MOJAVE RIVER BASINS GROUNDWATER RECHARGE STUDY FINAL REPORT
VOLUME 1

Mojave Water Agency
Victorville, California

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MOJAVE WATER AGENCY
VICTORVILLE, CALIFORNIA

MOJAVE RIVER BASINS GROUNDWATER RECHARGE STUDY

FINAL REPORT

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TABLE OF CONTENTS

		Page
1.0	EXECUTIVE SUMMARY	1 - 1
2.0	INTRODUCTION	2 - 1
2.1	BACKGROUND	2 - 1
2.2	PURPOSE AND SCOPE	2 - 1
3.0	IDENTIFICATION OF POTENTIAL RECHARGE SITES	3 - 1
3.1	LITERATURE REVIEW	3 - 1
3.2	OVERVIEW OF SITE SCREENING AND IDENTIFICATION PROCESS	3 - 1
3.3	RESTRICTIVE CRITERIA	3 - 2
3.3.1	Exclusionary Criteria	3 - 3
3.3.2	Low Priority Locations	3 - 4
3.4	SUPPORTIVE CRITERIA	3 - 5
3.5	POTENTIAL RECHARGE SITES	3 - 7
3.5.1	Upper Basin / Mojave River Site	3 - 7
3.5.2	Upper Basin / Oro Grande Wash Site	3 - 9
3.5.3	Middle Basin / Hinkley Valley Site	3 - 11
3.5.4	Middle Basin / Waterman Valley Site	3 - 13
3.5.5	Lower Basin / Newberry Valley Site	3 - 15
4.0	SOURCES OF RECHARGE WATER	4 - 1
4.1	GENERAL	4 - 1
4.2	MOJAVE RIVER STORM FLOWS	4 - 1
4.2.1	Streamflow Measurement	4 - 1
4.2.2	Streamflow Discharge Data	4 - 2
4.2.3	Streamflow Discharge/Infiltration Relationship	4 - 3
4.2.4	Streamflow Duration	4 - 3
4.2.5	Streamflow Quantity	4 - 4
4.2.6	Clogging Potential	4 - 5
4.3	STATE WATER PROJECT WATER	4 - 5
4.3.1	Quantity of SWP Water	4 - 6
4.3.2	Clogging Potential	4 - 6

MALCOLM PIRNIE

TABLE OF CONTENTS (Continued)

	Page
5.0 RECHARGE CONCEPT OPTIONS	5 - 1
5.1 STREAM CHANNEL RECHARGE	5 - 1
5.1.1 Advantages of Stream Channel Recharge	5 - 2
5.1.2 Disadvantages of Stream Channel Recharge	5 - 2
5.2 INFILTRATION BASINS	5 - 2
5.2.1 In-Channel Infiltration Basins	5 - 3
5.2.1.1 Advantages of In-Channel Infiltration Basins	5 - 3
5.2.1.2 Disadvantages of In-Channel Infiltration Basins	5 - 3
5.2.2 Off-Channel Infiltration Basins	5 - 4
5.2.2.1 Advantages of Off-Channel Infiltration Basins	5 - 4
5.2.2.2 Disadvantages of Off-Channel Infiltration Basins	5 - 5
5.3 INJECTION WELLS	5 - 5
5.3.1 Advantages of Well Injection Recharge	5 - 5
5.3.2 Disadvantages of Well Injection Recharge	5 - 6
5.4 OTHER METHODS	5 - 6
5.5 RANKING	5 - 6
6.0 EVALUATION OF RECHARGE CONCEPTS	6 - 1
6.1 GENERAL	6 - 1
6.2 SUSTAINED INFILTRATION RATES	6 - 2
6.3 RECHARGE OF STATE WATER PROJECT WATER	6 - 3
6.3.1 Mounding Analysis	6 - 3
6.3.1.1 Mojave River Sites	6 - 4
6.3.1.2 Upper Basin / Oro Grande Wash Site	6 - 5
6.3.2 Land Requirements	6 - 6
6.3.3 Recharge Water Quality	6 - 7

MALCOLM PIRNIE

TABLE OF CONTENTS (Continued)

	Page
6.4 RECHARGE OF STORM FLOWS	6 - 7
6.4.1 Recharge Basin Requirements	6 - 7
6.4.2 Land Requirements	6 - 9
6.4.3 Effects on Channel Flow	6 - 10
6.4.4 Available Storage	6 - 11
6.4.5 Groundwater Quality	6 - 11
7.0 CAPITAL AND OPERATING COSTS	7 - 1
7.1 CAPITAL COSTS	7 - 1
7.1.1 Pilot Study	7 - 1
7.1.2 Conveyance Facilities Construction	7 - 2
7.1.3 Earthwork Construction Estimates	7 - 3
7.1.4 Land Acquisition	7 - 3
7.2 HABITAT RELOCATION	7 - 3
7.3 OPERATION AND MAINTENANCE COSTS	7 - 4
7.4 PUBLIC FUNDING SOURCES	7 - 4
8.0 IMPLEMENTATION REQUIREMENTS	8 - 1
8.1 PILOT STUDY	8 - 1
8.2 ENVIRONMENTAL IMPACT STUDY	8 - 2
8.3 PERMITTING	8 - 2
8.3.1 Federal Requirements	8 - 2
8.3.2 California State Requirements	8 - 3
8.3.3 County Permits	8 - 3
8.4 LAND PURCHASES OR LEASES	8 - 3
8.5 IMPLEMENTATION SCHEDULE	8 - 4
REFERENCES	R - 1

MALCOLM PIRNIE

TABLE OF CONTENTS (Continued)

LIST OF TABLES

Table No.	Description	Follows Page No.
4-1	Mojave River Stream Gaging Stations	4 - 1
4-2	Mean Annual Discharge Flows (CFS) (Mojave River)	4 - 2
4-3	Mean Monthly Discharge Flows (CFS) (Mojave River)	4 - 2
4-4	Unregulated Recurrence Interval Peak Flows at Forks Dam (Mojave River)	4 - 3
5-1	Ranking of Recharge Facility Operations	5 - 7
6-1	Calculated Increase in Water Levels After 60 Days of Recharge	6 - 9
6-2	Approximate Reduction in Downstream Flows (Mojave River)	6 - 11
7-1	Summary of Capital Costs	7 - 2

LIST OF FIGURES

Figure No.	Description	Follows Page No.
2-1	Location Map	2 - 1
4-1	Peak Flow at the Forks Dam Area Using Deep Creek and West Fork Gage Data	4 - 2
4-2	Mean Annual Streamflow Record: Combined Deep Creek and West Fork Gage Data	4 - 2
6-1	Predicted Groundwater Mound Along Width (90%) of Recharge Basin: Mojave River Site (State Water Project)	6 - 4
6-2	Predicted Groundwater Mound Along Length (0°) of Recharge Basin: Mojave River Site (State Water Project)	6 - 4

MALCOLM PIRNIE

TABLE OF CONTENTS (Continued)

LIST OF FIGURES (cont'd)

Figure No.	Description	Follows Page No.
6-3	Predicted Groundwater Mound Along Width (90°) of Recharge Basin: Upper Basin / Oro Grande Wash Site (State Water Project)	6 - 6
6-4	Predicted Groundwater Mound Along Length (0°) of Recharge Basin: Upper Basin / Oro Grande Wash Site (State Water Project)	6 - 6
6-5	Predicted Groundwater Mound Along Width (90°) of Recharge Basin: Mojave River Site (Storm Flow)	6 - 9
6-6	Predicted Groundwater Mound Along Length (0°) of Recharge Basin: Mojave River Site (Storm Flow)	6 - 9
8-1	Implementation Schedule	8 - 4
A-1	Generalized Cross Section of the Upper Basin from the Forks Dam to the Lower Narrows at Victorville	A - 7
A-2	Generalized Cross Section of the Newberry Basin from the Calico-Newberry Fault to Manix Wash	A - 7

LIST OF APPENDICES

Appendix	Description
A	Recharge Facility Site Selection Considerations
B	Storm Flow Infiltration (Mojave River)
C	Estimated Mounding Data for the Mojave River Site (SWP Water)
D	Estimated Mounding Data for the Upper Basin / Oro Grande Wash Site (SWP Water)
E	Estimated Mounding Data for the Mojave River Site (Streamflow Water)

MALCOLM PIRNIE

TABLE OF CONTENTS (Continued)

LIST OF PLATES

Plate No.	Description
1	Wildlife Habitat and Native Riparian Vegetation
2	Land Ownership
3	Soils and Aquifer Properties
4	1981 Groundwater Elevations
5	Geologic Cross Sections A-A' and B-B'
6	Geologic Cross Sections C-C' and D-D'
7	Potential Recharge Sites

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1.0 EXECUTIVE SUMMARY

The Mojave River Basins Groundwater Recharge Study has been performed to identify potential recharge locations and examine the feasibility of constructing recharge facilities within the Mojave River Basins, San Bernardino County, California. The results of the study provide the locations of potentially feasible recharge locations in several of the Mojave River Basins currently subject to overdraft conditions, and estimate the quantity of water available for the recharge efforts.

Siting criteria consisting of demographic, environmental, geologic and hydrogeologic data have been applied to the areas within the basins of the Mojave River to develop potential recharge locations. Potential recharge sites were identified within the Mojave River channel in the Upper Mojave basin above Victorville, in the Middle Mojave basin near Hinkley, in the Lower Mojave basin within Waterman Valley, and in Newberry Valley. In addition, an alternate potential recharge location has been identified within the Oro Grande Wash, north of the California Aqueduct.

Potential sources of recharge water have been studied to determine long-term available sources and quantities. Mojave River storm flows have been evaluated to assess flow volumes and frequencies, and to determine the feasibility of capturing storm flows for recharge efforts. Based on this assessment, it has been determined that the capture of 90% of the flow events may be possible. It should be noted that the frequency of the flows is unpredictable and that peak flow capture is not feasible. The State Water Project as a recharge water source has been evaluated to determine the most feasible locations for such recharge, and the effects of recharging this source into the aquifer. A total of 60 cubic feet per second is available for recharge on a long-term basis. Based on infiltration relationships studied, there is evidence to suggest that it may be feasible to recharge the State Water Project water in the Upper Mojave basin river channel to promote additional downstream flood flow to the Middle and Lower Mojave basins.

Historic cost estimates were reviewed to determine the optimum and most cost-effective method of recharge. Based on this analysis, it appears that both in-channel and off-channel recharge infiltration basins require the least capital and operating expenses for long-term recharge efforts.

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2.0 INTRODUCTION

2.1 BACKGROUND

Water in the Southwest is a valuable, but often rare, commodity. Because of this fact, Federal, State and local agencies are continually attempting to effectively manage water use and discourage water misuse. Groundwater recharge is one effective means of water resources management. To this end, the Mojave Water Agency (MWA) is considering groundwater recharge to assist in the management of groundwater basins within its jurisdiction to reduce losses of potential resources through surface outflow and to reduce the effects of continued basin overdraft. If feasible, the project will allow the storage and subsequent recovery of additional water resources for the basins adjacent to the Mojave River.

The MWA Groundwater Recharge Study Area includes groundwater basins adjacent to the Mojave River and within the MWA boundaries (Figure 2-1, Location Map). These basins are, from southwest to northeast, the Upper Mojave, Middle Mojave, and Lower Mojave basins and are collectively referred to as the Mojave River Basins. Surface water drainages direct surface flow from surrounding highlands to the Mojave River, which is the major recharge water source for the basins within the Study Area. Currently, several subbasins in the Study Area are in various stages of overdraft.

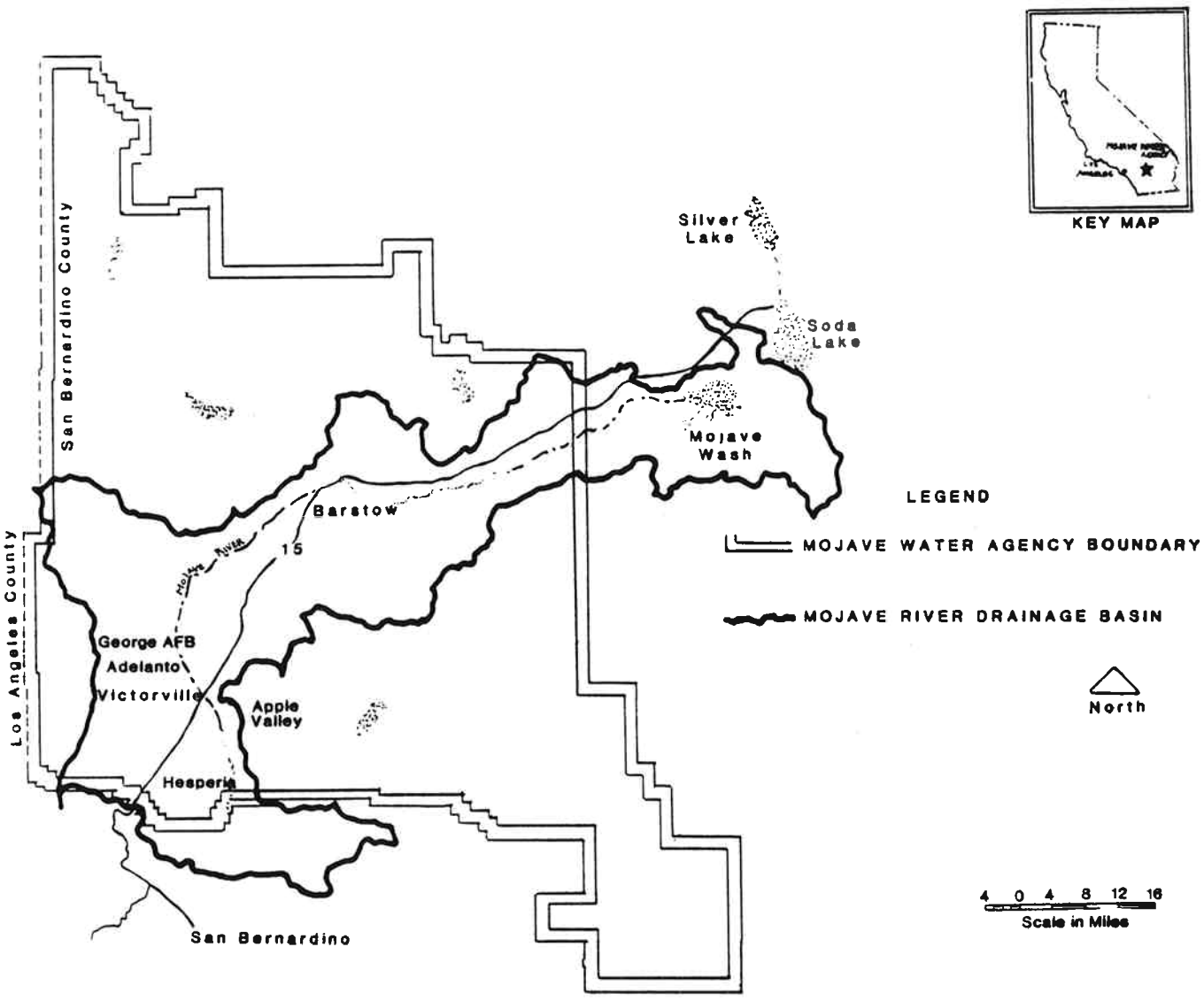
2.2 PURPOSE AND SCOPE

The MWA has retained Malcolm Pirnie to conduct a preliminary feasibility study for the location and development of recharge facilities within the Mojave River Basins, San Bernardino County, California.

The scope of work for this study has included:

Task 1. Assemble and Review Background Data

- Review and compile available information pertaining to the geologic, hydrogeologic, and surface water characteristics of the Mojave River Basins.
- Review and compile available data and information developed for similar water conservation and recharge investigations and operations in the Southwest.



SOURCE : CALIFORNIA STATE POLYTECHNIC UNIVERSITY, POMONA (1987).

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LOCATION MAP

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FIGURE 2-1

Task 2. Identify and Evaluate Potential Recharge Sites

- Identify potential groundwater recharge sites based on a review of previous studies concerning recharge in the Mojave Basin, and application of screening criteria developed for the recharge concept. The screening criteria included consideration of compatible land uses, proximity to potential sources of groundwater contamination, proximity of environmentally sensitive areas, and land ownership and availability.

- Evaluate the suitability of identified sites for recharge operations based on aquifer and regional geologic characteristics, and potential groundwater quality impacts.

Task 3. Develop and Evaluate Storm Flow Recharge Concept

- Evaluate the potential for recharging Mojave River storm water flows including estimates of potential frequency and quantities of storm flows, identify the most appropriate methods and sites to recharge the storm flows, develop preliminary sizing for recharge facilities, and estimate the area of influence and potential benefactors of recharged water.

Task 4. Develop and Evaluate State Water Project Water Recharge Concept

- Evaluate the potential for recharging State Water Project (SWP) water including identification of quantities of SWP flows available for recharge, identification of locations and methods most suitable for recharging SWP deliveries, estimate preliminary facility requirements, and estimate the area of influence and potential benefactors of recharge operations.

Task 5. Estimate Capital and Operating Expenses

- Develop estimated construction costs and annual operating and maintenance costs for various recharge facility components.

- Estimate the quantity and quality of recoverable groundwater.

Task 6. Identify Implementation Requirements

- Identify potential environmental and other detrimental impacts associated with operation of recharge facilities and mitigation measures.

Using the potential recharge source volumes anticipated, preliminary recharge facility design requirements were developed for infiltration basins to estimate the effects of recharge on the surrounding aquifer. Both short-term and continuous infiltration recharge from different sources were modeled to assist in the design and feasibility estimates for the infiltration basin sizing needs, and to observe the effects of the recharged water in the surrounding aquifer.

Preliminary implementation requirements have been developed to provide the recommended approach to construct, operate, and maintain recharge facilities. The requirements include the development of a pilot study to verify published estimates of aquifer parameters, permitting needs, and environmental concerns. A schedule for implementing the proposed recharge effort is also included.

- Assess necessary permits, clearances, and approvals.

- Prepare a preliminary implementation schedule to affect the smooth and timely development of the proposed recharge project, if feasible.

Task 7. Prepare a Summary Report

- Prepare a formal report summarizing the results of the study and incorporating the input of the MWA.

Task 8. Participate in Project Review Meetings/Special Assignments

- Attend scheduled project review meetings and performance of special assignments not included in the scope of work outlined above.

This Report represents the work performed to date on all tasks described above.

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3.0 IDENTIFICATION OF POTENTIAL RECHARGE SITES

3.1 LITERATURE REVIEW

Available literature from various sources was collected and reviewed for pertinent information on the geologic, hydrogeologic, surface water, environmental, and cultural characteristics of the Mojave River Basins. The information included: summaries of land use patterns, wildlife habitats and endangered species areas; native riparian vegetation distribution; soil permeability and aquifer characteristics; historic groundwater and surface water elevations; flood plain restrictions; and various recharge methodologies and feasibility studies. The information obtained from this research has been applied in the analyses presented in the remainder of this report. A complete list of the reference literature is provided in the References section following the main body of the text.

3.2 OVERVIEW OF SITE SCREENING AND IDENTIFICATION PROCESS

The selection of potential recharge sites for groundwater recharge facilities within the Mojave River Basins incorporated numerous site selection considerations that are discussed in detail in Appendix A. The complete summary of recharge facility site selection considerations includes an analyses of the following subjects:

- Environmentally sensitive areas including the identification of wildlife habitat and the distribution of native riparian vegetation.
- Land use patterns.
- Land ownership considerations including the locations of military reservations, Bureau of Land Management (BLM), State, and privately owned land.
- Geologic considerations including the description and areal extent of non-waterbearing and waterbearing formations.
    - o The location and distribution of aquitards within valley-fill sediments.
    - o The location of faults that influence groundwater movement.

  - o The distribution of non-waterbearing materials forming barriers to groundwater flow.

- Hydrogeologic considerations including:

  - o The distribution of soil types and compilation of soil permeability rates.

  - o The distribution of transmissivity values for aquifer materials as well as estimates of storage capacity and aquifer specific yield .

  - o A summary of groundwater elevations, movement, and quality

  - o A discussion of the areas currently identified as having groundwater quality problems including landfills, existing identified contaminated areas, and domestic effluent disposal facilities.

Based on the analyses of these considerations, site selection screening criteria were developed and applied to determine the most appropriate locations for groundwater recharge facilities in the Mojave River Basins.

The considerations presented in Appendix A were categorized into restrictive and supportive criteria. Restrictive criteria were utilized to place low priority on, or to eliminate portions of, the study area from consideration as a potential recharge site. Supportive criteria were then applied to the remaining, or higher priority areas to determine the most appropriate sites for groundwater recharge operations.

The remaining sections of this Chapter present summaries of the screening categories and criteria that have been developed and the application of those criteria to site selection. Additionally, the technical characteristics of the sites identified as the most appropriate to accommodate recharge facilities are discussed in detail. Appendix A should be referenced for detailed discussions on the basis for the development of the screening criteria.

3.3 RESTRICTIVE CRITERIA

Based on the data presented in Appendix A, it is apparent that some of the screening criteria could be considered restrictive to development of recharge facilities, some criteria would absolutely eliminate areas from consideration

(exclusionary criteria), and other screening criteria could be used to prioritize potential recharge sites (priority criteria).

3.3.1 Exclusionary Criteria

Exclusionary criteria serve to eliminate areas from consideration that are obviously unsuitable for development of recharge facilities. These criteria, and their respective applications are summarized below:

Non-waterbearing Geologic Formations: Non-waterbearing formations do not contain appreciable amounts of water and, due to low infiltration rates and storage capacities, are typically not useful for recharge efforts. These generally include the mountain regions bounding the Mojave River. The general distribution of the non-waterbearing materials is illustrated on Plate 1, Wildlife Habitat and Native Riparian Vegetation,

Faults: Areas with historic groundwater levels at near-surface elevations that are the result of the barrier effects to groundwater flow from faulting have been eliminated from consideration due to the limited amount of storage capacity. Structural features of the Mojave River Basins are presented on Plate 1, Wildlife Habitat and Native Riparian Vegetation.

Groundwater Contamination Potential: Several locations within the study area have been identified as having potentially contaminated groundwater. Because of the potential for further contamination of the groundwater due to increased flow from induced recharge, these areas have been eliminated as possible sites for recharge facilities. The following areas of known groundwater contamination are presented on Plate 2, Land Ownership, and have been eliminated from consideration:

1. Areas immediately upgradient and downgradient of George Air Force Base.

2. Areas downgradient of Barstow to the Waterman Fault.

3. Areas adjacent to known landfill sites, including the Victorville, Lenwood-Hinkley, Yermo, and Newberry landfills.

Developed Areas: Developed lands within the corporate boundaries of the cities and towns within the Mojave River Basins were excluded from consideration because of the lack of availability of these lands. Developed areas are illustrated on Plate 2.

Military Installations: Lands supporting military installations (including bases, armories and general facilities) are not available for purchase or use to the MWA. Military installation are depicted on Plate 2. Areas within the boundaries of George Air Force Base; the

Marine Corps Supply Station near Nebo; and the Marine Corps Supply Station at Yermo have been eliminated from consideration.

3.3.2 Low Priority Locations

Some of the criteria applied to the study area resulted in the development of low priority areas that were considered to be relatively undesirable for development of recharge facilities. Screening criteria that have resulting in low priority areas, and their manner of application, are summarized below:

Wildlife Habitats: Certain wildlife present in the study area have been identified as sensitive, protected, or endangered species. Thus, their habitats should also be considered sensitive, and be given low priorities as potential recharge sites (Plate 1). These areas are not totally eliminated from consideration. Although development within the habitats is not entirely prohibited, these areas are subject to regulatory scrutiny. For these reasons, the habitats of the following wildlife species have been given low priority:

- Golden Eagle
- Western Pond Turtle
- Summer Tanager
- Desert Tortoise
- Mojave Tui Chub

Native Riparian Vegetation: Areas of riparian vegetation provide wildlife habitat for such animals as the beaver, raccoon, ringtail cat, turtles, and migratory birds. Because of the habitat provided by the riparian vegetation, these areas have been considered environmentally sensitive, and were given low priorities as potential recharge sites (Plate 1). Areas covered by riparian vegetation were also given low priorities due to the large quantities of groundwater consumptively used to sustain the growth requirements of the vegetation. Recharge efforts in areas of riparian vegetation would encourage the growth of the vegetation and reduce the amount of water available for recovery from recharge efforts.

Floodplains: Recharge basins within the Mojave River channel would be subject to possible damage due to intermittent storm flows. Although land within the floodplain may be available for use, any permanent potential recharge sites should be located above acceptable flood levels to reduce costs from damages while still effectively transmitting water

to the aquifer. Temporary recharge facilities may be located within the floodplain, provided construction of the facilities and the subsequent loss is cost-effective in promoting recharge.

Septic Tanks and Leach Lines: Groundwater quality of recharged water may be affected by leaking septic tanks and leach lines. For this reason, it is recommended that recharge facilities be located away from these potential sources of contamination.

3.4 SUPPORTIVE CRITERIA

After the restrictive criteria were applied to the study area, the areas not eliminated (including low priority areas) were re-examined using supportive criteria. These criteria were developed to judge the relative desirability of areas not eliminated for siting of recharge facilities. The majority of these criteria were technical in nature and related to relative feasibilities of developing recharge facilities in certain areas. The supportive criteria that have been developed, and their manner of application, include:

Land Ownership: Certain lands, including State and BLM, and certain patented lands can be purchased or leased for recharge efforts. For this reason, these lands have been given higher priorities than other, restricted lands (Plate 2).

Waterbearing Geologic Formations: Waterbearing formations include various consolidated and semi-consolidated units within the Mojave River Basin valleys (Plate 3, Soils and Aquifer Properties). Geologic and hydrogeologic properties considered for recharge efforts include the following:

- Soils Distribution and Permeability Rates: For the purposes of recharge, areas with good-to-high soil infiltration characteristics are desired so that water can be easily transmitted to the subsurface, evaporation can be minimized, and the amount of water that can be transferred to the aquifer is maximized. Areas defined as having good and high infiltration characteristics have been given high priority. Soil permeability rates for sediments in and adjacent to the Mojave River and Oro Grande Wash drainages range from moderately rapid (4.0 to 12.0 feet per day) to rapid (12.0 to 40.0 feet per day) (U.S. Department of Agriculture, 1986).

  As the result of the evaluation of soil distribution and related infiltration characteristics, areas of known high soil infiltration and permeability were considered for potential

recharge sites. These areas of good and high soil infiltration defined by California Polytechnic University (1987) are distributed primarily within and adjacent to the Mojave River channel and its tributary drainages and are located on Plate 3.

- Transmissivity: The rate at which water is transmitted from the recharge facility to the aquifer and surrounding areas controls the volume of water that can be recharged at a facility of a given size. For this reason, aquifers that are capable of transmitting large volumes of water in relatively short time periods are desirable for recharge efforts. Highly transmissive aquifers reduce both surface land requirements and lessen the effects of groundwater mounding beneath the recharge facility.

  Areas of high aquifer transmissivity (100,000 to 200,000 gpd/ft) were given high priority. Transmissivity contours for the Study Area were developed by Hardt (1971) and are presented on Plate 3.

- Specific Yield and Storage Capacity: The specific yield of a sedimentary deposit is the ratio of the volume of water that saturated materials will yield by gravity drainage over a period of time to the total volume of the saturated materials. The specific yield of an unconfined aquifer is equivalent to the storage coefficient (Plate 3). The greater the specific yield of the sedimentary deposits, the greater the volume of water that can be retrieved.

  The available storage capacity is defined as the amount of available storage space between the ground surface and water table levels (Plate 4, 1981 Groundwater Elevations). Recharge facilities typically are placed in areas where storage capacities are sufficient to store the amounts of water planned to be recharged. For this report, storage capacities have been calculated by multiplying the volume of unsaturated material by the porosity of the aquifer.

  The retrievable storage capacity of the aquifer may be defined as the volume of the aquifer multiplied by the specific yield of the formation. The retrievable storage capacity is less than the available storage capacity. Calculations for total available maximum storage capacity and retrievable storage capacity are presented for each potential recharge facility. Not all water will be recoverable due to the deficit caused by wetting the alluvium to field soil moisture capacity. This loss is best explained as the difference between porosity (assumed to range from 25 to 30%) and specific yield (assumed to range from 8 to 15%). The difference of 15 to 17% of the volume of recharge water will not drain readily from the sediments. After the alluvium is brought to saturation, water

recharged to the system will be recovered according to its specific yield.

Areas with greater depths to groundwater levels and with higher specific yields were given higher priority as potential recharge sites because of their higher retrievable storage capacities (Plates 5 and 6, Geologic Cross Sections A-A' and B-B', and Geologic Cross Sections C-C' and D-D', respectively).

3.5 POTENTIAL RECHARGE SITES

Based on the application of the screening criteria discussed above, a total of five potential recharge locations have been identified. Site specific information pertinent to the potential recharge sites is presented below and includes:

- Description of potential recharge site location.
- Physical characteristics of soils.
- Estimated soil permeability rates.
- Transmissivity values.
- Groundwater levels and quality.
- Estimates of total maximum available and retrievable storage capacity.
- Inferred potential effect of recharge activities on local groundwater movement.
- Local land use.
- Environmental restrictions.

The potential recharge facility locations are illustrated on Plate 7, Potential Recharge Sites.

3.5.1 Upper Basin / Mojave River Site

The Upper Basin / Mojave River site is located downgradient from the Forks Dam for a distance of approximately five miles along the Mojave River. This potential recharge site is located entirely within an area defined by California Polytechnic University (1987) as being suitable for the capture,

retention, and infiltration of storm flow runoff water. It is located within the Mojave River channel deposits consisting of stream bed gravels, sands, silts and other associated stream deposited sediments. The perimeter of the potential recharge site contains older alluvial deposits of the Victorville fan and valley alluvium to the west, and younger alluvial deposits and valley fill sediments to the east.

Permeability rates at the site are moderately rapid to rapid, from 4.0 feet/day to 40+ feet/day (U.S. Department of Agriculture, 1986). Transmissivity values reportedly range from 50,000 gpd/ft just below the Forks Dam to 150,000 gpd/ft downgradient (Hardt, 1971).

The potential recharge site aquifer is subject to perched conditions due to an aquitard at a depth of approximately 100 to 200 feet below the ground surface (Hardt, 1971). This aquitard has been documented to extend nearly eight miles to the north of the Forks Dam, and apparently underlies the total potential recharge site (Plate 5). Groundwater levels in 1981 at the potential recharge site averaged approximately 50 feet below the ground surface in the unconfined aquifer above the aquitard. Groundwater flow is primarily to the north, parallel to the Mojave River channel (Plate 4).

Groundwater in the area tends to be of excellent quality with TDS concentrations of approximately 200 mg/l. Areas downstream of the potential recharge site, however, are subject to isolated high concentrations of nitrate due to agricultural development. These areas should not significantly effect recharge water in the uppermost portion of the basin.

The total maximum available storage capacity directly beneath the site, using an average depth to water of 50 feet, a total recharge area of 12.5 square miles, and a porosity of 0.30 (30%), is approximately 120,000 acre feet. It is unlikely that there is a significant soil moisture deficiency within the soils at this potential recharge site. Due to an unquantifiable volume of soil moisture held through specific retention, the actual volume of water required to saturate the aquifer sediments at this site will be substantially less. Soil moisture deficiencies would decline rapidly following the introduction of continuous recharge.

The retrievable storage capacity of the site can be calculated by multiplying the volume of unsaturated aquifer by the specific yield of the unconfined aquifer. The retrievable storage capacity directly below this site, using an average depth to water of 50 feet, an approximate recharge area of 12.5 square miles, and a conservative average specific yield of 0.15, is approximately 60,000 acre feet. As indicated above, the available storage capacity is greater than the retrievable storage capacity. This is due to the need to satisfy initial soil moisture deficiencies and bring the water content of the sedimentary materials up to field capacity. Once field capacity has been reached, the available storage capacity will be equivalent to the retrievable storage capacity.

These values of storage capacity should be considered a maximum, since it assumes that groundwater elevations will be at the ground surface. Maintaining groundwater levels at near surface elevations can result in many undesirable conditions, including losses to evaporation and growth of vegetation.

Mounding and spreading effects from continuous recharge will result in water migrating into surrounding areas, thus increasing the available storage capacity of the site. Because of the laterally decreasing transmissivity values adjacent to the river channel, the recharge mound and associated spreading should extend in the downstream direction forming an elongate elliptical shape. Continued recharge may cause water to flow further in the downstream direction, until it extends beyond the aquitard and reaches an area of increased storage capacity south of the Bear Valley cutoff.

All lands within the potential recharge site are patented and should be available to use under current State statutes. There are currently no identified environmental restrictions in the area.

3.5.2 Upper Basin / Oro Grande Wash Site

The Upper Basin / Oro Grande Wash potential recharge site is located along Oro Grande Wash from the California Aqueduct to the intersection of Interstate 15 and State Highway 18, approximately 3 miles southwest of Victorville (Plate 7). California Polytechnic University (1987) has defined the area in which this potential recharge site is located as being suitable

for the capture, retention, and infiltration of storm flow runoff water. Six square miles of the potential recharge site overlays two main stratigraphic units, both of which are aquifers. The upper 3.5 miles of the potential site lies within the Victorville fan deposits consisting of various mixtures of sand, gravel and clay. Transmissivities in the area reportedly range from 25,000 gpd/ft to 50,000 gpd/ft (Hardt, 1971), while permeability rates are designated as moderately rapid to rapid, ranging from 4.0 to 40 feet/day (U.S. Department of Agriculture, 1986).

The lower portion of the potential recharge site lies on older alluvial fill deposits consisting of unconsolidated to moderately consolidated gravel, sand, silt and clay. These deposits are typically finer grained and probably exhibit slightly lower permeability rates than the surrounding fan deposits. The aquifer materials are reported to have similar transmissivities as the upper aquifer materials within the Victorville fan.

The area is not reported to have deposits of continuous fine-grained materials that may cause perched water conditions, but the presence of thin clay layers reported in driller logs indicates that there may be localized areas that are subject to variable perched conditions. Groundwater levels in 1981 ranged from approximately 60 to 300 feet below the ground surface. Groundwater contours indicate a northeasterly flow direction (Plate 3). Groundwater quality in the area tends to be very similar to the Upper Basin Mojave River potential recharge site, with slightly higher TDS concentrations.

The maximum available storage capacity directly beneath the site, using an average depth to water of 100 feet, a total recharge area of 6.0 square miles, and a porosity of 0.25, is approximately 96,000 acre feet. It is unlikely that there is a significant deficiency of soil moisture within the soils at this potential recharge site. This site is within the channel deposits of the Oro Grande Wash, which periodically receives infiltration of surface flows contained within the channel. Soil moisture deficiencies would decline following the introduction of continuous recharge.

The retrievable storage capacity directly beneath this site, using an average depth to water of 100 feet, a recharge area of 6.0 square miles, and a conservative specific yield of 0.08, is approximately 30,720 acre feet. As

previously indicated, the available storage capacity is greater than the retrievable storage capacity. This is due to the need to satisfy initial soil moisture deficiencies and bring the water content of the sedimentary materials up to field capacity. Once field capacity has been reached, the available storage capacity will be equivalent to the retrievable storage capacity. Because of the mounding and spreading effects from recharge, water will migrate into surrounding areas, thus increasing the available storage capacity of the site. Again, actual storage capacities are somewhat lower because the desired depth to water is less than the ground surface elevations.

Because of the laterally increasing transmissivity values to the east, the mound created by the recharge may tend to expand eastward toward the Mojave River channel. The northeasterly groundwater gradient in the area and assumed greater horizontal permeabilities to the north will also cause recharged waters to spread in the downgradient (northerly) direction when the recharged water becomes part of the groundwater system.

Long-term recharge will probably infiltrate in two general directions: 1) toward the unconfined aquifer south of Victorville, and; 2) toward the Lower Narrows north of Victorville. Recharge in Oro Grande Wash would therefore augment groundwater supplies to support water demands in areas south of Victorville that may be in overdraft conditions.

All lands within the potential recharge site are privately owned and available for use under current State statutes. There are currently no environmental restrictions in the area, although there is heavy residential development in the vicinity of the proposed potential recharge site. In addition, distance from the existing SWP turnout must be considered in evaluating this site. Areas of potential downgradient contamination to the recharged water include George Air Force Base and the Victorville Landfill. These areas should not have a significant impact on the recharge efforts due to their distance from the recharge sources.

3.5.3 Middle Basin / Hinkley Valley Site

The Middle Basin / Hinkley Valley potential recharge site is located within the Mojave River channel south of Hinkley valley. The potential re-

charge site is located from just northeast of Hodge and Iron Mountain, and extends to the west to within approximately one mile the Lenwood Fault. The geology of the site suggests that the area is underlain by predominantly younger Mojave River deposits consisting of unconsolidated fluvial gravels, sands, and silts. Sediments observed in the surrounding area include interfingering dune sands and younger and older valley alluvium, sporadically interrupted by small outcroppings of uplifted volcanics and consolidated older alluvium.

Transmissivity values reportedly exceed 100,000 gpd/ft (Hardt, 1971), while permeability rates are moderately rapid to rapid, 4.0 feet/day to 40.0 feet/day (U.S. Department of Agriculture, 1986). Groundwater contours in the area indicate that flow occurs in a downstream direction due to laterally decreasing transmissivity values. Groundwater flow is influenced by large pumping depressions caused by historic groundwater extractions in Hinkley valley.

Groundwater within the potential recharge area tends to be of good quality with TDS values well below 500 mg/l. Local groundwater quality in areas in and near Hinkley valley have historically exhibited high concentrations of sulfate and fluoride. Most of these groundwater quality problems are apparently due to both the migration of poor quality water into areas of excessive pumping and agricultural irrigation return flow. The overall good quality of storm flow water within the Mojave River channel deposits should enhance the water quality in adjacent areas through recharge efforts. The migration of good quality recharge water may result in an improvement of water quality downstream of the potential site.

The maximum storage capacity of the area directly beneath the site, using an average depth to water of 50 feet, a total recharge area of 4.5 square miles, and a porosity of .30 (30%), is approximately 43,200 acre feet. The actual storage capacity of the site is probably less, due to an unquantifiable amount of water held in storage by specific retention. This site, as with other sites within the Mojave River and Oro Grande Wash channels, receives periodic recharge through infiltration of storm flows. Thus, soil moisture deficiencies may be low.

The maximum retrievable storage capacity of this site, using an average depth to water of 50 feet, a total recharge area of 4.5 square miles, and a

conservative specific yield of 0.15, is approximately 21,600 acre feet of water. As indicated previously, the available storage capacity is greater than the retrievable storage capacity. This is due to the need to satisfy initial soil moisture deficiencies and bring the water content of the sedimentary materials up to field capacity. Once field capacity has been reached, the available storage capacity will be equivalent to the retrievable storage capacity.

Mounding and spreading effects from continuous recharge will result in the migration of recharge water into surrounding areas, thus increasing the available storage capacity of the site. Because of laterally increasing transmissivity values, the recharge mound will tend to expand toward Hinkley valley. The northeasterly groundwater gradient in the area, however, will also cause recharged waters to spread in the downstream direction. Recharge will infiltrate in two general directions: 1) toward the unconfined aquifer in Hinkley valley, and; 2) toward the constriction at the Barstow Narrows along the Mojave River. Artificial recharge would therefore augment natural recharge to support water demands in areas that are presently susceptible to overdraft conditions, and possibly increase flow past the Barstow Narrows to aid in downstream recharge efforts.

The Hinkley valley potential recharge site lies within the boundary of the state protected Desert Tortoise. An environmental assessment of the area would be required before implementation of any recharge effort. Other actions may be required depending on the findings of the environmental assessment. Land use patterns shown on Plate 2 indicate both private and BLM land ownership is present within the potential recharge area. Private lands can be utilized under current State statutes, but BLM lands will require either a lease agreement or purchase. BLM lands may not be available depending on their regulations and requirements. Further contact with the BLM in the area is necessary to assess the availability of this site.

3.5.4 Middle Basin / Waterman Valley Site

The Middle Basin / Waterman Valley potential recharge site is located within the Mojave River channel deposits in Waterman valley. The potential

recharge site is located approximately two miles east of Elephant Hill, and extends approximately three miles downgradient along the Mojave River channel. The geology of the site suggests that the site is underlain predominantly by younger fluvial deposits consisting of unconsolidated gravels, sands, and silts. Surrounding areas are underlain by interfingering dune sands and younger and older valley alluvium.

Transmissivity values reportedly exceed 200,000 gpd/ft (Hardt, 1971), while permeability rates are moderately rapid to rapid, 4.0 to 40.0 feet per day (U.S. Department of Agriculture, 1986). Groundwater contours in the area indicate that groundwater flow occurs in the down stream direction due to laterally decreasing transmissivity values. In areas to the south of the Mojave River, continued pumping has caused some depletion of the groundwater in storage and associated local changes in groundwater elevations. Groundwater elevations near the Mojave River channel, however, have remained stable.

Groundwater within the potential recharge area tends to be of good quality with TDS values below 500 mg/l. Local groundwater quality in areas in and near surrounding mountains have historically exhibited high concentrations of TDS, sulfate, and fluoride. The overall good quality of water within the Mojave River channel deposits should be enhanced by recharge efforts. The further migration and mixing of good quality recharge waters may also result in an improvement of water quality in surrounding areas.

The maximum available storage capacity directly beneath this site, using an average depth to water of 50 feet, a total recharge area of 3.0 square miles, and a porosity of 0.30 (30%), is approximately 28,800 acre feet. Due to an unquantifiable volume of water held within the soils through specific retention, the actual volume of water required to saturate aquifer sediments at the site will be substantially less.

The retrievable storage capacity of this site, using an average depth to water of 50 feet, a total recharge area of 3.0 square miles, and a specific yield of 0.15, is approximately 14,400 acre feet of water. As indicated previously, the available storage capacity is greater than the retrievable storage capacity. This is due to the need to satisfy initial soil moisture

deficiencies and bring the water content of the sedimentary materials to field capacity. Once field capacity has been reached, the available storage capacity will be equivalent to the retrievable storage capacity.

Mounding and spreading of recharge water will result in the migration into surrounding areas, thus increasing the available storage capacity of the site. Because of the laterally decreasing transmissivity values adjacent to the Mojave River channel, most of the recharge mound will probably expand downgradient toward the Lower Mojave Basin. A portion of the recharged water will probably infiltrate into the valleys to the south, where pumping has increased the local groundwater gradients. Recharge would therefore augment groundwater supplies to support water demands in areas that are reportedly in overdraft conditions.

The Waterman valley potential recharge site is within BLM administered and privately owned lands. Private lands can be utilized under current State statutes, but BLM lands will require either a lease agreement or purchase. BLM lands may not be available depending on governmental regulations and requirements. Further contact with the associated parties in the area is necessary to assess the availability of the site. There are currently no other environmental restrictions in the area.

3.5.5 Lower Basin / Newberry Valley Site

The Lower Basin / Newberry valley site is located just downgradient from the Calico-Newberry Fault and extends approximately three miles within the Mojave River channel. The site is located within the Mojave River channel deposits, which consist of fluvial gravels, sands, silts and other associated stream deposited sediments. The perimeter of the recharge site contains interfingering dune sands and older alluvial sands and gravels.

Permeability rates at the site are moderately rapid to rapid, ranging from 12.0 to 40.0 feet/day (U.S. Department of Agriculture, 1986). Transmissivity values range from 150,000 gpd/ft downgradient of the Calico-Newberry Fault, to 100,000 gpd/ft at the eastern most edge of the potential recharge site (Hardt, 1971) (Plate 3).

The potential recharge site is located within Newberry basin above an unconfined portion of the aquifer. Groundwater infiltration at this location may recharge a semi-confined lower aquifer in hydraulic continuity with the unconfined aquifer. The lower aquifer is presently under overdraft conditions due to pumping near the Town of Newberry.

In general the groundwater quality of the Lower Mojave Basin is fair-to-good with TDS values rarely exceeding 600 ppm along the Mojave River channel. Within the southern portion of Newberry basin and near Troy Lake, groundwater quality is poor with TDS values up to 3200 ppm and associated high concentrations of boron and fluoride.

The maximum available storage capacity of the area directly below the site, using an average depth to water of 50 feet, a total recharge area of 6.0 square miles, and a porosity of 0.30 (30%), is approximately 57,600 acre feet. The retrievable storage capacity of this site, using an average depth to water of 50 feet, a total recharge area of 6.0 square miles, and a conservative specific yield of 0.15, is approximately 28,800 acre feet. As indicated previously, the available storage capacity is greater than the retrievable storage capacity.

Mounding and spreading effects from recharge water will result in a migration of recharge water into surrounding areas, thus increasing the available storage capacity of the site. Recharge infiltration will gradually spread out into the surrounding areas but may eventually mound up from the water table or other constricting layers. Because of the laterally decreasing transmissivity values adjacent to the Mojave River channel, a portion of the recharge mound will probably expand downgradient toward the Camp Cady. A large portion of the recharged water will probably infiltrate into the lower aquifer and migrate to the south where pumping has increased the local groundwater gradients. Artificial recharge would, therefore, augment natural groundwater supplies to support water demands in areas that are presently susceptible to overdraft conditions.

The Lower Mojave Basin potential recharge site lies on lands that are within BLM administered and privately owned areas. Private lands can be utilized under State Statutes, but BLM lands will require either a lease

agreement or purchase. Lands administered by the BLM may not be available depending on governmental regulations and requirements. Further contact with the associated parties is necessary to assess the availability of the site. There are currently no other environmental restrictions in the area.

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4.0 SOURCES OF RECHARGE WATER

4.1 GENERAL

Two primary sources of water that could be recharged in the Mojave River Basins have been identified. These include:

- Mojave River Storm Flows
- MWA Entitlement of the STATE WATER PROJECT

This chapter presents an evaluation of the potential quantity, frequency, and quality of each potential source of water.

4.2 MOJAVE RIVER STORM FLOWS

The primary source of recharge for the basins along the Mojave River is derived from infiltration of infrequent storm flow runoff. This source of water constitutes the largest single source of available recharge water. To estimate the volume of water that may be available for recharge and determine the feasibility of capturing portions of the storm flow, the historic stream flow records from recording gages in the Mojave River channel have been reviewed, along with U.S. Army Corps of Engineers studies and published information pertaining to observations of previous flow events. As identified by the Corps of Engineers (U.S. Army Corps of Engineer, Los Angeles District, 1985c), environmental considerations (the Mojave Tui Chub) may affect the feasibility of utilizing storm flow in the Mojave River channel.

4.2.1 Streamflow Measurement

Historically, there have been eight U.S.G.S gaging stations along the Mojave River between the San Bernardino Mountains and Afton Canyon. The location of gaging stagions are presented on Plate 4. Seven of these stations are actively measured, while the gage near Helendale has not been actively measured since 1970. Table 4-1, Mojave River Stream Gaging Stations, provides a summary of the gaging stations from the headwaters of the Mojave River downstream to Afton Canyon. All streamflow data from these gages have been obtained from the U.S. Geological Survey in Sacramento, California.

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TABLE 4-1

MOJAVE RIVER
STREAMFLOW GAGING STATIONS

1. Deep Creek near Hesperia, CA
   (U.S.G.S. #10260500) (1905-1986)
   Located on Deep Creek, upstream of the Forks Dam

2. West Fork Mojave River near Hesperia, CA
   (U.S.G.S. #10261000) (1930-1986)
   Located on the West Fork of the Mojave River, upstream of the Forks Dam.

3. Mojave River Below Forks Reservoir near Hesperia, CA
   (U.S.G.S. #10261100) (1972-1986)

4. Mojave River at Lower Narrows near Victorville, CA
   (U.S.G.S. #10261500) (1899-1986)

5. Mojave River at Wild Crossing near Helendale, CA
   (U.S.G.S. #10261900) (1966-1970)

6. Mojave River near Hodge, CA
   (U.S.G.S. #10262000) (1971-1986)

7. Mojave River at Barstow, CA
   (U.S.G.S. #10262500) (1931-1986)

8. Mojave River at Afton, CA
   (U.S.G.S. #10263000) (1930-1986)

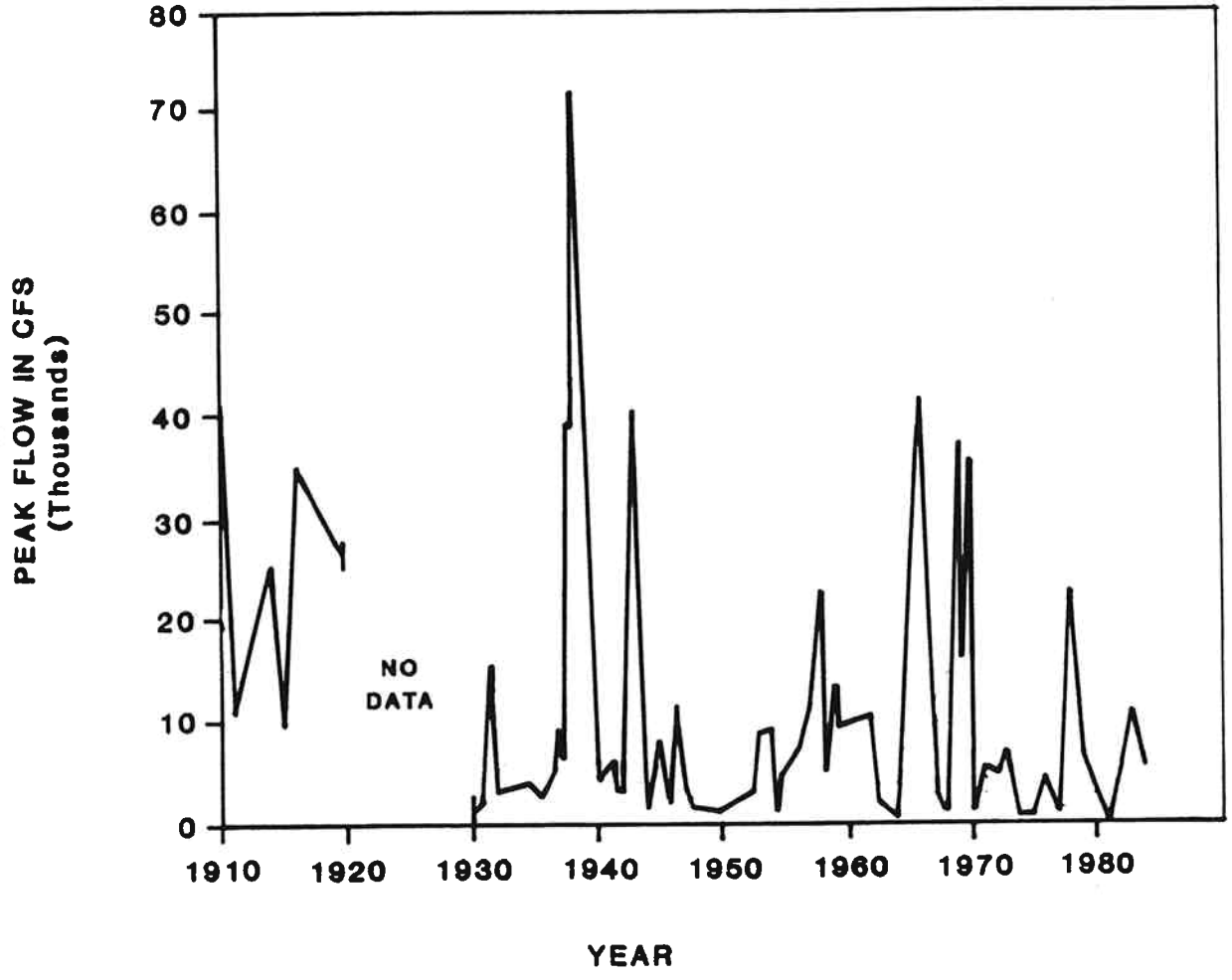
Source: U.S. Geological Survey, 1988

4.2.2 Streamflow Discharge Data

Streamflow along the Mojave River was unregulated until 1971 when construction of the Forks Dam was completed. This dam was primarily engineered to regulate flood discharges downstream, and currently restricts flow in the Mojave River to a maximum peak discharge of 23,500 cubic feet per second (cfs). Peak discharges for the Forks Dam area can be analyzed from the combined records of Deep Creek and West Fork gaging stations. Peak flows for events of record average 10,340 cfs, but have historically exceeded peak flows for single events of 70,000 cfs (Figure 4-1, Peak Flow at the Forks Dam Area, Using Deep Creek and West Fork Gage Data).

Discharge data obtained from the U.S. Geological Survey (1988) and discussed below provides gaged discharge flows for mean annual, average annual, mean monthly, and daily analysis. Mean annual discharge data obtained from each gaging station along the Mojave River and from the Forks Dam are provided on Table 4-2, Mean Annual Discharge (CFS) (Mojave River). As shown, annual average flow volumes generally tend to decrease downstream, due to infiltration and other losses. Since the annual average discharge measurements are more representative of long term conditions as the period of gage activity increases, gaging stations with longer periods of record have been utilized for determining the average flow volumes within the river channel. Mean annual discharge data obtained from gaging stations at the Forks Dam, Helendale, and Hodge have a relatively short period of record, and may not accurately represent long term flow conditions (Table 4-2). For example, the Helendale gage was active for only four years (1966-1970), one of which was 1969; that was a year subject to a 30-year flood event. Annual average discharge for this gage is skewed due to this event. Mean annual discharge from the Forks Dam area are graphically represented on Figure 4-2, Mean Annual Streamflow, Combined Deep Creek, and West Fork Gage Data.

Mean monthly flow readings from each gage along the Mojave River are shown on Table 4-3, Mean Monthly Discharge Flows (CFS) (Mojave River). Flow volumes reflect periods of high precipitation or snow melting in the San Bernardino Mountains during the winter and spring months. January, February, March, and April have the highest average discharges throughout the Mojave River reach.



SOURCE: U.S.G.S., 1988

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PEAK FLOW AT THE
FORKS DAM AREA USING DEEP CREEK
AND WEST FORK GAGE DATA

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FIGURE 4-1

TABLE 4-2

MEAN ANNUAL DISCHARGE (CFS) (MOJAVE RIVER)

	DEEP CREEK (10260500)	WEST FORK (10261000)	FORKS DAM (10261100)	LOWER NARROWS (10261500)	HELENDALE (10261900)	HODGE (10262000)	BARSTOW (10262500)	AFTON (10263000)
ANNUAL AVE	72.00	34.00	83.40	73.40	94.60	33.90	25.70	6.88
1899								
1900				34.20				
1901				142.00				
1902								
1903								
1904				47.70				
1905	77.50			135.00				
1906	121.00							
1907	190.00							
1908	53.60							
1909	79.10							
1910	126.00							
1911	120.00							
1912	37.10							
1913	20.50							
1914	138.00							
1915	124.00							
1916	255.00							
1917	45.10							
1918	56.90							
1919	16.00							
1920	74.50							
1921	41.40							
1922	244.00							
1923								
1924								
1925								
1926								
1927								
1928								
1929								
1930	30.00							1.31

TABLE 4-2 (CONT.)

MEAN ANNUAL DISCHARGE (CFS) (MOJAVE RIVER)

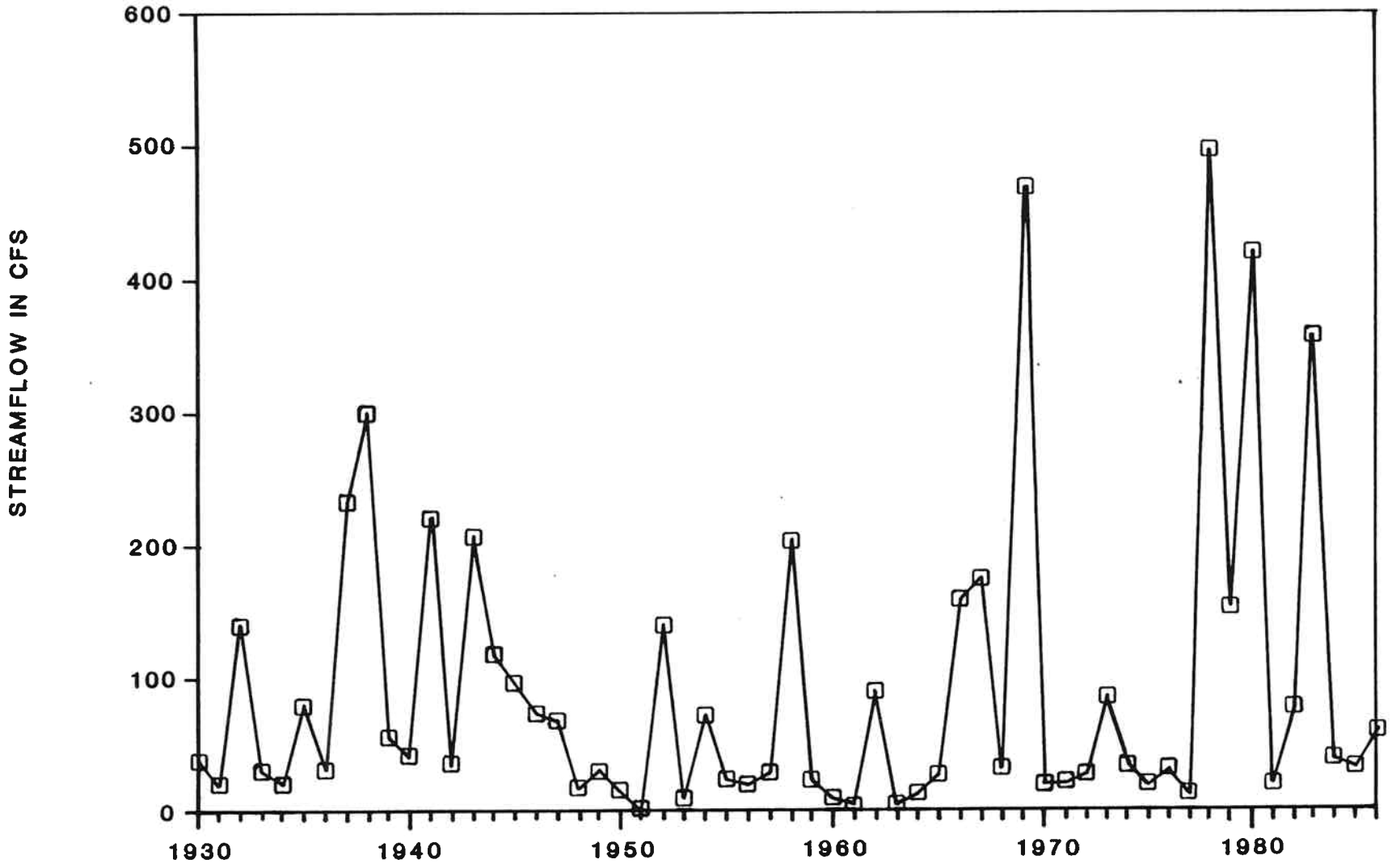
	DEEP CREEK (10260500)	WEST FORK (10261000)	FORKS DAM (10261100)	LOWER NARROWS (10261500)	HELENDALE (10261900)	HODGE (10262000)	BARSTOW (10262500)	AFTON (10263000)
1931	17.10	4.27		31.00			0.00	1.75
1932	92.60	47.60		116.00			51.60	10.90
1933	20.00	11.00		33.00			0.00	
1934	16.10	6.12		32.90			0.00	
1935	55.20	24.30		46.70			1.64	
1936	25.90	7.25		28.10			0.00	
1937	154.00	79.60		208.00			143.00	
1938	196.00	106.00		260.00			191.00	
1939	41.40	14.50		41.00			0.76	
1940	33.20	9.71		37.80			0.00	
1941	142.00	80.10		198.00			133.00	
1942	24.80	11.10		35.60			0.14	
1943	128.00	79.30		176.00			126.00	
1944	66.40	53.10		107.00			49.90	
1945	64.00	33.70		75.50			30.50	
1946	55.00	20.30		59.70			17.40	
1947	37.60	31.80		51.40			3.97	
1948	14.50	4.30		36.30			0.00	
1949	21.40	10.40		31.60			0.00	
1950	12.10	5.04		29.90			0.00	
1951	3.06	0.00		28.80			0.00	
1952	81.40	60.40		92.00			17.30	
1953	9.25	2.93		30.10			0.00	1.37
1954	51.50	23.60		43.10			0.00	1.32
1955	18.10	6.63		31.10			0.00	1.26
1956	19.40	2.91		30.00			0.00	1.24
1957	25.90	4.55		28.40			0.00	1.04
1958	142.00	63.40		135.00			27.70	3.85
1959	18.90	6.49		28.10			0.01	0.82
1960	12.00	0.10		26.60			0.00	0.94

TABLE 4-2 (CONT.)

MEAN ANNUAL DISCHARGE (CFS) (MOJAVE RIVER)

	DEEP CREEK (10260500)	WEST FORK (10261000)	FORKS DAM (10261100)	LOWER NARROWS (10261500)	HELENDALE (10261900)	HODGE (10262000)	BARSTOW (10262500)	AFTON (10263000)
1961	5.85	0.34		26.10			0.00	0.92
1962	70.40	22.50		37.00			1.01	0.78
1963	7.68	0.12		23.50			0.00	1.04
1964	14.00	1.01		23.60			0.00	0.74
1965	20.90	8.74		23.20			0.01	0.78
1966	114.00	46.50		70.50			8.77	6.60
1967	112.00	65.10		103.00	56.60		10.60	2.02
1968	23.50	10.40		25.90	0.02		0.00	0.49
1969	301.00	171.00		402.00	316.00		202.00	100.00
1970	19.40	4.23		31.90	5.21		0.00	0.75
1971	20.50			28.20		0.00	0.00	0.50
1972	29.90		32.10	31.40		0.91	0.06	0.82
1973	56.20		88.90	48.00		6.06	0.21	0.43
1974	25.30		37.60	24.50		0.01	0.00	0.60
1975	16.80	6.47		23.00		0.00	0.00	0.22
1976	24.10	8.55		27.80		0.00	0.00	0.41
1977	13.60	2.56		39.00		0.01	0.00	1.24
142,718 1978	GPM 318.00	183.00		289.00		204.00	69.70	64.60
50,715 1979	" 113.00	42.10		99.90		44.00	7.68	
119,830 1980	" 267.00	156.00		316.00		237.00	190.00	12.70
1981	16.00	6.23	22.40	32.00		0.00	0.00	1.91
1982	57.10	22.70	82.60	48.80		14.00	0.00	1.45
~~730,800 GPM~~ 1983	91,106. 203.00 GPM	159.00	362.00	162,466 GPM			128.00	18.40
1984	30.30	10.10	37.70	37.20		2.71		2.50
1985	22.40	11.50	31.00	29.10		0.00	0.00	0.94
1986	45.70	17.80	56.90	23.40		0.00	0.00	0.76

SOURCE: U. S. GEOLOGICAL SURVEY, 1988



SOURCE U.S.G.S., 1988

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MEAN ANNUAL STREAMFLOW RECORD
COMBINED DEEP CREEK AND WEST FORK GAGE DATA

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FIGURE 4-2

TABLE 4-3

MEAN MONTHLY DISCHARGE FLOWS (CFS) (MOJAVE RIVER)

MONTH	DEEP CREEK (10260500)	WEST FORK (10261000)	FORKS DAM (10261100)	LOWER NARROWS (10261500)	HELENDALE (10261900)	HODGE (10262000)	BARSTOW (10262500)	AFTON (10263000)
RECORD LENGTH (YEARS)	1905-1986	1930-1986	1972-1986	1899-1986	1966-1970	1971-1986	1931-1986	1930-1986
OCTOBER	5.41	0.39	9.25	28.20	0.00	0.00	0.00	0.76
NOVEMBER	21.20	8.01	24.80	41.80	1.08	0.00	0.45	1.00
DECEMBER	62.40	21.70	92.60	57.30	56.70	1.38	4.27	3.33
JANUARY	118.00	46.50	66.90	83.90	237.00	8.15	22.80	11.10
FEBRUARY	194.00	115.00	202.00	196.00	424.00	153.00	87.80	38.20
MARCH	221.00	126.00	358.00	216.00	177.00	161.00	138.00	22.40
APRIL	153.00	58.10	166.00	141.00	135.00	63.00	51.60	3.57
MAY	66.70	21.10	68.70	49.90	40.90	18.50	6.59	0.81
JUNE	18.10	5.72	13.50	25.20	0.35	7.52	0.00	0.50
JULY	5.82	0.17	3.04	18.60	0.03	0.00	0.00	0.55
AUGUST	3.29	0.03	3.07	18.90	0.02	0.00	0.02	1.77
SEPTEMBER	3.75	0.18	1.69	21.50	0.00	0.00	0.01	0.81

SOURCE: U.S. GEOLOGICAL SURVEY, 1988

Average monthly flows generally tend to decrease in the downstream direction, with the overall monthly frequency remaining relatively constant. It should be noted that the average discharge observed from these stations represents an average of all years of record, and does not necessarily indicate the discharge that may be observed from a single storm event or combination of storm events within a given season at all gage locations. There are some years of no flow.

Daily flows are extremely variable, and are influenced by individual and unpredictable storm events. Daily discharge tables have also been obtained; however, the tables are not included in this report due to the volume of the records.

An analysis of recorded (unregulated, pre-Forks Dam) peak flows was performed by the U.S. Army Corps of Engineers (1985). The recurrence intervals of 5-, 10-, 25-, 50-, and 100-year discharge in cfs are presented on Table 4-4. As previously stated, Forks Dam currently restricts flow in the Mojave River to a maximum of 23,500 cfs.

4.2.3 Storm Flow Discharge/Infiltration Relationship

Infiltration rates between stations were developed using data supplied by Durbin and Hardt, 1974. Regression analyses of infiltration rate versus discharge rate data produced a logarithmic relationship, which was used to calculate downstream flow reductions at 50 cfs intervals. The calculated downstream flow volumes, assuming that pre-wetted channel conditions existed at the time of sustained flow, are presented in Appendix B. Due to the variable intensity, frequency, and duration of storm flows within the Mojave River channel, it was not possible to develop a significant correlation of flow infiltration rates with distance for dry channel conditions. These data have been used to assist in calculating recharge basin sizing requirements to capture average storm events.

4.2.4 Streamflow Duration

Streamflow along the Mojave River channel is intermittent except at three locations: downstream of the Forks Dam for about 1 mile due to perennial flow in Deep Creek; upstream of the Lower Narrows near Victorville due to ground-

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TABLE 4-4

PEAK FLOW RECURRENCE INTERVAL
FORKS DAM, MOJAVE RIVER

5-Year Discharge (cfs)	10-Year Discharge (cfs)*	25-Year Discharge (cfs)*	50-Year Discharge (cfs)*	100-Year Discharge (cfs)*
18,000	33,000	61,000	89,900	126,000

Source: U.S. Army Corps of Engineers (1985).

Note:

* Forks Dam regulates flow in the Mojave River Channel to a maximum of 23,500 cfs.

water flow constrictions; and near Camp Cady, above Afton Canyon, again because of groundwater flow constrictions.

Intermittent storm flow within the Mojave River is highly variable and dependant on several factors including: the duration and intensity of the storm event; previous storm durations and intensities; and the available storage capacity of the channel. A survey of 18 floods between 1930-72 that reached Barstow (Durbin and Hardt, 1974) indicates that the duration of streamflow within the Mojave River channel ranged from 9 to 112 days at the Forks, and 1 to 111 days at Barstow. The average duration for events of streamflow that reached Barstow was approximately 60 days.

4.2.5 Streamflow Quantity

Although the linear relationship between flow volumes versus the duration of flow shows a poor correlation, averaging of streamflow data has been used to estimate probable volumes of recurrent flows, and provide a means of determining recharge basin sizing requirements. It should be noted that the frequency of any flow event in any season is unpredictable, and that there are many years of no surface flow within the channel. The analysis contained herein has attempted to provide a reasonable estimate of the average volume of flows within any year in order to develop an estimate of the water that may be available for recharge purposes.

The average duration of the 18 storm flows studied by Durbin and Hardt (1974) is 60 days (measured at Barstow), with an associated average discharge from the Forks Dam of 1000 cfs. Frequency-duration curves developed from the gage data indicate that a 60 day sustained 1000 cfs flow from the Forks Dam (using the longer term combined records of Deep Creek and West Fork gages) represents 90 percent of the flow events observed within the channel in the Upper Mojave basin that produced flow at Barstow.

For the purpose of recharge basin sizing and planning (discussed in Chapter 6), the flow volume of 1,000 cfs at the Forks has been used to represent the average 60 day sustained flow for a flood flow capable of producing flow at the Barstow station. This estimate allows for the capture of 90 percent of the sustained flow events with the recharge basin sizing that

has been developed. Peak flows in the river are unpredictable, and efforts to capture peak flows do not appear to be feasible.

4.2.6 Clogging Potential

Clogging potential is dependant on several factors, including the amount of suspended solids in the source water, siltation rate, and biological activity. Suspended solids from the recharged water settle and gradually reduce further infiltration. Siltation of the basin, either from sediment carried within the recharge water or from eolian (wind carried) sources will also settle and reduce the permeability of the recharge basin. Microbiological activity, typically in the form of algae growth, may also reduce the permeability of the recharge basin.

Turbulent storm water from the San Bernardino Mountains collect suspended sediments from erosion of the surrounding formations. Some settling of the sediments may occur at the Forks Dam where downstream releases are controlled, but relatively high amounts of suspended particulates may also be transmitted downstream. Therefore, storm water may have a relatively high clogging potential throughout the Mojave River Basins. Recharge plans should be developed that include the estimated sediment loading to account for this potential source of clogging.

4.3 STATE WATER PROJECT WATER

The second source of recharge water for the basins along the Mojave River may be SWP water. In 1951, the State of California became involved in the development of State water resources with a project called the SWP. In 1963 the State of California Department of Water Resources initiated a plan to allow distribution of SWP water through the California Aqueduct. To obtain SWP water from the California Aqueduct, several local water agencies entered into contractual agreements with the State. As part of the contractual agreement, it became the responsibility of the local water agencies to wholesale the SWP water within their jurisdiction.

4.3.1 Quantity of SWP Water

The MWA's entitlement of SWP water consists of a maximum 50,800 acre-feet per year, at a maximum discharge rate of 69.5 cfs. This entitlement is intended to be divided among the separate basins within the jurisdiction of the Mojave Water Agency. For the purposes of this study, a maximum sustained discharge of 60 cfs has been assumed for recharge basin sizing requirements in the Mojave River Basins.

4.3.2 Clogging Potential

Water from the California Aqueduct which is concrete lined may have lower suspended solids than storm water due to the lack of contact with natural geologic materials. The delivered water may, however, contain variable amounts of algae grown during transportation that may tend to clog infiltration basins. Future plans for recharge of any water should include methods for reducing the recharge basin clogging potential.

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5.0 RECHARGE CONCEPT OPTIONS

Several recharge techniques have been developed in past recharge efforts. These can be divided into four general conceptual design types: open stream channel recharge, infiltration basins, injection wells, and other methods. Presented in Sections 5.1 through 5.4 is a discussion of the characteristics, advantages, and disadvantages of each design recharge facility.

Section 5.5, Ranking of Recharge Option, provides the relative ranking of each recharge concept with respect to six sets of criteria that include initial capital cost, operation and maintenance, long term construction cost, system control, system flexibility, and land requirements. In addition to information presented in Section 5.1 through 5.4 for the ranking of recharge options, capital and operation and maintenance costs information provided from other recharge projects was reviewed. These recharge projects include:

- The proposed in-channel spreading facilities of the Agua Fria River Recharge Demonstration Project (Camp Dresser and McKee, Inc. and W.R. Mills and Associates, 1986);
- Orange County Water District surface spreading facilities currently operating within the Santa Ana River channel (Mills and Postillion, 1987), and
- The Dominguez Gap Well Injection Program in Los Angeles, California that currently utilizes deep well injection techniques to control sea water intrusion (Mills and Postillion, 1987).

5.1 STREAM CHANNEL RECHARGE

Two main types of stream channel recharge are prevalent in past practices, open channel flow and T levee methods. Open channel flow recharge methods simply require the controlled release of water within a stream channel. To regulate the releases and provide additional control of flows, the most commonly used stream channel recharge method design is the T levee system. This consists of a stream channel dissected by a series of evenly distributed T shaped berms. Levee systems reduce the flow velocities of streamflow waters, thereby increasing both residence time and infiltration.

5.1.1 Advantages of Stream Channel Recharge

Advantages to stream channel recharge methods have been realized in past efforts. The primary advantage of stream channel recharge methods is cost. Because of minimal construction requirements, stream channel recharge facilities require low initial costs and work effort. Construction costs for T levee systems would require minimal earthwork while open channel facilities may only require some scraping and cleaning of the channel. The main cost for stream channel recharge facilities would be the cost of construction of conveyance facilities.

5.1.2 Disadvantages of Stream Channel Recharge

Several disadvantages to stream channel recharge methods are noted in past facilities. These include:

- Quantification of Results - The definition of physical parameters, including flow velocities, infiltration rates, and evapotranspiration losses is a disadvantage to stream channel recharge. These parameters cannot be adequately quantified once recharge water leaves the discharge valve. The lack of available information of these parameters at any recharge site may mask periods of low efficiency.

- Flexibility - In case of clogging and subsequent reduction in infiltration rates, extended period of recharge facility shut down will occur for scraping, declogging and devegetation operations. Wetting and drying cycles used to facilitate cleaning operations can only be controlled by totally discontinuing inflow to the stream channel. This lack of flexibility may hamper recharge efforts and may result in drying of the soils and a reduction of the recharge mound.

- Cleaning Costs - Continuous recharge will cause growth of plants along the wetted reach. Significant operation and maintenance costs are typically associated with the periodic removal of vegetation and potential restrictions to infiltration of recharge waters (siltation, obstructions, etc.).

5.2 INFILTRATION BASINS

Infiltration basins are typically man made basins of various sizes and shapes. Two types of basins are typically used; in-channel and off-channel.

5.2.1 In-Channel Infiltration Basins

The in-channel infiltration basin is constructed within the active portion of a river channel. These basins typically consist of a rectangular area surrounded by retaining berms. Several linked basins may be necessary to accommodate flows to be recharged. Water to be recharged is then ponded within the basins and allowed to infiltrate. These systems are predominantly used in intermittent rivers or streams.

5.2.1.1 Advantages of In-Channel Infiltration Basins

Several advantages to in channel infiltration basin designs are provided, as follows:

- Quantifiable Results - Recharge water is controlled within the basin, therefore enabling the quantification of infiltration rates, recharged volumes, and evaporation losses.
- Flexibility - Basins can be periodically scraped and cleaned when clogging affects infiltration rates. Several basins working in tandem provide the flexibility to allow cleaning of one basin while maintaining the groundwater mound through infiltration of recharge water in adjacent infiltration basins.
- Easily Cleaned and Devegetated - Basins are easily scraped and vegetation removed with bulldozers or other construction equipment.
- Construction Costs - Construction costs are typically less than $5.00 per acre foot (Bouwer, 1988).
- Rebuilding Costs - Rebuilding costs due to peak flow washouts are typically similar or less than the initial construction cost.
- Site Selection - Basins can be located in areas of high infiltration, low property costs, and best potential use. This allows construction of recharge facilities where the recharge may be directed to a specific use.

5.2.1.2 Disadvantages of In-Channel Infiltration Basins

Certain disadvantages are realized with in-channel infiltration basin designs. The disadvantages are as follows:

TABLE 5-1

RANKING OF RECHARGE FACILITY OPTIONS

Facility Type	Initial Capital Costs	Operation and Maintenance	Long-Term Construction Costs	System Control	System Flexibility	Land Requirements	TOTAL
Open Channel Recharge	1	4	1	5	5	5	21
In Channel T Levee	3	3	4	4	3	3	20
In Channel Infiltration Basins	2	1	3	3	1	2	12
Off Channel Infiltration Basins	4	2	2	2	2	4	16
Injection Wells	5	5	5	1	4	1	21

Ranking (from best to worst)

1. In Channel Infiltration Basins
2. Off Channel Infiltration Basins
3. In Channel T Levee
4. Open Channel Recharge and Injection Wells

- Site Selection - Basins can be located in areas of high infiltration, low property costs, and best potential use. This allows construction of recharge facilities where recharge water may be directed to a specific use.

5.2.2.2 Disadvantages of Off-Channel Infiltration Basins

Certain disadvantages are observed with off-channel recharge basin designs, as follows:

- Washouts - Facilities within the channel may be subject to periodic washouts due to heavy flood flows. This typically requires complete reconstruction of the facility.

- Siltation - The facilities may periodically clog due to siltation.

- Construction Costs - Off-channel facilities are typically designed as semi-permanent structures. Construction and reconstruction costs of these structures may initially be higher than for temporary facilities, but have lower long-term reconstruction requirements.

5.3 INJECTION WELLS

The third type of recharge facility design historically used includes the installation of injection wells. Three types of injection well fields have been described in past efforts, and include: single well injection systems, multiple well injection systems, and injection wall systems. Single well injection system consist of a single recharge well perforated in a highly permeable aquifer above or below the groundwater table. Multiple well injection system include several wells spaced at intervals to best recharge the subsurface aquifers. The injection wall system includes a series of closely spaced wells typically within a panel of gravel.

5.3.1 Advantages of Well Injection Recharge

The advantages of well injection recharge are listed as follows:

- Land Costs - Due to low surface area requirement of wells, the costs for the purchase of land is minimized.

- Quantifiable Results - Flow and velocity meters near the well head indicate the efficiency of the recharge effort.

- Effect - Recharged water is directly introduced to the aquifer. The downgradient effect of the recharged water can be observed in wells.

5.3.2 Disadvantages of Well Injection Recharge

Past studies indicate several disadvantages to well injection recharge methods. These are as follows:

- Installation Costs - The cost of installing wells for injection of water is typically considered to be excessive.
- Clogging Potential - Historical studies have indicated a high incidence of clogging of injection wells. Clogging will reduce infiltration rates and may necessitate periods of back flushing or well shutdown and maintenance.
- Maintenance Costs - Well pumps and other associated machinery require periodic maintenance, again increasing the total cost of the project.
- Life Span - Historical information indicates that injection wells may become totally clogged after as few as 5 years of operation.
- Treatment Requirements - Depending on water quality, recharged water may need to be treated to reduce clogging and bacterial potential. This treatment, again, increases the total cost of the project.

5.4 OTHER RECHARGE METHODS

Other methods of recharge include in-channel bar levees, inflatable dams, and permanent dams. These methods have been used in past recharge efforts, but do not appear to be feasible for the Mojave River channel for the following reasons:

- The Mojave River channel is not conducive to the construction of dams due to the lack of abutments on the sides of the channel. Dam axis lengths would also be excessive for the limited recharge realized.
- In channel dams are subject to washout from peak flows.
- Historical costs for dam facilities are typically high prohibitive.

5.5 RANKING OF RECHARGE OPTIONS

In order to subjectively qualify the usefulness of a particular recharge system the above facility types were ranked with respect to six evaluation criteria. These criteria are listed and described below:

- Initial Capital Cost - The initial cost for construction of the facility, including design, earthwork, and interbasin canals.

- Operation and Maintenance - Relative costs of regular maintenance of the facility. This includes periodic cleaning, scraping, and disking.

- Long Term Construction Costs - Relative cost of rebuilding facilities based on the temporal chance of a facility washout due to storm flows.

- System Control - The relative ability to control and quantify the physical parameters of recharge efforts for a specific facility. This includes the ability to gage or determine inflow velocities, infiltration rates, evapotranspiration losses and available returns.

- System Flexibility - The relative percent of management options inherent with a recharge system. For example: The ability to stop infiltration in one portion of the system while allowing infiltration to proceed in adjacent areas.

- Land Requirements - The relative area of land required by a system type to recharge equal volumes of water.

A summary of the ranking scores is presented in Table 5-1, Ranking of Recharge Facility Options. As shown, the lower score provided for each criteria represents the most favorable alternative.

The preliminary ranking indicates that, on the basis of the six evaluation criteria, the in- and off-channel infiltration basins, received the most favorable marks. Therefore, these two recharge designs are considered the best options for recharge facilities within the Mojave River Basins. The preliminary ranking indicates that both in-channel and off-channel infiltration basins are the most attractive alternatives when six subjective ranking criteria are considered. Therefore, these two recharge options are the apparent best alternatives and have been judged to be worthy of further evaluation. The remaining three alternatives, open channel recharge, in-channel T-levees, and injection wells, are less attractive and should only be considered in in-channel and off-channel infiltration basins are determined to be unworkable for this application.

6.0 BASIN DESIGN AND RECHARGE ANALYSIS

6.1 GENERAL

The feasibility of successfully recharging water into the Mojave River Basin aquifers is highly dependent on certain geologic, hydrologic and design criteria, including sustained infiltration rates, transmissivity, specific yields, potential source water inflow rates, and groundwater levels. Recharge facilities can be designed to minimize water loss from evaporation of standing and mounded water while maximizing the utility of any recharge basin through an overall management plan.

The overall goals of the recharge effort should focus on maximizing the amount of water successfully recharged to the groundwater system, while simultaneously relieving the overdraft conditions in those areas suffering from groundwater declines. Due to the large geographic extent of the Mojave River Basins, it is difficult to provide recharge sources at all locations currently experiencing overdraft conditions.

To assist in the distribution of a limited source of recharge water (including both storm flows and SWP water) throughout the basins adjacent to the Mojave River, it is necessary to develop a plan to conserve the limited resource available. Since the SWP water represents the only currently available continuous source of recharge water, the goals of the recharge efforts should promote infiltration of the purchased SWP water.

To reduce the costs of conveyance associated with the delivery of the SWP water to the recharge site, the SWP water should be recharged in the Upper Mojave Basin. As will be discussed in the following sections, there is data to suggest that continuous recharge efforts of SWP water in the Mojave River channel in the Upper Mojave Basin will result in a reduction of available storage in the river channel that may assist in promoting additional downstream flows in the Mojave River. The additional flow volumes may be captured in downstream infiltration basins.

Recharge of SWP water in the Upper Mojave Basin may thus provide a mechanism to satisfy both goals of water conservation and recharge for the purchased water supply, and increase surface flows in the Mojave River to downstream basins where additional supply is necessary to reverse the trend of declining groundwater levels.

6.2 SUSTAINED INFILTRATION RATES

Soil infiltration characteristics within the Mojave River Basins are highly variable and dependent on soil cover characteristics, including soil grain size, clay content, vegetative cover, and degree of disturbance by animals. Areas of good to high soil infiltration considered adequate for recharge are illustrated on Plate 3.

In general, soils within the Mojave River channel have estimated saturated permeability rates ranging from 15 feet per day [as determined in a study of the wetting produced from controlled releases at the Silverwood Reservoir by Durbin and Hardt, (1974) for the area within the river channel from the Forks Dam downstream for a distance of approximately 10.9 miles] to greater than 40 ft/day (U.S. Department of Agriculture, 1986). The saturated infiltration rates (permeability) determined by Durbin were considered to be high for long term estimates, and were not recommended for use as a long term estimate of the infiltration potential (Durbin and Hardt, 1974).

Long term infiltration rates (greater than 30 days) are typically reduced by up to 50 percent due to clogging, saturation of the vadose zone, and biological activity within a recharge basin (Bouwer, 1986). For the purposes of this study, a long term infiltration rate reduction factor of 50 percent has been assumed to estimate the infiltration rates within recharge basins. The direct observational data produced by Durbin and Hardt (1974) have been utilized due to their site-specific nature. A 50 percent reduction of the infiltration rates results in an approximate 7 ft/day infiltration (permeability) estimate for prolonged (greater than 30 day) recharge efforts. A further reduction in infiltration rates, as discussed by Bouwer (1986), may occur as groundwater levels increase beneath the recharge basins.

6.3 RECHARGE OF STATE WATER PROJECT WATER

Optimum recharge basin locations are dependant on several factors, including infiltration characteristics, land availability, hydrogeologic conditions, and proximity to a water source. Previously, several potential locations for recharge efforts within the Mojave River Basins were defined.

Recharge basins in close proximity to the California Aqueduct reduce transport and other associated costs of SWP water conveyance. Therefore, the potential locations selected for SWP recharge efforts are the Upper Basin / Mojave River site and the Upper Basin / Oro Grande Wash site. These sites have been selected due to both their favorable hydrogeologic conditions and proximity to the existing California Aqueduct turnouts. State Water Project allotments may be effectively recharged at the Upper Basin/Oro Grande Waste Site during the storm flow season that typically lasts 60 days a year. Although land requirements for recharge basin and spreading facilities and mounding estimates are only presented for two suggested sites, estimates for the Upper Basin/Mojave River site may be applied to downstream potential recharge sites if required.

6.3.1 Mounding Analysis

A mounding analysis of several recharge basin configurations was completed for both the Upper Basin / Mojave River (Mojave River site) and the Upper Basin/Oro Grande Wash potential recharge sites. The mounding analysis was performed using a numerical model that is a modification of Glover's solution for constant recharge from a rectangular basin (Sunada, 1985). Glover's solution is for a homogeneous, isotropic, unconfined aquifer with constant recharge and an initially horizontal water table, which is closely approximated by the sedimentary deposits within the Oro Grande Wash and Mojave River channel. The program is capable of graphically displaying the rise and decline of a recharge mound for either an infinite homogeneous medium or for a stream aquifer system. The model does not have the capability of changing infiltration rates with increasing water level elevations.

Initial calculations of the total infiltration area required to recharge SWP allottments were based on inflow and infiltration rates using the following equation:

Total Infiltration Area = Inflow (cfs)/Infiltration (ft/s)

These initial estimates were subsequently input to Sunada's model to develop mounding estimates with respect to basin size requirements. The total infiltration area for both sites is the same because of similiar infiltration rates and water supplies. The following discussion provides a summary of the modeled results.

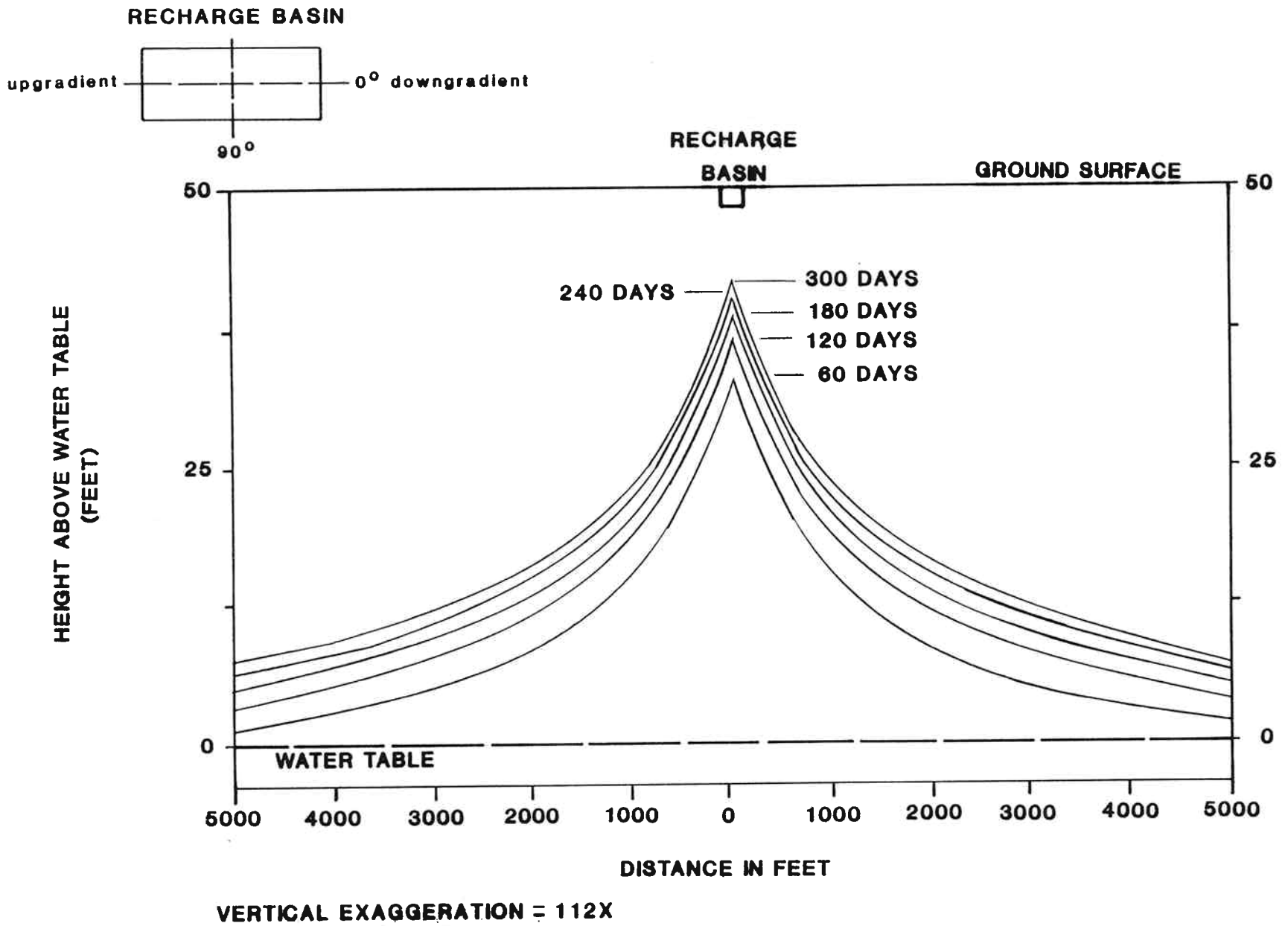
6.3.1.1 Mojave River Site

The Mojave River site is located within the flood plain of the Mojave River, as previously presented. It is anticipated that recharge operations will not be advantageous during the winter months of some years due to unpredictable storm flows within the channel. The following parameters, as previously defined, were used for basin design considerations:

Infiltration Rate	=	7 feet per day
Inflow Rate	=	60 cubic feet per second
Transmissivity	=	20,000 square feet per day (approximately 150,000 gallons per day per foot, as defined by Hardt, 1971)
Specific Yield	=	.15
Average depth to water	=	50 feet

Mounding analysis data for a recharge period of 365 days suggests that the optimal basin size is approximately 250 feet wide by 750 feet in length (approximately 4.3 acres). Continuous recharge at a larger basin would result in eventual mounding of the recharged water at the surface. In order to maintain the groundwater level at a depth of 10 feet below ground surface (to reduce evapotranspiration and discourage plant growth), four separate 4.3 acre basins are required to accommodate a 60 cfs flow. The modeled groundwater mound (profile for one basin) is shown on Figures 6-1, Predicted Groundwater Mound Along Width of Recharge Basin (90°); Mojave River Site (State Water Project), and Figure 6-2, Predicted Groundwater Mound Along Length (0°) of Recharge Basin Mojave River Site (State Water Project). Estimated mounding data for both basin axis are presented in Appendix C.

Minimum spacing requirements between recharge basins are determined by groundwater mound heights between the recharge basins. Groundwater mounding



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PREDICTED GROUNDWATER MOUND ALONG WIDTH (90°) OF RECHARGE BASIN
MOJAVE RIVER SITE (STATE WATER PROJECT)

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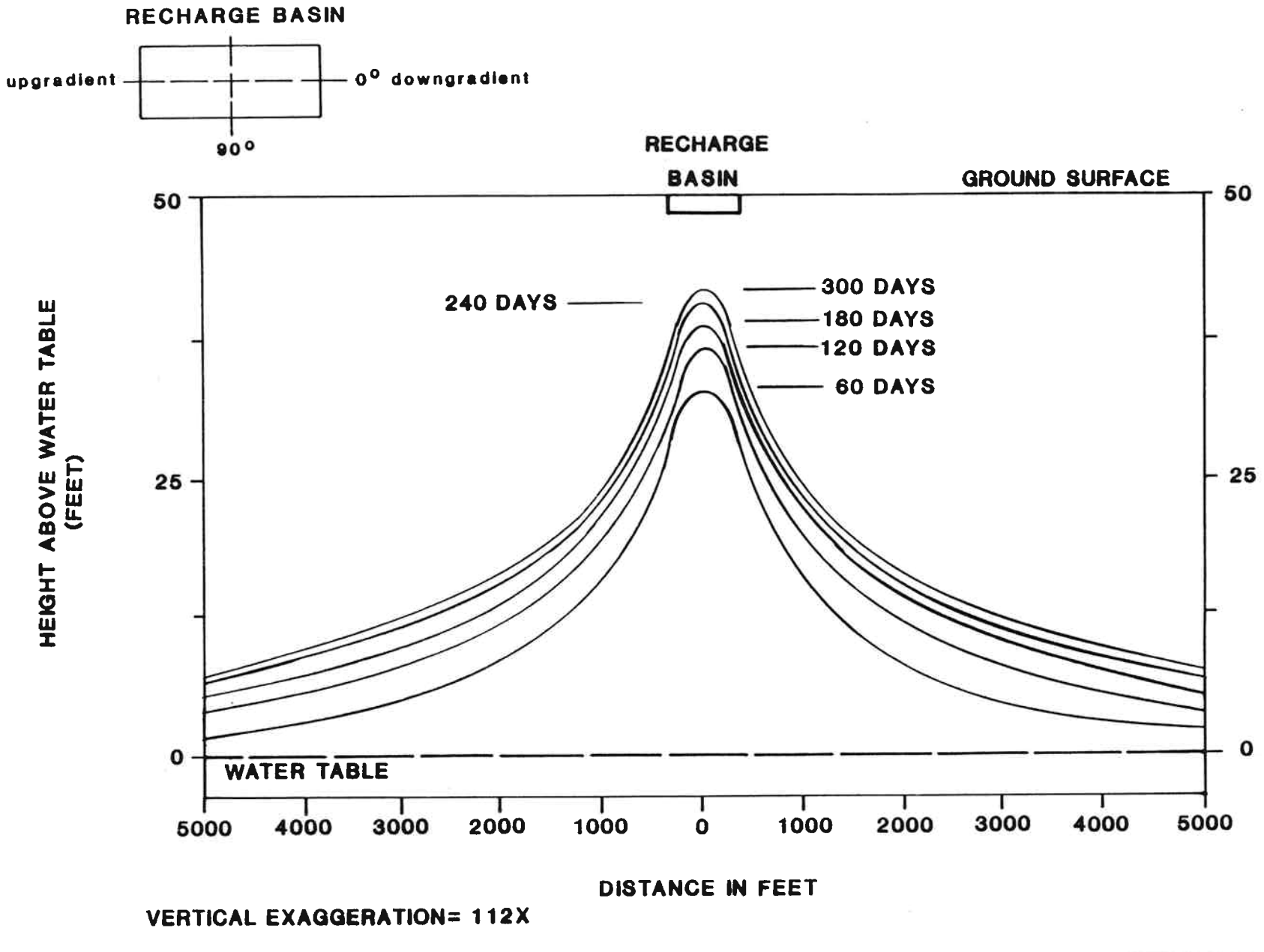
FIGURE 6-1



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PREDICTED GROUNDWATER MOUND ALONG LENGTH (0°) OF RECHARGE BASIN
MOJAVE RIVER SITE (STATE WATER PROJECT)

MALCOLM PIRNIE, INC.

FIGURE 6-2

between two adjacent recharge basins is cumulative. In order to reduce the effects of evaporation and transpiration, the composite mound of two adjacent basins should not exceed an elevation of 10 feet below the ground surface. Distribution of groundwater mounds created by the recharge efforts indicates that the distance between the recharge basins should be a minimum of 2000 feet. At this distance, a relatively constant depth to water of approximately 10 feet may be maintained within the river channel, based on the previous assumptions. Again, because of the higher transmissivity in Waterman valley, mounds can be expected to spread more rapidly and result in lesser mound heights.

The modeled results indicate that recharge of a 60 cfs flow for 365 days (in those years with little or no storm flow) could continue uninterrupted for approximately 4 years before the recharge mound reached the surface; however, the variability in site specific hydrogeologic conditions and unpredictable changes resulting from local groundwater uses in the vicinity of the potential recharge basins place a low level of confidence in the long range predictions obtained from the model. It is recommend that long-term recharge practices and actual facility sizing requirements be developed following the implementation of a pilot program designed to measure actual field conditions and aquifer response.

6.3.1.2 Upper Basin / Oro Grande Wash Site

The Upper Basin / Oro Grande Wash site was previously presented as an alternative for recharge efforts, and is located southwest of Victorville along the Oro Grande wash. During seasons of storm flow along the Mojave River, SWP water may be effectively recharged in areas along the Oro Grande Wash near the turnout of the California Aqueduct. Although potentially suitable for recharge efforts, this site may be difficult to develop due to surrounding land use patterns and the distance of the site from the aqueduct turnout.

Optimum recharge basin size was determined using the SWP entitlement of 60 cfs for a period of 60 days. The following parameters, as previously defined, were used for recharge basin design:

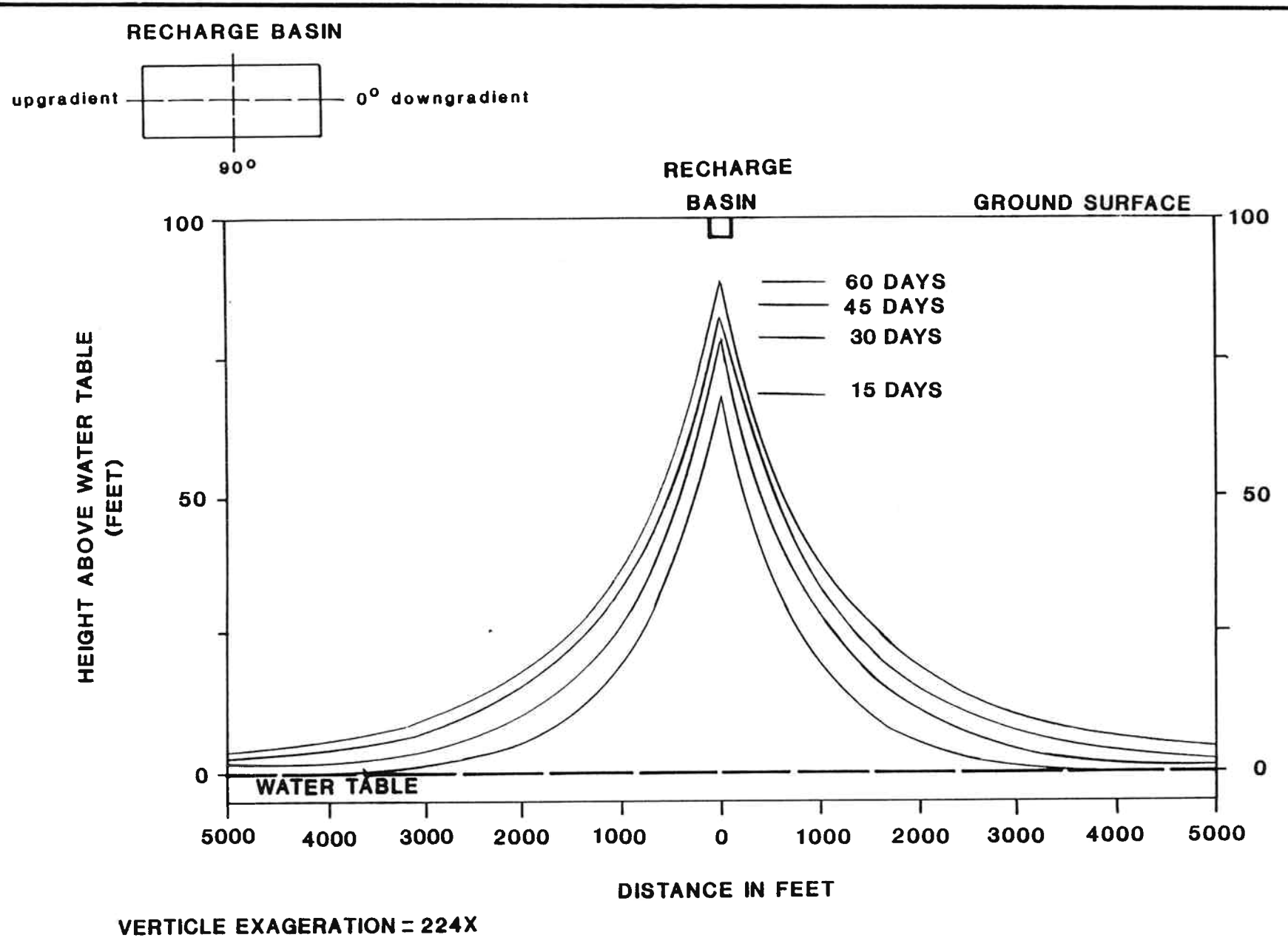
Infiltration Rate	=	7 feet per day
Inflow Rate	=	60 cubic feet per second
Transmissivity	=	7,000 square feet per day (approximately 50,000 gallons per day per foot, as defined by Hardt, 1971)
Specific Yield	=	.08
Average depth to water	=	100 feet

In order to limit the groundwater mound to 10 feet below ground surface, four separate basins are required to accommodate the 60 cfs flow. The rectangular basins utilized for the model are 250 feet wide by 750 feet long (4.3 acres). Additional surface area is required for retention berms and surface diversions, so that it should be anticipated that at least four 5 acre parcels may also be required for recharge efforts at this site.

Modeled estimates for groundwater mounding over a period of 60 days indicate that constant recharge will form a mound 88 feet above the water table. The modeled groundwater mound shape is shown on Figures 6-3, Predicted Groundwater Mound Along Width (90°) of Recharge Basin: Upper Basin/Oro Grande Wash Site (State Water Project), and 6-4, Predicted Groundwater Mound Along Length (0°) of Recharge Basin Upper Basin / Oro Grande Wash Site (State Water Project). Estimated mounding data for both basin axis are presented in Appendix D. Required minimum spacing between basins is determined by studying groundwater mound heights between basins. Modeled groundwater mounding results indicate a recommended distance between recharge basins of 750 feet.

6.3.2 Land Requirements

The land needed to construct infiltration basins and associated surface support facilities at each potential recharge site is dependent on the final configuration design and operational requirements. Modeling estimates presented above indicate that four - 5 acre basins spaced approximately 750 feet (Oro Grande Wash site) to 2,000 feet (Mojave River site) are the optimum conceptual configuration for recharge of SWP water. Operational requirements



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PREDICTED GROUNDWATER MOUND ALONG WIDTH (90°) OF RECHARGE BASIN
UPPER BASIN / ORO GRANDE WASH SITE (STATE WATER PROJECT)

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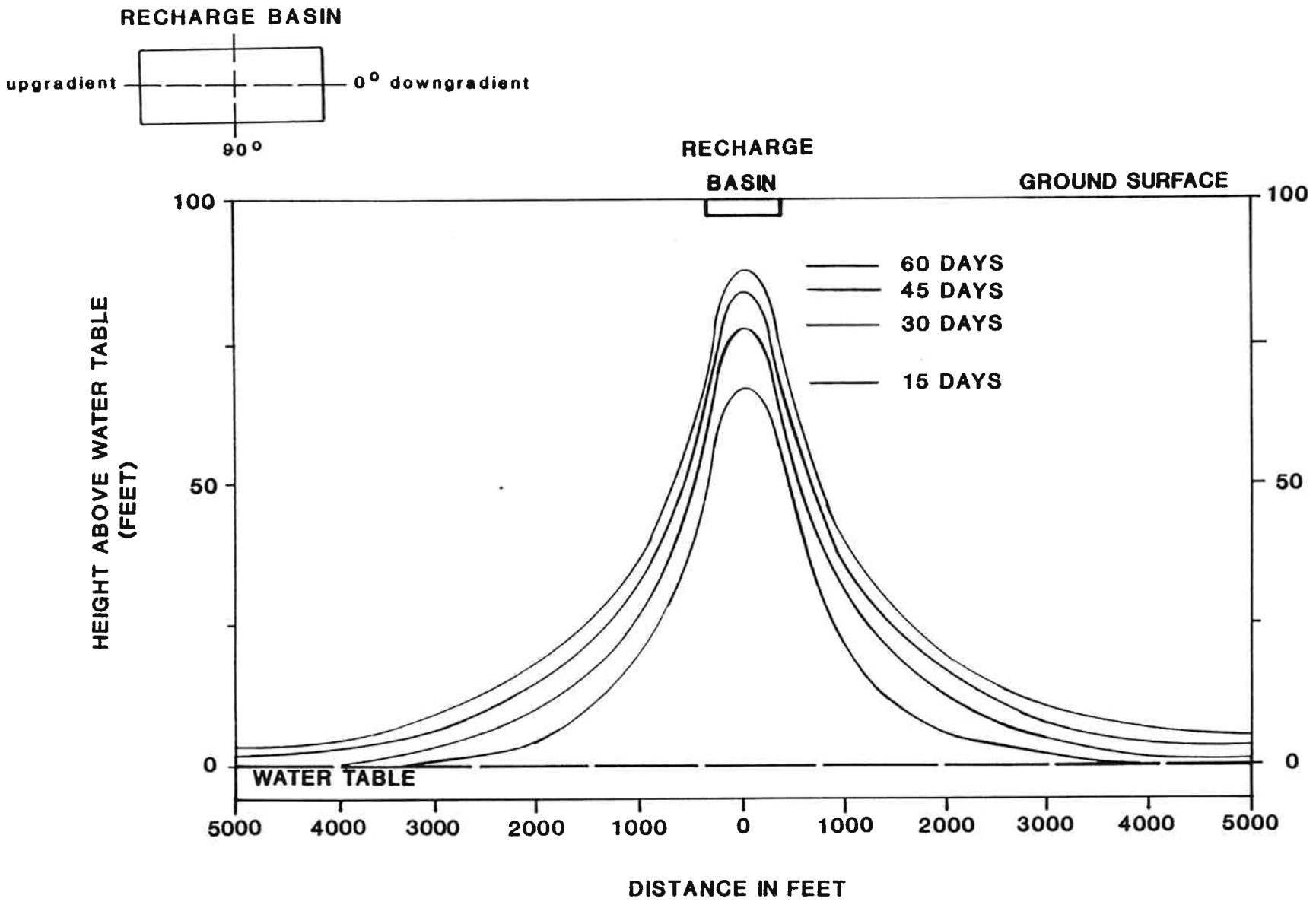
FIGURE 6-3



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PREDICTED GROUNDWATER MOUND ALONG LENGTH (0°) OF RECHARGE BASIN
UPPER BASIN / ORO GRANDE WASH SITE (STATE WATER PROJECT)

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FIGURE 6-4

necessitate that individual infiltration basins within the Upper Basin / Mojave River potential recharge site be periodically taken out of operation and cleaned to maintain optimal infiltration rates. To accomodate both the conceptual configuration and operational requirements, the final design configuration at the Upper Basin / Mojave River potential recharge site may include eight - 5 acre infiltration basins operating on a four on line, four off line rotation schedule.

Land requirements for the Upper Basin / Oro Grande Wash site are approximately 20 acres. Land requirements for the Upper Basin / Mojave River site are estimated to be approximately 40 acres. Additional land may be needed at both potential recharge sites for spacing requirements and conveyance right-of-way. If the land between infiltration basins is required to be purchased, land requirements in the Mojave River site will increase.

6.3.3 Recharge Water Quality

The proposed use of SWP water for recharge purposes is not anticipated to adversely affect the groundwater quality within the basins. The quality of SWP water is good, with a TDS concentration of approximately 250 mg/l and a nitrate concentration of approximately 1 mg/l. Treatment of the water for use in the recharge efforts is not necessary.

6.4 RECHARGE OF STORM FLOWS

The optimum recharge basin location for recharge of storm flow is within or adjacent to the Mojave River channel. Although land requirements for recharge basin and spreading facilities and mounding estimates are only presented for one suggested site, these estimates can be used for other potential sites downstream due to the similarity of geologic conditions.

6.4.1 Mounding Analysis

A mounding analysis of several recharge basin configurations was completed for the Mojave River potential recharge sites. Sunada's model using a modification of Glover's solution for constant recharge from a rectangular basin was utilized to develop basin sizes and groundwater mound estimates for storm water recharge facilities along the Mojave River.

Initial calculations of the total infiltration area required to recharge storm flows were based on inflow and infiltration rates using the following equation:

Total Infiltration Area = Inflow (cfs)/Infiltration (ft/s)

The inflow estimate used was based on the flow of 1,000 cfs from the Forks Dam and the estimated infiltration rate of 7 ft/day discussed in Section 6.2, Sustained Infiltration Rates. The optimum size of a recharge basin is dependant on the infiltration rate, inflow rate, and mounding potential. In order to decrease water losses from evaporation and transpiration, the height of the groundwater mound created by the recharge basins has been limited to a depth of 10 feet below the ground surface. Based on the flow of 1000 cfs from the Forks Dam, the stormflow infiltration correlation from all stations within the Mojave River channel (presented in Appendix B) has been utilized to design the optimum basin sizing to capture all downstream flow for the average 60 day flow duration. Again, because of the unpredictability of the peak flows within a given event, the capture of peak flows has not been incorporated into the basin sizing requirements.

A rectangular basin configuration has been assumed for the analyses. The following parameters were used for the basin design:

Infiltration rate = 7 feet per day

Transmissivity = 20,000 square feet per day (approximately 150,000 gallons per day per foot, as defined by Hardt,1971)

Specific Yield = .15

Average depth to water = 50 feet

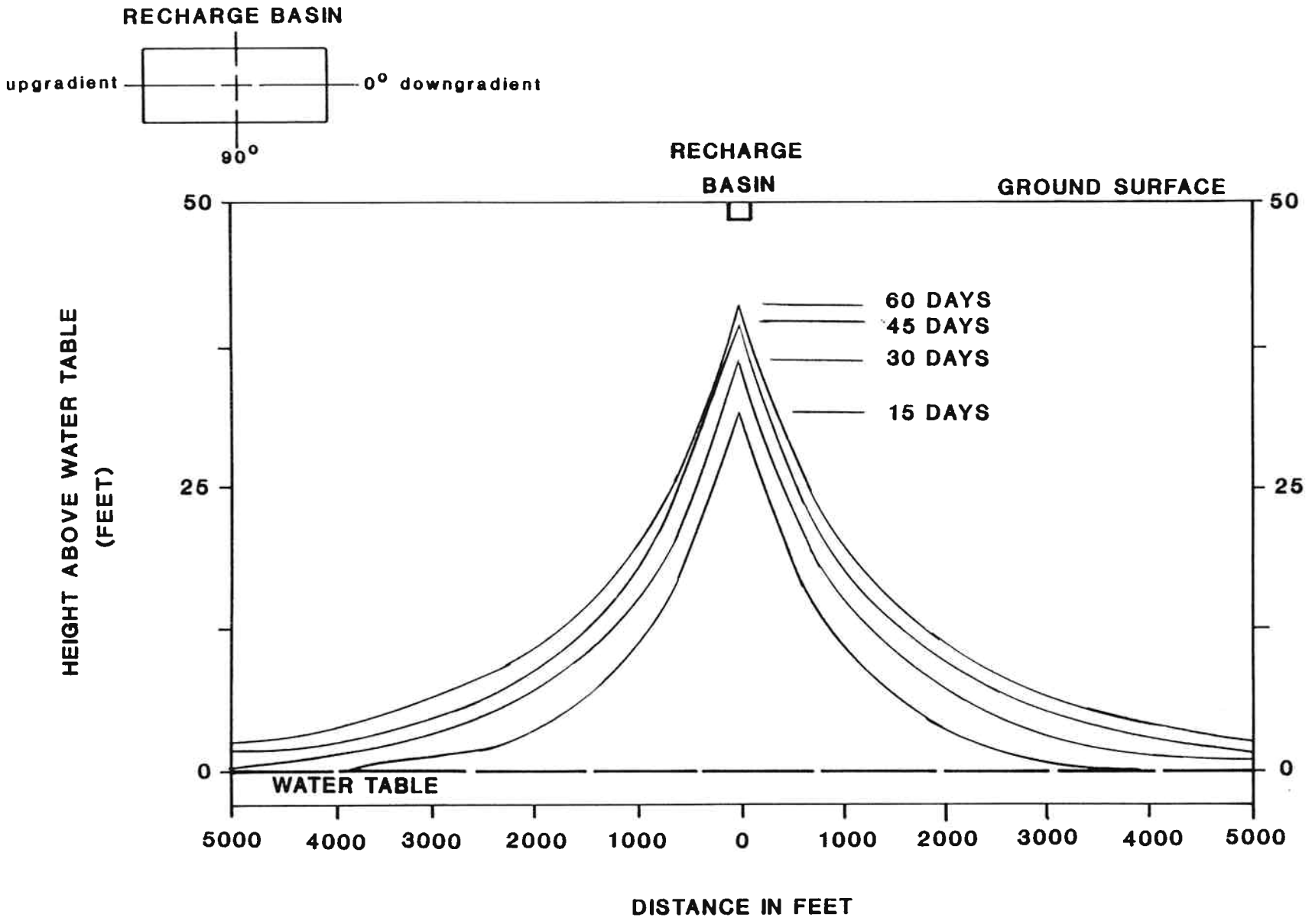
The optimum basin size and basin configuration was developed based on the analysis described above and the relationship of storm flow discharge to infiltration rates presented in Section 4.2.3, Streamflow Discharge/Infiltration Relationship. The optimum basin size to create a mound height that is approximately 10 feet below ground surface after 60 days of infiltration is approximately 5.7 acres (250 feet by 1000 feet). An individul basin of this size is capable of recharging approximately 20 cfs on a continuous basis

for 60 days using the previously mentioned aquifer parameters. In order to recharge all storm flow along the Mojave River approximately six separate 5.7 acre basins and one 2.8 acre basin per potential recharge site are required.

The basin sizing requirements presented above represent the actual area required for infiltration. Additional area will be required for construction of diversion works facilities and impoundment berms. To reduce the potential for mound interference with adjacent recharge facilities and to maintain an average water depth of 10 feet below ground surface, recharge basin spacings of approximately 2000 feet may be required to account for both channel flow and recharge basin mounding. Additional storage capacity for peak flow capture can also be obtained by the construction of recharge basins with greater berm heights.

Modeled estimates for groundwater mounding from a 20 cfs flow for a 60 day period within a 5.7 acre recharge basin are presented in Appendix E. Potential recharge sites throughout the Mojave River Basins generally show similar hydrogeologic conditions with depths to water averaging 50 feet, estimated prolonged infiltration rates of 7 ft/day, and transmissivities of 20,000 sq.ft/day. Assuming an average flow duration of 60 days, groundwater mounds below the potential recharge sites in the Mojave River channel can be assumed to be roughly equivalent for each recharge site. Transmissivities in the Waterman valley area are slightly higher (approximately 27,000 sq.ft/day), so that the mound created by the recharge basin can be expected to spread more rapidly and result in a lower mound height.

As previously mentioned, the distribution of the recharge mound resulting from the infiltration of 20 cfs of water over a period of 60 continuous days is presented in Appendix E. This Appendix provides a summary of the recharge mound configurations along both axis of the recharge basin. The respective axis of the recharge facilities are illustrated on Figures 6-5, Predicted Groundwater Mound Along Width (90°) of Recharge Basin: Mojave River Site (Storm Flow), and Figure 6-6, Predicted Groundwater Mound Along Length (0°) of Recharge Basin; Mojave River Site (Storm Flow). At the end of the infiltration period, the mound height has reached a depth of approximately 9 feet below ground surface directly beneath the recharge basin. Table 6-1, Increase



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PREDICTED GROUNDWATER MOUND ALONG WIDTH OF (90°) RECHARGE BASIN
MOJAVE RIVER SITE (STORM FLOW)

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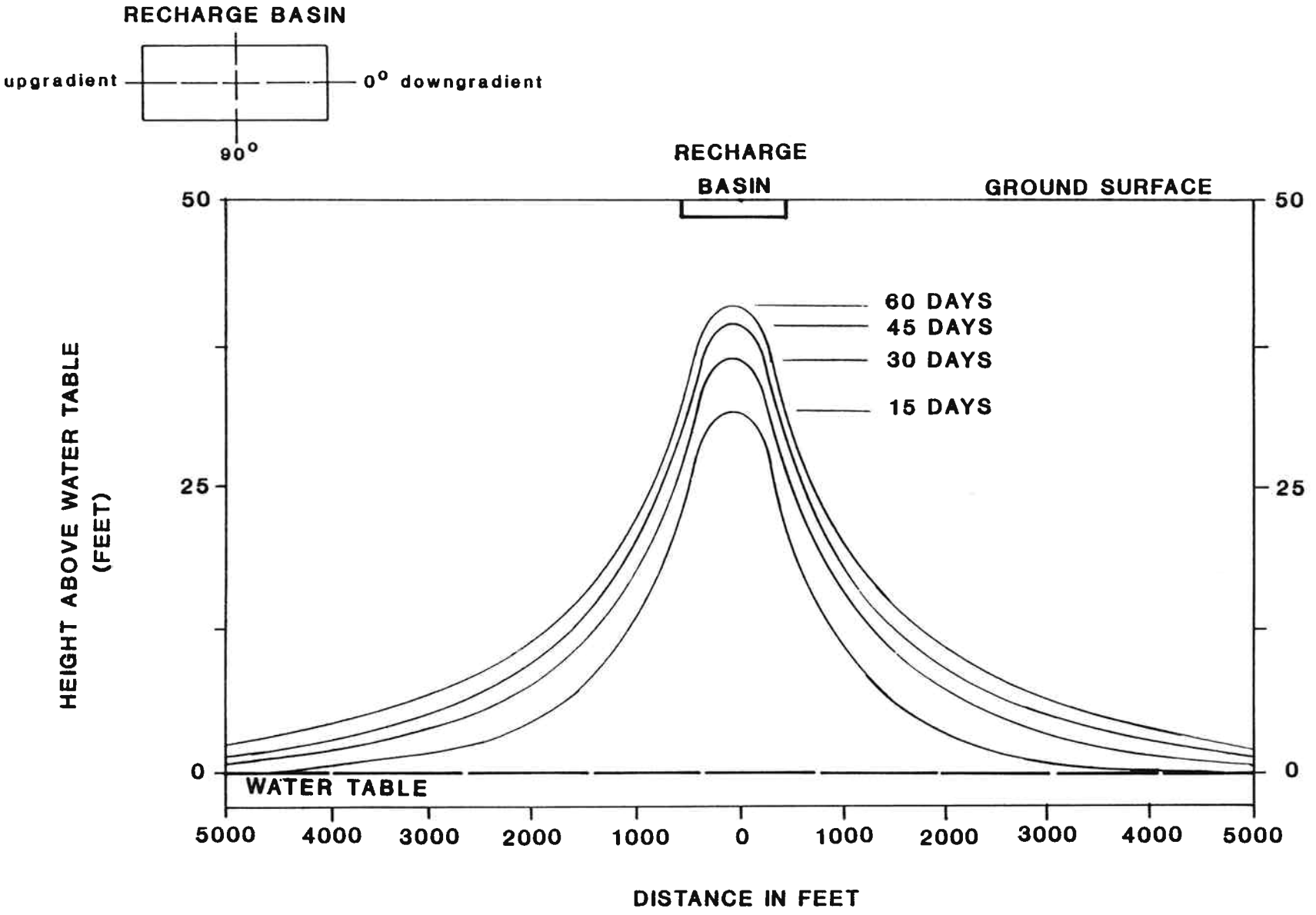
FIGURE 6-5



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PREDICTED GROUNDWATER MOUND ALONG LENGTH (0°) OF RECHARGE BASIN
MOJAVE RIVER SITE (STORM FLOW)

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FIGURE 6-6

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TABLE 6-1

PREDICTED INCREASE IN WATER LEVELS AFTER 60 DAYS OF RECHARGE

Downstream

Distance from center of basin (ft)	Increase in water level (ft)
0	41
100	40.8
1000	20.9
5000	2.4
10000	0.1

Adjacent to Channel

Distance from center of basin (ft)	Increase in water level (ft)
0	41
100	40.8
1000	19.8
5000	2.2
10000	0.1

in Water Levels After 60 Days of Recharge, presents a summary of the modeled estimates of the height of the groundwater mound at various distances both downstream and adjacent to the center of the recharge basin.

6.4.2 Land Requirements

The land needed to construct infiltration basins and associated surface support facilities at each potential recharge site is dependent on the final configurations, design and operational requirements. Modeling estimates presented above indicate that six 5.7 acre parcels and one 2.8 acre parcel are required for the infiltration of the average storm flow. Estimated additional area for support facilities increases the total land requirements for storm flow infiltration basins to approximately 43 acres per potential recharge site. Additional land may be needed for spacing requirements and conveyance right-of-way. If the land between infiltration basins is required to be purchased land requirements will increase.

6.4.3 Effects on Channel Flow

Recharge from the natural storm flows within the Mojave River channel at potential recharge sites will form an elongate mound rising to the ground surface within approximately 8 days of continuous flow. The modeled mound is steep sided, with increased water level depths of 50 feet immediately below the channel, and increased water level depths of less than one foot at a distance of approximately 3000 feet following the 60 day recharge period. Peak flows greater than the absorptive capacity of the channel and recharge basins will continue to result in surface water flows.

The construction of recharge facilities within or near the existing stream channel will result in increased infiltration in the aquifer materials within and closely adjacent to the channel. The increased infiltration produced by the recharge near the channel will result in less available storage space within the aquifer materials for storm flow, and may result in an increase in downstream flows of substantial duration. Therefore, to enhance downstream flow in the Mojave River channel from the Upper Mojave Basin to the Middle and Lower Mojave basins, recharge facilities should be constructed close to the active river channel in the Upper Mojave Basin to

reduce stream flow infiltration and enhance downstream flow. Recharge facilities constructed within the Middle and Lower Mojave basins should be offset from the active channel to promote overall recharge by providing sufficient storage for both storm flows and recharged storm flow water.

The downstream infiltration rate calculations presented in Appendix B indicate that the installation of approximately 37 acres of recharge facilities in each of the four identified potential recharge sites along the Mojave River Channel (a total of 148 acres) would result in the capture of all flow during a sustained 60 day flow of 1000 cfs. As shown on Table 6-2, Approximate Reduction in Downstream Flood Flows (Mojave River), a 1000 cfs flow originating at the Forks Dam would be reduced by 130 cfs through recharge efforts in the Upper Mojave Basin. The net change in downstream flow, as measured at the Hodge gaging station (upstream of the Hinkley Valley potential recharge site), would be reduced by both the 130 cfs recharge diversion, as well as an additional approximate 299 cfs reduction resulting from natural infiltration into the existing (pre-wetted) channel bed. Similar reductions from both the recharge operations and natural infiltration have been calculated for each of the remaining downstream basins and are presented in Appendix B.

6.4.4 Available Storage

The available storage of the stream channel aquifer will be influenced by both infiltration basin recharge activities and periodic storm flows. If SWP water is recharged into the Upper Mojave Basin channel aquifer through in-channel facilities, the available storage of the stream channel aquifer will be reduced, which may result in a reduction in infiltration of storm flows. These storm flows will continue downstream to Middle and Lower Mojave basins, and may be captured by off-channel infiltration facilities. The design recharge rate of 130 cfs for 60 days at each of the potential recharge sites will mound and recharge the Mojave River channel aquifer at a rate of approximately 15,470 acre feet per site. An additional amount of recharge will occur from the natural infiltration of storm flow into the existing (pre-wetted) channel bed, at the approximate volumes presented in the infiltration table in Appendix B. Following the cessation of stormflow

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TABLE 6-2

APPROXIMATE REDUCTION IN DOWNSTREAM FLOWS (MOJAVE RIVER)

LOCATION	GAGED FLOW	- RECHARGE	= REDUCED FLOW	- INFILTRATION	= NET FLOW AT NEXT GAGE
Forks Dam	1000 cfs	130 cfs	870 cfs	280 cfs	590 cfs
Hinkley Valley	590 cfs	130 cfs	460 cfs	113 cfs	347 cfs
Waterman Valley	347 cfs	130 cfs	217 cfs	38 cfs	179 cfs
Newberry Valley	179 cfs	130 cfs	49 cfs	49 cfs	0 cfs

recharge from a particular infiltration basin, groundwater levels directly beneath the recharge facility will decline over time. The decline in groundwater levels would result from the lateral movement of mounded water into the surrounding alluvial basin aquifer and, which would result in additional available storage of the stream channel aquifer for future storm flow events.

6.4.5 Groundwater Quality

The proposed use of storm flow within the Mojave River channel will not change the overall groundwater quality currently observed within the aquifer materials affected by the recharge, since the only current source of supply to the aquifer is derived from the storm flows. However, the 1986 Safe Drinking Water Act amendments may require disinfection of the recharged water prior to distribution through any potable distribution system. Regulations are currently under review, and when finalized, will provide a definition of "surface water" within the surface water treatment rule. Should the new regulation include recharged surface flow as a surface water source, the possibility exists that any recharged surface flows may require treatment prior to distribution. The most recent published information states the EPA will promulgate these regulations in early 1989, to become effective in 1993.

7.0 CAPITAL AND OPERATING COSTS

7.1 CAPITAL COSTS

Capital costs were estimated for both in-channel and off-channel infiltration basins, which are the two highest ranked facility designs from Section 5.5, Ranking. The cost estimates are presented for four facility requirements, including: pilot studies, conveyance facility construction, earthwork construction estimates, and land acquisition. Costs were developed based on the general recharge facility requirements developed in Sections 6.3.1, Mounding Analysis, and 6.4.1, Recharge Basin Requirements. These infiltration facilities were designed for inflow volumes of SWP water or of storm flows.

Estimated costs of stream channel recharge projects have been developed based on other similar projects. As part of a feasibility study for in channel spreading facilities along the Agua Fria River, Arizona, based on purchase of 200,000 acre feet/year, capital costs for excavation, conveyance canal, turnout structures and monitoring wells were estimated to be $4.85/acre foot. Spreading facilities using T levee methods that are currently operated by the Orange County Water District, California have historically cost an average of $7.80/acre foot of water recharged. The above capital costs were calculated for the first year of recharge. Years of continued recharge will cause the capital cost per acre foot of water recharged to be reduced. These costs do not include the purchase price of water or any associated land costs. Based on these projects the capital costs can be anticipated to range from $5.00/acre foot to $10.00/acre foot of water recharged. Other recharge projects such as the Dominguez Gap Well Injection Program record capital costs of up to $32/acre foot with overall long-term total costs at approximately $100/acre foot (Mills and Postillion, 1987).

In order to reduce initial costs and determine possible downstream effects of Upper Mojave Basin recharge efforts, it is recommended that MWA implement a phased management strategy by initiating SWP water recharge efforts in the Upper Basin/Mojave River potential recharge site. Pilot study and recharge efforts will then further define construction parameters to be implemented in downstream potential recharge sites, and assist in defining the effects recharge efforts may have on storm flow infiltration. Capital costs

presented below have therefore been developed for recharge of SWP water at the Upper Basin/Mojave River potential recharge site. A summary of anticipated costs associated with the implementation of the recharge effort is provided on Table 7-1, Summary of Capital Costs, and detailed in the following discussion.

7.1.1 Pilot Study

The cost estimates for facility development should include the anticipated costs of conducting pilot studies to provide quantitative estimates of the aquifer parameters near the potential recharge site. A full 6 month pilot study should be performed prior to the implementation of the design and construction of long-term recharge facilities to assure that the anticipated design parameters are feasible. A pilot study of each potential recharge site should include the following work tasks:

- Hydrogeologic Study - A hydrogeologic study of each potential recharge site is required by California State agencies. This includes site selection, field investigations, soil sampling and aquifer testing. A summary report is required to be submitted to appropriate governmental agencies for the permitting process to be finalized.

- Design and Implementation - Based on information gathered during the hydrogeologic study, recharge facilities are designed and constructed to specifications. This includes design and construction of infiltration basin, monitoring wells, extraction wells and diversion or conveyance facilities.

- Field Tests - This six month process will determine the effectiveness of the preliminary infiltration basin design. This phase includes groundwater, surface water, water quality and vadose zone monitoring.

- Data Reduction - Data gathered from the above work tasks would be evaluated to determine the effectiveness of the recharge facility. Changes then can be made to finalize the complete recharge design.

Each potential recharge site will require a site specific pilot study in order to finalize a complete recharge design. It is recommended that the Upper Basin / Mojave River potential recharge site be studied first due to the urgency of recharging SWP water. Downstream facilities can then be completed based on the downstream effect of recharge in the Upper Mojave Basin.

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TABLE 7-1

SUMMARY OF CAPITAL COSTS

	SWP Water Upper Basin / Mojave River
Pilot Study	$ 350,000
Conveyance Facilities	4,150,000
Recharge Facility	163,000
Land Acquisition @	400,000
Habitat Relocation#	--
Total	$5,063,000

@ Based on an average cost of $10,000/acre

Habitat relocation may only be needed for the Middle Basin / Hinkley Valley Potential Recharge Site.

Costs for a pilot study for a potential recharge site within the Mojave River Basins is estimated to be approximately $350,000.00 and is dependant on the size of the recharge basins, number of monitoring wells required and complexity of the project. Pilot study facilities can reduce the final overall project cost through proper design practices and by the integration of pilot study findings into the final recharge facility design.

7.1.2 Conveyance Facilities

SWP water from the California Aqueduct may be conveyed to the Upper Basin / Mojave River potential recharge site from the Hesperia Turnout to the Mojave River via a permanent pipeline. Approximately 24,000 feet of 48" pipe would be required to convey water to the recharge facility. The estimated cost of the conveyance pipeline is approximately $4,150,000. It may be possible to combine the proposed Morongo pipeline with required conveyance facilities for the recharge efforts to reduce overall costs.

Canals used for conveyance of water within the recharge facilities are anticipated to be unlined. Canal costs have been included in the general earthwork estimates.

7.1.3 Earthwork Construction Estimates

All suggested infiltration basins are designed to retain water within basins constructed from the native materials encountered within the channel. It is estimated that approximately 200 hours are required to construct one 250 feet by 750 feet basin using one small to medium sized scraper and one medium to large size bulldozer. The associated cost of construction of facilities at the Upper Basin/Mojave River potential recharge site using these estimates is approximately $163,000. An estimated $25,000.00 of additional grading may be required for conveyance canals and diversion canals to control flow through the recharge facilities. Long-term costs of construction maintenance, improvements, and operations of the recharge facility may range from $3.00 to $7.00 per acre foot of water recharged.

7.1.4 Land Acquisition

Land acquisition costs will be highly dependant on the proximity to established communities, access and distance from the Mojave River, and general prices at the time of land purchase or lease. Land costs within the flood plain of the Mojave River may be considerably less expensive than land located above the flood plain. Real estate brokers in the Victorville area have indicated that land costs can vary from less than $5,000 per acre to greater than $25,000 per acre. It is anticipated most of the land required would be in or adjacent to the river and therefore could be acquired within the lower range of land costs.

7.2 HABITAT RELOCATION

The Middle Basin / Hinkley Valley potential recharge site is located within the State Protected Species area of the Desert Tortoise. Prior to development of any facilities in this area, relocation of the species may be required. The cost associated with the relocation of the species is variable and dependant on the findings of an Environmental Impact Study, species density and ease of relocation. It is estimated that the total costs for Habitat relocation may range from $5,000 to $10,000. Upon initiation of a pilot study, governmental agencies can be contacted for an on-site estimation of charges for relocation of the Desert Tortoise.

7.3 OPERATION AND MAINTENANCE COSTS

Operation and maintenance costs for recharge facilities are dependant on the size and location of the facilities. Historic costs for recharge facilities in similar settings have typically ranged from $4.00 to $10.00/acre foot for T levee, open channel spreading facilities, and in-channel and off-channel recharge basins. These costs are associated with the maintenance and operational requirements of the facilities such as periodic grading, scraping, devegetation and rebuilding of berms. These costs do not include land acquisition costs or costs associated with the purchase of water. Due to the relatively high cost of conveyance facilities, pipelines and diversion works should be built to withstand periodic floods.

7.4 PUBLIC FUNDING SOURCES

During 1986, California Proposition 44 allocated public funds for artificial recharge and conservation efforts. These funds were appropriated as grants and low interest loans with maximum amounts not to exceed $5,000,000.00 for construction costs and $100,000 for feasibility studies for any one project. Funding allocated for Proposition 44 was depleted in April of 1987. The California Department of Water Resources (DWR) personnel have indicated that reauthorization will be included on the November, 1988 ballot. If approved, additional funding may be available through this source to offset feasibility and construction costs for the recharge project.

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8.0 IMPLEMENTATION REQUIREMENTS

The implementation requirements of any recharge facility begin with the design and testing of a pilot facility, followed by the development of design criteria and construction of recharge facilities, and result in the need for long-term operation and management of the recharge effort. The previous Chapter discussed potential costs associated with the design, construction, and operation of recharge efforts. This Chapter provides a review of the requirements associated with the implementation of the recharge efforts.

Consideration must be given to both the requirements for state, county, and local permits, as well as the need for environmental impact studies and site specific hydrogeologic studies. The site specific hydrogeologic investigations are typically undertaken in a pilot study. If recharge efforts appear to be feasible, land must be acquired, the recharge facility must be designed and permitted, and construction must be undertaken. Although there are very few official requirements to begin recharging non-effluent waters, several agencies may require reports to be reviewed by their personnel.

8.1 PILOT STUDY

A pilot study is required to verify the feasibility of the recharge effort. Design constraints and potential benefactors are determined based on the results of the pilot study. The development of a pilot study involves several steps, which are summarized below.

1. Determine hydrogeologic setting of site. This typically involves a) field investigation and the application of site screening criteria to determine the optimum location for recharge facilities, b) identifying available recharge and water sources which may include adjacent production wells, water supply systems, or any other continuous water supply, and c) subsurface excavation and testing of the geologic materials to develop an understanding of the stratigraphy beneath the site, and provide information on the physical characteristics of the native materials. In-situ and laboratory testing of the geologic materials provides information on the aquifer characteristics of the site to assist in the design of the pilot facility.

2. Design and construct the pilot facility. Requirements for this phase of the project include the design construction of water delivery and recharge basin facilities, construction monitoring

facilities (such as monitoring wells, flow measurement stations, etc..), and testing of the facility. Pilot recharge efforts should continue for a period of two to six months to determine the long-term effects of recharge on the aquifer system.

3. Compilation of the results from the pilot study in a formal report to provide the necessary information for the implementation of full-scale, long-term recharge efforts.

8.2 ENVIRONMENTAL IMPACT STUDIES

Recharge operations can affect the surrounding and downgradient environment. An environmental impact study may be required for each recharge facility. Included in this study may be an analysis of the affects of downstream flood flows that should be submitted to the San Bernadino County Flood Control office.

A study documenting the effects of recharge efforts on certain habitats may be required. The main issue to be considered is the potential impact of recharge efforts on the Mojave Tui Chub. Previous reports completed by the Army Corps of Engineers indicate that the Tui Chub has indirectly been supported by Mojave River peak flood flows (U.S. Army Corps of Engineers, Los Angeles District, 1985c). As indicated in Section 6.4 of this report, the recharge basins have not been designed to capture peak flow volumes. Also of concern may be the potential relocation of certain species, such as the Desert Tortoise.

8.3 PERMITTING

Permits must be obtained to construct the recharge facilities; however, discussions with the DWR and Regional Water Quality Control Board (RWQCB) have indicated that there are very few official requirements for the implementation of a recharge operation.

8.3.1 Federal Requirements

To date there are no Federal requirements that has been identified for recharge projects. State regulatory agencies currently control the permitting processes necessary for implementation of recharge projects.

8.3.2 California State Requirements

The RWQCB has never received a permit application for a project similar to the Mojave River Recharge Project. The RWQCB indicated that requirements for the pilot study could be waived due to the short term of operation, but a full-scale project would require permitting. The permit application and approval would require a groundwater quality impact investigation regarding the water quality effects from recharge operations. The necessary information to comply with this requirement can be developed within the pilot study project.

The Department of Water Resources (DWR) indicated that the Mojave River Recharge Project would be considered a non-project levee, which does not require a permit. In order to add further technical merit to the project, however, they believe that the MWA should submit an application for a DWR review and response to the Pilot Study findings, hydrogeological studies, and proposed site specifications.

8.3.3 County Permits

County excavation and construction permits may be needed to remove earth from certain properties, and build the necessary structures for the recharge efforts. In addition, if recharge facilities are located on San Bernadino County Flood Control right-of-way lands, MWA will be required to negotiate an agreement for the use of lands for recharge purposes. Recharge facilities on non-right-of-way lands are not required to be permitted but County Flood Control personnel have indicated that a review of the facility plans may reduce future problems. The San Bernadino County Planning Office will require any plans to be reviewed by their personnel but will not require a permit to be issued.

8.4 LAND PURCHASES OR LEASES

Lands along the Mojave River are owned by several entities including the State of California, Bureau of Land Management (BLM), the Department of Defense, and private entities. Some of these lands may be purchased or leased for recharge efforts.

State of California lands can typically be leased through the State Land Department. Prices for these lands are set during a bidding procedure.

Lands belonging to the BLM can also be leased through a public bidding procedure. This includes the submittal of a notification or request of lease of lands, followed by a public notification period, a public response and objection period, and final negotiation of lease or purchase price and provisions. The BLM has indicated that, although it is possible to purchase or trade for BLM lands, lease options are much more common and typically easier to obtain.

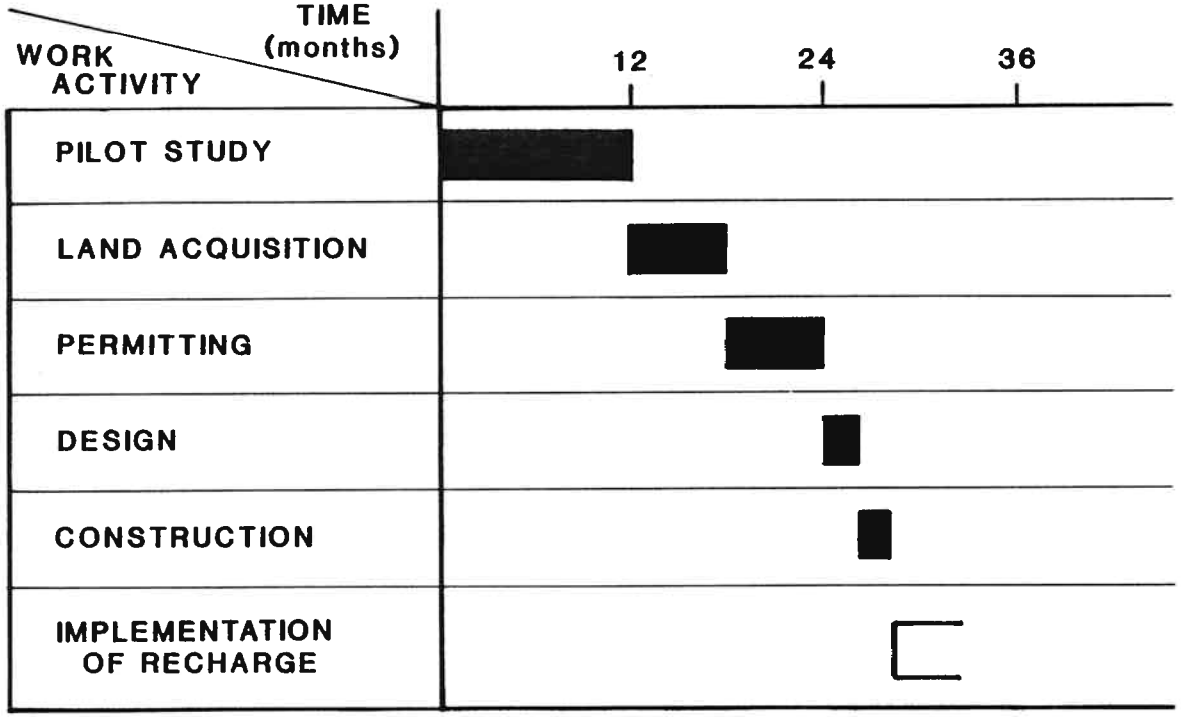
The Department of Defense (military) lands are not available for lease or purchase.

Private lands are available for purchase from the owner at market prices. In addition, private lands within eminent domain may be condemned and purchased for market value if private entities are unwilling to negotiate the sale of required lands.

8.5 IMPLEMENTATION SCHEDULE

A preliminary schedule has been developed to provide an estimate of the timing necessary to implement the program. The times provided represent the cumulative elapsed time since project inception.

The preliminary schedule presented in Figure 8-1, Implementation Schedule, suggests that recharge efforts could commence approximately 48 months following the inception of the pilot study.



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MOJAVE RIVER RECHARGE STUDY

IMPLEMENTATION SCHEDULE

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FIGURE 8-1

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