P., Kwicklis, E.M., and Gillies, D.C., eds., Hydrogeology of the unsaturated zone, North Ramp area of the Exploratory Studies Facility, Yucca Mountain, Nevada: U.S. Geological Survey Water-Resources Investigations Report 98-4050, 244 p.

Lichty, R.W., and McKinley, P.W., 1995, Estimates of ground-water recharge rates for two small basins in central Nevada: U.S. Geological Survey Water-Resources Investigations Report 94-4104, 31 p.

Maxey, G.B., and Eakin, T.E., 1949, Ground water in White River Valley, White Pine, Nye, and Lincoln Counties, Nevada: Nevada State Engineer, Water Resources Bulletin no. 8, 59 p.

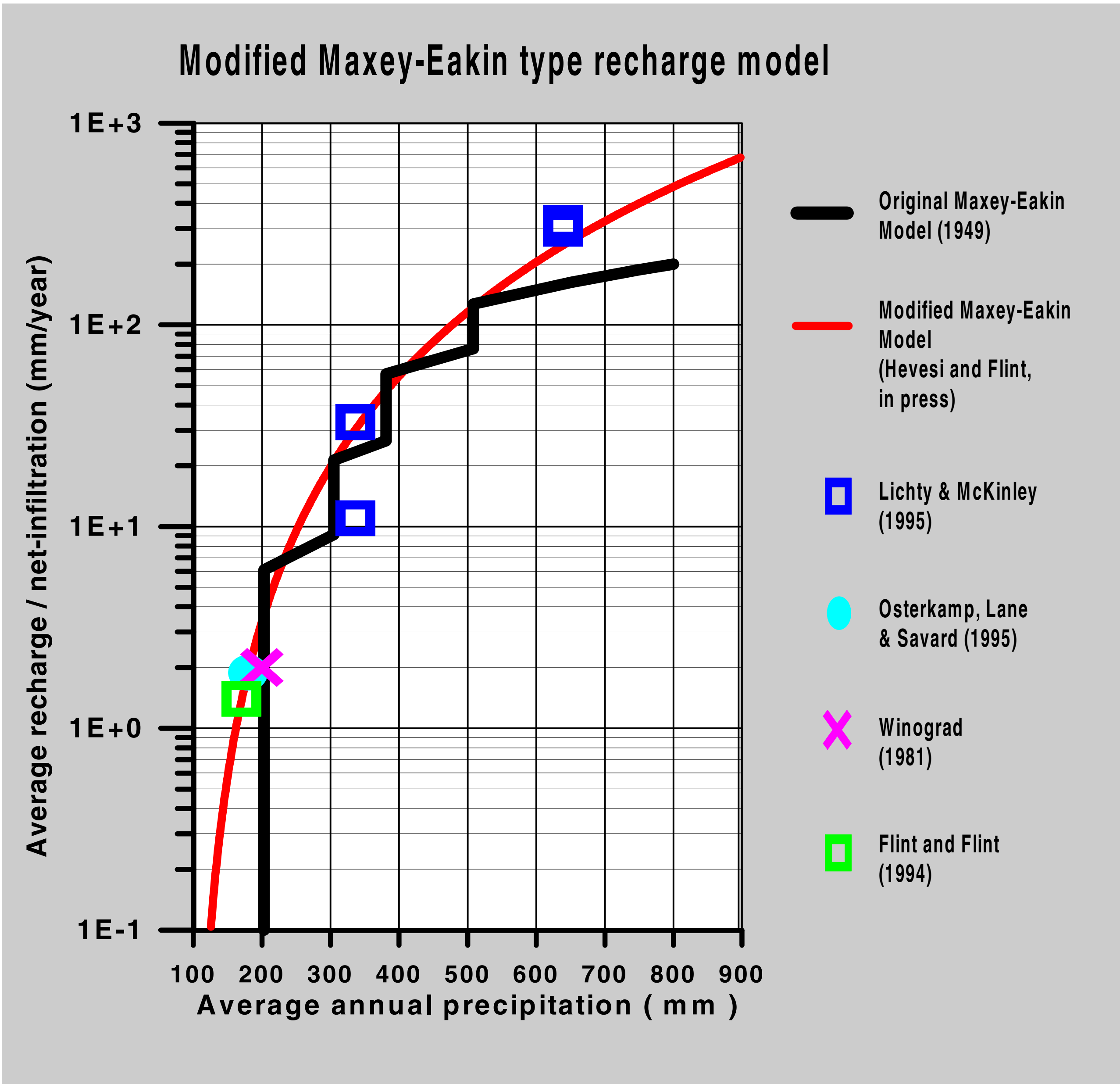
Nichols, W.D., 1987, Geohydrology of the unsaturated zone at the burial site for low level radioactive waste near Beatty, Nye County, Nevada: U.S. Geological Survey Water-Supply Paper 2312, 52 p.

Osterkamp, W.R., Lane, L.J., and Savard, C.S., 1994, Recharge estimates using a geomorphic/distributed-parameter simulation approach, Amargosa River Basin: Water Resources Bulletin, v. 30, no. 3, p. 493-507.

Rush, F.E., 1970, Regional ground-water system in the Nevada Test Site area, Nye, Lincoln, and Clark Counties, Nevada: Nevada Department of Conservation and Natural Resources Reconnaissance Series Report 54, 25 p.

Winograd, I.J., 1981, Radioactive waste disposal in thick unsaturated zones: Science, v. 212, no. 4502, p. 1457-1464.

FIGURE 1—MAXEY-EAKIN MODEL AND RECHARGE ESTIMATES IN THE GREAT BASIN AND MOJAVE DESERTS



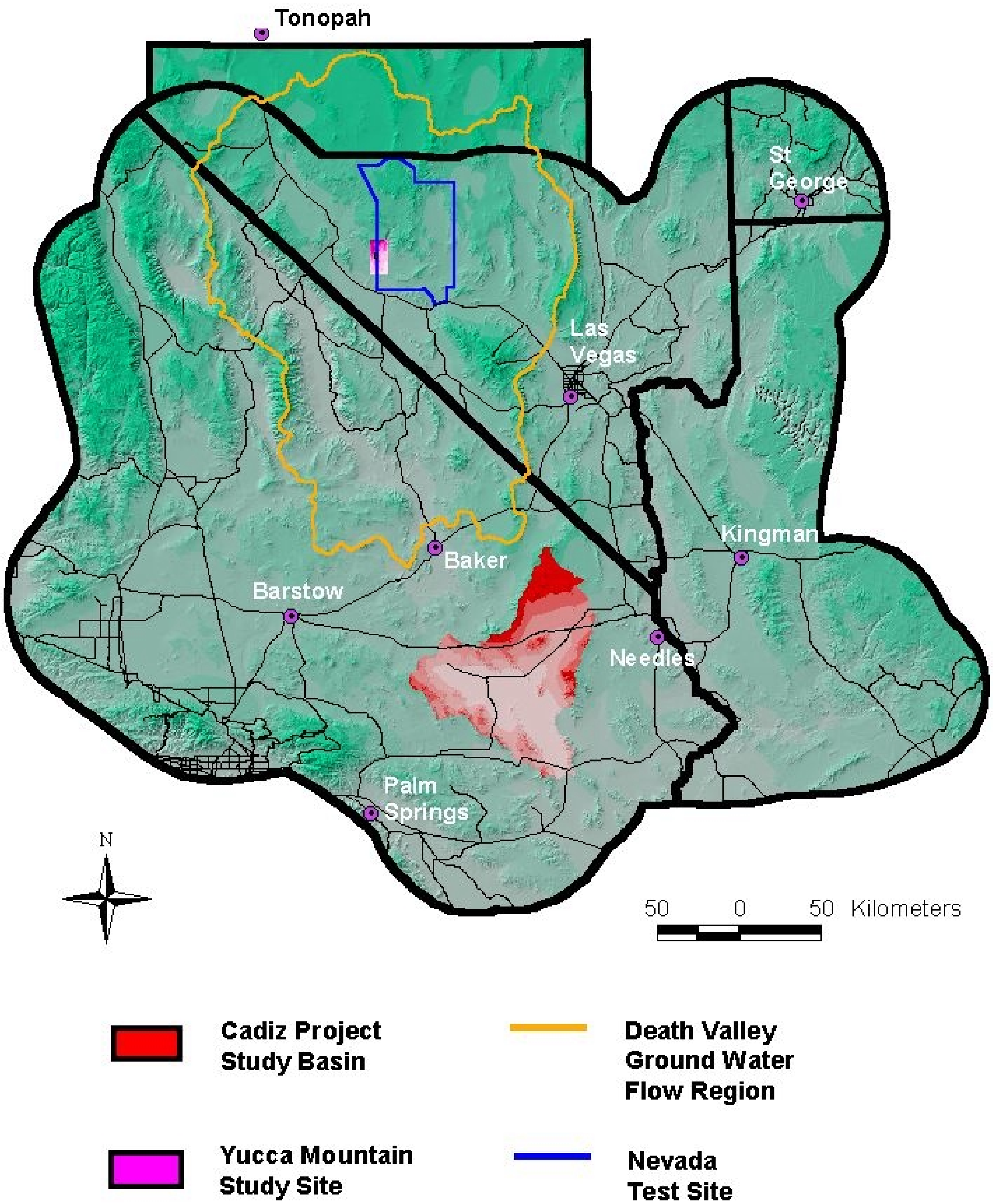


FIGURE 2--PROJECT STUDY AREA

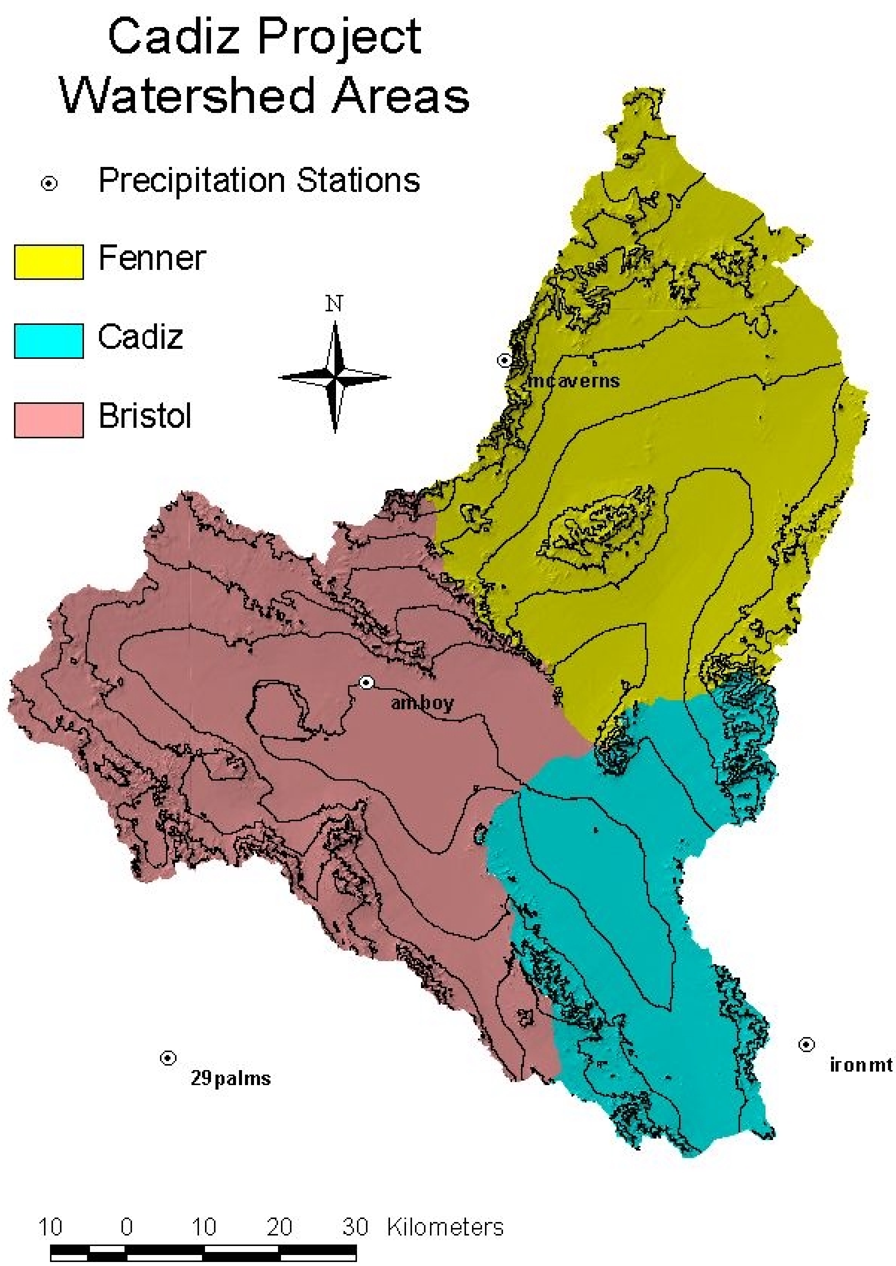


FIGURE 3--WATERSHED AREAS FOR THE FENNER, CADIZ, AND BRISTOL SURFACE WATER BASINS DEFINING THE DRAFT REPORT STUDY AREA

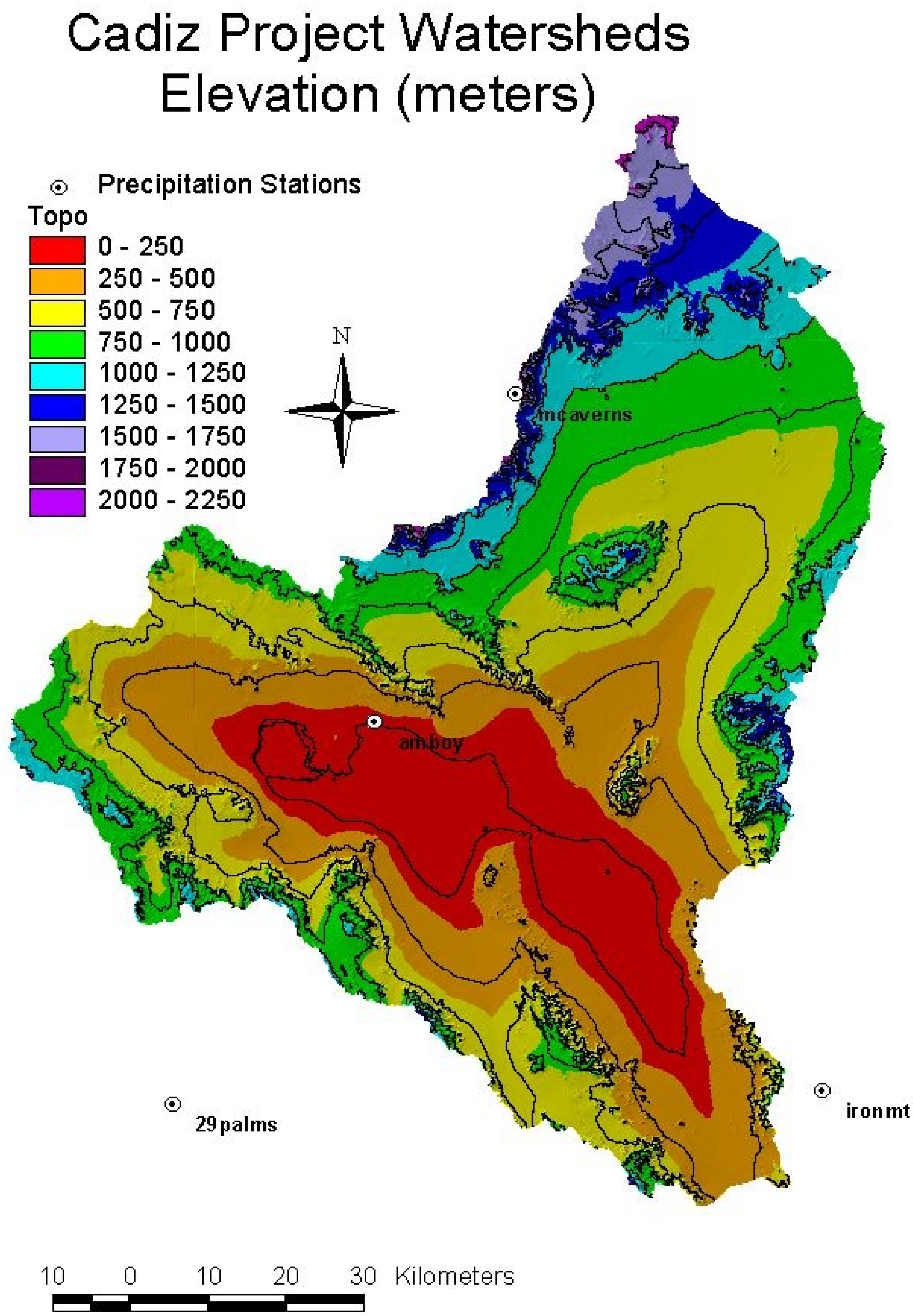
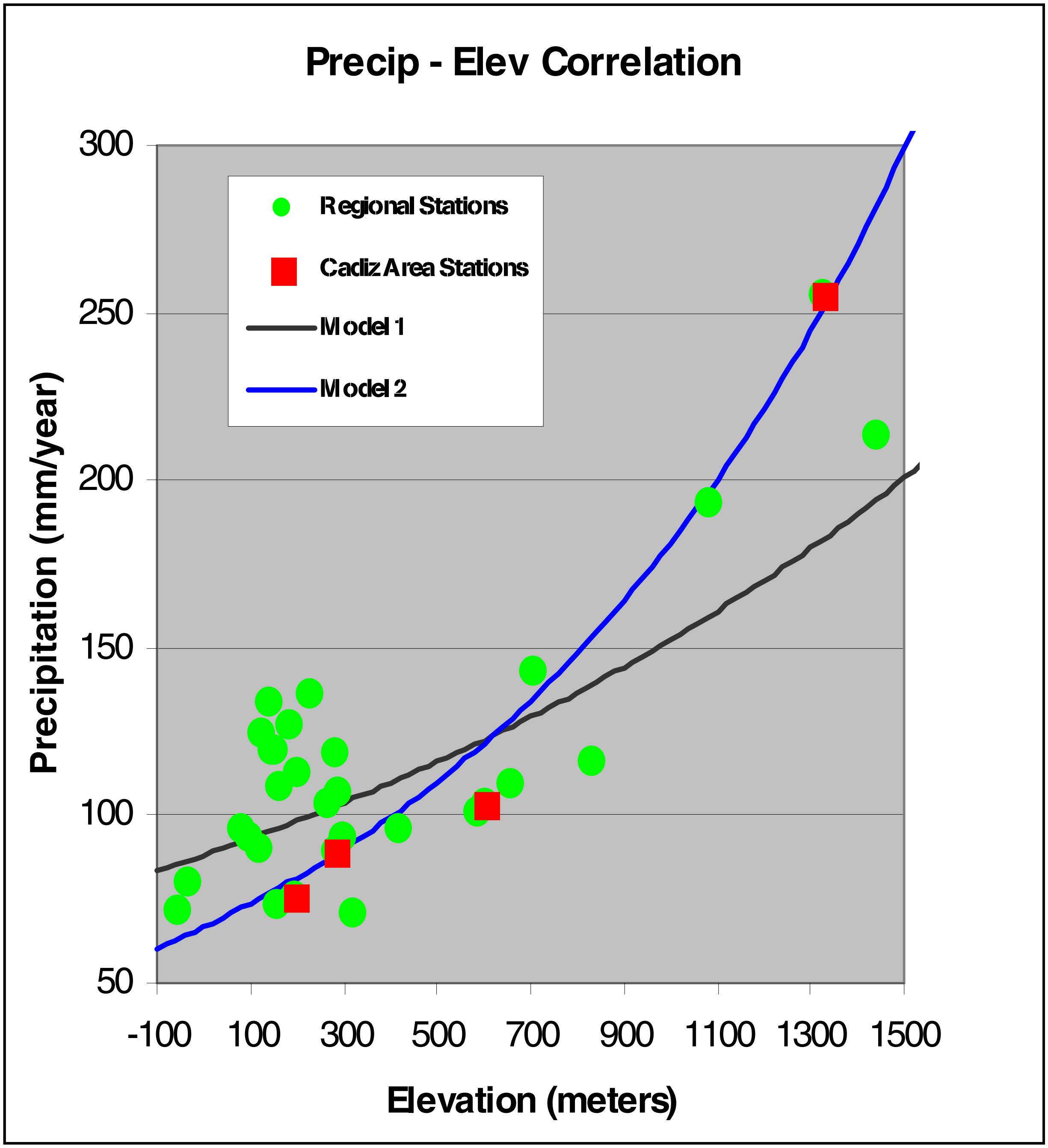


FIGURE 4--ELEVATION OF WATERSHEDS FOR THE CADIZ PROJECT

FIGURE 5--RELATIONSHIP BETWEEN ELEVATION AND PRECIPITATION



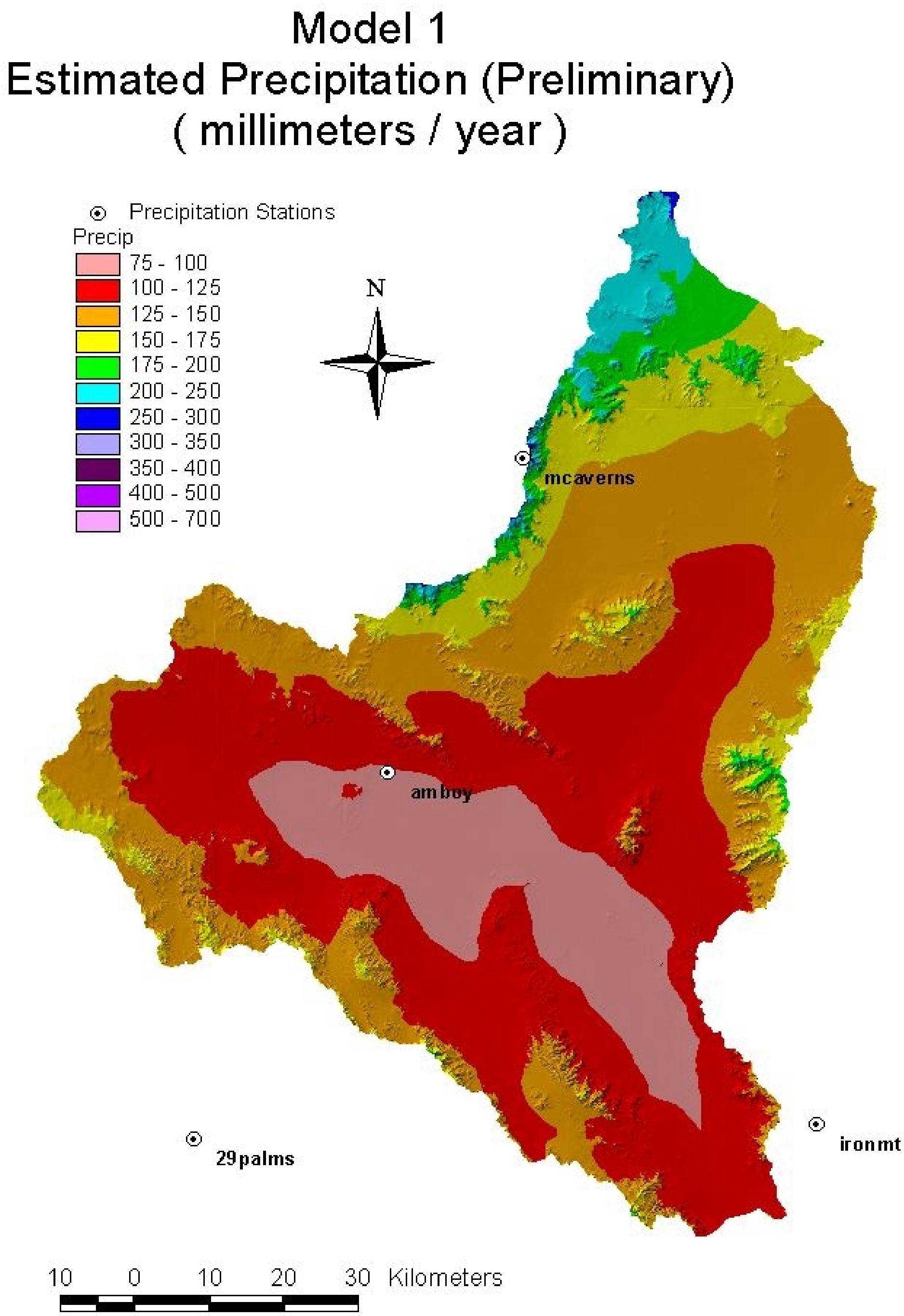


FIGURE 6--MODEL 1 PRECIPITATION FOR THE CADIZ PROJECT STUDY AREA

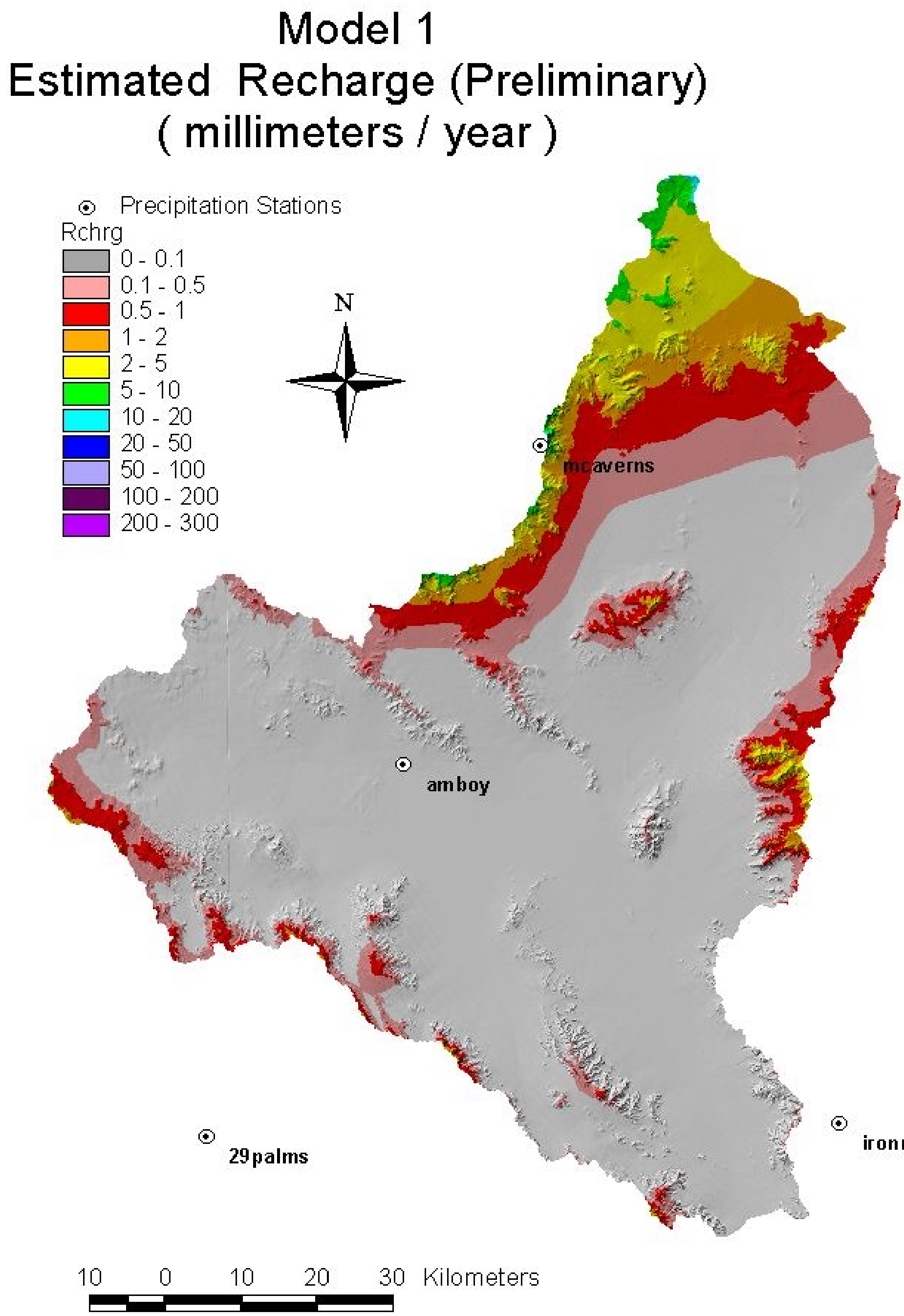


FIGURE 7--MODEL 1 ESTIMATEDRECHARGE FOR THE CADIZ PROJECT STUDY AREA

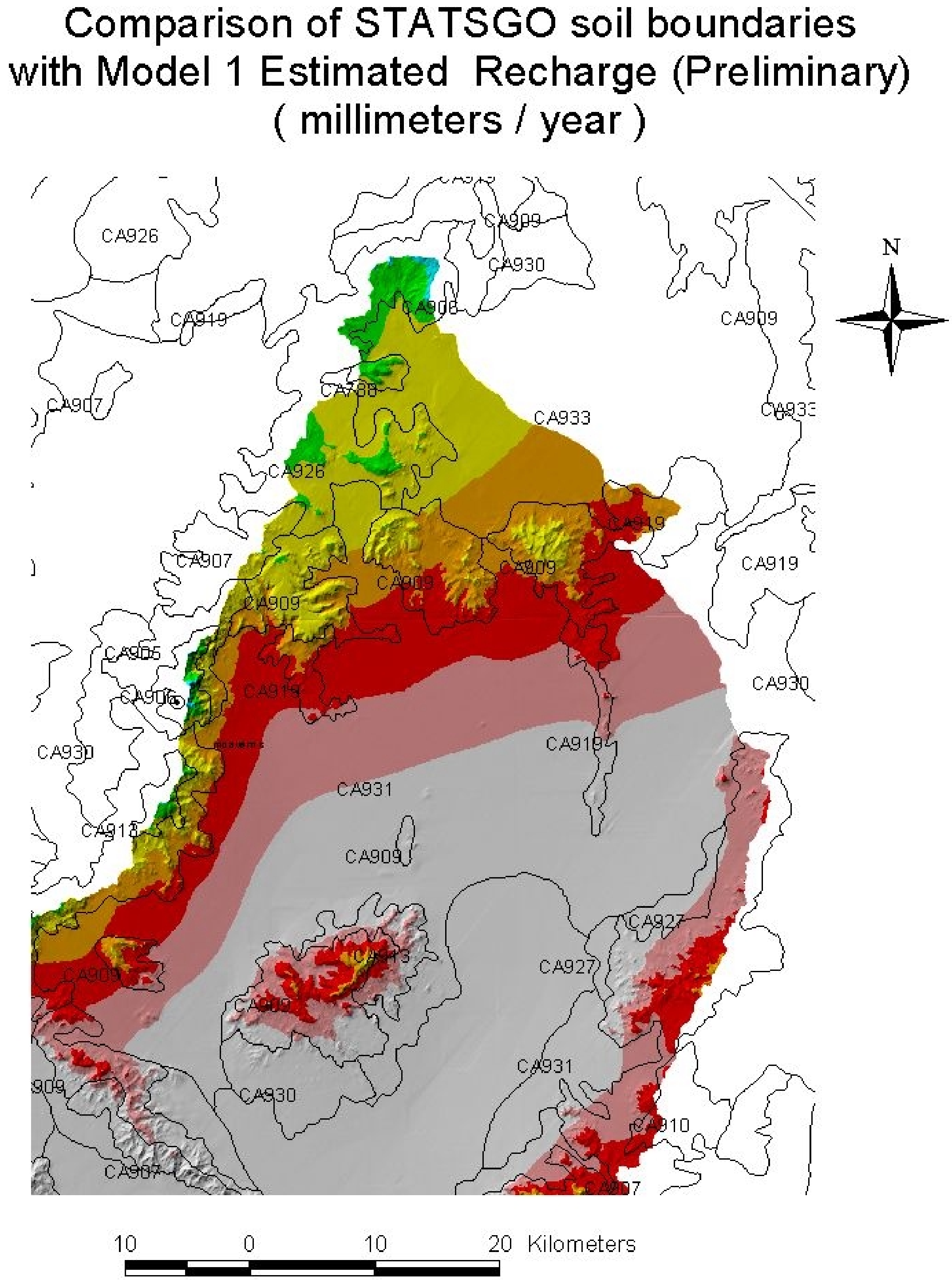


FIGURE 8— COMPARISON OF STATSGO SOIL MAP GROUPS WITH MODEL 1 ESTIMATED RECHARGE FOR THE HIGH RECHARGE AREAS

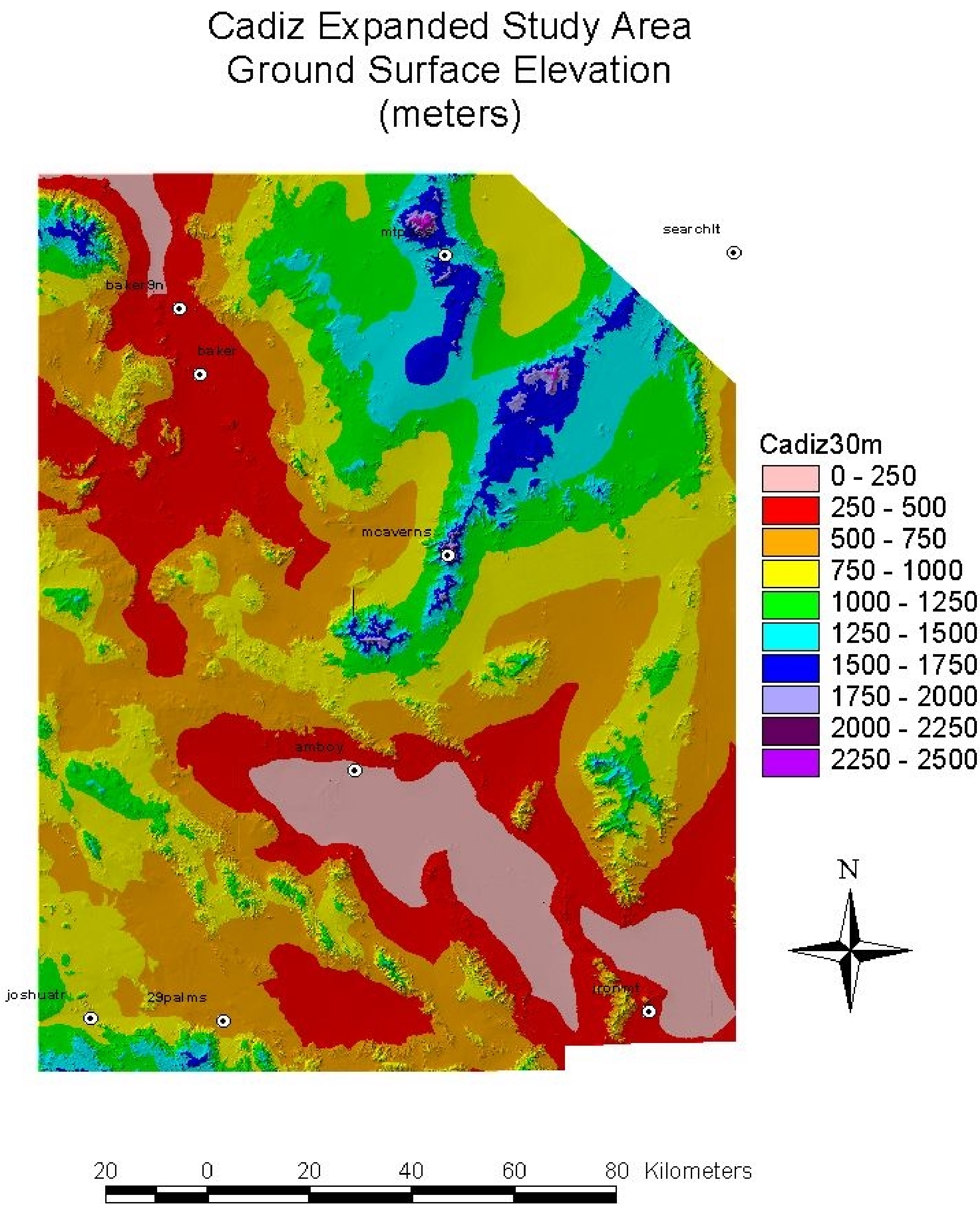


FIGURE 9--MODEL 1 EXPANDED AREA ELEVATION

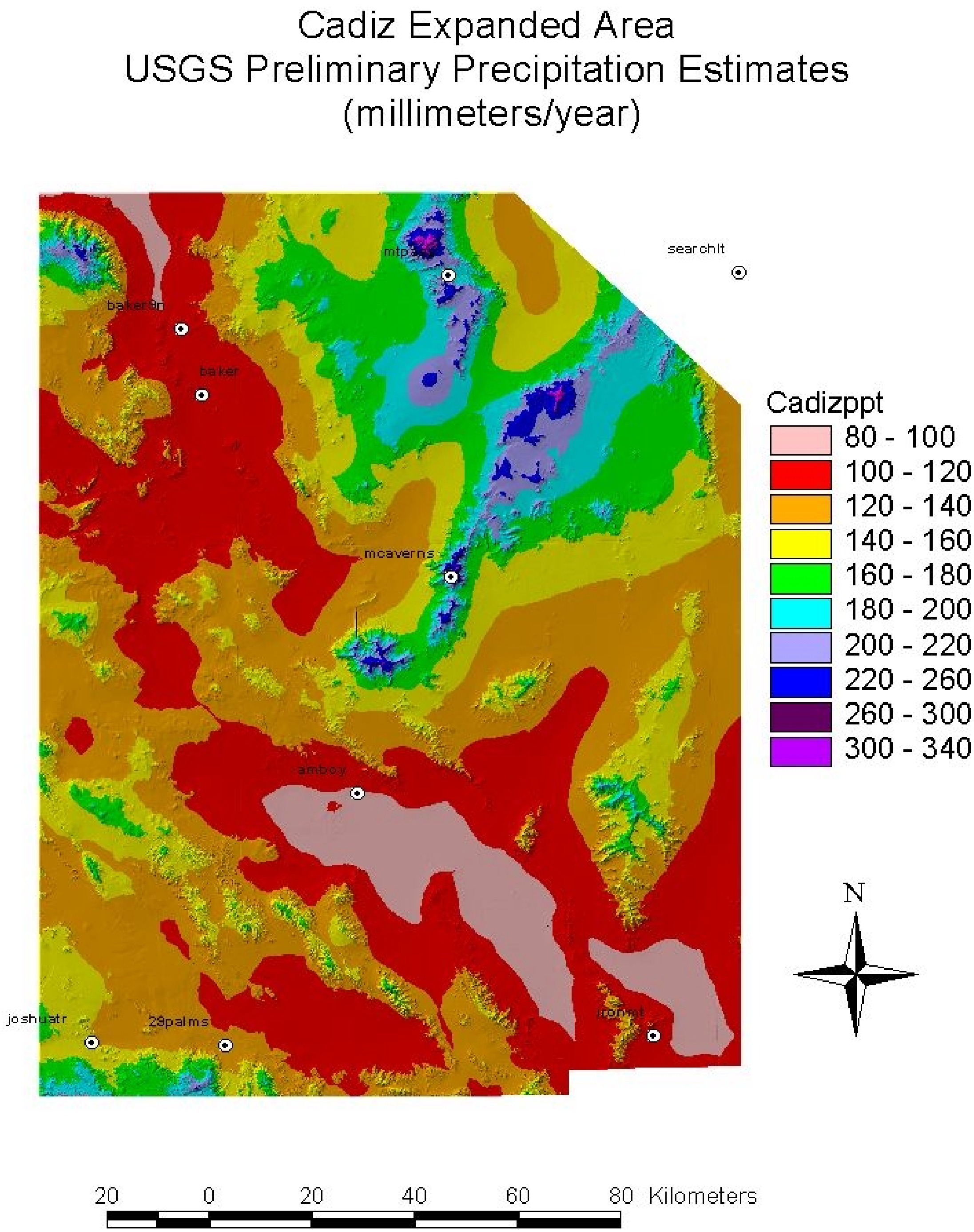


FIGURE 10--MODEL 1 EXPANDED AREA ESTIMATED PRECIPITATION

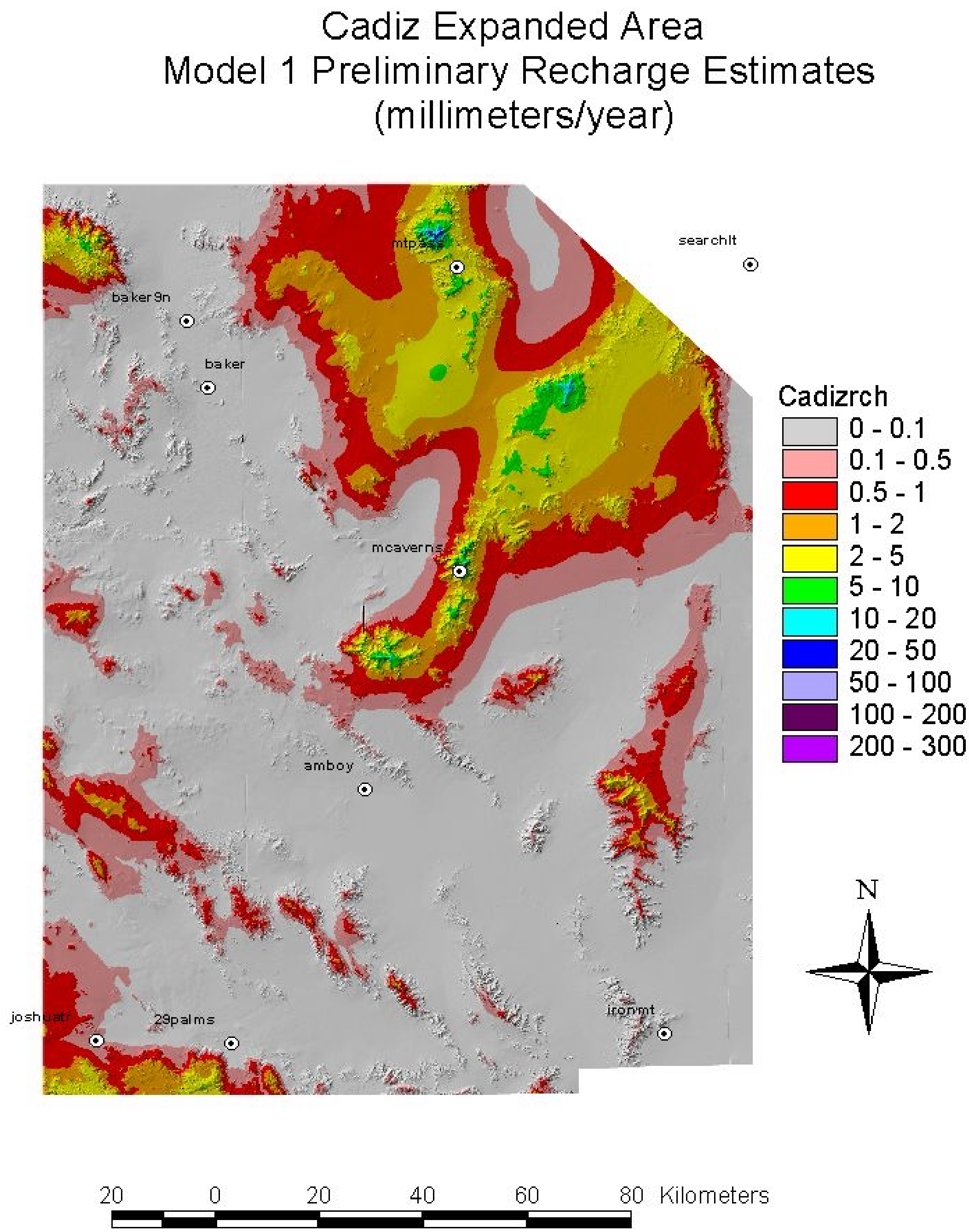


FIGURE 11--MODEL1 EXPANDED AREA ESTIMATED RECHARGE

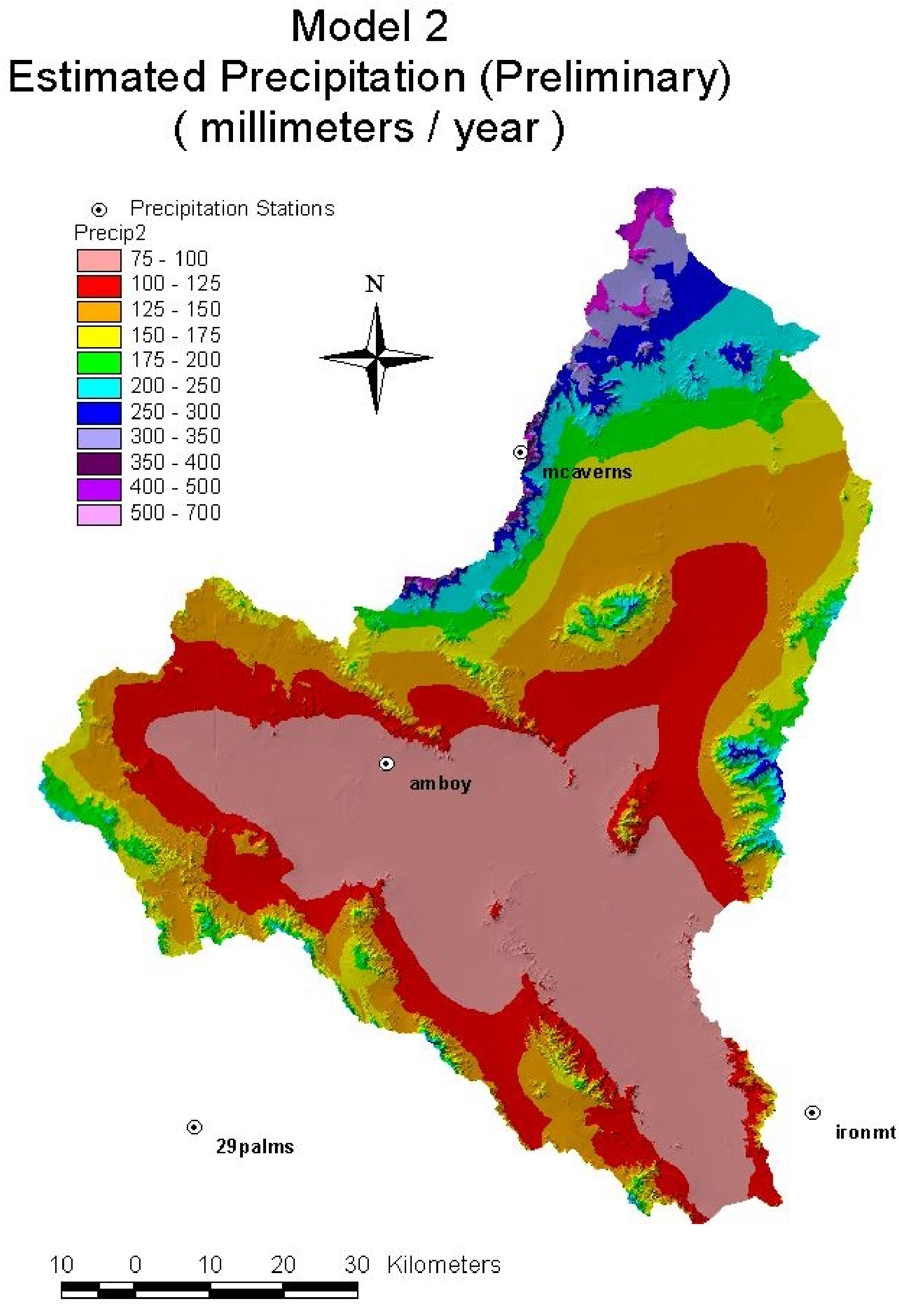


FIGURE 12--MODEL 2 ESTIMATED PRECIPITATION FOR CADIZ PROJECT STUDY AREA

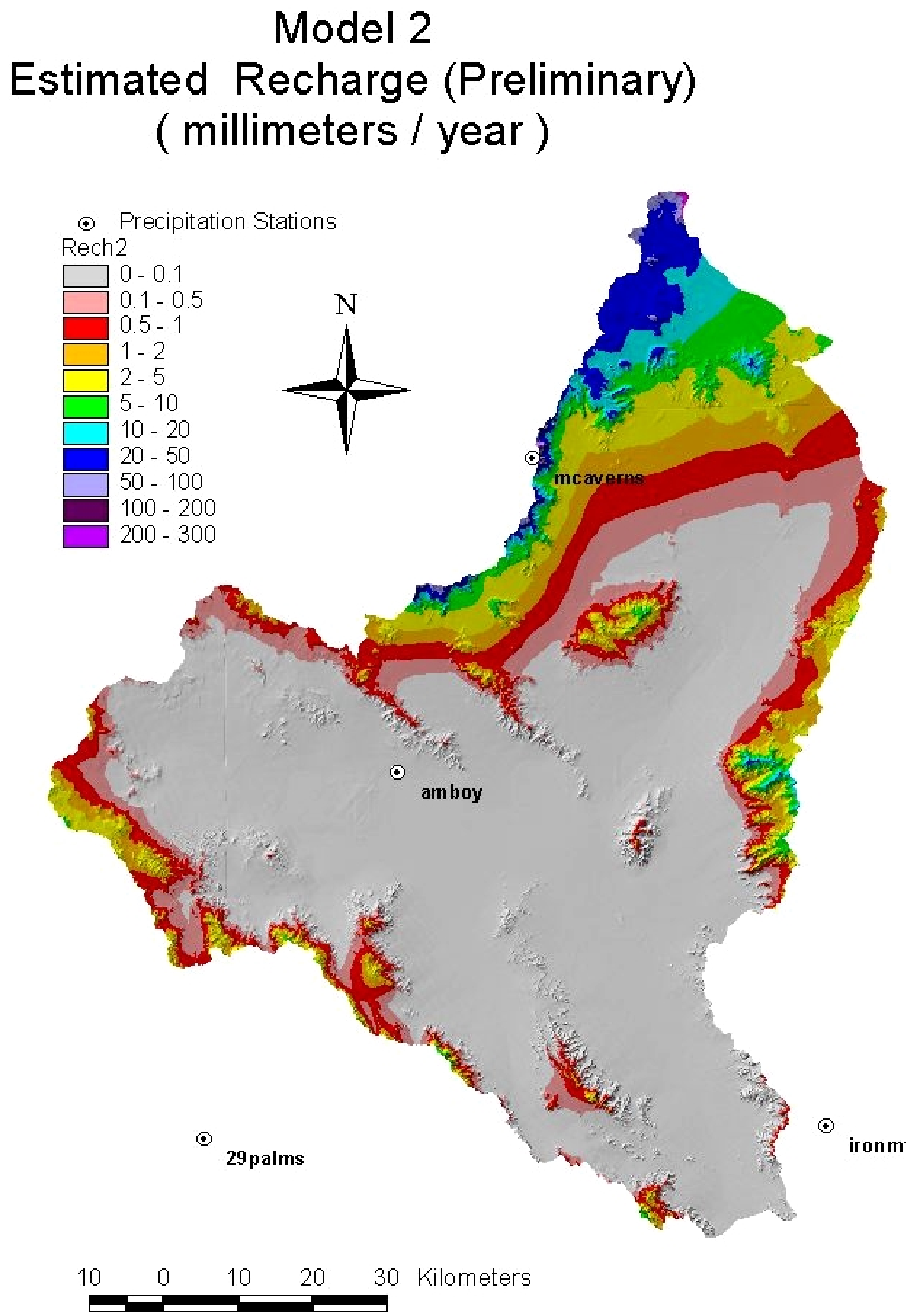


FIGURE 13--MODEL 2 ESTIMATED RECHARGE FOR CADIZ PROJECT STUDY AREA

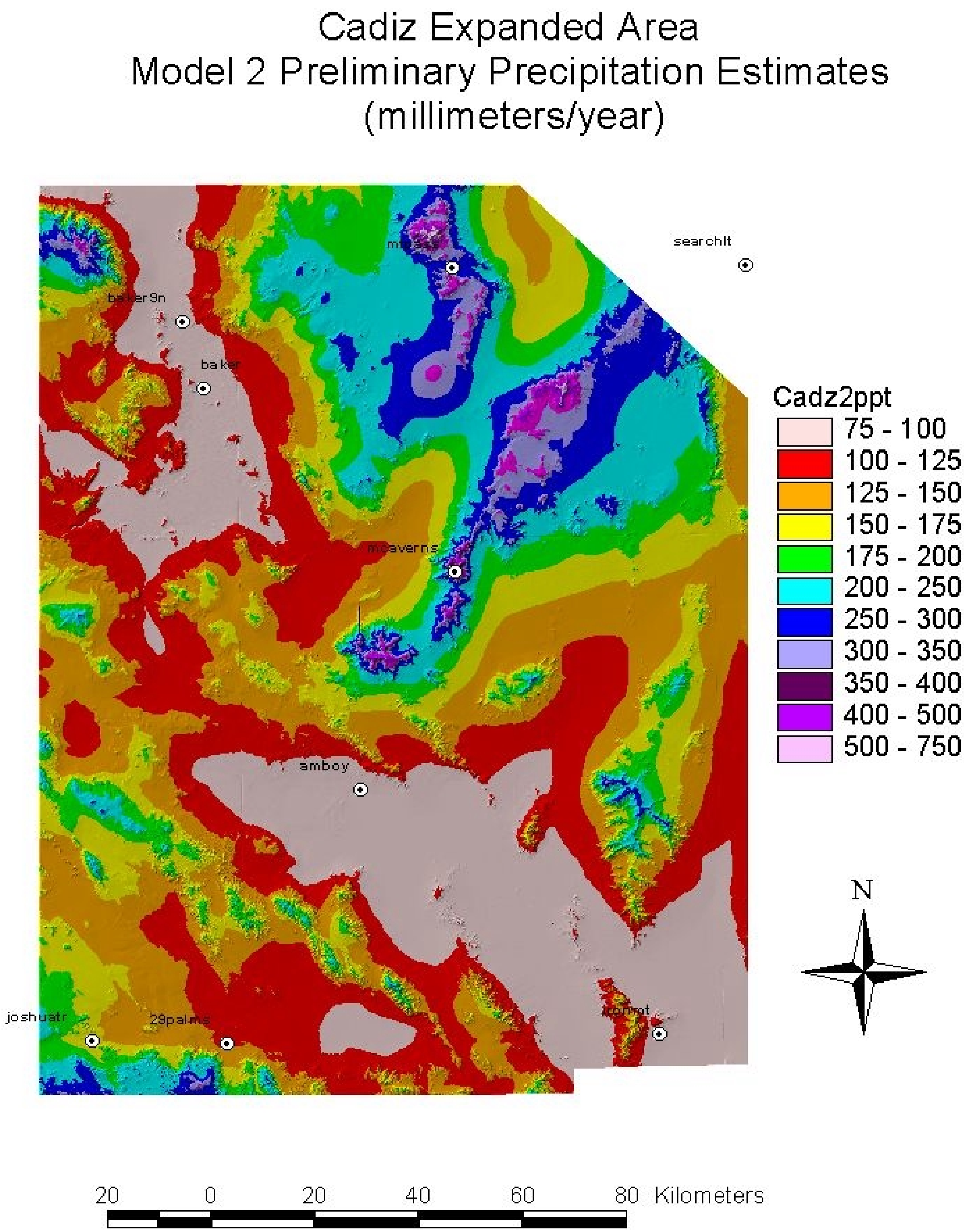


FIGURE 14--MODEL 2 EXPANDED AREA ESTIMATED PRECIPITATION

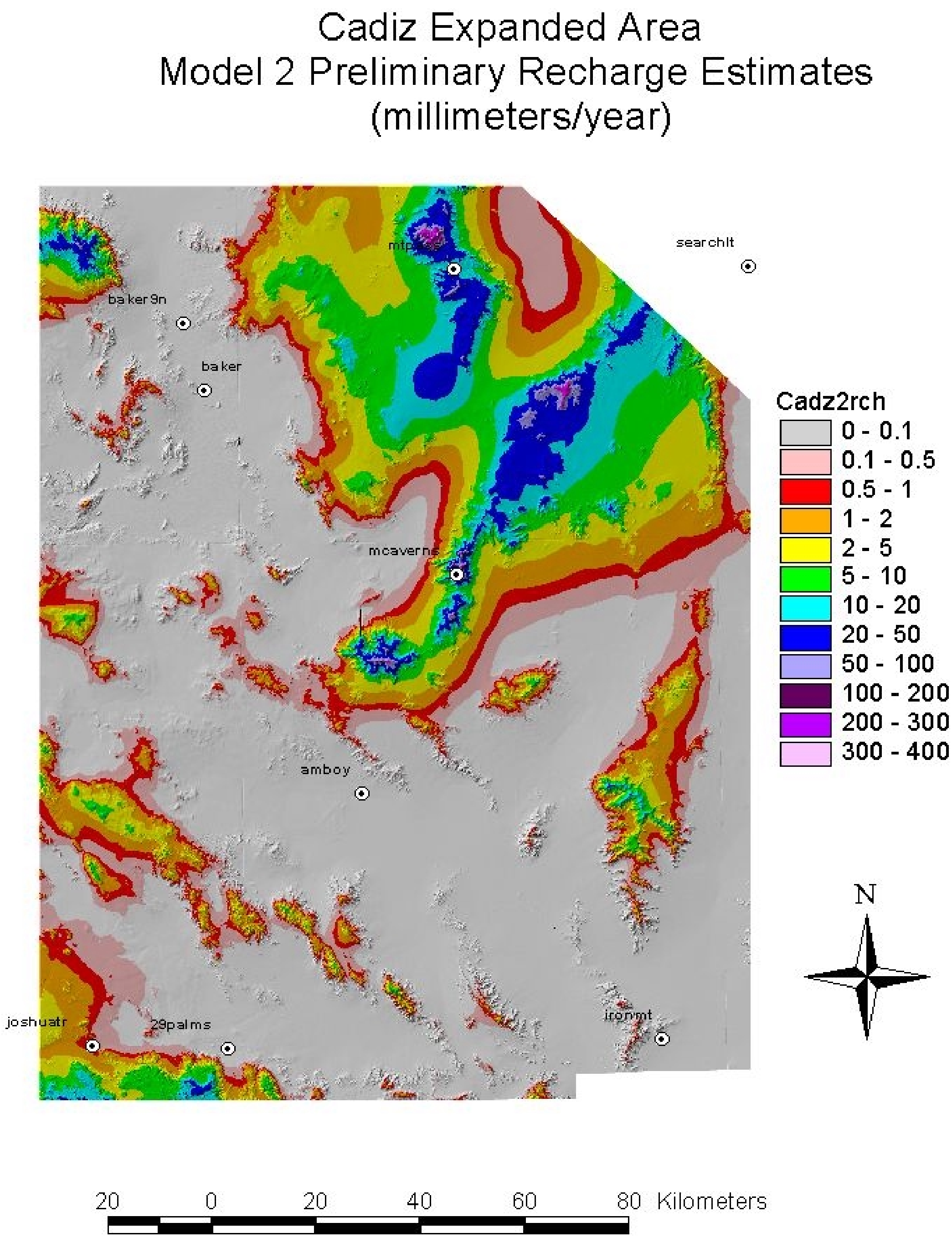


FIGURE 15--MODEL 2 EXPANDED AREA ESTIMATED RECHARGE

Refer
to comment
F2-38

Attachment 2:
Groundwater Contours from Cadiz, Inc.

Refer to Comment F2-38

SCENARIO 5 (AVERAGE) MAXIMUM DRAWDOWN (YEAR 34)