

Sacramento Valley Water Resource Monitoring, Data Collection and Evaluation Framework

The sustainable management of both surface and groundwater resources in the Sacramento Valley was a primary driver in the development of the Sacramento Valley Integrated Regional Water Management Plan (SVIRWMP). Among the many water management needs identified in the SVIRWMP was the need for improved coordination, development, and sharing of data associated with surface and groundwater monitoring. While monitoring currently occurs throughout the valley, it is recognized that improvements can be made with respect to data collection/monitoring approach and focus at both the project and regional level. Accordingly, an informal panel (“panel”) of Sacramento Valley water resources scientists and engineers developed a proposed framework aimed toward assisting in improved regional and project-specific water resource monitoring, data collection, information exchange, and evaluation to better understand the valleys’ water resources to improve upon their management. It is hoped that this framework will provide a basis to guide the development of data collection/monitoring programs across the Sacramento Valley, recognizing that individual projects and programs have their own unique focus, characteristics, and financial constraints.

Intended Use of the Framework

The proposed framework is intended to assist in obtaining and sharing information to:

- Characterize existing surface water and groundwater resources,
- Identify the interaction between, and within, these resources,
- Examine the opportunities to increase local/regional supply through local/regional water resource management while ensuring sustainable use, and
- Determine the resources response to natural changes in water supply, or changes associated with a given project or program.

The coordinated collection and sharing of data is intended to be used as a guideline to help evaluate, define, and design effective surface and groundwater monitoring infrastructure at a the local and regional level. In addition, it is hoped that this framework will assist in supporting the development of a coordinated regional data collection, monitoring, and investigation program for the SVIRWMP area.

Primary Objectives of the Framework

The primary objectives of this regional resource monitoring, data collection, and evaluation framework are as follows:

- Support the collection of sufficient data to establish baseline conditions throughout the valley
- Establish standardized data collection methodologies to improve the consistency and comparability of data currently being collected as well as data collected in the future
- Provide for the monitoring of the effects of existing and future groundwater use and irrigation practices on the groundwater resource

- Propose methods of employing numerical, analytical, and graphical tools to analyze and interpret data
- Provide sufficient data to improve understanding of the degree of hydraulic interaction between the surface water and groundwater system across the valley
- Support the evaluation of any potential effects of future changing management practices on groundwater and surface water resources in the valley
- Serve as a living document to accommodate new information and incorporate changes, as needed, to address additional data needs and further evaluate local and regional changes in water resource management.

Regional/Project-Specific Approach

The monitoring and data collection approach outlined in this framework is intended to facilitate and support improved water resource management at both a regional and project level. It is not intended to prescribe or limit the application of alternative methods for effective data collection and management, or serve as a cookbook of pre-approved methods for implementation of projects that change or alter existing water management practices at a regional or local level. A number of monitoring objectives ranging from project performance to water quality assessment are identified -- some or all of which are relevant to any existing or proposed project or program. As proposed, the framework would provide guidance in the development and/or refinement of a monitoring program, as is applicable, within the given context of the project/program objectives. Continued use of the framework over time would further encourage the consistent application of monitoring approaches and sharing of data and ideas. The resulting monitoring data could in turn be used by counties and other entities that currently track and evaluate groundwater levels through various methods (e.g. basin management objectives) to refine their individual objectives as appropriate.

It should be noted that this document is intended to provide general recommendations regarding the types of data that should be collected across the region to allow improved analysis and understanding of the state of the groundwater resource over time. It is strongly recommended that any project that proposes to significantly increase groundwater extraction or change existing water management practices develop a project-specific monitoring and data collection plan of sufficient detail and frequency to adequately analyze the regional and local scale effects of project activities within the context of the project location and regulatory requirements. It is intended that the data and approaches developed and utilized through the regional framework process will support project-level monitoring and improved water management.

Next Steps

It is intended that the proposed framework be distributed across the SVIRWMP region as a guidance document. Depending on the overall response, the panel is planning to begin an inventory of on-going baseline and program-related data collection/monitoring efforts across the region to ultimately identify potential data gaps and additional monitoring needs. Once these gaps have been identified, the panel will provide a findings summary as well as recommendations for filling these data gaps with respect to known areas of concern, proposed development, and/or areas with limited existing data. These recommendations will assist Sacramento Valley water resource stakeholders prioritize future project, infrastructure, and

modeling needs, and secure appropriate funding. Additional panel activities are proposed to be driven by input from water users and stakeholders in the SVIRWMP region.

1.0 Introduction

Adequate supply and distribution of water resources within the Sacramento Valley are components vital to the economic and environmental sustainability of the region. On a regional scale, the surface and groundwater resources in the Sacramento Valley provide a collective water supply that is reliable and adequate to meet current demand. However, local reliability does vary, and shortages do exist, for some areas even in normal water years. Regional coordination of water resource monitoring and data collection, coupled with collaborative investigation of integrated regional management opportunities, can help improve the management of the Sacramento Valley's water resources to meet the ever changing and growing demand.

Over the years, the agricultural, urban, environmental, and recreational water demands have changed based on changes in irrigation technology, increased urbanization, and the need for maintenance/enhancement of environmental assets. Accordingly, competition for finite water resources will result in future changes in water demand, and with it an increasing need for regional management to effectively accommodate these needs while sustaining the future viability of these resources.

Numerous Sacramento Valley counties and water districts have developed groundwater management and monitoring plans. Similarly, most surface water purveyors have surface water management and monitoring plans. However, in most cases, these monitoring and management plans have been independently implemented and have not necessarily capitalized on the potential to share data and coordinate management efforts. Monitoring, collecting, and sharing of the data by local, state, or federal water interests will greatly assist in the identification, analysis, and better understanding of the existing baseline conditions and the effective evaluation of the potential benefits and/or impacts associated with changes water resource management.

The framework is intended to be a living document -- implemented in a phased approach, as the necessary resources become available. It is intended to supplement on-going monitoring and data collection efforts being conducted by the Bureau of Reclamation (Reclamation), the U.S. Geological Survey (USGS), the Department of Water Resources (DWR), County staff, watershed groups, water districts, and independent water resource users. In an attempt to develop the most efficient and comprehensive water resource data collection network possible, the framework considers all existing surface water and groundwater monitoring, as well as monitoring proposed under the various grant opportunities. The resultant data collection and analysis activities are intended to collectively serve the needs of resource stakeholders by improving the local and regional monitoring and characterization of the surface water and groundwater systems, and the sharing of information within the SVIRWMP area. Data collected and shared under this plan is intended to help evaluate and design future surface water, groundwater, and land subsidence monitoring infrastructure. It is hoped that these

efforts will ultimately support the development of a single, unified and stakeholder driven, data collection, monitoring, and investigation program for the SVIRWMP area.

Surface water, groundwater and aquifer characterization data collected under this program is proposed to be used in conjunction with, and in support of, numerical groundwater modeling tool development to augment data interpretation. It is universally understood that numerical modeling is an essential tool to assist in the evaluation of the benefits/impacts associated with proposed changes to water resource management practices. It is also understood that numerical modeling results are limited by the quantity and quality of the existing data. The framework approach to data collection and monitoring is intended to help provide baseline data of sufficient quantity and quality to build a regional-scale model which, when coupled with compatible project-scale models, can adequately assist in evaluating the regional and cumulative effects associated with proposed changes in water resource management. It is hoped that this framework will help guide development of data collection and monitoring programs across the Sacramento Valley, while being flexible enough to accommodate the unique focus, characteristics, and financial constraints of local resource managers.

As mentioned above, the implementation of this program is envisioned to occur in a phased manner, over an extended period of time, as resources become available. During the extended implementation period, as stream and aquifer data become available, these data would be interpreted, aquifer and streambed properties estimated, and the selected regional modeling tool updated to reflect the new information. Simulations could then be performed to further identify the effects to surface water and groundwater systems resulting from changing water resource supply and demand, and the application of artificial recharge. This feedback loop is intended to continue, as necessary, to support the needs and requirements of the water interests through the Sacramento Valley.

2.0 Monitoring and Data Collection Activities

The monitoring and data collection activities are intended to collectively improve the local and regional understanding of the water resources and provide baseline characterization of the surface water and groundwater systems within the SVIRWMP area. Improving the baseline understanding will help identify and evaluate local and regional changes to the water resources resulting from local and regional changes in water resource management practices. It is understood that the focus of data collection objectives may change as information is collected and management alternatives are evaluated. A bulleted list of the initial monitoring and data collection activities are provided below, followed by a brief description of their existing need.

- Groundwater Performance Monitoring
- Surface Water/Groundwater Interaction Monitoring
- Habitat Monitoring
- Water Quality Monitoring
- Land Subsidence Monitoring
- Basin Recharge Monitoring
- Hydrogeologic Characterization of Aquifer Systems

2.1 Groundwater Performance Monitoring

Groundwater performance monitoring is required to identify the rate, volume, and location of groundwater extraction wells which currently provide groundwater supply under existing water resource management practices, and extraction wells intended to participate in proposed water resource management or groundwater substitution programs (with and without recharge components). Baseline and project specific groundwater extraction data will help evaluate existing resource management practices and the benefits and/or impacts associated with programs proposing changes in water resource management at the local or regional level. For water management programs which propose groundwater extraction from an aquifer with little previous production history, new test-production wells along with dedicated observation wells may be required to facilitate data collection and allow for adequate evaluation of the benefit and/or impact associated with program related pumping.

2.2 Surface Water/Groundwater Interaction Monitoring

Understanding the natural interaction between surface water and groundwater resources allows for more effective examination of potential alternatives to existing water resource management practices and more accurate evaluation of the local and regional effects associated with the implementation of these proposed changes. The collection of baseline data to build an understanding of the local and regional connection between surface water and groundwater resources is an important monitoring plan activity. To quantitatively assess the degree, timing, and flow path associated with the hydraulic connection of surface water and groundwater systems, an appropriate type and level of monitoring data must be collected. Groundwater level and quality data can be obtained from a combination of multiple-completion monitoring wells and stream stage gauging stations located in close proximity to one another. River stage fluctuations and water quality would be measured seasonally during base flow and in response to storm events, and compared with groundwater-level fluctuations and water quality measured in the aquifers adjacent to the surface water systems. These data will support calculated estimates of the quantity of extracted groundwater that is contributed from surface water systems as the direct results of induced leakage, or by the indirect interception of groundwater that would otherwise have discharged to the surface water system. Delineation of the timing and magnitude of this interconnection is essential to properly assess the local and regional affects associated with isolated and cumulative changes in water resource management practices (determination of real water versus paper water).

2.3 Habitat Monitoring

The long-term health of riparian vegetation, wetland species, and number of other native habitat are commonly associated with maintaining a minimum range of groundwater levels and an appropriate level of interaction between surface water and groundwater resources. The lowering of groundwater levels due to natural climatic changes or the interception of groundwater underflow to surface water systems due to the increased groundwater extraction associated with water management programs, have the potential to impact the native habitat areas. Baseline habitat monitoring is an important data collection objective because it allows for a better understanding of the existing water resource requirements of the native habitat and the evaluation of potential impacts associated with potential changes in water resource management practices. In order to identify potential habitat impacts associated with potential changes in water management practices, a program-specific network of shallow monitor monitoring wells should be developed to detect changes in water levels over the shallowest

portion of the aquifer. In evaluating impacts to certain wetlands species, it is important to discern both the rate of groundwater level change, as well as the cumulative change over the entire year. Data collection and monitoring frequency should be appropriately selected to support the temporal and long-term evaluations.

2.4 Water Quality Monitoring

The general quality of surface water and groundwater systems in the Sacramento Valley is high. However, localized areas of lower quality water, due to naturally occurring and man-made sources, exist that can impact domestic and agricultural groundwater use. Detailed baseline water quality sampling can help identify and protect against potential sources of poor quality water and can also help define the source of groundwater recharge, the age of groundwater being extracted, the path of water flow, and the degree of connection between adjacent aquifer systems. Baseline and project-specific water quality sampling can help identify the source and timing of aquifer recharge and can help ensure that the groundwater pumping does not directly extract, or induce migration of, poorer quality groundwater. Sampling and analytical testing for baseline and project specific water quality data should be conducted so as to allow for consistent and meaningful comparison and analysis of the data. At a minimum, water quality testing should include the standard suite of minerals, metals, and nutrients analysis. In addition, water quality sampling for oxygen isotopes, age dating, and low-level volatile organic compounds are recommended to help identify the source and timing of aquifer recharge, and the direction of water movement. If artificial recharge activities play a significant role in water management activities, the potential impact on groundwater quality due to the introduction of differing quality water should also be evaluated.

2.5 Land Subsidence Monitoring

Historic data indicates that permanent land subsidence has occurred over portions of the Sacramento Valley. Regional baseline and local project specific collection of land subsidence data is important objective to help limit further land subsidence due to groundwater extraction. Adequate monitoring and responsible management of future groundwater extraction should eliminate the possibility of further land subsidence. Land subsidence data collection activities should include the use of extensometers along with a regional GPS monitoring network. Extensometers provide continuous monitoring of local conditions, while a GPS land subsidence network provides the opportunity for periodic measurements at a regional scale. Several extensometers, along with local GPS monitoring networks, currently exist within the SVIRWMP region. The frequency, density, and type of monitoring should be adjusted as needed to match the local susceptibility, existing groundwater demand, and potential changes in demand associated with local and regional changes in water resource management.

2.6 Basin Recharge Monitoring

Understanding of the source and timing of the natural recharge to the aquifer systems is an important aspect to successful water resource management. Regional groundwater elevation data indicates that, under the existing level of demand, the majority of aquifers within the Sacramento Valley groundwater basin recover during the winter months to previous spring levels in all but the driest water years. However, localized areas of these same aquifer systems also exhibit a slow decline in spring-to-spring groundwater levels even in normal water years. Proper collection and utilization of basin recharge data can help identify and evaluate current water resource management practices, and design alternatives that will better balance the local

water supply and demand; thereby minimizing local aquifer impacts while maximizing regional yield and recharge potential. Although data collection in support of basin recharge evaluation is currently being conducted, an increase in the location and timing of surface water flow, groundwater level, and detailed water quality monitoring is recommended to further examine the timing and spatial distribution of natural recharge during multiple water year types. These data will help further the understanding of principal processes that act to replenish groundwater levels following each irrigation season and throughout the year in areas of continuous urban demand.

2.7 Hydrogeologic Characterization of Aquifer Systems

Much work has been done to characterize the aquifer systems in the Sacramento Valley; however, questions regarding geologic stratigraphy, the lateral continuity of aquifers within this geologic framework, and the vertical continuity or interconnection of the multiple aquifer systems still exist. As new monitoring wells are drilled and constructed, an important objective to furthering the hydrogeologic understanding of the region should include development of standard geologic sampling and data collection procedures. Standard data collection protocol for geologic sampling, geophysical logging, and well development would allow for more accurate comparison of these data, which translates to a more accurate modeling of the system and more thorough assessment of the potential effects associated with local and regional changes in water management practices.

3.0 Data Collection and Management

Responsible management of water resources in the SVIRWMP region requires the collection of a significant quantity of data including surface and groundwater use, groundwater levels, stream flow, groundwater quality, land subsidence, land use, and other environmental data.

Numerous data collection and analysis activities are currently on-going in the Sacramento Valley. These efforts are being conducted by the DWR in cooperation with county and water district personnel. In addition, grant funding to various agencies within the SVIRWMP region will provide further opportunities for collaboration of data collection, management and distribution with State, county, watershed groups, water district staff, and independent water resources users. Some of the current primary data collection efforts are summarized below:

- Aquifer parameters data from aquifer performance testing
- Groundwater level data
- Groundwater storage data from change in groundwater level analysis
- Stream-aquifer recharge data from instream flow monitoring
- Land and water use data
- Groundwater and surface water quality data
- Land subsidence data
- Subsurface geologic data associated with monitoring well drilling
- Well infrastructure data associated with Well Completion Reports

Effective utilization and sharing of these data will require a significant level of coordination with respect to the collection, quality control, management, and distribution of these data sets.

One possible approach to managing the regional data would be to utilize the existing Water Data Library (WDL) developed and maintained by the DWR. DWR is currently in the process of developing WDL into a GIS based Information Management System (IMS) that will allow more effective storage, retrieval, and sharing of data. Similarly, several counties in the northern Sacramento Valley are in the process of developing their own internet based GIS information management system which will allow storage, maintenance, and retrieval of a number of local data sets. It is envisioned that the State and county internet based information management systems would have the ability to serve up the data they store and maintain, to help facilitate the seamless sharing of both local and regional data, regardless of the data storage location.

A generalized work plan to develop protocols for the collection, management, exchange, and dissemination of the data is presented below. A general overview of how the State WDL, or State and county GIS IMS, could support future data collection and management activities are listed and organized according to data parameter, along with recommendations for enhancements to achieve the required additional functionality. It is important to recognize that development and coordination of data management systems is a very dynamic process and will require on-going adjustments to the systems to meet the changing technology and the overall needs associated with collecting, managing, and distributing multiple types of high-quality water resource related data.

Conceptual Data Collection and Management Work Plan

1. Meet with local and regional data users and providers
 - a. Develop a data management subcommittee and identify stakeholder representation.
 - b. Identify structure and process for data management development.
2. Develop a regional baseline monitoring plan
 - a. Identify data components (groundwater levels, quality, pumping, land subsidence, etc.).
 - b. Identify data collection locations and frequency.
3. Identify data analysis and reporting needs.
 - a. Develop data reporting specifications needed to conduct analyses or provide resource status updates.
4. Develop a data management and exchange strategy.
 - a. Canvass existing data management methods and systems.
 - b. Specify the local and regional needs for data management and exchange .
 - c. Identify data management and exchange deficiencies of WDL or the local IMS.
 - d. Upgrade the WDL or local IMS to meet deficiencies.
 - e. Identify specifications for data flow - into the WDL or local IMS from data collection cooperators and from the WDL or local IMS to analysis tools.
 - f. Develop methods for exchanging data.
5. Develop QA Plan.
 - a. Develop field manual specifying standard methods of data collection.
6. Train data collection cooperators.
 - a. Field collection techniques and quality control standards.
 - b. Data reporting requirements and quality control standards.
7. Implement monitoring program.
 - a. Collect and exchange data.

- b. Report and analyze data.
- c. Modify data collection, management, and reports as required.

4.0 Data Collection Elements

The following section presents the specific data elements that are proposed to be meet the monitoring and data collection objectives of the draft framework for Sacramento Valley water resource data collection, monitoring and evaluation program.

4.1 Groundwater Pumping

Understanding the location, volume, and duration of groundwater extraction is important data element for meeting a number of the overall data collection objectives listed above. Baseline estimates of groundwater pumping/extraction may be derived from land and water use analysis but there is limited direct monitoring of groundwater extraction, and no historical database of agricultural groundwater pumping data for the Sacramento Valley. Consequently, no mechanism for the storage, management, and dissemination of agricultural water extraction data has been developed. The Hydstra (HY) module of the WDL is capable of handling the storage and retrieval of either manual or automatic groundwater extraction measurements over a number of monitoring frequencies. Historically, there has been significant resistance to the baseline collection of this type of data. As the framework for Sacramento Valley monitoring and data collection is developed, the benefits of developing accurate groundwater extraction data to assist in the planning and projection of future water resource needs, versus continuing to project water resource needs from groundwater extraction estimates based on crop demand and water supply estimates, should be revisited.

Baseline information for groundwater wells should include well location, construction, production rate, and the annual production volume. In addition to these baseline needs, a more detailed inventory of production well data should be developed for wells proposed to operate in local or regional-scale projects that increase groundwater extraction. The detailed well inventory should be developed prior to the start of the proposed program and should include the following data:

- Well Completion Report (driller's log): This data is needed to identifying well construction (depth, casing size/type, perforations, seals, etc), drill date, and driller's lithology picks. If a Well Completion Report is unavailable, a borehole video should be required to document well construction and production interval prior to allowing participation in a pumping program.
- Well Location: This data should include Township, Range, Section, Assessor Parcel Number & GPS coordinates.
- Well Capacity: Estimated pumping rate for program related pumping and estimated average annual well operation (time and volume), i.e., 90-days, & 600 ac-ft per year.
- Groundwater Levels: Static and pumping groundwater levels should be provided.
- Power Source & Energy Demand Requirement: The proposed source of power should be identified along with estimated energy demand requirement per volume of water.
- Well Efficiency: The results from recent well operation efficiency testing.

- **Groundwater Quality:** Electrical conductivity, general minerals, metals, nutrients, and oxygen isotope analysis should be provided in order to characterize the overall groundwater water quality and estimate source of groundwater recharge, prior to the start of a proposed pumping program.

In addition to the one-time inventory of production well data, water level and water quality monitoring should be conducted annually, with a frequency that provides sufficient data to document the seasonal and long-term fluctuation over a number of water year types. These data will help facilitate analysis of the effects to groundwater and surface water systems over a series of water year types for which the proposed project may operate.

4.2 Groundwater Levels

Groundwater levels directly reflect water in storage and provide an important data element for analysis of flow patterns, stream-aquifer interaction, basin recharge, habitat health, and the overall effects associated with proposed changes to water resource management practices. DWR, along with federal, county, and local cooperators, currently maintains and monitors a large network of active and abandoned wells which are manually measured on a semiannual, quarterly, or monthly basis. The data from most of these groundwater level monitoring programs are currently stored, managed, and disseminated through the WDL groundwater module. Over the last 70 years, over 200,000 measurements have been made from about 2,300 Sacramento Valley wells.

DWR, with cooperator assistance, also monitors a network of dedicated observation wells using dataloggers which automatically record groundwater level and temperature data. As of August, 2007, approximately 180 data loggers were installed at 80 dedicated monitoring well sites in the Sacramento Valley portion of Colusa, Glenn, Butte, Tehama and Shasta Counties. These dataloggers are typically set to record and store groundwater level and temperature data on an hourly basis, resulting in very large data sets. The WDL was recently expanded to manage the large quantity of "continuous" time-series data, using the Hydstra (HY) module. Data from the continuous recorders are typically downloaded from the datalogger and uploaded into the WDL HY module database on a quarterly basis.

The existing level of effort required to maintain the groundwater dataloggers and manage the data is quite large. Changes in water resources management practices that further increase groundwater extraction will likely increase the need for additional dedicated monitoring wells -- subsequently increasing the level of effort associated with groundwater data collection and management. The frequency of manual groundwater level measurements and datalogger downloads by DWR staff is proposed to continue at the present rate. The frequency of groundwater level monitoring is discussed in Section 5.2. Table 1 in Section 5.1 provides a breakdown of proposed data collection frequencies for a groundwater monitoring network designed to assess the potential effects of expanded groundwater production on surrounding groundwater users and surface water systems. Initially, agencies cooperating with groundwater level data collection would be required to submit this data to DWR for quality assurance and quality control (QA/QC) and uploading to the WDL HY module. DWR would work with the data collection cooperators to develop procedures whereby the cooperation agency could QA/QC the data and directly upload data into WDL.

4.3 Streamflow

Streamflow and/or stage height is measured by several agencies along the Sacramento River and its tributaries. Data for stations managed by DWR are stored in the HY module of the WDL. The HY module also includes an import routine to obtain California Data Exchange Center (CDEC) data. Additional effort will be required to import data from stations that are not currently in the DWR network and the CDEC system.

4.4 Water Quality

A number of local interest groups, private and public water purveyors, county, state, and federal agencies participate in groundwater quality monitoring outside the required regulatory programs run by the State Water Resources Control Board (SWRCB), the Department of Health Services (DHS), and the Department of Pesticide Regulation (DPR).

DWR conducts annual water quality monitoring of surface water systems and groundwater aquifers throughout the Sacramento Valley. These monitoring programs focus primarily on collection of long-term baseline data which includes analysis for naturally occurring indicators of groundwater quality such as metals, minerals, and nutrient content. DWR also collaborates with counties, water purveyors, Lawrence Livermore National Laboratory (LLNL), and the United States Geological Survey (USGS) to provide a more detailed analysis of surface water and aquifer chemistry. These detailed sampling efforts are typically program or project-related and focus on specific characterization of the resource and delineation of human-induced impacts. Detailed groundwater quality sampling is often utilizes dedicated monitoring wells to provide isolated analysis of discrete aquifer intervals. Since 1998, data analyzed at DWR Bryte Laboratory have been stored in the WDL, and contain complete QA/QC in accordance with DWR's Water Resource Engineering Manual (WREM) 60. Data from 1990-1998, are stored at the corresponding DWR district office in a local database or in hard copy form. Prior to 1990, these data were stored in microfiche files or in DWR's former data management system, WDIS. The pre-1990 data were developed without a formal QA/QC program, although some of this information could be reconstituted using historical records on file at Bryte Lab.

The Northern Sacramento Valley counties have developed a *Four County Strategy* to promote regional collaboration among Butte, Colusa, Glenn, and Tehama counties. The *Strategy*, implemented through the *Four County Drinking Water Quality Program*, promotes regional collaboration for effective coordination and analysis of shared drinking water resources, and contributes to local, regional, and statewide water quality goals. Part of this program includes an ongoing assessment of current groundwater quality. Many of the dedicated monitoring wells currently sampled by DWR are owned by the local counties and thus contribute to local groundwater quality assessment. A number of counties also incorporate groundwater quality sampling as part of the local Basin Management Objectives (BMOs) of the groundwater management plan. Data collected as part of these management activities are stored at the local county. The QA/QC methods associated with the collection and storage of local county data is unknown.

As part of the California Aquifer Susceptibility (CAS) Program and the Groundwater Ambient Monitoring and Assessment Program (GAMA), DWR coordinated with the USGS and LLNL to sample detailed water quality at numerous public supply and dedicated monitoring wells in

Butte, Glenn, Tehama, and Shasta Counties. These data are stored at the USGS, LLNL and DWR.

Water quality grab samples or more detailed analysis can be managed within the existing Water Quality (WQ) module of the WDL. More frequent time series samples of temperature, electrical conductivity (EC), and total dissolved solids (TDS) data can be managed within the WDL WQ module, WDL HY module, or local data management system.

4.5 Land Subsidence

Existing land subsidence monitoring in the Sacramento Valley consists of borehole extensometers and GPS monitoring stations. Thirteen extensometers are currently operating in the Sacramento Valley, including two in Yolo County, one in Sutter County, two in Colusa County, three in Glenn County, and five in Butte County. Maintenance and operation of the extensometers are conducted by DWR. The accuracy of the extensometer monitoring varies according to the type and method of installation. Land subsidence, water level and estimated accuracy of these data are stored in the WDL.

GPS land subsidence monitoring in the Sacramento Valley includes continuous GPS monitoring stations and non-instrumented GPS monuments. GPS land subsidence stations are capable of monitoring vertical displacement (subsidence) as well as horizontal movement of the land surface. Vertical accuracy of these stations is typically plus or minus one centimeter, although greater accuracy is possible. Unlike extensometers, GPS monitoring stations are not limited by depth and record all land subsidence occurring at a particular location. However, most of the GPS land subsidence networks are not instrumented with continuous recording equipment and are dependent upon periodic resurveying of the network. At present, there are eight Continuously Operating Reference Stations (CORS) in the Sacramento Valley. Data from these stations are uploaded via satellite and are then accessible on Internet sites operated by the National Geodetic Survey (NGS) and the California Spatial Reference Center (CSRC).

There are also three non-instrumented GPS monitoring networks in the Sacramento Valley. One is located in the Sacramento-San Joaquin Delta consisting of about 120 stations, one is in Yolo County consisting of 58 stations, and one is in Glenn County consisting of 56 stations. Current efforts are underway to combine and expand these GPS land subsidence monitoring networks into one inclusive network for the entire Sacramento Valley. Installation and survey of benchmarks is scheduled for spring 2008.

Any new GPS land subsidence monitoring stations constructed to monitor the potential effects of future groundwater production activities would likely be operated by DWR, and would be incorporated into the CSRC network so that the data would be managed and disseminated by CSRC.

4.6 Other Data

It is intended that the framework for monitoring, data collection, and evaluation is a living document and will evolve as information is collected and data gaps are identified. As the need for additional data are identified, standard methods for collection and distribution of these data will need to be incorporated into the framework for SVIRWMP monitoring program. One additional data set which should be considered for collection, management, and distribution, is

land use data. Land use data is currently being collected by DWR, county agriculture departments, and local water districts. DWR land use surveys are conducted by county. The survey frequency varies by district, but is typically once every five years. Since the mid-90's most of these surveys have been developed electronically and are available upon request. Annual reporting of crop type, acreage, etc., is typically submitted to the local county agriculture commissioner. These data are merged and distributed via an annual report. More detailed land use data is typically collected at the water district level. Understanding land use, and the associated water supply supporting the land use, is important aspect to understanding baseline changes in supply and demand, and program related effects of water resource management alternatives.

5.0 Monitoring Frequency

5.1 Groundwater Production Monitoring

Groundwater extraction data, associated with existing demand for overlying agricultural and domestic use, should be monitored monthly and reported annually. Groundwater production well data, associated with projects that increase the existing level of groundwater extraction, should be monitored weekly during the irrigation season (April through October), and monthly during the recharge season (November through March), and reported monthly for one-year after the start of program-related groundwater extraction.

Baseline well construction information for existing agricultural and public supply wells should be collected and incorporated into the existing Well Completion Report (WCR) data on file at DWR. The DWR WCR database should be updated to fill-in missing reports, data gaps, and accurate well location. Protocol for coordination between DWR and county environmental health departments should be explored to allow for better tracking of the number of well drilling permits issued at the county level, against the actual number of WCR received at DWR. Production well construction information, associated with wells participating in program that increase the existing level of groundwater extraction, should be collected prior to the start of a pumping program.

5.2 Groundwater Levels

The frequency of manual groundwater level monitoring should be dependent upon the area and the intended use of the data. In many areas, monitoring of groundwater levels three to four times a year is adequate for baseline evaluation of seasonal fluctuation, annual trend comparison, and assessment of regional groundwater flow. In areas of high groundwater demand or program related pumping, a density of the monitoring grid and the frequency of measurements should be increased, as needed to adequately document the local and regional effects associated with the pumping program. Table 1 lists a suggested frequency for manual monitoring of groundwater levels for wells within areas of program-related pumping. As data becomes available, a decrease in manual monitoring frequency may be appropriate. Continuous recording of groundwater levels in dedicated monitoring wells equipped with dataloggers should be conducted at hourly intervals and downloaded in conjunction with the schedule for manual monitoring in Table 1.

Table 1
Suggested Frequency of Manual Groundwater Level Monitoring

Period	Frequency
April	Bi-weekly
May	Bi-weekly
June	Weekly
July	Weekly
August	Weekly
September	Bi-weekly
October	Bi-weekly
November	Bi-weekly
December	Bi-weekly
January	Bi-weekly
February	Bi-weekly
March	Bi-weekly

5.3 Stream-Aquifer Interaction

Groundwater levels and river stage data used to evaluate stream-aquifer interactions should be collected at 15 minute intervals, using synchronized dataloggers, until a consistent pattern of stream-aquifer interaction can be identified. Subsequently, the monitoring frequency could be reduced as required to support continued analysis of stream and aquifer interaction.

5.4 Water Quality

Baseline water quality sampling is recommended for each well included in the groundwater level monitoring network. Baseline sampling should include minerals, metals, and nutrients analysis. In addition, production wells participating in program-related groundwater extraction, should also conduct water quality analysis for oxygen isotopes, age dating, and low-level volatile organic compounds to help identify the source of extracted groundwater, the timing of aquifer recharge, and the direction of water movement. On-going water quality monitoring could be conducted annually and would likely include basic indicating parameters of water quality (EC/TDS). If major changes are noted in the EC/TDS values, the baseline sampling suite could be repeated and/or expanded as appropriate to investigate the nature and significance of the observed changes. The baseline sampling suite for all wells in the network may be repeated every 5 years to monitor long-term trends in quality.

5.5 Land Subsidence

Data from the existing extensometers are currently collected hourly and downloaded monthly. To simplify data management, review of less frequent data collection should be explored. The continuously operating GPS monitoring stations take readings at intervals ranging from one to 30 seconds, and a daily average is calculated from all of the data. The resurvey schedule for the Sacramento Valley GPS land subsidence network, planned for initial installation and survey in spring 2008, should be reviewed and established.

6.0 Data Interpretation

Information generated by the data collection activities of this monitoring plan should be interpreted using an array of graphical and analytical techniques, in conjunction with the numerical surface water and groundwater modeling. This section discusses some of the data interpretation techniques that could be employed to evaluate local, regional and cumulative changes to the existing surface water and groundwater systems as the result of one or all of the following scenarios: increased groundwater extraction associated with program-related changes in water resource management, changes in land and water use due to urbanization, short-term changes in water supply availability due to periods of drought, and long-term changes in hydrology due to changing climate conditions.

Effective planning and interpretation of water resource management alternatives will likely require the use local and regional-scale hydrologic models that have the ability to integrated regional operations and planning scenarios into local project-level assessments. Multiple models are needed to accurately and efficiently evaluate the local, regional, and cumulative effects to the stream/aquifer interaction associated with isolated local projects, as well as, integrated regional-scale projects which propose to increase groundwater extraction or significantly alter existing water resource management practices.

The Department of Water Resources (DWR) is currently in the process of inventorying and evaluating the existing groundwater and hydrologic models in the Sacramento Valley and developing recommendations for an integrated approach to local and regional modeling. The overall goal is to develop a standard modeling approach that will meet the regional needs associated with state planning and cumulative programmatic assessment, and the local project needs associated with impact assessment, through the integrated sharing of data within a compatible modeling platform.

6.1 Groundwater Pumping/Artificial Recharge

Groundwater extraction, along with the rate and volume of aquifer recharge over time, should be collected from each production well or artificial recharge facility associated with the implementation of programs that implement changes in local or regional water resource management practices. These data would be summarized and distributed for analysis and comparison to groundwater extraction versus land use, irrigation methods, and seasonal groundwater level fluctuations.

6.2 Groundwater Levels and Pumping Impacts

Groundwater level data will be collected from a regional baseline monitoring network in addition to a denser site specific monitoring network. The site specific network will be developed to adequately monitor local changes in groundwater levels associated with implementation of programs that increase groundwater extraction or implement significant changes in local groundwater resource management practices. Groundwater level data will be collected from multiple depths to identify changes in groundwater levels over a range of aquifer intervals. These data will also be analyzed to determine the magnitude of groundwater level drawdown and the rate of recovery in the months that follow. The groundwater level data will be evaluated spatially and temporally through groundwater elevation contouring and hydrographs showing drawdown over time, and distance versus drawdown at the local level.

Changes in groundwater gradients and flow paths should be developed for multiple extraction periods. Groundwater level data should be correlated with precipitation and streamflow data to further investigate the effect of precipitation patterns and streamflow on the rate of groundwater level recovery observed during the following winter and spring. These data will also be evaluated in the context of existing BMOs established in the Sacramento Valley.

The depression of groundwater levels due to groundwater extraction near critical habitat such as riparian vegetation and wetlands should also be evaluated. The groundwater monitoring network should contain shallow monitoring wells that will record changes to the water table elevation in the vicinity of these sensitive habitat areas. For some sensitive species, the rate of change of groundwater levels is as critical, or more critical, than the absolute change. The frequency of monitoring will be of sufficient resolution to allow assessment of the effects of program related pumping to riparian and wetland habitat.

6.3 Surface Water/Groundwater Interaction

The use of groundwater modeling tools to interpret data collected as part of the assessments of surface water/groundwater interaction is especially critical because the anticipated magnitude of the streamflow impacts associated with groundwater extraction are likely smaller than can be directly measured. However, it is still important to estimate the percentage of groundwater extraction that is either directly abstracted from surface water systems, or indirectly removed through interception of groundwater that would have discharged to the surface water systems. The timing of these impacts should be closely evaluated; what may be a significant impact to a stream during one time of year may not be significant at a time when flows are higher or critical fish species are not present.

The proposed approach to estimate the degree of hydraulic connection between surface water and groundwater systems will require measurement of stream stage in conjunction with nearby groundwater elevation data from a dedicated wells monitoring at multiple aquifer depths. During the winter months, stream stage varies considerably (in excess of 10 to 15 feet on major streams) in response to storm events. As the stage in a stream rises, a pressure wave is propagated through the underlying aquifer and can be detected in groundwater level data collected from surrounding wells. The timing and magnitude of the pressure wave as it passes through the well, i.e. the time-series of groundwater levels measured in the well, is indicative of the distribution and magnitude of aquifer transmissivity, aquifer storage, hydraulic conductivity of the streambed, and the vertical hydraulic conductivity of the aquifer.

The stage and groundwater elevation data collected during these winter storm events can be interpreted using a local scale model -- developed and calibrated to estimate the surface water/groundwater response to groundwater extraction and/or artificial aquifer recharge. The observed changes in river stage will be input to the groundwater model, and the aquifer and streambed properties adjusted until good agreement is achieved between the simulated and observed groundwater elevations in wells near the river. If possible, it is desirable to have an independent estimate of the aquifer transmissivity near the stream when performing this analysis. For this reason, it is preferable to construct a stage gage/monitoring well pair in close proximity to a production well so that an aquifer test using the production well can be conducted in conjunction with the surface water/groundwater analysis. The results of this analysis will be a refined estimate of the spatial distribution of aquifer properties near the

monitoring well(s), and an estimate of the vertical leakance (streambed permeability divided by thickness) of the riverbed. These data can then be input to a groundwater model to provide improved estimates of the magnitude and timing of stream impacts resulting from groundwater pumping in the Sacramento Valley.

6.4 Aquifer Properties

To accurately forecast the timing and magnitude of groundwater extraction impacts on the surrounding groundwater levels, an accurate measure of the transmissivity, storage properties, and ratio of horizontal to vertical hydraulic conductivity of the aquifer system is required. Since all of these aquifer properties vary spatially and with depth in the aquifer, it is desirable to collect information from as many locations and depths as is possible. Additional production and groundwater monitoring wells, installed to support future groundwater production programs, can be used to conduct numerous aquifer tests across the northern valley. The analysis of the data collected during these tests will greatly improve existing estimates of aquifer properties over a significant part of the Sacramento Valley.

The primary type of data that is required to estimate aquifer properties are time-variant groundwater level data that occurs in response to groundwater pumping at a known rate, location, and depth. It is ideal to collect these data from a series of monitoring wells during a period of relative quiescence in the aquifer, i.e. when little surrounding groundwater pumping is occurring other than that from the instrumented well(s). However, significant information with respect to aquifer properties can still be obtained from measuring groundwater levels in the pumping wells during periods when groundwater pumping in surrounding areas is being conducted. It is anticipated that during the course of implementation of any groundwater production program, groundwater level data will be collected under a variety of conditions; both during designed aquifer tests when background pumping is at a minimum (i.e. during non-irrigation periods), and during the course of the irrigation season while program wells are operating.

The overall approach to data interpretation will be to employ a series of analytical and numerical modeling tools that can reasonably replicate the observed distribution of drawdown at various depths and distances surrounding the pumping well(s) when the groundwater pumping information (schedule, rate, depth, location) is given. When good agreement is obtained between simulated and measured drawdown, the distribution of aquifer properties in the model are concluded to be sufficiently accurate. Associated with the application of these analytical tools, boring logs and geophysical logs will be evaluated to develop a conceptual model of the stratigraphy at the site. To accurately interpret the aquifer test data, it is essential that the underlying interpretation of aquifer and aquitard configuration is reasonably accurate. The existing superposition groundwater flow model, or a similar numerical tool, can be modified as appropriate to incorporate the refined estimates of aquifer properties along with any revisions in geologic interpretation.

6.5 Groundwater Quality

Prior to the implementation of programs that propose to significantly increase groundwater extraction, or change existing water management practices, baseline groundwater quality sampling should be performed on selected wells in the program area to provide baseline information on groundwater quality. The baseline sampling suite should consist of general

mineral constituents, inorganic elements, nutrients, and oxygen isotope data. Subsequent water quality monitoring should be conducted annually. The level of analysis would be dependent upon estimated program operations and findings from the baseline water quality data. In some instances, annual monitoring of general field parameters such as EC and TDS may be needed. If major changes in EC or TDS are noted, the baseline sampling suite could be repeated or more focused monitoring conducted. At a minimum, the baseline sampling suite for all wells in the network should be repeated once every 5 years to monitor the long-term water quality trend.

6.6 Overall Basin Condition (Recharge)

Groundwater level data from existing and new monitoring wells will provide additional information about the response of groundwater levels to winter recharge patterns during a variety of water year types. Historical groundwater elevation data obtained throughout the valley indicates that, under existing demand, the majority of the groundwater basin recovers during the winter months to previous spring levels in all but the driest water years. However, under the existing level of demand, some local regions are experiencing a slow decline in spring-to-spring groundwater levels even in normal water years. The timing of groundwater level monitoring should be evaluated in order to determine if the frequency is sufficient to fully identify the local recharge pattern. In some areas, monthly monitoring may be required over a number of water year types. These data will provide more complete information regarding the response of the basin to winter recharge periods in a variety of year types.

7.0 Integration with Impact Assessment Tool(s)

The data interpretation strategies outlined above will yield improved estimates of various hydrologic parameters at numerous locations throughout the Sacramento Valley. However, the ultimate goal of this data collection and monitoring program is to use these data to improve our understanding of groundwater flow, land subsidence, recharge processes, and the interaction between surface water and groundwater systems. To achieve this objective, it is necessary to integrate the refined hydrogeologic information into a numerical model to assist estimating short-term and long-term changes to groundwater levels and surface water flows at the local and regional level. As discussed above, several modeling tools could be used to support this effort, and an evaluation of potential options should be conducted prior to performing the data evaluation task. Once developed, local and regional models can be used to help investigate multiple water resource management alternatives, over multiple water year types, under multiple land use scenarios.