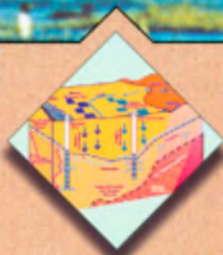


# Farmington

Groundwater Recharge Seasonal Habitat Study



Final Report  
August 2001

# **Farmington Groundwater Recharge/Seasonal Habitat Study**

## **Final Report**

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**For:**

**U.S. Army Corps of Engineers  
Sacramento District**

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## LIST OF ACRONYMS AND ABBREVIATIONS

|           |                                                            |
|-----------|------------------------------------------------------------|
| af        | acre-feet                                                  |
| af/yr     | acre-feet per year                                         |
| API       | aerial photography interpretation                          |
| ARWRI     | American River Water Resources Investigation               |
| ASTM      | American Society for Testing Materials                     |
| bgs       | below ground surface                                       |
| BNSF      | Burlington Northern and Sante Fe                           |
| USBR      | U.S. Bureau of Reclamation                                 |
| CALFED    | California Federal Bay-Delta Program                       |
| CalSites  | California Environmental Protection Agency Site Listings   |
| Cal Water | California Water Service Company                           |
| CCWD      | Calaveras County Water District                            |
| CDFG      | California Department of Fish and Game                     |
| CEQA      | California Environmental Quality Act                       |
| cfs       | cubic-feet per second                                      |
| CNPS      | California Native Plant Society                            |
| Corps     | U.S. Army Corps of Engineers                               |
| CSJWCD    | Central San Joaquin Water Conservation District            |
| CVP       | Central Valley Project                                     |
| CVPIA     | Central Valley Project Improvement Act                     |
| DBCP      | dibromochloropropane                                       |
| DMG       | Division of Mines and Geology                              |
| DMM       | Data Management Model                                      |
| DPR       | California Department of Pesticide Regulation              |
| DWR       | Department of Water Resources                              |
| EA/FONSI  | Environmental Assessment/Finding of No Significant Impact  |
| EBMUD     | East Bay Municipal Utility District                        |
| ECC       | Executive Coordinating Committee                           |
| EDB       | ethylene dibromide                                         |
| EIS/EIR   | Environmental Impact Statement/Environmental Impact Report |
| EPA       | California Environmental Protection Agency                 |
| ESA       | Environmental Site Assessment                              |
| ESJP      | Eastern San Joaquin Parties                                |
| ESJPWA    | Eastern San Joaquin Parties Water Authority                |
| FCWCD     | Flood Control and Water Conservation District              |
| FS        | Feasibility Study                                          |
| FSCA      | Feasibility Study Cost Sharing Agreement                   |
| ft        | Feet                                                       |
| ft/day    | feet per day                                               |
| FWS       | U.S. Fish and Wildlife Service                             |
| GIS       | geographic information system                              |
| HCP       | Habitat Conservation Plan                                  |

|              |                                                                                       |
|--------------|---------------------------------------------------------------------------------------|
| HTRW         | Hazardous Toxic Radiologic Waste                                                      |
| IGSM         | integrated groundwater and surface water model                                        |
| IS/ND        | Initial Study/Negative Declaration                                                    |
| LCSA         | local sponsor cost sharing agreement                                                  |
| LER          | leases, easements, and right-of-way                                                   |
| LUST         | leaking underground storage tank                                                      |
| MARS         | Mokelumne Aquifer Recharge and Storage                                                |
| mg/l         | milligrams per liter                                                                  |
| MRA          | Mokelumne River Aqueduct                                                              |
| M&I          | Municipal and Industrial                                                              |
| NA           | not applicable                                                                        |
| NEPA         | National Environmental Policy Act                                                     |
| NOI/NOP      | Notice of Intent/Notice of Preparation                                                |
| NRCS         | National Resource Conservation Service                                                |
| NSJWCD       | North San Joaquin Water Conservation District                                         |
| NTU          | Nephelometric Turbidity Units                                                         |
| PED          | pre-construction engineering and design                                               |
| ppm          | parts per million                                                                     |
| REP          | Real Estate Plan                                                                      |
| RWQCB        | California Regional Water Quality Control Board                                       |
| SAR          | sodium absorption ratio                                                               |
| SCS          | Soil Conservation Service                                                             |
| SESA         | Standard Environmental Site Assessment                                                |
| SEWD         | Stockton East Water District                                                          |
| SJAFCA       | San Joaquin Area Flood Control Agency                                                 |
| SJCGP        | San Joaquin County General Plan                                                       |
| SJMSCP       | San Joaquin County Multi-Species Habitat Conservation and Open Space Plan             |
| SLIC/DOD/DOE | Spills, Leaks, Investigations, and Cleanup/Department of Defense/Department of Energy |
| SMARA        | California Surface Mining and Reclamation Act of 1975                                 |
| SMT          | Study Management Team                                                                 |
| SSJID        | South San Joaquin Irrigation District                                                 |
| TDS          | total dissolved solids                                                                |
| TM           | Technical Memorandum                                                                  |
| USCS         | Unified Soil Classification System                                                    |
| USDA         | U.S. Department of Agriculture                                                        |
| USGS         | U.S. Geological Survey                                                                |
| UST          | underground storage tank                                                              |
| VAMP         | Vernalis Adaptive Management Plan                                                     |
| VOC          | volatile organic compound                                                             |
| WID          | water irrigation district                                                             |
| WRDA         | Water Resources Development Act                                                       |
| 1,2-D        | 1,2-dichloropropane                                                                   |

# **FARMINGTON GROUNDWATER RECHARGE/ SEASONAL HABITAT STUDY**

## **FINAL REPORT**

### **EXECUTIVE SUMMARY**

#### **INTRODUCTION**

This report presents results of planning and technical studies begun in June 1999 by the U.S. Army Corps of Engineers in partnership with Stockton East Water District and other local sponsors to determine the potential for development of integrated groundwater recharge and seasonal habitat improvements in eastern San Joaquin County, California. The studies were developed by the U.S. Army Corps of Engineers and Stockton East Water District, other local agencies, and in collaboration with concerned Federal and State agencies and stakeholders, in response to a series of Congressional authorizations. The report describes the purpose, need, and objectives for a possible base project\*; existing and likely future conditions in the study area if no plan or project is implemented; supporting technical analyses; development and evaluation of alternative groundwater recharge and seasonal habitat facilities; description of a strategy for phased implementation; findings and conclusions; proposal for future design work and environmental impact assessment and compliance. The findings presented in this report were developed based on existing information that was supplemented with geologic investigations and recharge pilot tests at several locations in the study area.

#### **STUDY BACKGROUND, PROBLEMS, AND OPPORTUNITIES**

Recent studies by the U.S. Army Corps of Engineers, Stockton East Water District, and others recognize that a severe groundwater overdraft condition exists in the eastern San Joaquin County. Long-term groundwater pumping in excess of natural replenishment has lowered groundwater levels, allowing the intrusion of saline water to portions of the aquifer. If groundwater overdraft is allowed to persist, saline intrusion is expected to continue, causing an irretrievable loss of the groundwater resource and economic losses to urban and agricultural areas dependent upon the groundwater.

In 1997, under the direction of Section 411(b) of the Water Resources and Development Act of 1996 (Public Law 104-303), the U.S. Army Corps of Engineers completed the Farmington Dam and Reservoir Conjunctive Use Study (revised December 1998), which evaluated potential structural and operation changes at the U.S. Army Corps of Engineers' Farmington Dam and Reservoir to help reduce the groundwater overdraft problem. Conjunctive use is the planned use of groundwater in conjunction with surface water to optimize total water resources (Ridenbaugh Press, 2001).

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*\* The base project is a series of phased implementation actions identified by the study team to reach an eventual recharge capacity of 35,000 acre-feet per year. Those actions include demonstration projects, monitoring, conveyance improvements and up to 1,200 acres of recharge fields which would require site specific study, design, environmental compliance and project approvals.*

The Conjunctive Use Study found that long-term water storage at Farmington Reservoir does not appear to be cost effective; however, operations modifications to Farmington Dam and construction of groundwater recharge facilities appear cost effective. The Conjunctive Use Study recommended that the feasibility of groundwater recharge with integrated seasonal wetland areas in eastern San Joaquin County be evaluated.

This study was therefore initiated as a follow-up to the Conjunctive Use Study under the 1996 Water Resources and Development Act, Section 411(b) authorization to study the feasibility of a groundwater recharge program in eastern San Joaquin County. However, the purpose, scope, and intent of the study were significantly altered when Congress enacted Section 502, *Environmental Infrastructure*, of the 1999 Water Resources and Development Act (Public Law 106-53), authorizing \$25 million for construction of groundwater recharge and conjunctive use projects in Stockton East Water District, California. The study team then modified the study strategy to focus more on the implementation of a groundwater recharge and conjunctive use base project than justifying a new project authorization.

Because of the large size of the study area and broad range of potential solutions, this study evaluates a range of alternative recharge techniques and identifies favorable recharge areas within the study area. The study found that soils and geologic conditions that influence groundwater recharge effectiveness vary considerably throughout the region. To maximize local benefits, a successful groundwater recharge project would need to begin with small components and add project sites through a careful implementation program of site selection, evaluation, and testing. The proposed base project therefore specifies the preferred recharge technique and general recharge area, and includes a recommendation for demonstration-scale test projects as a start to a phased implementation plan.

## DEVELOPMENT AND EVALUATION OF ALTERNATIVE PLANS

The development and evaluation of alternative plans was guided by recognition that replacement water supplies are needed in the study area to reduce the groundwater overdraft and the eastward migration of salinity. The preferred approach to reducing groundwater overdraft and salinity intrusion includes recharging flood-season water supplies. In addition, the opportunity exists to restore seasonal habitat that is currently severely lacking in the study area. Study objectives include (1) decreasing salinity intrusion by reducing groundwater overdraft and (2) the development of seasonal habitat areas.

As part of this study, small-scale pilot tests of alternative groundwater recharge and habitat restoration measures were completed at several sites in the study area. Measures tested included excavated pits, shallow ponds, and flooded fields. Sites were selected with the objective that results from pilot test areas would be representative of potential recharge and seasonal habitat facility conditions within other areas of similar geologic conditions. The pilot tests were conducted over several months to evaluate comparative effectiveness, but were not intended to address long-term design and operation issues. Through this testing, it was found that flooded fields provide the most cost-effective combination of groundwater recharge performance and opportunities for seasonal habitat restoration (as indicated in [Table ES-1](#)).

TABLE ES-1

SUMMARY OF COSTS AND ENVIRONMENTAL IMPACTS  
OF MEASURES CONSIDERED

| Measure                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | Costs                                    |                                       |                                       | Potential Ecosystem Benefits                                                                                                                                                  |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------|---------------------------------------|---------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | Capital Cost<br>(\$1,000\$) <sup>3</sup> | Annual O&M<br>Costs<br>(\$1,000)      | Annual Cost<br>\$/acre-feet           |                                                                                                                                                                               |
| Flooded Fields<br>(80 acre site)                                                                                                                                                                                                                                                                                                                                                                                                                                                              | \$517 <sup>1</sup> - \$531 <sup>2</sup>  | \$32 <sup>1</sup> - \$40 <sup>2</sup> | \$28 <sup>2</sup> - \$50 <sup>1</sup> | <ul style="list-style-type: none"> <li>Water depths from zero to 12 inches</li> <li>Most desirable waterfowl habitat</li> </ul>                                               |
| Spreading Basins<br>(80 acre site)                                                                                                                                                                                                                                                                                                                                                                                                                                                            | \$1,966                                  | \$33                                  | \$117                                 | <ul style="list-style-type: none"> <li>Large areas of ponded water with gradually sloped sides</li> <li>Desirable habitat for waterfowl</li> </ul>                            |
| Excavated Recharge<br>Pits (40 acre site)                                                                                                                                                                                                                                                                                                                                                                                                                                                     | \$909                                    | \$23                                  | \$413                                 | <ul style="list-style-type: none"> <li>Smaller areas of ponded water with steeply sloped sides</li> <li>Fair habitat for waterfowl</li> </ul>                                 |
| Unlined Flat<br>Canal                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | \$15,819                                 | \$84                                  | \$244                                 | <ul style="list-style-type: none"> <li>Similar to excavated pits</li> <li>Opportunity for continuous corridor</li> </ul>                                                      |
| Dry Wells                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | \$1,651                                  | \$220                                 | \$275                                 | <ul style="list-style-type: none"> <li>Would not create waterfowl habitat</li> <li>If combined with surcharge ponds, benefits would be similar to spreading basins</li> </ul> |
| Injection Wells<br>(4 wells)                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | \$4,510                                  | \$646                                 | \$173                                 | <ul style="list-style-type: none"> <li>Would not create waterfowl habitat</li> </ul>                                                                                          |
| Enhance Recharge<br>through Streams                                                                                                                                                                                                                                                                                                                                                                                                                                                           | \$2,657                                  | \$32                                  | \$119                                 | <ul style="list-style-type: none"> <li>Broadened floodplain areas along streams would provide additional riparian habitat</li> </ul>                                          |
| Flood Detention<br>Basins                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | \$500 <sup>4</sup>                       | \$38                                  | \$48                                  | <ul style="list-style-type: none"> <li>Similar to flooded fields for shallow flooding</li> <li>Similar to excavated pits during flood events</li> </ul>                       |
| In-Lieu Delivery<br>(agricultural delivery program)                                                                                                                                                                                                                                                                                                                                                                                                                                           | \$7,098 - \$14,195 <sup>5</sup>          | \$177                                 | \$224                                 | <ul style="list-style-type: none"> <li>Would not create waterfowl habitat</li> </ul>                                                                                          |
| Notes:                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                          |                                       |                                       |                                                                                                                                                                               |
| <ol style="list-style-type: none"> <li>Assumes infiltration rate of 0.25 ft/day.</li> <li>Assumes infiltration rate of 0.5 ft/day.</li> <li>Capital costs include all first costs including land acquisition, construction, PED, contingency, etc. (<a href="#">Appendix E</a>).</li> <li>Cost does not include conveyance modifications that may be necessary to support recharge.</li> <li>Low and high cost estimates assume a pipeline length of 5 and 10 miles, respectively.</li> </ol> |                                          |                                       |                                       |                                                                                                                                                                               |

This study was undertaken at a programmatic level to provide planning and technical guidance and direction regarding the development of groundwater recharge and seasonal habitat facilities. It compares the effectiveness of recharge at different areas of the study area toward meeting planning objectives. The study team found that recharge in the western portion of the study area (east of Stockton, and roughly between Highway 99 and Jack Tone Road, north of Manteca and south of the Mokelumne River) was most effective in reducing the eastward migration of salinity in the aquifer.

This report describes a base project that was developed on the basis of existing and potentially available water supplies that could be used for flood-season recharge. A review of available supplies revealed that the amount of water that would be available varies greatly, and exceeds 100,000 acre-feet during extremely wet years. The base project however, would require land acquisition and was therefore limited to supplies that would be available in most years. An average water supply up to 35,000 acre-feet per year was used to develop the base project as summarized in [Table ES-2](#).

**TABLE ES-2**  
**POTENTIAL WATER SUPPLIES FOR BASE PROJECT**

| <b>Water Source</b>                          | <b>Flood Season Supply for Base Project</b>                                                              |
|----------------------------------------------|----------------------------------------------------------------------------------------------------------|
| <b>Stanislaus River</b>                      | <b>10,000 af/yr</b><br>CVP deliveries from New Melones that can be routed through Farmington Reservoir   |
| <b>Littlejohns Creek</b>                     | <b>10,000 af/yr</b><br>Local inflow to Farmington Res. after meeting instream flows on Littlejohns Creek |
| <b>Calaveras River</b>                       | <b>5,000 af/yr</b><br>Rescheduled deliveries to Stockton East Water District from New Hogan Reservoir    |
| <b>Mokelumne River</b>                       | <b>10,000 af/yr</b><br>Unused NSJWCD water right                                                         |
| <b>South San Joaquin Irrigation District</b> | None                                                                                                     |
| <b>EBMUD American River Diversion</b>        | None                                                                                                     |
| <b>Stockton Delta Diversion</b>              | None                                                                                                     |
| <b>TOTAL</b>                                 | <b>35,000 af/yr</b>                                                                                      |

## FINDINGS AND CONCLUSIONS

The potential base project would include the development of up to 1,200 acres of land for groundwater recharge and seasonal habitat areas, as shown in the following figure. In addition, modifications to existing and construction of new conveyance facilities included in the base project would increase flexibility in water distribution and to support deliveries of recharge water to areas that are not currently served by existing facilities. One specific site for a demonstration project is identified in the study, on a 60-acre parcel adjacent to the Stockton East Water District water treatment plant. No other specific sites for demonstration projects are identified, although a second demonstration site in the in the Stockton East Water District or Central San Joaquin Water Conservation District is a possible future action.

Estimated costs for the base project are presented as a range, in recognition that recharge rates will likely vary from site to site, as observed in the pilot testing phase of the study. The total estimated costs for the base project range from about \$12.8 million to about \$25.5 million, with total annualized costs ranging from approximately \$1.3 million to \$2.4 million, as summarized in [Table ES-3](#). [Table ES-4](#) shows a summary of estimated annual base project costs for the first ten years.

**TABLE ES-3**  
**SUMMARY OF ESTIMATED BASE PROJECT COSTS**

| <b>Capital Costs<sup>1</sup></b><br><b>(\$1,000)</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                     | <b>Annualized</b><br><b>Capital Costs</b><br><b>(\$1,000)</b> |             | <b>Annual O&amp;M</b><br><b>Costs</b><br><b>(\$1,000)<sup>2</sup></b> |             | <b>Total Annual</b><br><b>Costs</b><br><b>(\$1,000)<sup>3</sup></b> |             |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------|---------------------------------------------------------------|-------------|-----------------------------------------------------------------------|-------------|---------------------------------------------------------------------|-------------|
| <b>Low</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | <b>High</b>         | <b>Low</b>                                                    | <b>High</b> | <b>Low</b>                                                            | <b>High</b> | <b>Low</b>                                                          | <b>High</b> |
| 12,793 <sup>4</sup>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | 25,484 <sup>4</sup> | 979                                                           | 1,951       | 341                                                                   | 479         | 1,268                                                               | 2,359       |
| Notes:<br>1. Low and high cost estimates assume infiltration rates of 0.5 and 0.25 ft/day, respectively. The components of the potential base project are itemized in <a href="#">Table VI-4</a> . All costs at 2000 price levels, 6-3/8%<br>2. Assumes recharging 100 days/year, 65% of years; see <a href="#">Appendix E</a> .<br>3. Includes annual revenue of \$90 per acre for agricultural production on the property.<br>4. Total capital costs include real estate acquisition costs for flooded fields of \$3,000,000 to \$6,000,000 for 600 to 1,200 acres of flooded fields respectively. |                     |                                                               |             |                                                                       |             |                                                                     |             |

**TABLE ES-4**  
**SUMMARY OF ESTIMATED ANNUAL BASE PROJECT COSTS**  
**(\$1,000)**

|                                                                                                                                                                                                                                                                                                                                                                                                                          | <b>2002</b> | <b>2003</b> | <b>2004</b> | <b>2005</b> | <b>2006</b> | <b>2007</b> | <b>2008</b> | <b>2009</b> | <b>2010</b> | <b>2011</b> |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
| <b>Annual Total<sup>1</sup></b>                                                                                                                                                                                                                                                                                                                                                                                          | 9           | 422         | 1,341       | 2,735       | 2,681       | 4,404       | 4,454       | 518         | 1,021       | 543         |
| <b>Cumulative Costs<sup>1,2,3</sup></b>                                                                                                                                                                                                                                                                                                                                                                                  | 9           | 431         | 1,772       | 4,507       | 7,188       | 11,592      | 16,046      | 16,564      | 17,585      | 18,128      |
| Note:<br>1. Number of acres and timing of specific projects are subject to change. The components of the potential base project are itemized in <a href="#">Table VI-9</a> . Costs at 2000 price levels, 6-3/8%<br>2. Capital construction costs include real estate acquisition costs of \$3,900,000 for 780 acres of flooded fields.<br>3. Net present value of project implemented over 10 years equals \$12,400,000. |             |             |             |             |             |             |             |             |             |             |

The environmental impacts of the potential base project phased program have not been identified and evaluated in detail. Many of the potential issues of environmental concern are site-specific and would be addressed in future site-specific studies. Although the formal scoping process and Environmental Impact Statement/Environmental Impact Report were not part of the current study, stakeholder outreach and identification of potential environmental impacts have been an integral part of the base project to date and are summarized in this document. An assessment of the environmental impacts and associated permits for the first proposed demonstration scale project and for each future site of the program will be prepared at the appropriate time.

## **PLAN IMPLEMENTATION**

The potential base project described in this report would support the objectives of many Federal State and local agency programs. For example, the salinity control and water supply benefits fit within the primary objectives of CALFED, State of California Proposition 13 and CVPIA implementation by the Bureau of Reclamation and U.S. Fish and Wildlife Service.

Before such a large-scale groundwater project could be successfully developed, demonstration-scale projects will be needed to address remaining questions about the best design and layout of a large-scale flooded field program and potential environmental impacts. The implementation plan in the report provides guidance for site screening, investigation, testing, development, and operation and maintenance of potential sites for long-term groundwater recharge and seasonal habitat areas.

The demonstration projects identified in the report are currently being pursued by Stockton East Water District, San Joaquin County water agencies, and the State of California. A demonstration-scale recharge and seasonal habitat facility will likely be developed in Stockton East Water District in 2002.

The Corps of Engineers participation in demonstration projects or other aspects of the base project would require Congressional direction. The 1999 Water Resources and Development Act (Public Law 106-53) authorized \$25 million for the Army Corps of Engineers to assist in the construction of groundwater recharge and conjunctive use projects in Stockton East Water District, California. However, no funding has yet been appropriated under this authorization.

# CHAPTER I

## INTRODUCTION

Recent studies by the U.S Army Corps of Engineers (USACE) and others have concluded that a serious groundwater overdraft problem exists in eastern San Joaquin County, California. Long-term groundwater pumping in excess of natural replenishment has lowered groundwater levels, allowing the intrusion of saline water to portions of the aquifer. If groundwater overdraft is allowed to persist, saline intrusion is expected to continue, causing an irretrievable loss of the groundwater resource. The loss of groundwater resources in eastern San Joaquin County would have significant economic and environmental consequences.

During the past several decades, local water districts in eastern San Joaquin County have considered numerous alternatives to reduce groundwater overdraft. The USACE completed the Farmington Dam and Reservoir Conjunctive Use Study (December 1997), which evaluated potential structural and operation changes at Farmington Dam and Reservoir to help reduce the groundwater overdraft problem. Conjunctive use is the planned use of groundwater in conjunction with surface water to optimize total water resources (Ridenbaugh Press, 2001). The Conjunctive Use Study found that long-term water storage at Farmington Reservoir does not appear to be cost effective; however, operations modifications to Farmington Dam and the construction of groundwater recharge facilities appear cost effective. The Conjunctive Use Study recommended that the feasibility of groundwater recharge with integrated seasonal habitats in eastern San Joaquin County be evaluated. In order to avoid the implication that the project would create permanent wetlands, the term seasonal habitat is instead used in this report.

This report presents the results of the study to evaluate the feasibility of groundwater recharge with integrated seasonal habitat in eastern San Joaquin County. It provides a description of existing and future without project conditions in the study area, groundwater recharge and seasonal habitat measures considered, development of alternatives, a description of the recommended plan and associated economic and environmental benefits and impacts, and an implementation plan.

### PURPOSE AND SCOPE OF STUDY

The Farmington Groundwater Recharge/Seasonal Habitat Study is a cost-shared study by the USACE and a group of local sponsors that include Stockton East Water District (SEWD), Central San Joaquin Water Conservation District (CSJWCD), North San Joaquin Water Conservation District (NSJWCD), City of Stockton, San Joaquin County, and the California Water Service Company (Cal Water). The study evaluates groundwater recharge and habitat restoration opportunities in eastern San Joaquin County (Plate 1). The study evaluates alternatives for developing a multi-purpose groundwater recharge and habitat project in the areas of SEWD, CSJWCD, and NSJWCD. The study focuses on where and how recharge could be accomplished on a regional basis and describes opportunities for integrated seasonal habitat development.

The study is being prepared during a time of substantial water need in eastern San Joaquin County. Over the past several years, the study partners and other parties in San Joaquin County have considered numerous projects that could increase water supplies to meet agricultural and urban needs in the county. The study partners recognize that a regional groundwater recharge project would be an important part of an overall water management and habitat restoration plan for San Joaquin County.

The availability and reliability of long-term water supplies will be necessary for development of a successful groundwater recharge and seasonal habitat project in eastern San Joaquin County. The local sponsors have determined that water for this project may be available from a variety of sources including local runoff, Central Valley Project (CVP) deliveries, and water purchases from other water districts. To date, efforts to identify and/or secure potential additional water supplies have been pursued separately from this study by some of the local study partners. The study will therefore formulate a project that can be supported with existing water supplies. If additional water supplies are secured at some future date, the project could be expanded beyond the plan recommended in this study to take advantage of available water supplies.

Alternatives considered in the study were formulated in consideration of the widely varied geology and soils conditions in the study area. Because the study is presented at a programmatic level of detail, it has not been practical to collect site-specific information at all potential groundwater recharge and seasonal habitat locations in the study area. Rather, the study describes the distribution of common geologic and soils characteristics in the study area and utilizes results of site-specific pilot recharge testing at representative locations to estimate potential recharge effectiveness at sites with similar conditions. Where possible, results of previous testing by others are utilized in the assessment. Implementation of the project will require additional site-specific testing to assess local geologic and groundwater conditions at candidate locations for long-term recharge facilities.

The study does not include major new work on surface water or groundwater modeling but instead relies on results available from other recent studies. Several previous and ongoing studies have developed and/or utilized analytical tools to evaluate water supply availability and groundwater conditions in eastern San Joaquin County. These include studies associated with implementation of the Central Valley Project Improvement Act (CVPIA) and the California Federal Bay-Delta Program (CALFED); the American River Water Resources Investigation (ARWRI); recent and ongoing studies by the Eastern San Joaquin Parties (ESJP) and East Bay Municipal Utility District (EBMUD); and planning studies undertaken by San Joaquin County to define and assess groundwater and surface water resources. During preparation of this study, the study team coordinated with local interests, other ongoing projects and programs, and Federal, State and local agencies that will be involved in the review of the documents and may be involved in project implementation.

The study was developed over an 18-month period that included selection, design, and operation of pilot-scale groundwater recharge test sites to identify characteristics associated with different recharge techniques and geologic conditions. Four tasks guided development of the study.

1. **Identify Areas Potentially Suitable for Recharge and/or Seasonal Habitat Development.** Information on geologic, water distribution, land use, and habitat suitability in the study area was collected and compiled. Areas in eastern San Joaquin County with favorable geologic conditions for recharge and locations where seasonal habitat areas could be established and sustained were identified. Information was compiled and stored in a geographic information system to allow comparison of related data and presentation of results. This information was used to identify potential sites for pilot testing and was presented in Technical Memorandum (TM) 1, December 1999 (MW, 1999).
2. **Select Pilot Test Sites and Evaluate Recharge Techniques.** Four locations were selected for pilot-scale testing such that the range of geologic conditions present within the study area and potential percolation techniques could be evaluated. Geologic data was collected at each test site and at least one piezometer was installed to monitor groundwater levels. TM-2 summarized geologic data collection and interpretation at the four selected pilot-scale test locations and included conceptual designs of the pilot scale test facilities (MW, 2000a).
3. **Design and Conduct Pilot Recharge Tests.** Temporary groundwater recharge facilities were designed, constructed, and operated at the selected pilot-scale test sites. Techniques tested at pilot-scale recharge sites included excavated pits, shallow spreading basins, and bermed on-grade flooded fields. Results of pilot-scale groundwater recharge tests were presented in TM-3 (MW, 2000b).
4. **Final Project Report.** This study develops a potential base project for groundwater recharge and seasonal habitat development in eastern San Joaquin County based on existing water supplies available at the time of the report.

## STUDY AUTHORITY

This study has resulted from direction contained in House of Representatives Report 104-146 (June 20, 1995) which states:

*"The Committee has provided \$600,000 for the Corps of Engineers to complete a reconnaissance study to determine the extent and nature of a flood control project for the Stockton, California, Area. Funds may also be spent to determine the viability of Farmington Dam for conjunctive use and flood control purposes."*

Subsequent to the initiation of the reconnaissance report, the following additional direction was provided in the Water Resources Development Act (WRDA) 1996:

### Section 411 (b) FARMINGTON DAM, CALIFORNIA

(1) **CONJUNCTIVE USE STUDY** - The Secretary shall continue participation in the Stockton, California, Metropolitan Area Flood Control Study, including an evaluation of the feasibility of storage of water at Farmington Dam and implementation of a conjunctive use plan.

(2) CONSULTATION - In conducting the study, the Secretary shall consult with the Stockton East Water District concerning joint operation or potential transfer of Farmington Dam.

(3) REPORT - Not later than 1 year after the date of the enactment of this act, the Secretary shall submit a report to Congress -

(A) concerning the feasibility of a conjunctive use plan using Farmington Dam for water storage; and

(B) containing recommendations on facility transfers and operational alternatives.

The Conjunctive Use Study, completed December 1997, found that modifications to Farmington Dam for water storage did not appear cost effective at this time, but that conjunctive use would be enabled through development of groundwater recharge capabilities in the study area. The Conjunctive Use Study found that conjunctive use could be improved if year-round diversions to the Lower Farmington Canal were permitted and concluded that the Dam and Reservoir should remain owned and operated by the USACE. The Study recommended that a feasibility study be initiated to evaluate potential groundwater recharge and integrated seasonal habitat development in the SEWD.

Under the authority of Section 411 of WRDA 1996, the USACE and SEWD initiated a 50/50 cost shared feasibility study, the Farmington Groundwater Recharge/Seasonal Habitat Study in May 1999.

Subsequent to the initiation of the study, Congress passed WRDA 99 which included Section 502 ENVIRONMENTAL INFRASTRUCTURE, authorizing: "East San Joaquin County, California, \$25,000,000 for groundwater recharge and conjunctive use projects in Stockton East Water District, California."

As of August 2001, no funding has been appropriated by Congress to implement the project authorized by Section 502.

## STUDY PARTICIPANTS AND COORDINATION

The local sponsor for the study is SEWD. On June 1, 1999, shortly following execution of the FSCA, several local entities entered into local sponsor agreements with SEWD to participate in and share the local costs of the study. These include:

- San Joaquin County
- City of Stockton
- CSJWCD
- NSJWCD
- Cal Water

The local sponsors are managing and coordinating the study through their participation on two committees that provide both policy and technical direction for the study.

- Executive Coordinating Committee (ECC), which provides general oversight and addresses policy and financial issues; and
- Study Management Team (SMT), which provides technical direction, coordinates the study, and reports to the ECC.

The local sponsors have also provided in-kind services to meet some of the needs of the study. In-kind services include coordination with project staff and local land owners, data gathering, database development, site access and land leasing for exploration and pilot test sites, construction of pilot testing facilities, and operation and monitoring of the pilot recharge tests.

The USACE and local sponsors kept the following other interested agencies informed through invitations to committee meetings or separate briefings:

- U.S. Bureau of Reclamation (USBR)
- CALFED
- California Department of Fish & Game
- California Department of Water Resources (DWR)
- East Bay Municipal Utility District
- Friends of the River
- U.S. Fish and Wildlife Service (FWS)
- National Marine Fisheries Service

## **PRIOR STUDIES AND REPORTS**

Modifications to Farmington Dam, groundwater overdraft, and conjunctive water management have been the subject of numerous studies addressing long-term water issues in San Joaquin County. The following studies contain information directly relevant to the development of groundwater recharge in eastern San Joaquin County. Many other sources of relevant information have been consulted, as presented in the References section of this report.

### **U.S. Army Corps of Engineers - Sacramento District**

- Reconnaissance Report for Flood Control on Duck Creek, San Joaquin County, California,” 20 February 1959.
- Reservoir Regulation Manual, Farmington Reservoir, California, Revised October 1967.
- Unpublished Office Study “Feasibility of Storing Conservation Water in Farmington Reservoir, Littlejohns and Rock Creeks, California,” June 1974.
- Flood Plain Information Report, Southeast Stream Group, Stockton, California, June 1974.

- Flood Plain Information Report, Southwest Stream Group, Stockton, California, December 1975.
- Reconnaissance Report, Littlejohns Creek Stream Group Investigation, June 1981.
- Hydrology Office Report, Littlejohns Creek Stream Group, California, June 1983.
- Reconnaissance Report, “Stockton Metropolitan Area, California,” April 1997.
- Conjunctive Use Study, “Farmington Dam and Reservoir, California, WRDA 1996 -Section 411 Conjunctive Use Study, December 1997.

#### **U. S. Department of the Interior - Bureau of Reclamation, Mid-Pacific Region**

- American River Water Resources Investigation Planning Report and Draft Environmental Impact Report/Environmental Impact Statement, January 1995.
- Folsom South - Lower American River Alternatives, Central Valley Project, California, November 1975.

#### **State and Local Agencies**

- “Farmington Canal Project, Draft Environmental Impact Report,” EIP Associates for Stockton East Water District, December 1987.
- Mokelumne Aquifer Recharge and Storage Project, prepared for EBMUD and the eastern San Joaquin Parties by Montgomery Watson and CH2M HILL, January 1996.
- “Stockton Intermodal Facility, Final Environmental Impact Report,” August 1999. Prepared for the County of San Joaquin.
- “San Joaquin County Groundwater Investigation,” California Department of Water Resources, 1967.
- “Eastern San Joaquin County Groundwater Study,” San Joaquin County Flood Control and Water Conservation District, 1985.

#### **U. S. Geological Survey (USGS)**

- Preliminary Evaluation of the Potential for Artificial Ground-Water Recharge in Eastern San Joaquin County, California. USGS Open-File Report 82-123 (by H. T. Mitten, 1982).
- Evaluation of the Potential for Artificial Ground-Water Recharge in Eastern San Joaquin County, California—Phase 2. USGS Open File Report 83-4207 (by R. V. Ireland, 1983).

- Evaluation of the Potential for Artificial Ground-Water Recharge in Eastern San Joaquin County, California—Phase 3. Water Resources Investigations Report 87-4164 (by S. N. Hamlin, 1987).

## CHAPTER II

### EXISTING CONDITIONS

#### DESCRIPTION OF STUDY AREA

The study area is the eastern portion of San Joaquin County, California, and roughly extends from the Sacramento County boundary on the north to Lone Tree Creek on the south, and Highway 99 on the west to the east edge of the County (Plate 1). The primary area of interest is the combined area of the CSJWCD, SEWD, and NSJWCD (Plate 2). The major hydrologic features include the Stanislaus River, the Calaveras River, Mormon Slough, the Mokelumne River, and the Littlejohns-Rock creek drainages.

San Joaquin County is located at the northern end of the San Joaquin Valley between the Sacramento-San Joaquin River Delta and the Sierra Nevada foothills. Hydrographically, San Joaquin County is divided by the San Joaquin River, which enters the county at its confluence with the Stanislaus River in the south, flows northward past confluences with Littlejohns and Lone Tree creeks and the Calaveras River, and then turns westward into the Delta (Plate 1).

The study area generally slopes gently westward to the San Joaquin River, with elevations in the foothills up to 650 feet above mean sea level just east of the County at New Hogan Reservoir, to approximately 20 feet above sea level in Stockton. The foothills run along the eastern border of San Joaquin County and are characterized by gently rolling terrain and westward flowing rivers and streams. Water storage and flood control facilities in the foothills include New Melones Reservoir (Stanislaus River), New Hogan Reservoir (Calaveras River), Pardee and Camanche reservoirs (Mokelumne River) and Farmington Reservoir (Littlejohns and Rock creeks) (Plates 1 and 2).

The area has a semiarid, two-season Mediterranean climate typical of the great Central Valley of California, characterized by long, warm, dry summer seasons from May to October and cool rainy winter seasons. Average annual precipitation totals approximately 14 inches, with 70 percent of the rainfall occurring from December through March. Snow rarely falls on the area and snowmelt is not a significant factor in runoff from large storms, but spring snowmelt from higher elevations in the Sierra Nevada is significant on the Stanislaus and Mokelumne rivers.

Land uses in the area include urban areas in the cities of Stockton and Lodi and vast agricultural areas to the east. Water supplies for agricultural and municipal and industrial (M&I) land uses historically have been, and remain, heavily dependent on groundwater. Long-term overdraft has resulted in an extensive area of depressed groundwater levels that draws groundwater toward the depression from all directions. Below the city of Stockton, groundwater that has migrated from the west is characterized by elevated salinity and dissolved solids levels that, in some cases, exceed drinking water standards.

During the past 25 years, a portion of the water supply for M&I and agricultural demands has been met with surface water from the Calaveras and Mokelumne rivers. Since 1994, CVP

water supplies of up to about 50,000 af/yr and water pursuant to the OID/s SJID water transfer agreement have been made available from the Stanislaus River for agricultural and urban uses in the study area. The amount of reliable surface water from the Mokelumne, Calaveras and Stanislaus rivers has not been sufficient to correct the groundwater overdraft problem in the study area.

The economy of San Joaquin County is primarily based on agriculture and related services. The value of farm commodities in San Joaquin County exceeds \$1.2 billion, placing the county fifth nationwide in agricultural production. Agricultural production is accomplished primarily by family farm operations, with average farm sizes of less than 200 acres. A regional economic study found that roughly one of every three jobs in the county is dependent on agriculture.

## GEOLOGIC SETTING

The study focuses on development of a groundwater recharge and seasonal habitats project. Hence, an understanding of characteristics that affect water infiltration and percolation to the groundwater table is paramount. This section describes the geologic setting with particular emphasis placed on the effect that geologic factors have had on the recharge characteristics of soils. Available data regarding geology, soils, groundwater recharge potential, faults and seismicity, and mineral resources of the study area were compiled and entered into a Geographic Information System (GIS) for compilation and analysis. Three maps were developed to support discussions in this section.

- [Plate 3- Geology](#)
- [Plate 4- Soil Permeability](#)
- [Plate 5- Geologic Subregions and Previous Recharge Data](#)

Soils in Eastern San Joaquin County are chiefly comprised of sedimentary deposits that originated in the Sierra Nevada Mountains. The recharge potential of these soils varies considerably and is dependent on primary and secondary geologic effects. Primary geologic patterns that influence permeability relate to grain size and sorting, which is a result of depositional characteristics. Secondary geologic effects that influence soil recharge characteristics are associated with post-depositional events, consolidation, lithification, and weathering, including the development of hardpan soils. These characteristics are discussed in the following sections. A generalized map of permeability for the upper five feet of soil is shown in [Plate 4](#), as developed by the National Resource Conservation Service (NRCS) of the U.S. Department of Agriculture (USDA) (formerly Soil Conservation Service, or SCS). Many of the geologic features described in this section, including the geologic subregions shown in [Plate 5](#), are most visible on the soils map ([Plate 4](#)).

## Geology

Geologic information for eastern San Joaquin County was compiled from published 7.5 and 15 minute series geologic quadrangles mapped by or for the USGS ([Montgomery Watson, 1999](#)). Data were digitized from published maps, except for the Stockton East and Manteca

quadrangles for which preliminary digital data was obtained from William Lettis and Associates, Inc. of Walnut Creek, California. A generalized geologic map, based on these data, is shown on [Plate 3](#).

In general, the sedimentary units dip westward with the oldest Tertiary sedimentary formations exposed in the east. The older Tertiary units, primarily Mehrten and Laguna formations, consist of moderately consolidated conglomerate, sandstone, and mudstone. The Tertiary units are overlain by younger Quaternary alluvium (stream deposits) that include the lower to middle Pleistocene Riverbank Formation and upper Pleistocene Modesto Formation. These formations are broadly correlative with the Victor Formation in the Sacramento area.

The primary (original) geologic permeability of the pre-Modesto formations is variable depending on the grain size, but in general is low due to secondary (post-depositional) effects including the development of hardpan soils discussed below. However, the units are heterogeneous (variable) and permeable channels are not uncommon beneath the hardpan.

The primary permeability of the Modesto Formation varies both east-west and north-south due to grain size differences in the original depositional environments. On any given drainage (such as the Calaveras River), the alluvium is generally coarsest (and most permeable) in the east where the gradient is steepest and the relatively high energy stream carries and deposits a high proportion of coarse bedload of sand and gravel (the proximal fan). Suspended sediment (clay and silt) is generally not deposited until it is carried farther west to a lower energy environment (the distal fan). As a result, the average permeability (and thus the average recharge rates) of the alluvial fan decreases overall from east to west.

The grain size distribution produced from each watershed depends on several characteristics, including the type of geologic materials in the source area, the watershed's gradient and total area, and the portions of the watershed subject to rainfall and snowmelt runoff. Some of the characteristics that influence average grain size (and thus permeability) of individual drainages in the study are as summarized in Table II-1 below (from the Farmington Dam Conjunctive Use Study (USACE, 1997)).

During the Pleistocene Epoch when the Modesto and Riverbank formations were deposited (approximately 1 million to 10,000 years before present), a colder, wetter climate produced a lower snowline than at present, and coarse glacial outwash dominated the major streams originating in the interior of the Sierra (Mokelumne and Stanislaus). Alluvium of the smaller foothill watersheds consists primarily of fine-grained material in interfan areas (Bear Creek and Littlejohns/Rock creek drainages). The Calaveras River drainage is intermediate between the two, forming a moderately coarse alluvial fan between the Calaveras River and Mormon Slough.

**TABLE II-1**  
**DRAINAGE CHARACTERISTICS**

| <b>Watershed</b>                                                       | <b>Maximum Elevation (ft.)</b> | <b>Watershed Area (sq. mi.)</b> | <b>Percent Area Above Typical Snowline</b> |
|------------------------------------------------------------------------|--------------------------------|---------------------------------|--------------------------------------------|
| Mokelumne River (at Woodbridge)                                        | 10,000                         | 661                             | 35%                                        |
| Calaveras River (at Bellota)                                           | 5,000                          | 470                             | 0%                                         |
| Littlejohns & Rock Creeks (at Farmington Dam, w/o Duck Creek Drainage) | 3,000                          | 212                             | 0%                                         |
| Stanislaus River (at Ripon)                                            | 11,500                         | 1,075                           | 40%                                        |

Within this overall framework, the alluvial fans of each drainage contain coarse-grained channel and levee deposits of relatively high permeability within finer-grained overbank and floodbasin deposits of low permeability. In this depositional environment, stream channels migrate and abruptly jump to new locations over time, creating deposits that are heterogeneous both laterally and vertically. As a result of this depositional environment, localized silt and clay lenses are common even in the alluvial fan areas. However, no regional clay layer is expected to exist that would severely reduce or inhibit vertical migration of water. The recent (Holocene) alluvium in the current incised river floodplains (Mokelumne and Calaveras) and windblown (eolian) sand deposits are of limited extent but relatively permeable.

### **Soil Permeability**

The soils survey of San Joaquin County at a scale of 1:24,000 was obtained digitally directly from the agency (SCS, 1992). Of the many soil characteristics mapped and interpreted by the SCS, two were selected for presentation and analysis on [Plate 4](#).

- Hydrologic Groups (based on relative infiltration rates):
  - A: high (red)
  - B: medium (yellow)
  - C: slow (green)
  - D: very slow (blue)
- Hardpan (if present, as thin or thick)

The hydrologic group is an estimation of the infiltration rate of the first five feet of soil based on both its depositional characteristics (mostly grain size and sorting) and secondary characteristics (compaction, lithification, and weathering), including hardpan if present.

Hardpan is a strongly cemented weathering profile that limits infiltration unless it is modified by ripping or excavated.

The broad geologic features described under the Geology heading of this section reflect the river drainage elevations, areas, and percent above snowline are also apparent in the map of soils distribution (Plate 4). The Stanislaus alluvial fan has the overall highest infiltration rate followed by the Mokelumne and Calaveras fans. The smaller foothill watersheds have the lowest average infiltration rates. The relatively high permeability of windblown sands on the Mokelumne and Stanislaus fans and the recent alluvium of the current Mokelumne and Calaveras river floodplains are recognizable on Plate 4.

The thickness and extent of hardpan shown on Plate 4 has significance to the study. Some hardpan is discontinuous and relatively shallow (located at a depth of five feet or less) and can be and often is ripped with a bulldozer for agricultural purposes. However, in other areas, particularly in the older pre-Modesto formations, the hardpan is more continuous and extends to depths that can not be reached by ripping methods. The vernal pools developed on the pre-Quaternary units on the east side of the county are in large part due to the extensive hardpan developed in these older soils.

### Geologic Subregions and Previous Recharge Data

The differences between the alluvial fans described above are less apparent on the geologic map (Plate 3) than the soils map (Plate 4). Through consideration of both maps, six generalized geologic subregions were identified for the purpose of characterizing recharge potential (Plate 5, north to south):

- Pre-Modesto formations
- Mokelumne River fan
- Bear Creek interfan
- Calaveras River fan
- Littlejohns Creek interfan
- Stanislaus River fan

The Stanislaus River fan is south of the study area and therefore will not be further characterized in this study. The Bear Creek interfan area is relatively small and is similar in character to the Littlejohns Creek interfan. Each of the other four subregions (Pre-Modesto formations, Mokelumne River fan, Calaveras River fan, and Littlejohns Creek interfan) is considered unique. In each of these subregions, previous recharge test data and/or pilot testing conducted during the development of this study were collected to characterize each shallow soil conditions with respect to infiltration and recharge potential. The previous recharge test data is shown on Plate 5, as is previously mapped sand holes (primarily windblown dune deposits), shallow resistivity test profiles completed by SEWD, and borehole permeability tests. It should be noted that most of the previous studies of groundwater recharge potential have been relatively short-term tests and that the anticipated results of longer-term tests and performance of constructed projects are expected to vary. The existing data are integrated with new data

collected from the study pilot testing to characterize the groundwater recharge and wetland potential of each geologic subregion in [Chapter V](#).

## Hydrogeology

The following studies contain information relevant to the hydrogeology of Eastern San Joaquin County. Many other sources of relevant information have also been consulted for this report.

***DWR Bulletin 146, San Joaquin County Groundwater Investigation, 1967.*** DWR Bulletin No. 146 ([DWR, 1967](#)) includes an extensive analysis of the water bearing and non-water bearing formations that underlie the San Joaquin County. It describes 1967 overdraft groundwater conditions and saline intrusion into the Stockton area, and offers possible solutions to both problems. The investigation identified the saline front in the Stockton area (defined by chloride concentrations of 300 ppm) for 1953 and 1963 conditions. The report concluded that extensive groundwater pumping in ESJC has induced a flow of poor quality groundwater from the west into the City of Stockton.

***Eastern San Joaquin County Groundwater Study (ESJCGS), San Joaquin County Flood Control and Water Conservation District (SJCFWCD), 1985.*** This report, prepared by Brown & Caldwell in 1985 for the SJCFWCD, found that water levels in the study area declined at an average rate of 1.7 ft/yr from 1947 to 1984, and that water levels in the pumping depression located east of Stockton were over 60 ft below sea level in 1980. Also, during the time from 1963 to 1983, the study determined that the saline front had advanced about one mile inland. The study concluded that if no surface water were provided to the area, by 2020 groundwater levels would decline to as much as 160 ft below sea level. It further concluded that if additional water supplies are not imported to the basin, the saline front would advance approximately two miles by the year 2020, placing the front east of Airport Way, and possibly as far east as Highway 99. The study found that if supplemental surface water were brought into the basin groundwater level declines could be offset and even restored to 1985 levels, and migration of the saline front would be minimized ([SJCFWCD, 1985](#)).

***U.S. Geological Survey (USGS) Professional Paper 1401-D, Ground-Water Flow in the Central Valley, California, 1989.*** This USGS report is part of the Regional Aquifer-System Analysis Program for quantitative appraisals of major groundwater basins in the United States. The report compiles geologic, hydrologic, and geochemical data to analyze the basin and develop an effective management system of the water supply.

The groundwater basin underlying San Joaquin County is part of the contiguous Central Valley aquifer system, which supplies groundwater to agricultural, domestic, and industrial water users from Redding to Bakersfield. DWR Bulletin 146 identifies the usable aquifer in the eastern portion of San Joaquin County as the continental deposits of Miocene and younger age. The thickness of the usable aquifer ranges from less than 100 ft in the eastern edge of the county to over 3,000 ft in the southwestern edge, and is approximately 1000 ft beneath Stockton.

The producing zones beneath Stockton include the Laguna Formation, which starts at about 100 ft below ground surface (bgs) and continues to approximately 1000 ft bgs. Below this zone is the Mehrten Formation which ranges between 500 to 700 ft thick in the Stockton area. DWR describes the base of freshwater to be at approximately 1000 ft beneath Stockton (DWR, 1967). In general, this freshwater exists in the Laguna Formation within its various sequences of deposits of interbedded and discontinuous gravels, sands, silts and clays. The Laguna Formation is generally unconfined, though the heterogeneous nature causes it to behave as semi-confined at depth in some areas. The general flow of groundwater under natural conditions is from northeast to southwest. However, historical groundwater pumping has altered this flow direction which is now towards groundwater depressions. Groundwater pumping in San Joaquin County averaged 830,000 acre-ft for the 1970-1990 period. The historical use of groundwater has lowered water levels to over 70 ft below mean sea level (msl) (over 100 ft bgs) beneath some portions of the Eastern San Joaquin Basin. The freshwater-bearing units generally overlie the saline or brackish water bearing units. Areas of poor quality water are also prevalent in the Delta area west of Stockton.

Recent groundwater contour maps (Montgomery Watson, December 2000) indicate that the groundwater depression east of Stockton is generally comparable to that present in 1980 (SJCFWCWD, 1985). The deepest portions of the depression are still east of Stockton. However, the depression has broadened and migrated a few miles to the northeast and southeast and is up to -80 ft msl. Groundwater flow directions also remain generally similar to 1980. Regionally, groundwater flows toward the depression from recharge areas in the foothills to the east, Mokelumne River to the north, and Stanislaus River to the south. Unfortunately, the pumping depression east of Stockton also produces a reversal of the natural westward groundwater flow direction of normal (predevelopment) conditions. This eastward groundwater flow direction in the Stockton area began about 50 years ago. The eastward horizontal gradient remains at least as steep as in 1980 (10 ft to 20 ft per mile).

## Faults and Seismicity

The Central Valley of California is considered to be an area of relatively low seismicity in a state that is characterized by moderate-to-high seismic activity. During the formation of the Coast Ranges and the Sierra Nevada Mountains, numerous faults and shear zones developed. These faults are primarily in the Sierra Nevada foothills and the Coast Ranges. The boundary between the Coast Ranges and the Great Valley geomorphic provinces coincides with the tectonic boundary between the Coast Ranges and the Sierra Nevada tectonic blocks and is known as the Coast Ranges/Sierran-Block Boundary Zone. The boundary zone is assumed to extend from approximately Winters on the north to Los Banos on the south (the boundary zone is approximately 20 miles west of the study area) (Kleinfelder, August 1998).

Major faults that have historically produced the greatest magnitude earthquakes in central California are the Calaveras, Hayward, and San Andreas faults in the Coastal Ranges; the Greenville and Midland (suspected) faults on the west side of the Great Valley; and the Sierra Nevada and Owens Valley faults east of the Sierra Nevada mountains. The closest of these faults is approximately 10 to 20 miles west of the study area (the Vernalis and Midland faults) (Division of Mines and Geology (DMG), 1992). The closest fault system to the east of the

project site is the Foothills fault system containing the Bear Mountains and Melones fault zones, located approximately 20 miles east of the study area (DMG, 1992). Based on the 1975 Oroville event, it has been proposed that a magnitude 6.5 earthquake may occur in the Foothills fault system.

The study area is not located within a Fault-Rupture Hazard Zone as delineated by the Alquist-Priolo Earthquake Fault Zoning Act according to the California Department of Conservation Division of Mines and Geology web page ([www.conservation.ca.gov/dmg/rghm/ap/mapidx/index](http://www.conservation.ca.gov/dmg/rghm/ap/mapidx/index)). According to the San Joaquin County Seismic Safety Element, no active or potentially active faults are known to reach the surface within the eastern San Joaquin County study area. Several faults beneath the valley that displace “basement” rocks and some of the overlying sediments are suspected from borings conducted during subsurface oil and gas exploration in the region. The only one of these suspected buried faults in the study area is the Stockton fault, which trends northeast from Stockton to the vicinity of Linden. There is no evidence to suggest that the fault is active (DMG, 1992).

## Mineral Resources

The mineral resources in San Joaquin County were identified and classified by the State Geologist in Special Report 160, issued August 1988, pursuant to the California Surface Mining and Reclamation Act of 1975 (SMARA). The primary extractive resources include sand, gravel, and natural gas with peat soil; placer gold and silver extracted to a much lesser degree. Sand and gravel are important resources used primarily for construction materials such as asphalt and concrete. Also consistent with SMARA, the State Mines Geology Board has designated the sand and gravel deposits that are of regional and statewide significance. The principal deposits currently being extracted are located in the southwestern portion of the County along the Corral Hollow Creek alluvial fan (not included in study area) and along the major rivers in the eastern portion of the County. No other significant mineral resource deposits are known to be located in the study area (San Joaquin County, 1992).

## ENVIRONMENTAL RESOURCES & ISSUES

### Land Use

Current land use in the eastern San Joaquin County study area was obtained from land use maps on the DWR Web Page (DWR, 1996) and is shown on Plate 6. As shown, the majority of lands in the study area have been developed for agricultural and urban uses. Remaining areas of native, undisturbed lands are limited to the eastern extent of the study area in the foothills.

The San Joaquin County Multi-Species Habitat Conservation and Open Space Plan (SJMSCP) characterizes native vegetation as land that is not irrigated and has not been cultivated. These lands primarily include riparian, vernal pool, and grassland habitat (SJMSCP, March 1999). In the study area, native vegetation is primarily found as vernal pool grasslands located in the eastern foothills on the older pre-Modesto formations (Plates 3 & 7) or as riparian vegetation along the larger creeks and rivers. Native vegetation is considered to have the most valuable plant, fish, and wildlife habitat.

Agricultural lands are defined as irrigated and cultivated lands characterized with having annual or permanent crops. In the study area, these lands are predominantly found on the fan and interfan areas. Urban lands are defined as lands that have been converted for urban use. Urban use is concentrated in the western portion of the study area along State Highway 99 (primarily Stockton and Lodi). Dominant land uses in each geologic subregion considered in this study are summarized in [Table II-2](#).

**TABLE II-2**  
**LAND USES OF GEOLOGIC SUBREGIONS**

| Geologic Subregion     | Dominant Land Use            |
|------------------------|------------------------------|
| Pre-Modesto formations | Native Vegetation            |
| Mokelumne fan          | Agricultural (Grapes)        |
| Bear Creek interfan    | Agricultural (Miscellaneous) |
| Calaveras fan          | Agricultural (Orchards)      |
| Littlejohns interfan   | Agricultural (Annual Crops)  |
| Stanislaus fan         | Agricultural (Orchards)      |

The dominant land uses in each subregion are in large part related to the geology and soils present in the subregion. For example, thick hardpan in older, more deeply weathered pre-Modesto formations in the eastern portion of the study area has limited or prevented agricultural development. Consequently, this area is characterized by native vegetation and pastureland ([Plates 3 and 6](#)). In contrast, coarse permeable deposits in the major river fans are relatively well drained and support intense agricultural production in orchards and vineyards. The relatively fine interfan deposits are more suited to annual and miscellaneous crops that are not hampered by relatively poor drainage.

### **Fisheries and Wildlife**

Annual grassland in the region typically provides habitat for a variety of small mammals, birds, reptiles, and invertebrates and predators of these species. Species potentially present in the region include California ground squirrel, California vole, blacktailed hare, pocket gopher, coyote, western meadowlark, mourning dove, red-tailed hawk, and turkey vulture. Irrigated agriculture provides habitat for a variety of small mammals and is used for foraging by predator species.

Vernal pool zones, as identified in [plate 7](#), are native pool grasslands primarily located in the eastern foothills. The SJMSCP identifies the various plants, crustaceans, reptiles, birds that inhabit the vernal pool zone. Plant species occupying this habitat may include Colusa grass, Greene's tuctoria, succulent owl's clover, Boggs Lake hege-hyssop, legenere, bristly sedge, Red Bluff dwarf rush, and Hoover's calycadenia. Crustaceans including the vernal pool fairy shrimp and reptiles such as the San Joaquin whipsnake and the California horned lizard are known to exist in the vernal pool zone. In addition, bird species including the tricolored blackbird,

Ferruginous hawk, northern harrier, merlin, California horned lark, loggerhead shrike, and burrowing owl typically inhabit the vernal pool zone (SJMSCP, March 1999).

Riparian zones, such as those along large creeks and rivers, provide habitat for a variety of mammals, birds, reptiles, amphibians, and invertebrates. Mammal species occupying this habitat include raccoon, opossum, striped skunk, and a variety of rodents, as well as a number of species that visit riparian habitats for foraging. Mature trees in riparian vegetation provide nesting opportunities for many bird species including great blue heron, Cooper's hawk, and Swainson's hawk, and an assortment of passerine species. Reptiles typically include common kingsnake, garter snake, western fence lizard, and rattlesnake.

Seasonal habitats and freshwater marshes provide habitat for waterbirds, including great blue heron and great egret, as well as migrating waterfowl and a variety of invertebrates. These habitats provide nesting/breeding opportunities for red-winged blackbird, garter snake, the introduced bullfrog, western toad, Pacific tree frog, and potentially several special-status species.

Perennial riverine habitat is occupied or used by amphibians, warm-water fish species, shorebirds and waterfowl, provides a water and foraging source for a variety of mammal and bird species that typically occupy adjacent habitats.

### **Special-Status Species**

Special-status species in the region are those listed as threatened, endangered, candidate, species of concern, or species of special concern by the FWS or the California Department of Fish and Game (CDFG). Species listed as endangered that were identified by the FWS and in the SJMSCP as potentially present in habitats in the region include San Joaquin kit fox, vernal pool fairy shrimp, winter-run chinook salmon, and palmate bracted bird's beak. Species listed as threatened that were identified by the FWS as potentially present in the study area include bald eagle, giant garter snake, California red-legged frog, delta smelt, vernal pool fairy shrimp, valley elderberry longhorn beetle, and Aleutian Canada goose. Species proposed for listing as threatened or endangered include Sacramento splittail and Greene's tuctoria. Candidate species identified by the FWS as potentially present in the project area include San Joaquin Valley woodrat, riparian brush rabbit, mountain plover, California tiger salamander, and Ione manzanita.

Appendix A lists the 100 species covered by the SJMSCP. These species are listed under the California and Federal Endangered Species Acts as threatened or endangered; species proposed for listing as threatened or endangered; birds covered by the Migratory Bird Treaty Act; species protected by the Bald and Golden Eagle Protection Act; and species which may be of concern pursuant to the California Environmental Quality Act (CEQA) and National Environmental Policy Act (NEPA) including California Native Plant Society (CNPS) list CNPS 1a, CNPS 1b, and CNPS 2 plants; state-listed species of special concern; state listed special animals and special plants; state-designated fully protected species; and federal species of concern (SJMSCP, March 1999).

## SOCIOECONOMIC CONDITIONS

San Joaquin County is the fifth richest agricultural county in the country. The county encompasses 851,220 acres in the Central Valley of California and has a current population of 545,000. Land use in the study area is predominantly agricultural with some interspersed residential developments. The cities of Stockton (location of the county government) and Lodi, with populations of 243,700 and 51,874 respectively, are the main urban areas in the study area. These cities are located along State Highway 99 in the western part of the study area.

The San Joaquin County General Plan 2010 Review (SJCGP) forecasts that the county population will increase to approximately 750,000 by the year 2010. This increase would primarily be from continued pressure for affordable housing from the expanding Tri-Valley (Livermore) area to the west of San Joaquin County. Most of the growth is expected to occur in the urban communities, both in incorporated cities and in planned new communities, with a small portion of the growth expected in unincorporated areas. The commercial sectors of retail, service, office, and manufacturing are expected to be the predominant growth industries. Employment in the agricultural industry is projected to decline (SJCGP, March 2000).

A number of regional and local highways and railways service San Joaquin County. In the study area, State Highway 4, State Highway 12, State Highway 26, State Highway 99, and State Highway 120 provide regional highway access. The Burlington Northern and Santa Fe (BNSF) railroad operates in the study area and is currently constructing a 470-acre Intermodal Facility seven miles southeast of the City of Stockton. The purpose of this facility is to expand BNSF's existing downtown facility to meet the demand for shipment of agricultural crops. Expansion of existing transportation facilities is expected in the urban and western areas of San Joaquin County. Existing transportation facilities in the study area are considered sufficient to support forecasted conditions in the near future.

## CULTURAL RESOURCES

Human groups have been living in the Central Valley of California for at least 10,000 years. San Joaquin County has been the home of the Miwok Indians in the North, and the Yokut Indians in the South from the 1700's to the 1900's. It is known that the Yokuts occupied areas along the Calaveras River whereas the Miwok were concentrated along Littlejohns Creek. In the early 1800's, when the Spanish missionaries arrived, 80,000 Native Americans were in the Central Valley. It is believed that a combination of disease and "missionization" destroyed the population base and lifestyle of the Native American tribes in San Joaquin County (Stockton Intermodal Facility EIR, August 1999).

The first Anglo-European settlement in the San Joaquin area was located in the southeastern portion of the study area at French Camp in 1832. This site became a popular location for trappers in the area. In 1848, gold was discovered in the eastern foothills at the town of Coloma. Stockton was originally created by Captain Charles M. Weber in 1849, for the main purpose of supplying miners traveling to the eastern foothills. By 1850, San Joaquin County was established and Stockton, with a population of 5,000, soon became the industrial, commercial, economic, and social center in the northern San Joaquin Valley (Stockton Intermodal Facility

EIR, August 1999). With the introduction of agriculture coinciding with the coming of railroads, San Joaquin County rapidly grew into a major agricultural center.

Table II-3 lists California State Historical Landmarks in the study area. The data is provided by the Office of Historic Preservation-California Department of Parks and Recreation and was compiled on the web page ([ceres.ca.gov/geo\\_area/counties/San\\_Joaquin/](http://ceres.ca.gov/geo_area/counties/San_Joaquin/)).

**TABLE II-3**  
**CALIFORNIA STATE HISTORICAL LANDMARKS**  
**IN THE STUDY AREA**

| Number  | Name                                         |
|---------|----------------------------------------------|
| No. 155 | Lone Star Mill                               |
| No. 365 | Lockford (Lock's Ford)                       |
| No. 995 | Trail of the John C. Frémont 1844 expedition |

## RECREATION

Recreational activities in the study area include but are not limited to hiking, biking, fishing, and wildlife viewing. There are no state parks located within the study area, although recreationists are most commonly drawn to the reservoirs east of San Joaquin County. Abundant recreational facilities at Pardee, Camanche, New Hogan, and New Melones reservoirs accommodate swimming, boating, waterskiing, fishing, picnicking, and camping.

## HAZARDOUS AND TOXIC WASTE SITES

Groundwater recharge in areas with hazardous compounds in soil or groundwater would present special challenges and could ultimately prevent the development of sites if adequate mitigation measures cannot be defined and implemented. The Hazardous Toxic Radiologic Waste (HTRW) data sources consulted for this study included publicly-available HTRW lists and pesticide leaching potential and groundwater monitoring results.

### Known HTRW Sites

Point sources of contamination in the study area known to State or Federal agencies have been compiled from three sources.

- California Regional Water Quality Control Board (RWQCB) - Central Valley Region (Spills, Leaks, Investigations, and Cleanup/Department of Defense/Department of Energy (SLIC/DOD/DOE) Sites)
- State of California Environmental Protection Agency (EPA) Site Listings (CalSites)

- California RWQCB -Central Valley Region (Leaking Underground Storage Tank (LUST) Sites)

The existing known HTRW sites are generally concentrated in the urban areas of Stockton, Lodi, and smaller communities. The RWQCB SLIC/DOD/DOE and EPA CalSites lists show that no contamination sources have been identified in the eastern portion of San Joaquin County.

### **Pesticide Leaching Potential**

The use of pesticides in agricultural areas such as eastern San Joaquin County creates the potential for leaching of pesticides from soils with resulting negative water quality impacts. Prior to the late 1970s, compounds such as 1,2-dibromochloropropane (DBCP) and related breakdown compounds ethylene dibromide (EDB) and 1,2-dichloropropane (1,2-D) were applied as nematocides to protect grapevine roots. The leaching potential of these pesticides has been evaluated by the California Department of Pesticide Regulation (DPR) (DPR, 1999). DPR data was presented in a 1992 report on Groundwater Quality Management Strategies for East San Joaquin County, Section 205j (SEWD, 1992). The pesticide leaching potential for San Joaquin County soils was ranked by section based on land use, soil permeabilities, and depth to water. The primary areas of concern are long-established vineyards in the vicinity of Lodi. The pesticide leaching potential for the remainder of the area was judged to be low to moderate.

### **Pesticide Groundwater Monitoring Results**

DPR data was also compiled for the Groundwater Quality Management Strategies for East San Joaquin County as maps showing the results of monitoring programs for pesticides in groundwater (Stockton East Water District, 1992). Sections where one or more pesticides have been detected are concentrated near the west edge of the study area between Stockton and Lodi. With the exception of a small area northeast of Linden, pesticides have not been detected in the remainder of the study area.

## **GROUNDWATER LEVELS AND SALINITY INTRUSION**

Measurements over the past 40 years reveal a fairly continuous decline in groundwater levels in Eastern San Joaquin County. Groundwater levels have declined at an average rate of 1.7 feet per year and have dropped as much as 100 feet in some areas. It is estimated that groundwater overdraft during the past 40 years has reduced storage in the Eastern San Joaquin County Groundwater Basin by as much as 2 million acre-feet. As shown in plate 8, the most severe areas of groundwater overdraft are in the northeastern portion of San Joaquin County, below SEWD and CSJWCD. Groundwater overdraft in eastern San Joaquin County has allowed the eastward migration of saline water to the aquifer. In some areas beneath the City of Stockton, salinity concentrations in groundwater exceed public health standards and the groundwater cannot be served to domestic users.

As early as the 1920s, the rate of groundwater withdrawal in San Joaquin County had exceeded the rate of replenishment, and the rate of extraction was continuing to increase. At that

time, and during the following three decades, the major extraction of groundwater was centered in the Stockton area. The California Water Service Company, the urban water purveyor, installed wells and distribution systems in the city of Stockton. As the use of groundwater for both M&I and agricultural uses in the region grew, groundwater levels declined. By the 1950s, groundwater levels in the Stockton area had dropped below sea level.

By the mid-1960s a large pumping depression had formed below the City of Stockton, due to an annual overdraft of approximately 73,000 acre-feet (DWR, 1967). The lowering of the groundwater table below sea level induced the movement of saline water from deposits under the Delta to the western portion of the aquifer below the City of Stockton (DWR, 1967). The intrusion of saline water below Stockton resulted in groundwater with chloride levels in excess of 250 milligrams per liter (mg/l), which is considered unsuitable for continuous municipal supply purposes. The beginning of surface water delivery from New Hogan Reservoir in the 1960s coincided with the abandonment of several wells in the western part of Stockton that could no longer be operated for direct delivery because of elevated salinity concentrations (Brown & Caldwell, 1985).

In 1970, San Joaquin County began semi-annual water level monitoring and annual water quality sampling. Information was used to identify year-to-year changes in water levels and the location of the 300 ppm chloride concentration “saline front”. In 1967, DWR used the chloride concentration as an indicator of overall mineral quality of groundwater, and defined the 300 ppm chloride concentration as the boundary between good quality fresh water and poor quality saline water (DWR, 1967). Since that time, the 300 ppm chloride concentration has been used by the County as the line of the saline front in the semiannual groundwater monitoring reports (FCWCD, 1975-1999). The characterization of the location of groundwater with average chloride concentration of 300 ppm as a “front” is somewhat of a misnomer. Water samples used to develop these maps were collected from wells that are screened over large intervals and commonly penetrate several water production zones in the aquifer. Consequently, the concentration of chlorides in water extracted from these wells reflects the blending of water from several locations in the aquifer. The concentration of the extracted water is affected by the relative productivity of the well at different depths. Although it has not been confirmed throughout the study area, some data suggest that the highest chloride concentrations are present in shallow groundwater, and that chloride concentration generally decreases with increasing depth.

The County does not monitor groundwater quality northwest of the Stockton city limits. Data collected by the County suggests that the salinity front trends to the northwest toward Interstate 5 north of the City (Plate 8). Low concentrations of total dissolved solids (TDS) in the City of Lodi supply wells also suggest that saline intrusion has not progressed as far easterly in the northern portion of the study area as it has below the City of Stockton. Additional definition of the eastern extent of saline water migration north of the City of Stockton may be possible upon review of drip index analyses collected for water irrigation districts (WID) at locations west of Highway 99.

By the late 1970s, the center of groundwater extraction began shifting to areas east of the city of Stockton. This shift in the location of the groundwater depression occurred in part

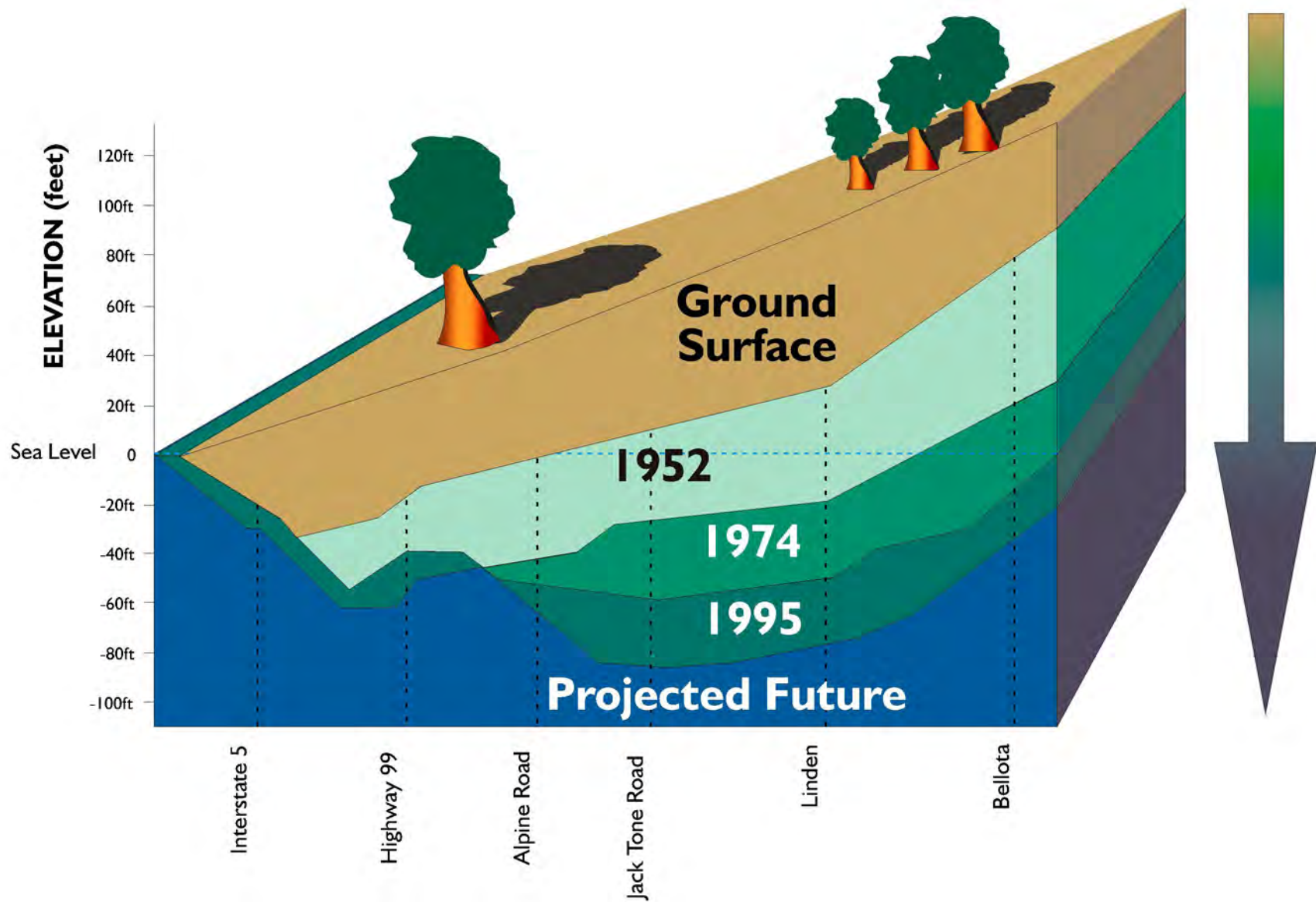
because surface water supplies from New Hogan Reservoir replaced a portion of the groundwater pumping in the western portion of Stockton. In addition, agriculture that is completely dependent on groundwater developed in the eastern portion of the county. The eastward expansion of the area of groundwater depression is illustrated in [Figure II-1](#), which shows historical groundwater levels along a southwest to northeast alignment through SEWD. Current groundwater levels following several recent wet years are higher than the 1995 levels shown.

As compared to conditions during the 1970s, recent groundwater levels are approximately 10 feet higher in the western portion of Stockton and a groundwater mound has formed below the diverting canal that divides the overdraft area from saline water. Elsewhere in the region, groundwater levels have continued to decline, as replacement surface water supplies have not yet been developed to reduce or eliminate the overdraft. South of the SEWD water treatment plant, the overdraft depression extends below the city and appears to include areas of saline water. Estimated groundwater pumping in San Joaquin County averaged 830,000 af/yr for the 1970-1990 time period according to the Integrated Ground and Surface Water Model (IGSM) (USBR, 1999). Before the introduction of agriculture, groundwater was at or near the surface in most of eastern San Joaquin County. The historical use of the groundwater resource has lowered water levels to over 70 feet below sea level, and to over 100 feet below ground surface (bgs) beneath some of the study area.

Natural groundwater recharge from the vicinity of the Mokelumne and Stanislaus rivers is evident on the groundwater level map presented in [Plate 8](#). Estimates of the seepage losses from individual rivers and creeks to the groundwater are available from the San Joaquin County IGSM (1970 to 1995 mean from the USBR, 1999) or from local water agencies. These estimates are summarized in [Table II-4](#) in annual acre-feet of gain (+) to the river or loss (-) from the river to groundwater.

A review of the groundwater elevation map on [Plate 8](#) reveals the following important features:

- A large groundwater pumping depression, as evidenced by lower groundwater elevations, is present in the central portion of the study area.
- Significant groundwater recharge derives from the general areas of the Stanislaus and Mokelumne River fans, as evidenced by higher groundwater elevations in these areas.
- Relatively minor groundwater recharge derives from areas of the lower Calaveras River and from smaller creeks.



Eastward Migration of  
Groundwater Depression

Figure II-1

**TABLE II-4**  
**ESTIMATES OF SEEPAGE LOSSES**

| River/Creek                                                          | IGSM<br>Estimates (af/yr) | Other<br>Estimates                                                                   |
|----------------------------------------------------------------------|---------------------------|--------------------------------------------------------------------------------------|
| Mokelumne River<br>(Clements to Lodi)                                | -57,031                   |                                                                                      |
| Calaveras River<br>(Bellota to San Joaquin River)                    | -32,752                   |                                                                                      |
| Mormon Slough<br>(Below Bellota)                                     | —                         | Relatively minor losses inferred (SEWD)                                              |
| Littlejohns Creek<br>(Below Farmington)                              | —                         | Observable but minor and not quantifiable<br>losses along localized reaches (CSJWCD) |
| Stanislaus River                                                     | 40,365                    |                                                                                      |
| Note: Negative values indicate losses from the river to the aquifer. |                           |                                                                                      |

As shown in [plate 9](#), the location of the salinity front based on the 300 ppm chloride concentration has fluctuated over time, most likely due to changes in the monitoring well network and pumping patterns, but has apparently migrated eastward from its location in 1953. Previous studies projected a continued eastward migration of saline water. San Joaquin County is currently evaluating saline groundwater conditions, with a focus on defining its sources and likely extent.

## WATER SUPPLY AND FLOOD CONTROL FACILITIES

The main water supply and flood control in the study area includes projects on the Mokelumne, Calaveras, and Stanislaus rivers and on Littlejohns Creek. These include Pardee and Camanche reservoirs on the Mokelumne River, New Hogan Reservoir on the Calaveras River, New Melones Reservoir on the Stanislaus River, and the Farmington Flood Control Project on Littlejohns Creek. In addition, water conveyance facilities have been constructed by NSJWCD to provide surface water supplies from Camanche reservoir, and by SEWD to provide surface water supplies from New Hogan and New Melones reservoirs. Major water supply and flood control facilities in the study area are shown on [Plate 2](#) and described below.

### Pardee Reservoir

Pardee Reservoir is on the Mokelumne River approximately 30 miles northeast of the City of Stockton. The reservoir is operated by EBMUD for domestic water supply and has a total gross storage capacity of 210,000 acre-feet (ARWRI, 1996). Water is diverted from Pardee Reservoir into the Mokelumne Aqueduct and conveyed to terminal storage and treatment facilities in the East Bay.

## **Camanche Reservoir**

Camanche Reservoir is located on the Mokelumne River downstream from Pardee Reservoir. The reservoir completed in 1964, is operated by EBMUD for domestic water supply and has a total gross storage capacity of 417,000 acre-feet (ARWRI, 1996). The combined seasonal flood control space of Camanche and Pardee reservoirs is up to 200,000 acre-feet. NSJWCD has a direct diversion right of up to 80 cubic-feet per second (cfs) from December 1 through July 1.

## **New Hogan Dam and Reservoir**

New Hogan Reservoir is on the Calaveras River approximately 28 miles northeast of the City of Stockton. The multipurpose reservoir, completed by the USACE in 1964, replaced an older storage project owned and operated by the City of Stockton for water conservation and partial flood control. The total gross storage capacity of New Hogan Reservoir is 317,000 acre-feet, of which up to 165,000 acre-feet is seasonally reserved for flood control storage.

Pursuant to a contract between the USBR, SEWD, and Calaveras County Water District (CCWD), about 57 percent of the New Hogan safe yield is allocated to SEWD and about 43 percent of the yield is allocated to CCWD. An agreement between SEWD and CCWD provides SEWD interim use of a portion of CCWD's allocation, pending development in Calaveras County. The safe yield of New Hogan Reservoir was estimated at 84,100 af/yr, as stated in the contract dated August 25, 1970 and referenced in the 1983 New Hogan Water Control Manual. In recent years, CCWD demands on New Hogan yield have been about 3,500 af/yr, riparian demands were about 13,000 af/yr, and SEWD has taken average annual deliveries of about 71,000 af/yr from New Hogan Reservoir.

## **New Melones Reservoir**

New Melones Dam and Reservoir (Figure I-1) was authorized in the Flood Control Act of December 22, 1944, for construction on the Stanislaus River by the USACE to help alleviate serious flooding problems along the Stanislaus and lower San Joaquin rivers. In 1962, Congress expanded and reauthorized the project (Public Law 87-874) for operation by the Secretary of the Interior as an integral part of the CVP. Construction of New Melones was completed in 1979, and the facility was transferred in 1980 to USBR for operation as part of the East Side Division of the CVP.

New Melones Reservoir, located approximately 60 miles upstream from the confluence of the Stanislaus River with the San Joaquin River, has a total storage capacity of 2.4 million acre-feet. The USBR is responsible for operating New Melones for the primary purposes of water supply, flood control, power generation, fishery enhancement, water quality improvement, and recreation. Flood control operations are conducted in accordance with USACE regulatory requirements.

The main water diversion point on the Stanislaus River is Goodwin Dam, about 1.9 miles downstream from Tulloch Dam. Goodwin Dam regulates releases from the Tulloch Powerplant

and provides for diversions to canals north and south of the Stanislaus River. Goodwin Dam also provides for the diversion of water into the Goodwin Tunnel for delivery to CSJWCD and SEWD.

During the past decade, USBR has had difficulty meeting all obligations of water delivery from New Melones Reservoir due to highly variable annual hydrologic conditions, including the most severe drought on record for the Stanislaus River watershed. Operations of New Melones have been further affected by the passage and implementation of the CVPIA, which requires the operation of CVP facilities to improve conditions for the protection and natural production of anadromous fish. Consequently, recent deliveries pursuant to CVP water service contracts to CSJWCD and SEWD have been intermittent and less than the full contract amounts. The USBR is undertaking water management planning action for both the interim and long-term operations of New Melones Reservoir.

### **Goodwin Tunnel and Upper Farmington Canal**

CVP water from the Stanislaus River for delivery to CSJWCD and SEWD is diverted during the irrigation season through the Goodwin Tunnel, and conveyed through the Upper Farmington Canal (Plate 1). The Goodwin Tunnel, completed in 1992, is approximately 3.3 miles long and 14 feet in diameter, with a design flow capacity of 850 cfs. It originates on the north bank of the Stanislaus River, just upstream from Goodwin Diversion Dam in Calaveras County. The Goodwin Tunnel connects with the Upper Farmington Canal, an open trapezoidal channel that extends approximately 7.9 miles to the Shirley Creek turnout with a flow capacity of 550 cfs. Water conveyed through Upper Farmington Canal flows through the natural creek system of Shirley, Hoods, and Rock Creeks and enters Farmington Reservoir via Rock Creek.

During the floods of January 1997, SEWD was requested to help flood control operations on the Stanislaus River by diverting up to 500 cfs through the upper Farmington Canal and into Farmington Reservoir. This action helped New Melones Reservoir flood control operations by reducing the duration of high flows that result in seepage damage to lands adjacent to the lower Stanislaus River. During this operation, damage occurred to the trash racks on the Goodwin Tunnel diversion, and erosion occurred in Shirley Creek and other natural stream channels used to convey Stanislaus River water.

### **Farmington Flood Control Project**

The Farmington Flood Control Project is a normally dry, flood control-only project on Littlejohns and Rock Creeks that was constructed and is operated and maintained by the Sacramento District, USACE. The project includes Farmington Dam and Reservoir, the Duck Creek Diversion on Duck Creek downstream from Farmington Dam, North Littlejohns Creek Diversion, and extensive channel improvements. The Farmington Project was authorized by the Flood Control Act of 1944 (Public Law 534, 78th Congress, 2nd Session). Construction of Farmington Dam and appurtenances began in July 1949 and was completed on November 1, 1951.

**Farmington Dam and Reservoir.** Farmington Dam is a homogeneous earthfill embankment, about 7,800 feet long that extends across both Littlejohns Creek and Rock Creek, a major tributary to Littlejohns Creek, approximately 1.5 miles upstream from their confluence. The main outlet works are located on the Rock Creek channel, near the right abutment of the dam, and auxiliary outlet works are located on the Littlejohns Creek channel. A connecting channel, located parallel to and behind the dam, conveys flow in Littlejohns Creek to Rock Creek for discharge through the main outlet works.

Farmington Dam was designed and constructed exclusively for flood control and is not intended to impound water over long periods of time. The dam rests on a pervious foundation with a minimal cutoff trench and has no positive cutoff, such as a grout curtain. In addition, the dam does not have an impervious core or transition zone. As a result, seepage losses occur, resulting in hydraulic uplift forces at the downstream toe during high pool levels. The hydraulic uplift forces are controlled by a series of relief wells along the downstream toe of the dam. There is additional concern of seismic activity when the dam foundation is saturated. The foundation could be subject to liquefaction and possible failure if an earthquake occurred while the foundation was saturated. As a flood-control-only structure, the chance of an earthquake occurring while the dam is impounding water is very low. However, irrigation season diversions of Stanislaus River water through Farmington Dam and the Rock Creek Diversion Structure by SEWD causes saturated foundation conditions for extended periods.

The existing 52,000 acre-foot reservoir covers an area of 4,100 acres in the Littlejohns and Rock Creek watersheds. Most of the reservoir lands are not owned in fee, but the USACE has flood control easements. The reservoir controls runoff from 212 square miles of foothill area drained by Littlejohns and Rock creeks. This area represents approximately 96 percent of the runoff area upstream from the town of Farmington. During the non-flood season, reservoir lands are used for agricultural and grazing purposes.

Inflow to the reservoir is derived mainly from rainfall, without significant effect from snowmelt, and is mainly concentrated in winter and spring months. Annual inflow to Farmington Reservoir has ranged from a minimum of zero in 1977 to a maximum of 219,000 acre-feet in 1983. Littlejohns Creek has zero flows from about June through October.

**Duck Creek Diversion.** The Duck Creek Diversion ([Plate 1](#)), approximately 3 miles northwest of Farmington Dam, is operated and maintained by San Joaquin County. Completed in November 1951 as part of the Farmington Project, the diversion works consist of a low compacted earth diversion dam across Duck Creek, outlet structures for releases to Duck Creek, and an unlined diversion channel which feeds into Littlejohns Creek. The Duck Creek Diversion provides flood protection to downstream areas along Duck Creek.

The outlet structure that controls releases to Duck Creek has a maximum capacity of 500 cfs, which is less than the downstream channel capacity of 700 cfs. An ungated concrete spillway discharges Duck Creek flows in excess of 500 cfs into an unlined channel, which extends southward about 5,000 feet to Littlejohns Creek. The design capacity of the diversion channel is 2,000 cfs with a 3-foot freeboard. Downstream from the Duck Creek diversion,

Littlejohns Creek and Lone Tree Creek converge at French Camp Slough, which discharges into the San Joaquin River south of the City of Stockton.

### **Rock Creek Diversion and Lower Farmington Canal**

The SEWD Rock Creek Diversion Structure, completed in 1994, is located within the Rock Creek channel approximately 140 feet downstream from the Farmington Dam main outlet works stilling basin. The structure diverts water from Rock Creek into the lower Farmington Canal. The diversion structure includes two radial gates on the main channel, a side weir on the left bank of the stilling basin that functions as a spillway, and four slide gates over the diversion ports into the canal.

The Rock Creek Diversion was designed for year-round operations, although the current water control manual for Farmington Dam limits its operation to the non-flood season. During recent years, the USACE has provided a temporary deviation to the water control manual that provided for flood-season diversions to the Lower Farmington Canal. SEWD has applied for a permanent deviation in the operation of the Rock Creek Diversion structure to permit year-round diversion of water to the Lower Farmington Canal. With the exception of the National Marine Fisheries Service (NMFS), all other coordinating agencies have concurred with the proposed revised operations. Through the winter of 2001-02, the SEWD will be allowed to divert year-round pursuant to the temporary deviation permit.

The Lower Farmington Canal, constructed by SEWD, conveys water from the Rock Creek Diversion Structure approximately 9.5 miles northwest to its terminus point near Peters. The canal is an open, trapezoidal channel 36 feet wide and 7 to 8 feet deep, with a capacity of approximately 300 cfs from the Rock Creek Diversion to Duck Creek, and a capacity of 200 cfs from Duck Creek to the terminus. At its terminus, the Lower Farmington Canal discharges into a 78-inch pipeline which, in-turn, feeds both a 54-inch pipeline to the SEWD Water Treatment Plant and a 66-inch pipeline serving the agricultural industry. Agricultural water deliveries are made at turnouts along the canal.

## **WATER DISTRICTS**

Surface water supplies in the study area are provided by CSJWCD, SEWD, and NSJWCD. [Plate 2](#) shows the locations of water districts included in and near the project study area.

### **Stockton East Water District**

SEWD is an agricultural and M&I water supplier in the northeastern portion of San Joaquin County. The district includes a total of 115,000 acres; (75,000 acres agricultural and 40,000 acres urban), serving a population of approximately 280,000. SEWD serves water to the City of Stockton and to agricultural areas east of Stockton. Total water use in SEWD is approximately 225,000 af/yr, with about 70 percent of the water used for agriculture, and about 30 percent for M&I use.

SEWD obtains surface water from the Calaveras and Stanislaus rivers. Both of these surface water sources have conveyance systems in place to transport water through agricultural areas to SEWD's water treatment plant for delivery to M&I customers. In addition, landowners within SEWD obtain water from the ground pumped from wells located throughout the District and distributed through private distribution systems. Annual groundwater pumping in SEWD is estimated at 150,000 af/yr, which exceeds the rate of groundwater replenishment in the SEWD area. SEWD overlies the central portion of the Eastern San Joaquin Groundwater Basin, where groundwater overdraft is most severe.

### **Central San Joaquin Water Conservation District**

CSJWCD overlies a portion of the Eastern San Joaquin County Groundwater Basin that is currently in severe overdraft conditions. Land uses within the CSJWCD are almost entirely agricultural. Water supplies are derived primarily from groundwater, with a portion of demands met by CVP surface water conveyed from the Stanislaus River.

Surface water delivered to CSJWCD is diverted by water users at multiple locations from the network of streams downstream of Farmington Dam. Because deliveries have only begun recently, diversion capacity on Littlejohns Creek has not yet been sufficiently developed to receive the full CVP contract level. Because CSJWCD and SEWD share similar water supply problems and both receive CVP water from the Stanislaus River, they closely coordinate the management of surface water supplies from the Stanislaus River to maximize the use of available surface water in the region. Groundwater pumping in CSJWCD is estimated at 120,000 af/yr.

### **North San Joaquin Water Conservation District**

NSJWCD overlies the northern portion of the Eastern San Joaquin County Groundwater Basin that is currently in severe overdraft conditions. Land uses within the NSJWCD includes urban uses within the City of Lodi, and agricultural uses, with vineyards the dominant crop, in the remaining areas of the district. Water supplies are derived primarily from groundwater, with a very small portion of demands met by surface water conveyed from the Mokelumne River.

## **REGIONAL WATER DEMANDS AND SUPPLY**

The water demands and supplies of Eastern San Joaquin County have been studied on numerous occasions, most recently in the USBR's ARWRI, completed January 1996. Owing to the regional characteristics of the Eastern San Joaquin County Aquifer, presentation of total demands and supplies is most informative when considered in a regional context. [Table II-5](#) presents a summary of total surface water and groundwater demands and supplies in Eastern San Joaquin County, as reported in the ARWRI.

**TABLE II-5**  
**CURRENT WATER SUPPLIES AND DEMANDS**  
**FOR EASTERN SAN JOAQUIN COUNTY<sup>1</sup>**

| Item                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | 1990 Levels (af/year) |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------|
| <b>Supply</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                       |
| Surface Water                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | 500,000               |
| Groundwater <sup>2</sup>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | <u>731,000</u>        |
| Total                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | 1,231,000             |
| <b>Demand</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                       |
| Applied                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                       |
| Agricultural                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | 1,120,000             |
| M&I                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | <u>111,000</u>        |
| Subtotal                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | 1,231,000             |
| Additional                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                       |
| Saline Intrusion Control <sup>3</sup>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | 70,000                |
| Groundwater Overdraft Control                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | <u>113,000</u>        |
| Subtotal <sup>4</sup>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | <u>183,000</u>        |
| Total                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | 1,414,000             |
| <b>Unmet Need</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | 183,000               |
| <p>1. Surface water and groundwater estimates are for Eastern San Joaquin County, including the areas served by: Oakdale Irrigation District, South San Joaquin Irrigation District, Central San Joaquin Water Conservation District, Stockton East Water District, North San Joaquin Water Conservation District, Woodbridge Irrigation District, the City of Lodi, and the City of Stockton.</p> <p>2. The sustainable groundwater yield of the Eastern San Joaquin Groundwater Basin is estimated at 618,000 acre-feet per year. Groundwater in excess of this amount is required to meet current demands, resulting in groundwater overdraft.</p> <p>3. Water needed to control saline water intrusion by establishing and maintaining a hydraulic barrier between an area of saline groundwater below the Delta and the groundwater depression east of Stockton.</p> <p>4. Total water demands exceed sustainable yield. This is the amount of additional water needed to meet current demands on a long-term basis.</p> <p>Source: American River Water Resources Investigation, USBR, 1996</p> |                       |

## **Demands**

As shown in [Table II-5](#), estimated annual groundwater pumping in San Joaquin County totals approximately 731,000 af/yr, which exceeds the estimated safe yield of the aquifer (618,000 af/yr) resulting in estimated groundwater overdraft of 113,000 af/yr. About 70,000 af/yr of the groundwater overdraft is due to pumping in northeastern San Joaquin County, with roughly 35,000 af/yr overdraft in the SEWD service area.

As described above, the lowering of the groundwater table has allowed the intrusion of saline water to the aquifer. If groundwater pumping in the region is reduced by 113,000 af/yr, the groundwater levels would remain depressed, and salinity intrusion would continue. Therefore, additional water would be required to provide salinity intrusion protection.

In the ARWRI, it was estimated that an additional 70,000 af/yr would be required to provide protection against salinity intrusion. A portion of this water would be recharged to the aquifer just east of the salinity front to establish a hydraulic barrier against further saline intrusion. The remaining water would be delivered to M&I areas that overlie the area of saline intrusion in replacement of current groundwater pumping. At present, no plans exist to develop groundwater injection facilities for salinity intrusion protection. The current combined unmet demands for groundwater overdraft and saline water intrusion are estimated at 183,000 af/yr.

## **Surface Water Supplies**

**Camanche Water Supply.** Camanche Reservoir, on the Mokelumne River, is owned and operated by EBMUD in conjunction with Pardee Reservoir to provide surface water supplies to EBMUD, Woodbridge Irrigation District, and the NSJWCD. Water supplies available to NSJWCD are based on a water right that provides up to 20,000 af/yr during most years. With the exception of the critically dry years of 1976-77 and 1987-92, this water right has been available to NSJWCD. However, the lack of water supply during these drought periods, coupled with recent trends in irrigation technologies has resulted in a decrease in the use of this water right.

Prior to the 1987-92 drought period, annual diversion for delivery to NSJWCD water users exceeded 13,000 af/yr. During the drought, many water users made additional investments in groundwater pumping and conveyance facilities and have not accepted surface water deliveries since that time. In addition, the rise in the use of micro-drip irrigation for vineyards has further discouraged surface water use because these systems are generally designed for direct delivery of groundwater, which can be provided at controlled pressures and with more consistent water quality.

Recent surface water diversions to NSJWCD have been as low as 3,000 af/yr. The remaining 17,000 acre-feet is available for diversion during the irrigation season. Delivery of this water during the non-irrigation season would be dependent on storage in Pardee or Camanche reservoirs.

**New Hogan Water Supply.** New Hogan Reservoir provides water for both agricultural and M&I water uses. Water for agricultural uses is diverted along the Calaveras

River for delivery to SEWD water users and is subject to conveyance losses of approximately 50 percent, which primarily returns to groundwater in the SEWD service area. M&I water from New Hogan is conveyed via a pipeline from the Calaveras River at Bellota Weir to the SEWD water treatment plant with no losses.

Current SEWD operations are based on up to 40,000 af/yr for M&I demands and 60,000 af/yr for agricultural water uses. Approximately 50 percent of the diverted agricultural water is lost through streambed percolation for underground recharge. Approximately 40,000 af/yr of the above described New Hogan Reservoir yield is available to SEWD as an interim water supply that will reduce as demands in Calaveras County increase.

**New Melones Water Supply.** SEWD and CSJWCD have long-term water service contracts with USBR for CVP water from New Melones Reservoir. CVP water conveyed to Farmington Reservoir is released to Rock Creek. The water either remains in Rock Creek for downstream diversion by water users in the CSJWCD, or is diverted at the Rock Creek Diversion Structure into the Lower Farmington Canal for delivery to SEWD, and to CSJWCD via Duck Creek.

The combined CSJWCD and SEWD contracts for CVP water supplies total 155,000 af/yr. The CSJWCD water service contract is for 80,000 af/yr, and includes 49,000 af/yr based on a firm water supply, and 31,000 af/yr based on an interim water supply. The SEWD water service contract, for 75,000 af/yr, is based on an interim water supply. The contracts specify that water would be delivered to CSJWCD first. Existing CSJWCD water diversion capacity downstream of Farmington Dam is limited to approximately 50,000 af/yr. Based on information provided by SEWD, CVP allocations to CSJWCD in excess of 50,000 af/yr are made available to SEWD.

As described previously, the availability of water from New Melones Reservoir allocated to the CSJWCD and SEWD contracts has been limited. The USBR completed an interim water management plan that allocated water supplies to multiple uses based on water availability. A long-term operations plan will be developed to allocate New Melones Reservoir water supplies. Analyses by USBR for interim water management programs on the Stanislaus River include projected combined CVP allocations to CSJWCD and SEWD. Over the simulation period, the year-to-year variability of the combined allocations to these districts ranges from zero to 90,000 af/yr, with higher quantities during wetter years.

**Water Transfer from SSJID.** SEWD has an agreement with SSJID for the annual acquisition of up to 30,000 af/yr. Actual annual quantities are determined based on hydrologic conditions, and may range from a minimum of 8,000 af/yr to a maximum of 30,000 af/yr. The acquired water is diverted at from the Stanislaus River through the Goodwin Tunnel and conveyed through the New Melones Conveyance system to SEWD.

## Water Conveyance Facilities

Regional water conveyance facility information was compiled from a variety of sources, including published maps and local water agency maps, files, and staff interviews. In the study area, surface water is conveyed through a combination of natural stream channels (controlled by check-structures), canals and pipelines. [Plate 2](#) shows the locations of streams used for conveyance, canals, and pipelines. Local and on-farm distribution systems are not shown.

## **CHAPTER III**

### **FUTURE CONDITIONS WITHOUT PROJECT**

This chapter describes projected future conditions for resources that are expected to change significantly over the 50-year time frame for the project. Due to the continuing groundwater overdraft and associated salinity intrusion problems, this chapter places particular importance on the projection of future water demands and supplies, and the impacts that could result from a loss of groundwater resources. With no development of groundwater recharge projects, the groundwater overdraft and salinity intrusion would further degrade the aquifer, and would ultimately result in a partial or total loss of the aquifer. The loss of a groundwater supply in eastern San Joaquin County would result in catastrophic economic consequences to the region.

The purpose of this chapter is to present projected future conditions that may occur if no groundwater recharge project were developed to meet all or portions of the groundwater overdraft and salinity intrusion demands. The without-project condition serves as the base against which the alternatives will be evaluated to determine effectiveness and to identify potential impacts and economic benefits.

#### **PROJECTED WATER DEMANDS AND SUPPLIES**

During the past several years, many water management agencies in the study area have been pursuing water supply projects in San Joaquin County. Although numerous studies have addressed the region's water supply problem, no project has been developed sufficiently to assume its implementation in the foreseeable future. Therefore, the future without-project condition includes no new water supply or conveyance facilities in the study area. Existing water supply facilities, as described in [Chapter II](#), would continue to operate according to existing practices.

#### **Projected Regional Water Demands and Supply**

Projected water demands and supplies in Eastern San Joaquin County for the year 2030, as presented in the USBR's ARWRI, form the basis for Future Without Project Conditions, as summarized in [Table III-1](#). These projections assume that the dominant land uses in the study area would remain agricultural, and that some agricultural and natural land uses would be converted to urban uses to accommodate population increases. Future urbanization would consist of low to medium density residential development, with supporting commercial, institutional, and industrial land uses. The year 2054 water demand is assumed similar to the year 2030 estimates.

TABLE III-1

**CURRENT AND PROJECTED WATER SUPPLIES AND DEMANDS  
FOR EASTERN SAN JOAQUIN COUNTY<sup>1</sup>**

| Item                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | 1990 Levels<br>(af/year) | 2030 Levels<br>(af/year) |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------|--------------------------|
| <b>Supply</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                          |                          |
| Surface Water                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | 500,000                  | 500,000 <sup>2</sup>     |
| Groundwater <sup>3</sup>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | <u>731.00</u>            | <u>747.000</u>           |
| Total                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | 1,231,000                | 1,247,000                |
| <b>Demand</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                          |                          |
| Applied                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |                          |                          |
| Agricultural                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 1,120,000                | 1,011,000                |
| M&I                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | <u>111.000</u>           | <u>236.000</u>           |
| Subtotal                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | 1,231,000                | 1,247,000                |
| Additional                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                          |                          |
| Saline Intrusion Control <sup>4</sup>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | 70,000                   | 70,000                   |
| Groundwater Overdraft Control                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | <u>113.000</u>           | <u>129.000</u>           |
| Subtotal <sup>5</sup>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | <u>183.000</u>           | <u>199.0000</u>          |
| Total                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | 1,414,000                | 1,446,000                |
| <b>Unmet Need</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | 183,000                  | 199,000                  |
| <p>1. Surface water and groundwater estimates are for Eastern San Joaquin County, including the areas served by: Oakdale Irrigation District, South San Joaquin Irrigation District, Central San Joaquin Water Conservation District, Stockton East Water District, North San Joaquin Water Conservation District, Woodbridge Irrigation District, the City of Lodi, and the City of Stockton.</p> <p>2. This amount does not reflect potential reduction of up to 40,000 af/yr in New Hogan Reservoir supply that is available to Calaveras County Water District.</p> <p>3. The sustainable groundwater yield is estimated at 618,000 acre-feet. Currently, groundwater overdraft is meeting the full demand.</p> <p>4. Water to maintain a hydraulic barrier between saline Delta groundwater and the groundwater depression below the Stockton area to control saline water intrusion.</p> <p>5. Total water demands exceed sustainable yield. This is the amount of additional water needed to meet current demands on a long-term basis.</p> <p>Source: American River Water Resources Investigation, USBR, 1996</p> |                          |                          |

As shown in [Table III-1](#), the annual groundwater overdraft in Eastern San Joaquin County is projected to increase from 113,000 af/yr to 129,000 af/yr (USBR, 1996). Based on conditions described in the ARWRI, an additional 70,000 af/yr would also be required for salinity intrusion protection. As a result, total unmet demands are projected to increase from 183,000 to 199,000 af/yr between 1990 and 2030. Although the projected increase is relatively small compared to existing total demand without a project, the additional unmet demand would be served by groundwater pumping in a basin already in severe groundwater overdraft conditions.

As noted on [Table III-1](#), the projected available surface water supply to Eastern San Joaquin County of 500,000 af/yr has not been reduced to reflect potential growth in Calaveras County beyond the planning horizon. As described in [Chapter II](#), SEWD is currently using approximately 40,000 af/yr of yield from New Hogan Reservoir on an interim basis. As Calaveras County water demands increase, this supply will decrease. If Calaveras County uses its full allocation of New Hogan Reservoir safe yield the available surface water supply to San Joaquin County would decrease to 460,000 af/yr and unmet demands would increase to nearly 240,000 af/yr.

Several other trends may increase the unmet demands in the study area. For example, large areas of land in the eastern portion of the county are being converted from dry farming to irrigation for vineyards. These lands are reliant on groundwater only, since they are not within the service areas of the water districts. San Joaquin County is undertaking a surface and groundwater management study that will update demand projections, but that study has not yet been completed. In addition, there has been a shift in preference from surface water to groundwater for some agricultural uses. During the extended 1987-1992 drought period when little or no surface water was available in the study area, many surface water users turned to groundwater to meet their needs. In some cases, wells were installed or deepened to accommodate these needs. Since that time, some water users have not chosen to purchase surface water, recognizing that groundwater pumping capacity would be needed at all times.

The introduction of micro-drip irrigation technology has also affected surface water use in the study area. When this technology is applied to existing vineyards, total water demands are reduced, but the demand shifts entirely to groundwater resulting in reductions in surface water deliveries and increased groundwater pumping. This trend has been evident within SSJID and NSJWCD service areas. When applied to new developments where no water demand existed previously, such as those in the eastern portion of the study area, groundwater demands increase.

The recent designation of the Calaveras River and Mormon Slough below New Hogan as critical habitat for Central Valley steelhead trout may affect future operations of New Hogan Reservoir. South of the study area, South San Joaquin Irrigation District (SSJID) has been making changes to water use practices to make water available for sale to other agencies in San Joaquin County, including SEWD. Water conservation and potential increased groundwater pumping in the SSJID area could reduce groundwater recharge on the Stanislaus River Fan thereby reducing the rate of subsurface flow to the southern portion of the overdrafted aquifer. The magnitude of this potential effect is not known.

## **SEWD and CSJWCD Water Demands and Supply**

Under future without project conditions in the year 2030, SEWD would continue to obtain water from three sources; groundwater, surface water from the Calaveras River (New Hogan Reservoir), and surface water from the Stanislaus River (New Melones Reservoir). CSJWCD would continue to obtain water from groundwater and surface water from the Stanislaus River (CVP deliveries). The without project condition does not include the development of new water supplies, or storage, conveyance, and treatment facilities in the study area.

With the continued use of existing water supplies and facilities, SEWD estimates that without project surface water requirements will rise to 95,000 af/yr. This would consist of 60,000 af/yr for SEWD M&I demands and 35,000 af/yr SEWD agricultural demands. If these demands can not be met using existing supplies from New Hogan and New Melones Reservoirs, projected groundwater pumping in SEWD would increase above current levels.

CSJWCD would continue to obtain water from groundwater and CVP deliveries of surface water from the Stanislaus River. After surface water supplies are utilized, remaining demands would be met from groundwater pumping, and groundwater overdraft would continue. It is assumed that CSJWCD water diversion facilities along Littlejohns Creek would remain at a maximum capacity of 50,000 af/yr. Groundwater would remain the largest source of water to the district, and would be used to satisfy unmet demands, resulting in the continuation of groundwater overdraft.

Analyses by USBR for interim water management programs on the Stanislaus River include projected combined CVP allocations to CSJWCD and SEWD. Over the simulation period, the year-to-year variability of the combined allocations to these districts ranges from zero to 90,000 af/yr, with higher quantities during wetter years. Deliveries of CVP water from New Melones Reservoir in excess of 50,000 af/yr would be made available to SEWD for M&I or agricultural uses. The New Hogan supply would include the interim use of up to 40,000 af/yr of CCWD allocation. As demands in Calaveras County increase, the availability of this supply would decrease.

In summary, it is anticipated that the total overdraft in the SEWD and CSJWCD areas would remain at approximately 70,000 af/yr under the future without project condition. However, if the interim water supply from New Hogan Reservoir becomes unavailable due to increased demands by CCWD, this amount could increase to 110,000 af/yr, with approximately 70,000 af/yr overdraft in the SEWD area.

## **NSJWCD Water Demands and Supply**

As described in [Chapter II](#), NSJWCD has reduced its use of surface water from the Mokelumne River in recent years from a peak of about 13,000 af/yr to about 3,000 af/yr. It is anticipated that the unavailability of surface water during critically dry years, coupled with irrigation requirements for micro-drip systems and cost differences would continue to discourage water users from using surface water supplies.

If NSJWCD does not put this water right to beneficial use, it risks losing access to the unused portion, potentially as much as 17,000 acre-feet in some years. For the purposes of this study, it is estimated that the water right would be maintained and that up to 17,000 af/yr could be available for additional surface water diversion during non-drought years. If this water is not diverted during the irrigation season, it would need to be stored in Camanche or Pardee reservoirs by EBMUD for use by NSJWCD. This study does not address operations of EBMUD facilities. For the purposes of this planning study, therefore, it is estimated that a long-term average of 10,000 af/yr would be available to NSJWCD for non-irrigation season diversion.

## **GROUNDWATER LEVELS AND SALINITY INTRUSION**

As described above, the available surface water supplies to SEWD and CSJWCD will not be adequate to meet their demands, and groundwater overdraft would continue to meet a portion of the total demands. The continued groundwater overdraft to meet agricultural and urban water demands will further deplete groundwater reserves, resulting in a wide range of direct and indirect consequences.

Previous studies have indicated that as groundwater reserves in the eastern San Joaquin County groundwater basin are further depleted, groundwater levels would continue to decline and the area of the groundwater depression would enlarge (SJCFC & WCD, 1985). The expansion and deepening of the groundwater depression would induce continued salinity intrusion from the west (SJCFC & WCD, 1985). Salinity intrusion results in the nearly irretrievable loss of the groundwater resource.

Recently, agricultural land uses in eastern San Joaquin County, outside of the SEWD service area, have been gradually shifting from dry pasture to permanent crops. It is anticipated that this trend would continue, and that groundwater pumping to support the permanent crops will also increase. An increase in groundwater pumping east of SEWD would reduce the rate of groundwater recharge from Sierra Nevada runoff, and may further contribute to declining regional groundwater levels.

If allowed to continue, the groundwater overdraft would result in the loss of groundwater supplies for both urban and agricultural water uses. In addition, the decline of groundwater levels could result in land subsidence that would jeopardize the public's investment in important infrastructure.

## **Economic Impacts of Groundwater Overdraft**

Estimating the range of economic impacts associated with future aquifer deterioration requires an estimate of the rate of deterioration. This study does not include a simulation of projected groundwater levels or groundwater quality conditions, and therefore does not project aquifer conditions at a specific future time, or identify a time by which the aquifer would become deteriorated beyond productive use. However, previous estimates have indicated eastward migration rates of approximately 150 to 250 ft/yr (DWR, 1985).

As groundwater overdraft of the eastern San Joaquin County Groundwater Basin continues, the depletion and irretrievable loss of groundwater resources would result in a wide range of economic impacts. If overdraft is allowed to continue indefinitely, the groundwater resource would eventually become unusable. As described above, current and projected agricultural and M&I groundwater use in the county exceeds 700,000 af/yr. As the aquifer continues to deteriorate, portions of agricultural production dependent on groundwater would be affected, and potentially lost, resulting in economic and social consequences. In addition, continued municipal water service would require treatment or the importation of replacement supplies. The following discussion describes the economic consequences associated with these losses.

**Impacts to Agricultural Water Use.** Agricultural water use in San Joaquin County would be affected by the deepening of groundwater levels and increased levels of salinity. As water levels continue to decline and the area of groundwater depression expands, more energy will be required to pump groundwater, resulting in an increased cost of water to agricultural water users. This could affect the continued economic viability of some agricultural operations, and may induce changes in crop selection.

Rising salinity levels can affect irrigation water use, crop yields, and crop selection. To date, most of the groundwater in the county used for irrigation is not saline enough to cause any affect on crops because most of the agricultural production is sufficiently east of the current area of salinity intrusion. However, some individual wells within the saline intrusion area below the urban area have chloride at levels unacceptable for production of salt-sensitive crops. If the extent of salinity intrusion continues to expand eastward, agricultural areas would become affected and economic damages would result from equipment deterioration and cropping pattern changes. Generally, crops with higher salt tolerance levels provide lower revenue than many of the crops currently grown in the region.

**Impacts to M&I Water Use.** As water levels continue to decline, water costs to M&I water users will increase. Energy costs will increase in proportion to the additional pumping lift required to extract groundwater. Additional pumping equipment may be required, and wells would need to be deepened or replaced to maintain groundwater extraction capacity.

Increased salinity would also affect the ability to continue using some wells for M&I service. As the area of saline water continues to enlarge, more wells would be affected by elevated salinity, and may need to be abandoned or operated under limited circumstances, because the ability to blend groundwater with surface water supplies would be reduced.

At times, especially during drought periods, it is possible that salinity levels in some parts of the City would be at or near economically damaging levels. This would result in end-user salinity damages, and would accelerate corrosion in wells and pumps that are subjected to elevated salinity levels. Corrosion of distribution and delivery equipment could result in significant costs to local water districts their end-users.

Presently, if it becomes necessary to remove a well from service, water supplies are not reduced because excess pumping capacity is available in the system. As more wells become affected by salinity, the available excess capacity would be reduced and the flexibility to modify operations to meet demands with existing pumping capacity would diminish. Replacement wells could be constructed at a cost of \$750,000 each elsewhere in or near the City. Relocation of wells in response to aquifer deterioration, however, may ultimately exacerbate the problem by shifting the pumping locations eastward and accelerating the rate of saline intrusion.

**Impacts Associated with Loss of the Aquifer.** The impacts to agricultural and M&I water users described above represent losses associated with a reduction in the extractive value of groundwater. It must be recognized that groundwater is a natural asset that provides both extractive and in-situ resource benefits. In-situ benefits provided by groundwater in the Eastern San Joaquin Groundwater Basin include a buffer value against drought, subsidence avoidance, saline water intrusion avoidance, long-term water reserves, and ecological service.

Groundwater provides a buffer, or insurance service, when managed conjunctively with surface water supplies. Since surface water supplies fluctuate, groundwater acts as important insurance to the maintenance of continuous water supply levels. In periods of low surface water availability, groundwater is extracted more heavily to meet agricultural and M&I demands. In eastern San Joaquin County, groundwater is conjunctively used with surface water supplies from the Mokelumne, Calaveras and Stanislaus rivers. The lack of off-stream storage or groundwater recharge facilities, however, limits the use of available surface water during wet periods.

As groundwater levels continue to decline, the potential for land subsidence in areas not currently impacted by severe groundwater overdraft will increase. Historical and recent subsidence in the study area has been minor, and has not resulted in significant economic losses. Subsidence would result in damages to major infrastructure, such as transportation, water distribution, and sewer collection systems. Replacement and repair and costs associated with these damages could be high. The compaction of aquifer materials that causes subsidence would also impair the aquifer as a storage reservoir. Compaction results in an irretrievable loss of aquifer storage capacity that would not be recovered if groundwater levels rise.

As salinity intrusion continues to deteriorate groundwater conditions, the existing groundwater freshwater reserve becomes threatened, and the aquifer's value as a fresh water distribution system would be severely reduced. The current pattern of water use inherently relies on the availability of groundwater at the locations of the wells. Recharge to the aquifer occurs from the east, from agricultural and M&I return flows, and from stream channels in the study area. The recharged water is distributed at no cost to the water user through the aquifer materials. This historical and current benefit would be lost if the aquifer becomes degraded from salinity. Water distribution systems would be required, at significant capital, operations, and maintenance costs.

## **VEGETATION, WILDLIFE, FISH, AND SPECIAL-STATUS SPECIES**

The extensive agricultural development in eastern San Joaquin County provides ancillary environmental benefits that would be affected if land uses are forced to change in response to losses in groundwater supply. These include foraging areas for wildlife species, the flow of irrigation water through natural stream channels, which promotes riparian vegetation and fisheries habitat, and the islands of habitat created by drainage canals. If land uses continue as described above, these conditions would remain in place. If regional agricultural land uses were significantly modified or eliminated due to the loss of the groundwater resource, these conditions would be substantially affected and potentially lost.

## **CHAPTER IV**

### **PROBLEMS AND OPPORTUNITIES**

#### **WATER RESOURCES PROBLEMS AND NEEDS**

The primary water resources problem in the study area under current and future conditions is groundwater overdraft and associated salinity intrusion. This problem has been growing for over 50 years, and will continue if replacement water supplies are not obtained to reduce or eliminate over-reliance on groundwater to meet agricultural and M&I demands. With no development of water supply projects to reduce groundwater overdraft, salinity intrusion will continue and may ultimately result in a loss of portions of the aquifer. The implementation of water management improvements, such as more efficient irrigation practices or urban water conservation, are already in place (e.g. “Sally-Save-Water” campaign by SEWD) and will help delay the deterioration of the aquifer, but water savings from such measures are not adequate to overcome projected groundwater overdraft. The need for replacement water supplies to offset continued groundwater pumping is high, and must be met as soon as possible to reduce the risk of continued losses of the aquifer.

During the past several years, many water management entities, including SEWD, have been pursuing additional water supply projects in San Joaquin County. Although numerous studies have addressed the region’s water supply problem, no project has developed sufficiently to assume its implementation in the foreseeable future. Previous studies in the region have also shown that no single project would provide adequate water supply to completely overcome the severe groundwater overdraft problem. Thus, any individual project must be considered to be part of a total solution, and should be evaluated on its ability to provide a portion of the total needs and reduce the severity of the problem.

#### **Groundwater Depletion**

As discussed in [Chapters II and III](#), the current groundwater overdraft problem in eastern San Joaquin County is projected to continue and intensify in the future. As groundwater depletion in eastern San Joaquin County continues, the salinity intrusion will likely expand eastward from its current location. As the area of saline intrusion expands, larger portions of the aquifer will become affected by degraded water quality that may be unsuitable for continued M&I uses or the current level of agricultural production.

The historical preference for the use of groundwater in meeting urban and agricultural needs in San Joaquin County reflects some of the benefits that groundwater provides. These include stability of supply, high water quality (no treatment is required), and ease of access (no collection and conveyance system is required). These benefits have been realized in San Joaquin County for decades as groundwater has provided a buffer against surface water supply shortages, and has provided a built-in distribution system in the aquifer. The stability afforded with a reliable groundwater supply has helped

Stockton grow into the eleventh largest city in California and contributes significantly to the \$1.2 billion annual agricultural output. The future economic viability of this region is therefore dependent on the protection of existing water resources and the development of supplemental water supplies to maintain a strong economy and to sustain healthy growth in the future.

As groundwater levels decline, the impacts to agricultural and urban water users become evident. The deepening and lateral expansion of the groundwater depression area would likely induce continued eastward migration of saline water, which would expand the area of degraded fresh water reserves in the aquifer. Urban areas would be affected by increased costs for additional treatment to remove chlorides, construct replacement wells, or import replacement supplies. Continued operation of wells in higher saline conditions will increase corrosion on pumping, distribution, and end-user equipment, resulting in higher operations and maintenance costs. The increased costs for replacement water supplies may affect industrial and residential choices, and potentially result in further increases in groundwater pumping.

Increased chlorides or other salts in groundwater could also reduce agricultural yields, force the conversion to lower value salt-tolerant crops, or ultimately render lands unsuitable for crop production. Each of these changes would result in reduced agricultural revenues to the region. For both M&I and agricultural groundwater users, increased energy will be required to provide the pumping lift to extract water from greater depths, resulting in higher water costs.

## Water Supply Needs and Trends

Projected water demands for San Joaquin County assume that the predominant land use would remain agricultural and that some agricultural and natural land uses would be converted to urban uses to accommodate population increases. Future urbanization would consist of low to medium density residential development, with supporting commercial, institutional, and industrial land uses.

As described in [Chapters II and III](#), San Joaquin County has a significant need for additional surface water supplies to reverse the current over-reliance on groundwater. That need will continue and slightly increase over the next 30 to 50 years, as projected unmet demands are expected to be satisfied through additional groundwater pumping. It is anticipated that between 1990 and 2030 the annual groundwater overdraft would increase from 113,000 af/yr to 129,000 af/yr, and that 70,000 af/yr would continue to be required for salinity intrusion protection. Thus, the total unmet demand would increase from 183,000 af/yr to 199,000 af/yr. Although the projected increase in total demand is relatively small as compared to existing levels of over 1.4 million acre-feet, meeting this additional demand through groundwater pumping would further contribute to the groundwater overdraft and salinity intrusion problems.

As noted on [Table III-1](#), the projected available surface water supply to San Joaquin County of 500,000 af/yr has not been reduced to reflect potential growth in Calaveras County beyond the planning horizon. SEWD is currently using approximately 40,000 af/yr of yield from New Hogan Reservoir that would be available to support Calaveras County water demands. As Calaveras County water

demands increase, the supply available to eastern San Joaquin County will decrease further contributing to the groundwater overdraft problems.

Groundwater would remain the largest source of water to SEWD and CSJWCD, and would be used to satisfy unmet surface water demands, resulting in the continuation of groundwater overdraft. For this study, it is anticipated that the amount of groundwater overdraft within SEWD and CSJWCD areas would remain at approximately 70,000 af/yr. As described in [Chapter III](#), the projected surface water shortage in the SEWD and CSJWCD areas is estimated at approximately 49,000 af/yr. This amount is based on the continued operation of existing facilities and does not include demands to restore groundwater levels or repel salinity intrusion.

In addition to the surface water supply shortage in eastern San Joaquin County, it is likely that overdraft will further expand in response to recent trends in land developments, water user preferences, and irrigation technologies. As described in [Chapter III](#), water demands will increase due to large areas of land in the eastern portion of the county that have been recently brought into irrigation for vineyards. Also as described in [Chapter III](#), water users in some portions of the study area have reduced their use of surface water over the past 10 years. The expansion of micro-drip irrigation technologies for vineyards has further reduced demands on existing surface water supplies and increased groundwater demands.

## OPPORTUNITIES FOR RECHARGE OF UNUTILIZED SURFACE WATER

The opportunity exists to recharge unutilized surface water available during both the flood season and the irrigation season. Available and potentially available supplies include flood season releases from New Melones, New Hogan, and Camanche reservoirs, Farmington Dam, and unused irrigation supplies from the Calaveras and Stanislaus Rivers. Recharging excess water will help alleviate groundwater overdraft and reduce the rate of saline water intrusion while maintaining current supplies. A summary of potential water supplies and their availability is provided in [Table IV-1](#) and a discussion follows.

### Stanislaus River Water Supplies

Water from the Stanislaus River is diverted from an impoundment created by Goodwin Dam. Diverted water is conveyed through the Goodwin Tunnel to the upper Farmington Canal and discharged to Shirley Creek. The water flows along Shirley Creek into the Farmington Flood Detention Basin where it is released to Rock Creek through the Farmington Dam outlet structure. Below Farmington Dam, water can be diverted from Rock Creek to the Lower Farmington Canal for delivery to SEWD or to several distributary streams that convey water to users in CSJWCD.

The draft Farmington Dam water control manual restricts the operation of the Rock Creek diversion to the Lower Farmington Canal to non-flood periods (May 16 through September 30). SEWD has applied for a permanent deviation from this restriction that would allow diversions year-round. In recent years, the USACE has issued interim deviation permits to allow winter diversion.

SEWD, the USACE, and NMFS are presently involved in a review of potential impacts to fisheries that would result from a permanent deviation. With the exception of NFMS, all cooperating agencies have agreed with the proposed permanent deviation.

Table IV-1

POTENTIAL WATER SUPPLIES FOR BASE PROJECT

| Water Source                                         | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                               | Flood Season<br>Supply for Base<br>Project                                                                    | Frequency<br>for<br>Base Project | Irrigation Season<br>Supply for Base<br>Project (Optional) |
|------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------|----------------------------------|------------------------------------------------------------|
| <b>Stanislaus River</b>                              | Under Stanislaus River interim operations, SEWD and CSJWCD CVP contract allocations would be up to 90,000 af/yr. BOR planning simulations show the maximum allocation would be available in 1 of 3 years. The maximum allocation is 35,000 af above current demand of 55,000 af/yr. Assume 10,000 af/yr for base project                                                                                                                                                  | 10,000 af/yr<br>CVP deliveries from<br>New Melones that can<br>be routed through<br>Farmington Reservoir      | Greater than<br>1 in 3 yrs       | None                                                       |
| <b>Littlejohns<br/>Creek</b>                         | SEWD has applied for a water right on Littlejohns Creek. Average runoff is about 51,000 af/yr. Assume 10,000 af/yr for base project.                                                                                                                                                                                                                                                                                                                                      | 10,000 af/yr<br>Local inflow to<br>Farmington Res. after<br>meeting instream<br>flows on Littlejohns<br>Creek | ~2 in 3 yrs                      | None                                                       |
| <b>Calaveras River</b>                               | SEWD receives an average delivery of 71,000 af/yr from New Hogan Reservoir. Diverted water flows through streams for delivery to irrigation customers. Measured system end losses in 1997 totaled 19,000 af. SEWD can revise operations to reduce losses and recover downstream flows for application to recharge facilities. Assume 5,000af/yr, or 25% of end losses, can be recovered. SEWD can also reschedule New Hogan allocation to provide flood season deliveries | 5,000 af/yr<br>Rescheduled<br>deliveries to SEWD<br>from New Hogan<br>Reservoir                               | ~2 in 3 yrs                      | 5,000 af/yr<br>Recovered portion of<br>end- losses         |
| <b>Mokelumne<br/>River</b>                           | North San Joaquin Water Conservation District holds a water right for 20,000 af/yr that is available in all but critical years. Recent deliveries have been about 3,000 af/yr, leaving up to 17,000 af/yr available for diversion.                                                                                                                                                                                                                                        | <b>10,000 af/yr<br/>Unused NSJWCD<br/>water right</b>                                                         | ~2 in 3 yrs                      | 7,000 af/yr                                                |
| <b>South San<br/>Joaquin<br/>Irrigation District</b> | Annual water purchase pursuant to agreement would range from 8,000 af to 30,000 af, depending on hydrologic conditions. Assume average availability of 10,000 af/yr.                                                                                                                                                                                                                                                                                                      | None                                                                                                          | Every year<br>(amount varies)    | None                                                       |
| <b>EBMUD<br/>American River<br/>Diversion</b>        | San Joaquin County is pursuing a portion of the water supply.                                                                                                                                                                                                                                                                                                                                                                                                             | None                                                                                                          | Non-dry years                    | None                                                       |
| <b>Stockton Delta<br/>Diversion</b>                  | Potential for 4,500 af in 2015 increasing to 44,000 af by 2050 (Montgomery Watson, Feb. 2001)                                                                                                                                                                                                                                                                                                                                                                             | None                                                                                                          | All years                        | None                                                       |
| <b>TOTAL</b>                                         |                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | 35,000 af/yr                                                                                                  | ~2 in 3 years                    | 12,000 af/yr                                               |

Estimates of Stanislaus River operations were derived from USBR model simulations for the Stanislaus River Interim Operations Plan using the STANMOD spreadsheet model. This model is used to evaluate alternative allocation of supplies from New Melones Reservoir. The version of STANMOD used in this analysis does not include water acquisitions for the Vernalis Adaptive Management Plan (VAMP), or the recently proposed CVPIA (b)(2) management plan. In the STANMOD analysis used for this study, New Melones Reservoir is operated to meet flow and water quality objectives on the San Joaquin River with no additional water from other sources. It is anticipated that, when complete, an analysis of VAMP will result in equivalent or slightly higher deliveries to CVP contractors.

**CVP Water Service Contracts.** SEWD and CSJWCD hold water service contracts with the USBR for delivery of water conserved in New Melones Reservoir. Water deliveries under these contracts are subject to reductions due to hydrologic limitations and environmental requirements in the Stanislaus River and the San Joaquin River. Based on recently completed long-term model simulations for the Stanislaus River Interim Operations Plan, combined annual allocations of CVP water supplies to SEWD and CSJWCD range from a maximum of 90,000 af/yr in wet years to zero in critically dry and some dry years. Current demand of CVP water supplies by SEWD and CSJWCD are limited to about 55,000 af/yr. The analyses show that about 90,000 acre-feet would be allocated during 35 percent of the years, which provides a supply of about 35,000 acre-feet above current demands during those years.

**Flood Water Releases.** The SEWD and CSJWCD contracts with the USBR provide for the delivery of additional water above the contract quantities if available. In addition, the United States permits delivery of “a temporary supply of water not storable for project purposes of infrequent and otherwise unmanaged flood flows or short duration” under annual contracts (referred to as 215 water). These have been offered to the districts in the past. Finally, over the past few years the USBR and the Fish and Wildlife Service have requested SEWD to take flood release water through its conveyance facilities during non-irrigation periods in order to reduce the quantity of flow released in to the Stanislaus River.

Recently completed long-term model simulations for the Stanislaus River Interim Operations Plan include an accounting of releases for rain flood events. Annual amounts that could be diverted through the existing facilities vary widely, and would depend on the coincident operations of Farmington Dam and New Melones Dam. Water deliveries from the Stanislaus River to the study area are conveyed through the Farmington Flood Control Basin. The conveyance of Stanislaus River water would need to be coordinated with timing of local inflow to Farmington Flood Control Basin, so that flood protection below Farmington Dam is not reduced.

During extremely wet yet years, such as 1986 and 1997, flood water would be available from New Melones Dam over a 6-month period, which would provide opportunities for diversion of more than 50,000 acre-feet from the Stanislaus River to the New Melones Conveyance System. However, wet years such as these are rare, and average annual amounts would be considerably less. More typical years include opportunities during February and March, which would be limited by Farmington Dam operations. For the purposes of this study, potential flood water diversions from the Stanislaus River

have not been included in potential recharge estimates (Table VI-1).

### Littlejohns Creek Water Supplies

Inflow from rain events into Farmington Reservoir is released to Rock and Littlejohns creeks at Farmington Dam in accordance with the Farmington Dam water control manual. Water is released as quickly as possible within the constraints of the outlet works and downstream channel capacity, thus no water is stored behind Farmington Dam for extended durations.

Daily discharges from Farmington Dam from October 1949 through September 2000 were reviewed to identify potential water supplies for groundwater recharge. The simulations assumed for conservative planning purposes that between 50 and 65 percent of the water released from Farmington Dam could be diverted for project purposes. It was further assumed that a total diversion capacity ranging from 200 cfs to 500 cfs could be developed within the SEWD and CSJWCD areas. It is unlikely that water would be diverted at a single location, rather, it would be diverted at several locations. For example, 300 cfs could be diverted into the Lower Farmington Canal and an additional 200 cfs could be diverted at several locations along Littlejohns Creek.

Assuming 50 percent of the release from Farmington Dam could be utilized, and that a total diversion capacity 500 cfs is available, the Littlejohns Creek would provide an average supply of about 16,000 af/yr for a recharge project, as shown in Table IV-1. This average, however, includes amounts in excess of 40,000 acre-feet in wet years. For the purposes of this study, an average annual amount of 10,000 acre-feet is assumed to be potentially available.

**TABLE IV-2**

#### **POTENTIAL LITTLEJOHNS CREEK WATER SUPPLY**

| <b>Water Year Type</b>                                                          | <b>Average Available Supply<br/>(1,000 af)</b> |
|---------------------------------------------------------------------------------|------------------------------------------------|
| Wet                                                                             | 42                                             |
| Above Normal                                                                    | 22                                             |
| Below Normal                                                                    | 8                                              |
| Dry                                                                             | 11                                             |
| Critically Dry                                                                  | 3                                              |
| Average                                                                         | 16                                             |
| <b>Assumed Amount for Study</b>                                                 | <b>10</b>                                      |
| Assumptions:                                                                    |                                                |
| 1. Up to 50 percent of releases from Farmington Dam are available for diversion |                                                |
| 2. Total diversion capacity of 500 cfs                                          |                                                |

Presently, SEWD does not hold a water right permit to divert flows that originate in the Littlejohns Creek watershed, but has submitted an application to the State Water Resources Control Board.

### Calaveras River Water Supplies

SEWD diverts water from the Calaveras River at the Bellota Weir, which controls releases from the River to Mormon Slough. Water is conveyed through Mormon Slough, the Old Calaveras River channel, and other distributaries including Mosher Slough to agricultural water users. It is estimated that up to 50 percent of the water conveyed through natural channels percolates to groundwater. A pipeline conveys a portion of the water supply to the SEWD treatment plant for delivery to M&I customers. No agricultural water deliveries are made from the pipeline.

The USBR holds a water right to conserve water in New Hogan Reservoir. The USBR contracts 43 percent of project yield to Calaveras County Water District (CCWD) and 57 percent of project yield to SEWD. The long-term average yield is about 71,100 af per year, including approximately 13,000 af/yr that is released to satisfy riparian water rights.

Historically, CCWD has used about 3,500 af/yr and allowed SEWD to use the remainder of the project yield. Between 1976 and 1999, diversions for SEWD averaged 76,211 af/yr. This study assumes that this amount would continue to be available to SEWD. If a portion of this water supply is reduced due to increased demand by CCWD, groundwater pumping in SEWD would increase.

**System End-Losses.** In 1997, SEWD made daily measurements of flows below the most down-stream diversion points on the Calaveras River, Mosher Slough, and Mormon Slough. The results of these measurements show that during June through September, a total of about 19,000 acre-feet flowed past these three points. SEWD has further determined that a portion of these flows could either be re-captured at the downstream points or system operations could be modified through tailwater management programs to reduce these flows and make a portion of this water available for groundwater recharge. For the purposes of this study, it is estimated that about 30 percent of the end losses could be recovered for use, providing a water supply of about 5,000 af/yr.

### Mokelumne River Water Supplies

As discussed in [Chapter II](#), approximately 17,000 acre-feet of NSJWCD's 20,000 acre-feet water right is available for diversion during the irrigation season during most years. As shown in [Table VI-1](#), the average unused portion of NSJWCD water right during the flood season that is available for the base project is assumed to be 10,000 af/yr.

## OPPORTUNITIES FOR SEASONAL HABITAT DEVELOPMENT

The development of urban and agricultural areas over the past century combined with the construction of flood control and water supply facilities has caused a loss of seasonal habitat areas in

eastern San Joaquin County. An opportunity exists to simultaneously reduce salinity intrusion by methods that reduce groundwater overdraft and provide seasonal habitat in the study area.

Seasonal wetland habitats are among the most biologically productive natural ecosystems in the world. Such seasonal habitat provides shelter and produce immense volumes of food for birds, insects, and plants. They are especially important to the survival of several threatened and endangered species. The FWS estimates that up to 43 percent of the threatened and endangered species rely directly or indirectly on seasonal wetland habitat for their survival (EPA, August 2000). In addition to their habitat importance, seasonal wetlands help improve water quality, process organic and inorganic wastes, and reduce sediment.

A variety of seasonal habitat types could be developed, including shallow seasonal habitat areas adjacent to riverine habitats along streams and creeks, permanently dedicated lands that would provide seasonal habitats in the winter with native habitat in the summer, and seasonally flooded fields with little vegetative growth. If winter flood water is to be recharged, a seasonal habitats habitat would be a valuable asset not only to migrating waterfowl, but would also improve groundwater recharge capabilities by filtering turbid water before it is recharged into the aquifer.

## **OPPORTUNITIES FOR INCREASED FLOOD DAMAGE REDUCTION**

The diversion of flood waters to recharge and seasonal habitat areas could reduce in-stream flows and downstream stages during flooding events. These areas could serve as bypasses, by slowing down and eventually recharging flood flows. In addition, the ability to divert water to recharge and seasonal habitat areas could enhance the evacuation of water from flood control space in existing facilities. The resulting increase in flexibility in the operation of flood damage reduction facilities could provide both economic and environmental benefits.

## **OPPORTUNITIES FOR RECREATION AND EDUCATION**

More than half of all U.S. adults hunt, fish, birdwatch, or photograph wildlife. These activities rely heavily on seasonal habitats and substantially add to the national economy. In fact, each year an estimated 50 million people spend \$10 billion dollars observing and photographing seasonal habitat-dependent birds (EPA, August 2000). Seasonal habitats provide many educational possibilities as well, including the opportunity to learn about and see wildlife up close in a natural state. By creating seasonal habitats, recreational and educational opportunities in eastern San Joaquin County would bring substantial money into the local economy.

## **CHAPTER V**

### **DRILLING AND TESTING**

During the winter and spring of 1999-2000, potential groundwater recharge areas were identified and drilled and recharge locations and techniques tested at four pilot-scale recharge sites in the study area (Plate 2). The purpose of the pilot tests was to evaluate recharge characteristics and techniques in the various geologic regions in the study area to verify assumptions regarding recharge project viability based on previous recharge tests.

This chapter summarizes the rationale and activities behind the selection of pilot test sites and groundwater recharge techniques, the design, operation, and results of the pilot tests, and draws conclusions from the tests in light of previous tests and related geologic data. The results of additional mapping and trenching in the western part of the study area are also summarized.

#### **SELECTION OF PILOT RECHARGE TEST SITES**

Due to the time constraints associated with the need to conduct the pilot tests during the winter and spring of 1999-2000, a search was conducted to identify candidate sites for pilot tests concurrent with the compilation and analysis of the existing data to identify regional areas favorable for groundwater recharge. A total of 13 candidate sites were identified in coordination with the project's local sponsors and landowners. The following variables were considered in reviewing candidate sites for pilot testing:

- Geology
- Soils (including presence or absence of hardpan)
- Previous recharge data
- Groundwater data
- Water conveyance and availability
- Land use and availability (including willingness of the landowner)
- Site accessibility (including accessibility in the winter months)
- Sensitive habitat zones
- Potential HTRW or pesticide contamination

In addition, local input and field reconnaissance was used in selecting pilot test sites. The complete results of this compilation were described in a technical memorandum and the regional data is summarized in [Chapter II](#) of this study.

A matrix summarizing the site selection variables was developed and each variable was evaluated to identify sites that would provide the most representative data for the geologic subregion and be feasible to test during winter-spring 2000 (Montgomery Watson, 1999). The best pilot recharge test sites were selected based primarily on the following more limited criteria:

- Geologic conditions representative of the geologic subregions
- Land availability (willingness of a property owner to lease the property)
- Water availability (surface water for the test)
- Site accessibility (for monitoring during anticipated wet winter conditions)
- Absence of environmental issues (such as HTRW contamination that could impact the feasibility of the test)

After analysis of the variables, four sites were tentatively selected for pilot testing for winter-spring 2000 (Lakso, Allen, SEWD, and Thompson, each of which are named after the property owner and identified in [Plate 2](#)).

## SELECTION OF PILOT RECHARGE TECHNIQUES

The study considered a variety of groundwater recharge measures including: an unlined canal, three surface recharge techniques (flooded fields, shallow spreading basins, and excavated basins), dry wells, injection wells, stream-bed enhancement, detention basins, and surface water delivery in-lieu of pumping. Previous recharge studies and projects in the area have provided at least some information on the benefits and limitations of some of the recharge measures. Each measure is discussed in greater detail in [Chapter VI](#).

Based on cost, environmental setting, other existing projects, and the project goal of seasonally recharging floodwater while establishing seasonal habitat, three primary measures were selected for pilot-scale testing:

- Excavated pits
- Shallow spreading basins
- Flooded fields (undisturbed and ripped)

A drilling program was conducted in November – December 1999 to confirm the suitability of candidate sites for pilot testing, to aid in selection of appropriate recharge techniques and design parameters, and to obtain additional information regarding the geologic conditions of the unsaturated zone at the test sites.

## DRILLING PROGRAM RESULTS AND PILOT TEST DESIGNS

The drilling included at least one exploratory boring to the water table and installation of at least one piezometer to monitor the effects of the pilot testing on the water table at each site. The drilling program results and the on-site and background monitoring piezometers are summarized at each site are summarized in [Table V-1](#). Complete results, including boring logs and piezometer construction details, were presented in a technical memorandum and are included in [Appendix B](#). The study boring logs and selected existing well drillers logs in the study area were entered to the San Joaquin County Groundwater Data Management Model (DMM). Data in the DMM were used to assess the regional geology by the construction of four geologic cross sections through the study area ([Appendix B](#)).

**TABLE V-1**  
**DRILLING AND PIEZOMETER SUMMARY**

| Site                                                                                                             | On-Site Drilling <sup>2</sup> |                                 | Background Monitoring Piezometer Or Existing Well                                                          | Approximate Pre-Test Depth to Water (ft) | Hardpan (Depth in feet if present) |
|------------------------------------------------------------------------------------------------------------------|-------------------------------|---------------------------------|------------------------------------------------------------------------------------------------------------|------------------------------------------|------------------------------------|
|                                                                                                                  | Site Piezometer               | Additional Shallow Soil Borings |                                                                                                            |                                          |                                    |
| <b>Lakso</b>                                                                                                     | LA-PZ-01                      |                                 | LA-PZ-02                                                                                                   | 88                                       | Not present                        |
| <b>Allen</b>                                                                                                     | AL-PZ-01                      | AL-SB-02<br>AL-SB-03            | AL-PZ-02                                                                                                   | 118                                      | 4 – 5.5                            |
| <b>SEWD</b>                                                                                                      | SEWD-PZ-01                    |                                 | Cutter <sup>1</sup><br>Boz-So <sup>1</sup><br>T-1 <sup>1</sup><br>A-4 <sup>1</sup><br>60-acre <sup>1</sup> | 34                                       | Not present                        |
| <b>Thompson</b>                                                                                                  | TH-PZ-01                      |                                 | Neilsen <sup>1</sup>                                                                                       | 80                                       | 6 - 8                              |
| Notes:                                                                                                           |                               |                                 |                                                                                                            |                                          |                                    |
| 1. Existing well being used for background monitoring.                                                           |                               |                                 |                                                                                                            |                                          |                                    |
| 2. Locations of all piezometers and borings completed for the study are included in <a href="#">Appendix B</a> . |                               |                                 |                                                                                                            |                                          |                                    |

Based on existing data and the results of the drilling program, the recharge techniques to be tested at each site were selected. Summaries of the pilot test designs are included in [Appendix C.1](#). The recharge techniques tested at each site are summarized in [Table V-2](#) and discussed in more detail in [Chapter VI](#). Three surface recharge techniques were selected for testing ([Figure V-1](#)):

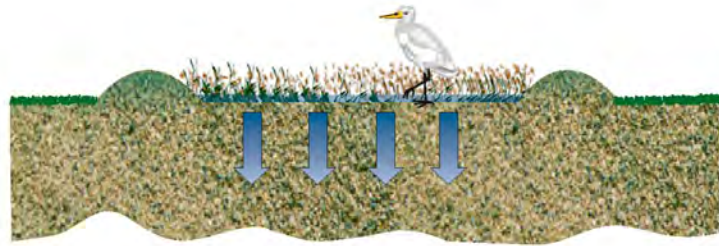
- **Flooded Fields-** Field flooding was tested under a variety of conditions common in the study area. These included undisturbed soils where hardpan was absent (Lakso), undisturbed soils where hardpan was present (Allen and Thompson), and a field that has previously been disturbed by ripping (SEWD).
- **Shallow Spreading Basins-** Where fine-grained surface soils restrict percolation or where water storage facilities might double as recharge facilities (SEWD).
- **Excavated Pits-** Where deep hardpan would normally restrict percolation (Allen and Thompson).

Each pilot test included one on-site piezometer and a least one background well or piezometer to allow the effects of the groundwater recharge to be distinguished from normal water level changes due to precipitation. The groundwater monitoring did not address potential water quality issues, which were intended to be addressed in a subsequent demonstration project as necessary.

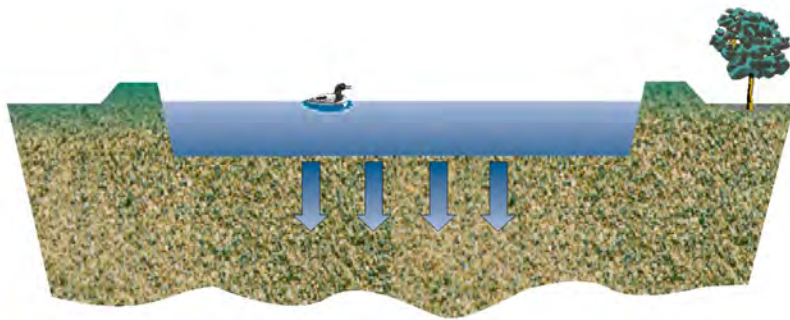
**TABLE V-2**  
**LOCATIONS OF TESTED RECHARGE MEASURES**

| Geologic Conditions                                                                                                                                                                                                                                                  |                     | Groundwater Recharge Technique |        |                               |               |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------|--------------------------------|--------|-------------------------------|---------------|
| Geologic Subregion                                                                                                                                                                                                                                                   | Geologic Formation  | Flooded Field                  |        | Shallow Spreading Basin       | Excavated Pit |
|                                                                                                                                                                                                                                                                      |                     | Undisturbed                    | Ripped |                               |               |
| Pre-Modesto formations                                                                                                                                                                                                                                               | Riverbank Formation | Allen                          |        |                               | Allen (2)     |
| Mokelumne Fan                                                                                                                                                                                                                                                        | Modesto Formation   | Lakso                          |        | Lockeford (USGS) <sup>1</sup> |               |
| Calaveras Fan                                                                                                                                                                                                                                                        | Modesto Formation   |                                |        | Linden (USGS) <sup>1</sup>    |               |
| Littlejohns and Bear Creek Interfans                                                                                                                                                                                                                                 | Modesto Formation   | Thompson                       | SEWD   | SEWD (2)                      | Thompson (2)  |
| Note:<br>1. Two recharge tests were conducted prior to this study in the 1980's by the United States Geological Survey (USGS); the resulting favorable recharge rates and were discussed in TM 1 (MW, 1999) and are summarized in this chapter of this study Report. |                     |                                |        |                               |               |

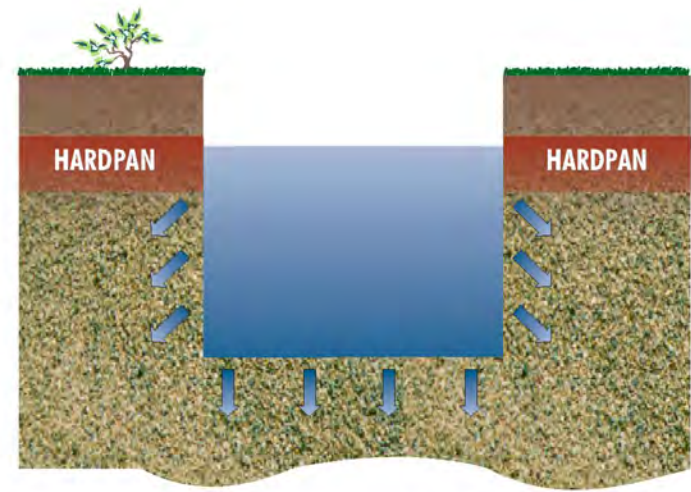
## Surface Groundwater Recharge Techniques



Field Flooding



Spreading Basin



Excavated Pit

Figure V-I

## RESULTS OF PILOT TEST PROGRAM

This section presents the results of pilot-scale testing and interpretations concerning groundwater flow directions and rates, potential for perching in the vadose zone, and the potential effects of recharge on the aquifer's water levels.

### Field Flooding (Undisturbed and Ripped)

The field flooding technique refers to the groundwater recharge method of applying shallow water to a field that has not been excavated. To maximize recharge, this technique is most appropriate at locations where shallow impediments to vertical flow, such as hardpan, are either not present or have been penetrated, usually by ripping. Field flooding was done at all four pilot test sites during the study.

- **Lakso**- located on the Mokelumne River Fan near the town of Lockeford; has not been modified by deep ripping.
- **Allen**- underlain by undisturbed hardpan; located on a Pre-Modesto formation near the town of Peters.
- **SEWD**- a 60-acre parcel adjacent to the water treatment plant; modified by deep ripping prior to this study.
- **Thompson**- located approximately one mile south of the town of Collegeville; has not been modified by ripping.

#### ***Lakso Site Flooded Field.***

**Site Conditions** - The Lakso site is located on the Mokelumne River Fan, north of the river near the town of Lockeford. Prior to testing, the site had been cleared of a previous orchard. Shallow soils at this site have not been deeply ripped. Data collected from the drilling program, field reconnaissance, and aerial photography indicated that an undisturbed flooded field would be the most appropriate groundwater recharge technique at this site given its sandy soils and lack of hardpan. The off-site piezometer LA-PZ-02 was located approximately 1200 feet to the northeast of the test site to provide background water levels in response to rainfall and regional water level changes.

A bermed flooded field, approximately 100-ft by 100-ft square on undisturbed ground, was constructed, operated and monitored by NSJWCD from December 1999 through the middle of February 2000. Water was conveyed from the Mokelumne River to the pilot test site via the NSJWCD pipeline. An on-site piezometer (LA-PZ-01) adjacent to the test and a background piezometer (LA-PZ-02) were installed for monitoring of groundwater levels. A site map of the property is included in [Appendix C.1 \(Lakso site diagram\)](#).

A total of 7.2 AF of water was recharged over the six-week test period ([Appendix C.1](#)). Continuous testing at this site indicated a relatively consistent infiltration rate of approximately 0.75 ft/day through the duration of pilot testing ([Appendix C.1](#)). During the winter test period, turbidity of the source water was low, evaporation losses were minimal, and algae growth was non-existent. Precipitation during and subsequent to the test is also included in [Appendix C.1](#) to aid in the interpretation of the data. Almost four inches of precipitation occurred during the week of January 31, 2000, and a slight rise in background piezometer PZ-LA-02 is apparent. A noticeable groundwater rise began in LA-PZ-01 after three weeks of pilot testing as compared to the background piezometer LA-PZ-02 as shown in the hydrograph ([Appendix C.1](#)). Background piezometer LA-PZ-02 had a much more muted response during the same period, indicating that most of the response in LA-PZ-01 is due to the recharge from the test. The response of LA-PZ-02 to agricultural pumping beginning in May is also apparent. The sustained percolation rate and rapid response in on-site groundwater elevation indicate that the recharged water was reaching the water table approximately 85 feet bgs. After completion of the test, groundwater levels in LA-PZ-01 steadily declined as regional groundwater use resumed with the start of the summer irrigation season.

**Groundwater Flow Direction and Rate** - The average direction and rate of movement of recharged water that reaches the water table was estimated using the formula for average linear groundwater velocity of Fetter (1988) ([Appendix D.1](#)). At the Lakso site, primarily silty sands and sands were encountered in the site boring, and the grain size analyses conducted on the drilling samples indicated an effective grain size of 0.2 mm for the sands. The hydraulic conductivity (K) of the sands can be estimated at 90 ft/day using the Hazen method (Fetter, 1988). Since the site is located near the groundwater divide beneath the Mokelumne River ([Plate 8](#)), recharged water could eventually flow either southward toward the ESJ groundwater depression or northward toward Sacramento County depending on seasonal and annual conditions. The analysis of groundwater direction and rates is summarized below in [Table V-3](#) for all four test sites.

**Potential for Vadose Zone Perching** - Recharged groundwater typically moves downward through the vadose zone at a velocity that is approximately equal to the vertical hydraulic conductivity (K) ([Bouwer, 1999](#)), which is generally about a tenth of the horizontal hydraulic conductivity. At the Lakso site, the recharged groundwater could thus be expected to migrate vertically at approximately 1 to 10 ft/day. The water table is at approximately 85-ft bgs and the recharged groundwater reached the water table in approximately 21 days ([Appendix C.1](#)). These data indicate that the actual average vertical hydraulic conductivity is near the middle of this range at approximately 4 ft/day.

If stratigraphic horizons are present in the vadose zone with a lower permeability than the bottom of the basin, then perching above the restricting horizon will occur and a groundwater mound will form. The relatively rapid response of the water table to both the start and end of recharge ([Appendix C.1](#)) suggests perched groundwater mounding at the site was not significant, but confirmation would require piezometers in the vadose zone. The theoretical height of perched mounding was estimated using an equation for water table mounding presented in [Bouwer \(1999\)](#) ([Appendix D.1](#)). The only apparent potential restricting horizon in the boring log for LA-PZ-01 is a silt to silty sand zone between 36 and 43 feet bgs ([Appendix B](#)). This layer was assumed to have a vertical hydraulic

conductivity of one order of magnitude (one-tenth) less than that in the average for the overlying horizons. The results ([Appendix D.1](#)) indicate that the resulting mound would reach a height of roughly 6 to 27 feet above the top of the restricting layer, and would have the potential to reach the bottom of the recharge basin and reduce the recharge rate. However, the height of the mound is often overestimated by this technique because it assumes lateral continuity, and low permeability horizons are generally discontinuous in alluvial sediments.

TABLE V-3

## SUMMARY OF HORIZONTAL GROUNDWATER FLOW DIRECTIONS AND RATES

| Site                                                                                    | Groundwater Data <sup>1</sup> |                    | Estimated Average Horizontal Hydraulic Conductivity (ft/day) <sup>2</sup> | Resulting Average Regional Horizontal Velocity (ft/year) <sup>3</sup> | Eventual Fate of Recharge Water <sup>4</sup>       |
|-----------------------------------------------------------------------------------------|-------------------------------|--------------------|---------------------------------------------------------------------------|-----------------------------------------------------------------------|----------------------------------------------------|
|                                                                                         | Direction                     | Gradient (ft/mile) |                                                                           |                                                                       |                                                    |
| Lakso                                                                                   | North-northeast to east       | 7 to 26            | 10 to 100<br>(silty sand to sand)                                         | 24 to 900                                                             | Uncertain<br>(could flow north or south; see text) |
| Allen                                                                                   | West to southwest             | 4 to 7.5           | 10 to 100<br>(silty sand to sand)                                         | 14 to 260                                                             | ESJ GW depression                                  |
| SEWD                                                                                    | Northeast to Southwest        | 6.6 to 11          | 1 to 10<br>(silt to silty sands)                                          | 2 to 38                                                               | ESJ GW depression                                  |
| Thompson                                                                                | North-northwest               | 8 to 10            | 1 to 10<br>(silt to fine sands)                                           | 3 to 36                                                               | ESJ GW depression                                  |
| Notes:                                                                                  |                               |                    |                                                                           |                                                                       |                                                    |
| 1. Based on SJC FC&WCD (1998, 1999) semi-annual Groundwater Monitoring Program reports  |                               |                    |                                                                           |                                                                       |                                                    |
| 2. Estimated based on site-specific boring logs, Hazen method, and/or DWR regional data |                               |                    |                                                                           |                                                                       |                                                    |
| 3. Using equation in <a href="#">Appendix D.1</a> for flow velocity                     |                               |                    |                                                                           |                                                                       |                                                    |
| 4. Based on SJC FC&WCD (1998, 1999) semi-annual Groundwater Monitoring Program reports  |                               |                    |                                                                           |                                                                       |                                                    |

**Potential for Groundwater Mounding** - The Lakso groundwater monitoring data indicate that a mound of approx. 3.6 feet formed in the water table beneath the site relative to the background piezometer LA-PZ-02 ([Appendix C.1](#)). The mound was continuing to grow at the end of the six-week test, indicating that equilibrium had not been reached. Additional piezometers would have been needed to monitor the diameter of the mound because the effects of seasonal natural recharge cannot be distinguished from the effects of the test in the single background piezometer, which was

approximately 500 feet downgradient to the northeast.

The height and the rate of growth of a mound at the water table is governed by the recharge rate, physical size of the basin, and hydraulic characteristics of the soils (Davies, 2000). A model using Hantush's equation (Bouwer, 1978) was used to estimate the height of a site-specific mound above the water table (Appendix D.1). Using actual and estimated parameters, the site-specific estimated height of the water table mound at the end of the six-week pilot test would theoretically range from 0.5 to 4 ft (Table V-5).

The model based on the Hantush equation was also used to model a hypothetical 80-acre recharge site at the Lakso property with seasonal recharge (100 continuous days/year for 3 wet years in a row) at an average recharge rate of 0.5 ft/day. If the hydraulic conductivity is assumed to be 10 ft/day, the resulting mound would rise to approximately 60 to 70 ft above the water table. If the hydraulic conductivity is assumed to be 1 ft/day, the resulting mound would be at the ground surface within the first season of recharge, and the recharge rate would be negatively impacted.

#### **Potential Regional Groundwater Effect (10,000af/yr Base Project) -**

A groundwater mound would produce local radial groundwater flow outward from the recharge site during and for some period of time following recharge. Such radial flow from a single 80-acre site would generally be inconsequential on a regional scale, but since the site is located near the groundwater divide beneath the Mokelumne River (Plate 8), a project at this particular site could have a significant local effect. A potential base project in the northern part of the study area (NSJWCD distribution system) was modeled using the IGSM (Appendix D.2). The simulation indicates that recharge of 10,000 af/year in the area of NSJWCD (in combination with either western or distributed recharge in SEWD and CSJWCD) would create a regional rise in water levels of 10 feet or less (Appendix D.2). The IGSM thus indicates that the recharged water will not have a significant impact on regional flow patterns.

The interpretations of the test data in this chapter are based on very limited geologic data and groundwater monitoring, a relatively small volume and duration of recharge testing, and theoretical modeling based on a number of untested simplifying assumptions (including the presence of uniform, isotropic layering of infinite lateral extent). The long-term demonstration and base projects will require more extensive geologic investigation, modeling, and groundwater monitoring to predict and confirm the response of the vadose zone and aquifer to groundwater recharge (Chapter VIII).

TABLE V-4

## SUMMARY OF VADOSE ZONE VERTICAL FLOW AND PERCHING POTENTIAL

| Site<br>(& Approx.<br>Depth to<br>Water)                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | Vadose Zone Average Vertical Flow<br>(K <sub>v</sub> ) |                                                      | Potential<br>Restricting Layer<br>(bgs) <sup>3</sup> | Estimated<br>Restricting<br>Layer Vertical<br>K (ft/day) <sup>4</sup> | Height of Mound<br>above<br>Restricting<br>Layer<br>(& bgs) <sup>5</sup> |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------|------------------------------------------------------|------------------------------------------------------|-----------------------------------------------------------------------|--------------------------------------------------------------------------|
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | Apparent Rate<br>(ft/day) and<br>Period <sup>1</sup>   | Expected Rate<br>(ft/day) and<br>Period <sup>2</sup> |                                                      |                                                                       |                                                                          |
| <b>Lakso</b><br>(85 ft)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | 4<br>(21 days)                                         | 1 to 10<br>(8 to 85 days)                            | Silt & silty sand<br>from 36 to 43 ft                | 0.2 to 0.4 ft/day                                                     | 6 to 27 ft<br>(9 to 30 ft bgs)                                           |
| <b>Allen</b><br>(120 ft)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | ND                                                     | 0.1 to 1<br>(120 to 1200<br>days)                    | Silty to clayey zone<br>from 34 to 44 ft             | 0.05 to 0.2<br>ft/day                                                 | 20 ft to GS<br>(14 to 0 ft bgs)                                          |
| <b>SEWD</b><br>(34 ft)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | ND                                                     | 0.1 to 1<br>(34 to 340 days)                         | No discrete layer<br>present                         | NA                                                                    | NA                                                                       |
| <b>Thompson</b><br>(80 ft)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | ND                                                     | 0.1 to 1<br>(80 to 180 days)                         | No discrete layer<br>present                         | NA                                                                    | NA                                                                       |
| Notes:<br>1. Based on water table response during pilot tests; ND = not determined due to lack of water table response<br>2. 10 % of estimated horizontal hydraulic conductivity (based on boring log) and depth to water<br>3. Based on site boring log<br>4. Estimated based on boring log and/or apparent flow rate; overlying layer assumed to be 10 % of this value for calculation<br>5. Using Bouwer's (1999) equation in <a href="#">Appendix D.1</a> ; Bgs = below ground surface; NA = not applicable |                                                        |                                                      |                                                      |                                                                       |                                                                          |

A total of 6.5 AF of water was recharged over the five-month test period at the Allen pilot test site ([Appendix C.1](#)). An initial infiltration rate of approximately 0.14 ft/day declined rapidly to less than 0.05 ft/day, presumably as the layer of soil above the hardpan became saturated ([Appendix C.1](#)). Shortly after testing began, waterfowl (including ducks and cranes) were observed nesting and feeding on sedge, which grew in parts of the test site. There were no noticeable changes in the groundwater levels that can be attributed to the pilot tests on the Allen property. The flooded field test on the Allen property indicates that an undisturbed flooded field over thick hardpan is not an efficient method for recharging groundwater. Because relatively little water infiltrated in the Allen flooded field, an analysis of the effects of recharged groundwater at the site is provided below in the discussion of the Allen excavated pits.

The interpretations of the Lakso test data are based on very limited groundwater monitoring (only two piezometers), a relatively small volume and duration of recharge testing, and relatively simple modeling based on a number of assumptions. Each site in the long term demonstration and base projects will require more extensive groundwater monitoring to predict and confirm the response of the vadose zone and aquifer to groundwater recharge ([Chapter VIII](#)).

**TABLE V-5**  
**SUMMARY OF GROUNDWATER MOUNDING POTENTIAL**

| Site<br>(& Test Period &<br>Infiltration Rate)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | Site Data                                     |                                 | Static Depth<br>to Water<br>(ft bgs) <sup>3</sup> | Estimated<br>Horizontal<br>Hydraulic<br>Conductivity<br>(ft/day) <sup>4</sup> | Theoretical Mound<br>Height (ft) <sup>5</sup> |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------|---------------------------------|---------------------------------------------------|-------------------------------------------------------------------------------|-----------------------------------------------|
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | Apparent<br>Mound<br>Height (ft) <sup>1</sup> | Site<br>Dimensions <sup>2</sup> |                                                   |                                                                               |                                               |
| <b>Lakso Pilot Test</b><br>(6 weeks;<br>0.7 ft/day)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | 3.6                                           | 100 x 100 ft                    | 85                                                | 1<br>10<br>100                                                                | 4<br>< 1<br>0                                 |
| <b>Lakso<br/>Demonstration<br/>Project</b><br>(100 days for 3 years;<br>0.5 ft/day) <sup>6</sup>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | NA                                            | 80-acres                        | 85                                                | 1<br>10<br>100                                                                | G.S. <sup>7</sup><br>49-57<br>8-9             |
| <b>Allen Pilot Test</b><br>(2 months, 1 ft/day)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | None<br>detected                              | 2000 sq. ft.                    | 120                                               | 1<br>10                                                                       | 1.6<br>0                                      |
| <b>Allen Demonstration<br/>Project</b><br>(100 days for 3 years;<br>1 ft/day) <sup>6</sup>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | NA                                            | 80-acres                        | 120                                               | 1<br>10                                                                       | G.S. <sup>7</sup><br>100-120                  |
| <b>SEWD Pilot Test</b><br>(2 months; 0.8 ft/day)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | None<br>detected                              | 2000 sq. ft.                    | 34                                                | 1<br>10                                                                       | 1<br>0                                        |
| <b>SEWD<br/>Demonstration<br/>Project</b><br>(100 days for 3 years;<br>0.5 ft/day) <sup>6</sup>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | NA                                            | 80-acres                        | 34                                                | 1<br>10                                                                       | G.S. <sup>7</sup><br>G.S. <sup>7</sup>        |
| <b>Thompson Pilot Test</b><br>(10 weeks,<br>2 ft/day)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | None<br>detected                              | 20 x 20 ft                      | 80                                                | 1<br>10                                                                       | <1<br>0                                       |
| <b>Thompson<br/>Demonstration<br/>Project</b><br>(100 days for 3 years,<br>1 ft/day) <sup>6</sup>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | NA                                            | 80-acres                        | 80                                                | 1<br>10                                                                       | G.S. <sup>7</sup><br>G.S. <sup>7</sup>        |
| Notes:<br>1. Based on water table response during pilot tests; NA = not applicable (for hypothetical 80-acre project).<br>2. Actual<br>3. Based on site boring log.<br>4. Estimated based on boring log and/or apparent flow rate; overlying layer assumed to be 10 % of this value.<br>5. Modeled using Hantush equation (Bouwer, 1999); see <a href="#">Appendix D.2</a> .<br>6. Hypothetical example for discussion purposes only.<br>7. G.S. indicates mound reaches ground surface or bottom of excavation. Range of results for demonstration projects reflects 3 annual cycles of recharge. |                                               |                                 |                                                   |                                                                               |                                               |

**SEWD Flooded Fields.** The SEWD site is a 60-acre parcel located east of and adjacent to the SEWD water treatment plant. Groundwater recharge testing was underway at the SEWD site for nearly four years prior to pilot-scale testing. According to SEWD, previous flooding of portions of the 60-acre parcel with backwash water from the water treatment plant had indicated an average long-term infiltration rate of approximately 0.8 ft/day. At least some portion of the 60-acre parcel had been previously ripped to a depth of approximately 5 to 8 feet below ground surface. An on-site piezometer (SEWD-PZ-01) was installed and a network of five existing background wells near the test site were monitored to provide regional background groundwater levels for comparison to SEWD-PZ-01 ([Appendix C.1](#)).

Operation and monitoring of the SEWD east flooded field was conducted from May through September of 2000. Backwash water from the SEWD treatment plant was conveyed to the 100 ft by 100 ft flooded field where it was contained in a two-foot high perimeter berm. Initial infiltration rates of approximately 10 ft/day steadily decreased to approximately 2 ft/day in September ([Appendix C.1](#)).

The anomalously high infiltration rates for the flooded field led to further investigations of the site. Old aerial photographs obtained by SEWD indicate that the site is in the approximate location of a former house. It is possible that the presence of an underground leach line or other conduit associated with this former structure contributed to the high infiltration rates. As a result, the southeast flooded field was constructed significantly away from the location of the former structure. Initial percolation rates in the southeast flooded field were approximately 4 ft/day and have steadily declined to approximately 1.5 ft/day ([Appendix C.1](#)). A total of approximately 50 AF of water has been recharged over the test period at the SEWD pilot test site ([Appendix C.1](#)).

Water levels in piezometer SEWD-PZ-01 and other background wells in the vicinity fluctuated during the testing, but SEWD-PZ-01 did not show a clear response to recharge relative to background wells. Prior to pilot testing, it was noted that the SEWD site overlies a groundwater mound that is believed to be due to previous and on-going recharge from the SEWD Groundwater Recharge Project, infiltration from the water treatment facility ponds, and/or losses from the Stockton Diverting Canal. As a result, local groundwater levels at this site are high compared to regional levels. The lack of water table response to testing is likely due to a combination of low permeability horizons in the vadose zone that cause water to spread laterally and the relatively small amount of recharged test water in comparison to ongoing recharge from other nearby sources. Additional analysis is provided below in the discussion of the SEWD spreading basin results.

**Thompson Site Flooded Field.** The Thompson property near Collegeville was identified when the property owner reported fine to medium sand in his excavated pond and noted that water was infiltrating at a rate of approximately 1 to 2 ft/day. The site has not been ripped to depths that would penetrate the hardpan. An on-site piezometer (TH-PZ-01) and a nearby background private well were used for background groundwater level measurements.

The 50 ft by 50 ft flooded field was constructed approximately 100 ft north of TH-PZ-01 as shown in [Appendix C.1](#) ([Thompson site diagram](#)). Initial infiltration rates of about 0.1 ft/day quickly

declined to near zero ([Appendix C.1](#)). This low infiltration rate is most likely due to the effect of impermeable hardpan and/or compacted Stockton adobe soil that was not disked prior to the test. Due to the lack of significant recharge in the flooded field test, the effects of recharge are evaluated below in the section on excavated basins.

## Spreading Basins

Spreading basins are ponds excavated to relatively shallow depths through low permeability soils and/or through shallow hardpan typically to depths less than 5 ft below ground surface. This technique is appropriate under a variety of circumstances. Shallow spreading basins are commonly used in large-scale applications, such as those in the southern San Joaquin Valley, and in southern California and Arizona. Spreading basins provide surcharge capacity to accept peak flows and provide efficient conveyance of water through a recharge project and are applicable in a variety of geologic conditions. At sites where shallow vertical impediments, such as organic clay soils or a thin veneer of hardpan are present, the construction of shallow basins can remove or reduce the effect of these materials thereby increasing infiltration effectiveness.

**SEWD Spreading Basins.** Two shallow spreading basins were constructed at the SEWD groundwater recharge test site. Data collected during the drilling program and field reconnaissance indicated that a weakly consolidated weathered zone was present beneath the adobe topsoil. The two basins, each 50-ft by 20 ft, were excavated to depths of two feet (south basin) and four feet (north basin) below ground surface. Operation and monitoring of the SEWD basins began in January 2000 and continued through September 2000. Backwash water from the SEWD treatment plant was used as a water source for testing in these basins.

In the south basin (2 feet deep bgs), water levels were maintained at a depth between 10-15 inches since testing began. Throughout the eight-month test period, percolation rates in the south basin have been approximately 0.8ft/day ([Appendix C.1](#)), which is similar to the rates observed at the SEWD flooded field.

Water levels in the north 4-foot-deep basin varied between 14 and 36 inches. Initial infiltration rates of approximately 3.5 ft/day fluctuated depending on water levels but generally declined to approximately 1.0 ft/day. The percolation rate appeared to decline as the head from standing water increased, perhaps due to the compaction of silts and clays in the bottom of the basin. There was no apparent response in the water table to this small-scale testing ([Appendix C.1](#)).

The direction of groundwater movement, horizontal gradient, estimated average hydraulic conductivity, resulting estimated range of average regional groundwater flow velocities, and eventual fate of recharged water are summarized in [Table V-3](#). The boring log at the site indicates that no identifiable discrete low permeability horizons exist above the water table, so no perched mounding would be expected. However, if the vertical hydraulic conductivity is less than the infiltration rate, recharged water will form a mound. The lack of a response in the water table to recharge ([Table V-6](#)) is most likely due to the silty nature of the sediments beneath the site, but confirmation would require

piezometers in the vadose zone.

The mounding model input parameters and results are summarized in [Table V-5](#). The modeling results are consistent with the apparent lack of mounding in the on-site piezometer relative to the background wells during the pilot test. The modeling of a hypothetical 80-acre demonstration project at this site indicates that the resulting mound would reach the bottom of the facility and retard infiltration rates.

The IGSM simulation of a potential base project in the western part of the study area (western SEWD and CSJWCD) indicates that recharge of 40,000 AF/yr. would create a regional rise in water levels of 10 feet or less ([Appendix D.2](#)). The IGSM thus indicates that the recharged water would decrease the eastward hydraulic gradient in the vicinity of Highway 99.

The above interpretations of the test data are based on very limited geologic and groundwater monitoring data (only one piezometer), a relatively small volume and duration of recharge testing, and modeling based on a number of untested simplifying assumptions.

## Excavated Pits

Excavated pits were used to evaluate recharge effectiveness in areas where vertical impediments such as hardpan are evident at depths greater than five feet bgs. Excavated pits were tested at two sites.

**Allen Site Excavated Pits.** Prior to beginning the study, SEWD began testing the recharge effectiveness of excavated pits at the Allen site and observed recharge rates ranging from one to nine feet per day. The drilling program and previous excavations at the Allen site indicated the presence of a thick layer of hardpan starting at depths of three to five feet below ground surface in the area of the pits. Testing of excavated pits on the property was selected to determine the recharge potential of soils below the hardpan layer.

Two excavated pits were tested on the Allen property, referred to as the South and North pits and located adjacent to the on-site piezometer AL-PZ-01. Each was excavated to a total depth of approximately 15 feet bgs ([Appendix C.1](#)). The hardpan in the pits was approximately 3 feet to 5 feet bgs.

Operation and monitoring of the Allen pits for the study began in February 2000 and continued through the middle of April 2000. The depth of water in the pits was maintained at approximately 10 to 12 feet. A total of approximately 6.5 AF was recharged at the Allen pilot test site. Initial infiltration rates were approximately 3.5 ft/day in the South Pit and 1.25 ft/day in the North Pit ([Appendix C.1](#)). However, within a week of continued testing, rates in both pits gradually began to steadily decline. At the completion of two months of testing, the infiltration rate in the South and North pits had decreased to approximately 1.1 ft/day and 0.25 ft/day, respectively.

The difference between the percolation rate in the pits may be attributable to differences in geologic conditions and/or pit configuration. Soils below the base of the hardpan at 5 feet below ground surface in the South Pit included very clean sand that continued to the bottom of the pit at 15 feet bgs. In the North Pit, soils below the hardpan layer were more heterogeneous, with some deeper weathered zones and relatively little clean sand. Construction differences in the pits also probably contributed to significant differences in infiltration. The considerably greater side wall area resulting from sloped walls in the South Pit exposed more surface area and likely resulted in a higher amount of horizontal infiltration. Although the computed infiltration rates are based on wetted area, the rate of horizontal infiltration is normally greater than the rate of vertical infiltration due to a higher horizontal hydraulic conductivity.

Water levels in on-site piezometer AL-PZ-01 and background piezometer AL-PZ-02 rose similarly during the testing due to heavy precipitation in late January through early March, but AL-PZ-01 did not show a response to recharge relative to background well ([Appendix C.1](#)). This lack of response is probably due to the relatively small amount of water recharged, relatively thick vadose zone, and/or mounding in the vadose zone.

Based on the above site data and the estimated parameters in [Table V-3](#), the expected horizontal migration rate of recharged water that reaches the water table and the average groundwater velocity in the underlying aquifer are estimated. Recharged water would flow west toward the main ESJ groundwater depression.

The boring logs at the Allen site also indicate a heterogeneous (variable) vadose zone ([Appendix B](#)) with the potential to restrict downward migration of the recharged water, so significant mounding in the vadose zone could occur. Mounding above a restricting layer at 34 to 44 feet has the potential to reach the bottom of the recharge basin and reduce the recharge rate ([Table V-4](#)), which may have occurred during the pilot test period.

Using Hantush's equation ([Bouwer, 1978](#)) and the actual and estimated values above, the site-specific estimated height of the water table mound for a 2000-square-foot area pilot test (the equivalent of the two excavated pits) would theoretically be one foot or less at the end of the two-month test. The absence of a response in the water table relative to background piezometer is consistent with this theoretical estimate ([Appendix C.1](#)). Modeling of a hypothetical 80-acre recharge site at the property indicates that the resulting mound could approach the bottom of the facility and retard recharge ([Table V-5](#), [Appendix D.1](#)).

A potential base project distributed across the SEWD and CSJWCD portion of the study area including the Allen site was modeled using the IGSM. The simulation indicates that recharge of 40,000 af/year (in combination with northern recharge in NSJWCD) would create a regional rise in water levels of 20 feet or less ([Appendix D.2](#)). The IGSM thus indicates that distributed recharged water will produce a minimal decrease the eastward hydraulic gradient in the vicinity of Highway 99.

The above interpretations of the test data are based on very limited geologic and groundwater monitoring data (only one piezometer), a relatively small volume and duration of recharge testing, and

modeling based on a number of untested simplifying assumptions.

**Thompson Site Excavated Pits.** Two excavated pits were constructed at the Thompson site (the South and North pits ([Appendix C.1](#)). The Thompson pits were operated and monitored by CSJWCD from January 2000 through the end of March 2000. Groundwater was pumped from a distant well and conveyed through Littlejohns Creek for the first month of pilot testing until surface water from Littlejohns Creek became available. The turbidity of Littlejohns Creek water was considerably higher than the groundwater, but this did not appear to have adverse effects on infiltration rates. Evaporation and biological effects such as algae growth were minimal during testing.

Infiltration rates in the South and North pits were about 3.0 and 1.0 ft/day, respectively, near the end of the test period. No response was detected in the on-site water table piezometer relative to the background well ([Appendix C.1](#)).

Based on the above site data and the estimated parameters in Table V-3, the expected horizontal migration rate of recharged water when it reaches the water table and the average groundwater velocity in the aquifer are estimated. Recharged water would flow northward toward the main ESJ groundwater depression ([Table V-3](#), [Appendix D.1](#)).

Water levels in on-site piezometer TH-PZ-01 and the Nilsson background well rose similarly during the testing due to heavy precipitation in late January through early March, but TH-PZ-01 did not show a response to recharge relative to background well ([Appendix C.1](#)). This lack of response is probably due to the relatively small amount of water recharged and/or mounding in the vadose zone.

The lack of a response in the water table piezometer neither during the 10-week pilot test (nor during subsequent adjacent field flooding) is consistent with the estimated vertical migration rate in [Table V-4](#). The boring log at the Thompson site indicates a heterogeneous (variable) vadose zone but only thin clay zones that are less than 2 feet thick and most likely discontinuous. These zones would not be expected to individually cause significant mounding in the vadose zone. However, since the expected vertical permeability of much of the vadose zone is less than the measured infiltration rates, mounding would be likely to occur in the vadose zone and may reduce the infiltration rate ([Table V-4](#), [Appendix D.1](#)).

The results of the mounding model for a 400-square-foot pilot test (the approximate dimensions of each test pit) indicate that the recharge water reaching the water table would have a negligible effect on the water table at the end of the 10-week test ([Table V-5](#)). The absence of a response in the water table relative to background well is consistent with this estimate ([Appendix C.1](#)). For a hypothetical 80-acre recharge site at the property, the resulting mound would reach the ground surface by the end of each recharge season ([Table V-5](#)).

The IGSM simulations for a potential base project in the western portion of the SEWD and CSJWCD districts (including the Thompson site) would create a regional rise in water levels of 10 to 20 feet or less ([Appendix D.2](#)). The IGSM also indicates that western area recharge would produce a significant decrease the eastward hydraulic gradient in the vicinity of Highway 99.

The above interpretations of the test data are based on very limited geologic and groundwater

monitoring data (only one piezometer), a relatively small volume and duration of recharge testing, and modeling based on a number of untested simplifying assumptions.

## ADDITIONAL MAPPING AND TRENCHING RESULTS

After completion of the pilot tests and as the plan proposed in [Chapter VI](#) was being formulated, the SMT identified the need for verification that the pilot test results at the SEWD and Thompson sites were representative. This verification was requested to ensure that the pilot test results could be used for the design of a demonstration and base project in the western part of the study area. Two subsequent activities were therefore conducted to fill this data gap:

- Regional reconnaissance mapping of soil exposures in streams and similar outcrops
- Trenching and mapping of soils and short-term infiltration tests at four sites

### Reconnaissance Mapping Results

The results of the September 2000 regional reconnaissance mapping are included in [Appendix C.2 \(Table C.2-1\)](#) and summarized on [Figure V-2](#). Exposures were located at the intersections of streams with several north-south roads in the western part of the study area (between Highway 99 and Jack Tone Road). Exposures were also mapped near the Stockton Intermodal Facility near the North Fork of Littlejohns Creek. In general, the results indicate that hardpan is widespread in the western part of the study area but is usually not more than 1 to 2 feet thick. At most locations the hardpan occurs at depths that can be ripped to improve recharge (eight feet or less).

### Trenching Results

The following four properties were trenched using a backhoe during early November 2000 to allow mapping of the hardpan and associated soils ([Figure V-2](#)):

- SEWD Water Treatment Facility (SEWD)
- Sanguinetti (SAN)
- Nilsson- Kaiser Road (NIK)
- Nilsson- Verdon Road (NIV)

The trenching results are summarized in [Appendix C.2 \(Table C.2-2\)](#) and maps for each site). The trenching indicates that hardpan is generally present at these sites, and 2 or 3 thin zones of hardpan are locally present. The hardpan is variable across the sites but usually not thick or present deeper than 8 feet. However, primarily silty soils are present below the hardpan that would be expected to percolate slowly, although the soils are similar to those at SEWD where the pilot tests indicated

# Farmington Groundwater Recharge/ Seasonal Habitat Study

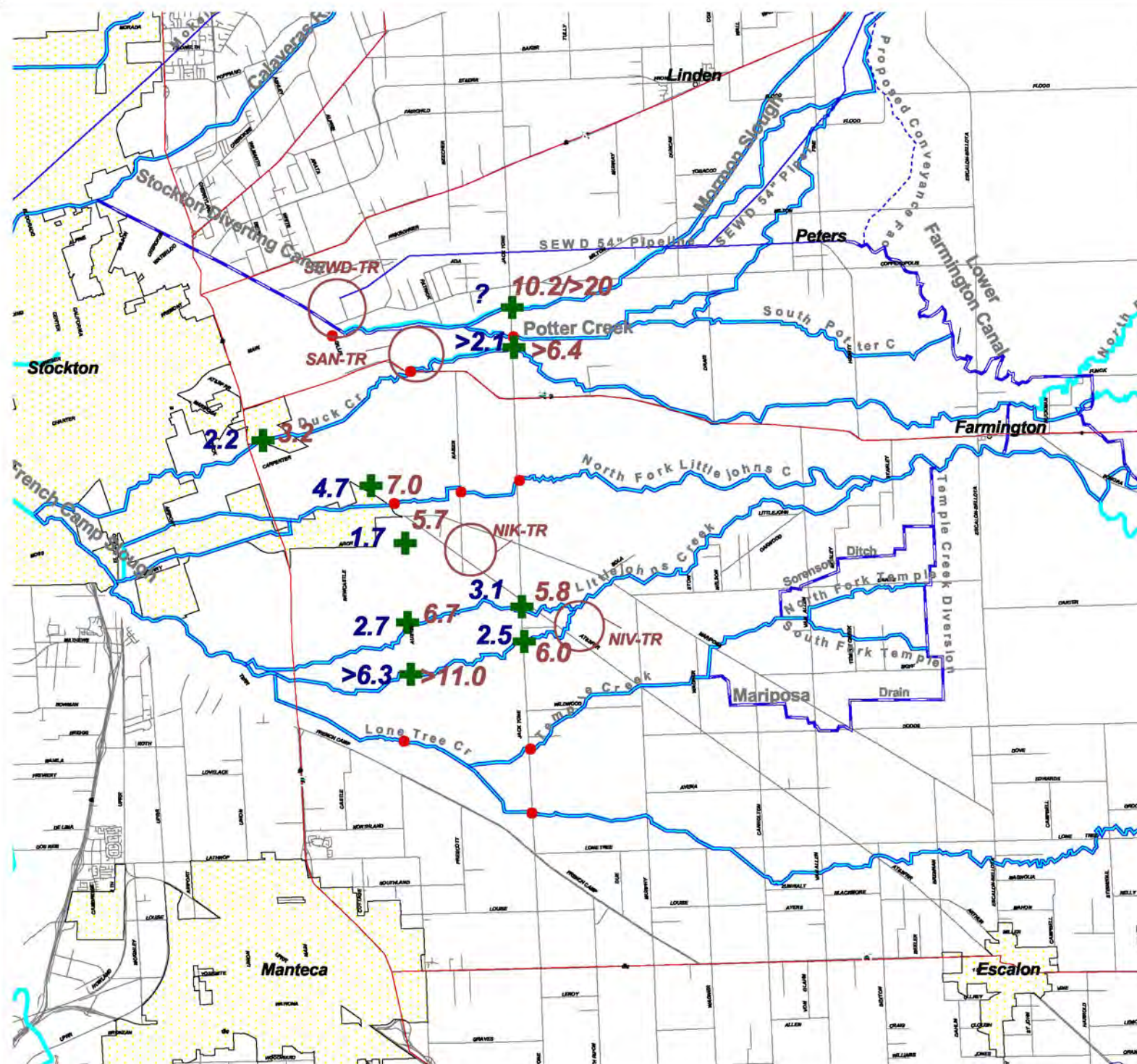
## Legend

- + Hardpan Exposure
- No Exposure
- 2.7 Thickness of Hardpan (in feet bgs)
- 6.7 Base of Hardpan (in feet bgs)

## Western Recharge Area Hardpan Extent

**Figure V-2**

Note: Reconnaissance level data collected by Montgomery Watson, 9/20/00. Trenching occurred from 11/6 to 11/8/00.



favorable infiltration rates.

Regional mapping by the SCS (1992) for the four sites is summarized indicates that four different soil units are present at the sites. The SCS mapping (to a maximum depth of 5 feet) indicates that all four sites are underlain by soils with thick cemented hard pan with low infiltration rates ([Appendix C.2; Table C.2-3](#)). Most of the trenched sites are underlain by either Stockton clay or Hollenbeck silty clay (SCS, 1992). The trench results are generally consistent with the SCS mapping, indicating that the hardpan is variable but usually less than one foot thick. However, the data also indicate that some discontinuous hard pan is present below the maximum depth of SCS investigation (five feet).

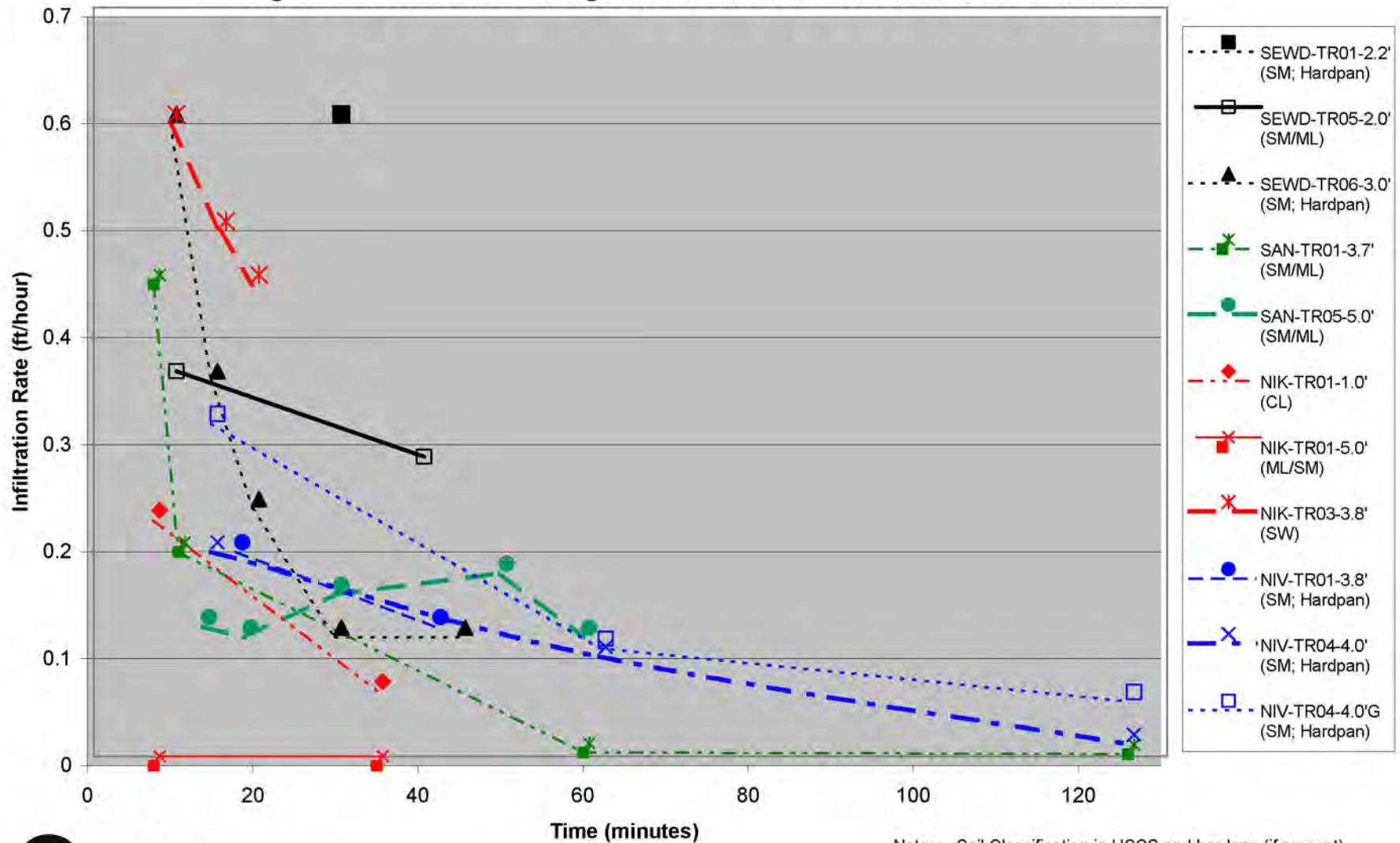
Eleven short-term single-ring infiltration tests were conducted at selected depths in some of the trenches to determine if relative infiltration rates could be estimated with this rapid and inexpensive technique. To perform the test, the bottom was removed from a new one-gallon paint can, which was then driven into the soil and sealed around the outside with clay. The can was then filled with water and the drop in water level recorded to estimate the short-term infiltration rate. These short-term tests serve only as rough approximations of initial infiltration rates, and the results should not be extrapolated to infer long-term rates. However, the tests do provide useful data and demonstrate that such a technique is useful for estimating relative rates. More sophisticated double-ring infiltration tests are recommended for inclusion in the field investigations in the plan implementation ([Chapter IX](#)).

The short-term infiltration test results ([Appendix C.2](#)) are graphed in [Figure V-3](#) and indicate that the initial infiltration rates are highest at the SEWD trenches and a sandy horizon at the NIK site. In general, the infiltration rates declined to approximately 0.1 ft/hour within an hour and continued to decline for those tests that lasted longer. Approximately one cup of gypsum was added to the water in one test (NIV-TR04-4.0'G), but the resulting infiltration rate was only slightly higher than the control test. Overall, the test results are consistent with the SCS (1992) results, which indicated hard pan permeability rates of 0.005 - 0.017 ft/hour. The trench results therefore confirm that the relatively high percolation rates in the SEWD flooded field pilot tests are probably at the high end of what can typically be expected for the western part of the study area, and the lower rates assumed below are more appropriate. In any case, site-specific investigations will be necessary at all potential project sites as part of the site evaluation process to determine recharge favorability.

## SUMMARY OF FINDINGS

The results of the study pilot tests and the two previous USGS recharge tests are summarized in [Table V-6](#). The pilot tests provided much-improved estimates of expected recharge rates for the three surface recharge techniques in the local geologic environments than was previously available (as well as valuable insights into design parameters and operational issues). In addition, the observations and mounding modeling suggest that recharge facilities may create local perching of recharged water and high water table conditions that could cause decreased infiltration rates and problems for adjacent land uses. The additional mapping and trenching conducted in the western part of the study area also confirm the heterogeneity of the geology and soils. Site-specific evaluations as part of the site selection

Figure V-3. Western Recharge Area Estimated Short-term Infiltration Rates



process will thus be critical for a successful project. Additional groundwater monitoring will be necessary as part of a demonstration project to further evaluate potential problems.

The data collected during field testing is considered sufficient for the study evaluation of the relative effectiveness of different surface recharge techniques over a range of geologic conditions. However, it should be noted that although most of the pilot tests operated for several months, average sustainable long-term recharge rates for a full-scale operation facility are expected to be lower than the end-of-test results shown in [Table V-4](#). Long-term reductions in recharge rates can result from a number of factors, including the following (as summarized from Bouwer, 2000):

- Accumulation of suspended solids, algae, biofilms, chemical precipitates, and other clogging layers on the bottom of the basin
- Fine particle movement and accumulation to form subsurface clogging layers
- Subsoil compaction by the weight of the water in the basin and/or disking or ripping to mitigate clogging layers
- Microbial production of gases that block soil pores to form a “gas barrier”
- Changes in soil clays due to ions in the recharge water
- Vegetation growth and “die-off” in the basin forming a clogging layer
- Rising groundwater levels from perched mounding or the aquifer itself
- Interference by adjacent basins that are part of a large facility
- Downtime for parts of the facility for basin maintenance or problems with high water tables

As a result of the above considerations, the following conservative average sustainable long-term recharge rates are recommended for estimating and design purposes for a full-scale operation facility:

- Flooded Fields (Ripped hardpan or sites without hardpan)- 0.25 to 0.50 ft/day
- Shallow Spreading Basins- 0.5 ft/day
- Excavated Pits- 1.0 ft/day

**TABLE V-6**  
**SUMMARY OF PILOT TEST RESULTS**

| Technique                                                                                                                                                                                                                                                                                                         | Site Name (Property) | Operating Agency | Test Name                             | Test Duration        | Range of Percolation Rate <sup>1</sup> (ft/day) | Water Table Response |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------|------------------|---------------------------------------|----------------------|-------------------------------------------------|----------------------|
| <b>Flooded Field</b>                                                                                                                                                                                                                                                                                              | Lakso                | NSJWCD           | Lakso (undisturbed)                   | 1/1/00 to 2/11/00    | 0.8 to 0.75                                     | Yes                  |
|                                                                                                                                                                                                                                                                                                                   | Allen                | SEWD             | Allen Flooded Field (undisturbed)     | 2/11/00 to 5/11/00   | 0.14 to 0.01                                    | No                   |
|                                                                                                                                                                                                                                                                                                                   | SEWD                 | SEWD             | SEWD East Flooded Field (ripped)      | 5/16/00 to present   | 12.0 to 2.0 <sup>3</sup>                        | No                   |
|                                                                                                                                                                                                                                                                                                                   | SEWD                 | SEWD             | SEWD Southeast Flooded Field (ripped) | 8/18/00 to present   | 4.0 to 1.5 <sup>3</sup>                         | No                   |
| <b>Spreading Basins</b>                                                                                                                                                                                                                                                                                           | SEWD                 | SEWD             | South Basin                           | 12/28/99 to present  | 0.9 to 0.7                                      | No                   |
|                                                                                                                                                                                                                                                                                                                   | SEWD                 | SEWD             | North Basin                           | 12/28/99 to present  | 3.5 to 1.0                                      | No                   |
|                                                                                                                                                                                                                                                                                                                   | Linden               | USGS             | Linden <sup>2</sup>                   | 11/26/84 to 12/28/94 | 11.2 to 2.6                                     | Yes                  |
|                                                                                                                                                                                                                                                                                                                   | Lockeford            | USGS             | Lockeford <sup>2</sup>                | 1/6/84 to 1/20/84    | 10.5 to 6.7                                     | Yes                  |
| <b>Excavated Pits</b>                                                                                                                                                                                                                                                                                             | Allen                | SEWD             | North Pit                             | 1/29/00 to 4/13/00   | 1.25 to 0.25                                    | No                   |
|                                                                                                                                                                                                                                                                                                                   | Allen                | SEWD             | South Pit                             | 1/29/00 to 3/17/00   | 3.5 to 1.1                                      | No                   |
|                                                                                                                                                                                                                                                                                                                   | Thompson             | CSJWCD           | South Pit                             | 1/12/00 to 3/22/00   | 5.0 to 2.6                                      | No                   |
|                                                                                                                                                                                                                                                                                                                   | Thompson             | CSJWCD           | North Pit                             | 1/12/00 to 3/22/00   | 1.3 to 0.7                                      | No                   |
| Notes:<br>1. Detailed recharge and groundwater level data is located in <a href="#">Appendix C.1</a> ; initial rates are likely exaggerated due to wetting effects and should not be expected to reflect long-term operational rates<br>2. Source of data is USGS, 1987<br>3. Qualified data as discussed in text |                      |                  |                                       |                      |                                                 |                      |