AQUIFER STORAGE AND RECOVERY FOR THE CITY OF ROSEVILLE: A CONJUNCTIVE USE PILOT PROJECT

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ABSTRACT

The City of Roseville (the City) is located in the Central Valley of California near the State Capital of Sacramento. The City is studying the feasibility of Aquifer Storage and Recovery (ASR) using dual purpose (injection/extraction) wells to sustain water supply reliability in one of the fastest growing regions of the state.

Sacramento and the surrounding areas are going at an alarming rate. Sustaining a reliable water supply is a challenge because existing supplies are fully allocated and taking more surface water from the American River would have a detrimental impact on downstream the environments. Conjunctive Use is the coordinated management of surface water and groundwater supplies to increase the yield of both. This process can be enhanced by storing excess water supplies underground during wet years for use during the dry years – a form of drought proofing.

The City's ASR program is a potential element of a comprehensive, regional conjunctive use program being implemented in southern Placer County and northern Sacramento County. The ASR program will provide 1) reliability for local water purveyors and 2) opportunities to increase flows to the Bay-Delta system during dry periods through groundwater banking and surface water exchange.

The principal purpose of the Roseville ASR Feasibility Study / Demonstration Project is to evaluate opportunities to store treated surface water from Folsom Lake in the groundwater basin underlying Placer County by direct injection during "wet" years for extraction to supplement the City's surface water supply during "dry" years. The key areas being investigated include 1) Hydrogeologic and water quality issues 2) Water rights and contract entitlements, and 3) Regulatory and institutional issues.

Testing performed to date has shown ASR to very successful in this location and the City is planning to expand the program to include 8 wells installed over the next 3-5 years.

KEYWORDS

Conjunctive Use, Aquifer Storage and Recovery, Groundwater Storage, Disinfection Byproducts, Groundwater Management

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INTRODUCTION

The City of Roseville (the City) is located in the Central Valley of California near the State Capital of Sacramento (Figure 1). The City is studying the feasibility of Aquifer Storage and Recovery (ASR) using dual purpose (injection/extraction) wells to sustain water supply reliability in one of the fastest growing regions of the state.

Aquifer Storage and Recovery (ASR) is a type of conjunctive use project involving the integrated management of surface water and ground water resources to increase water supply reliability. ASR consists of three phases: surface water injection, storage, and extraction. The first phase involves injecting treated surface water through a well and storing it in a confined aquifer. During the injection phase, surface water travels away from the injection well in a radial fashion, displacing the existing groundwater and forming an irregular column of injected water around the well; the longer the injection period the wider the column of injected water. During the storage phase the rate and direction of groundwater movement is controlled by the natural groundwater gradient and hydraulic conductivity of the formation, and is generally very slow. During the water extraction phase, the injected column of surface water is recovered and the diameter of the column is reduced. Figure 2 is a schematic representation of the ASR process.

Figure 1 – Project Location Map

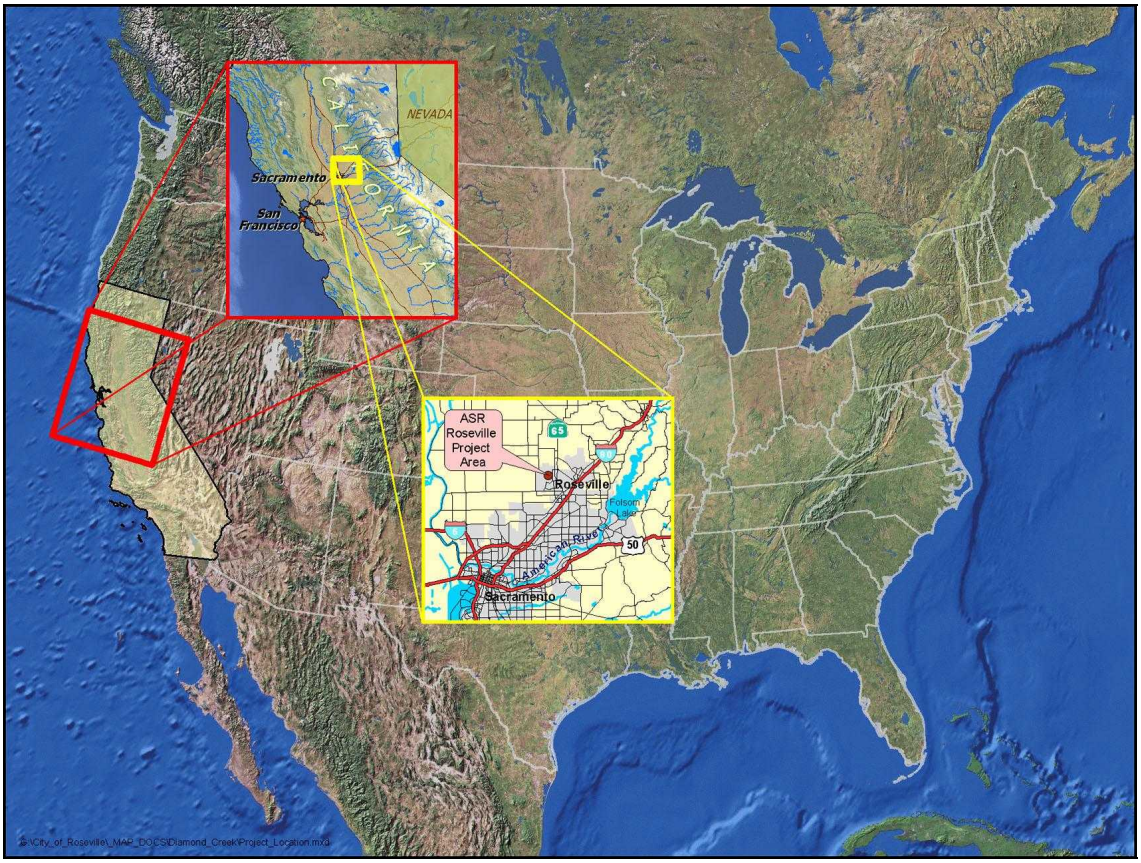

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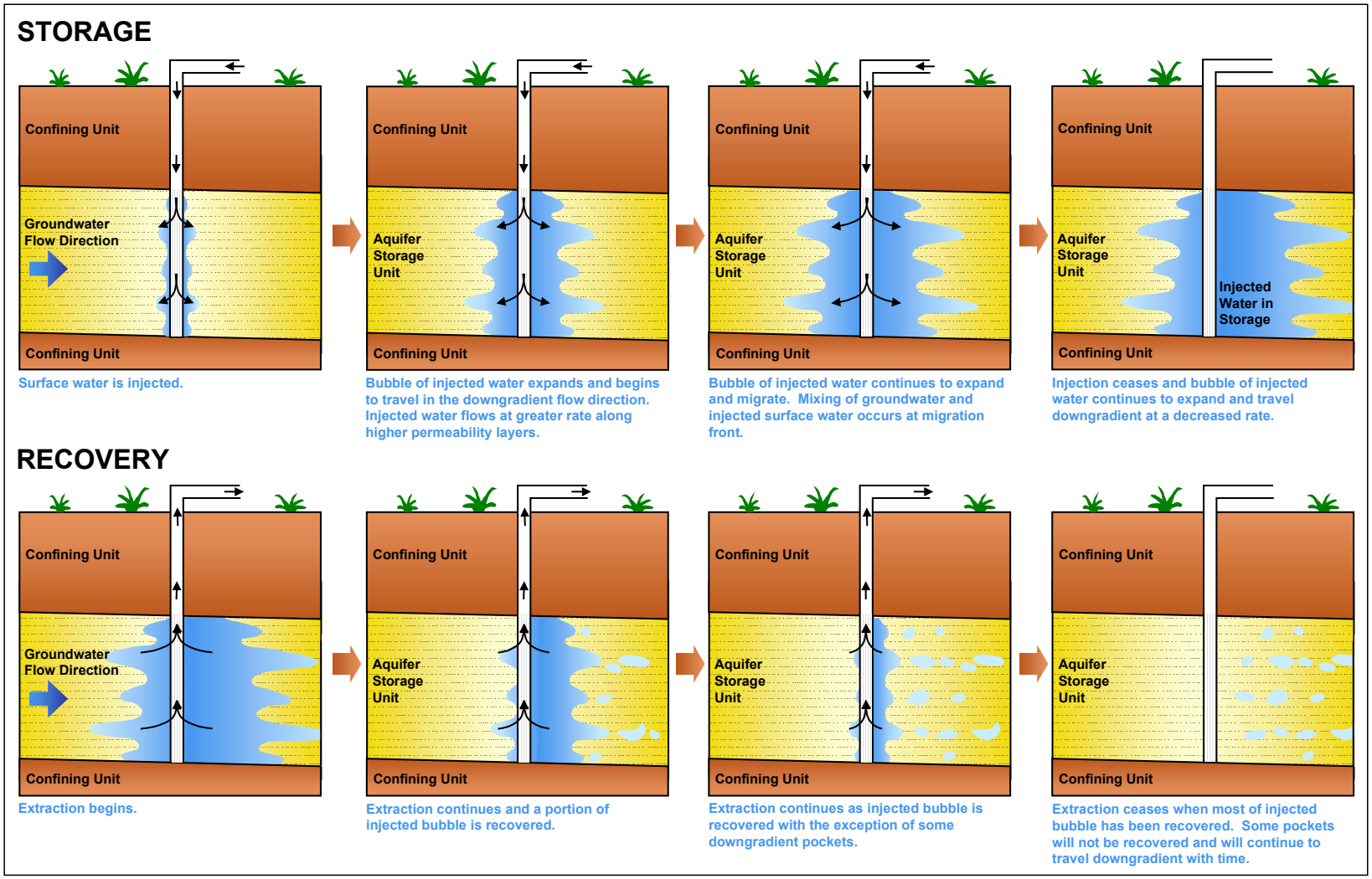
Figure 2 - Schematic of Aquifer Storage and Recovery Process



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WATER SUPPLY PLANNING AT THE STATE, REGIONAL AND LOCAL SCALE

In California, on average, 15 million acre-feet of groundwater are extracted from wells each year. With more than half of all Californians relying on groundwater for at least a portion of their water supply, groundwater supplies approximately 30 percent of urban and agricultural demands. In drought years, this percentage increases to more than 40 percent (DWR, 2003). The state's population is expected to reach 47.5 million by 2020. With this growth will come an increased reliance on groundwater. Despite the integral role that above ground reservoirs can have in conjunctive use, they are expensive to build and are viewed by some as environmentally damaging. Thus, greater use of storage capacity in aquifers via conjunctive use has become an increasingly popular alternative for water storage, thereby improving California's water supply.

STATE SUPPORT FOR CONJUNCTIVE USE

The California Department of Water Resources (DWR) Conjunctive Water Management Program consists of a number of integrated efforts to assist local agencies in improving groundwater management and increasing water supply reliability. One goal of the Integrated Storage Investigations (ISI) Program, an element of the Bay-Delta program, is to increase water supply reliability statewide through the planned, coordinated management and use of groundwater and surface water resources. The effort emphasizes forming working partnerships with local agencies and stakeholders to share technical data and costs for planning and developing locally controlled and managed conjunctive water management projects. Toward that end, the Conjunctive Water Management Program has:

- Developed a vision in which DWR would assist local agencies throughout the State so that these agencies can effectively manage groundwater resources,
- Adopted a set of working principles to ensure local planning; local control, operation, and management of conjunctive use projects; voluntary implementation of projects; and local benefits from the proposed projects,
- Executed memoranda of understanding with 30 local agency partners and provided technical and financial assistance to study groundwater basins and assess opportunities for conjunctive water management,
- Provided technical assistance in the form of groundwater monitoring, groundwater modeling, and local water management planning, as well as a review of numerous regional and statewide planning efforts on a variety of water issues, and
- Provided facilitation assistance to promote broad stakeholder involvement in regional water management planning processes.

DWR staff review proposals and distribute grants pursuant to the Local Groundwater Management Assistance Act of 2000 (AB 303). To date, DWR has awarded more than $15 million to local agencies to fund 71 projects dealing with groundwater investigation, monitoring, or management.

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With funds provided under Proposition 13 and Proposition 50, DWR has awarded over $200 million in loans and grants for groundwater recharge and storage studies and projects to local agencies throughout the State. Applicant estimates of the water supply reliability increases that will be realized from these projects exceed 150 thousand acre-feet annually. Recipients of loans and grants must provide progress reports to allow an evaluation of the successes of the various programs.

Both grant programs have active outreach efforts to inform and to assist agencies in preparation of applications. Selection of projects for funding relies in part on input from advisory committees composed of stakeholders from throughout the State.

REGIONAL LEVEL PLANNING

Over the past several decades, water resources in the greater Sacramento metropolitan region have been impacted by:

- Increasing water demand
- Prolonged drought and associated water supply shortages
- Increasing pressure to dedicate surface water supplies for environmental purposes
- Declining groundwater elevations
- Growing threats to surface water and groundwater quality
- Increasingly stringent water quality and effluent discharge standards.
- To address these problems, municipalities and water purveyors in the region have invested millions of dollars and thousands of hours in a progression of regional planning efforts including:
    - The Sacramento Area Water Forum process (or Water Forum)
    - The American River Basin Cooperating Agencies Regional Water Master Plan (ARBCA RWMP)
    - Regional Water Authority (RWA) projects, programs, and activities
    - Sacramento Groundwater Agency (SGA) projects, programs, and activities

Each of these regional planning efforts is discussed further below and the relative timing illustrated on Figure 3.

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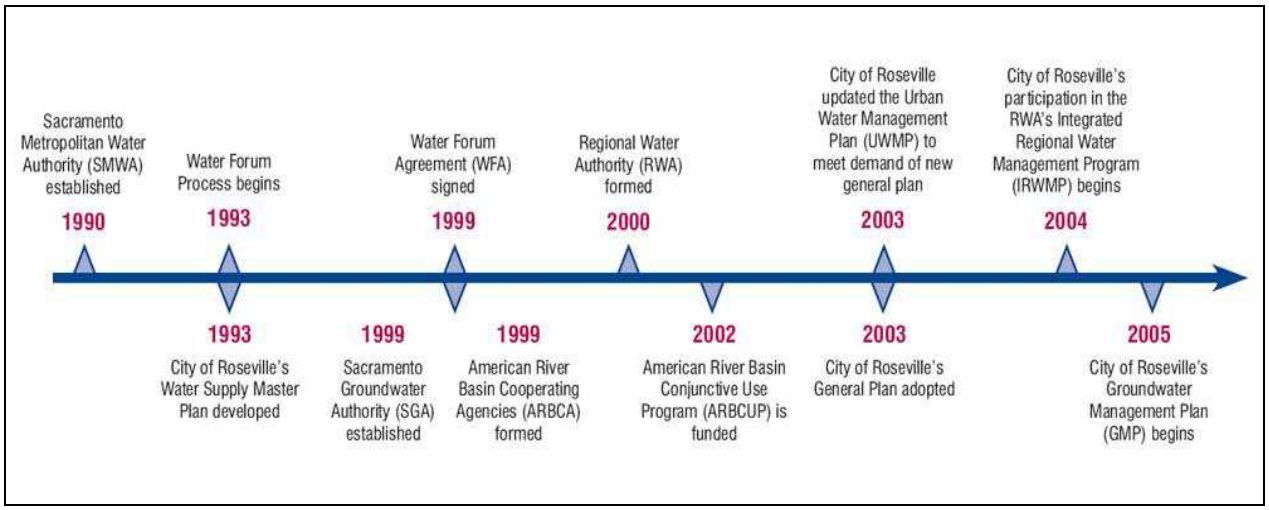
Figure 3 - Timeline of Various Events Affecting the City of Roseville's Water Resource Management Activities



Sacramento Area Water Forum

Begun in 1993, the Water Forum is a consensus-based, stakeholder process involving over forty representatives of the water purveyor, environmental, business, and public interest communities. The co-equal objectives of the Water Forum are:

- To provide a reliable and safe water supply for the region's economic health and planned development through the year 2030
- To preserve the fishery, wildlife, recreational, and aesthetic values of the lower American River

After six years, the Water Forum completed the Water Forum Agreement (WFA), which prescribed a regional conjunctive use program for Folsom Lake, the lower American River, and the connected groundwater basin.

Implementation of the WFA includes adherence to an agreed upon long-term average annual pumping limit (sustainable yield) for each of the three geographic sub-areas of the groundwater basin within Sacramento County: 131,000 acre-feet ("AF") for the North Area (north of the American River); 273,000 AF for the Central Area (between the American and Cosumnes rivers, not including the Delta); and 115,000 AF for the Galt or South Area (south of the Cosumnes River). These geographic sub-areas are shown on Figure 4. Any proposed water supply project or groundwater management structure must satisfy the groundwater conditions specified in the WFA for the 2030 projected level of development.

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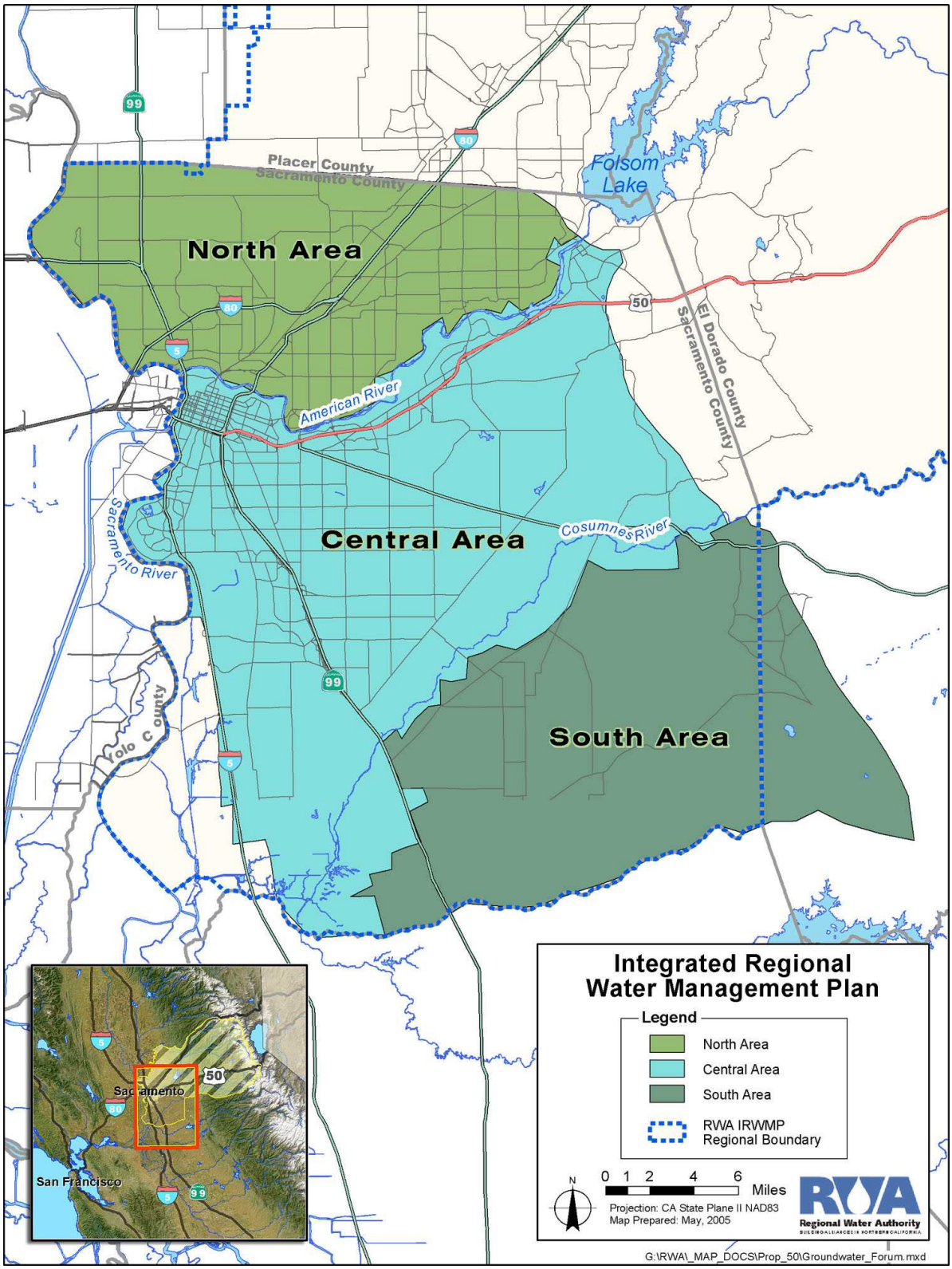
Figure 4 - Water Forum Sub-Area Map



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American River Basin Cooperating Agencies

ARBCA (or Cooperating Agencies) was an ad-hoc group of fifteen water purveyors in northern Sacramento and Placer counties. ARBCA was formed to develop and complete a RWMP, the objective of which was to identify the facilities and operational agreements necessary to implement the WFA. Each of the Cooperating Agencies was a signatory of the WFA.

The RWMP effort was conducted in two phases. Phase I identified and described a "menu" of project and program alternatives for implementing the WFA north of the American River. Phase II provided detailed hydrologic (including surface water and groundwater modeling), engineering (including conceptual design, operational analyses, and estimates of cost), and legal/institutional (including operational agreements and funding) evaluations of those projects and programs that best aligned with the goals and objectives of the agencies and the WFA.

The Cooperating Agencies that signed a Memorandum of Understanding committing to financial support for the RWMP included:

- Carmichael Water District
- Citizens Utilities Company of California
- Citrus Heights Water District
- City of Folsom
- City of Roseville
- City of Sacramento
- Fair Oaks Water District
- Rio Linda/Elverta Community Water District
- Sacramento County
- Sacramento Suburban Water District
- San Juan Water District

Regional Water Authority

The RWA is a Joint Powers Authority (JPA) formed as a policy forum to discuss and address regional water issues. One of the principal missions of the RWA is facilitating implementation of the conjunctive use program prescribed by the WFA and the RWMP. The RWA has eighteen members (including each of the Cooperating Agencies mentioned previously) and three associate members. Nearly all of the RWA members are signatories of the WFA.

Sacramento Groundwater Authority

The SGA is a JPA formed pursuant to the recommendations of the WFA. Comprised largely of the same water purveyors that made up the Cooperating Agencies and the RWA, the SGA has the legal authority to manage and protect the groundwater basin underlying Sacramento County north of the American River. In addition to water purveyors, agricultural and self-supplied groundwater users (e.g., parks and golf courses) are represented on the SGA Board of Directors. The SGA has developed and is implementing an SB-1938 compliant Groundwater Management Plan that incorporates both the RWMP and the WFA.

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RWA's Integrated Regional Water Management Program

In April of 2004, sixteen of RWA's members and associate members elected to embark upon the development of an Integrated Regional Water Management Plan (IRWMP) on behalf of the entire RWA membership. Development of the IRWMP was originally contemplated during the ARBCA RWMP effort and was included in the 1999 Federal Water Resource Development Act (WRDA) authorization, sponsored by congressional representatives from the region. The U.S. Army Corps of Engineers (Corps) was designated as the lead federal agency for WRDA implementation efforts. Towards this end, the Corps participated in developing the scope of the IRWMP and is providing financial support of portions of the IRWMP development, to the extent possible.

The RWA and IRWMP Project Committee have identified a number of potential projects, including the City of Roseville's ASR Program, and programs to be considered during the development and implementation of the IRWMP. The proposed IRWMP will investigate new water resource management strategies and expand the breadth and depth of past regional planning efforts. The IRWMP development process will benefit greatly from the institutional knowledge developed over many years and millions of dollars of planning efforts conducted previously in the region.

LOCAL LEVEL PLANNING

The City's primary water supply source is surface water from the Folsom Reservoir on the American River. In 1997, the Department of Environmental Utilities supplied water to 66,901 persons through approximately 21,000 residential and 2,400 commercial water connections. The City's water needs have been steadily rising, with deliveries increasing from 14,242 acre-feet (AF) in 1990 to 21,143 AF in 1996, and expected need projected to continue to 54,900 acre-feet annually (AFA) by build out (City of Roseville, 1992). The City provides water from Folsom Reservoir through two sources: a water contract with the Central Valley Project for 32,000 AFA, and purchased water rights water from Placer County Water Agency for 30,000 AFA. Acknowledging its total entitlements of 62,000 AFA, the City has agreed to limit its surface water supply to 54,900 AFA in 2030, consistent with the Sacramento Area Water Forum and the City's current General Plan build out demand. The City has been planning a citywide ASR program to meet these water supply reliability needs.

The City's planned citywide ASR would be the first implemented in the Central Valley. This program would build on the findings 19 ASR projects of similar or greater magnitude that have been operating in Southern California and along the Pacific Coast for up to 40 years. The City has identified five potential well sites with ASR capabilities, for eventual use as part of a citywide ASR system, and has constructed the first, the Diamond Creek Well.

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WATER RESOURCES SETTING

The City of Roseville is located within the North American sub-basin. This sections provides an overview of the physical conditions within the groundwater basin regionally and in the vicinity of Roseville ASR pilot project.

BASIN CHARACTERISTICS

The North American sub-basin lies in the eastern central portion of the Sacramento Groundwater Basin and covers a surface area of 548 square miles in Sutter, Placer, and Sacramento Counties (Figure 5). It is bounded by the Bear River to the north, the Feather and Sacramento Rivers to the west, and the American River to the south. As defined by DWR Bulletin 118 (2003), the eastern boundary is defined by a north-south line extending from the Bear River to Folsom Lake. This boundary passes approximately 2 miles east of the town of Lincoln and represents the approximate edge of the alluvial basin at its contact with the bedrock of the Sierra Nevada foothills (DWR, 2003).

Little or no water flows into or out of the rock of the Sierra Nevada (DWR, 1997). Low rolling dissected uplands characterize the eastern portion of the basin near Lincoln. Towards the west, in Sutter County, the topography becomes a flat flood basin for the Bear, Feather, Sacramento, and American Rivers. The direction of drainage is towards the southwest.

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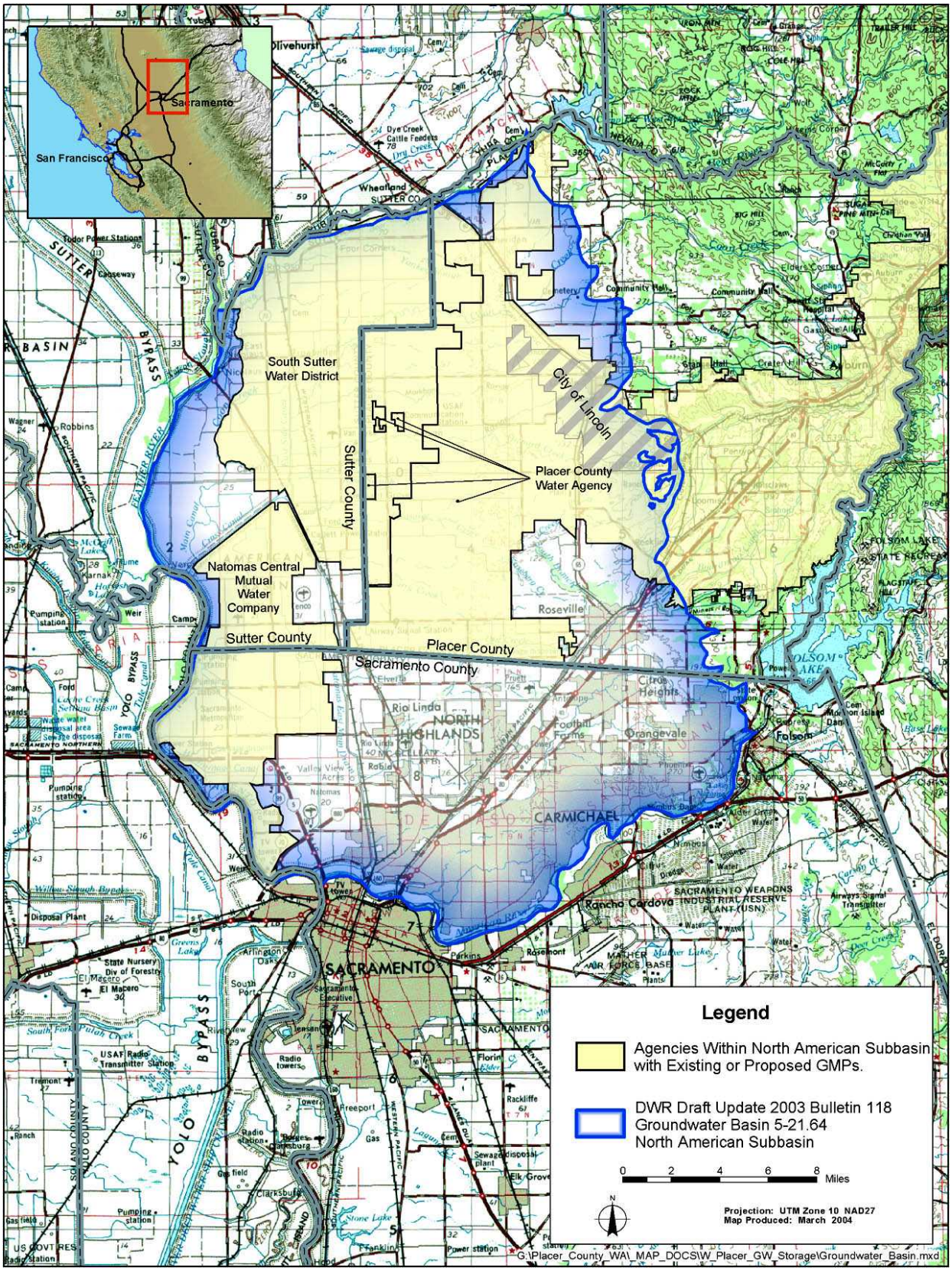
Figure 5 - North American Groundwater Sub-basin



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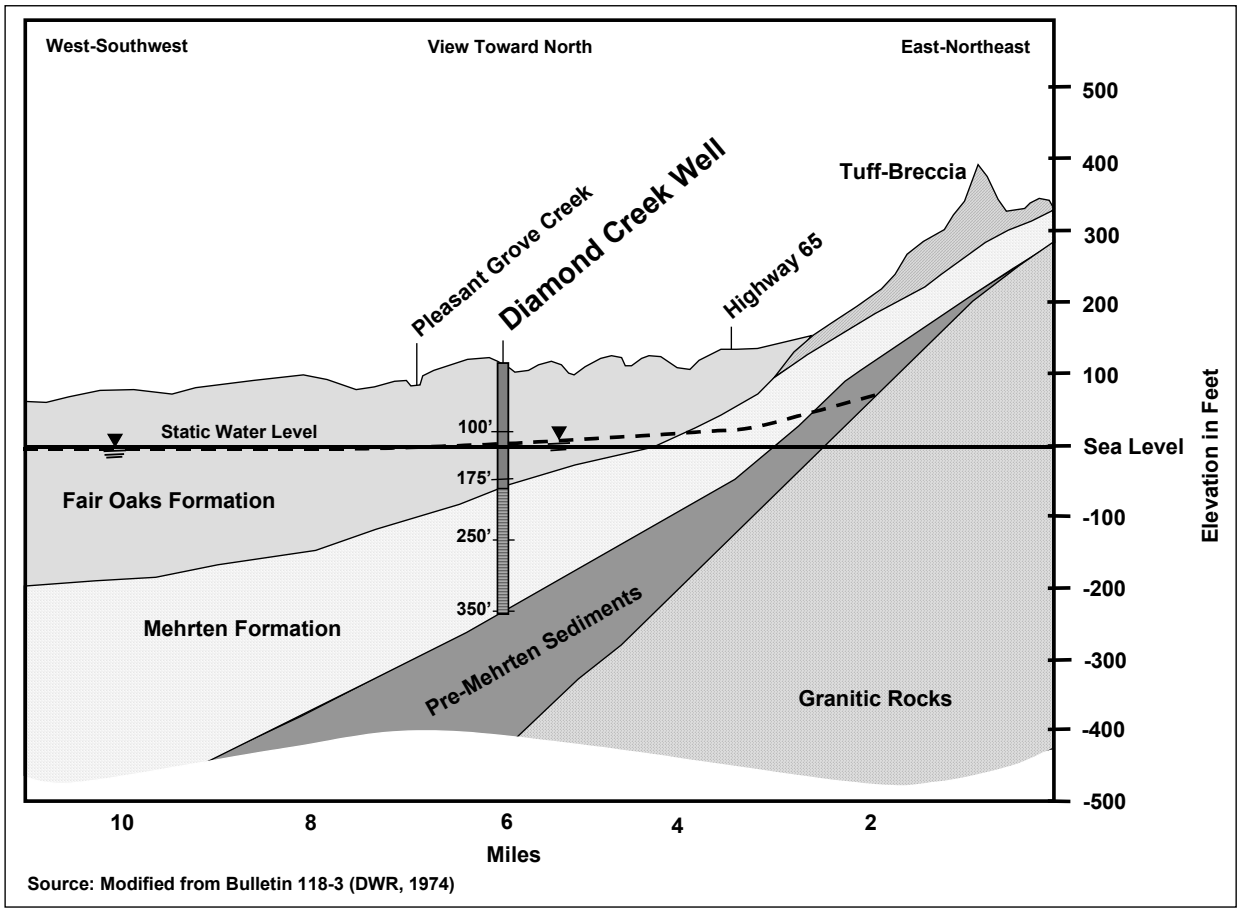
REGIONAL GEOLOGIC SETTING

DWR Bulletin 118-3 (1980, 2003) identifies and describes various geologic formations that constitute water-bearing deposits underlying the North American Sub-Basin, where the project site is located. These formations include an upper, unconfined aquifer system consisting of the Riverbank (formerly known as Victor) and Turlock Lake/Laguna (formerly known as Fair Oaks-Laguna) formations, and a lower, semi-confined aquifer system consisting primarily of the Mehrten Formation. These formations are typically composed of lenses of inter-bedded sand, silt, and clay, interlaced with coarse-grained stream channel deposits. Figure 6 provides a conceptual representation, and shows that the formations form a wedge that generally thickens from east to west to a maximum thickness of about 2,000 feet under the Sacramento and Feather rivers.

Figure 6 - Regional Geologic Cross Section Through Diamond Creek Cycle Testing Project Site



SITE-SPECIFIC HYDROGEOLOGY

A summary of subsurface lithologic data recorded at the DCW and three monitoring well sites is shown in Figure 7. Lithology at the DCW consists almost solely of clay and silt

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from the ground surface to approximately 310 feet below ground surface (bgs). From 310 to 450 feet bgs, the predominate soil material encountered consists of sands and gravels. Soils were returned to silts and clays from approximately 450 feet bgs to the total depth of the borehole, 502 feet bgs. This 140-foot-thick confined aquifer and was designated as part of the Mehrten Formation based on the volcanic and "black sand" lithologic characteristics observed (Figure 7). Similar lithologic conditions were observed in DCMW-1 and DCMW-2 with approximate Mehrten Formation top depths at 310 and 305 feet bgs, respectively. The bottom of the Mehrten Formation was not identified at these locations.

Figure 7 provides a cross-section of the local site geology, based on observed subsurface lithology.

GROUNDWATER FLOW, RECHARGE AND DISCHARGE AREAS

Figure 8 shows groundwater elevation contour maps for the entire North American sub-basin for the Spring of 2002. Figure 8 shows that groundwater elevation ranges from the high of approximately 80 feet above mean sea level (msl) in the eastern study area to a low of approximately 40 feet below msl in the north-central portion of Sacramento County.

From this figure, the following can be concluded:

- Groundwater flows through the sub-basin from areas of recharge at higher groundwater elevations to areas of lower groundwater elevations.
- A persistent regional cone of depression has formed in the northern Sacramento and southern Placer County areas. This has occurred mostly due to groundwater pumping to meet the municipal, agricultural and industrial needs in northern Sacramento County.

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Figure 7 - Cross-Section of the Project Site

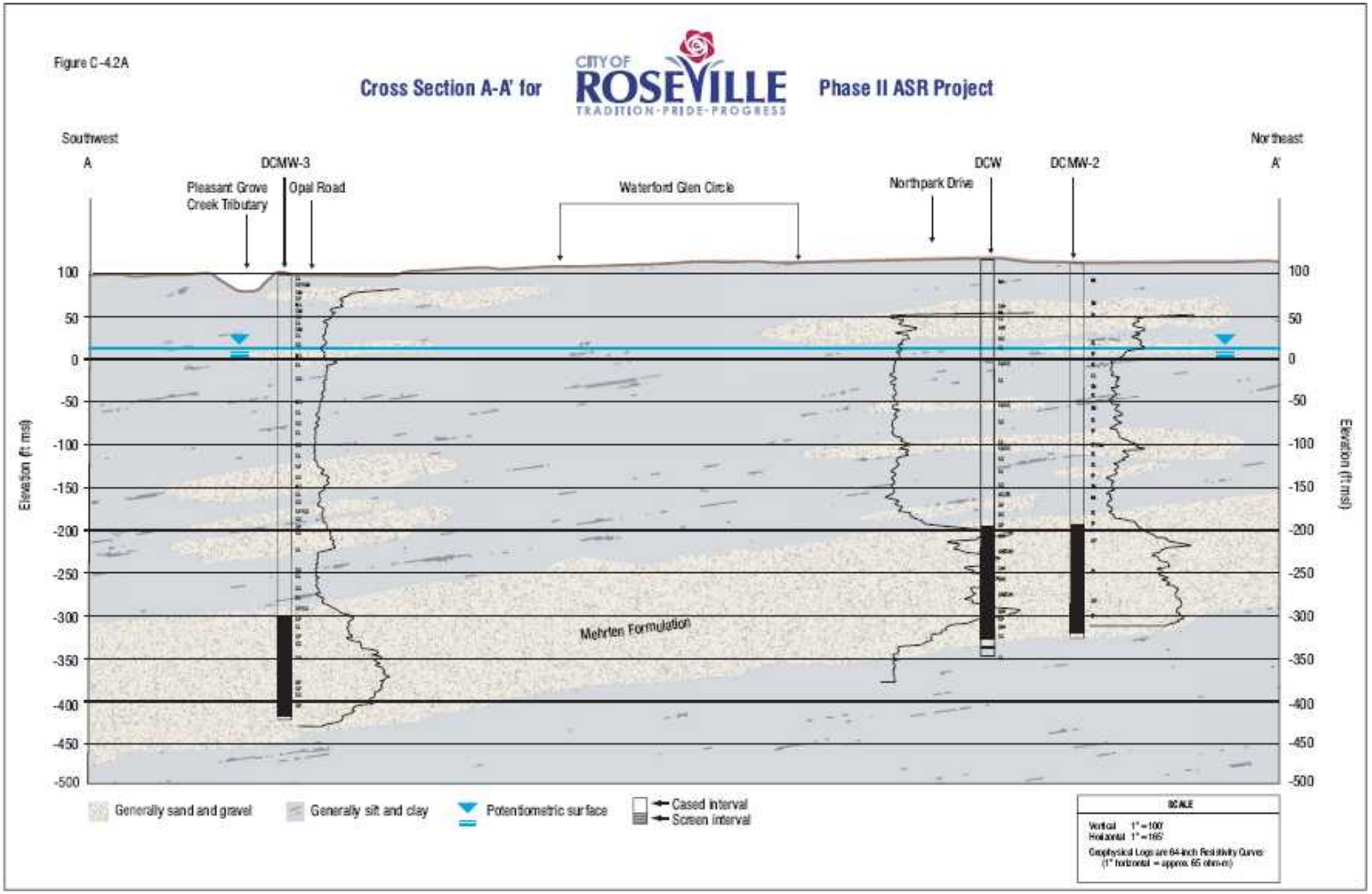

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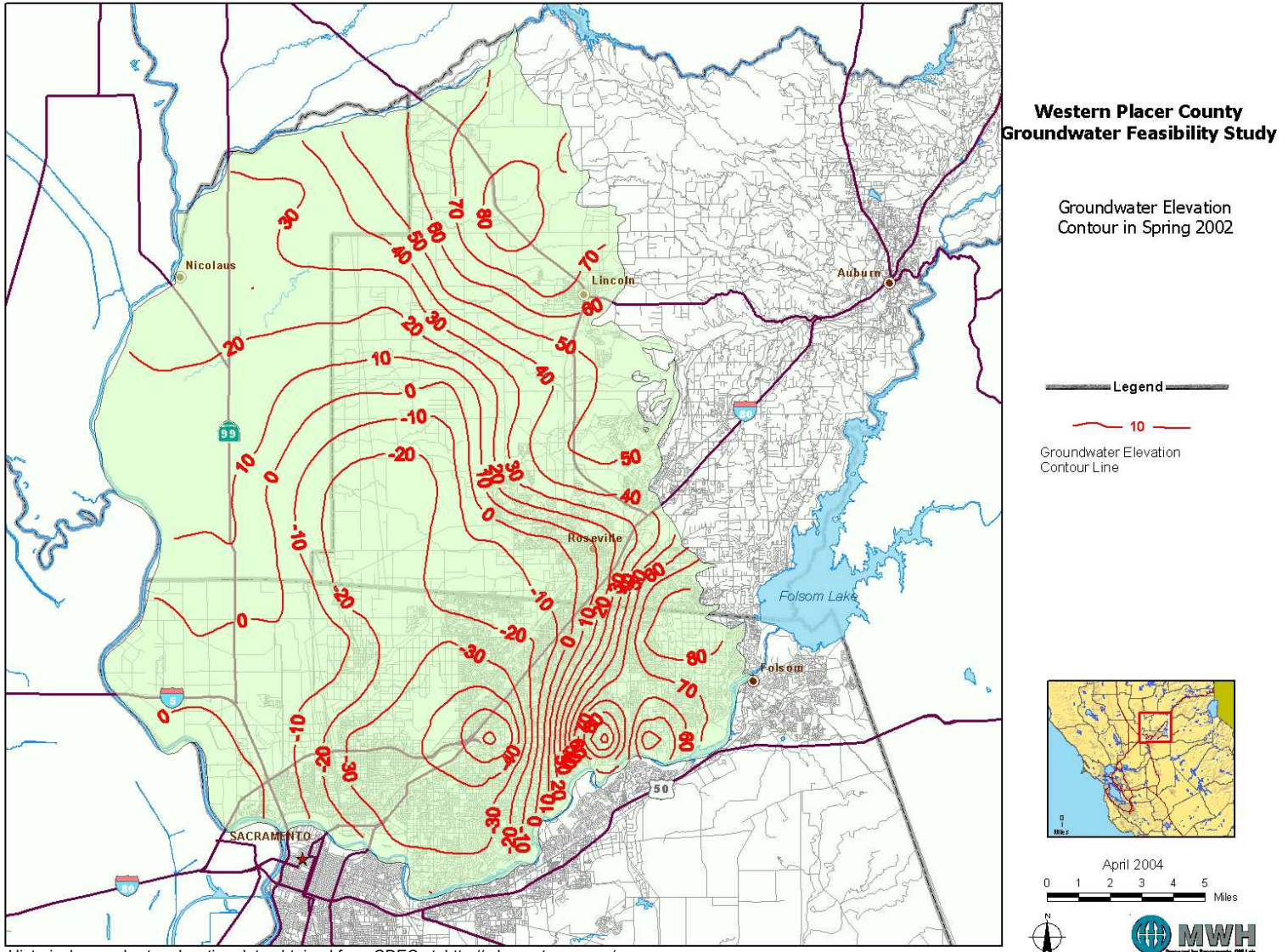
Figure 8 - Groundwater Elevation Contours for Spring 2002



Historical groundwater elevation data obtained from CDEC at http://cdec.water.ca.gov/

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REGULATORY CONSIDERATIONS

Aquifer Storage and Recovery is a new water management strategy within the Central Valley of California. For this reason, a regulatory precedent has not yet been established. Due to water quality considerations associated with ASR projects involving potable water, the regulating body is the Central Valley Regional Water Quality Control Board (RWQCB).

STATE WATER RESOURCES CONTROL BOARD

The mission of the State Water Resources Control Board (SWRCB) is to ensure the highest reasonable quality of waters of the State, while allocating those waters to achieve the optimum balance of beneficial uses. In turn, the nine RWQCBs develop and enforce water quality objectives and implement plans to protect the beneficial uses of the State's waters, recognizing differences in climate, topography, geology, and hydrology.

Other SWRCB/RWQCB activities related to groundwater protection include:

- developing basin plans that identify existing and potential beneficial uses of marine water, groundwater, and surface waters;
- regulating the discharge of waste that may affect water quality in California;
- monitoring of landfills and hazardous waste facilities;
- establishing standards for the construction and monitoring of underground storage tanks;
- establishing management plans for control of nonpoint source pollutants; and issuing cleanup and abatement orders that require corrective actions by the responsible party for a surface water or groundwater pollution problem or nuisance.

CENTRAL VALLEY REGIONAL WATER QUALITY CONTROL BOARD

The project area lies within the purview of the Central Valley RWQCB's Water Quality Control Plan (Basin Plan). The Basin Plan defines the beneficial uses of surface and groundwater in the Central Valley and establishes water quality objectives to satisfy those beneficial uses (Central Valley RWQCB, 1998). Unless otherwise designated by the Central Valley RWQCB, the beneficial uses of all ground waters in the Central Valley include municipal and domestic water supply, agricultural supply, industrial service supply, and industrial process supply (Central Valley RWQCB, 1998).

The Central Valley RWQCB recognizes that ASR projects present some unique issues with respect to regulating water quality. In a recent staff report, the Central Valley RWQCB (2005), while recognizing the potential value of ASR projects, identified two general issues of concern with regard to regulating ASR projects: potential aquifer water quality degradation, in general, and contamination from chlorine disinfection byproducts (DBP), in particular (Central Valley RWQCB, 2005). The Central Valley RWQCB addressed the issue of regulating general water quality degradation by citing the State Water Resources Control Board's Antidegradation Policy (Resolution No. 68-16). ASR projects generally use treated drinking water for aquifer injection, so this water must meet Basin Plan drinking water standards, which are based on Title 22

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Maximum Concentration Levels (MCLs). However, even if the water satisfies the MCLs it may have poorer water quality than that of the water in the aquifer. If so, injecting the water into the aquifer may risk degrading the quality of the ground water, which could violate the Antidegradation Policy. Under this policy, the quality of any water that meets or exceeds levels needed to protect existing and probable future beneficial uses must be maintained until or unless it has been demonstrated that any change in water quality will be consistent with the maximum benefit to the people of the state, will not unreasonably affect beneficial uses of such water, and will not result in the violation of any water quality objectives (Central Valley RWQCB, 2005 and 2003). In short, if the injection of water into an aquifer results in reduced water quality in the aquifer, the Central Valley RWQCB could treat such injection as a harmful discharge of waste even if no water quality objectives were violated

The Central Valley RWQCB (2005), in its staff report, discussed the issue of regulating contamination of an aquifer from chlorine DBPs both with respect to the Antidegradation Policy and specific water quality objectives. Many municipalities treat their water supplies with chlorine to eliminate pathogens and thereby make the water safe to drink. The chlorinated water often contains significant concentrations of DBPs, including trihalomethanes (THM) and halocetic acids (HAAs), which present health risks at certain concentrations. The native groundwater of an aquifer generally has none of these DBPs, so injection of treated water would degrade the aquifer with respect to these chemicals, potentially violating the Antidegradation Policy. In addition, the Central Valley RWQCB (2005) posited that injection of treated water into the aquifer could result in a violation of the toxicity water quality objectives for these chemicals. The Central Valley RWQCB (2005 and 2003) does not consider the drinking water standards (MCLs) for the DBPs to be adequately protective of groundwater. These standards were derived by balancing the health benefit provided by chlorination with the potential toxicity of DBPs, in consideration also of the high costs of alternative water treatment processes. However, because the effects of chlorination are not germane with respect to the native groundwater, which may be free of pathogens and serve other beneficial uses than drinking water, the Central Valley RWQCB (2003) requires the toxicity objectives for DBPs in groundwater be based on much lower levels of health risk than those used for the MCLs.

WAIVER PROCESS

The Central Valley RWQCB (2005) recognizes that burdensome regulation of ASR projects would risk inhibiting their development and that this would be undesirable given the high potential value of such projects. Therefore, the staff report recommends that pilot and demonstration projects be regulated under a conditional waiver of waste discharge requirements (WDR). As stated in the report, “In general, the waiver would allow groundwater pollution for a short-term, controlled project, contingent upon (a) adequate monitoring to determine the nature and extent of water quality impacts from the short-term testing and to predict long-term impacts from full implementation of the ASR project, (b) submittal and implementation of contingency plans to clean up or abate unintended impacts on groundwater quality should the demonstration project result in violation of water quality objectives beyond the predicted injection front or violation of water quality objectives after the injected water has been extracted.” The City’s Phase 1 Pilot Study received a conditional waiver of WDRs from the Central Valley RWQCB. The results of the pilot study, described below, show that the demonstration test can be expected

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to have transient, largely beneficial effects on aquifer water quality with a less-than-significant impact on native groundwater.

ASR PILOT TESTING

ASR pilot testing is being completed in two phases. Phase I was a short-term pilot test conducted in the spring and summer of 2004. The results of this initial test indicated that ASR is feasible in Roseville, but that a longer-term test is required to understand the fate and transport of DBPs in the subsurface. Phase II (Demonstration) testing is planned to begin in Fall of 2005. This section provides an overview of the project setting, results of short term testing and the plan for longer term testing.

PROJECT SETTING

The pilot testing is being conducted at the newly constructed Diamond Creek Well, which is located on Parkside Drive in the Diamond Creek Subdivision, Roseville, California (as shown on Figure 9). The project location also encompasses three existing monitoring wells, referred to as Diamond Creek Monitoring Well No. 1 (DCMW-1), Diamond Creek Monitoring Well No. 2 (DCMW-2), and Diamond Creek Monitoring Well No. 3 (DCMW-3), near the vicinity of the Diamond Creek Well.

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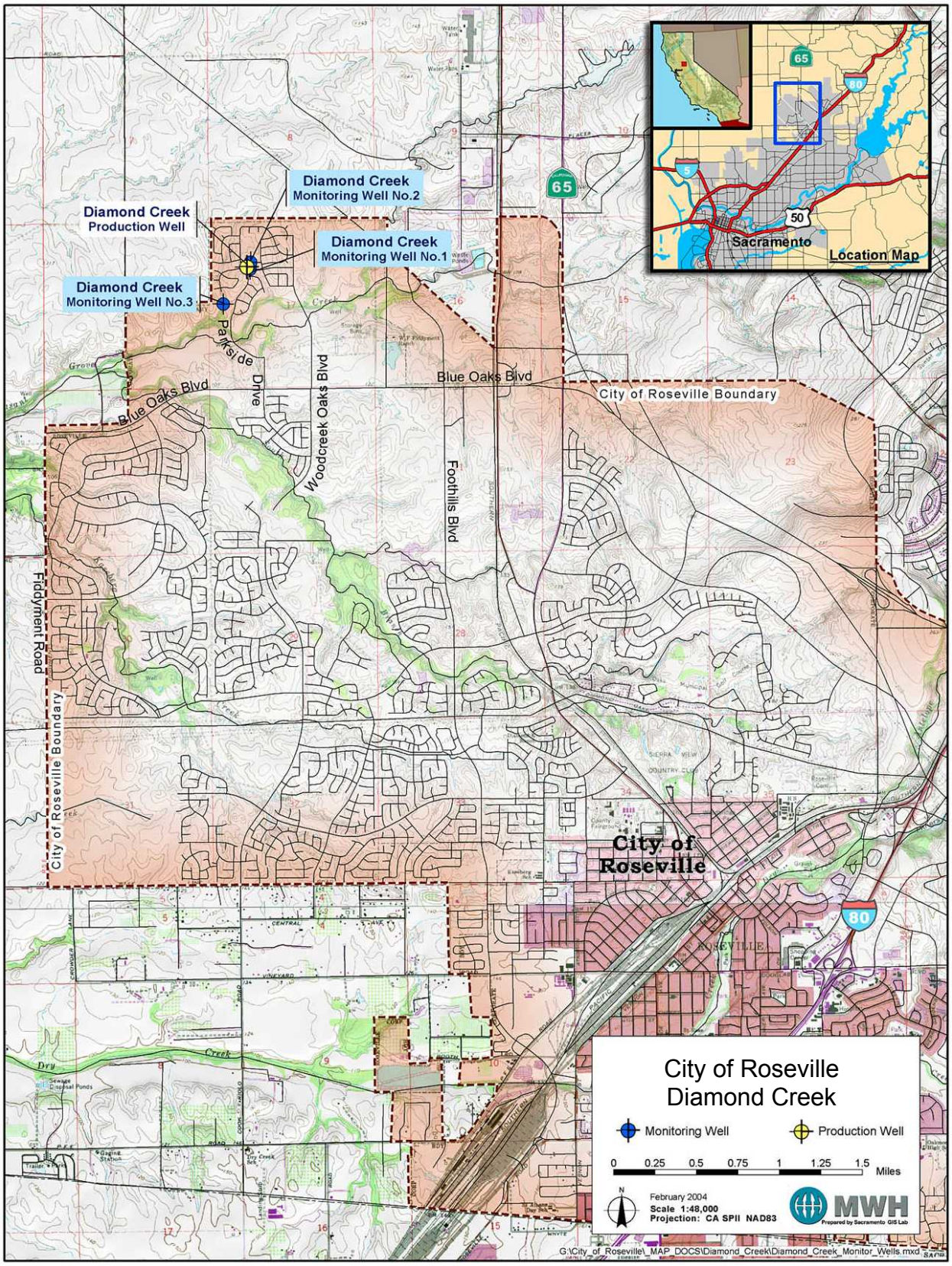
Figure 9 - Diamond Creek Pilot-Scale Cycle Testing Site Vicinity and Location Map Phase 1 Methods



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OVERVIEW OF PHASE I PILOT TEST

The Phase I ASR pilot-scale at the Diamond Creek Well was performed from May 5 to September 20, 2004. Cycle testing was conducted using potable water that originates in the Sierra Nevada, flows into the American River watershed, and is stored in Folsom Lake. The City conveys all of its surface water to its water treatment plant (WTP) for treatment to drinking water standards. During the cycle test, this potable (treated) water was conveyed to the Diamond Creek Well, through the City's drinking water infrastructure, and injected into the aquifer (the Mehrten formation) to evaluate the overall technical feasibility of ASR at the site.

The pilot study, conducted from May to September 2004, consisted of three steps: baseline monitoring, injection, and extraction (Figure 10). Baseline monitoring and sampling included a series of monitoring and sampling events performed from May 5 to June 16, 2004. During this period, no water was injected at the Diamond Creek Well. The purpose of baseline monitoring and sampling was to establish the groundwater elevations and water quality in the aquifer before injecting the aquifer with treated water.

The injection portion of the cycle test consisted of 26 days of continuous surface water injection followed by two days of rest, or storage. The total volume of water injected was 158 AF (51,500,000 gallons). Injection water was transported to the Diamond Creek Well site using the City's existing drinking water distribution system. The injection portion of cycle test included four monitoring and sampling events, performed from June 16 through July 12, 2004, to determine changes in groundwater elevations and water quality of the aquifer, at various distances from the injection well, during and following the injection period. System pressure and injection flow rate were also monitored during the injection phase of the pilot test.
There were three extraction phases during the study: July 14 through 26, August 3 through 9, and September 9 through 20, 2004. The three extraction phases were separated by storage periods lasting 8 and 31 days. The total volume of water extracted during all three phases was 439 AF (143,000,000 gallons), representing 278 percent of injected water volume. The volume extracted substantially exceeded that injected to ensure that essentially all of the injected water was removed from the aquifer. Eleven monitoring and sampling events were conducted at the Diamond Creek Well and six monitoring and sampling events were conducted at the three monitoring wells to determine changes in groundwater elevations and water quality of the aquifer, at various distances from the injection well, during and following the extraction period.

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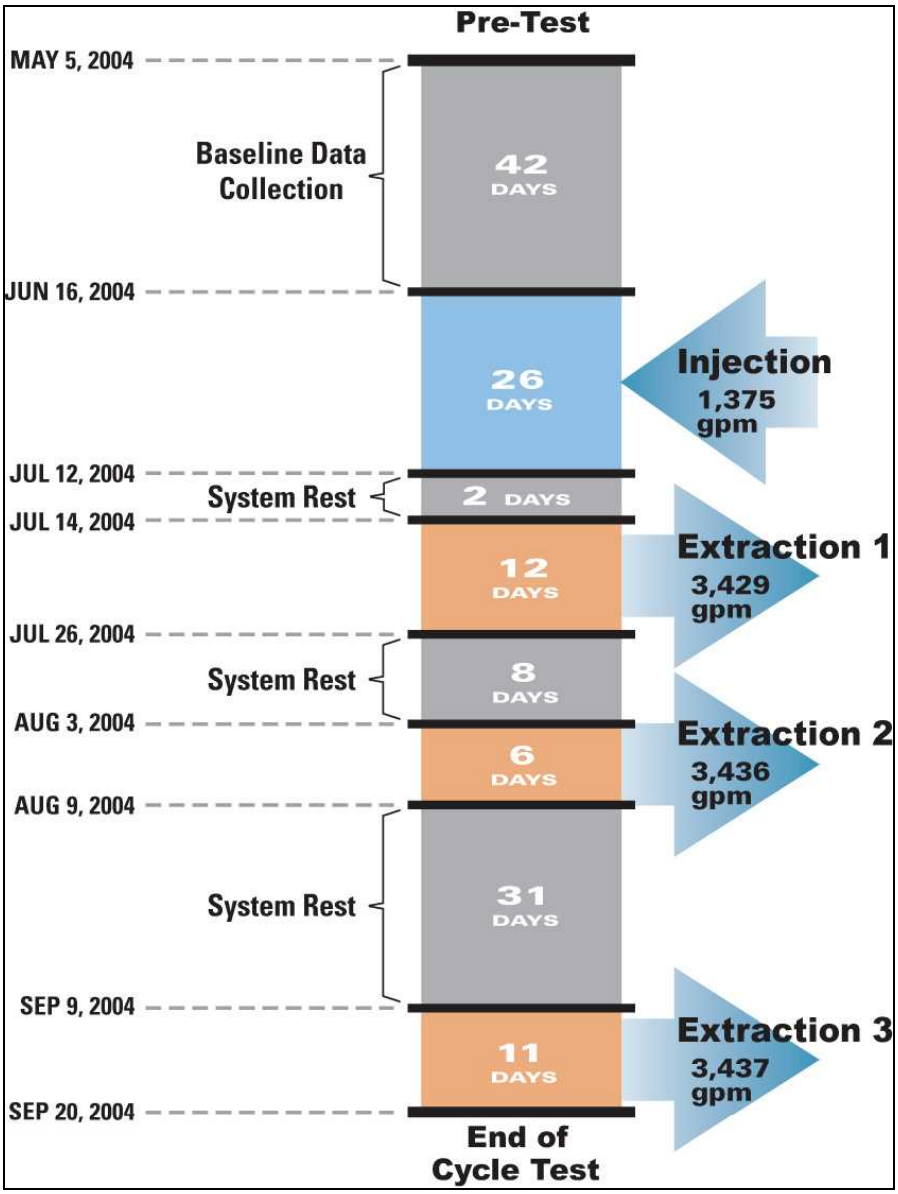
Figure 10 - Summary of Phase I ASR Pilot Testing at Diamond Creek Well



Phase I Groundwater Elevation Observations

Groundwater elevations vs. time with respect to the injection, storage, and extraction phases in the DCW, DCMW-1, DCMW-2, and DCMW-3 are presented in Figure 11. The average height of groundwater elevation increase, or mounding, during the injection phase in DCW was 25 feet with a maximum of 36 feet. The average amount of groundwater elevation decrease or drawdown in the DCW during the entire extraction phase was 60 feet with a maximum of 65 feet.

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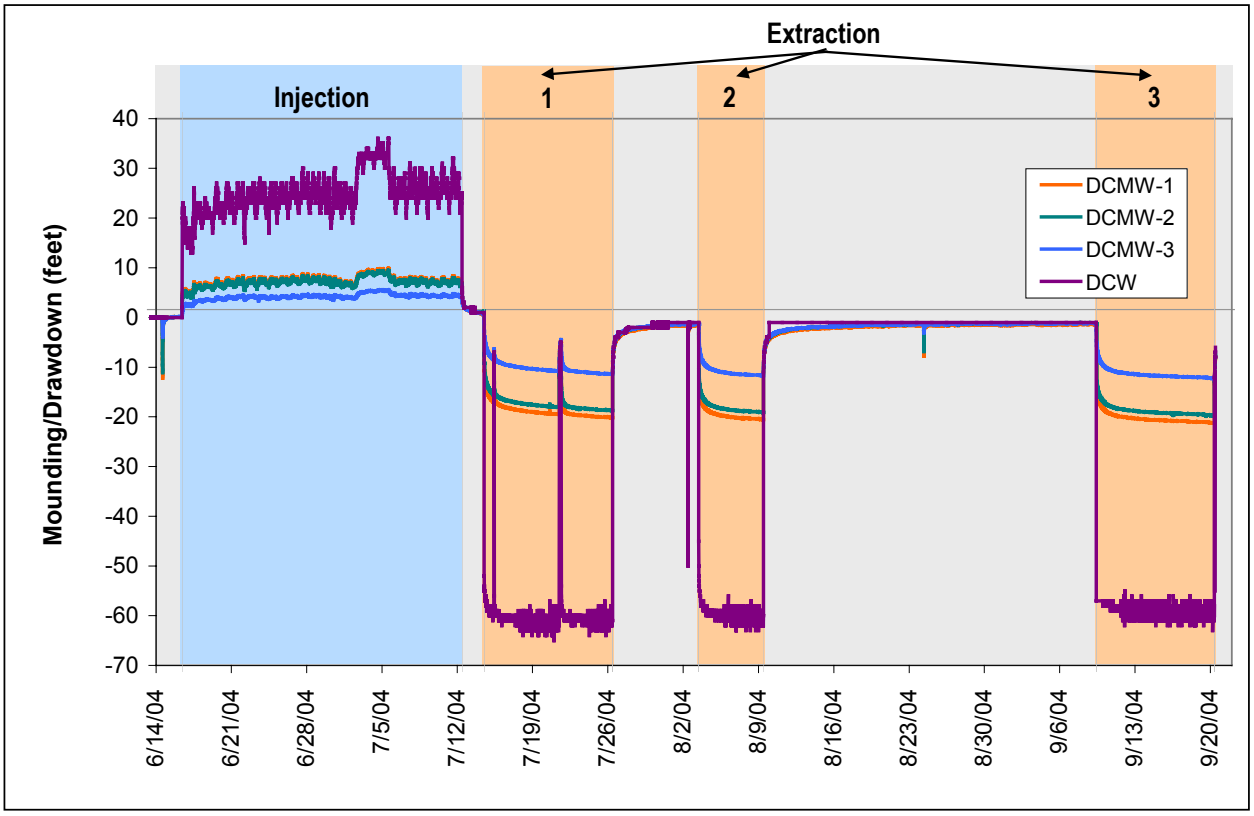
Figure 11 - Groundwater Elevation Changes vs. Time in the Diamond Creek Production and Monitoring Wells



Phase I Water Quality Observations

General chemistry trends of the DCW and for DCMW-1, DCMW-2, and DCMW-3 can be compared by the use of stiff diagrams. Stiff diagrams are a graphical representation of four anions (chloride, bicarbonate, carbonate, and sulfate) and four cations (sodium, potassium, calcium, and magnesium) (see example stiff diagram in Figure 12). Shape and size of each plot represent the TDS characterization. Units are typically displayed in milliequivalents per liter (meq/L), which are calculated by multiplying mg/L by the valence (charge of the species) and then dividing by molecular weight.

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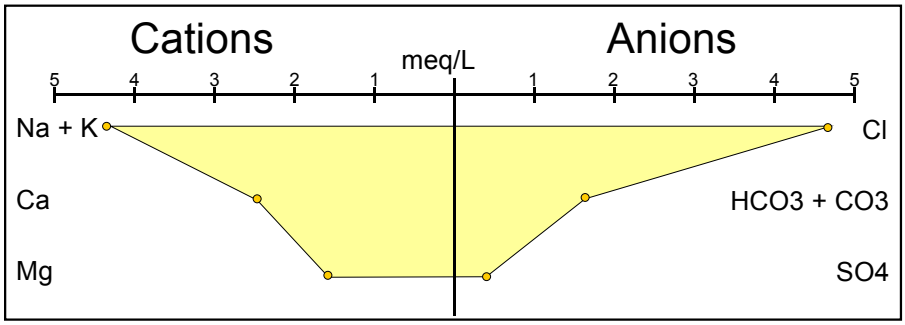
Figure 12 - Sample Stiff Plot Diagram



Stiff diagrams for the DCW and for DCMW-1, DCMW-2, and DCMW-3 are depicted vs. time in Figure 13. Baseline conditions are plotted as shapes in the first two rows (May 5 and 19, 2004). No sample was collected from DCMW-1 on May 19, 2004, because of mechanical complications with the down-well pump. The next five rows of data (from June 16, 2004, through July 14, 2004) represent conditions at DCMW-1 and DCMW-2. The final four rows of data (July 21, 2004, through September 9, 2004) represent conditions during extraction and show groundwater conditions have returned to baseline conditions. The shape and size of the stiff plot for DCMW-3 does not appear to have changed during cycle testing.

The City recognizes that some constituents, primarily THMs and HAAs, were temporarily introduced into the aquifer in the injected water, at trace concentrations. The City expected total THM concentrations to increase slightly during the storage phase of cycle testing as residual chlorine in the potable water continued to react with the DOC in the potable water. Figure 14 shows that THM concentrations increased in the aquifer, as expected, but concentrations decreased very quickly during the storage and extraction portions of the short-term pilot test.

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Figure 13 - Stiff Diagrams for the DCW, DCMW-1, DCMW-2, and DCMW-3

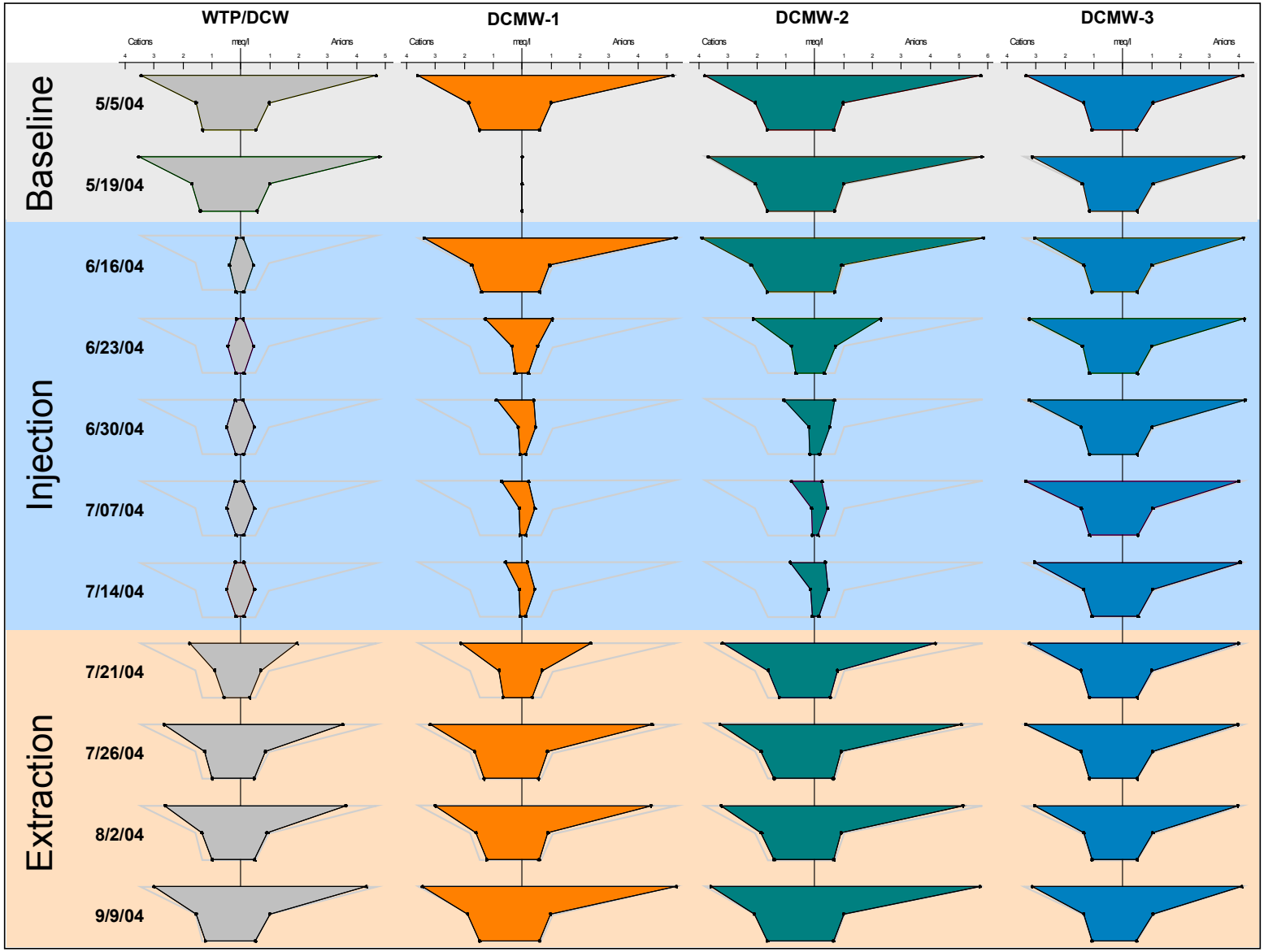

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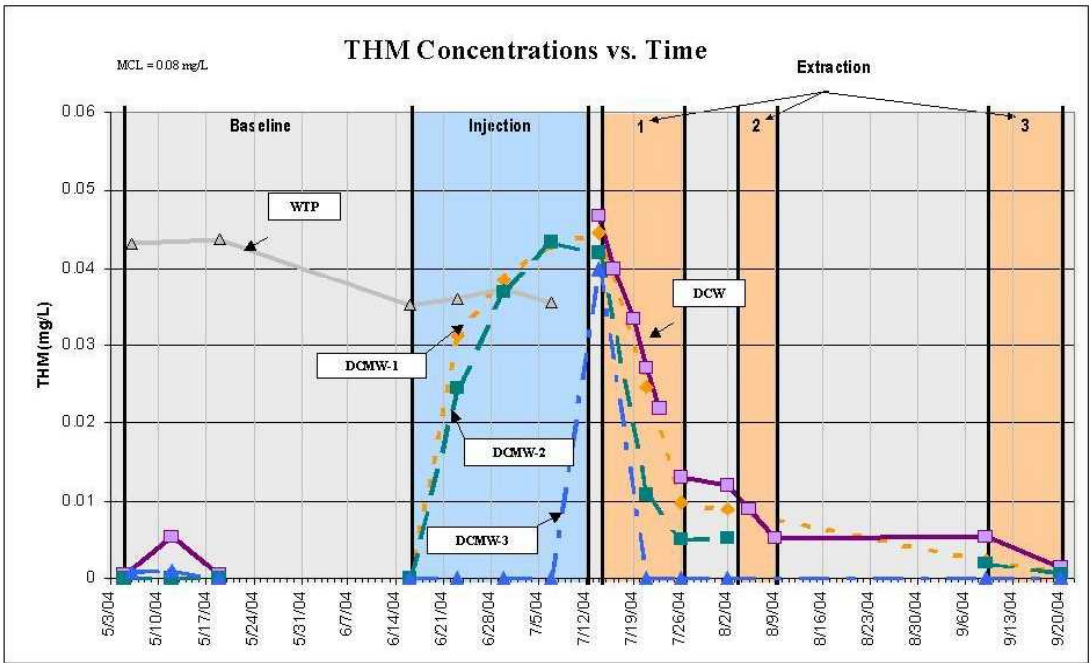
Figure 14 - Total THM Concentration vs. Time in the Diamond Creek Production and Monitoring Wells



OVERVIEW OF PROPOSED PHASE II DEMONSTRATION TESTING

Figure 15 summarizes the proposed Phase II ASR test at the Diamond Creek Well. Again, this test will involve injecting/extracting drinking water into and out of the Mehrten formation. The anticipated injection rate of the Phase II Test is 1,375 gallons per minute (gpm) and the anticipated extraction rate is 2,500 gpm. Based on the projected duration of the Phase II Test and the expected flow rates in the DCW, the volume of water injected into the Mehrten formation is approximately 1,094 acre-feet (AF), and the volume of water extracted from the aquifer is approximately 3,314 AF. As shown by the information listed in Table 1, the volume of water recovered is approximately 300 percent of what was injected. Water quality samples again be collected from the injection source, the DCW and each of the three monitoring wells.

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Figure 15 - Phase II Demonstration Test Schedule

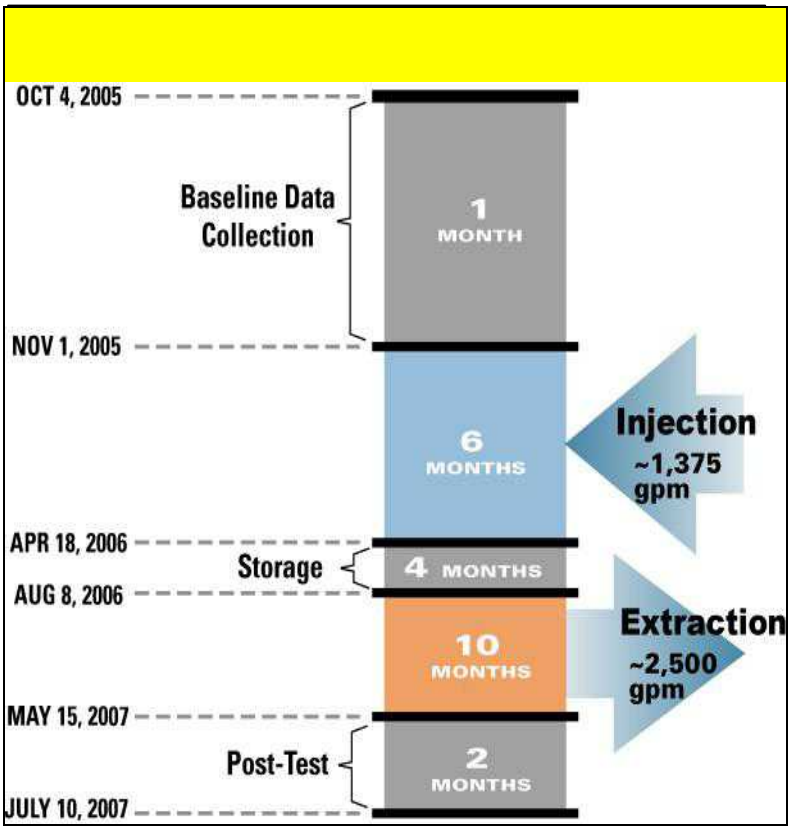

Table 1 - Anticipated Volume of Injected and Extracted Drinking Water During Phase II Test

	Injection Phase	Extraction Phase
PHASE DURATION	6 months / 180 days	10 months / 300 days
Average Flow Rate (gpm)	1,375	2,500
Average Flow Rate (AF/day)	6.08	11.05
Total Volume (gallons)	3.56×10^8	1.08×10^9
Total Volume (AF)	1,094	3,314
Volume Extracted (minus) Volume Injected (AF)		2,220
VOLUME EXTRACTED VS. VOLUME INJECTED		303%

It is possible that natural reduction of THMs and other DBPs may occur in the aquifer during the demonstration test, which may mitigate the impacts of these chemicals. There is evidence that THMs and HAAs are biologically degraded, or chemically adsorbed, in groundwater aquifers, which reduces their concentrations (AWWRF, 2005). Because the demonstration test will last substantially longer than the pilot study and will include a four-month storage phase, there will be more opportunity for such a reduction of the

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THMs and HAAs to occur. A reduction in these chemicals would be detectable by groundwater monitoring. If such a reduction occurred, the time needed for the extraction phase of the test could be reduced.

CONCLUSIONS

Consistent with State and Regional water resources planning efforts, the City of Roseville is implementing Aquifer Storage and Recovery to extend water supply reliability in an area of the state experiencing explosive growth. Roseville has completed construction of one ASR well and short-term pilot testing indicates that ASR is technical feasible in this hydrogeologic environment. The larger obstacle to implementation of full scale ASR in the region arises due to a lack of regulatory precedent for ASR and concerns over groundwater quality degradation that could result by introducing DBPs present in treated drinking water into the groundwater aquifer. The results of short-term ASR pilot testing indicate that groundwater quality generally improves as the result of injecting surface water with a lower total dissolved solid load into the groundwater aquifer. However, trace amounts of DBPs are present at concentrations below MCLs in the drinking being stored and these compounds are not present in native groundwater. For this reason, the Central Valley Regional Water Quality Control Board is advocating complete removal of even trace concentrations of DBPs before injection into the groundwater aquifer. However, if longer term pilot testing indicates that DBPs naturally attenuate in the aquifer, pre-injection DBP removal may not be required by the RWQCB.

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