



Well Field Optimization Project

Final Report – May 2007

Stanislaus and
Tuolumne Rivers
Groundwater Basin
Association



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Date: June 28, 2007
Project No: 054030

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Abbreviations and Acronyms

Association	Stanislaus and Tuolumne Rivers Groundwater Basin Association
Basin	Modesto Groundwater Subbasin (DWR #5-22.02)
B-E/GEI	Bookman-Edmonston, a division of GEI Consultants, Inc.
BMOs	Basin Management Objectives
CAD	Computer Aided Design
cfs	cubic feet per second
DMS	Database Management System
DSS	Decision Support System
ft-bgs	feet below ground surface
ft-btoc	feet below top of casing
GIS	Geographic Information System
GPS	Global Positioning System
HP	horsepower
IRGMP	Integrated Regional Groundwater Management Plan
Kh	killowatt hours
MID	Modesto Irrigation District
OID	Oakdale Irrigation District
Program	Well Optimization Program
Project	Well Field Optimization Project
RPM	revolutions per minute
SCADA	Supervisory Control and Data Acquisition
TDS	total dissolved solids
USGS	U.S. Geological Survey
WFO	Well Field Optimization (Computer Program)
WPS	Well Production Scenarios

Executive Summary

The Stanislaus and Tuolumne River Basin Groundwater Association (Association) was formed in 1994 by six agencies interested in improving the management of the Modesto Groundwater Subbasin (Basin). Notable among the Association's accomplishments is the preparation of the *Integrated Regional Groundwater Management Plan for the Modesto Subbasin* (IRGMP) in 2005. The current project, the Well Field Optimization Project (Project), is also notable because it is the first IRGMP recommendation funded for implementation. The goal of the Project is to improve understanding of the groundwater system and its infrastructure and to develop tools for optimizing operations of the well field in conjunction with the surface water resources of the Basin.

The Project is the first of a three-phase Well Optimization Program (Program). Objectives of the Program are to:

- Operate wells to meet water supply demands of the districts
- Lower power costs per unit of water pumped by prioritizing well usage by cost of operations
- Maintain groundwater levels that satisfy the Basin Management Objectives (BMOs) established in the Groundwater Management Plan
- Manage the water quality of groundwater discharged into the surface water delivery system
- Increase the effectiveness of shallow groundwater management

In the current phase, the Project was completed for Modesto and Oakdale Irrigation Districts. Implementation of future phases (depending on funding availability) will automate the system for real-time conjunctive use management and will expand to the other Association member agencies' service areas. The Project includes a data Management System (DMS) and a Decision Support System (DSS). Districts' facilities and wells are inventoried and data collected are stored in the database. Using the data stored in the DMS, the DSS optimizes well field operations according to pumping energy costs, water quality objectives, and/or water conservation. The DSS provides operational flexibility to the districts for conjunctively managing surface and groundwater resources on a real-time basis.

The Project can be broken down into four major components as listed below.

- **Facilities Inventory and Mapping**
- **Production Well Evaluations**
- **Database Management System**
- **Decision Support System**

A summary of each component follows.

Facilities Inventory and Mapping and Well Evaluations

Existing district facilities, wells and laterals, were inventoried and mapped. First steps of the inventory and mapping included gathering all available data and assessing the quality of the data for use in the Well Performance Evaluations, DMS, and DSS. Next, data gaps were identified and prioritized for field surveys. Finally, all available and newly collected data were entered in the DMS and/or Geographic Information System (GIS) for use in the DSS and performance evaluations.

Well evaluations were completed to rank district wells and identify wells with acceptable efficiency and performance. This information was also used in the DSS. Recommendations for repairs or replacements of non-efficient wells were prepared and prioritized and associated cost estimates provided to the districts.

Database Management System

A Database Management System (DMS) was developed for storage, retrieval, and evaluation of groundwater data. The DMS is a Microsoft Access® database with a custom interface for entering well data into a database, viewing data, and generating reports. For example, the DMS can be used for storage and retrieval of production data as well as water level and water quality data collected by Association member agencies' monitoring programs. The DMS also interacts with the DSS, supplying well data used in the DSS decision algorithm and logging well operation status as orders are placed.

Decision Support System

The Decision Support System (DSS) was developed to optimize the conjunctive use of surface and groundwater resources to meet objectives developed for each district. The DSS is a custom tool within Microsoft Access® that interacts with the DMS, retrieving data and updating well operation status as orders are placed.

The main function of the DSS is to automate the decision process for system operators in selecting wells to meet deliveries. The DSS optimizes well selection based on criteria input by the operator, including location, time of delivery, flow rate, efficiency, cost of energy for

pumping the water, and water quality. DSS output includes a list of available wells that meet the selection criteria. The user can select from among the eligible wells to satisfy the order.

The Well Field Optimization (WFO) program was developed to combine data evaluation capabilities of the DMS with the decision support capabilities of the DSS into a single, easy to use interface.

Findings and Recommendations

Well Replacement and Repair of Existing Wells

The well evaluation project has identified 18 wells that need repairs in order to improve their performance to an acceptable level. This includes 11 Modesto Irrigation District (MID) wells and 7 Oakdale Irrigation District (OID) wells. It is recommended that OID and MID schedule and budget repair of these wells as soon as possible. The specific work that must be performed is identified by well in the evaluation report.

The well evaluation project also identified six wells that must be replaced, including one OID well and five MID wells. The existing wells should be decommissioned and properly destroyed and new wells should be drilled and developed. It is also recommended that the districts budget and schedule a well replacement program for these wells.

Implement Phase II of the Well Field Optimization (WFO) Program

This phase of the program expands the WFO to include service areas of other water purveyors in the Basin. This will include expanding the well evaluations, DMS, and DSS. The DMS will also be modified to become web-based to provide access by all Association member agencies.

Implement Phase III of the Well Field Optimization Program

This phase will fully automate the DSS and conjunctive management operations, which will include:

- Using remote sensing to collect real-time groundwater level and water quality data as well as water quantities and quality in the agencies' main laterals and pipelines
- Establishing a process to assess the water requirement in each lateral
- Installing a SCADA system to monitor, control, manage, and optimize groundwater pumping, surface water quantities in the laterals, groundwater levels, and operational outflows

Financial Plan

A financial plan should be developed to facilitate orderly development and implementation of the recommendations listed above, including identification of potential grant funding.

1 Introduction

In April 1994, six agencies formed the Stanislaus and Tuolumne Rivers Groundwater Basin Association (Association) to provide a forum for coordinated planning and management of the Modesto Groundwater Subbasin (Basin). The six Association member agencies are the City of Modesto, MID, City of Oakdale, OID, City of Riverbank, and Stanislaus County.

In April 2005, the Association made a significant contribution to management of the Basin with the publication of the *Integrated Regional Groundwater Management Plan for the Modesto Subbasin* (IRGMP). The IRGMP identified nine basin-wide management actions with the following common purpose:

...(to) encourage a balance of surface water and groundwater use that will protect resources of the basin and maximize the reliable supply of high quality water to meet municipal, agricultural, and industrial demands now and in the future.

The goal of the Well Field Optimization Project (Project), which is the focus of this report, is to implement the first of the nine IRGMP management actions: *Management and optimization of well field operations*. The Project was funded through a grant to the Association from the Department of Water Resources Local Groundwater Assistance Program. The Project and its components are described in this report and its appendices.

The purpose of this introductory section is to describe the background and setting for the Project.

1.1 Stanislaus and Tuolumne Rivers Groundwater Association

Since its inception in 1994, the Association has been actively engaged in management of the Basin. The stated purposes of the Association are as follows:

- To determine and evaluate the Basin's groundwater supply
- To promote coordination of groundwater management planning activities
- To develop a hydrologic groundwater model of the groundwater basin
- To determine the Basin's need for additional or improved water extraction, storage, delivery, conservation, and recharge facilities
- To provide information and guidance for the management, preservation, protection, and enhancement of groundwater quality and quantity in the Basin

The publication of the IRGMP in 2005 was a major accomplishment of the Association and an indication of the successful collaboration and dedication of its member agencies. The current Project is a direct result of the IRGMP recommendations and is significant because it is the first recommended management action to be completed.

1.2 Study Area

The study area for the IRGMP includes the entire Modesto Groundwater Subbasin, part of the Eastern San Joaquin Groundwater Subbasin, and the service areas of all or most of the six agencies constituting the Association.

The Modesto Groundwater Subbasin underlies all of MID, the City of Oakdale, the City of Riverbank, and a portion of OID. The remainder of OID is within the Eastern San Joaquin Groundwater Basin, and a portion of the City of Modesto service area is within the Turlock Groundwater Basin. Because the portion of the City of Modesto's service area within the Turlock Basin is covered in the Turlock groundwater planning process, it has been excluded from the study area. Almost the entire Basin is within Stanislaus County.

The locations of the Association's agencies and groundwater subbasin boundaries are shown in Figure 1.

The Project study area in Phase I includes the OID and MID service areas. Future phases will add the service areas of other water purveyors in the Basin.

1.3 Project Description

The current Project is Phase I of a three-phase Well Optimization Program (Program). Key objectives of the Program are to:

- Operate wells to meet water supply demands
- Lower power costs per unit of water pumped by prioritizing well usage by cost of operation
- Maintain groundwater levels that satisfy the BMOs
- Manage the water quality of discharged water
- Increase the effectiveness of shallow groundwater management

During this first phase, a well field optimization project was developed for the MID and OID service areas. In future phases, the remainder of the Association's service areas will be added, and the system will be automated to enable real-time conjunctive use management. The three phases of the Program are described below.

1.3.1 Phase I - Well Field Optimization Project

This phase was funded by a grant from the Department of Water Resources under the AB 303 program and is the focus of this report.

The four major components of the Project are briefly described below. These are addressed in subsequent sections of this report as indicated.

Facilities Inventory and Mapping, Section 2: Inventory and mapping of existing wells and their characteristics and mapping of conveyance systems and the districts' infrastructure.

Production Well Evaluations, Section 3: Selection of wells that meet the districts' management objectives for each ditch tender area; identification and planning to destroy wells with unacceptable efficiency and performance.

Database Management System, Section 4: Development of a DMS for storage, retrieval, and evaluation of groundwater data. The database is used for operation of the DSS.

Decision Support System, Section 5: Development of a DSS to optimize the conjunctive use of surface and groundwater resources to meet objectives developed for each district.

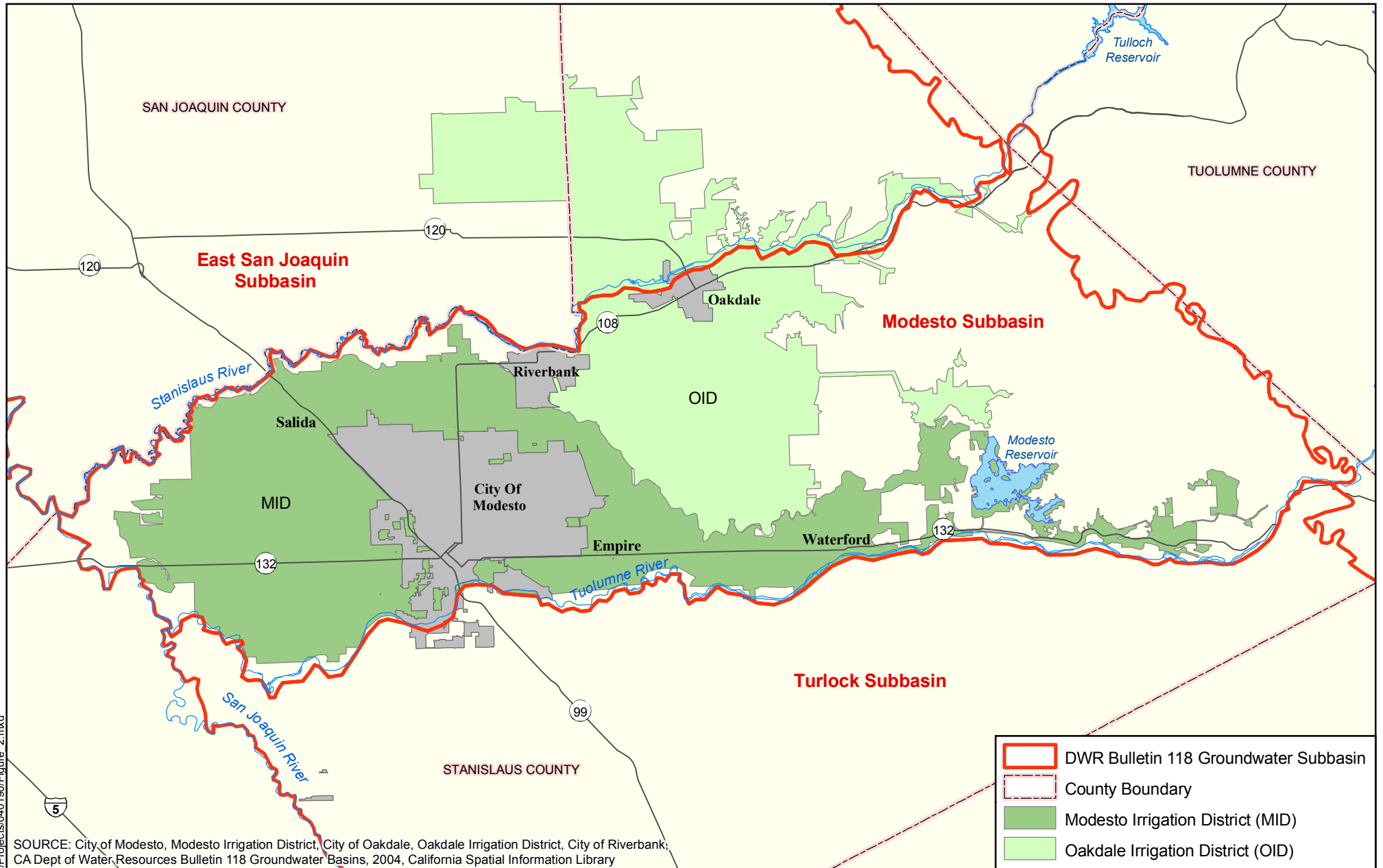
1.3.2 Phase II

During this phase, the Program will be expanded to cover service areas of other water purveyors in the Basin.

1.3.3 Phase III

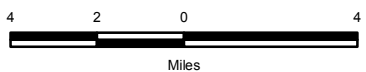
This phase of the project will automate the system, including the following:

- Remote sensing to collect real-time groundwater levels and water quality data as well as water quantities and quality in the districts' main laterals. Establish a process to assess the water requirements in each lateral.
- Install a SCADA system to monitor, control, manage, and optimize groundwater pumping, surface water quantities in the laterals, groundwater levels, and lateral spillage.



SOURCE: City of Modesto, Modesto Irrigation District, City of Oakdale, Oakdale Irrigation District, City of Riverbank, CA Dept of Water, Resources Bulletin 118 Groundwater Basins, 2004, California Spatial Information Library

09-May-07 S:\GIS\Projects\040190\Figure 2.mxd



Well Field Optimization Project

Stanislaus and Tuolumne Rivers
Basin Groundwater Association



Modesto Groundwater Subbasin
And Association Agency Boundaries

MAY 2007

FIGURE 1

2 Facilities Inventory and Mapping

A complete inventory and mapping of the districts' facilities were required for the Project's three subsequent components: Well Performance Evaluations, DMS, and DSS. This section describes the facilities inventory and mapping efforts of the districts and Bookman-Edmonston, a division of GEI Consultants, Inc. (B-E/GEI).

2.1 Approach

First steps of the inventory and mapping included gathering all available data and assessing the quality of the data for use in the Well Performance Evaluations, DMS, and DSS. Next, data gaps were identified and prioritized for field surveys. Finally, all available and newly collected data were entered in the DMS and/or GIS for use in the DSS and performance evaluations.

Available well facility and monitoring data were provided by the districts in digital and paper format. Through close communication with the districts, the data were organized for entry into Microsoft Access®, GIS, and for use in performance evaluations.

Missing facilities data were collected by the districts through field surveys. The districts collected facilities inventory data using a standard field form provided by OID. The forms were provided to B-E/GEI for analysis and input into the database.

Available and collected data were entered (paper data) or imported (digital data) into a Microsoft Access® database and organized in a structure that makes sense for the DSS and DMS. Well data were linked to GIS well location data for analysis and mapping within GIS. Conversely, data developed in GIS, such as lateral lengths and well assignment to laterals, were exported for use in the DMS and DSS. Data entry was quality controlled by B-E/GEI staff.

2.2 Preliminary Well Evaluations

The purpose of this task was to develop an organized approach to collecting and managing data for 127 wells operated by the districts. A standard summary form was developed by OID to include all the information needed to complete the well inventory. The information available in the district offices was added to the forms prior to mobilizing to the field to facilitate more effective field surveys. The following information was collected:

- Motor make and horsepower (HP)
- Nameplate amps, volts, and revolutions per minute (RPM)

- Pump make
- Height of the reference point above ground surface for water level measurements
- Pump curves were provided by the districts where available

Existing information was entered on the well summary forms and used to identify missing information that needed to be collected during the field surveys.

2.3 Field Surveys

Field surveys and well inspections were needed to complete the well summary forms. This task included:

- Planning and coordinating the overall field program
- Conducting a Global Position System (GPS) survey of the well locations and elevations
- Conducting the well inspections
- Conducting well efficiency tests or completing additional well efficiency tests on selected wells

Field survey data were entered into the Project database. The GPS well locations were used for mapping the districts' facilities. Well efficiency tests were used for the well evaluations (Section 3) to determine the condition of the wells and production characteristics, such as cost of production.

2.4 Facilities Inventory

A database was developed and populated by B-E/GEI containing all the facility data obtained during the preliminary well evaluations, the development of the geographic datasets, and field surveys. A database user-interface, the DMS, was designed to allow for the input of data from field forms or importation from other electronic files, the output of data in graphical or tabular form for review and reporting. The DMS is described in Section 2.

Quality control checks of the database were performed to ensure that each well was correctly represented. During these checks, individual wells were spot-checked to confirm the accuracy of the data.

2.5 Facilities Mapping

District facilities including wells, well discharge locations, surface water distribution facilities, canals, laterals, drains, and reclamation facilities were mapped on a GIS platform.

MID and OID provided digital facilities mapping data, including Computer Aided Design (CAD) and GIS layers, showing well and lateral locations. These data were combined with well specification data to create a complete facilities map of each district.

The location of the wells and associated laterals, and well efficiency data are critical to the operation of the DSS because they provided a basis for determining which wells can serve a given location and the cost to operate these wells. Well discharge points were located using spatial relationships and input from the districts. The discharge location was defined as a distance along the lateral. Lateral reaches (between junctions) were also identified and labeled. Upstream laterals that feed a given lateral were also defined and included in the database for complete analysis of the distribution capabilities to a given point.

Additional layers used in mapping include streams, agency service areas, county, groundwater subbasins, and U.S. Geological Survey (USGS) quadrangles. The facility mapping has been reviewed by the districts' staff for accuracy and completeness and presented at project meetings for additional QA/QC from the project team. Completed facilities maps for MID and OID are shown in Figures 2 and 3, respectively.

2.6 Summary

The facilities inventory information was input into the project database for storage and used by the DSS. The well efficiency tests were also used as part of the well evaluations performed by B-E/GEI to assess well conditions.

Figure 2 MID Facilities Map

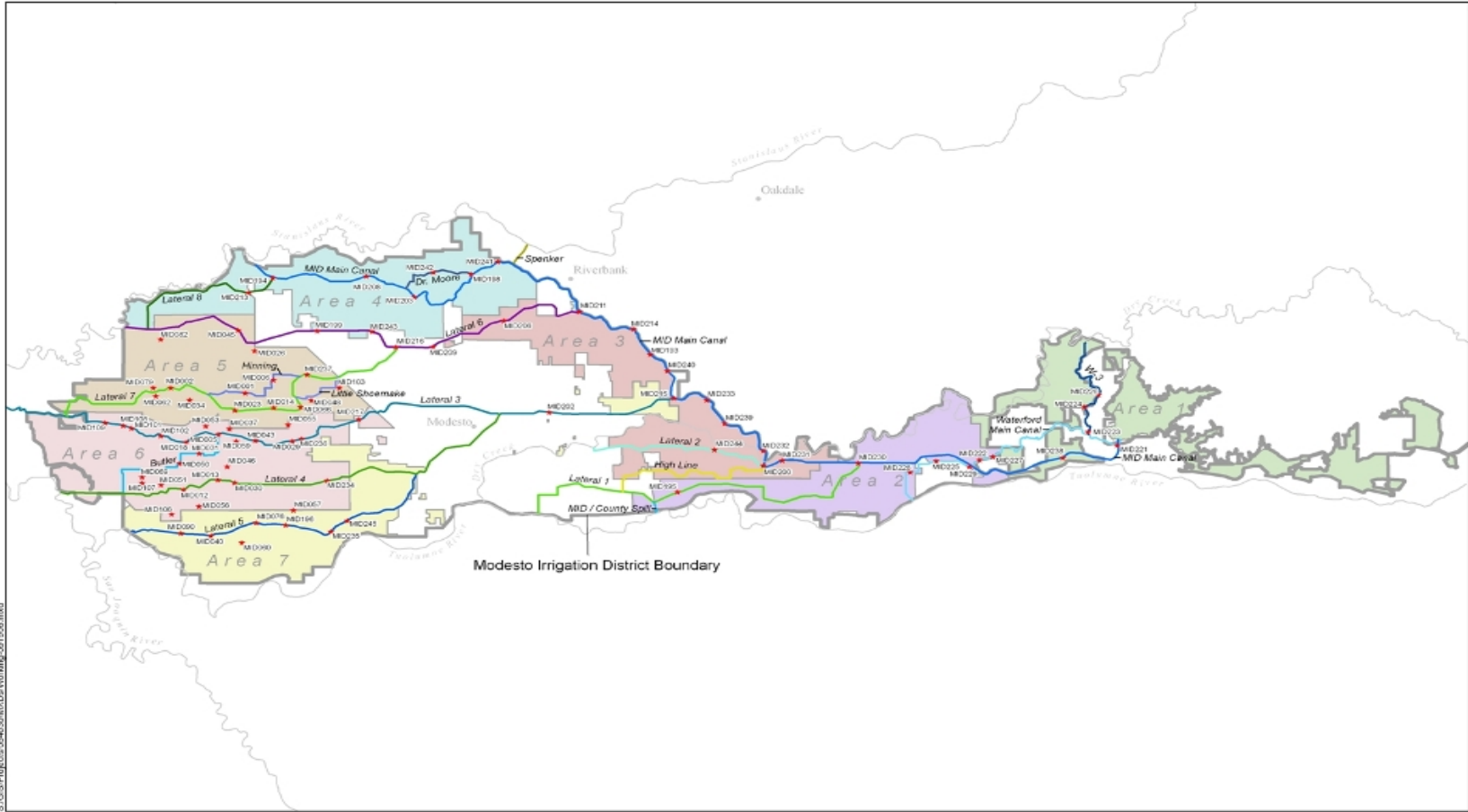
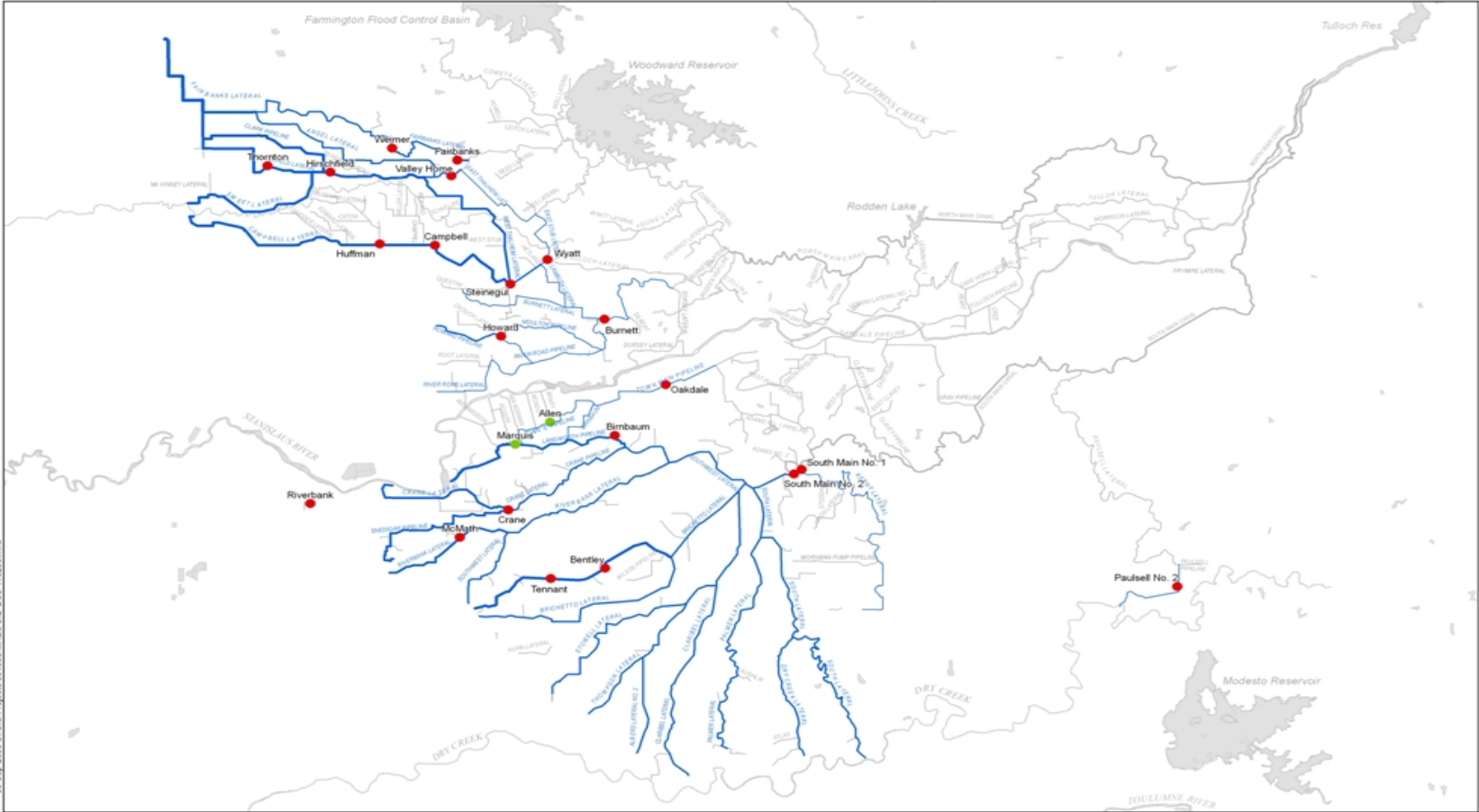


Figure 3 OID Facilities



3 Production Well Evaluations

MID and OID production wells were evaluated by B-E/GEI to determine the condition of the wells and to provide information for use in the DSS. The work was designed to rank the wells and to focus on investigating particular problems at each well (i.e. mismatched pump and motor size, plugging of the well screen, etc.). The goal was to improve the performance of the wells and validate the need for maintenance. Recommendations were presented, with repairs prioritized to obtain the greatest benefit for the dollars invested. Where rehabilitations or replacements were recommended, cost estimates were provided for each well. This section summarizes the well evaluation reports, which are included in full in the appendices.

3.1 Well Evaluation Considerations

Poor well performance can affect the cost of production on both an immediate and long-term scale. The immediate costs are generally the power consumption costs, which are driven up by poor motor or pump operation. Poor operation can be the result of normal wear and tear or incompatibilities between the well, pump, or motor. Poor well condition, typically caused by plugging of the well screens, can inflate the production costs by increasing the amount of drawdown in the well required to produce a given flow. As conditions at a well change and efficient operating ranges are exceeded, the power consumption and cost of production increases.

The long-term costs arise as motors, pumps, and wells deteriorate and need replacement. The short-term issues discussed previously can typically accelerate the deterioration process and result in repeated motor or pump replacements or less than expected well longevity.

3.2 Well Assessments

The assessments were performed by evaluating existing information contained in the districts' files and interviewing personnel involved in the operation and maintenance of the wells. An initial evaluation was performed by the districts based on well usage. The assessment was then organized to determine whether each well required maintenance and/or replacement based on power consumption, plant efficiencies, and specific capacities. The well maintenance assessment showed whether the well needs rehabilitation or the pump and/or motor needs repair or replacement. The analysis was then expanded to account for conditions at each well that would potentially modify the initial ranking based on well age or other special considerations. Other alternatives such as well destruction as opposed to rehabilitation were also explored.

3.3 Summary of Findings

Below is a summary of the findings for MID and OID system wells. Tables 1 through 3 show the recommendations for each well. Tables 1 and 2 show the summary of MID wells. Table 3 shows the summary of OID wells. Discussion of the production well evaluations for the districts is provided in Appendices A and B.

3.3.1 MID System

MID identified 102 wells it plans to use for irrigation and drainage control. Of the 102 wells evaluated, only 16 were identified as needing additional work, and 12 wells were identified as needing additional testing. Recommendations vary for the 16 wells needing additional work, but generally consist of well cleaning, pump or motor replacement or reconfiguration, or installation of flow control devices or sounding tubes. Five of the 16 wells are drainage wells that need pump rehabilitation or well cleaning, but these actions could result in collapsing of the well. Therefore, we recommend replacing these drainage wells. Pumps in at least four of these wells will need rehabilitation before reuse.

Additional testing is recommended for 11 wells where the information provided was either inconclusive or an indication of a potential situation that does not require immediate attention, but may need to be addressed in the future. A flow control valve will need to be installed on two of these wells before the testing begins. The pumps are breaking suction at these two wells and preventing the collection of valid data. These recommendations are discussed further in Appendix A.

3.3.2 OID System

OID provided information for 23 wells that it plans to use for irrigation and drainage. Of the 23 wells evaluated, only eight were identified as needing additional work, and six were identified as needing additional testing. Recommendations vary for the eight wells needing additional work, but generally consist of well cleaning, pump or motor replacement or reconfiguration, or installation of flow control devices or sounding tubes. One of the eight wells needs pump rehabilitation, but these actions could result in collapsing of the well. Therefore, we recommend replacing this well. The pump from the well will need rehabilitation before reuse.

Additional testing is recommended for six wells where the information provided was either inconclusive or an indication of a potential situation that does not require immediate attention, but may need to be addressed in the future. A sounding tube will need to be installed on all of these wells before the testing begins to facilitate the collection of valid data. These recommendations are discussed further in Appendix B.

**TABLE 1
IRRIGATION WELL RECOMMENDATIONS
Modesto Irrigation District**

MID No.	COMMON NAME	Well Ranking	2005 PRODUCTION (acre-feet)	Recommended for Additional Testing	RECOMMENDED FOR REHABILITATION						ESTIMATED COST (\$)	POTENTIAL BENEFITS
					Well Cleaning	Pump/Motor Rehab.	Sounding Tube	Install Flow Control Valve	Pump/Motor Replacement or Reconfiguration	Well Replacement		
109	Fitzpatrick	Bench	862	X				X			\$800	Reduce long-term maintenance costs
241	Langdon Merle	A-Team	387		No action recommended at this time							
5	Butler	A-Team	340			X			X		\$84,800	Reduce long-term maintenance costs
233	Wellsford	A-Team	255	X				X			\$800	Reduce long-term maintenance costs
231	Roscoe	A-Team	235		No action recommended at this time							
230	Blossom	A-Team	211		No action recommended at this time							
198	Dr. Moore	A-Team	171		No action recommended at this time							
43	VanBuren	A-Team	159		X	X					\$20,800	Protection of pump and motor; Lowering operating costs
221	Lehmkuhl	A-Team	150		X						\$67,600	Lowering operating costs
236	Gisler	A-Team	127	X							\$300	Reduce long-term maintenance costs
30	Pearson	A-Team	82			X					\$27,300	Lowering operating costs
238	Hazeldean	A-Team	67		No action recommended at this time							
229	Waterford	A-Team	57	X							\$300	Reduce long-term maintenance costs
228	Jones	A-Team	55	X							\$300	Reduce long-term maintenance costs
225	Moore	Bench	49		No action recommended at this time							
193	Naegele	A-Team	39						X		\$55,800	Lowering operating costs
240	Langworth	A-Team	30						X		\$55,800	Lowering operating costs
224	Gold	A-Team	20	X							\$300	Reduce long-term maintenance costs
232	Albers	Scrub	14	X							\$300	Reduce long-term maintenance costs
195	Lateral 1	A-Team	5			X					\$16,300	Reduce long-term maintenance costs; Lowering operational costs
222	Bashor	Scrub	4		No action recommended at this time							
197	Highline	A-Team	0	X							\$300	Reduce long-term maintenance costs

**TABLE 1
IRRIGATION WELL RECOMMENDATIONS
Modesto Irrigation District**

MID No.	COMMON NAME	Well Ranking	2005 PRODUCTION (acre-feet)	Recommended for Additional Testing	RECOMMENDED FOR REHABILITATION						ESTIMATED COST (\$)	POTENTIAL BENEFITS
					Well Cleaning	Pump/Motor Rehab.	Sounding Tube	Install Flow Control Valve	Pump/Motor Replacement or Reconfiguration	Well Replacement		
226	Erickson	A-Team	0	X							\$300	Reduce long-term maintenance costs
227	Schmidt	A-Team	0					X			\$500	Reduce long-term maintenance costs
244	Cummings	Bench	0		No action recommended at this time							

**TABLE 2
DRAINAGE WELL RECOMMENDATIONS
Modesto Irrigation District**

MID No.	COMMON NAME	2005 PRODUCTION (acre-feet)	Recommended for Additional Testing	RECOMMENDED FOR REHABILITATION						ESTIMATED COST (\$)	POTENTIAL BENEFITS
				Well Cleaning	Pump/Motor Rehab.	Sounding Tube	Install Flow Control Valve	Pump/Motor Replacement or Reconfiguration	Well Replacement		
62	Lombardi #1	1425		No action recommended at this time							
79	Lombardi #2	1018		No action recommended at this time							
102	Shackelford	929	X							\$300	Reduce long-term maintenance costs
36	Shoemake	866		No action recommended at this time							
50	Wilkinson	653		No action recommended at this time							
51	Maze	600		No action recommended at this time							
69	Katen	592			X				X	\$39,300	Reduce long-term maintenance costs; Reduce operational costs
108	Lateral 3	509	X							\$300	Reduce long-term maintenance costs
13	Edwards	461		X					X	\$28,800	Reduce long-term maintenance costs
46	Warnock	332			X				X	\$39,300	Reduce long-term maintenance costs; Reduce operational costs
23	Machado	90	X							\$800	Reduce long-term maintenance costs
57	Aiken	86			X	X		X		\$91,300	Reduce operational costs
55	Cover	66		No action recommended at this time							
107	Russell Rd.	40		Not evaluated-No action recommended at this time							
66	Corson	13				X				\$1,200	Reduce long-term maintenance costs
48	White	0			X				X	\$39,300	Reduce long-term maintenance costs; Reduce operational costs
90	Canfield	0		X	X					\$18,000	Reduce long-term maintenance costs; Reduce operational costs
83	Jackson	0	X						X	\$28,800	Reduce long-term maintenance costs
26	McComas	0		No action recommended at this time							

**TABLE 3
AGRICULTURAL WELL RECOMMENDATIONS
Oakdale Irrigation District**

WELL NAME	WELL RANKING	2005 PRODUCTION (mil gallons)	Recommended for Additional Testing	RECOMMENDED FOR REHABILITATION					ESTIMATED COST (\$)	POTENTIAL BENEFITS
				Well Cleaning	Pump/Motor Rehab.	Sounding Tube	Pump Replacement or Reconfiguration	Well Replacement		
Thornton	A	258.7			X	X			\$17,500	Reduce long-term maintenance costs; Reduce operational cost;
Hirschfeld	A	245.2		No action recommended at this time						
Mc Math	A	202.9			X	X			\$17,500	Reduce long-term maintenance costs; Reduce operational cost;
Tennant	B	170.2			X				\$15,800	Reduce long-term maintenance costs
Howard	A-	160.4	X			X			\$1,500	Reduce long-term maintenance costs
Burnett	A	139			X				\$16,300	Reduce long-term maintenance costs; Reduce operational cost;
Weimer	A-	132.4			X				\$27,600	Reduce long-term maintenance costs; Reduce operational cost;
Allen	C	129.6		No action recommended at this time						
Oakdale	A-	92.5		X		X	X		\$92,500	Increase Production; Reduce maintenance costs; Reduce operational costs
Huffman	A	49.5	X			X	X		\$2,000	Reduce long-term maintenance costs
Fairbanks	B	48.8	X			X			\$1,500	Reduce long-term maintenance costs
Riverbank	A-	39.9			X	X			\$17,500	Reduce long-term maintenance costs; Reduce operational cost;
Marquis	C	32						X	\$28,800	Reduce long-term maintenance costs; Reduce operational cost;
Steinegul	A	27.4	X			X			\$1,500	Reduce long-term maintenance costs
Birnbaum	A-	3.2		No action recommended at this time						
South Main #1	B	?	X			X			\$1,500	Reduce long-term maintenance costs
South Main #2	B	?	X			X			\$1,500	Reduce long-term maintenance costs

4 Data Management System

The DMS is a Microsoft Access® database with a custom interface for entering well data into a database, viewing data, and generating reports. The DMS interacts with the DSS, supplying well data used in the DSS decision algorithm and logging well operation status as orders are placed.

Well data collected through monitoring or maintenance activities are entered directly into the DMS. These data may include water quality parameters, static and pumping water levels, and production data. Parameters that remain static over time, such as well location and identification, are included in the Specifications table.

The DMS interface allows the user to generate tabular and graphical reports for a particular well or group of wells for a specified time period. The Comparison menu is a powerful graphical tool that allows for simultaneous viewing of three time series plots of monitoring data at a single well. For example, the user may view water level, production, and total dissolved solids (TDS) over a single time period or may choose to view a single parameter at three different time periods. Additional graphics are included under the Maintenance menu, which plots well efficiency parameters.

This section summarizes the development and components of the DMS. The WFO User's Manual in Appendix C provides more detailed information about operation of the DMS.

4.1 DMS Development

The DMS was designed with input from the Association as one of three components of the Project. Together with the DSS and system-wide well evaluations, the DMS will serve the Association's need to effectively manage and optimize well field operations.

The DMS is structured to serve the Association's member agencies. That is, there is a single DMS (and thus a single database) in which all well production, monitoring, and maintenance data are stored. The DMS interface is divided into management zones by "system," "district," or "operator." In the current prototype (version 1.0), only MID and OID have been included. Eventually, the DMS can be expanded to include all management zones within the Association.

4.2 Summary Description of DMS

The DMS is a custom user interface constructed within the Microsoft Access® environment using Microsoft Access® VBA code. The user interface allows the user to enter and display

data filtered by a number of parameters, including well selection, time periods, and data types (e.g. production, water levels, and water quality).

4.2.1 Input

Data are input to the DMS through the “Data Entry” sub-menus, including Production Data, Water Levels, Water Quality, Well Specifications, Well Evaluation Data, and Lateral Reaches. These data are stored within the DMS for analysis and use in the DSS.

Production data can be entered into the DMS using four different data types: Acre-Feet, Gallons, Hours Operational, and Meter Readings in kilowatt hours. Data are stored in the database with units of acre-feet and gallons. Using the chosen data type, values input are converted to the stored units. Data input using the “Hours Operational” data type converts the value entered to acre-feet using the flow measured from the well evaluations discussed in Section 3 of this report. In a similar manner, the conversion of kilowatt hours to acre-feet is accomplished by using the pumping water level and well efficiency data collected from well evaluations.

Water level data are input and stored in the database as feet below top of casing (ft-btoc). The two categories of water level data stored are static and pumping water levels. In addition to the static and pumping water levels, the discharge head and correction numbers can be stored through the well evaluation input form discussed later in this section.

Water Quality is input into the database based on the units selected by the user. The water quality input form has standard inputs for many constituents that are tested on a regular basis. These constituents have their units set automatically, but can be changed if necessary. On this form there is also an entry box for “one-time” constituent tests, which can be entered with units selected by the user.

The well evaluations performed by the water districts can be input into the DMS through the Well Evaluation form. The form resembles the field forms used to record data during the evaluation. The most critical data items are the kilowatt per acre-foot, cubic feet per second (cfs), and efficiency rating. These values are important because they are used by the DMS and DSS for calculations and sorting purposes throughout the application, most important of which is converting values to acre-feet for production inputs and determining wells in the DSS.

4.2.2 Updates

Three forms are included in the data update portion of the main menu: Lateral Reaches, Run Log, and Ditch Tender Areas.

Lateral information can be entered into the DMS through the Lateral Reach form. The Lateral Reach form allows users to add new laterals to the system, or to update reach working capacity and reach velocity for existing laterals, if needed.

The Run Log is available for update in the case wells are not run according to the requests made. Allowing the user to update the run log will result in the best performance of the system.

Ditch Tender Areas are available for update in case the district changes its system organization by adding or removing areas.

4.2.3 Output

DMS output includes tabular and graphical data reports that can be viewed, saved, and printed from the “Data Review” sub-menus: Production, Water Level, Water Quality, Comparison, Maintenance, Specifications, and Well Statistics.

Data Entry Sub-Menu	Description of Output
Production	Tabular production data by date
Water Level	Tabular static and pumping levels by date
Water Quality	Tabular water quality data by date
Comparison	Graphical plots (three per page) for comparison of any production, water level, or water quality parameters for any time period for a single well
Maintenance	Graphical and tabular well efficiency data
Specifications	Tabular well details, construction, and pump information
Well Statistics	Report of annual statistics for all wells

Appendix C, DMS User’s Manual, includes a description and examples of output for each sub-menu listed above. Two examples are included in Figure 4 to illustrate the basic format of tabular and graphical output for the DMS.

4.2.4 Security

The DMS will be password protected. Details of the password protection are currently being developed.

4.2.5 Integration with DSS

- The DMS and DSS use two-way data transfer to assist the water operator in determining which wells should run to produce water based on requests. Using customized queries and data processing, the DSS determines the wells most

suited to fulfill water requests. The DSS then stores the selected wells in the DMS for future use and review.

4.2.6 Assumptions and Limitations

- The user is limited to entering/reviewing data in the units provided for each parameter. Where applicable, more than one unit system is provided; otherwise, industry standards are used.
- Water quality constituents are limited to the list of 30 provided. Additional constituents can be added by using the Water Quality input form. On this form there is a blank box at the end for adding “One Time” data inputs for a well. Once the constituent has been added for the first time, it will be available in a drop-down list; however, a standard input will not be added to the page, and the user will have to manually type in this constituent if there is a reading. **Note: Adding a new constituent is DMS-wide and not specific to certain wells.**
- Wells serving multiple laterals must be assigned to the upstream lateral and have a distance along lateral that is prior to the lateral split.
- When wells are added using the “New Well” box, they are not added to the map. Wells can only be added to the map by creating a new map in another application and then adding the new image to the map form. After creating the new map, the buttons used for well selection must be updated on the form itself.
- Only one set of specification data for each well can be stored in the database. Old specifications for refurbished wells are overwritten.
- Wells that become abandoned can be removed from DSS processing and data review portions of the application by marking the well as inactive in the well specifications portion of the DMS.

Abandoned wells still appear on the map. To remove abandoned wells from the map, a new map must be created. The buttons on the form used to select wells must then be updated to match the wells on the new map.

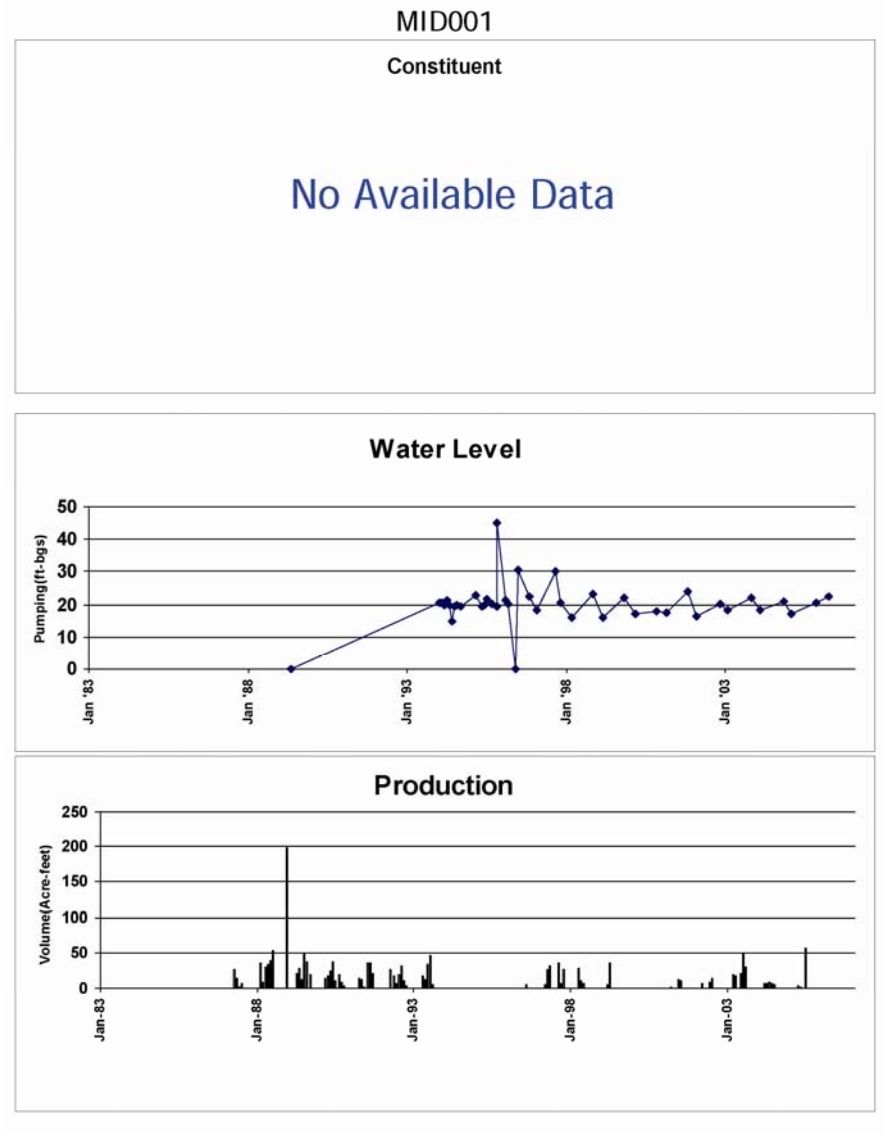
Figure 4 Example of DMS Tabular and Graphical Reports.

Monthly Production with Annual Totals

MID001

Well: Adair

<i>Well ID</i>	<i>Date</i>	<i>Gallons</i>	<i>Acre-feet</i>
MID001	Jan-1987		0.00
MID001	Feb-1987		0.00
MID001	Mar-1987		0.00
MID001	Apr-1987		26.00
MID001	May-1987		14.00
MID001	Jun-1987		2.00
MID001	Jul-1987		7.00
MID001	Aug-1987		0.00
MID001	Sep-1987		0.00
MID001	Oct-1987		0.00
MID001	Nov-1987		0.00
MID001	Dec-1987		0.00
Total Annual Production	1987		49.00



5 Decision Support System Development

The DSS is a custom tool within Microsoft Access® for optimizing the operation of wells. The DSS interacts with the DMS, retrieving well data from the DMS and updating well operation status as orders are placed. The WFO application is built on a Microsoft Access® database platform combining the DMS and DSS into one location.

The main function of the DSS is to automate the decision process for system operators in selecting wells to meet deliveries. The DSS optimizes well selection based on criteria input by the operator, including location, time of delivery, flow rate, efficiency, and water quality (optional). DSS output includes a list of available wells that meet the selection criteria. The user can select from among the eligible wells to satisfy the order.

This section provides a summary description of the DSS development and features. The WFO User's Manual in Appendix C provides more detailed information about the DSS.

5.1 Data Analysis - Target Operating Parameters

5.1.1 Efficiency and Operating Cost

In order to make the well selection process economical for the Association, the available wells are sorted in order of the power consumption. The values for power consumption are taken from the well tests performed by the district.

5.2 DSS Development

The DSS was designed with input from the Association as one of three components of the WFO Project. Together with the DMS and system-wide well evaluations, the DSS will serve the Association's need to effectively manage and optimize well field operations.

The DSS is structured to serve the Association. That is, there is a single DSS interface for the whole Association, which is divided into management zones by "system," "operator," or "district." In the current prototype (version 1.0), only MID and OID have been included. Eventually, the DSS can be expanded to include all management zones within the Stanislaus and Tuolumne Rivers Basin.

In addition, the DSS will eventually link to a SCADA system, which will allow for real-time, remote operation.

5.3 Summary Description of DSS

The DSS is an interactive software program constructed within the Microsoft Access® environment using Microsoft Access® VBA code. The DSS user interface requires user input of well selection criteria and outputs a list of eligible wells that satisfies well selection criteria based on the DSS algorithm.

5.3.1 Input

Delivery information including delivery location, time, required flow, and optional water quality criteria are input to the DSS. Delivery locations are selected from an interactive system map. The system maps for OID and MID are included in this document as Figures 5 and 6, respectively.

5.3.2 Output

The DSS outputs a selectable list of all available wells meeting the specified delivery and water quality criteria. The user selects wells from the list based on additional information listed for each well, i.e., start delivery time, well efficiency, power consumption, and water quality. As wells are added to the selection, the total flow and water quality amounts are shown so that the user knows when the delivery request is met. At that time, the order can be submitted, which effectively reserves the selected wells for the specified period of time and produces a printable order sheet.

5.3.3 Integration with DMS

The DMS houses all information about the wells. This information is used in the DSS algorithm to eliminate wells that do not meet the specified delivery criteria. Once an order is placed, the order information is saved to the DMS so that the well operation information can be tracked and used in subsequent orders.

5.3.4 Assumptions

- All wells have up-to-date efficiency tests, and data have been input into the DMS.
- All wells have correct distance along lateral. (See limitations pertaining to wells serving multiple laterals.)
- All lateral velocities are correct. These values are used to calculate the travel time for delivery.

5.3.5 Limitations

- Wells that are located at lateral splits that are located at lateral splits and have the ability to serve both downstream laterals will need to be assigned to the lateral reach upstream of the lateral split with a distance along the lateral not greater

than the cumulative lateral distance stored in the DMS for that reach. For the purpose of the WFO, a lateral reach is any non-interrupted length of the lateral. Assigning well locations in this manner allows the DSS algorithm to recognize that the well can serve either lateral.

- Wells are removed by the DSS algorithm if any of the maximum permissive values input by the requestor for Water Quality are not met. If the blended option is selected, all wells that meet all other criteria will be shown and the requestor can make the decision to use the well at his/her discretion.
- Mixed constituent values are calculated as a weighted average based on the flow of each well selected to fulfill a request. This value does not take into account the dissolution of each constituent along the lateral.
- Delivery points for the DSS tool are limited to the well locations provided on the system map and the lateral termination points. The travel time between the selected well and the actual delivery point is not taken into account.
- The safety check to prevent overflow is based on values input by the user, which may be estimated.

5.4 DSS Implementation and Testing

5.4.1 Implementation

In order to implement the DSS, all data from the well evaluations as discussed in Section 3 of this report must be input into the DMS system. Data such as flow rates and power consumption are integral to the DSS algorithm and are necessary for the DSS to give the best results to the user.

5.4.2 Testing

The DSS system has been tested to confirm that the proper wells are being displayed based on the parameters requested and the operational status of upstream wells. The parameters that affect the availability of a well are well type, travel time, required flow, and constituent levels. Each of the parameters has been tested to verify that wells meeting these parameters pass through to the well selection window.

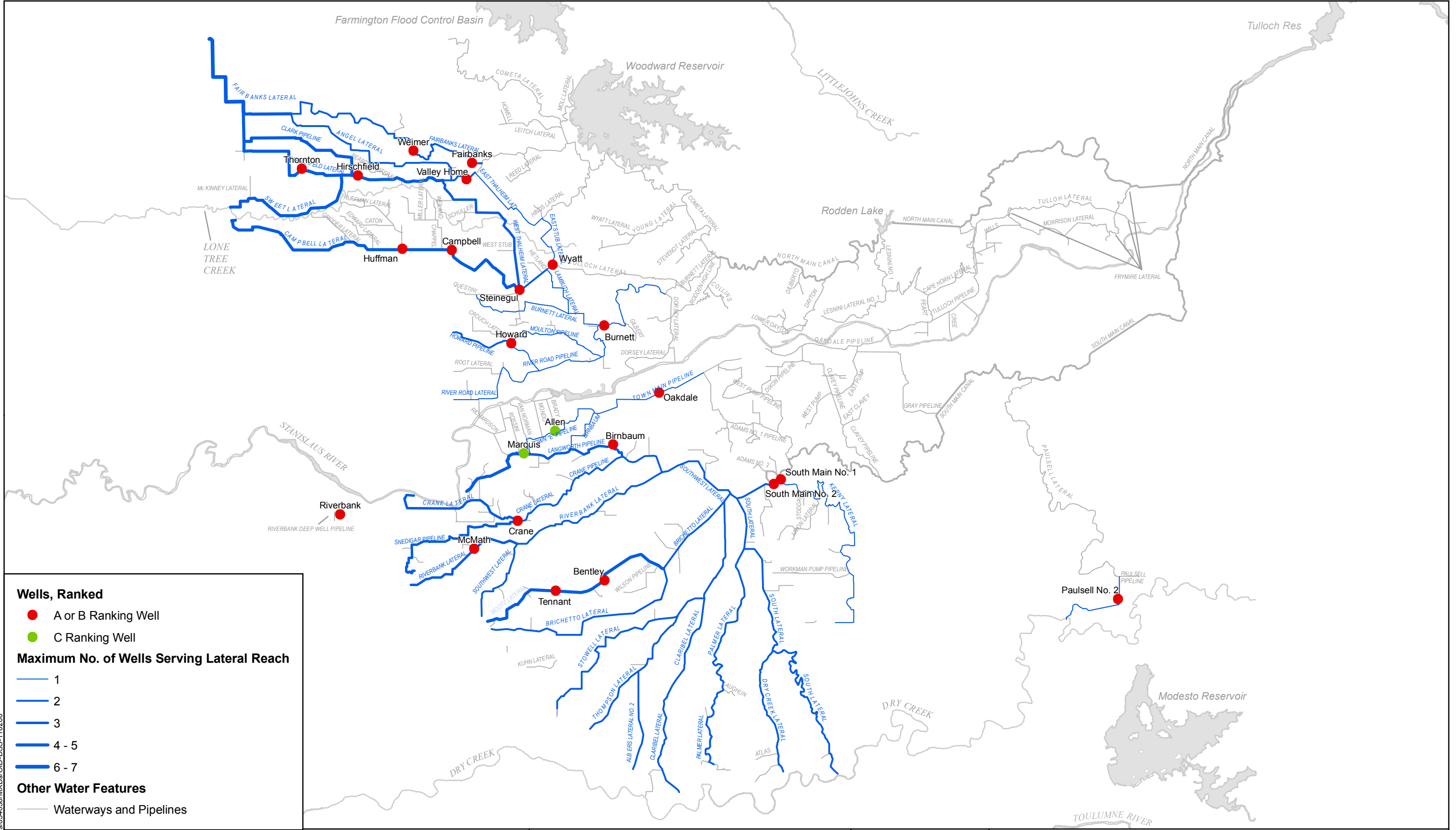
When requesting water delivery, the DSS may remove some wells from the list of available wells presented to the user. The reasons for such removals are:

- Well Type – Wells are removed from the list of available wells if “type” is not set to “Production,” “Drainage,” or “Deep Wells.” Well type is set in the DMS system.

- Travel Time – Travel Time is based on the distance between the delivery well selected and the well in question, and the velocities of the laterals between the two. If the travel time is too great to meet the delivery start time, the well will be removed from the list of available wells.
- Required Flow – Wells are removed if the well’s flow value exceeds the value of the requested flow.
- Constituent Levels – Wells are removed if any of the constituents chosen are given a maximum permissive value and the level of the well in question exceeds that value.

5.5 Well Production Scenarios

Well Production Scenarios (WPS) give the user the ability to run scenarios for different volumes or flows over the entire district, selected ditch tender areas, selected laterals, or selected wells. The scenario will output wells based on power consumption until the requested volume or flow is met. This tool is meant for planning purposes only and does not store results into the DMS. The WFO User’s Manual in Appendix C provides more detailed information about the WPS capabilities.



Wells, Ranked

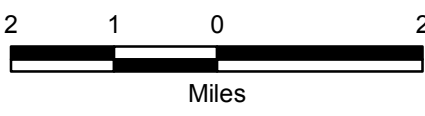
- A or B Ranking Well
- C Ranking Well

Maximum No. of Wells Serving Lateral Reach

- 1
- 2
- 3
- 4 - 5
- 6 - 7

Other Water Features

- Waterways and Pipelines



Wellfield Optimization Project

Stanislaus and Tuolumne Rivers
Groundwater Basin Association

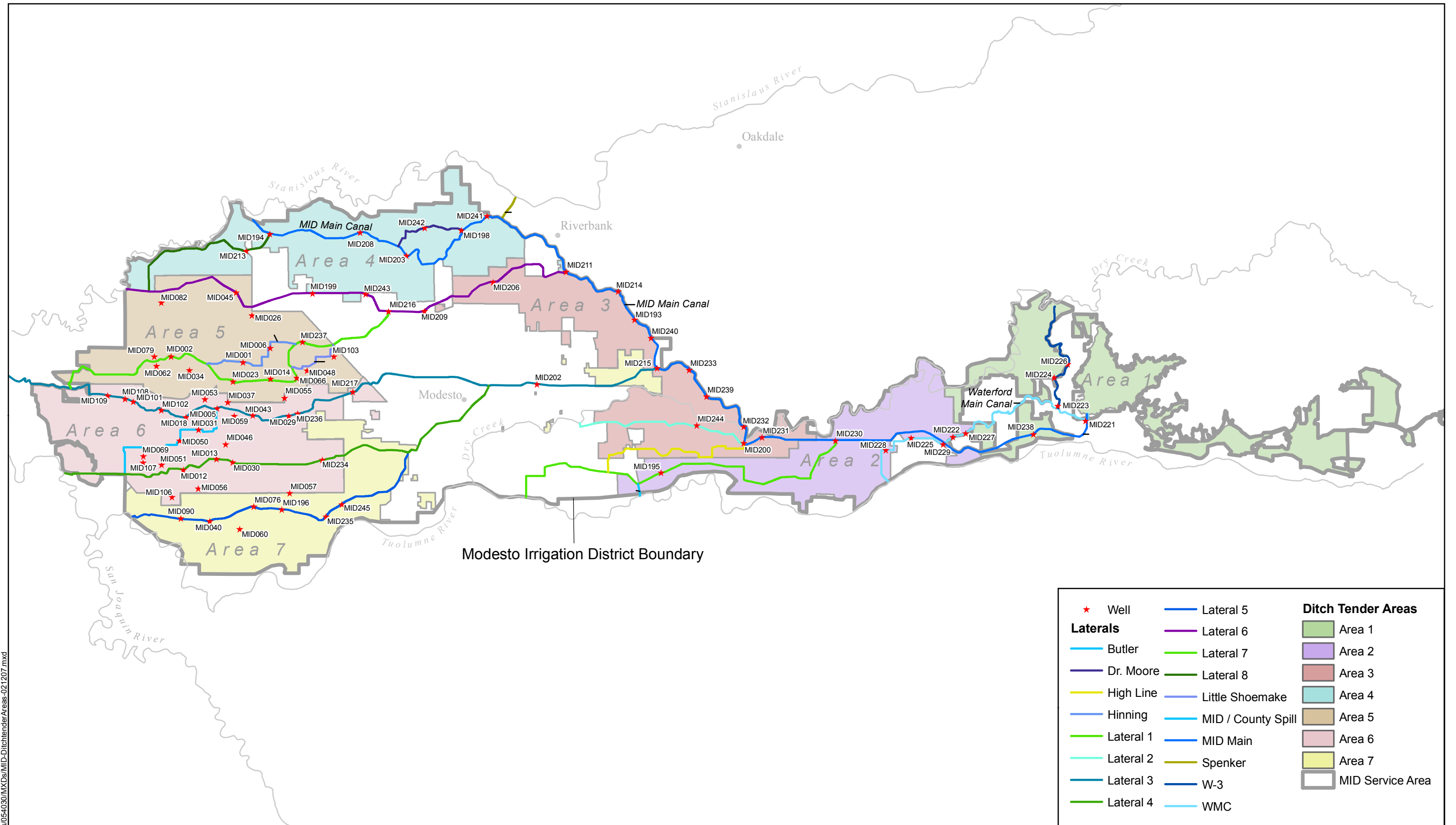


OID DSS Interactive Well Selection Map

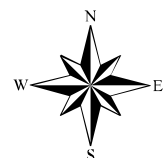
MAY 2007

FIGURE 5

14-May-07 S:\GIS\Projects\054030\MXD\OID-DSS-110206



★ Well	— Lateral 5	Ditch Tender Areas
Laterals	— Lateral 6	Area 1
— Butler	— Lateral 7	Area 2
— Dr. Moore	— Lateral 8	Area 3
— High Line	— Little Shoemake	Area 4
— Hinning	— MID / County Spill	Area 5
— Lateral 1	— MID Main	Area 6
— Lateral 2	— Spenker	Area 7
— Lateral 3	— W-3	MID Service Area
— Lateral 4	— WMC	



Wellfield Optimization Project

Stanislaus and Tuolumne Rivers
Groundwater Basin Association



MID DSS Interactive Map

MAY 2007

FIGURE 6

6 Findings and Recommendations

6.1 Repair of Existing Wells

The well evaluation project has identified 18 wells that need repairs in order to improve their performance to an acceptable level. This includes 11 MID wells and 7 OID wells. It is recommended that OID and MID schedule and budget maintenance of these wells as soon as possible. The specific work that must be performed is identified by well in the evaluation report.

6.2 Well Replacement Program

The well evaluation project also identified six wells that must be replaced, including one OID well and five MID wells. The existing wells should be decommissioned and properly destroyed and new wells should be drilled and developed. It is also recommended that the districts budget and schedule a well replacement program for these wells and also budget to meet future well replacement needs

6.3 Implement Phase II of the Well Field Optimization Program

This phase of the program expands the WFO to include service areas of other water purveyors in the Basin. This will include expanding the well evaluations, DMS, and DSS. The DMS will also be modified to become web-based to provide access by all Association member agencies.

6.4 Implement Phase III of the Well Field Optimization Program

This phase will fully automate the conjunctive management operations, which will include:

- Using remote sensing to collect real-time groundwater level and water quality data as well as water quantities and quality in the districts' main laterals.
- Establishing a process to assess the water requirement in each lateral.
- Installing a SCADA system to monitor, control, manage, and optimize groundwater pumping, surface water quantities in the laterals, groundwater levels, and lateral spillage.

6.5 Financial Plan

A financial plan should be developed to facilitate orderly development and implementation of the recommendations listed above, including identification of potential grant programs.

Appendix A - MID Well Evaluations

Appendix B - Old Well Evaluations

Appendix C – Well Field Optimization (WFO) User’s Manual

