
Draft Remedial Investigation Feasibility Study Workplan

City of Modesto Well Field RIFS
Grant Agreement No. D1712514
Modesto, California
April 26, 2019

Prepared for:

City of Modesto Utilities Department
1010 Tenth Street, Suite 4000
Modesto, California 95353

Prepared by:



9083 Foothills Blvd., Suite 370
Roseville, California 95747
916.367.5111



1631 Alhambra Boulevard, Suite 220
Sacramento, California 95816
916.970-0507

Draft Remedial Investigation Feasibility Study Workplan

City of Modesto Well Field RIFS
Grant Agreement No. D1712514
Modesto, California

April 26, 2019

Prepared By

Juliet Hutchins
Staff Scientist, Jacobson James & Associates, Inc.

Terri Herson
Project Manager, Jacobson James & Associates, Inc.

Reviewed By

Mike Tietze
Senior Engineering Geologist/Hydrogeologist
Formation Environmental LLC

TABLE OF CONTENTS

PAGE II

LIST OF TABLES	Page iv
LIST OF FIGURES	Page iv
LIST OF APPENDICES.....	Page v
LIST OF ACRONYMS AND ABBREVIATIONS	Page vi
1.0 INTRODUCTION	1-1
1.1 OBJECTIVES	1-1
1.2 REQUIREMENTS AND APPROACH.....	1-3
1.3 DISCLOSURE	1-5
2.0 BACKGROUND	2-1
2.1 SETTING	2-1
2.2 HYDROGEOLOGY	2-1
2.3 GROUNDWATER SUPPLY	2-3
2.4 GROUNDWATER QUALITY	2-4
2.5 PRIOR STUDIES AND INVESTIGATIONS	2-7
3.0 CONCEPTUAL SITE MODEL	3-1
3.1 HYDROGEOLOGY	3-1
3.2 CONTAMINANT SOURCES AND TRANSPORT.....	3-3
4.0 APPROACH	4-1
4.1 DATA OBJECTIVES.....	4-1
4.2 DATA NEEDS, CONSTRAINTS, AND OPPORTUNITIES	4-1
4.3 DATA EVALUATION	4-3
4.4 LIMITATIONS AND REMAINING DATA GAPS.....	4-3
5.0 REMEDIAL INVESTIGATION	5-1
5.1 DATA COMPILATION	5-1
5.2 GROUNDWATER LEVEL AND QUALITY MONITORING	5-2
5.3 SUPPLY WELL PROFILING	5-2
5.4 RECHARGE WATER PILOT TESTS.....	5-3
6.0 FEASIBILITY STUDY	6-1
6.1 OVERVIEW	6-1
6.2 TECHNOLOGY SCREENING	6-1
6.3 IDENTIFICATION OF PROJECT ALTERNATIVES	6-2
6.4 GROUNDWATER MODELING	6-3
6.4.1 MODELING OBJECTIVES	6-3

ii

DRAFT RIFS WORKPLAN

CITY OF MODESTO WELL FIELD RIFS, MODESTO, CALIFORNIA – APRIL 26, 2019

6.4.2	MODEL SELECTION	6-4
6.4.3	GEOCHEMICAL EVALUATION	6-4
6.4.3.1	GEOCHEMICAL MODELING OF PUBLIC SUPPLY WELLS AND USGS MONITORING WELLS	6-5
6.4.3.2	GEOCHEMICAL MODELING OF RECHARGE WATER PILOT TEST	6-5
6.4.3.3	DEVELOPMENT OF SOLUTE TRANSPORT MODELING SOURCE TERMS AND DISTRIBUTION/ RETARDATION COEFFICIENTS	6-6
6.4.4	GROUNDWATER FLOW AND SOLUTE TRANSPORT MODELING	6-7
6.4.4.1	REGIONAL GROUNDWATER FLOW MODEL DEVELOPMENT	6-7
6.4.4.2	REGIONAL SOLUTE TRANSPORT MODEL DEVELOPMENT AND VALIDATION	6-8
6.4.4.3	SUBREGIONAL GROUNDWATER FLOW MODEL DEVELOPMENT	6-9
6.4.4.4	SUBREGIONAL SOLUTE TRANSPORT MODEL DEVELOPMENT	6-10
6.4.4.5	SUBREGIONAL SOLUTE TRANSPORT MODEL CALIBRATION	6-11
6.4.4.6	SIMULATION OF REMEDIAL ALTERNATIVES	6-11
6.4.4.7	SENSITIVITY ANALYSIS	6-12
6.5	FEASIBILITY ANALYSIS	6-12
6.6	RECOMMENDED PROJECT(S)	6-13
7.0	SCHEDULE AND DELIVERABLES	7-1
7.1	SCHEDULE	7-1
8.0	REFERENCES	8-1

LIST OF TABLES

Table 1-1	Approach to RIFS Components
Table 2-1	Summary of Groundwater Subbasins
Table 3-1	Arsenic Conceptual Site Model
Table 3-2	Nitrate Conceptual Site Model
Table 3-3	Uranium Conceptual Site Model
Table 4-1	Data Objectives and Modeling Applications
Table 4-2	List of Conceptual Project Approaches
Table 5-1	Prior Studies and Data Sources
Table 5-2	Wells Designated for Sampling or Profiling and Rationale
Table 6-1	Model Layering

LIST OF FIGURES

Figure 2-1	Location Map, City of Modesto
Figure 2-2	City of Modesto RIFS Study Area
Figure 2-3	Municipal Wells Impacted by Arsenic, Nitrate and/or Uranium
Figure 2-4	Municipal Wells Taken Off-Line Due to Arsenic, Nitrate and/or Uranium
Figure 2-5	Shallow Aquifer Zone Well Map Arsenic Concentrations (2015 – 2017)
Figure 2-6	Intermediate Aquifer Zone Well Map Arsenic Concentrations (2015 – 2017)
Figure 2-7	Deep Aquifer Zone Well Map Arsenic Concentrations (2015 – 2017)
Figure 2-8	Shallow Aquifer Zone Well Map Nitrate Concentrations (2015 – 2017)
Figure 2-9	Intermediate Aquifer Zone Well Map Nitrate Concentrations (2015 – 2017)
Figure 2-10	Deep Aquifer Zone Well Map Nitrate Concentrations (2015 – 2017)
Figure 2-11	Shallow Aquifer Zone Well Map Uranium Concentrations (2015 – 2017)
Figure 2-12	Intermediate Aquifer Zone Well Map Uranium Concentrations (2015 – 2017)
Figure 2-13	Deep Aquifer Zone Well Map Uranium Concentrations (2015 – 2017)
Figure 3-1	City of Modesto RIFS Study Area Regional Model Section View
Figure 3-2	Conceptual Models of Hydrologic Processes
Figure 4-1	Sampling and Profiling Well Map

LIST OF FIGURES (CONTINUED)

- | | |
|------------|---|
| Figure 6-1 | City of Modesto RIFS Study Area and Regional Model Boundary |
| Figure 6-2 | City of Modesto RIFS Study Area Model Boundary Conditions |

LIST OF APPENDICES

- | | |
|------------|--------------------------------|
| Appendix A | Monitoring and Reporting Plan |
| Appendix B | Quality Assurance Project Plan |

LIST OF ACRONYMS AND ABBREVIATIONS

AGR	agricultural supply
ASR	Aquifer Storage and Recovery
$\text{Ca}_2\text{UO}_2(\text{CO}_3)_3(\text{aq})$	calcium-uranyl-carbonate complex
City	City of Modesto
CVRWQCB	California Regional Water Quality Control Board, Central Valley Region
DBCP	dibromo-chloro-propane
DMS	database management system
DSS	decision support system
DWR	California Department of Water Resources
FS	Feasibility Study
Grant Agreement	Grant Agreement No. D1712514 between the city of Modesto and the SWRCB
GAMA	Groundwater Ambient Monitoring and Assessment Program
GUI	Graphical user interface
IND	industrial service supply
JJ&A	Jacobson James & Associates, Inc.
LGA	Local Groundwater Assistance
LRGSS	Local Refined Grid Steady-State
m	meter
MAR	Managed Aquifer Recharge
MCL	maximum contaminant level
MGD	million gallon per day
MID	Modesto Irrigation District
MRP	Monitoring and Reporting Plan
MUN	municipal and domestic supply
OID	Oakdale Irrigation District
PCE	perchloroethylene
PRO	Industrial process supply
Project	City of Modesto Wellfield Remedial Investigation/Feasibility Study
QAPP	Quality Assurance Project Plan
RI	Remedial Investigation
RIFS	Remedial Investigation Feasibility Study
SJVGB	San Joaquin Valley Groundwater Basin
STRGBA	Stanislaus and Tuolumne Rivers Groundwater Basin Association

LIST OF ACRONYMS AND ABBREVIATIONS (CONTINUED)

SWAT	Soil and Water Assessment Tool
SWRCB	California State Water Resources Control Board
TID	Turlock Irrigation District
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
UWMP	Urban Water Management Plan
VOC	volatile organic compound
Workplan	Remedial Investigation/Feasibility Study Workplan
1,2,3-TCP	1,2,3-trichloropropane
%	percent

1.0 INTRODUCTION

The City of Modesto (City) faces ongoing challenges with natural and anthropogenic contamination in its drinking water aquifers. Nitrate, arsenic, and uranium contamination has led to the abandonment of a significant number of supply wells, and threatens other wells. As a result, 18 of the City's water supply wells, representing over 16 million gallons per day (MGD) of the system's total groundwater production capacity (48 MGD), have already been inactivated, abandoned, destroyed, or removed from potable use due to contamination. In addition, the City has installed deeper wells and implemented wellhead treatment or blending programs to maintain compliance with drinking water Maximum Contaminant Levels (MCL). These responses to non-point source pollution are similar to other communities in the San Joaquin Valley. It is expected that continued contaminant plume migration and more stringent regulation of drinking water in the future may require the City to shut down, replace, or modify additional wells, or to provide additional treatment or blending strategies. At the same time, the City anticipates placing increased demand on its groundwater supplies in the future as population continues to grow and as competition for the limited available surface water supplies in the region intensifies. The City has been actively exploring the implementation of groundwater recharge projects.

The City of Modesto Wellfield Remedial Investigation/Feasibility Study (RIFS) (Project) will evaluate alternatives to implement wellfield operational or modification strategies that can provide clean drinking water while protecting uncontaminated portions of the aquifer from contaminant migration, and recharge strategies that can improve groundwater quality over time while enhancing the resilience of local groundwater supplies. This RIFS Workplan (Workplan) presents the background, rationale, and procedures to implement the RIFS.

1.1 OBJECTIVES

The overall purpose of the Project is to identify and prioritize one or two implementable projects that prevent the spread of arsenic, nitrate, or uranium contamination within the drinking water aquifer that underlies the City, prevent additional release of arsenic or uranium, and/or clean up the aquifer (i.e., improve water quality) over time. The Project is being funded under a grant from the California State Water Resources Control Board (SWRCB) Proposition 1 Groundwater Sustainability Grant Program. This Workplan has been developed in accordance with Grant Agreement No. D1712514 between the City of Modesto and the SWRCB (Grant Agreement), which was executed on November 30, 2018. It is consistent with the requirements and limitations of the scope of work, schedule and budget described in the Grant Agreement. To address this overall purpose, the RIFS consists of the following two primary components, the specific objectives of which are described below:

Remedial Investigation (RI). The RI will provide the data and information necessary to perform a comparative analysis of potential projects (alternatives) in the Feasibility Study (FS). The RI will use

existing data supplemented with newly collected data to improve the conceptual understanding of contaminant distribution and transport. Specifically, data collection efforts will focus on developing a deeper understanding of the vertical distribution, behavior, and migration of arsenic, nitrate, and uranium, and on the hydrologic interaction of supply wells with the aquifer, so that solute transport models can be developed as part of the FS that are adequate to evaluate the effectiveness of project alternatives. Efforts will focus on areas known to be impacted and where existing data can be built upon to construct refined solute transport models. Suitable locations for collection of supplemental data will be constrained by the locations of existing wells that are suitable for collecting data based on screen lengths, water quality impacts, access, and available infrastructure to meet testing requirements.

Feasibility Study (FS). The FS will identify one or two recommended projects through a comparative evaluation of project alternatives and present a conceptual design for the recommended project(s). The FS will initially screen potential technologies that can prevent the spread or release of contamination or clean up groundwater over time, and then assemble the screened technologies into project alternatives for evaluation. Up to six potential project alternatives will be developed for evaluation based on two main strategies:

1. wellfield operation or modification approaches that help protect water quality in uncontaminated areas or prevent the release of additional contamination; and,
2. aquifer recharge that, in combination with groundwater extraction, could improve groundwater quality by flushing the aquifer, while at the same time improving the quantity of groundwater available for extraction.

The specific project alternatives to be evaluated will be defined in a consultative workshop during the final phase of the RI, when the existing data have been compiled and evaluated, and most of the new data collected during the RI are available for consideration. The project alternatives will represent the most promising alternatives for each type of approach, in the judgment of the workshop group based on the data available, opportunities, and constraints posed by City needs, site conditions, available infrastructure, and other considerations.

The FS will use solute transport modeling to evaluate the effectiveness of the project alternatives. Model development will include refinement of an existing regional model and development of subregional groundwater solute transport models. The purpose of the regional model is to define boundary conditions for the subregional models. The areas of the subregional models will be selected to facilitate evaluation of the identified projects. The objective of this solute transport modeling work is to develop a model of adequate capability to evaluate and compare the project concepts in terms of their relative effectiveness using a superposition approach (i.e., to perform an evaluation of project effects compared to a baseline no-project condition). The comparative modeling results of project effectiveness will be used in the FS along with consideration of other feasibility criteria described later

in this document to compare, rank, and identify the one or two recommended projects for implementation. A conceptual design will be provided for the recommended project(s).

1.2 REQUIREMENTS AND APPROACH

The Grant Agreement presents the requirements of the RIFS Workplan, as summarized below:

1. An investigation plan, modeling plan, and feasibility evaluation criteria that will address significant data gap(s) in the Project area(s) for nitrate, arsenic, and uranium contamination in groundwater.
2. Identification of the proposed Project area(s) including a description of monitoring well sample locations and the rationale for addressing data gaps in the Project area.
3. A description of the tasks necessary for conceptual model development and data compilation.
4. A description of the dynamic well flow/concentration profile testing that will be conducted to evaluate the vertical distribution of and a description of the proposed aquifer testing.
5. Identification of the tasks necessary to conduct a feasibility study, including screening potentially effective technologies and defining and prioritizing potential implementation projects.
6. A discussion of the groundwater solute transport modeling for the Project area and how it will be utilized.

This Project differs from a traditional RIFS for a contaminated site because the objective is to identify and evaluate potential project alternatives that can be implemented within portions of an existing operating wellfield, rather than developing alternatives, as needed, to remediate an existing contamination plume wherever it occurs. The primary difference is whereas a traditional RIFS focuses on characterization of the full nature and extent of contamination and on siting remedial actions wherever needed, the Modesto RIFS will target existing wells that are suitable for implementation of potential projects within a larger area that is impacted by non-point source pollutants. The locations of these projects will be selected by virtue of (1) impacts by arsenic, nitrate, and/or uranium; (2) availability of existing data that can be built upon to characterize aquifer/well interactions and vertical contaminant distribution; and (3) suitability of wells to collect additional data needed to develop an adequate solute transport model for project evaluation. These differences are summarized in Table 1-1, below.

TABLE 1-1 APPROACH TO RIFS COMPONENTS

RIFS Component	Traditional RIFS	Modesto Wellfield RIFS
Remedial Investigation Approach	Characterize the full vertical and lateral extent and nature of contamination prior to identification and siting of remedial alternatives.	Characterize distribution and nature of contamination within the zone of influence of existing supply wells where projects can be implemented, with an emphasis on vertical distribution.
Identification of Data Gaps	Identify data gaps related to the nature and extent of contamination in the impacted area.	The primary data gaps are known: (1) interaction of long screen wells with the aquifer; (2) vertical distribution of contaminants; and (3) interaction of recharge water with the aquifer.

RIFS Component	Traditional RIFS	Modesto Wellfield RIFS
Addressing Data Gaps	Collect data wherever characterization is incomplete.	Refine existing datasets for transport modeling to support FS evaluation of potential projects, with focus on existing long-screen supply wells suitable for further characterization.
Nature of Alternatives Evaluated	Design remedial alternatives for optimal hydraulic control or cleanup, based on characterization of contamination plumes.	Take a multi-benefit approach. Modify the operation/completion of existing wells, and site new wells and recharge projects to meet the regional water quality objectives of prevention and cleanup, with dual consideration to water supply resilience objectives.
Siting of Remedial Alternatives	Site remedial operations at optimal locations for hydraulic control, containment, or cleanup.	Use or modify existing wells, add new wells to augment wellfield operation, and implement recharge projects where both water supply and water quality objectives can be met.

The remainder of this RIFS Workplan includes the following sections and approach:

Section 2.0 Background. This section summarizes the background pertinent to understanding the RIFS scope and approach and provides context for understanding the RI investigation scope used to address the data gaps, as defined above.

Section 3.0 Conceptual Site Model. This section presents our conceptual understanding of the hydrogeologic system and contaminant behavior that must be simulated in order to evaluate the effectiveness of the project alternatives in the FS.

Section 4.0 Approach. This section describes the approach taken to data gathering in the RI and identifies any inherent limitations in the RI and what further data may be needed to support design of any resulting implementation projects.

Section 5.0 Remedial Investigation. A summary of the RI objectives and scope of work is presented in this section, and a detailed Monitoring and Reporting Plan (MRP) is included as Appendix A. Appendix B includes a Quality Assurance Project Plan (QAPP) for the RI.

Section 6.0 Feasibility Study. This section describes how the project alternatives will be identified, summarizes the approach to the groundwater modeling component of the FS, and presents the approach to engineering evaluation and ranking of the project alternatives.

Section 7.0 Schedule and Deliverables. This section describes the proposed schedule and deliverables for the Project.

Section 8.0 References. This section includes the sources cited in this RIFS Workplan.

1.3 DISCLOSURE

Funding for this project has been provided in full or in part through an agreement with the State Water Resources Control Board using funds from Proposition 1. The contents of this document do not necessarily reflect the views and policies of the foregoing, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

2.0 BACKGROUND

2.1 SETTING

The Study Area for the proposed RIFS is the contiguous water service area for the City, which includes the City and portions of Salida to the north and Ceres to the south (Figures 2-1 and 2-2). The City is located within Stanislaus County in the northern San Joaquin Valley. Topography ranges from gently rolling hills to the east to alluvial plains in the west. This area comprises urban development with surrounding agricultural lands. The urban areas include residences, commercial districts, and industrial plants, including several large food processing facilities in south Modesto. The City lies in the northern portion of the San Joaquin River Hydrologic Region. Major drainages entering the area from the east include the Stanislaus and Tuolumne Rivers. They are fed by storm runoff and snowmelt from the Sierra Nevada and constitute an important water supply for the region. Flow in these rivers is regulated by releases from major storage reservoirs in the Sierra Nevada foothills east of the county. Reservoir operations are controlled to provide water supply to downstream water right holders, attenuate peak flood flows, and meet mandated ecological flow requirements. These rivers are tributary to the San Joaquin River that flows north-northwestward through the low point of the San Joaquin Valley. The Tuolumne River flows in an east-west direction through the southern portion of the City, and Dry Creek (a major tributary of the Tuolumne River that also flows through the east/central portions of the City) flows north of the river to their confluence on the southeast side of downtown Modesto. Storm drainage in the Study Area is provided via a system of drop inlets and conveyance pipelines that drain runoff to a system of over 10,000 rock wells and storm water basins that promote subsurface recharge, as well as to outfalls to the Stanislaus River to the north, the Tuolumne River to the south, and Dry Creek. Wastewater service is provided through a system of sewer collection pipelines, although some outlying portions of the Study Area are served by septic systems. The City's wastewater treatment plant is located several miles to the west of the Study Area, near the San Joaquin River.

2.2 HYDROGEOLOGY

The Study Area is underlain by portions of the Modesto and Turlock Subbasins of the San Joaquin Valley Groundwater Basin (SJVGB). The subbasins are bounded to the east by relatively impermeable basement rocks of the Sierra Nevada foothills, to the west by the San Joaquin River, and to the north and south by the Stanislaus and Merced Rivers, respectively. The Tuolumne River divides the two subbasins in the southern portion of City. Summary information regarding these groundwater subbasins is presented in Table 2-1, below.

TABLE 2-1: SUMMARY OF GROUNDWATER SUBBASINS

Groundwater Subbasin (DWR Basin Number)	Approximate Area	CASGEM Priority	Critical Overdraft Listing
Modesto Subbasin (5-22.02)	385 mi ² (247,00 acres)	High	No
Turlock Subbasin (5-22.03)	542 mi ² (347,000 acres)	High	No

Sources:

California Department of Water Resources (DWR), 2003. *California's Groundwater, Bulletin 118*. Last update for Eastern San Joaquin, Turlock, and Delta-Mendota Subbasins: 2006; Modesto Subbasin: 2004.

DWR, 2016. *Water Management Planning Tool*. Website: <http://water.ca.gov/groundwater/boundaries.cfm>. Accessed July 12, 2017.

Aquifer systems in the SJVGB consist mostly of continental sediments derived from erosion of the Sierra Nevada foothills to the east and the Coast Ranges to the west, and deposited in the valley. The alluvial aquifer system, much of which occurs as fan deposits, consists of a complex set of interbedded aquifers and aquitards that function regionally as a single water-yielding system. The aquifers are relatively thick, with the upper approximately 500 to 800 feet providing the primary source of groundwater supply in the area. Aquifer materials consist of gravel and sand, which become increasingly interbedded with fine-grained silt, clay, and lakebed deposits toward the center of the valley. Regionally, the aquifer system of the SJVGB can be divided into an upper unconfined to semi-confined aquifer system, a series of geographically extensive confining clay layers, and a deep confined aquifer system that occupies the central portions of the basin. Toward the center of the valley, the distal, finer-grained facies of the alluvial deposits are interfingering and interbedded with flood plain and basin deposits. Buried river-channel deposits occur in the alluvial fan deposits at the margins of the valley and along Pleistocene and modern river courses (California Department of Water Resources [DWR], 2013).

The principal water-bearing formations on the east side of SJVGB include the semi-consolidated to consolidated Mehrten Formation (Miocene-Pliocene), the semi-consolidated to unconsolidated Turlock Lake Formation (Plio-Pleistocene), the unconsolidated Riverbank and Modesto Formations (Pleistocene), and the overlying unconsolidated Holocene Alluvium and Basin Deposits. These sedimentary deposits dip gently westward and increase in thickness with distance from the Sierra Nevada foothills and from north to south along the valley axis. Aquifers in these deposits tend to be unconfined to semi-confined near the valley margin, grading to semi-confined and confined near the valley axis (United States Geological Survey [USGS], 2004b; DWR, 2013a).

The Corcoran Clay is a well-defined regional confining layer that occurs between the Upper and Lower Turlock Lake Formation, and separates the shallow unconfined and semi-confined aquifers from deeper confined aquifers. In the Modesto area, the eastern extent of the Corcoran Clay roughly parallels State Highway 99

beneath the western portion of the City (Figure 2-1) (Phillips et al., 2015). West of the Modesto area, the Corcoran Clay has a maximum thickness of approximately 120 feet. The Corcoran Clay thins beneath the City and is not present beneath eastern portions of the City. East of the Corcoran Clay, the aquifer system transitions from unconfined conditions to semi-confined conditions with depth, due to the presence of clay lenses and paleosols in the Lower Turlock Lake, Laguna, and Upper Mehrten Formations.

Groundwater flow in the region surrounding the Study Area is generally to the southwest, following the dip of the basement rock and sedimentary units, and toward the San Joaquin River, with some local cones of depression around clusters of water supply wells (USGS, 2004b; Todd Groundwater and RMC Water and Environment [Todd and RMC], 2016). The Stanislaus and Tuolumne Rivers are groundwater-connected, and include both gaining and losing reaches (USGS, 2015; Turlock Groundwater Basin Association, 2008). The depth to groundwater varies from approximately 20 feet in the western portion of the Study Area, west of Highway 99, to over 50 feet in the easternmost portion of the Study Area (DWR, 2019). Groundwater levels in the Modesto area declined by approximately 20 feet through the 1980s and 1990s due to overdraft conditions but stabilized and recovered when the City began to derive a significant portion of its water supply from treated surface water provided by the Modesto Irrigation District beginning in 1994.

Groundwater elevation contour maps were developed by Todd Groundwater for July 2000 and April 2015, and hydrographs for selected municipal wells and USGS monitoring wells were evaluated to assess hydraulic gradients and groundwater flow directions, as well as elevation trends (Todd and RMC, 2016). Groundwater flow in July 2000 was generally from east to west, with localized cones of depression, the largest of which was in the north-central portion of the City near Wells 25, 48, and 50. Drawdown in this area was approximately 10 to 15 feet below groundwater levels in the surrounding area. Groundwater flow in the southeastern portion of the City was to the southwest towards the Tuolumne River or a cone of depression located on the south side of the City. Groundwater levels in April 2015 were generally approximately 5 to 10 feet lower than in July 2000. This is generally consistent with regional groundwater level declines during the latter portion of the recent drought (Jacobson James & Associates, Inc. [JJ&A], 2018). Groundwater flow was somewhat more southwesterly, also with localized cones of depression, the largest of which, with approximately 20 feet of drawdown relative to the surrounding area, was located near Well 16 in the west-central portion of the City. The groundwater flow direction in the southern portion of the City had shifted more southerly compared to July 2000 and was toward to the Tuolumne River to the south. Evaluation of selected well hydrographs showed strong cyclical patterns of summer time drawdown and winter recovery, consistent with City pumping rates and peak groundwater demand. Vertical gradients were generally downward, with the strongest vertical gradients evident in the summer (Todd and RMC, 2016; USGS, 2004b).

2.3 GROUNDWATER SUPPLY

Beneficial uses of groundwater in the Modesto area are identified as municipal and domestic supply (MUN), agricultural supply (AGR), industrial service supply (IND), and industrial process supply (PRO) (California Regional Water Quality Control Board [CVRWQCB], 2016).

The region relies on the conjunctive use of surface water and groundwater to meet a variety of water demands. The Stanislaus and Tuolumne Rivers are important AGR and MUN sources via diversions that occur under senior water rights held by Modesto Irrigation District (MID), Oakdale Irrigation District (OID), and Turlock Irrigation District (TID). The City of Modesto currently receives approximately 40 percent (%) of its water supply from MID, and a project is in progress for TID to deliver Tuolumne River water to the Cities of Ceres and Turlock in the near future.

The City owns and operates a contiguous system that supplies drinking water to the communities of Modesto, Salida, and North Ceres (Figure 2-2), and systems serving several outlying “service islands,” including Grayson, Del Rio, Walnut Manor, and portions of Turlock. The City’s water distribution system supplies water to approximately 260,000 residents, as well as commercial districts and industrial facilities, via approximately 75,000 connections (West Yost, 2016). Approximately 60% of the City’s drinking water supply is derived from groundwater, the remainder is treated surface water from the Tuolumne River that is provided by the MID. Surface water is distributed from the Modesto Regional Water Treatment Plant on the northeast side of the City. The City’s groundwater supply is presently sourced from approximately 100 active supply wells and surface water diverted from the Tuolumne River. The locations of shallow, intermediate, and deep wells that are part of the City’s water supply system are shown on Figure 2-2. Water for several food processing facilities in south Modesto (between Dry Creek and the Tuolumne River) is provided from private PRO wells that are operated by the facilities. Municipal groundwater pumping in Modesto is projected to increase by an average of 0.08% per year until 2040 (West Yost, 2016). Forecast groundwater drawdowns in the Study Area are predicted to be one foot in the shallow aquifer system and two to four feet in the deeper aquifer system by 2042, under maximum reasonable demand increases (JJ&A, 2018).

2.4 GROUNDWATER QUALITY

Todd Groundwater (Todd) compiled general chemistry data for groundwater in the Modesto area and plotted it on cross sections (Todd and RMC, 2016). In addition, as part of its studies in the area, the USGS investigated the lateral and vertical distribution of major cations and anions and their relationship to groundwater age in the area surrounding Well 25 (USGS, 2004b). The data indicated that whereas shallow to intermediate depth groundwater affected by modern recharge tended to be dominated by bicarbonate chemistry, deeper groundwater, which was unaffected (or less affected) by modern recharge, tended to contain lower concentrations of bicarbonate. Bicarbonate concentrations were highest near the water table.

Several water quality issues are noteworthy. On the eastern side of the San Joaquin Valley, some wells that serve the communities of Modesto, Ceres, and Salida have been impacted by arsenic and uranium in sediments derived from the Sierra Nevada foothills. Anthropogenic water quality degradation related to historical agricultural activities has impacted portions of the shallow aquifer system at various locations throughout the Study Area and has impacted municipal supply wells in some areas. Elevated concentrations of nitrate and soil fumigant residuals such as 1,2,3-trichloropropane (1,2,3-TCP) and dibromo-chloro-propane (DBCP) have been found in wells at various locations throughout the valley. Other anthropogenic

contaminants that have impacted the shallow aquifer beneath urban areas, such as Modesto and Turlock, include perchloroethylene (PCE) from historical dry-cleaning operations and locally fuel hydrocarbons.

The water quality issues noted above have resulted in 17 municipal supply wells being taken off-line; other wells have been fitted with treatment facilities or are used in blending strategies to meet MCLs. A map showing municipal wells in the Study Area that have been impacted by arsenic, uranium, and nitrate at concentrations near or above the MCL is included as Figure 2-3. Figure 2-4 shows the locations of wells which have been taken off-line (put on inactive status, designated for non-potable use, abandoned, or destroyed) as a result of arsenic, nitrate, or uranium concentrations. The locations of wells currently proposed for destruction is also shown. Additional information regarding these contaminants is summarized below.

Arsenic. Naturally-occurring arsenic is encountered at various locations and depths in the City's drinking water aquifers at concentrations that are approaching (and in some cases exceeding) the MCL for drinking water. Elevated arsenic concentrations have been detected in wells in the northwestern portion of the Study Area, especially in Salida, and in the southern portion of the Study Area (Figure 2-3). Two wells in the northwestern portion of the Study Area and one well in the south-central portion of the Study Area have been taken off-line due to arsenic impacts (Figure 2-4). While it has been postulated that arsenic concentrations in the aquifer are expected to be generally decreasing, in the Salida area concentrations appear to be stable in some wells, may be decreasing in some (although the significance of these trends has not been established), appear to be increasing in one well, and remain at or near the MCL in 70% of wells in this area.

Arsenic in the aquifer system is derived from Sierran sediments (USGS, 2008). It tends to occur at higher concentrations in older groundwater and is believed to be released to the aquifer by dissolution of iron or manganese oxyhydroxides under reducing conditions, desorption from aquifer sediments with increasing pH, and/or decreased resorption due to increasing pH, competing species, or lack of sorption sites (USGS, 2008 and 2010). In the San Joaquin Valley, mobilization of arsenic has also been proposed to occur from aquitards by dewatering (Smith, Knight, and Fendorf, 2018). The data indicate that migration of arsenic is facilitated by lateral and vertical gradients, created by municipal pumping, and by vertical movement through wells with long screened or perforated intervals (USGS, 2008). Examples of arsenic impacts include northern Modesto and Salida, where at least six supply wells produce water that contains arsenic at concentrations approaching or exceeding the MCL and opportunities for water blending are limited. Arsenic also occurs naturally within the aquifer system, and the available data suggest that the depth of the impacted zones is variable. Nevertheless, the data also indicate that migration of arsenic is being facilitated by lateral and vertical gradients created by municipal pumping, and by vertical movement through wells with long screened or perforated intervals. In addition, it is possible that geochemical changes in modern recharge water, such as high dissolved organic carbon concentrations, could contribute to the mobilization of arsenic in the aquifer system. Arsenic concentrations detected in wells sampled between 2015 and 2017 are shown on Figures 2-5, 2-6, and 2-7 for the shallow, intermediate, and deep aquifers, respectively.

Nitrate. Although low concentration of nitrate may be naturally occurring, elevated nitrate concentrations are present throughout much of the shallow aquifer underlying the City (Figure 2-3). Approximately one third of the City's water supply from wells contains nitrate at concentrations that exceed 50% of the MCL for drinking water. Six wells are currently out of service due to high nitrate concentrations (Figure 2-4), and water blending is being employed to reduce nitrate concentrations at other wells. Nitrate is present in the City's drinking water aquifers as a result of historical agricultural activities and wastewater management. Nitrate impacts primarily occur in the shallow aquifer system, but in some cases extend into the deeper aquifers when drawn down by pumping or through wells with long screened/perforated intervals (USGS, 2008). The migration of nitrate in the aquifer system is influenced by downward gradients created by municipal pumping; The available data suggest that elevated nitrate concentrations are being drawn deeper in the aquifer in areas where cones of depression are forming. Nitrate concentrations detected in wells sampled between 2015 and 2017 are shown on Figures 2-8, 2-9, and 2-10 for the shallow, intermediate, and deep aquifers, respectively.

Uranium. Naturally-occurring uranium is a relatively prevalent contaminant in the shallow and intermediate depth aquifers underlying the City, especially in the western, central, and southern portions of the Study Area (Figure 2-3). Fourteen wells have been taken out of service as a result of uranium (Figure 2-4), and blending strategies are being implemented at other wells. Uranium is naturally occurring in the aquifer materials derived from Sierran granitic rocks and its mobilization in the shallow and intermediate aquifer is likely influenced by elevated bicarbonate concentrations in modern recharge water resulting from agricultural activities (Jurgens, et al., 2009). The agricultural soils are rich in active biomes and contain elevated carbon dioxide levels, which causes recharge water to be exposed to relatively high partial pressures of carbon dioxide, resulting in a predominantly bicarbonate chemistry of modern recharge water. USGS studies indicate uranium is mobilized when bicarbonate-rich water percolates downwards through the aquifer and replaces older aquifer water with less bicarbonate. The presence of elevated uranium and bicarbonate concentrations in the shallow aquifer beneath areas that have been residentially developed for decades suggests that local recharge through rock wells could be contributing to the continuing generation of water with elevated bicarbonate concentrations. Uranium concentrations detected in wells sampled between 2015 and 2017 are shown on Figures 2-11, 2-12, and 2-13 for the shallow, intermediate, and deep aquifers, respectively.

Other anthropogenic compounds have been detected at various locations in the Study area. These anthropogenic compounds were not selected as part of the Grant Agreement/RIFS, but their presence is relevant background information to consider during definition of project alternatives that will be evaluated in the RIFS. Summary information is provided below.

Volatile Organic Compounds (VOC). VOCs have been detected in a number of wells in the downtown area and the McHenry Avenue corridor in the western commercial core of the City. The source of the VOCs is primarily attributed to historical dry cleaning operations. Currently, treatment to remove PCE, trichloroethylene, and/or Freon 113 is being conducted at City Well Nos. 1, 2, 3, 14, 21,

50, and 225 (Figure 2-2). Several of these wells are only being used for non-potable purposes, and are no longer connected to the City's water supply system. Sites that are of particular concern include the Modesto Groundwater Superfund Site (Halfords Cleaners), Elwood's Cleaners, McHenry Village Cleaners, Highgrade Service, and Sunshine Cleaners. Response actions to address PCE have included investigations, groundwater extraction to address shallow groundwater contamination, and soil vapor extraction to address source removal and potential vapor intrusion into buildings. In addition, monitoring of groundwater, soil vapor, and indoor air is being conducted at several sites. Comprehensive VOC plume maps are generally unavailable because the sites are the subject of a product liability lawsuit that has been ongoing for over 15 years. This contamination is not proposed to be investigated as part of the RIFS; however, the evaluation of potential implementation projects in areas that are impacted by VOCs will include consideration of the potential effect of their presence on the projects.

DBCP. DBCP was widely used as an agricultural soil fumigant until it was banned in the late 1970s. It is relatively mobile and toxic at low concentrations, and has locally presented a concern. It was detected in water from City Well Nos. 50, 212, 236, 247, 271, 291, and 292 at sufficient concentrations to warrant the use of wellhead treatment using granular activated carbon (USGS, 2008). These wells are mostly located in the southeastern portion of the City (Figure 2-2). DBCP has been detected at lower concentrations (well below MCLs) in water from City Well Nos. 38, 40, 42, 277, 307, 310, and 312, in the eastern portion of the City.

1,2,3-TCP. 1,2,3-TCP is an emerging contaminant that is of concern due to its extremely low MCL. It has reportedly been detected in water from several wells in the southeastern portion of the City, near the Empire area, and several other isolated wells, at concentrations above the MCL.

Pesticides. Pesticides have only been detected at trace concentrations (well below MCLs) in samples collected from monitoring wells in the shallow aquifer and have never been confirmed to be present in water that was pumped from the City's supply wells (USGS, 2008). While these compounds indicate a low level of shallow groundwater impact, they have not as yet been a significant concern for the City's drinking water supply.

2.5 PRIOR STUDIES AND INVESTIGATIONS

The project will build on an extensive body of hydrostratigraphic, water quality, and groundwater modeling data that has been collected during prior work performed by the City, USGS, and others. The RI will include compilation of data from these existing studies that pertain to investigation areas where project alternatives will be located. Several of the key previous studies and investigations are summarized below. Additional information regarding data sources and studies are included in Section 5.1.

USGS, 2008. *Scientific Investigations Report SIR 2008-5156: Hydrogeology, Water Chemistry, and Factors Affecting the Transport of Contaminants in the Zone of Contribution of a Public-Supply Well in Modesto,*

Eastern San Joaquin Valley, California. The USGS National Water Quality Assessment Program's topical team for Transport of Anthropogenic and Natural Contaminants to supply wells selected a study area in the City to evaluate the occurrence and behavior of nitrate, arsenic, and uranium near a municipal water supply well. City Well No. 25 was vertically profiled to assess flow within the well, and the vertical distribution of contaminants in the aquifer system. In addition, 23 monitoring wells were installed and sampled to record baseline hydraulic information and collect water quality samples. The monitoring wells were completed at four different depth intervals, ranging from the top of the water table to approximately 350 feet in depth, to characterize aquifer conditions and water quality at the depths in which most of the wells in the City have been completed. A wide range of geochemical analyses were performed to characterize contaminant sources and behavior. Analysis of age tracers indicated that groundwater age varied from recent recharge at the water table to more than 1,000 years in the deep part of the aquifer. Groundwater reaching the public supply well was a mixture of older intermediate and deep groundwater, along with young shallow groundwater that has been anthropogenically-influenced to a greater extent by contamination than intermediate groundwater.

Although pesticides and VOCs were detected at trace concentrations in groundwater from the public supply well and monitoring wells, uranium, nitrate, and arsenic were detected at concentrations approaching or exceeding MCLs in samples collected near the water table and in the shallow aquifer. Naturally-occurring uranium, which is commonly adsorbed to aquifer sediments derived from the Sierra Nevada foothills, was believed to have been mobilized by oxygen-rich, high-alkalinity recharge water, causing concentrations in some monitoring wells to be above the MCL. Adsorption experiments, sediment extractions, and uranium isotopes indicated that uranium in water table and shallow groundwater was leached from aquifer sediments by bicarbonate-rich water. As a result, continued downward movement (via pumping for water supply) of high-alkalinity, oxygen-rich groundwater will likely lead to larger portions of the aquifer having elevated uranium concentrations in the future.

Bexfield and Jurgens, 2014. Effects of Seasonal Operation on the Quality of Water Produced by Public-Supply Wells: in Groundwater Vol. 52. USGS scientists performed an investigation of the effects of seasonal variability in groundwater pumping rates on the quality of water produced by public supply wells. Analysis of historical water quality samples from 134 public supply wells indicated that in Modesto, supply wells are more likely to produce younger groundwater with higher nitrate and uranium concentrations during the summer (high) pumping season than during the winter (low) pumping season. However, in some wells, the opposite pattern is observed. Seasonal variability in contaminant concentrations is primarily influenced by the effects of summer pumping on vertical hydraulic gradients that drive the migration of shallow groundwater through the aquifer to the screened intervals of supply wells. In some wells the highest concentrations are observed at this time. In other wells, water quality is primarily influenced by the period of time that a supply well is idle, allowing its wellbore to act as a conduit for vertical groundwater flow and contaminant migration to deeper aquifers. This deeper contamination is recovered when pumping resumes, resulting in higher concentrations during intermittent winter-time pumping. The study concluded that changes to seasonal pumping patterns

and/or to depth of well completion can help reduce the aquifer's vulnerability to selected contaminants of either natural or anthropogenic origin.

Todd and RMC, 2016. Groundwater Characterization and Recharge Study: Study prepared under Local Groundwater Assistance Grant from the California Department of Water Resources. The City is exploring opportunities to improve the conjunctive management of its groundwater and surface water resources in the Modesto Subbasin. To support this initiative and investigate potential locations for Managed Aquifer Recharge, the City performed a study that included further characterization of the local aquifer system. This study was funded by a Local Groundwater Assistance grant that is administered by the DWR. Well log data were evaluated to prepare a series of hydrostratigraphic cross sections throughout the City's service area. Water quality data were compiled from the City's records, prior studies, and SWRCB's Geotracker Groundwater Ambient Monitoring and Assessment Program (GAMA) website, and evaluated. The results were plotted on the cross sections. A numerical model was extracted from the MERSTAN model of the region and refined to better simulate local groundwater flow conditions. This model is being used in the RIFS as a regional model to provide boundary conditions for subregional solute transport models that will be used to evaluate the effectiveness of project alternatives to address arsenic, nitrate, and uranium.

Brown & Caldwell, 2013. City of Modesto Well Field Optimization Study. A wellfield optimization project was conducted to compile groundwater and well data for the cities of Modesto, Riverbank, and Oakdale into a management database with a Web-based interface, to provide access for a database management system (DMS) and decision support system (DSS). Fifteen agencies involved in the project included the Stanislaus County and the Cities of Modesto, Riverbank, and Oakdale. Funding was provided from a Proposition 84 Local Groundwater Assistance Grant that was applied for through the Stanislaus and Tuolumne Rivers Groundwater Basin Association (STRGBA). The main project objective for the City was to set up a system to enable good groundwater basin management through data gathering and filling in data gaps - using field survey data, well condition assessment, and estimated rehabilitation effects, converting spreadsheet-based data to a database, providing easy data access while retaining data security, and providing user-friendly data tools that were integrated with geographic information systems. As a result of the project, an extensive database of current and accurate well- and groundwater-related information has been compiled and is now accessible through a Web-based DMS interface hosted by the City. The DSS uses this information to synthesize parameters for optimizing overall well system operation, and for efficiently allocating capital for well rehabilitation and replacement.

3.0 CONCEPTUAL SITE MODEL

3.1 HYDROGEOLOGY

The conceptual understanding of hydrogeological processes adopted in this RIFS is based on a steady state groundwater flow model and report developed by the USGS in 2007 to characterize groundwater flow in an area of the northeastern San Joaquin Valley roughly bounded by the Stanislaus and Merced Rivers to the north and south, respectively (USGS, 2007). Data regarding aquifer conditions, boundary conditions, water balance, and groundwater flow from this model were reviewed and updated to confirm their applicability to the RIFS project. The USGS steady state model simulates water budget conditions representing the year 2000. That year was chosen because the aquifer water budget was in an average and nearly steady-state condition at the time.

A portion of the USGS steady state model centered on Modesto was extracted and the grid was refined by Todd and RMC (2016). Todd's refined model, known as the Local Refined Grid Steady-State (LRGSS) model, used the USGS model to inform boundary conditions for a more detailed model in the subarea around Modesto. Just as the Todd study used the USGS model as a regional model to support a higher resolution model in a smaller area, the RIFS project will use Todd's LRGSS model as a regional model to inform parameters and boundary conditions for several subregional modeling areas where the performance of the project alternatives identified in the FS will be evaluated (refer to Section 6.4 for further details). In this RIFS, the term "LRGSS model" refers to the original Todd model. The LRGSS model is the template for the regional flow and transport model created for the RIFS project (the "RIFS Regional Model"). Certain updates and minor revisions will be made such that the resulting RIFS Regional Model will be unique. Within the RIFS Regional Model, transient subregional models will be developed to evaluate specific project alternatives to address arsenic, nitrate, and uranium in the City's drinking water aquifers (the "RIFS Subregional Models").

Todd states that the local (LRGSS) model input parameters are essentially identical to those in the regional (USGS) model. Thus, the original source of conceptual model information, including aquifer parameters for the RIFS, is the USGS regional model (USGS, 2007). The only exception to this is Todd's use of actual 2015 pumping rates for City of Modesto wells to simulate baseline conditions, and projected pumping rates for 2020 to 2035 that were derived from the 2010 Urban Water Management Plan (UWMP) (West Yost, 2011). The City wells pump a substantially smaller volume than agricultural wells in the model domain, so this is not a significant departure from 2000 water-budget conditions.

The RIFS hydrogeologic conceptual model was developed using the USGS (2007) report, other available literature, the hydrogeologic cross-sections included in the Todd (2016) report, and evaluation of the City's well database. As the data collection tasks described in Section 5.0 of the Workplan are performed, additional information to refine the conceptual model will be available and used to refine our understanding, especially in areas where subregional models are developed to assess the performance of the project alternatives

evaluated in the FS. These data include results of groundwater monitoring, vertical profiling, and recharge injection testing described in Section 5.0.

Hydrostratigraphic units in the RIFS conceptual model include three primary aquifer zones based on cross-sections in the Todd and RMC report (2016) and the USGS (2008). The Shallow Zone includes the Riverbank and Upper Turlock Lake formations, the Intermediate Aquifer Zone consists of the Lower Turlock Lake Formation, and the Deep Aquifer Zone includes the Laguna Formation. Wells in the RIFS Regional Model area of flow simulation (Figure 3-1) are being classified according to the aquifer zone screened by each well (Figure 2-2). The Corcoran Clay is a prominent marker bed at a depth of approximately 165 to 195 feet in the western model area, generally west of Highway 99. It is a regional aquitard composed of lacustrine sediments, which separates the Shallow and Intermediate Aquifer Zones (Figure 3-1). Above the Corcoran Clay, Pleistocene alluvial fan deposits account for most of the permeable sediments and are composed of silt, silty sand, or sand (USGS, 2007). These sediments are about 50% coarse-grained and become finer below the Corcoran Clay.

The water budget adopted in the RIFS analysis is defined by the USGS regional model and the LRGS. The LRGS model has prescribed head boundaries. Boundary conditions from the USGS regional model will be adapted to the RIFS Regional Model, as described in Section 6.2. For the RIFS Regional Model, projected City water-supply pumping for 2015 to 2035 will be based on the City's projected 2020 pumping rate, contained in their 2015 UWMP; average 2010 UWMP projections were used for the LRGS model. Irrigation well pumping estimated by the USGS (2007) was incorporated into the LRGS model and will be carried forward in the RIFS Regional Model, with seasonal variations defined and simulated in the transient RIFS Subregional Models.

Water table elevation contours in spring 2000 (USGS, 2007; Todd and RMC, 2016) indicate regional horizontal hydraulic gradients ranging from approximately 0.0015 to 0.0022. For perspective, assuming a typical hydraulic conductivity for fine sand of about 10^{-2} centimeters per second and an effective porosity of 0.25, the average velocity of shallow groundwater flow in the study area is estimated to range from about 60 to 90 feet per year.

Water-budget components will reflect the year 2000, matching the Todd and USGS models. Seasonal variations in municipal and agricultural pumping result in the development of significant vertical gradients that are important to understanding contaminant migration within the Study Area (USGS, 2008; Bexfield and Jurgens, 2014). Thus, the transient RIFS Subregional Models will use monthly time steps to incorporate seasonal pumping variations based on actual municipal and estimated agricultural production for the year 2000 or 2015. Variations in agricultural pumping will be simulated to occur only during the irrigation season, which is typically March 1 through October 31 (MID, 2015).

3.2 CONTAMINANT SOURCES AND TRANSPORT

USGS scientists performed an investigation of the effects of seasonal variability in groundwater pumping rates on the quality of water produced by public supply wells (Bexfield and Jurgens, 2014). Their analysis of historical water quality samples from 134 public supply wells indicated that in Modesto, multi-aquifer supply wells tend to produce blended water containing a greater proportion of (shallow) younger groundwater with higher nitrate and uranium concentrations during the summer (high) pumping season than the winter (low) pumping season. Seasonal variability in contaminant concentrations is primarily influenced by summer pumping when vertical hydraulic gradients are steeper and drive the migration of shallow, younger groundwater through the aquifer to the deeper screened intervals of supply wells. In some wells, the highest concentrations are observed at this time. However, in some wells, the opposite pattern is observed. For inactive or intermittent wells, observed water quality is primarily influenced by the period of time that the well is idle; the wellbore can act as a conduit for vertical groundwater flow and contaminant migration to deeper aquifers. This deeper contamination is recovered when pumping resumes, temporarily resulting in higher concentrations. The study concluded that changes to seasonal pumping patterns and/or to depth of well completion can help reduce the aquifer's vulnerability to selected contaminants of either natural or anthropogenic origin. A figure presenting the conceptual relationship between pumping seasonality and contaminant concentrations is presented as Figure 3-2.

A primary objective of the solute transport modeling described in Section 6.2 will be to simulate the hydraulic interaction between public supply wells and concentrations of arsenic, nitrate, and uranium in the aquifer system. Equally important considerations are the distribution, sources, and fate and transport characteristics of these constituents. Figures 2-3 and 2-4 present the locations of wells that have been identified by the City as being impacted by concentrations of these constituents that are either near or above the MCL. Figures 2-5 to 2-12 depict concentrations of these constituents detected in samples collected from wells completed in each aquifer zone between 2015 and 2017. During the RI, these data will be augmented with data from additional wells located outside the Study Area, and samples collected from monitoring or public supply wells during the field data collection phase of the RI in 2019. The combined data set will be contoured and used to develop the initial concentrations used in the solute transport model.

Our conceptual understanding of the geochemical behavior of arsenic, nitrate, and uranium is based on existing studies of site groundwater and aquifer sediments and the factors that control sources and concentrations in groundwater (USGS, 2003; USGS, 2008; USGS, 2010). This conceptual model is summarized in Tables 3-1, 3-2, and 3-3 for arsenic, nitrate, and uranium, respectively, and includes a discussion of surface, vadose zone, and saturated zone sources, transport pathways, chemical transformations, sinks, and modeling implications. This conceptual model will be refined as new groundwater data are collected and the results incorporated into the solute transport models developed for the FS, as appropriate.

Site groundwater has a mixed-cation/bicarbonate composition, with cations mainly dominated by calcium, magnesium, and sodium (USGS, 2008). At some locations in the deeper portions of the aquifer, sodium

chloride water is present and may be a relic of a more dominant geochemistry existing before the aquifer was invaded by recharge water affected by anthropogenic processes. Groundwater affected by agricultural fertilizers and soil amendments has relatively high (>30%) proportions of nitrate and sulfate, as well as elevated bicarbonate resulting from increased soil microbiological activity. Groundwater ages increase with depth, with shallow groundwater (up to 60 meters [m]) ages determined to be young (<50 years old) and deep groundwater (>100 m) determined to be premodern (before 1950). Groundwater in the depth range of 60 to 100 m has a mixture of modern and premodern ages. Study Area groundwater is generally oxic, although some reducing microenvironments may be present within the aquifer sediments, and reducing conditions may predominate in some aquitards. Abundant irrigation recharge in the areas surrounding Modesto and groundwater withdrawals within the City cause agricultural recharge to move downward and laterally through the aquifers toward the City. Consequently, the chemistry of shallow groundwater has affected the intermediate and deeper zone groundwater chemistry in the Study Area. Specific conductance, alkalinity and nitrate concentrations are highest near the water table and decrease with depth (USGS, 2008). Groundwater pH is inversely related to alkalinity, varying from 6.8 at the water table to 8.1 in deep monitoring wells (USGS, 2008).

Nitrate is present in Study Area water-table and shallow groundwater because of the influence of irrigation recharge affected by fertilizers, soil amendments, and confined animal feeding operations (Table 3-2). At some locations, nitrate has migrated deeper into the aquifer system, likely by migration through inactive wells driven by the vertical gradients induced by nearby pumping. Nitrate is negatively correlated with groundwater depth and positively correlated with dissolved oxygen, sulfate, alkalinity, and specific conductance (USGS, 2008; USGS, 2010). Nitrate is expected to persist in the groundwater because generally oxic groundwater conditions will prevent significant denitrification, although small amounts of denitrification may occur in reducing microenvironments within the aquifer. Nitrate is not appreciably retarded by aquifer sediments, so nitrate will be modeled as a conservative constituent.

Uranium is a naturally occurring constituent in the Study Area but is not associated with surface sources (Table 3-3). Uranium in Study Area sediments comes from granitic rocks in the Sierra Nevada. The uranium was weathered from these rocks and oxidized and adsorbed to sediments that were transported to the eastern San Joaquin Valley by glacial and fluvial processes and deposited in the alluvial fans that now comprise the Study Area aquifers (USGS, 2008). This uranium is now being desorbed as geochemical conditions in the aquifer have changed due to the infiltration of recharge water with elevated bicarbonate concentrations. As a result, the aquifers contain mainly bicarbonate-rich oxic groundwater, and uranium in Study Area groundwater is present as the oxidized U(VI) species which is mobilized in the form of the calcium-uranyl-carbonate complex $\text{Ca}_2\text{UO}_2(\text{CO}_3)_3(\text{aq})$ (USGS, 2008).

Uranium concentrations are generally higher near the water table and in shallow groundwater and decrease significantly with depth. Saturation indices calculated for uranium minerals (USGS, 2008) and oxic conditions in the groundwater show that uranium mineral precipitation is unlikely to occur and that sorption processes on iron oxyhydroxides and fine-grained sediments control the mobility of uranium in the aquifer.

Groundwater uranium concentrations are positively correlated with dissolved oxygen, calcium, and bicarbonate alkalinity, reflecting the fact that increased bicarbonate concentrations in irrigation recharge result in desorption of uranium from aquifer sediments.¹ Further support for this interpretation is provided by uranium extraction and adsorption testing results obtained with site aquifer sediments. These results show that uranium has been depleted from sediments in the shallow aquifer, but that sediments in the intermediate to deep aquifer zones can still release considerable uranium to groundwater in response to ongoing changes in groundwater chemistry (USGS, 2008), driven by downward migration of young recharge water. U(IV) minerals may be present in deeper sediments or microenvironments where reducing conditions persist but are not expected to be a significant source of uranium to groundwater in the Study Area.

The geochemical conceptual model for arsenic is summarized in Table 3-1. Arsenic in site groundwater is naturally occurring and is not associated with surface sources (USGS, 2003). The original source of arsenic in groundwater and sediments in the Study Area is weathering of arsenic-bearing minerals in the Sierra Nevada foothills, sorption of arsenic to sediment grains, and transport of these sediments to the eastern San Joaquin Valley by glacial and fluvial processes (USGS, 2008). Groundwater arsenic concentrations are generally higher in older and deeper groundwater samples (USGS, 2010). Speciation of dissolved arsenic in site groundwater samples indicates that it is present as arsenate (As(V)), which forms the oxyanion HAsO_4^{2-} (USGS, 2008). Concentrations of arsenic and iron extracted from site sediments are weakly correlated, indicating that arsenic is attenuated by adsorption on iron oxyhydroxides (USGS, 2008). Both arsenate and the more reduced arsenite [As(III)] oxyanions are less strongly adsorbed under conditions with pH greater than 7.5 or in the presence of the competing orthophosphate anion (H_2PO_4^- or HPO_4^{2-}). In Study Area groundwater samples, arsenic was positively correlated with pH (USGS, 2003) and orthophosphate concentrations (USGS, 2008). Because of the oxic nature of the groundwater in the Study Area, sorption and desorption on iron oxyhydroxides is expected to be the most significant control on arsenic groundwater mobility, although reductive dissolution of iron oxyhydroxides with associated release of arsenic and oxidation of minerals in reducing microenvironments with release of arsenic may also occur.

¹ As presented in Table 3-3, the infiltration of urban runoff through rock wells, which are in widespread use in the City, may also be a source of significant bicarbonate-rich recharge.

4.0 APPROACH

4.1 DATA OBJECTIVES

The overall objective of the RIFS is to identify and prioritize project alternatives that will prevent or cleanup impacts to the drinking water aquifers underlying the City of Modesto by arsenic, nitrate, and uranium. A key component of this evaluation is the development of a solute transport model. The required features and capabilities of this model, the data needs and objectives for its development, and the rationale and approach for compiling or collecting the necessary data are summarized in Table 4-1. A description of the modeling objectives is provided in Section 6.0. Ultimately, the RIFS is intended to answer the question of what types of projects from the list presented in Table 4-2 are likely to be the most effective, and to prioritize one or two specific projects for potential implementation.

4.2 DATA NEEDS, CONSTRAINTS, AND OPPORTUNITIES

The modeling evaluation in the FS will build on previous modeling conducted by the USGS and Todd, as discussed in Section 3.0. An extensive existing dataset available from prior investigations by the USGS, the City of Modesto, and others, as well as available water quality and level data for City wells or available from public databases maintained by the DWR and the SWRCB will be compiled and analyzed. These data sources combined with the RI investigation data will be used to construct a regional solute transport model and subregional models where project alternatives will be evaluated. Additional data are needed to characterize aquifer properties and hydraulic conditions near the public supply wells that will be the focus of the study (i.e., where project alternatives involving these wells will be evaluated using subregional models), the vertical distribution of contaminants in the capture zones of these wells, and their interaction with the aquifer system. Data are also needed to supplement our understanding of arsenic, nitrate, and uranium sources and behavior in the aquifer system, and the potential geochemical changes that could occur in the aquifer system as recharge water is introduced into the aquifer.

The RI will use existing data supplemented with newly collected data to improve the conceptual understanding of contaminant distribution and transport. Specifically, data collection efforts will focus on developing a deeper understanding of the vertical distribution, behavior and migration of arsenic, nitrate, and uranium, and on the hydrologic interaction of supply wells with the aquifer, so that solute transport models can be developed as part of the FS that are adequate to evaluate the effectiveness of project alternatives. Efforts will focus on areas known to be impacted, locations where existing data can be leveraged and built upon to construct refined solute transport models, and locations where projects are likely to be implemented from a perspective of need and logistical constraints.

A central component of the RI is the vertical profiling of public supply wells to collect data regarding their interaction with the aquifer system and the vertical distribution contaminants in their vicinity. There are six wells for which profiling data have been collected in the Study Area. Additional wells will be profiled during

the RI, and one well will be reprofiled, in order to further characterize the wellfield aquifer and extend the data record to the present. Only a subset of wells is suitable for profiling from a data needs and logistics viewpoint. Considerations include the following:

- wells must be impacted by one or more of the contaminants being studied by the RIFS;
- wells must have relatively long screen intervals that penetrate aquifer zones of interest;
- access must be available for lowering tooling into the wells;
- for dynamic profiling, wells must have a flush line for disposal of purged groundwater (preferable) or be connected to the City supply system; and,
- for dynamic profiling, interruptions in supply pumping must be tolerable from a water distribution system operations viewpoint.

An additional data need is current water quality and water level data. The area around City Well 25 was extensively studied by the USGS during the early 2000's, but data have not been collected during the last approximately 15 years. Because this location would be ideal for the siting and evaluation of potential implementation projects during the FS, the collection of current water level and quality data is recommended. Additional opportunities for enhancing the existing water quality data set are afforded by the sampling of wells that were taken off-line as a result of contamination by arsenic, nitrate, or uranium, but for which recent data are not available. The sampling of these wells would provide a current snapshot of water quality and help to facilitate evaluation of their potential as a conduit for vertical contaminant migration.

To assess the potential physico-chemical interactions between recharge water and groundwater within the aquifers, pilot recharge testing is proposed to be conducted in two existing monitoring wells. Data needs and constraints for this task include the following:

- a shallow monitoring well completed near the water table is needed to evaluate effects associated with Managed Aquifer Recharge (MAR) by percolation through recharge basins or agricultural fields, and an intermediate or deep monitoring well is needed to assess effects associated with Aquifer Storage and Recovery (ASR) using injection and recovery wells;
- the test locations should be located in an impacted area in the central or eastern portions of the City, where groundwater levels are deeper; and,
- logistical and access challenges associated with injection water tankage, truck traffic, and security must be addressed.

The RI investigation tasks and sampling locations discussed in Section 5.0 and shown on Figure 4-1 have been selected to address the FS data needs by supplementing existing data at locations that are opportune for developing a refined understanding of aquifer conditions that supports development of RIFS Subregional Models, and that are suitable for siting potential implementation projects. The identified RI tasks include compilation of existing data, supplemental groundwater level and quality monitoring, ambient and dynamic supply well profiling, and recharge water injection pilot testing.

4.3 DATA EVALUATION

The FS purpose is to identify one or two recommended projects through a comparative evaluation of project alternatives and present a conceptual design for the recommended project(s). To do this, the FS will first screen a range of potential technologies that can prevent the spread or release of contamination or clean up groundwater over time. Technologies that pass this initial threshold screening will be considered for assembly into project concepts for evaluation (the project alternatives). We will develop up to six project alternatives that combine various technologies related to wellfield operation or modification approaches that help protect water quality in uncontaminated areas or prevent the release of additional contamination, and aquifer recharge that, in combination with groundwater extraction, could improve groundwater quality by flushing the aquifer, while at the same time improving the quantity of groundwater available for extraction. A list of conceptual approaches is included in Table 4-2.

The project alternatives will deploy these technologies to specific locations where they are most likely to be successful, and where the combination of existing data and data gathered during the RI facilitates their evaluation. The FS will include refinement of an existing regional model and development of subregional groundwater solute transport models to evaluate the performance of the project alternatives. The subregional model areas will be defined to facilitate evaluation of the identified project alternatives. These solute transport models must be of adequate capability to evaluate and compare the project concepts in terms of their relative effectiveness using a superposition approach. The comparative modeling results of project effectiveness will be used in the FS along with consideration of other criteria to compare, rank, and identify the one or two recommended projects for potential implementation. A conceptual design will be provided for the recommended project(s).

4.4 LIMITATIONS AND REMAINING DATA GAPS

While a solute transport model that supports evaluation and ranking of potential implementation project must be based on a sound conceptual understanding and adequate input data, it is not realistic or necessary, at the conceptual design stage, to construct a model that will include all aspects of contaminant fate and transport. Significant unresolved data gaps may remain, and some of these may need to be addressed to support detail design of the recommended project(s). These data gaps would be identified so they can be addressed, to the extent necessary, as part of future implementation projects. To summarize, the RIFS is focused on the initial step of identifying and prioritizing implementation projects and some data needs for detailed design will likely remain at the conclusion of this study.

5.0 REMEDIAL INVESTIGATION

A MRP describing the specific tasks and procedures to implement the RI is included as Appendix A. A QAPP is included as Appendix B. The primary RI tasks consist of the following:

- compilation and evaluation of existing data to develop an adequate conceptual model for the evaluation of project alternatives and to inform development of a groundwater flow and solute transport model;
- collection of supplemental groundwater level and quality data;
- flow and concentration profiling of selected public supply wells; and,
- conducting recharge water pilot testing at two monitoring wells.

The sections below summarize these tasks.

5.1 DATA COMPILATION

The first step in the RI process is to complete the compilation of data to inform the conceptual model of Study Area hydrogeology and arsenic, nitrate, and uranium sources and behavior. In addition, available well, groundwater level, and analytical data will be compiled into a database for use in selecting and characterizing the areas where project alternatives will be evaluated. Review and compilation of existing data includes, but will not be limited to, the references, prior studies, and data sources listed in Table 5-1.

Information entered into the project database includes well data (location, completion, operation, and status), analytical data, and water level data. Data sources include the City's well database and operational information, studies performed by USGS, Todd and RMC, and others, monitoring data from remediation sites in the Study Area, and the SWRCB's GeoTracker GAMA database. The initial development of the database is complete, and it will be updated as analytical and water level data from the RI field investigation and monitoring tasks becomes available. The database will be used to:

- assign wells to the correct aquifer zones and model layers based on their completion depths;
- develop concentration contour maps for arsenic, bicarbonate, nitrate, and uranium from which the model's initial solute concentrations will be determined;
- assess groundwater levels, lateral and vertical groundwater gradients, and seasonal variability in RIFS subregional model areas;
- assess contaminant concentrations and trends for more detailed characterization of RIFS subregional model areas; and,
- produce tables, figures and graphs to support data analysis, and reporting.

5.2 GROUNDWATER LEVEL AND QUALITY MONITORING

Collection of supplemental groundwater level and quality monitoring data will focus on monitoring wells installed by the USGS during studies in the vicinity of Well 25 and inactive supply wells for which recent water quality data are not available. Up to 23 monitoring wells and seven inactive supply wells will be gaged and sampled. The procedures for gaging and sampling of the wells are discussed in Appendix A. For inactive supply wells, priority is given to wells known to be impacted by arsenic, uranium, or nitrate, locations where additional sampling is judged to augment the existing data set, and wells with active supply pumps. The selected wells are shown on Figure 4-1 and listed in Table 5-2, along with an explanation of the rationale for their selection. An initial access and condition reconnaissance of the wells will be performed prior to sampling and, if necessary, alternate wells may be proposed. Groundwater level and analytical data from these wells will be added to the Project database.

5.3 SUPPLY WELL PROFILING

Hydraulic and water quality profiling of selected City supply wells is a central component of the RI and will inform development of the solute transport models to be used for evaluation of project alternative effectiveness in the FS. Detailed well profiling procedures are presented in Appendix A. Hydraulic profiling is conducted by lowering a miniaturized dye-tracer injection and detection apparatus into the wells to assess flow in the well bore and calculate the flow contribution of each well screen or perforated interval during dynamic (pumping) and/or ambient (non-pumping) conditions. Concentration profiling is performed using miniaturized sampling pumps to collect samples from various depths and assess analyte concentrations at the contributing depth intervals.

As shown on Figure 4-1, six public supply wells have already been profiled in the Study Area, and the additional profiling for the RI will add to this data set. Seven additional wells were selected for profiling during the RI, as shown on Figure 4-1. The designated wells were selected based on their location in areas known to be impacted by arsenic, nitrate, and/or uranium, the length of their screen intervals, the ability to dispose of purged groundwater during dynamic testing, and the ability to take active wells off-line prior to ambient testing. Table 5-2 lists the wells and presents the rationale for their selection. In several cases, wells were determined to be good candidates for profiling, but flush lines for disposal of purged water were not available, so these wells were designated for collection of ambient profiles only. Note that a potential list of candidate supply wells was vetted with the City and some locations were eliminated for study based on the status of the well and operational/logistical concerns. Additional consultation with the City and a reconnaissance of the wells (surface observation, lowering of a dummy tool, and conducting a video survey) is required to fully confirm well access and viability for study; substitute wells may be recommended if significant access concerns are encountered.

Analytical data from these wells will be added to the Project database. Dynamic and ambient flow data will be used to assess well interactions with the aquifer system and the vertical distribution of contaminants in

the vicinity of the study wells and will inform development and calibration of the RIFS Subregional Models, as discussed in Section 6.4.4.3 and 6.4.4.4.

5.4 RECHARGE WATER PILOT TESTS

To help support construction of the solute transport model described in Section 6.4, the potential chemical interaction of recharge water with aquifer water will be investigated by conducting Recharge Water Pilot Tests, which document chemical changes that occur when recharge water is introduced into the aquifer. The Recharge Water Pilot Tests will evaluate the geochemical interaction of recharge water with the aquifer, but does not aim to evaluate recharge project feasibility or investigate recharge project design parameters. Detailed procedures are presented in Appendix A. Pilot testing will be performed using two selected USGS-installed monitoring wells to evaluate the potential for recharge water to change the mobility or concentration of arsenic, nitrate, and uranium in the aquifer system by processes other than dilution, to otherwise affect water quality, or to cause precipitation or scaling that could affect well function or aquifer porosity. The results of these tests will be evaluated using a geochemical model that simulates the chemical behavior of solutes in the aquifer system when water mixing occurs and will aid in the simulation of water mixing and development of transport terms to be applied to the solute transport model.

Two monitoring wells located near Well 25 will be selected to infiltrate recharge water containing a low concentration of bromide tracer into the aquifer. Water from the test wells will be recovered after one week, one month, two months, and three months and analyzed for the tracer and a list of target analytes to assess any chemical changes resulting from water mixing, other than dilution. The first test will be performed using a shallow or water table monitoring well to simulate MAR using percolation basins or agricultural land. The water infiltrated into the aquifer during this test will be augmented with food-grade bicarbonate of soda to simulate the geochemical changes that occur in recharge water as it passes through the root zone. The second test will be performed using an intermediate depth or deep monitoring well to simulate recharge by ASR directly through an injection well. For this test, treated surface water from the City's surface water treatment plant will be utilized.

The candidate test wells for Recharge Water Pilot Test include the following, generally listed in order of increasing distance from Modesto Well No. 25:

- FPA (Well 1);
- PB (Wells 1, 2, 3);
- FPC (Wells 1, 2, 3);
- OFPA (Wells 1, 2, 3); or,
- FPD (Wells 1, 2, 3).

At this time, the preferred wells for these pilot tests are Well FPC-1 for the water table test and Well FPC-2 for the intermediate aquifer test. Consultation with the City and a reconnaissance of the well locations will be needed prior to finalizing this selection. If the location is not suitable, alternate locations may be recommended.

6.0 FEASIBILITY STUDY

6.1 OVERVIEW

The objective of the FS is to identify, evaluate, compare, and rank project alternatives, and identify one or two preferred alternatives for which conceptual designs will be developed. The FS consists of the following sequential components:

- technology screening to determine the types of technical approaches to be further evaluated;
- identification of project alternatives based on technologies that pass the threshold screening criteria of the first step;
- definition of subregional model area boundaries (project study areas) based on nature and location of the identified project alternatives;
- groundwater flow and solute transport model development based on data gathered during the RI and the established subregional model areas;
- evaluation, using the groundwater flow and solute transport model, of the effectiveness of the project alternatives to prevent or clean up contamination;
- feasibility evaluation, comparison, and ranking of the identified project alternatives; and,
- recommendation and preliminary design of one or two preferred alternatives.

6.2 TECHNOLOGY SCREENING

The FS will begin with identification and screening of technical approaches that may be useful to prevent the spread of contaminants in the aquifer system, prevent the release of additional contamination, or clean up the aquifer (i.e., improve water quality) over time. Technical approaches identified as being potentially applicable to date include the following:

- changes to the spatial and temporal distribution of pumping in the wellfield (e.g., using variable frequency drive pumps to keep wells pumping continually at a low rate, or changing the distribution pattern of pumping to avoid undesirable combinations or times);
- well modification (e.g., swaging to block off certain screen intervals and focus extraction on remaining uncontaminated or contaminated zones, well deepening, or other modification);
- construction of new wells (e.g., to target clean zones or to target and contain contaminated zones);
- well destruction (e.g., to seal potential conduits for contaminant migration);
- managed aquifer recharge (e.g., through percolation basins or on agricultural lands and using diverted flood flows or raw supply water);
- aquifer storage and recovery (e.g., injection of recharge water using wells);
- in situ chemical treatments (e.g., injection of reactants to destroy or immobilize contaminants); and,
- in situ physical treatments (e.g., construction of subsurface barriers through injection).

At this initial stage, the potential applications of these technical approaches will be described at a conceptual level, and evaluated using threshold acceptance screening criteria that include:

- regulatory compliance/acceptance;
- community acceptance;
- implementability; and,
- risk or uncertainty.

Technical approaches that are considered acceptable will be described and carried forward to the next phase of the FS.

6.3 IDENTIFICATION OF PROJECT ALTERNATIVES

Using the technical approaches that are considered acceptable based on comparison to the threshold screening criteria, up to six project alternatives will be developed for evaluation in the FS. Project alternatives will be assembled by considering the existing hydrogeologic and water quality dataset and previous characterization/studies, combined with the results of the RI, as well as City needs and the opportunities and limitations afforded by local site conditions and available infrastructure. A consultative workshop will be convened to make this selection based on the available information and will be attended by appropriate subject-matter experts and City engineering staff. The workshop will be conducted after the existing background data have been compiled and results are available from the monitoring and supply well sampling and profiling tasks. It is anticipated that these project Alternatives will include the following:

- Two alternatives would focus on wellfield spatial and temporal pumping strategies. It is anticipated that these alternatives would be located in the western portion of the City, where groundwater is relatively shallower.
- Two alternatives would focus on physical wellfield modification, including well modification, construction of new wells, and/or well destruction. Similar to the above alternatives, these projects would be located in the western portion of the City, where groundwater levels are shallower and much of the existing well infrastructure is aging.
- One alternative would be based on MAR. This alternative may be combined with spatial or temporal well operational modifications and/or physical wellfield modifications (including new wells) in order to capture recharged surface water and flush the aquifer.²
- One alternative would be based on ASR. Similar to the MAR alternative, this alternative would be combined with temporal, spatial, and/or physical wellfield modifications to flush the aquifer.

² The City has been actively pursuing identification of recharge projects with the STRGBA ([Water Resources & Information Management, Engineering, Inc.](#), 2007), through a Local Groundwater Assistance Grant (Todd and RMC, 2016), and most recently during preparation of a regional Stormwater Resources Management Plan in cooperation with Stanislaus County. These efforts will be considered when selecting recharge projects for evaluation.

The identified project alternatives will be evaluated using the solute transport modeling approach described below.

6.4 GROUNDWATER MODELING

This section presents an overview of the approach to the evaluation of the effectiveness of the identified project alternatives using a solute transport model. It is anticipated that model development will commence after the analytical results for the first round of recharge pilot test sampling are available. The approach consists of two principal components: geochemical modeling and groundwater flow and solute transport modeling. Geochemical modeling will be performed using the USGS PHREEQC modeling code (Parkhurst and Appelo, 2013). Groundwater flow and solute transport modeling will be performed using MODFLOW 2000 (Harbaugh, et al., 2000) to simulate groundwater flow, and MT3DMS v5.3+ (Zheng and Wang, 1999; Zheng, 2010) within the Groundwater Vistas v6® modeling environment.

Groundwater flow and solute transport modeling will begin with development of a steady state “RIFS Regional Model” based on the existing LGRSS model. The RIFS Regional Model will be used to provide boundary conditions to transient “RIFS Subregional Models” that will be developed around the areas where project alternatives are proposed. Both the regional model and the subregional models will initially be developed as groundwater flow models before a solute transport component is added. Subregional model boundaries will be established to best evaluate the identified project alternatives. At this time, it is anticipated that modeling subregions will be established to evaluate two wellfield modification operational/modification alternatives in the arsenic- and nitrate-impacted area in Salida, two wellfield operational/modification alternatives in the uranium- and nitrate-impacted area of western Modesto, and an MAR and an ASR project in eastern Modesto, in the area impacted by arsenic, nitrate, and uranium.

6.4.1 MODELING OBJECTIVES

The project modeling objectives are to perform quantitative simulations and relative comparisons of the identified project alternatives. Project alternatives will be evaluated using a superposition modeling approach; that is, changes in the predicted heads and concentrations for the project alternatives will be compared to a no-project baseline condition. Superposition or impact modeling focuses on evaluation of hydrologic or solute concentration changes, as opposed to absolute hydraulic heads or concentrations, and allows the modeler to focus more on the evaluation of the changes introduced by a project (Reilly, Franke, and Bennett, 1987). Using this approach, it is less important for model starting conditions to be precisely reflective of historical conditions, since it is the change relatively to the starting condition that is being mathematically isolated. The use of superposition modeling in hydrogeologic literature is well established, and this approach has been widely used to evaluate groundwater resources impacts. A sensitivity analysis will be performed, as described below, to assess the effects of uncertainties in model data on the predictive results obtained through superposition.

The modeling approach used in this RIFS will be to develop a steady state regional model (the RIFS Regional Model) that is refined from its USGS predecessor (USGS, 2007) to provide boundary conditions to several more refined, transient subregional models that will be used to evaluate the effectiveness of the identified project alternatives (the RIFS Subregional Models). The RIFS Regional Model will build upon and leverage an existing model (Todd and RMC, 2016), and refinements to the RIFS Regional Model will be implemented only to the extent needed to provide adequate boundary conditions to the RIFS Subregional Models. The RIFS Subregional Model boundaries will be selected to evaluate areas where vertical profiling data are adequate to build a refined understanding of vertical contaminant distribution, pumping influence, and intra-borehole flow.

6.4.2 MODEL SELECTION

The LRGSS model (Todd and RMC, 2016) is being adopted as the regional model for this study because it is based on the USGS regional model layering, orientation, and original texture data (USGS, 2007), but has a smaller footprint with higher resolution (finer grid mesh), and thus is better suited to supporting the three RIFS Subregional Models that will be used to evaluate the effectiveness of the project alternatives. Also, the model reflects the water budget for the year 2000, with the exception of pumping rates for City wells. The year 2000 was an average year for the water budget in the study area, with small changes in aquifer storage indicating near-steady-state conditions. The model does not include the latest textural or water budget updates to the MERSTAN model (USGS, 2015); however, the MERSTAN model was developed in MODFLOW-OWHM, for which a graphical user interface (GUI) is not commercially available. For the purpose of developing the RIFS Regional Model to evaluate the relative effectiveness of project alternatives using a superposition approach, the LRGSS is considered to be an adequate foundation.

The USGS regional and LRGSS models were constructed using the MODFLOW-2000 code and will operate in commercially-available GUIs. The RIFS model will continue the use of MODFLOW-2000 and will use MT3DMS for simulation of solute transport.

6.4.3 GEOCHEMICAL EVALUATION

The geochemical evaluation will quantitatively assess groundwater parameters (e.g., pH, alkalinity, orthophosphate concentrations, and redox conditions), sorption/desorption processes, and mineral-groundwater interactions that control groundwater concentrations of nitrate, uranium, and arsenic in the Study Area. The results of this assessment will be used to evaluate the effects of the proposed recharge of clean water to the aquifer by either ASR (using aquifer injection and downgradient recovery wells) or MAR (via percolation basins) on groundwater nitrate, uranium and arsenic transport and concentrations. The geochemical evaluation will also support MT3DMS transport modeling for uranium and arsenic in site groundwater by developing uranium and arsenic distribution coefficients based on the geochemical processes that control constituent concentrations in site groundwater. Finally, source terms for uranium and

arsenic will be developed based on the refined geochemical site conceptual model, which will be updated based on the data gathered in the RI and the geochemical equilibrium speciation modeling.

6.4.3.1 GEOCHEMICAL MODELING OF PUBLIC SUPPLY WELLS AND USGS MONITORING WELLS

Groundwater parameter correlations will be evaluated to assess likely controls on nitrate, uranium and arsenic concentrations and determine whether identified correlations are consistent with those previously observed by USGS (2008). Correlations that will be examined include:

- Fe/As, Mn/As, pH/As, PO43-/As, DO/As
- Alkalinity/U, PO43-/U, Ca/U, pH/U, DO/U, NO3-/U
- NO3-/specific conductance, NO3-/SO42-, NO3-/Alkalinity

Equilibrium geochemical modeling calculations will be performed using the PHREEQC geochemical modeling code (Parkhurst and Appelo, 2013) for all groundwater samples collected during flow and concentration profiling of the public supply wells, as described by the MRP in Appendix A (MRP Section 5.0), and for recent groundwater monitoring samples. Geochemical modeling will also be performed for samples from two public supply wells that have previously undergone depth profiling. The modeling results will be used to assess redox conditions, aqueous speciation, and mineral saturation indices in the groundwater and the effects of depth on these parameters for all samples collected, as specified by the MRP.

6.4.3.2 GEOCHEMICAL MODELING OF RECHARGE WATER PILOT TEST

To support development of a solute transport model for nitrate, uranium, and arsenic, the chemical interactions of clean recharge water with aquifer water will be investigated by conducting recharge water pilot tests (Section 5.4). These tests are designed to evaluate the groundwater chemistry changes that occur when clean recharge water is introduced into the aquifer by percolation to the water table or is injected into zones with groundwater that is only partially mixed with modern recharge water. Two tests will be conducted to investigate: (1) infiltration of surface water through percolation ponds or rock wells; and (2) direct injection of surface water through aquifer storage and recovery wells.

The test simulating surface infiltration via percolation basins or rock wells will use untreated Tuolumne River water obtained from the City's Regional Water Treatment Plant. To simulate the effects of near surface and root zone processes on the infiltrating water composition, the river water will be amended using food-grade bicarbonate. Before testing commences, the effects of adding bicarbonate to the recharge water will be calculated as a function of bicarbonate addition, including pH, mineral saturation indices, and carbon dioxide partial pressure (PCO2). The results of these calculations will be used to determine the optimum bicarbonate concentration for the test to simulate likely near-surface processes, and prevent any deleterious reactions, such as scale formation through calcium carbonate precipitation during the test. For both pilot tests, preliminary PHREEQC calculations will be carried out to identify and quantify geochemical reactions likely during tests, including:

- equilibrium geochemical modeling calculations to assess redox conditions, aqueous speciation, and mineral saturation indices of pre-test groundwater and recharge water;
- calculation of expected concentrations of iron oxyhydroxides in the aquifer sediments and initial concentrations of adsorbed uranium and arsenic for modeling groundwater uranium and arsenic interactions with aquifer sediments (these calculations will be performed using the available sediment extractions data [USGS, 2008] and groundwater quality data collected during the RI); and,
- preliminary groundwater/recharge water mixing and reaction modeling calculations to assess possible effects on permeability (such as calcite precipitation) during the pilot tests.

After the recharge water pilot tests have been performed, the actual water quality sampling results will be used to perform geochemical modeling calculations. These calculations will include an evaluation of the redox conditions, aqueous speciation and mineral saturation indices for all samples. In addition, the pre- and post-test sample analysis results will be used to perform recharge water/groundwater mixing and reaction path calculations to quantify the mineral dissolution, mineral precipitation, and sorption/desorption processes that controlled groundwater compositions before, during, and after the tests.

6.4.3.3 DEVELOPMENT OF SOLUTE TRANSPORT MODELING SOURCE TERMS AND DISTRIBUTION/ RETARDATION COEFFICIENTS

The results of the geochemical modeling calculations will be used to refine the existing geochemistry conceptual models for nitrate, uranium, and arsenic. The conceptual models will include descriptions of the sources of uranium and arsenic in the aquifer system and will identify the processes that contribute to mobilization of these constituents. This information will be used in collaboration with the transport modeling staff to develop source terms for uranium and arsenic within the saturated zone for use in the MT3DMS solute transport model. For example, the uranium source term concentrations within the saturated zone may be predicted based on the strong correlations previously identified with alkalinity and calcium concentrations (USGS, 2008). Similarly, arsenic source term concentrations may be predicted based on the identified relationships with depth, pH (USGS, 2003) and orthophosphate concentrations (USGS, 2008), and possible correlations with aquitards.

Site-specific uranium distribution coefficients will be evaluated using available uranium adsorption data and bicarbonate extraction data for aquifer solids (USGS, 2008). Site-specific arsenic distribution coefficients will be calculated using available nitric acid extraction data for aquifer solids (USGS, 2008). The calculated uranium and arsenic distribution coefficients will be supported by an evaluation of the ranges of values available in the scientific literature for similar aquifer conditions.

6.4.4 GROUNDWATER FLOW AND SOLUTE TRANSPORT MODELING

6.4.4.1 REGIONAL GROUNDWATER FLOW MODEL DEVELOPMENT

The domain for the RIFS Regional Model is shown on Figure 6-1. Consistent with the LRGSS model domain, the RIFS Regional Model is centered on the Modesto contiguous water service area (the Study Area) and extends approximately to natural hydrogeologic boundaries to the northeast (Sierra Nevada foothills), northwest (Stanislaus River), and southwest (San Joaquin River). The southeastern boundary is sub-parallel to the dominant natural groundwater flow direction (west-southwest), thus flow crossing this boundary is likely to be relatively small. As with the precursor models, the RIFS Regional Model grid is rotated 37 degrees counterclockwise from true north to better align with regional flow and boundary conditions.

The RIFS Regional Model boundary conditions are shown on Figure 6-2. The northeastern boundary is defined as no-flow, consistent with the USGS model (USGS, 2007). The northwest and southeast boundaries are closest to the Study Area, and are defined as general-head, based on adaption from the USGS model. In these aspects, the RIFS Regional Model differs from the LRGSS model. The southeastern boundary, representing the San Joaquin River and axis of the valley, is defined as prescribed-head, based on the LRGSS model. The three prescribed boundaries incorporate a vertical gradient consistent with the USGS and LRGSS models.

The RIFS Regional Model will be designed to simulate confined flow conditions, using 2,000 steady-state heads as an upper boundary surface in areas where the water table lies within a model layer. This affects Layers 1 through 7, as shown on Figure 6-2. The use of confined flow conditions will have a minimal impact on solute transport simulations for the project alternatives but will improve accuracy by eliminating potential issues with dry cells in MODFLOW-2000 (i.e., in areas where a layer's saturated thickness is small).

Figure 3-1 presents a cross-sectional view of the model layering in LRGSS row 154, which passes through the center of the study area, trending from southwest to northeast. Figure 3-1 also includes the hydro-stratigraphic boundaries for the tops of the Intermediate and Deep Aquifer Zones (discussed in Section 3.0). Dashed lines indicate areas where the zone boundary is currently uncertain and will be finalized before concentration contouring for the development of initial concentration inputs for the solute transport model (Section 6.4.5.1). Thus, Figure 3-1 illustrates the relationship between the aquifer zones defined by the conceptual model (i.e., hydrostratigraphic units where contaminant concentrations were sampled), and the RIFS Regional Model layers (i.e., numerical layers where groundwater flow is simulated). The table below illustrates this relationship.

TABLE 6-1 MODEL LAYERING

Aquifer Zone	Model Layers
Shallow (S)	1 - 8
Intermediate (I)	9
Deep (D)	10 - 16

6.4.4.2 REGIONAL SOLUTE TRANSPORT MODEL DEVELOPMENT AND VALIDATION

The steady-state RIFS Regional Model will be used to simulate transient nitrate transport using MT3DMS for parameter testing and model validation (i.e., verification that the regional model can simulate stable and realistic nitrate migration using the specified initial and boundary conditions, transport parameters, and source terms). Nitrate is selected for this validation because it is widely distributed spatially and temporally in the model area and is not expected to significantly sorb to aquifer materials or degrade, and because nitrate sources are better defined throughout the RIFS Regional Model domain than the other contaminants of interest. These regional model test runs will represent the period of 2015 to 2035. To facilitate these runs, initial nitrate concentrations must be established in the model domain, nitrate sources must be simulated, and transport parameters (i.e., dispersion, retardation) must be established.

Regional 2015 initial nitrate concentrations will be assigned to the model layers representing the three aquifer zones. Nitrate concentration contours will be developed for each of the three aquifer zones using data for 2015 to 2017, as shown in Figures 2-5 through 2-13, and augmented with data collected in 2019, as shown on Figure 4-1. Data from previously-profiled wells (Figure 4-1) will also be considered as appropriate (e.g., to fill gaps). The goal is to characterize the distribution of average concentrations in the RIFS Regional Model domain (Figures 6-1 and 6-2). Zone-specific concentrations will be used to compute average values for contouring. Multi-aquifer zone wells will not be used, except when depth-dependent vertical profiling analyses are available. In these cases, a wider range of dates would be considered (e.g., pre-2015 profiling data and 2019 vertical profiling samples would be included).

The MT3DMS Regional Model will simulate nitrate sources that support observed nitrate concentrations in the shallow zone. Transient nitrate loading sources will be simulated using a transport stress period of one month to facilitate seasonal variations in nitrate loading and pumping stresses. An existing Soil and Water Assessment Tool (SWAT) model (Neitsch, et al., 2011; Winchell, et al., 2013) will be used to provide monthly nitrate fluxes past the root zone for the period from 2015 to 2035 based on a repeated historical dataset, and assuming no changes in nitrate management or irrigation practices. Nitrate fluxes will be added directly at the water table in MT3DMS.

The SWAT model is currently under development by Formation Environmental for the entire Central Valley for the Management Practices Evaluation Program under the Irrigated Lands Regulatory Program overseen by the CVRWQCB, under a grant from the Natural Resources Conservation Service. SWAT allows a detailed field-scale analysis of root zone hydrologic and nitrate loading, based on watershed processes, climate, soil properties, land use, and agricultural practices. It considers comprehensive crop management information fed to the model for each crop, including calibration for yield and evapotranspiration.

The resulting simulated nitrate concentrations in 2035 for each aquifer zone will be evaluated for stability and trends by comparing them to the contoured initial concentrations. Predicted versus actual nitrate concentrations at supply wells will be compared for the period of 2015 through 2018. Under existing conditions (i.e., with no changes in nitrate management or loading at the source areas), nitrate concentrations

in the model domain are expected to change slowly during 2015 to 2035. Previous investigations have demonstrated that nitrate concentrations are generally highest in the shallow aquifer. Consistent with the prevailing downward vertical gradient, concentrations in the intermediate aquifer zone should increase slightly over time, while concentrations in the shallow zone may decrease slightly. The simulated rate of vertical migration will be compared to expectations inferred from previous evaluations of groundwater age stratification (e.g., USGS, 2008). The model's initial concentrations, sources, transport parameters, and boundary conditions will be adjusted if/as appropriate to improve stability and confirm trends for the simulated concentrations. Once this testing is complete, development of the RIFS Subregional Models will be undertaken.

6.4.4.3 SUBREGIONAL GROUNDWATER FLOW MODEL DEVELOPMENT

Transient RIFS Subregional Models will be developed in the areas around the identified project alternatives. The conceptual study area boundaries identified in the Grant Application are shown as examples of possible subregional model areas on Figures 6-1 and 6-2, relative to the RIFS Regional Model grid boundary. The final locations of the RIFS Subregional Model areas will be determined after the project alternatives are identified, as discussed in Section 6.3. The spatial and temporal discretization of these “daughter models” will be established based on the following:

- general head boundary conditions to allow the boundaries to respond to changes in pumping or other stresses with the model domains;
- a horizontal grid spacing of approximately 100 feet (versus 100 m for the RIFS Regional Model and 400 m for the USGS model) to provide greater resolution for simulating aquifer/well interaction and contaminant migration effects (e.g., a smaller grid cell volume is conducive to simulating the transport effects of intra-well vertical flux through inactive public supply wells);
- rows and columns aligned with the regional model grid rotation;
- identical layering to the regional model grid; and,
- a flow model stress period of one month to facilitate modeling seasonal variations in pumping, recharge, and contaminant loading.

Boundary initial heads, gradients, and resulting flows will be assigned using steady-state conditions extracted from the RIFS Regional Model. All physical parameters and internal stresses (except seasonal variations) will be interpolated from the RIFS Regional Model to the RIFS Subregional Models. Seasonal variations from the SWAT model for 2000, proportioned for monthly time steps, will be applied to steady-state areal recharge. Steady-state pumping rates from the RIFS Regional Model will also be proportioned for monthly time steps, with City well pumping rates proportioned based on actual 2000 or 2017 pumping, and agricultural well pumping set to take place with monthly variations during the irrigation season (March 1 through October 31). City well pumping will be distributed among model layers as determined by the well hydraulic profiling data. Where necessary and appropriate, pumping and flow data will be extrapolated from profiled wells to other nearby wells with similar completions.

6.4.4.4 SUBREGIONAL SOLUTE TRANSPORT MODEL DEVELOPMENT

To develop the subregional solute transport models, initial concentrations, source terms, transport parameters, and boundary fluxes must be established for each model area.

Initial nitrate concentrations for the RIFS Subregional Models will be interpolated from the verified and potentially updated RIFS Regional Model initial concentration contours for 2015 developed, as described above (Section 6.4.4.2). Boundary nitrate fluxes will be assigned using the stabilized depth-dependent concentrations predicted by the RIFS Regional Model at the RIFS Subregional Model boundaries. Nitrate loading sources (SWAT model) will be interpolated from the regional model grid to the subregional model grids. Temporal variations in nitrate source loading will be introduced based on the monthly stress periods used in the regional model. Regional model transport parameters (e.g., dispersion) will be considered as initial values in the RIFS Subregional Models and tested to confirm that nitrate transport results obtained from the smaller subregional grid mesh are generally consistent with regional model nitrate results and adjusted, if needed.

For arsenic, uranium, and bicarbonate, contours representing 2015 concentrations in each aquifer zone will be developed for the Study Area using similar contouring parameters/methodology to nitrate. Zone-specific concentrations will be used to compute averages for contouring, as was done for nitrate. Consistent with the methodology for nitrate, multi-aquifer wells would be used only when depth-dependent vertical profiling analyses (i.e., from prior investigations or the RI well profiling investigations) are available. Steady state boundary fluxes will be established by assigning interpolated concentrations to boundary flows entering the subregional models through the shallow, intermediate, and deep aquifer zones.

Uranium sources are conceptually related to the downward migration of bicarbonate and calcium, which enter the aquifer at the water table, combine with U(VI) to form the aqueous complex $\text{Ca}_2\text{UO}_2(\text{CO}_3)_3(\text{aq})$ and mobilize adsorbed uranium. U(VI) is retarded with respect to groundwater flow but is nevertheless highly mobile in oxic groundwaters in the presence of bicarbonate (i.e., in Study Area groundwater). Based on this understanding, source terms for uranium will be developed, as needed, to evaluate the identified project alternatives using an iterative approach based on the correlation between uranium, calcium, and bicarbonate in the aquifer system, and observations regarding predicated bicarbonate migration.

In contrast, the mechanisms that mobilize arsenic are less well understood. Natural arsenic concentrations in the Study Area appear to be greatest in deep anoxic groundwater (i.e., below the Corcoran Clay) or in anoxic aquitards, where adsorbed arsenic is released from dissolution of iron or manganese oxyhydroxides under iron- or manganese-reducing conditions (USGS, 2010). Positive correlations of arsenic in the groundwater with pH and orthophosphate concentrations also indicate that increased pH or orthophosphate concentrations play a role in desorption of arsenic from aquifer sediments. Source terms for arsenic will be developed, as needed, to evaluate the identified project alternatives using an iterative approach based on the locations and depths of potentially anoxic conditions, and the correlation between arsenic, pH, and

orthophosphate in the aquifer system, and observations regarding predicated bicarbonate migration as a surrogate for the migration of oxic groundwater into anoxic portions of the aquifer.

Site-specific distribution/retardation coefficients for arsenic and uranium will be developed based on prior studies conducted by USGS and the geochemical evaluation discussed in Section 6.4.3.

6.4.4.5 SUBREGIONAL SOLUTE TRANSPORT MODEL CALIBRATION

Baseline (no project) model runs will be reviewed and evaluated to determine whether refinement and adjustments to model calibration are needed to accurately simulate project alternatives using a superposition approach. The following calibration datasets will be used to make model performance comparisons and adjustments, as appropriate:

- comparing simulated heads and vertical gradients to measured values in monitoring wells in the RIFS Subregional Model domains and adjusting boundary general heads, as appropriate;
- comparing simulated ambient flow in inactive wells to corresponding flows measured during well profiling and adjusting horizontal and vertical well conductance values, as appropriate;
- comparing predicted to contoured contaminant concentrations and adjusting boundary contaminant fluxes, as appropriate; and,
- comparing simulated contaminant concentrations in water produced from designated implementation wells to their actual measured concentrations and adjusting aquifer initial concentrations, vertical well conductance values, and boundary fluxes, as appropriate.

While not explicitly used in calibration, information regarding groundwater age dating gathered by USGS for different aquifer depths (USGS, 2008) will be considered when making model adjustments. Wells designated for these comparisons and corresponding adjustments for model calibration refinement will be selected to coincide with those used for evaluating the project alternatives. Generally, these wells will be the same ones selected for vertical profiling in Section 5.0, or will have been previously profiled, and will, thus, have the most data available for comparison. These wells will also be considered representative of the RIFS Subregional Model domains in the event that adjustments must be made to wells that have not been profiled. Adjustment of model parameters will be considered complete when, based on professional judgment, the model can fully meet the objective of performing a relative comparison of the identified projects using a superposition approach.

6.4.4.6 SIMULATION OF REMEDIAL ALTERNATIVES

After successful review and calibration of the RIFS Subregional Models, up to six forecast model scenarios will be developed to evaluate the relative effectiveness of the identified project alternatives. Baseline scenarios (described above) will be simulated for each RIFS Subregional Model for 2015 through 2035 without the implementation of project alternatives. Modeling scenarios will then be developed and simulated over the same 20-year period to represent the project alternatives and assess the changes they induce. Changes will

be assessed by subtracting simulated concentrations for the baseline scenario from simulated concentrations for the alternative scenarios (i.e., superposition). The following characteristics will be assessed using time-series graphs or contour maps:

- changes in groundwater levels in the shallow, intermediate, and deep aquifer zones;
- changes in groundwater concentrations of arsenic, nitrate, and uranium in the shallow, intermediate, and deep aquifer zones;
- changes in the assimilative capacity (the amount by which the concentration of a contaminant is below the MCL); and,
- changes in the concentrations of arsenic, nitrate, and uranium in groundwater produced from designated wells.

The results will be assessed to evaluate the effectiveness of the project alternatives to prevent the migration of contamination to new areas, prevent the release of additional contamination, and improve water quality over time.

6.4.4.7 SENSITIVITY ANALYSIS

A sensitivity analysis will be performed to assess the effects of uncertainties in model data on the predictive results obtained through superposition. The baseline scenarios for the RIFS Subregional Models will be repeated with assumed variations in input parameters to assess the effects on predicted contaminant concentrations for two selected project alternatives. Input parameters that will be varied may include boundary contaminant fluxes, source terms and recharge rates, and other factors selected based on model performance characteristics (observed sensitivities) and the definition of individual project alternatives. The results will be displayed on time-versus-concentration graphs that include measured concentrations, where available. The effects of the uncertainties on the conclusions reached through predictive groundwater modeling will be discussed.

6.5 FEASIBILITY ANALYSIS

The potential project alternatives will be evaluated, compared, and scored based on their performance relative to a set of pre-established feasibility criteria. Each criterion will be assigned a rank score and a weighting factor, depending on its perceived importance to alternative selection. Depending on the comparative results, tied scores may be assigned for two or more project alternatives. The following will be considered:

- **Effectiveness.** Project effectiveness will be evaluated using the solute transport modeling approach described earlier in this section, based on the ability of a project alternative to prevent migration of contamination, prevent the release of additional contamination, or improve water quality over time. Scoring will consider changes in constituent assimilative capacity, the area or aquifer volume in which these changes occur, and the potential improvements in drinking water quality produced by nearby

wells. To develop a score, the projects will be assigned a relative score from 1 to 6, with 6 being the most effective. Because this is considered the most important criterion, it will be assigned a weighting factor of 2.

- **Cost.** Relative, approximate order of magnitude costs will be assigned to the project alternatives based on actuarial data and engineering judgment, and the projects will be assigned a relative score between 1 and 6, with 6 being the least expensive. Cost will be assigned a weighting factor of 1.5.
- **Risk/Uncertainty.** Risk and uncertainty were a threshold screening criterion for technology acceptance, with the goal of screening out technical approaches with inherently unacceptable levels of risk or uncertainty. At the feasibility evaluation stage of the FS, this criterion is meant to assess the level of remaining risk or uncertainty that must be considered during detail design and its potential impact on project schedules, costs, and/or effectiveness. The projects will be assigned relative scores between 1 and 6, with 6 having the greatest certainty of outcome/least risk of cost over-run. This criterion will be assigned a weighting factor of 1.25.
- **Promotion of Groundwater Sustainability.** Enhancement of groundwater supply resilience is a key benefit sought by the City that is related to groundwater quantity as well as quality. Projects will be assigned a score based on the length of time needed to achieve substantive improvements in assimilative capacity, allow development of new groundwater supplies without causing water quality degradation, and improvements in the quantity of groundwater available. Projects will be assigned relative scores between 1 and 6, with 6 showing the greatest improvements in sustainability. This criterion will be assigned a weighting factor of 1.0.
- **Grant Program Priorities and Preferences.** The grant program priorities and preferences include a number of factors of importance that are lumped into a single category. These include disadvantaged community benefits/human right to water, overall project priority, and contribution to innovation in groundwater management. Projects will be assigned a relative score from 1 to 6, with 6 showing the greatest benefits. This criterion will receive a weighting factor of 1.0.

A scoring matrix will be developed that presents the scores and weighting factors for each project alternative and briefly cites the justification of the assigned score with a reference to substantiating materials, if appropriate. Based on the assigned scores, the project alternatives will be ranked and prioritized for potential future implementation.

6.6 RECOMMENDED PROJECT(S)

Based on the feasibility evaluation process, one or two top-ranked projects will be proposed for implementation. A conceptual engineering design and cost estimate will be prepared for the selected project, to facilitate future grant applications for implementation projects. This will include preparation of the following:

DRAFT RIFS WORKPLAN

CITY OF MODESTO WELL FIELD RIFS, MODESTO, CALIFORNIA – APRIL 26, 2019

- a project description, including a project overview, a description of the project goals and objectives, the projected benefits of the project in terms of water quality improvements, an outline of major project implementation tasks, and an outline of any data gaps needing to be addressed;
- an outline of any applicable permitting and regulatory approval requirements;
- a site plan showing the location of any proposed facilities, such as wells, pipelines, and/or recharge basins;
- General Arrangement Plans for specific facilities, such as wellhead improvements or recharge basins;
- a major equipment list, if applicable;
- an implementation schedule; and,
- a preliminary cost estimate.

7.0 SCHEDULE AND DELIVERABLES

7.1 SCHEDULE

The project schedule is defined by the Grant Agreement Submittal Schedule A-6 and based on the following key deliverables and estimated dates:

- RI fieldwork in Quarters 2 and 3 2019, consistent with the approved Final RIFS Workplan
- RI Report in December 2019
- Groundwater Modeling and FS Report in March 2020
- Project Completion Report in June 2020

8.0 REFERENCES

- Bexfield and Jurgens, 2014. *Effects of Seasonal Operation on the Quality of Water Produced by Public-Supply Wells: in Groundwater Vol. 52.*
- Brown & Caldwell, 2013. *Phase II Well Field Optimization Study: Consulting report prepared for the City of Modesto, SCADA system data and On-line Data Management System.*
- California Department of Water Resources (DWR), 2003. *California's Groundwater, Bulletin 118. Last update for Eastern San Joaquin, Turlock, and Delta-Mendota Subbasins: 2006; Modesto Subbasin: 2004.*
- DWR, 2013. *California's Groundwater Update 2013, A Compilation of Enhanced Content for California Water Plan Update 2013, Chapter 8 – San Joaquin River Hydrologic Region.* April.
- DWR, 2016. Water Management Planning Tool. Website: <http://water.ca.gov/groundwater/boundaries.cfm>. Accessed July 12, 2017.
- California Regional Water Quality Control Board, Central Valley Region, 2016. *The Water Quality Control Plan (Basin Plan) for the California Regional Water Quality Control Board, Central Valley Region, Fourth Edition, The Sacramento River Basin and the San Joaquin River Basin.* Revised July.
- Harbaugh, Arlen W., Edward R. Banta, Mary C. Hill, and Michael G. McDonald, 2000. *MODFLOW-2000, The U.S. Geological Survey Modular Ground-Water Model—User Guide to Modularization Concepts and the Ground-Water Flow Process:* USGS Open File Report 00-92.
- Jacobson James & Associates, Inc. (JJ&A), 2018. *Final Program Environmental Impact Report for the Stanislaus County Discretionary Well Permitting and Management Program: Prepared for Stanislaus County.* June 11.
- Jurgens, et al., 2009. *Effects of Groundwater Development on Uranium: Central Valley, California, USA: Groundwater 10.1111/j.1745-6584.2009.00635.x*
- Modesto Irrigation District (MID), 2015. *Rules and Regulations Governing the Distribution of Irrigation Water within the Modesto Irrigation District.* April 15.
- Neitsch, S.L., J.G. Arnold, J.R. Kiniry, J.R. Williams, 2011. *Soil & Water Assessment Tool, Theoretical Documentation, Version 2009.* Texas Water Resources Institute Technical Report No. 406, Texas A&M University System. <http://swat.tamu.edu/software>.
- Parkhurst, D.L., and Appelo, C.A.J., 2013. Description of input and examples for PHREEQC version 3--A computer program for speciation, batch- reaction, one-dimensional transport, and inverse geochemical calculations: U.S. Geological Survey Techniques and Methods, book 6, chap. A43, 497 p. <http://pubs.usgs.gov/tm/06/a43>.
- Phillips, S.P., Rewis, D.L., and Traum, J.A., 2015. *Hydrologic model of the Modesto Region, California, 1960–2004:* U.S. Geological Survey Scientific Investigations Report, 2015–5045, 69 p., <http://dx.doi.org/10.3133/sir20155045>.
- Reilly, Thomas E., Franke, O. Lehn, and Bennett, Gordon D., 1987. *The Principle of Superposition and its Application in Ground-Water Hydraulics.* U.S. Geological Survey Techniques of Water-Resources Investigations 03-B6.

- Smith, Ryan, R. Knight, and S. Fendorf, 2018. *Overpumping leads to California groundwater arsenic threat*: in Nature Communications 9(1). December.
- Todd Groundwater and RMC Water and Environment, 2016. *Groundwater Characterization and Recharge Study, Modesto LGA Project*. June.
- Turlock Groundwater Basin Association, 2008. *Turlock Groundwater Basin, Groundwater Management Plan*. March 2008.
- United States Geological Survey (USGS), 2003. *Framework for a Ground-Water Quality Monitoring and Assessment Program for California*: Water-Resources Investigations Report 03-4166.
- USGS, 2004a. *Guidelines for Evaluating Ground-Water Flow Models*. Scientific Investigations Report 2004-5038.
- USGS, 2004b. *Hydrogeologic Characterization of the Modesto Area, San Joaquin Valley, California*. Scientific Investigations Report 2004-5232.
- USGS, 2007. *Simulation of multiscale ground-water flow in part of the northeastern San Joaquin Valley, California*: U.S. Geological Survey Scientific Investigations Report 2007-5009.
- USGS, 2008. *Hydrogeology, Water Chemistry, and Factors Affecting the Transport of Contaminants in the Zone of Contribution of a Public-Supply Well in Modesto, Eastern San Joaquin Valley, California*: Scientific Investigations Report SIR 2008-5156.
- USGS, 2010. *Status and understanding of groundwater quality in the Central–Eastside San Joaquin Basin, 2006: California GAMA Priority Basin project*. Scientific Investigations Report 2009–5266.
- USGS, 2015. *Hydrologic Model of the Modesto Region 1960-2004*: Scientific Investigations Report SIR 2009-5266.
- Water Resources & Information Management, Engineering, Inc., 2007. *Recharge Characterization for Stanislaus and Tuolumne Rivers Groundwater Basin Association*.
- West Yost Associates (West Yost), 2011. *City of Modesto & Modesto Irrigation District Joint 2010 Urban Water Management Plan, Final*.
- West Yost, 2016. *City of Modesto 2015 Urban Water Management Plan, Final*.
- Winchell, M., R. Srinivasan, M. DiLuzio, J. Arnold, 2013. *Arcswat Interface for SWAT2012, USER’S Guide*. <http://swat.tamu.edu/software>.
- Zheng, Chunmiao and P. Patrick Wang, 1999. *MT3DMS, A modular three-dimensional multispecies transport model for simulation of advection, dispersion and chemical reactions of contaminants in groundwater systems (Release DoD_3.50.A), Documentation and User’s Guide*: Prepared for U.S. Army Corps of Engineers, Washington, DC 20314-1000.
- Zheng, Chunmiao, 2010. *MT3DMS Supplemental User’s Guide: Department of Geological Sciences, The University of Alabama*. February.

DRAFT RIFS WORKPLAN

CITY OF MODESTO WELL FIELD RIFS, MODESTO, CALIFORNIA – APRIL 26, 2019

TABLES

LIST OF TABLES

Table 1-1	Approach to RIFS Components
Table 2-1	Summary of Groundwater Subbasins
Table 3-1	Arsenic Conceptual Site Model
Table 3-2	Nitrate Conceptual Site Model
Table 3-3	Uranium Conceptual Site Model
Table 4-1	Data Objectives and Modeling Applications
Table 4-2	List of Conceptual Project Approaches
Table 5-1	Prior Studies and Data Sources
Table 5-2	Wells Designated for Sampling or Profiling and Rationale
Table 6-1	Model Layering

Model Component	Sources	Chemical Transformations	Sinks	Transport	Data Gaps	Modeling Considerations
Surface	No significant arsenic sources.	Not applicable.	No significant sinks.	Not applicable.	Not applicable.	Surface processes are not an important source of arsenic in this area. Surface arsenic transport will not be modeled.
Vadose Zone	Arsenic containing minerals (especially sulfides) in Sierran-derived sediments.	Oxidation of sulfides.	Adsorption onto fine-grained sediments and organic carbon; Sorption to iron oxy-hydroxides and manganese oxides.	Transport occurs as arsenite in reducing environments and arsenate in oxidizing environments. The primary species detected in the aquifers in the study area is arsenate. The vadose zone is not expected to be a significant source of arsenic.	No significant data gaps.	The vadose zone is not an important source of groundwater arsenic in this area. Arsenic transport in the vadose zone will not be modeled.
	Arsenic that is adsorbed onto fine grained sediments and organic carbon.	Desorption, especially at pH ≥ 8 or in presence of elevated orthophosphate.	Resorption.			
	Arsenic adsorbed to iron and manganese oxyhydroxides.	Desorption, especially at pH ≥ 8 or in presence of elevated orthophosphate; Reduction of iron and manganese oxyhydroxides, releasing adsorbed arsenic.	Resorption to iron and manganese oxyhydroxides at lower pH levels.			
Saturated Zone	Arsenic containing minerals (especially sulfides) in Sierran-derived sediments.	Oxidation of sulfides.	Adsorption onto fine-grained sediments and organic carbon; Sorption to iron oxy-hydroxides and manganese oxides.	Transport occurs as arsenite in reducing environments and arsenate in oxidizing environments. The primary species detected in the aquifers in the study area is arsenate; however, arsenite may occur in more reducing environments, such as within aquitards. Transport will be affected by sorption/desorption processes.	Generally speaking, reducing environments and sorptive materials in the aquifer (fine grained sediments, organic carbon, and iron/manganese oxy-hydroxides) that serve as arsenic sources and sinks are understood to be associated with aquitards, paleosols, and other fine-grained deposits. The spatial distribution of these environments is heterogeneous at the meso and micro scale in alluvial aquifer systems, and therefore may not have been completely characterized by the existing sediment sampling data.	Assume negligible contribution of arsenic from sulfide oxidation based on weak correlation of groundwater arsenic concentrations with iron concentrations (Juergens et al. 2008)
	Arsenic that is adsorbed onto fine grained sediments and organic carbon. Fine grained sediments in oxidized portions of the aquifer would likely have adsorbed arsenate; in reducing microenvironments/aquitards, the species may be arsenite.	Desorption, especially at pH >7.5 or in the presence of orthophosphate; this may occur where aquifer waters (especially waters dominated by modern recharge) interact with fine grained aquitards where reducing conditions prevail. Adsorbed arsenite could be oxidized.	Resorption, especially at lower pH levels or lower orthophosphate concentrations.			Assume negligble based on correlation of HNO3 extractions of iron and manganese with arsenic (Juergens et al. 2008), which indicates arsenic is strongly associated with iron oxy-hydroxides in this area.
	Oxidized arsenic adsorbed to iron oxy-hydroxides and manganese oxides.	Desorption, especially at pH >7.5 or in the presence of orthophosphate, due to anion competition; Reductive dissolution of iron oxy-hydroxides and manganese oxides, releasing adsorbed arsenic.	Resorption, especially at lower pH levels or lower orthophosphate.			Calibrate PHREEQC model using measured groundwater arsenic concentration, results of extractions for arsenic and iron (Juergens et al. 2008)
	Pore water within aquitards, which may be more reducing and therefore contain elevated dissolved arsenic. Dewatering of aquitards following periods of heavy pumping.	Oxidation of arsenite, iron and manganese. Coprecipitation/adsorption of arsenic on iron and manganese oxy-hydroxides.	Adsorption onto fine-grained sediments, organic carbon, and iron and manganese oxy-hydroxides.			Because groundwater arsenic concentrations are only weakly correlated with dissolved iron and manganese concentrations (Juergens et al. 2008), release of reducing pore waters from aquitards is unlikely to be a significant process affecting arsenic concentrations in this area. In addition, groundwater drawdown below historical low levels is not anticipated.
Supply Well Interactions	Vertical migration through long screen supply wells when they are not pumping; vertical migration along unsealed annular completions.	No significant transformations are expected to occur as a result of interaction with wells.	Pumping wells removes arsenic mass from the system.	Accelerated vertical transport may take place near pumping wells; Vertical transport may take place through long-screen wells when they are not being pumped, especially during times of the year when vertical gradients are at a maximum (summer), or when nearby wells are pumping.	The rate of vertical migration through supply wells under ambient conditions has not been extensively evluated.	Modeling of induced vertical migration of solutes through existing municipal supply wells is a specific objective of the RIFS.

References:

Ayotte et al. (2011) Effects of human-induced alteration of groundwater flow on concentrations of naturally-occurring trace elements at water-supply wells. Applied Geochemistry 226:747-762.

Bexfield et al. (2011) USGS Scientific Investigations Report 2011-5020.

Brown et al. (2007) Arsenic and uranium in four aquifer settings: occurrence, distribution, and mechanisms for transport to supply wells. 2007 NGWA Naturally Occurring Contaminants Conference: Arsenic, Radium, Radon, Uranium, March 22-23, 2007, Charleston, SC.

Juergens et al. (2008) USGS Scientific Investigations Report 2008-5156.

Landon et al. (2009) USGS Scientific Investigations Report 2009-5266.

Smith et al. (2018) Overpumping leads to California groundwater arsenic threat. Nature Communications 9:1-6.



Model Component	Sources	Chemical Transformations	Sinks	Transport	Data Gaps	Modeling Considerations
Surface & Root Zone	Fertilization and irrigation.	Nitrification of ammonium, denitrification of nitrate in reducing environments/ micro-environments, mineralization of and immobilization into organic N pools.	Plant uptake, volatilization, denitrification in reducing environments/microenvironments.	Percolation, runoff, discharge to streams and drainage systems.	The RIFS will utilize a hydrologic and nitrate loading model being developed to support the Central Valley Region Irrigated Lands Regulatory Program. The uses the Surface Water Assessment Tool (SWAT) modeling code, which simulates hydrology, land use, soil conditions, climate, cropping, agricultural productivity, and nitrogen-cycling processes. The approach and limitations of the modeling approach are discussed in the references cited below, and include the following: - Crop productivity, nitrogen uptake, fertilization rates and irrigation efficiency could be verified and refined. - The SWAT model uses an aggregated urban loading rate based on other studies, and does not distinguish loading from distinct urban processes (e.g., landscape fertilization, sewer leakage, etc.). - Urban sources such as wastewater discharge ponds are added manually during post-processing.	Loading rates will be calculated using the SWAT model.
	Confined animal feeding operations (CAFOs).		Volatilization, denitrification in reducing environments/microenvironments.			
	Public sewage collection and treatment works.		Treatment, volatilization, denitrification in reducing environments/microenviron-ments.	Infiltration through sewer leaks, percolaton from discharge ponds, surface water discharge.		There are no sewage treatment works or discharge ponds in the model area that require special consideration. Potential leakage from the urban sewerage system is accounted for though application of a generalized urban loading rate.
	Septic systems.		Volatilization, denitrification in reducing environments/microenvironments.	Percolation.		Septic systems are simulated using default loading rates for rural residential development outside City service areas.
	Urban runoff and atmospheric deposition		Plant uptake, volatilization, denitrification in reducing environments/microenvironments.	Percolation, runoff, discharge to streams and drainage systems, infiltration through rock wells.		Urban nitrate loading will be simulated considering typical urban loading rates to permeable surface area. Permeable surface area will be adjusted to account for surface area drained to rock wells.
Vadose Zone (Below Root Zone)	Deep percolation from surface sources.	Some nitrification of ammonium/ ammonia may occur beneath to root zone; however, the vadose zone is generally oxic and significant denitrification is not past the root zone. In addition, significant nitrification would be expected only beneath areas with a high ammonia load, such as CAFOs or sewage ponds.	Long-term storage.	Deep percolation occurs without significant retardation. Percolation may be primarily through macro-porosity especially in the upper saturated zone.	Vadose zone flow below the root zone has not been explicilty simulated in existing hydrologic models of the study area; however, neglecting vadose zone transport below the root zone is not expected to significantly affect model outcomes. Nitrate loading from rock wells has not been explicitly modeled.	Nitrate loading will be added to the solute transport model directly at the water table. Nitrate loading from rock wells will be simulated as a part of urban area nitrate loading in SWAT.
	Nitrification of ammonium.					
	Infiltration through rock wells.					
Saturated Zone	Vertical migration through improperly sealed or abandoned wells.	The aquifer system beneath the City is considered generally oxic. Seepage through aquitards may expose dissolved nitrate to anoxic conditions where denitrification could occur.	Sinks are associated with the physical flow or extraction of groundwater from the system. This includes underflow out, discharge to streams and groundwater extraction. Denitrification is not expected to be a significant process within the aquifer system underlying the City.	Lateral and vertical migation through the aquifer; Vertical migration through improperly sealed or abandoned wells; vertical migration though existing wells (see below). Nitrate transport is assumed to take place without retardation.	The extent or influence of anoxic conditions within significant aquitards is not well characterized; however, this is not expected to represent a significant fate and transport process in the drinking water aquifer system underlying the City.	Nitrate will be modeled as conservative, consistent with simplifying assumptions used in similar models.
Supply Well Interactions	Vertical migration through long screen supply wells when they are not pumping; vertical migration along unsealed annular completions.	No significant transformations are expected to occur as a result of interaction with wells.	Pumping wells removes nitrate mass from the system.	Accelerated vertical transport may take place near pumping wells; Vertical transport may take place through long-screen wells when they are not being pumped, especially during times of the year when vertical gradients are at a maximum (summer), or when nearby wells are pumping.	The rate of vertical migration through supply wells under ambient conditions has not been extensively evaluated.	Modeling of induced vertical migration of solutes through existing municipal supply wells is a specific objective of the RIFS.

Notes and References:

Juergens et al. (2008) USGS Scientific Investigations Report 2008-5156

Kreitsinger-Grabert, Dalgish and Ashby, 2016. Technical Memorandum - Alta Irrigation District Management Zone: Aggressive Restoration Alternative Modeling Scenario Results.

Landon et al. (2009) USGS Scientific Investigations Report 2009-5266

Larry Walker Associates, 2016. CV-SALTS Management Zone Archetype Analysis: Alta Irrigation District. Consulting report prepared for San Joaquin Valley Drainage Authority.



Model Component	Sources	Chemical Transformations	Sinks	Transport	Data Gaps	Modeling Considerations
Surface	There are no significant surface sources of uranium in the study area; however, there are surface sources of bicarbonate and oxygen, which can mobilize uranium as discussed below.	Not applicable.	No significant sinks.	Not applicable.	Not applicable.	Surface processes are not an important source of uranium in this area and will not be modeled. Surface bicarbonate sources exist and could mobilize uranium. Bicarbonate loading rates will be modeled to supply recharge water at the same concentration as shallow groundwater.
Vadose Zone	Oxidized uranium (U(VI)) that is adsorbed onto fine grained sediments, organic carbon, and iron and manganese oxyhydroxides. Expected to be unimportant because bicarbonate extraction tests indicate shallow sediments are not a significant source for uranium (i.e., leachable uranium has been flushed from the system).	Enhanced biological activity in the shallow vadose zone increases pCO ₂ , resulting in elevated bicarbonate in recharge water. Dissolved bicarbonate forms Ca-U(VI)-CO ₃ aqueous species.	No significant sinks.	Not expected to be important based on bicarbonate leaching tests.	Not applicable.	The vadose zone is not an important source of groundwater uranium in this area. Transport in the vadose zone will not be modeled and bicarbonate loading will be applied directly at the water table.
Saturated Zone	Reduced uranium (U(IV)) minerals in sediments that are derived from granitic rocks of the Sierra Nevada. U(IV) minerals may persist in less-permeable, reducing microenvironments within the aquifer sediments.	U(IV) may be oxidized to U(VI) by available oxidants such as oxygen. Resulting U(VI) will form Ca-U(VI)-CO ₃ aqueous species..	U(VI) may be adsorbed onto fine grained sediments, organic carbon, and iron and manganese oxyhydroxides.	Ca-U(VI)-CO ₃ aqueous complexes are mobile and are postulated to be the primary mechanism for transport of uranium in the saturated zone. Transport will be affected by sorption/desorption processes. Distribution coefficients will be different in bicarbonate vs. non-bicarbonate waters and will change as mixing occurs.	Generally speaking, reducing microenvironments and sorptive materials in the aquifer (fine grained sediments, organic carbon, and iron/manganese oxy-hydroxides) that serve as uranium sources and sinks are understood to be associated with aquitards, paleosols, and other fine-grained deposits. The spatial distribution of these environments is heterogeneous at the meso and micro scale in alluvial aquifer systems, and therefore may not have been completely characterized by the existing sediment sampling data.	Assume negligible contribution of uranium from U(IV) oxidation, adsorption/desorption from iron oxyhydroxides is a more likely control on uranium transport.
	Oxidized uranium (U(VI)) that is adsorbed onto fine grained sediments, organic carbon, and iron and manganese oxyhydroxides. Leachable source concentrations tend to be higher with depth, in areas that are less invaded by modern, bicarbonate-rich, recharge water.	Invasion of the saturated zone by modern, bicarbonate-rich recharge water mobilizes adsorbed U(VI) through the formation of Ca-U(VI)-CO ₃ aqueous species.	No significant sinks.			Transport modeling will include assessment of the effectiveness of pore volume exchange to flush existing uranium from the system, and of the migration of bicarbonate through the aquifer to liberate residual uranium from areas/depths that have not been exposed to high bicarbonate concentrations. Calibrate PHREEQC geochemical model using measured groundwater uranium concentrations and results of sediment extractions data for uranium and iron (Juergens et al. 2008).
Supply Well Interactions	Vertical migration through long screen supply wells when they are not pumping; vertical migration along unsealed annular completions.	See below. Turbulence, pressure, and redox changes could cause precipitation of scale	Pumping wells removes uranium mass from the system.	Ca-U(VI)-CO ₃ aqueous species are postulated to be the primary mechanism of uranium transport to wells. Accelerated vertical transport may take place near pumping wells; Vertical transport may take place through long-screen wells when they are not being pumped, especially during times of the year when vertical gradients are at a maximum (summer), or when nearby wells are pumping.	The rate of vertical migration through supply wells under ambient conditions has not been extensively evaluated.	Modeling of induced vertical migration of solutes through existing municipal supply wells is a specific objective of the RIFS.
	Dissolved U(VI) Ca-U(VI)-CO ₃ aqueous species.	Coprecipitation and adsorption of U(VI) on carbonate minerals, especially in operating wells and when water levels fall below well screen intervals.	Formation of carbonate scale could sequester some uranium		Extent and uranium analytical data for carbonate scale in the City's well system.	The potential for uranium sequestration in scale will be evaluated using PHREEQC. Unless the potential for significant sequestration is identified (which is considered unlikely), this pathway will be neglected in the transport model.

References:

Ayotte et al. (2011) Effects of human-induced alteration of groundwater flow on concentrations of naturally-occurring trace elements at water-supply wells. Applied Geochemistry 226:747-762.

Bexfield et al. (2011) USGS Scientific Investigations Report 2011-5020.

Brown et al. (2007) Arsenic and uranium in four aquifer settings: occurrence, distribution, and mechanisms for transport to supply wells. 2007 NGWA Naturally Occurring Contaminants Conference: Arsenic, Radium, Radon, Uranium, March 22-23, 2007, Charleston, SC

Juergens et al. (2008) USGS Scientific Investigations Report 2008-5156

Landon et al. (2009) USGS Scientific Investigations Report 2009-5266



TABLE 4-1
DATA OBJECTIVES AND MODELING APPLICATIONS
Draft RIFS Monitoring Plan
City of Modesto
Modesto, California

Required Model Feature or Capability	Application	Data Objective	Rationale for Obtaining Data	Approach to Fill Data Need				
				Existing Data and Models	Well Sampling and Monitoring	Vertical Dynamic Profiling	Vertical Ambient Profiling	Recharge Test
Aquifer Characteristics	Aquifer geometry and parameters provide the framework for groundwater flow and response to recharge or pumping.	Aquifer geometry and parameters must be sufficiently characterized and calibrated for modeling predicted effects induced by the projects being evaluated using a superposition approach, and for relative comparison between projects. Accurate prediction of absolute heads, drawdowns and concentrations is not the primary emphasis.	Utilize the existing calibrated textural model and layering developed by USGS and used by Todd. Adjustments will be made near potential project areas only if warranted based on ambient and dynamic profiling data, or pressure response during recharge tests.	✓		✓	✓	✓
Groundwater Levels and Flow	Groundwater levels and flow are the dynamic input that controls contaminant transport.	Assessment of lateral and vertical head distributions and gradients is most important near areas where potential projects are evaluated (within the subregional models), less important in areas within the City's water service area (Study Area) outside the subregional models, and least important in the regional model areas outside the Study Area.	Sub-regional model boundary conditions will be adjusted near project locations as needed to better simulate heads and gradients observed during ambient profiling, dynamic profiling and well gaging, and water levels reported by the City for supply wells or in GeoTracker for monitoring wells.	✓	✓	✓	✓	
Boundary Conditions	The model boundary conditions are an integral component to the accurate simulation of groundwater flow and contaminant transport	Flow boundary conditions for all models will be set based on the existing USGS/Todd models and with the objective of simulating average steady-state conditions at the sub-regional model boundaries. The sub-regional models are most important because they are used to evaluate project performance. Nitrate, arsenic and uranium loading at the sub-regional model boundaries will be determined based on initial concentrations.	Establish steady state general head boundary conditions for the sub-regional models using the regional model. The sub-regional model boundaries will be adjusted if needed to improve the match of vertical head and concentration distributions observed during ambient and dynamic well profiling.	✓		✓	✓	
Water Budget	The water budget combined with groundwater levels and flow make up the dynamic portion of the model, which in a calibrated model is consistent with the aquifer characteristics	The existing year 2000 water budget of the calibrated USGS and Todd models will be maintained in order to maintain model fidelity and predictive accuracy. Variations between assumed and actual future conditions will be dampened when using the model in an superposition analysis. Use of an annual average water budget with seasonal variations is sufficient to inform the boundary conditions of the sub-regional models and will offer additional insight into vertical gradient variability and contaminant transport.	City groundwater pumping will be updated to provide baseline conditions for 2020. The source of this information will be monthly pumping data provided by the City and adjusted based on demand increases forecast in the City's 2015 UWMP. Thus, seasonal variations in urban pumping will be simulated in the sub-regional models. Agricultural pumping and all recharge will be provided by the USGS / Todd models, with seasonal variations derived from the SWAT and/or SCHM models.	✓				
Initial Contaminant Distribution	The initial distribution of contaminants is used as a starting point for transport simulation and as a baseline for evaluation of project performance.	Lateral and vertical initial contaminant distributions will be established throughout the regional model domain. Subregional model areas where potential projects would be simulated will be better characterized than the regional model through a combination of City data and MRP sampling.	The RI will augment existing data from supply and monitoring wells in areas that are impacted by contamination, where projects are likely to be located, and where vertical profiling of supply wells is possible.	✓	✓	✓	✓	



TABLE 4-2
LIST OF CONCEPTUAL PROJECT APPROACHES
Draft RIFS Workplan
City of Modesto
Modesto, California

Technology	Potential Application
Well Destruction	Destruction of wells that serve as conduits for contaminant migration
Well Modification	Modification of wells to prevent mixing of contaminated water with clean water either by extracting water from clean zones while not inducing contaminant migration, or extracting water from contaminated zones to prevent contaminant migration
New Well Installation	Installation of new wells to extract water from clean zones without inducing contaminant migration, or to extract water from contaminated zones to prevent contaminant migration
Operational Modification	Systematic well or well field operation targeted at preventing contaminant migration and/or promoting aquifer cleanup by removing or flushing contaminant mass
Aquifer Storage and Recovery	Targeted recharge using injection wells to flush contaminants from the aquifer, replace formation water with recharge water that is less prone to mobilize contaminants, in a way that avoids unintended water quality impacts
Managed Aquifer Recharge	Targeted recharge using percolation basins to flush contaminants from the aquifer, replace formation water with recharge water that is less prone to mobilize contaminants, in a way that avoids unintended water quality impacts
Chemical Augmentation	In-situ chemical treatment using injection, barriers or circulating wells to immobilize or sequester contaminants

TABLE 5-1
PRIOR STUDIES AND DATA SOURCES
Draft RIFS Workplan
City of Modesto
Modestos, California

Data Source/Reference	Summary
INFORMATION FROM USGS	
USGS, 2004. <i>Hydrogeologic Characterization of the Modesto Area, San Joaquin Valley, California</i> : Scientific Investigations Report 2004-5232.	• Comprehensive study of the geology and hydrogeology of freshwater aquifers in the Modesto area.
USGS, 2007. <i>Simulation of multiscale ground-water flow in part of the northeastern San Joaquin Valley, California</i> : U.S. Geological Survey Scientific Investigations Report 2007-5009.	Describes background for and development of a steady state groundwater flow model of the the region west of the San Joaquin River, approximately between the Stanislaus and Merced Rivers.
USGS, 2008. <i>Hydrogeology, Water Chemistry, and Factors Affecting the Transport of Contaminants in the Zone of Contribution of a Public-Supply Well in Modesto, Eastern San Joaquin Valley, California</i> : Scientific Investigations Report SIR 2008-5156.	• Detailed, vertically-integrated, well flow and contaminant transport data for City Well No. 25. • 2003 and 2004 groundwater level and quality data for 23 nested monitoring wells, including contaminants, arsenic speciation, and general water quality parameters. • Detailed boring logs and hydrostratigraphic data. • Aquifer solids chemical and mineralogical analysis. • Equilibrium chemical calculations relevant to contaminant transport.
USGS, 2008. <i>Simulations of Ground-Water Flow and Particle Pathline Analysis in the Zone of Contribution of a Public-Supply Well in Modesto, Eastern San Joaquin Valley, California</i> : Scientific Investigations Report SIR 2008-5035.	• Analysis of factors affecting contaminant fate and transport in the Modesto area. • Hydrochemical and physical aquifer data related to contaminant fate and transport. • Fate and transport model input, assumptions, and output data.
USGS, 2010. <i>Status and Understanding of Groundwater Quality in the Central-Eastside San Joaquin Basin, 2006: California GAMA Priority Basin Project</i> : Scientific Investigations Report SIR 2017-5032.	• Information regarding groundwater geochemical and water quality studies in the Modesto, Turlock and Merced Subbasins, including data regarding arsenic, nitrate and uranium.
USGS, 2015. <i>Hydrologic Model of the Modesto Region 1960-2004</i> : Scientific Investigations Report SIR 2009-5266.	• Refined numerical groundwater flow model of the area extending from the Stanislaus to the Merced Rivers using the MODFLOW-OWHM code, including updated water balance and hydrology information through 2004. • Detailed three dimensional analysis of aquifer hydrostratigraphy using geostatistical analysis techniques. • Groundwater modeling files for the calibrated model.

TABLE 5-1
PRIOR STUDIES AND DATA SOURCES
Draft RIFS Workplan
City of Modesto
Modestos, California

Data Source/Reference	Summary
USGS, 2017. <i>Groundwater Quality in the Western San Joaquin Valley Study Unit, 2010: California GAMA Priority Basin Project: Scientific Investigations Report SIR 2017-5032.</i>	• Information regarding groundwater geochemical and water quality studies in the western San Joaquin Valley, including data regarding arsenic, nitrate and uranium.
INFORMATION FROM CITY OF MODESTO	
Brown & Caldwell, 2013. <i>Phase II Well Field Optimization Study</i> : Consulting report prepared for the City of Modesto, SCADA system data and On-line Data Management System.	• Description of City wellfield and water supply infrastructure and operation. • Analytical data for selected contaminants through 2014. • Monthly well pumping data. • Well construction summary information and completion reports. • Well history and status information.
Bryant, 2014. <i>Feasibility Study, Uranium Impacted Wells 1, 4, 6, 16, 17 and 33</i> : Report prepared for the City of Modesto Utilities Department by City staff.	• Background information regarding conditions at six uranium-impacted wells. • Feasibility evaluation of options for above ground treatment, blending and well modification to address uranium contamination. • Feasibility study level cost estimates and comparisons.
Bryant 2015. <i>Feasibility Study, Well 299 Arsenic Treatment</i> : Report prepared for the City of Modesto Utilities Department by City staff.	• Analytical data for arsenic, arsenic speciation and other water quality parameters for various wells, especially in the Salida area. • Feasibility evaluation of options for above ground treatment, blending and well modification to address uranium contamination. • Feasibility study level cost estimates and comparisons. • Pilot testing results.
Larry Walker Associates, 2012. <i>City of Modesto Stormwater Management Program Rockwell Assessment Summary Report</i> : Prepared for City of Modesto Wastewater Division, NPDES Permit No. CAS083526; Order R5-2008-0092.	Report presenting the results of an investigation into the effects of rock wells on groundwater quality, including, among other things, bicarbonate and nitrate loading concentrations.
City of Modesto. Dynamic Well Profiling Reports for City Well Nos. 21, 61, 64, 66, 225 and 282, and water quality investigations for City Well Nos. 55 and 313.	Dynamic well profiling reports showing well completion details, well flow dynamics, contaminant concentrations in water from various depths in the aquifer, and contaminant loading from various aquifer zones.

TABLE 5-1
PRIOR STUDIES AND DATA SOURCES
Draft RIFS Workplan
City of Modesto
Modestos, California

Data Source/Reference	Summary
INFORMATION FROM CITY OF MODESTO (continued)	
City of Modesto. Public Drinking Water System Compliance Files.	• Source Assessment Reports. • Complete well analytical data. • Treatment system operational data. • Water blending plans and data. • Additional well testing reports. • Well performance reports. • GIS files of well locations, water system components, canals, storm water basins, rock wells.
Todd Groundwater and RMC Water and Environment, 2016. <i>Groundwater Characterization and Recharge Study</i> : Study prepared under Local Groundwater Assistance Grant from the California Department of Water Resources.	• Hydrostratigraphic cross sections interpreted from City well logs. • Compilation of water quality data from the GeoTracker GAMA site. • Hydrostratigraphic cross sections showing water quality data distribution. • Modeling files for a locally-refined groundwater flow model extracted from the USGS MERSTAN model. • Feasibility study and comparison of sites and alternatives for Managed Aquifer Recharge.
INFORMATION FROM OTHER STUDIES	
Ayotte, et al., 2011. Effects of Human-Induced Alteration of Groundwater Flow on Concentrations of Naturally-Occurring Trace Elements at Water-Supply Wells: Applied Geochemistry 26(2011)747–762.	• Evaluation of the effects of human-induced changes in aquifer recharge chemistry and circulation patterns on arsenic and uranium migration, including an evaluation of uranium transport in Modesto.
Bexfield and Jurgens, 2014. <i>Effects of Seasonal Operation on the Quality of Water Produced by Public-Supply Wells</i> : in Groundwater Vol. 52.	• Evaluation of the effects of well completion, well operation, and groundwater hydraulics on contaminant concentrations in water produced by public supply wells, with a section focusing on wells in Modesto. • Conceptual models of seasonal well behavior and resulting concentration trends.

TABLE 5-1
PRIOR STUDIES AND DATA SOURCES
Draft RIFS Workplan
City of Modesto
Modestos, California

Data Source/Reference	Summary
CDM Smith, 2016. <i>Nitrate Implementation Measures Study (NIMS)</i> : Prepared for San Joaquin Valley Drainage Authority. March 31.	Provides input to policymakers regarding implementation measures to reduce current ambient nitrate concentrations in groundwater to protect and restore beneficial uses. Measures are proposed to be phased, and a prioritization analysis is used to rank Initial Analysis Zones (IAZs) in order of priority – where risk reduction from nitrate in groundwater is optimized to facilitate use of the limited resources available. The study includes the following: • Summary of salient information about the occurrence, distribution, groundwater remediation, and drinking water treatment of nitrate from the literature. • Summary of existing or planned nitrate mitigation regulatory programs and how they relate to the objectives of NIMS. • A proposed phasing approach for implementation of various implementation measures to provide safe drinking water, reduce or eliminate impacts to drinking water sources, and where needed restore beneficial uses. • A prioritization methodology to rank groundwater basins, subbasins or management zones are ranked based on existing nitrate impacts and potential for future impacts to users of groundwater as a water supply. • Mass balance modeling of various nitrate management strategies in the Alta Irrigation District study area. • Conceptual cost estimates and implementation schedules to provide alternate sources of drinking water, source control measures, managed aquifer restoration, pumping and fertilization, blending, drilling deeper wells, in situ treatment, and treatment of pumped groundwater for beneficial uses including potable use. • Development of nitrate implementation measures in accordance with the requirements of the Salt and Nitrate Management Plan (SNMP)
Chapelle, Francis, et al., 2013. <i>Modeling the Long-Term Fate of Agricultural Nitrate in Groundwater in the San Joaquin Valley, California</i> : Chapter 6 of Current Perspectives in Contaminant Hydrology and Water Resources Sustainability.	• Nitrate contaminant fate and transport modeling data and assumptions for the San Joaquin Valley area. • Aquifer characteristics affecting nitrate fate and transport in the San Joaquin Valley area. • Information regarding denitrification kinetics.
GEI Consultants, Bookman Edmonston Division, 2007. <i>Well Field Optimization Project, Final Report - May 2007</i> : Report prepared for the Stanislaus and Tuolumne Rivers Groundwater Basin Association.	• Data regarding wells operated by the Modestos Irrigation District and the Oakdale Irrigation District. • Well database development.
Harter, Thomas, et al., 2017. <i>Nitrogen Fertilizer Loading to Groundwater in the Central Valley</i> : FPEP Projects 11-0301 and 15-0454. UC Davis.	Report regarding nitrogen loading from fertilizer applicaton in the California Central Valley.
Jurgens, et al., 2009. <i>Effects of Groundwater Development on Uranium: Central Valley, California, USA</i> : Groundwater 10.1111/j.1745-6584.2009.00635.	Evaluation of the effects of human-induced changes in aquifer recharge chemistry and circulation patterns on uranium mobilization and migration in Modesto.

TABLE 5-1
PRIOR STUDIES AND DATA SOURCES
Draft RIFS Workplan
City of Modesto
Modestos, California

Data Source/Reference	Summary
Konikow, Leonard and George Hornberger, 2006. <i>Modeling Effects of Multinode Wells on Solute Transport</i> : Ground Water Vol. 44, No. 5 pp. 648-660.	Paper regarding the use of MODFLOW Multi-Node Well Package to simulate intra-borehole contaminant transport through long-screen wells.
McMahon et al., 2008. <i>Simulated Response of Water Quality in Public Supply Wells to Land Use Change</i> : Water Resources Research, 44, W00A06	• Evaluation of the effects of land use change from agricultural to urban on nitrate loading, fate and transport, with a section focusing on evaluation of the Modesto, California aquifer system • Solute fate and transport modeling input parameters, assumptions, and results.
Ransom, Katherine, et al., 2016. <i>Bayesian nitrate source apportionment to individual groundwater wells in the Central Valley by use of elemental and isotopic tracers</i> : Water Resources Research 52, 5577-5597.	Investigation of the sources of nitrate loading to private wells in Stanislaus, Merced, Kings and Tulare Counties using elemental and stable isotope analyses.
Ransom, Katherine, et al., 2017. <i>A hybrid machine learning model to predict and visualize nitrate concentration throughout the Central Valley aquifer, California, USA</i> : Science of the Total Environment 601-602 (2017) 1160-1172	Parametric machine learning study evaluating 145 spatially variable properties as predictors of well nitrate concentrations.
Smith, Ryan, Rosemary Knight and Scott Fendorf, 2018. <i>Overpumping leads to California groundwater arsenic threat</i> : Nature Communications (2018)9:2089.	Paper regarding an observed correlation between groundwater level decline and subsidence, and groundwater arsenic concentrations in some portions of the San Joaquin Valley
Visser, Ate, et al., 2013. <i>Groundwater age distributions at a public drinking water supply well field derived from multiple age tracers (⁸⁵Kr, ³H/³He, and ³⁹Ar)</i> : Water Resources Research, Vol 49, 7778-7796.	Describes the use of isotopic tracers to age date groundwater contributions to different levels in public supply wells.
Yager, Richard, M. and Charles E. Heywood, 2014. <i>Simulation of the Effects of Seasonally Varying Pumping on Intraborehole Flow and the Vulnerability of Public-Supply Wells to Contamination</i> : Groundwater - Focus Issue, Vol 52 Pg. 40-52.	Evaluation of contaminant transport via intraborehole flow through public supply wells in Modesto, CA and Albuquerque, NM using MODFLOW and MT3DMS.

Notes:

USGS = United States Geological Survey

TABLE 5-2
WELLS DESIGNATED FOR SAMPLING OR PROFILING AND RATIONALE
Draft RIFS Workplan
City of Modesto
Modesto, California

Well No.	Study Area	Status	Depth	Screen Interval	Proposed Sampling			Rationale
					Dynamic	Ambient	Whole Well	
2	Nitrate/Uranium	Inactive/Non Potable	220	92 to 216 open bottom?			✓	Well was taken off line due to uranium in 2005, additional sampling would extend the data record, allow assessment of more recent trends, and provide additional data in the downtown area, where many wells have been impacted by uranium.
14	Nitrate/Uranium	Inactive/Non Potable	189	open bottom?			✓	Well was taken off line due to uranium in 2007, additional sampling would extend the data record, allow assessment of more recent trends, and provide additional data in the downtown area, where many wells have been impacted by uranium.
18	Recharge	Inactive/Non Potable	244	104 to 232 open bottom?		✓		Well was taken off line due to uranium in 2004, additional sampling would extend the period of record and allow assessment of more recent trends in the downtown area, where many wells have been impacted by uranium. The well is a good candiate for ambient profiling to determine contaminant migration from the shallow to the intermediate aquifer.
22	Nitrate/Uranium	Inactive/Non Potable w/ no flush capability	241	130 to 136 222 to 230		✓		Well was taken off line due to uranium in 2004, additional sampling would extend the period of record and allow assessment of more recent trends. The well is a good candiate for ambient profiling to determine contaminant migration from the shallow to the intermediate aquifer.
25	Recharge	Active w/ flush Line	366	91 to 366	✓			Well is impacted with arsenic, nitrate and uranium and was profiled by USGS in 2004. Repeat profiling would extend the period of record and would provide data for potential model history matching. The well is a good candidate for dynamic profiling due to the long screen interval and the presence of a flush line.
32	Recharge	Abandoned	216	open bottom?			✓	Well was abandoned in 2006 due to nitrate and DBCP. Additional sampling would extend the period of record and allow assessment of more recent trends, and support better characterization of the western portion of this study area. Need to verify well can be sampled.
33	Nitrate/Uranium	Active w/ flush Line	278	96 to 278	✓			Well is impacted with arsenic and uranium. It is a good candidate for dynamic profiling based on the long screen interval and presence of a flush line. Its location near Well 22 makes this well pair a good candidate for evaluating the impact of vertical contaminant migration through well 22 from the shallow to the intermediate aquifer.
37	Recharge	Inactive/Non Potable	218	102 to 214 open bottom?			✓	Well was taken off line due to uranium in 2003, additional sampling would extend the period of record and allow assessment of more recent trends, and support better characterization of the western portion of this study area.
214	None	Inactive	148	open bottom?			✓	Well was taken off line in 2007 due to nitrate and arsenic. It is located near the nitrate and recharge study areas and sampling it would extend the period of record and allow assessment of more recent trends and distribution near the study area boundaries.
226	None	Inactive	272	open bottom?			✓	Well was taken off line in 2006 due to arsenic and nitrate. It is located between the arsenic and nitrate study areas and sampling it would extend the period of record, allow assessment of more recent trends and provide data near the study area boundaries. In addition, it is located near wells 33 and 22, and data from this wells would allow closer characterization of contaminant distribution in this area.
229	Nitrate/Uranium	Inactive	230	174 to 226			✓	Well was taken off line in 2016 due to nitrate. It is located in the southern portion of the nitrate/uranium study area and sampling it would extend the period of record and allow assessment of more recent trends and contaminant distribution in this area.
236	Nitrate/Uranium	Active w/ flush Line	206	97 to 206	✓			Well is impacted with nitrate and is on the watch list for arsenic and uranium. The well is a good candidate for dynamic profiling due to the long screen interval and the presence of a flush line. Its location in the central portion of the nitrate/uranium study area would extend characterization in this area.



TABLE 5-2
WELLS DESIGNATED FOR SAMPLING OR PROFILING AND RATIONALE
Draft RIFS Workplan
City of Modesto
Modesto, California

Well No.	Study Area	Status	Depth	Screen Interval	Proposed Sampling			Rationale
					Dynamic	Ambient	Whole Well	
281	Arsenic	Inactive/Non Potable w/ no flush capability	365	??		✓		Well was taken off line due to arsenic and nitrate in 2013, additional sampling would extend the period of record and allow assessment of more recent trends. The well is a good candiate for ambient profiling to determine contaminant distribution and migration from the shallow to the intermediate aquifer.
313	Arsenic	Active w/ flush Line	322	171 to 187 225 to 235 307 to 322	✓			Well is on the watch list for arsenic. It is a good candidate for dynamic profiling based on the long screen interval and presence of a flush line. Its location near Well 281 makes this well pair a good candidate for evaluating the impact of vertical contaminant migration through Well 281 from the shallow to the intermediate aquifer.
USGS Wells	Recharge	Monitoring Wells	Various	Various			✓	Additional sampling will help to characterize long term trends and would support potential model history matching. In additon, groundwater level measurements will help to establish current groundwater gradients.

Notes:

Wells for dynamic profiling were selected based on (1) the existence of a long screen interval; (2) the presence of significant contaminant concentrations; (3) the existence of flush lines for disposing of large quantities of purge water; and (4) location of the wells in areas of interest within the designated study areas. Dynamic profiles will provide data regarding well behavior and vertical contaminant distribution useful for constructing solute transport models. These data will be used together with existing profiling data for wells 21, 25, 61, 64, 66 and 225. New data will be collected from Well 25 and the nearby monitoring wells in order to collect additional data for model refinement in this area. This level of data density is not available in other areas of the City, but will help in development of a more refined model in this area.

Wells for ambient profiling were selected based on the same criteria as wells for dynamic profiling, except that they were not equipped with a suitable means for disposign large volumes of purge water and therefore are not practical for dynamic profiling. Ambient samplign data will be more limited, but still useful for assessment of well behavior and vertical contaminant distribution. In addition, these data can be used to assess the rate of intra-borehole transport of contamination between aquifers.

Wells for whole-well sampling were selected based on (1) presence of contaminant impacts; (2) inactive status (i.e., no data available since well disconnection); (3) preferred ability to sample at the wellhead usign existing pumps; and (4) location of the wells in areas of interest within or near the boundaries of the designated study areas. Data from these wells will extend the period of record for trend analysis of "problem wells," and will provide useful characterization data for contaminant distribution and groundwater levels.

No. = number
USGS = United States Geological Survey



DRAFT RIFS WORKPLAN

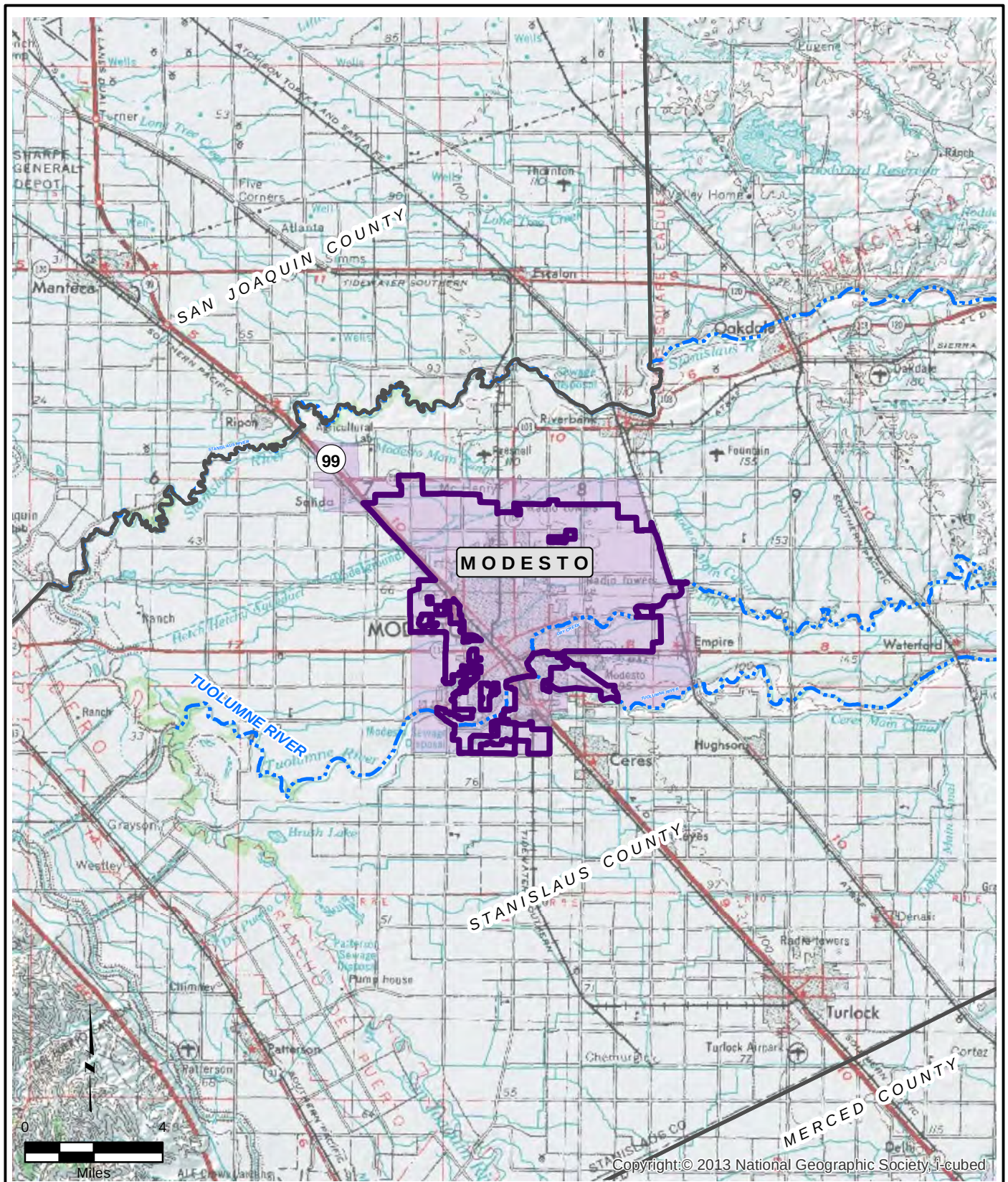
CITY OF MODESTO WELL FIELD RIFS, MODESTO, CALIFORNIA – APRIL 26, 2019

FIGURES

LIST OF FIGURES

Figure 2-1	Location Map, City of Modesto
Figure 2-2	City of Modesto RIFS Study Area
Figure 2-3	Municipal Wells Impacted by Arsenic, Nitrate and/or Uranium
Figure 2-4	Municipal Wells Taken Off-Line Due to Arsenic, Nitrate and/or Uranium
Figure 2-5	Shallow Aquifer Zone Well Map Arsenic Concentrations (2015 – 2017)
Figure 2-6	Intermediate Aquifer Zone Well Map Arsenic Concentrations (2015 – 2017)
Figure 2-7	Deep Aquifer Zone Well Map Arsenic Concentrations (2015 – 2017)
Figure 2-8	Shallow Aquifer Zone Well Map Nitrate Concentrations (2015 – 2017)
Figure 2-9	Intermediate Aquifer Zone Well Map Nitrate Concentrations (2015 – 2017)
Figure 2-10	Deep Aquifer Zone Well Map Nitrate Concentrations (2015 – 2017)
Figure 2-11	Shallow Aquifer Zone Well Map Uranium Concentrations (2015 – 2017)
Figure 2-12	Intermediate Aquifer Zone Well Map Uranium Concentrations (2015 – 2017)
Figure 2-13	Deep Aquifer Zone Well Map Uranium Concentrations (2015 – 2017)
Figure 3-1	City of Modesto RIFS Study Area Regional Model Section View
Figure 3-2	Conceptual Models of Hydrologic Processes
Figure 4-1	Sampling and Profiling Well Map
Figure 6-1	City of Modesto RIFS Study Area and Regional Model Boundary
Figure 6-2	City of Modesto RIFS Study Area Model Boundary Conditions

Path: J:\GIS\Modesto\2019\RI\FS\Workplan\Figure 2-1 Location Map.mxd



MODESTO CITY LIMITS



MODESTO CONTIGUOUS
WATER SERVICE AREA



DRAFT

LOCATION MAP CITY OF MODESTO

CITY OF MODESTO
STANISLAUS COUNTY CALIFORNIA



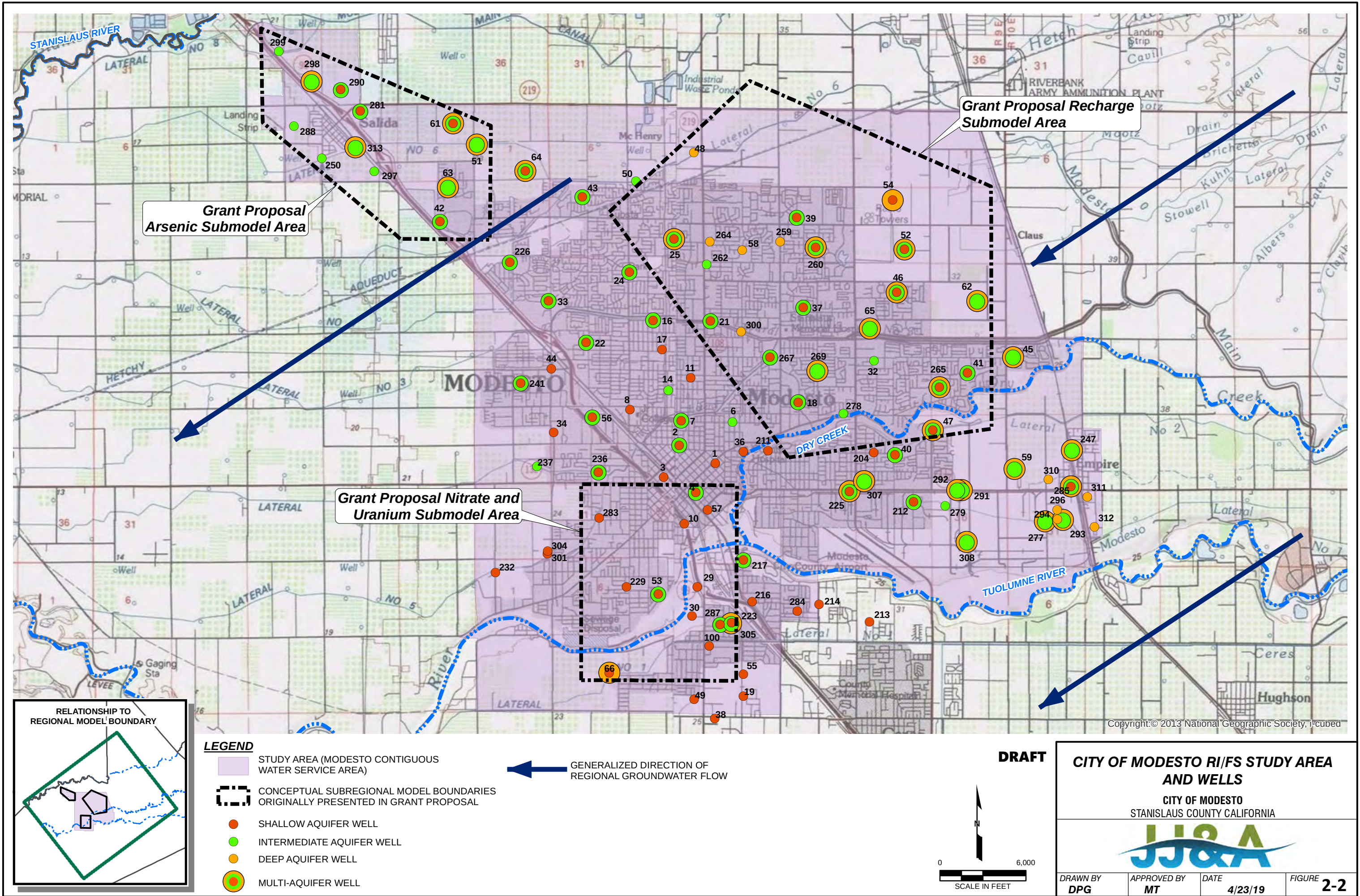
DRAWN BY
DPG

APPROVED BY
RS

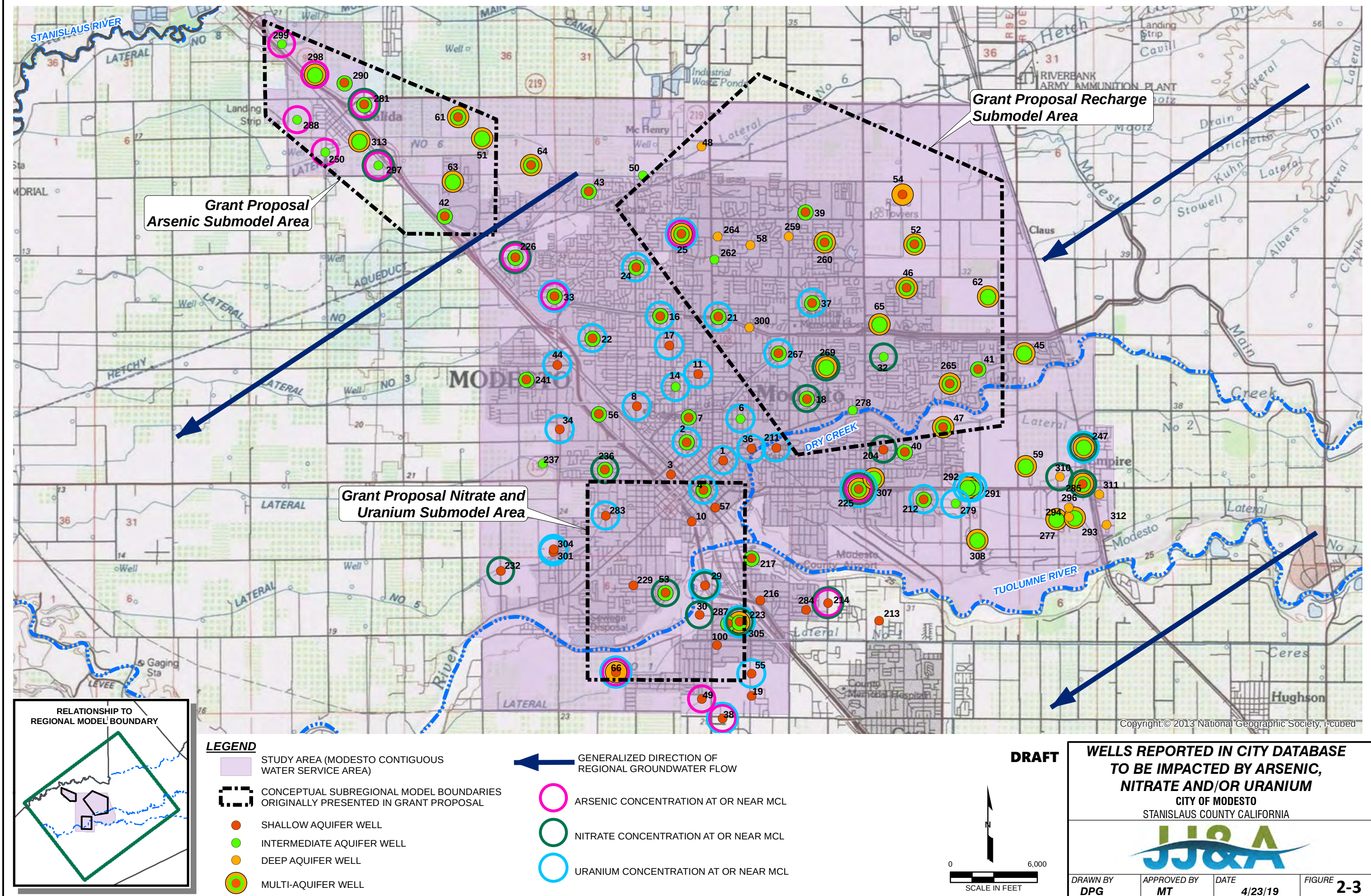
DATE
3/3/19

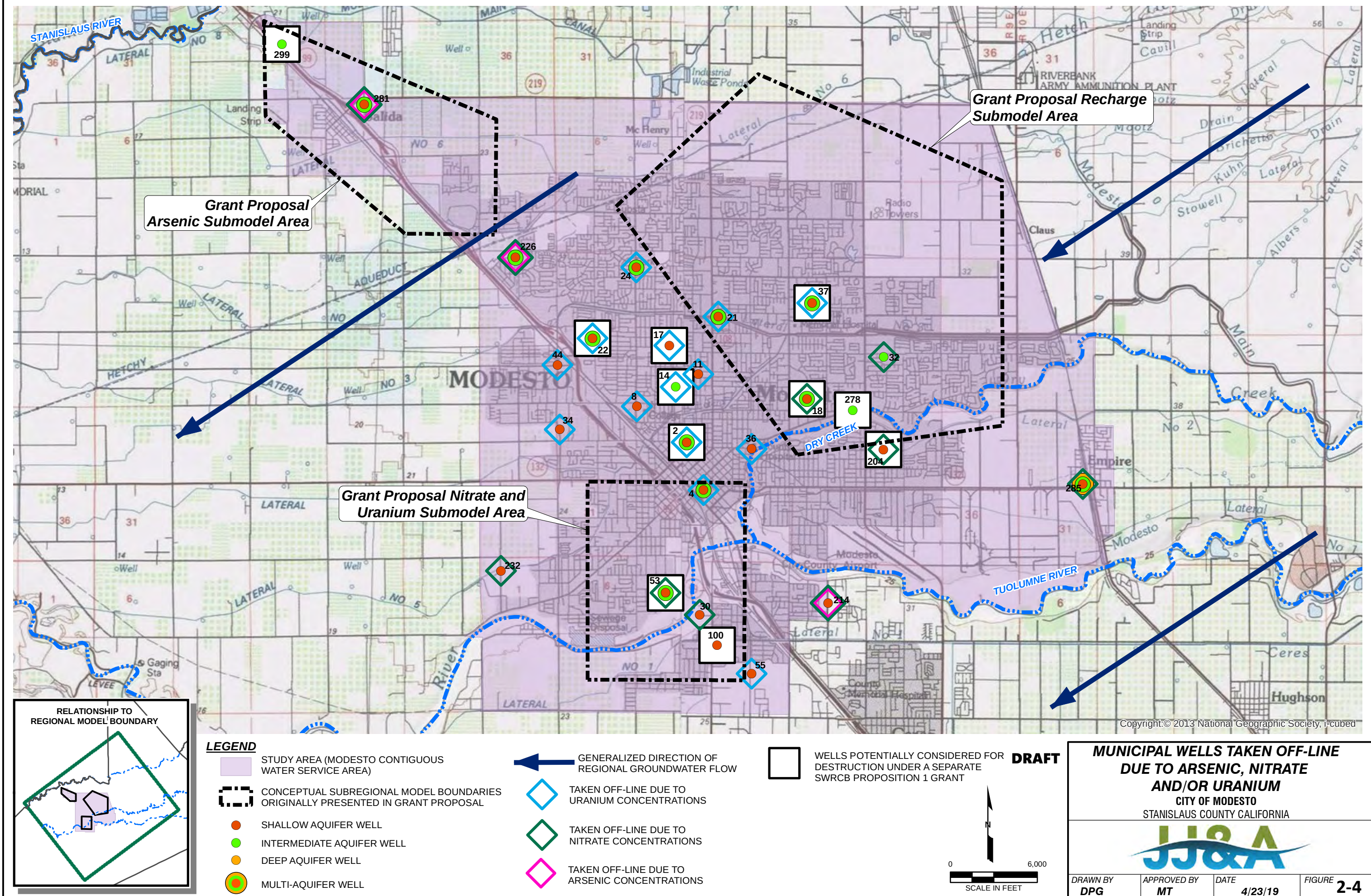
FIGURE

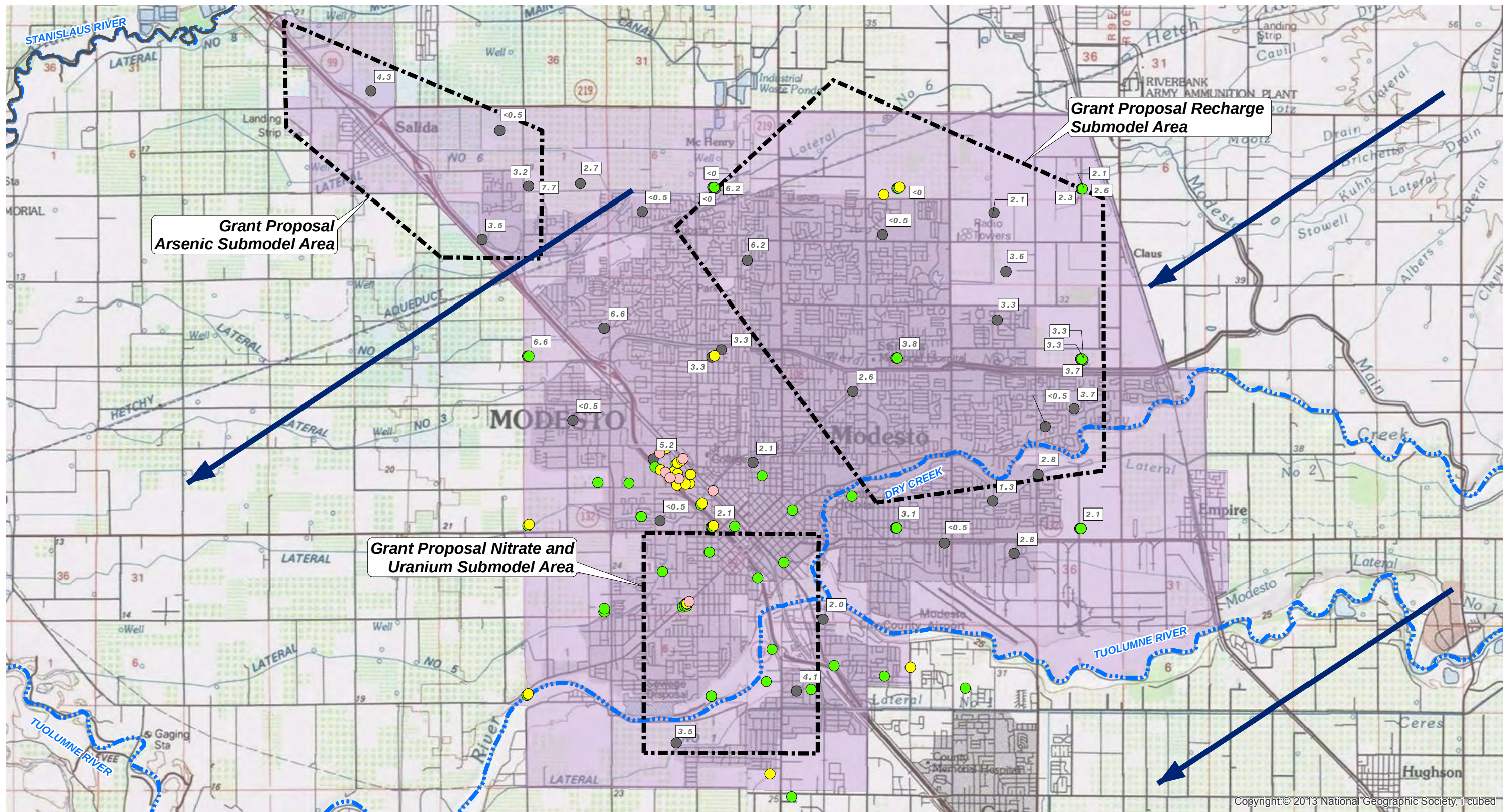
2-1



Copyright © 2013 National Geographic Society, I-cubed







LEGEND

- STUDY AREA (MODESTO CONTIGUOUS WATER SERVICE AREA)
- CONCEPTUAL SUBREGIONAL MODEL BOUNDARIES ORIGINALLY PRESENTED IN GRANT PROPOSAL
- MULTIPLE AQUIFER WELL
- SHALLOW AQUIFER WELL WITH CONCENTRATION BELOW 5 µg/L
- SHALLOW AQUIFER WELL WITH CONCENTRATION BETWEEN 5 µg/L AND 10 µg/L
- SHALLOW AQUIFER WELL WITH CONCENTRATION AT OR ABOVE 10 µg/L

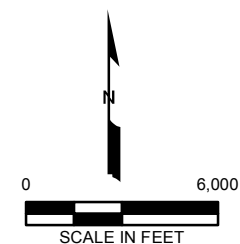
GENERALIZED DIRECTION OF REGIONAL GROUNDWATER FLOW

ARSENIC RESULTS ARE PRESENTED AS MICROGRAMS PER LITER (µg/L).

ARSENIC MAXIMUM CONTAMINANT LEVEL (MCL) = 10 µg/L

- 1 VALUES REPRESENT AN AVERAGE PER LOCATION FROM SAMPLES COLLECTED IN 2015, 2016 AND 2017. VALUES FROM PRIOR TO 2015 HAVE NOT COMPLETED A QUALITY CONTROL PROCESS.
- 2 REGIONAL WELLS WILL BE ADDED OUTSIDE THE STUDY AREA AND WELLS MAY BE CATEGORIZED TO DIFFERENT DEPTH INTERVALS AS ADDITIONAL DATA BECOME AVAILABLE DURING THE RI.

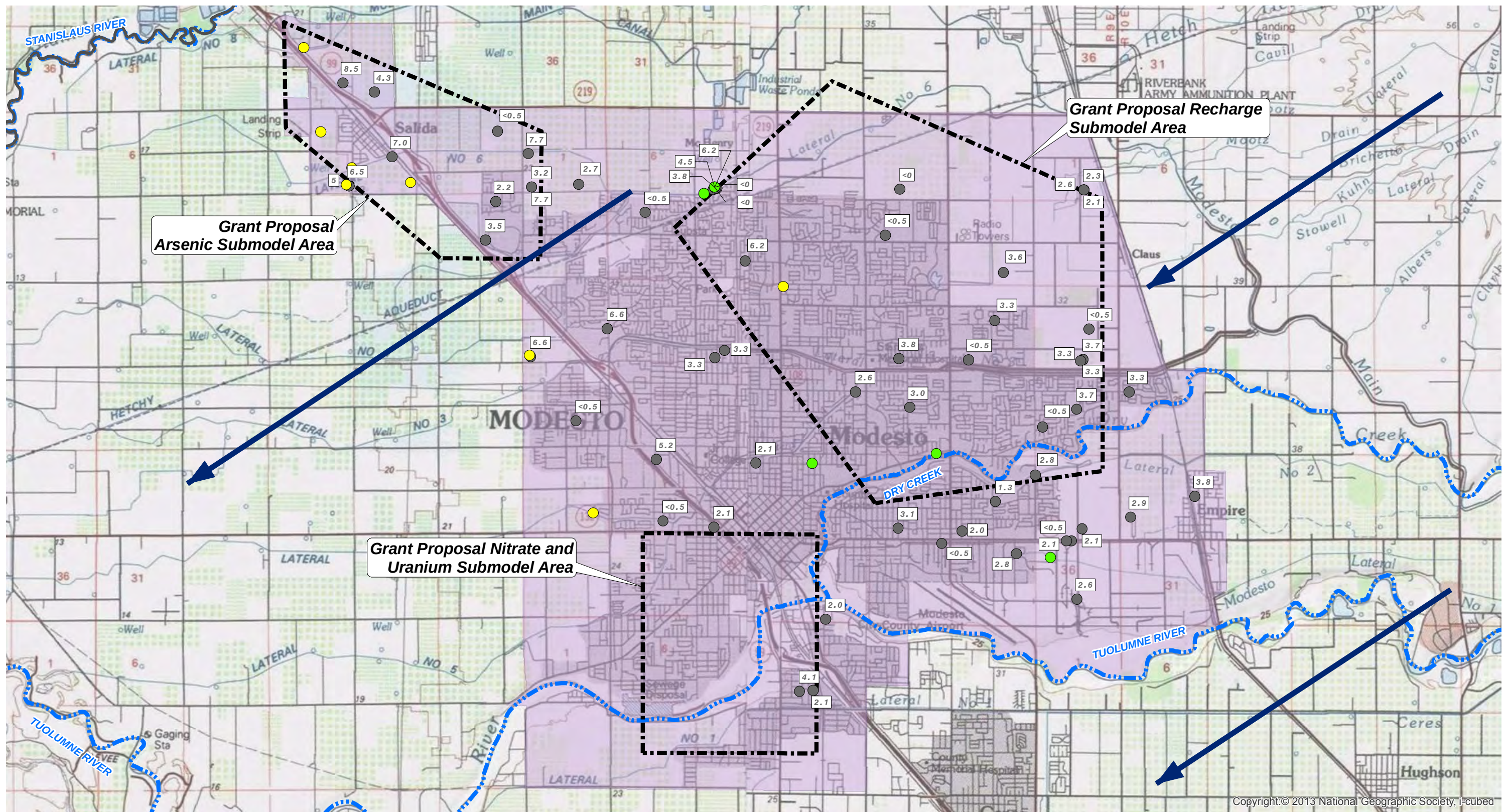
DRAFT



SHALLOW AQUIFER ZONE WELL MAP
ARSENIC CONCENTRATIONS
(2015-2017)¹
CITY OF MODESTO
STANISLAUS COUNTY CALIFORNIA



DRAWN BY DPG	APPROVED BY TH	DATE 4/17/19	FIGURE 2-5
-----------------	-------------------	-----------------	---------------



LEGEND

- STUDY AREA (MODESTO CONTIGUOUS WATER SERVICE AREA)
- CONCEPTUAL SUBREGIONAL MODEL BOUNDARIES ORIGINALLY PRESENTED IN GRANT PROPOSAL
- MULTIPLE AQUIFER WELL
- INTERMEDIATE AQUIFER WELL WITH CONCENTRATION BELOW 5 µg/L
- INTERMEDIATE AQUIFER WELL WITH CONCENTRATION BETWEEN 5 µg/L AND 10 µg/L
- INTERMEDIATE AQUIFER WELL WITH CONCENTRATION AT OR ABOVE 10 µg/L

- GENERALIZED DIRECTION OF REGIONAL GROUNDWATER FLOW
- ARSENIC RESULTS ARE PRESENTED AS MICROGRAMS PER LITER (µg/L).
- ARSENIC MAXIMUM CONTAMINANT LEVEL (MCL) = 10 µg/L

- VALUES REPRESENT AN AVERAGE PER LOCATION FROM SAMPLES COLLECTED IN 2015, 2016 AND 2017. VALUES FROM PRIOR TO 2015 HAVE NOT COMPLETED A QUALITY CONTROL PROCESS.
- REGIONAL WELLS WILL BE ADDED OUTSIDE THE STUDY AREA AND WELLS MAY BE CATEGORIZED TO DIFFERENT DEPTH INTERVALS AS ADDITIONAL DATA BECOME AVAILABLE DURING THE RI.

DRAFT

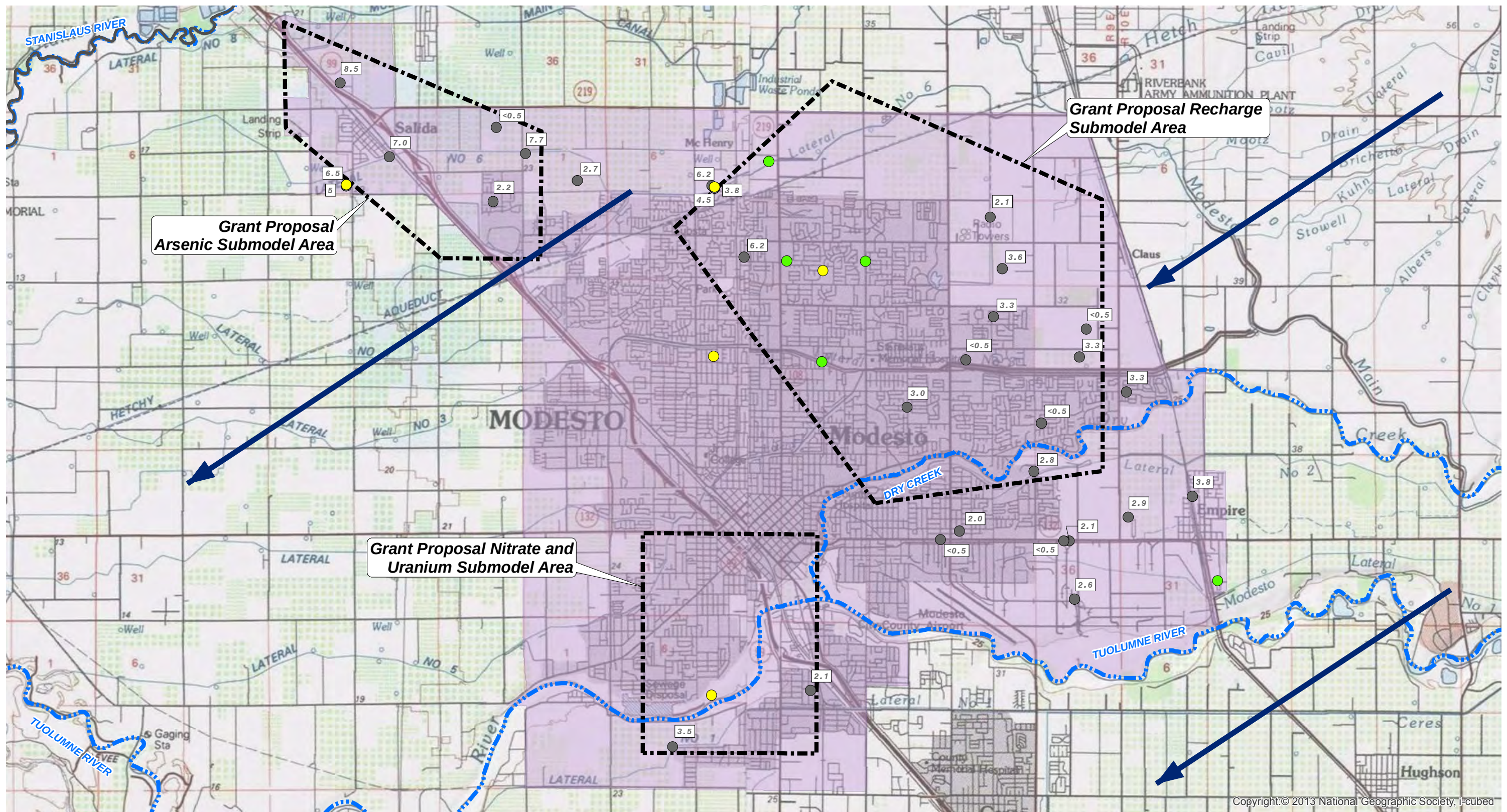
INTERMEDIATE AQUIFER ZONE WELL MAP ARSENIC CONCENTRATIONS (2015-2017)¹

CITY OF MODESTO
STANISLAUS COUNTY CALIFORNIA



DRAWN BY	APPROVED BY	DATE	FIGURE
DPG	TH	4/17/19	2-6

Path: J:\GIS\Modesto2019\RI\GIS\Workplan\Figure 2-7 Arsenic Zone D.mxd



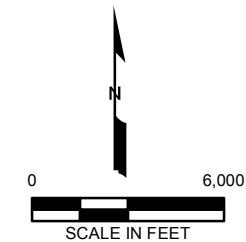
LEGEND

- STUDY AREA (MODESTO CONTIGUOUS WATER SERVICE AREA)
- CONCEPTUAL SUBREGIONAL MODEL BOUNDARIES ORIGINALLY PRESENTED IN GRANT PROPOSAL
- MULTIPLE AQUIFER WELL
- DEEP AQUIFER WELL WITH CONCENTRATION BELOW 5 µg/L
- DEEP AQUIFER WELL WITH CONCENTRATION BETWEEN 5 µg/L AND 10 µg/L
- DEEP AQUIFER WELL WITH CONCENTRATION AT OR ABOVE 10 µg/L

- GENERALIZED DIRECTION OF REGIONAL GROUNDWATER FLOW
- ARSENIC RESULTS ARE PRESENTED AS MICROGRAMS PER LITER (µg/L).
- ARSENIC MAXIMUM CONTAMINANT LEVEL (MCL) = 10 µg/L

- VALUES REPRESENT AN AVERAGE PER LOCATION FROM SAMPLES COLLECTED IN 2015, 2016 AND 2017. VALUES FROM PRIOR TO 2015 HAVE NOT COMPLETED A QUALITY CONTROL PROCESS.
- REGIONAL WELLS WILL BE ADDED OUTSIDE THE STUDY AREA AND WELLS MAY BE CATEGORIZED TO DIFFERENT DEPTH INTERVALS AS ADDITIONAL DATA BECOME AVAILABLE DURING THE RI.

DRAFT

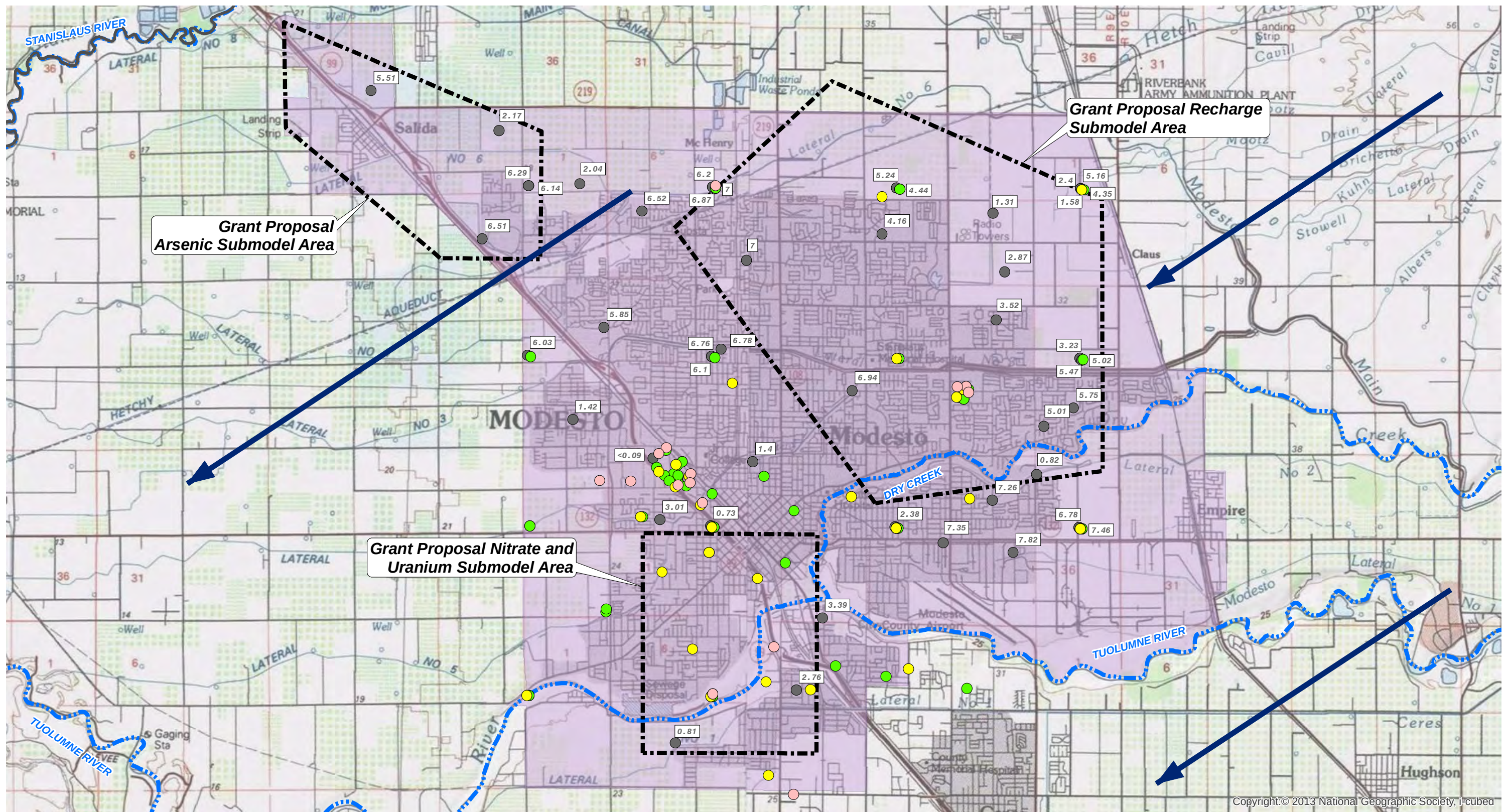


DEEP AQUIFER ZONE WELL MAP ARSENIC CONCENTRATIONS (2015-2017)¹ CITY OF MODESTO STANISLAUS COUNTY CALIFORNIA



DRAWN BY DPG	APPROVED BY TH	DATE 4/17/19	FIGURE 2-7
-----------------	-------------------	-----------------	---------------

Path: J:\GIS\Modesto\2019\RI\GIS\Workplan\Figure 2-8 Nitrate Zone S.mxd



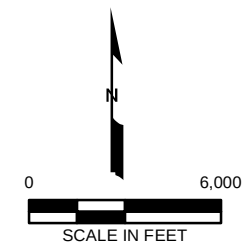
LEGEND

- STUDY AREA (MODESTO CONTIGUOUS WATER SERVICE AREA)
- CONCEPTUAL SUBREGIONAL MODEL BOUNDARIES ORIGINALLY PRESENTED IN GRANT PROPOSAL
- MULTIPLE AQUIFER WELL
- SHALLOW AQUIFER WELL WITH CONCENTRATION BELOW 5 mg/L
- SHALLOW AQUIFER WELL WITH CONCENTRATION BETWEEN 5 mg/L AND 10 mg/L
- SHALLOW AQUIFER WELL WITH CONCENTRATION AT OR ABOVE 10 mg/L

- GENERALIZED DIRECTION OF REGIONAL GROUNDWATER FLOW
- NITRATE RESULTS ARE PRESENTED AS MILLIGRAMS PER LITER (mg/L).
- NITRATE MAXIMUM CONTAMINANT LEVEL (MCL) = 10 mg/L

- ¹ VALUES REPRESENT AN AVERAGE PER LOCATION FROM SAMPLES COLLECTED IN 2015, 2016 AND 2017. VALUES FROM PRIOR TO 2015 HAVE NOT COMPLETED A QUALITY CONTROL PROCESS.
- ² REGIONAL WELLS WILL BE ADDED OUTSIDE THE STUDY AREA AND WELLS MAY BE CATEGORIZED TO DIFFERENT DEPTH INTERVALS AS ADDITIONAL DATA BECOME AVAILABLE DURING THE RI.

DRAFT



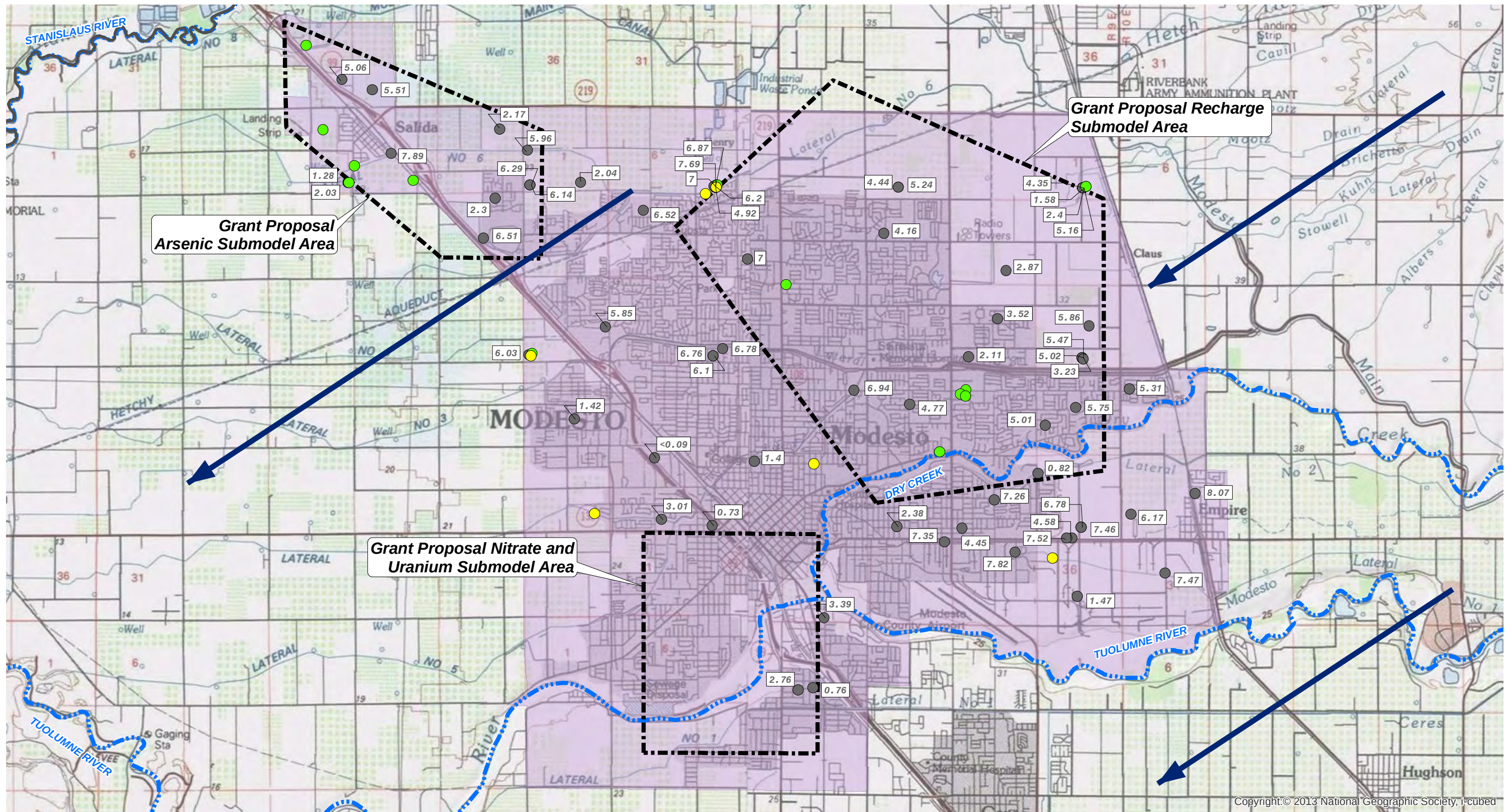
**SHALLOW AQUIFER ZONE WELL MAP
NITRATE CONCENTRATIONS**

(2015-2017)¹
CITY OF MODESTO
STANISLAUS COUNTY CALIFORNIA



DRAWN BY DPG	APPROVED BY TH	DATE 4/17/19	FIGURE 2-8
-----------------	-------------------	-----------------	----------------------

Path: J:\GIS\Modesto2019\RI\GIS\Workplan\Figure 2-9 Nitrate Zone 1.mxd



LEGEND

- STUDY AREA (MODESTO CONTIGUOUS WATER SERVICE AREA)
- CONCEPTUAL SUBREGIONAL MODEL BOUNDARIES ORIGINALLY PRESENTED IN GRANT PROPOSAL
- MULTIPLE AQUIFER WELL
- INTERMEDIATE AQUIFER WELL WITH CONCENTRATION BELOW 5 mg/L
- INTERMEDIATE AQUIFER WELL WITH CONCENTRATION BETWEEN 5 mg/L AND 10 mg/L
- INTERMEDIATE AQUIFER WELL WITH CONCENTRATION AT OR ABOVE 10 mg/L

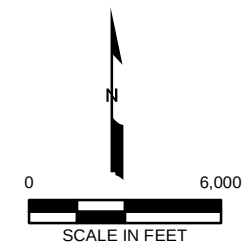
GENERALIZED DIRECTION OF REGIONAL GROUNDWATER FLOW

NITRATE RESULTS ARE PRESENTED AS MILLIGRAMS PER LITER (mg/L).

NITRATE MAXIMUM CONTAMINANT LEVEL (MCL) = 10 mg/L

- ¹ VALUES REPRESENT AN AVERAGE PER LOCATION FROM SAMPLES COLLECTED IN 2015, 2016 AND 2017. VALUES FROM PRIOR TO 2015 HAVE NOT COMPLETED A QUALITY CONTROL PROCESS.
- ² REGIONAL WELLS WILL BE ADDED OUTSIDE THE STUDY AREA AND WELLS MAY BE CATEGORIZED TO DIFFERENT DEPTH INTERVALS AS ADDITIONAL DATA BECOME AVAILABLE DURING THE RI.

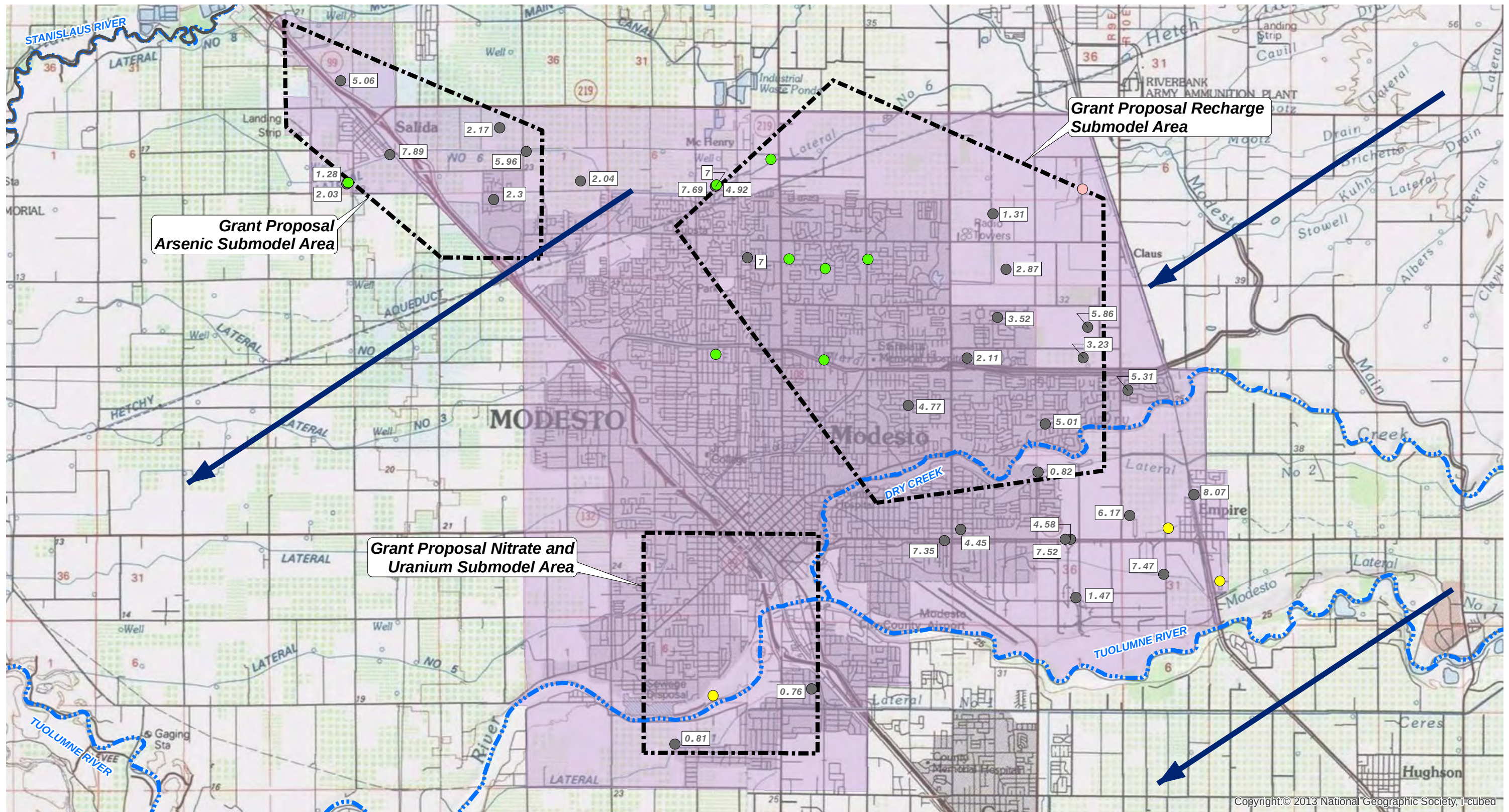
DRAFT



INTERMEDIATE AQUIFER ZONE WELL MAP
NITRATE CONCENTRATIONS
(2015-2017)¹
CITY OF MODESTO
STANISLAUS COUNTY CALIFORNIA



DRAWN BY DPG	APPROVED BY TH	DATE 4/17/19	FIGURE 2-9
-----------------	-------------------	-----------------	---------------



LEGEND

- STUDY AREA (MODESTO CONTIGUOUS WATER SERVICE AREA)
- CONCEPTUAL SUBREGIONAL MODEL BOUNDARIES ORIGINALLY PRESENTED IN GRANT PROPOSAL
- MULTIPLE AQUIFER WELL
- DEEP AQUIFER WELL WITH CONCENTRATION BELOW 5 mg/L
- DEEP AQUIFER WELL WITH CONCENTRATION BETWEEN 5 mg/L AND 10 mg/L
- DEEP AQUIFER WELL WITH CONCENTRATION AT OR ABOVE 10 mg/L

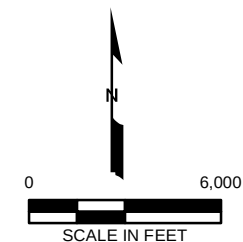
GENERALIZED DIRECTION OF REGIONAL GROUNDWATER FLOW

NITRATE RESULTS ARE PRESENTED AS MILLIGRAMS PER LITER (mg/L).

NITRATE MAXIMUM CONTAMINANT LEVEL (MCL) = 10 mg/L

- ¹ VALUES REPRESENT AN AVERAGE PER LOCATION FROM SAMPLES COLLECTED IN 2015, 2016 AND 2017. VALUES FROM PRIOR TO 2015 HAVE NOT COMPLETED A QUALITY CONTROL PROCESS.
- ² REGIONAL WELLS WILL BE ADDED OUTSIDE THE STUDY AREA AND WELLS MAY BE CATEGORIZED TO DIFFERENT DEPTH INTERVALS AS ADDITIONAL DATA BECOME AVAILABLE DURING THE RI.

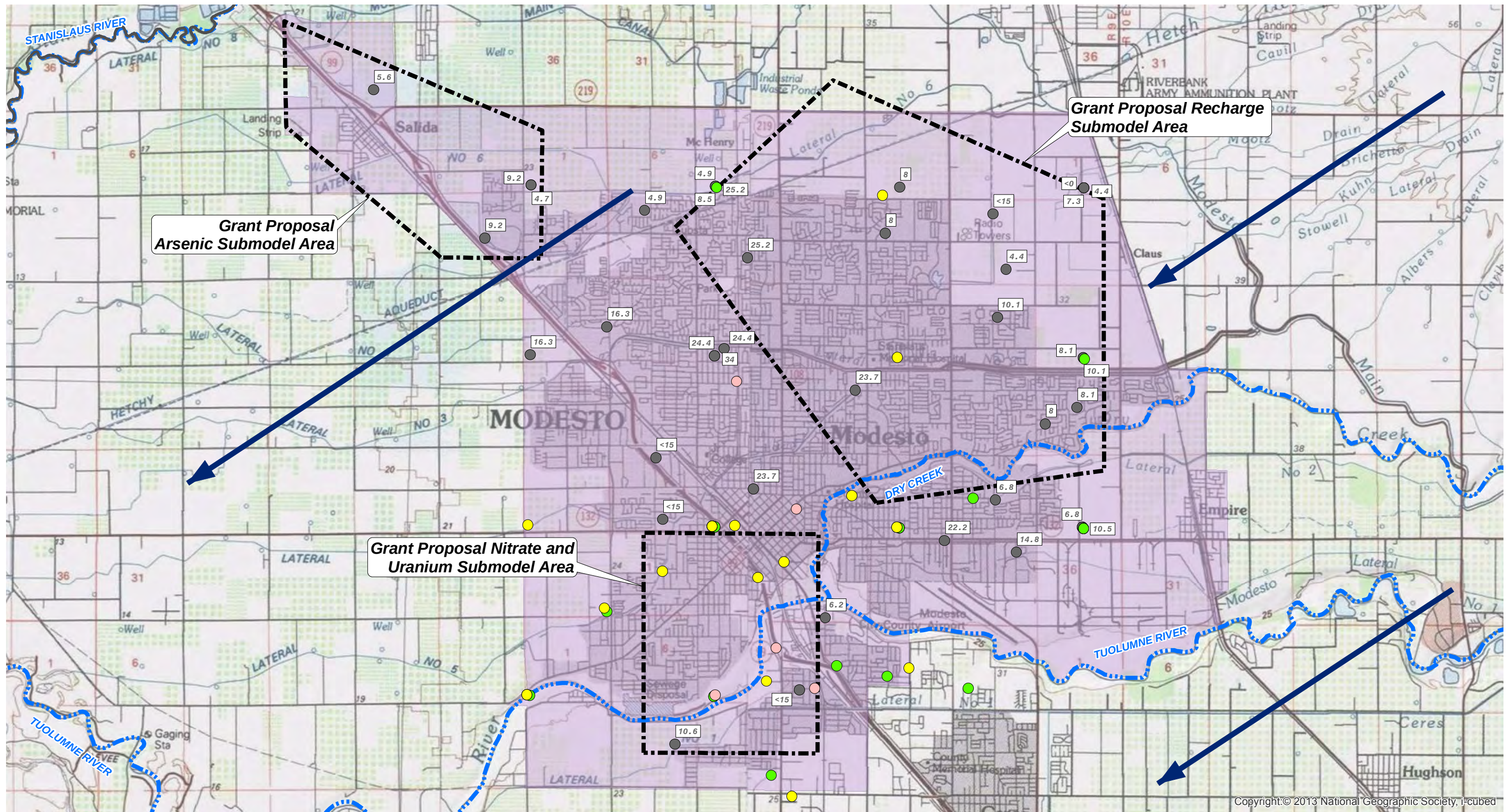
DRAFT



DEEP AQUIFER ZONE WELL MAP
NITRATE CONCENTRATIONS
(2015-2017)¹
CITY OF MODESTO
STANISLAUS COUNTY CALIFORNIA



DRAWN BY	APPROVED BY	DATE	FIGURE
DPG	TH	4/17/19	2-10



LEGEND

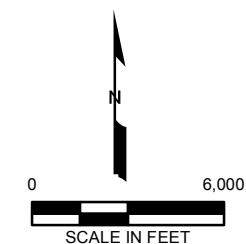
- STUDY AREA (MODESTO CONTIGUOUS WATER SERVICE AREA)
- CONCEPTUAL SUBREGIONAL MODEL BOUNDARIES ORIGINALLY PRESENTED IN GRANT PROPOSAL
- MULTIPLE AQUIFER WELL
- SHALLOW AQUIFER WELL WITH CONCENTRATION BELOW 15 µg/L
- SHALLOW AQUIFER WELL WITH CONCENTRATION BETWEEN 15 µg/L AND 30 µg/L
- SHALLOW AQUIFER WELL WITH CONCENTRATION AT OR ABOVE 30 µg/L

- GENERALIZED DIRECTION OF REGIONAL GROUNDWATER FLOW
- URANIUM RESULTS ARE PRESENTED AS MICROGRAMS PER LITER (µg/L).
- URANIUM MAXIMUM CONTAMINANT LEVEL (MCL) = 30 µg/L

1 VALUES REPRESENT AN AVERAGE PER LOCATION FROM SAMPLES COLLECTED IN 2015, 2016 AND 2017. VALUES FROM PRIOR TO 2015 HAVE NOT COMPLETED A QUALITY CONTROL PROCESS.

2 REGIONAL WELLS WILL BE ADDED OUTSIDE THE STUDY AREA AND WELLS MAY BE CATEGORIZED TO DIFFERENT DEPTH INTERVALS AS ADDITIONAL DATA BECOME AVAILABLE DURING THE RI.

DRAFT

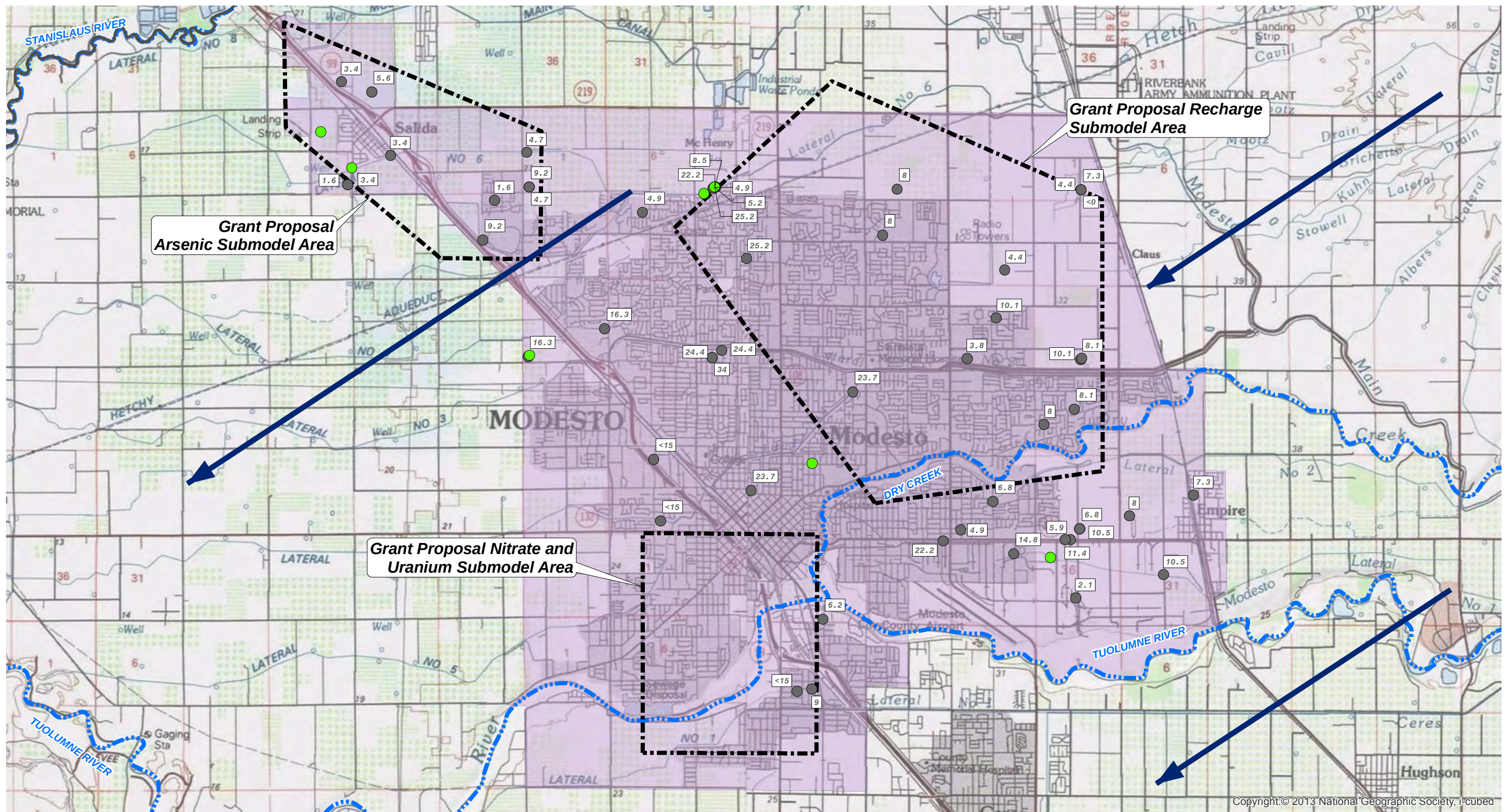


**SHALLOW AQUIFER ZONE WELL MAP
URANIUM CONCENTRATIONS**

(2015-2017)¹
CITY OF MODESTO
STANISLAUS COUNTY CALIFORNIA



DRAWN BY	APPROVED BY	DATE	FIGURE
DPG	TH	4/17/19	2-11



Copyright © 2013 National Geographic Society, I-cubed

LEGEND

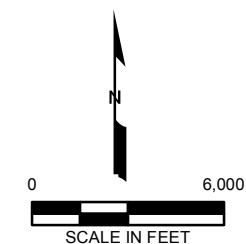
- STUDY AREA (MODESTO CONTIGUOUS WATER SERVICE AREA)
- CONCEPTUAL SUBREGIONAL MODEL BOUNDARIES ORIGINALLY PRESENTED IN GRANT PROPOSAL
- MULTIPLE AQUIFER WELL
- INTERMEDIATE AQUIFER WELL WITH CONCENTRATION BELOW 15 µg/L
- INTERMEDIATE AQUIFER WELL WITH CONCENTRATION BETWEEN 15 µg/L AND 30 µg/L
- INTERMEDIATE AQUIFER WELL WITH CONCENTRATION AT OR ABOVE 30 µg/L

- GENERALIZED DIRECTION OF REGIONAL GROUNDWATER FLOW
- URANIUM RESULTS ARE PRESENTED AS MICROGRAMS PER LITER (µg/L).
- URANIUM MAXIMUM CONTAMINANT LEVEL (MCL) = 30 µg/L

1 VALUES REPRESENT AN AVERAGE PER LOCATION FROM SAMPLES COLLECTED IN 2015, 2016 AND 2017. VALUES FROM PRIOR TO 2015 HAVE NOT COMPLETED A QUALITY CONTROL PROCESS.

2 REGIONAL WELLS WILL BE ADDED OUTSIDE THE STUDY AREA AND WELLS MAY BE CATEGORIZED TO DIFFERENT DEPTH INTERVALS AS ADDITIONAL DATA BECOME AVAILABLE DURING THE RI.

DRAFT

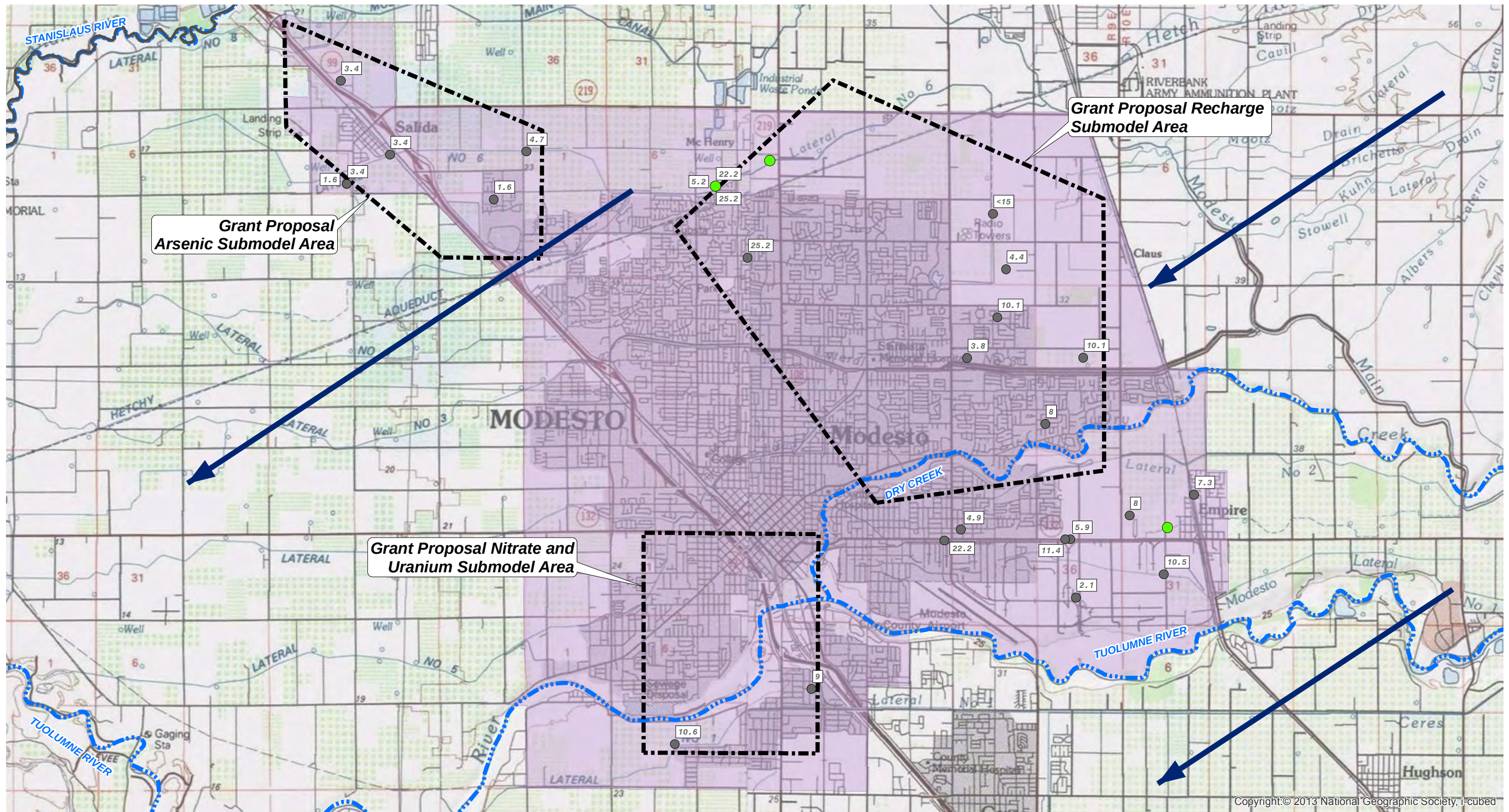


INTERMEDIATE AQUIFER ZONE WELL MAP URANIUM CONCENTRATIONS (2015-2017)¹

CITY OF MODESTO
STANISLAUS COUNTY CALIFORNIA



DRAWN BY DPG	APPROVED BY TH	DATE 4/17/19	FIGURE 2-12
-----------------	-------------------	-----------------	-----------------------

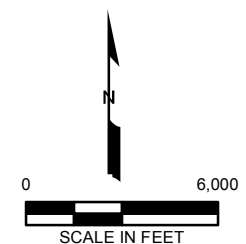


LEGEND

- STUDY AREA (MODESTO CONTIGUOUS WATER SERVICE AREA)
- CONCEPTUAL SUBREGIONAL MODEL BOUNDARIES ORIGINALLY PRESENTED IN GRANT PROPOSAL
- MULTIPLE AQUIFER WELL
- DEEP AQUIFER WELL WITH CONCENTRATION BELOW 15 µg/L
- DEEP AQUIFER WELL WITH CONCENTRATION BETWEEN 15 µg/L AND 30 µg/L
- DEEP AQUIFER WELL WITH CONCENTRATION AT OR ABOVE 30 µg/L

- GENERALIZED DIRECTION OF REGIONAL GROUNDWATER FLOW
- URANIUM RESULTS ARE PRESENTED AS MICROGRAMS PER LITER (µg/L).
- URANIUM MAXIMUM CONTAMINANT LEVEL (MCL) = 30 µg/L
- 1 VALUES REPRESENT AN AVERAGE PER LOCATION FROM SAMPLES COLLECTED IN 2015, 2016 AND 2017. VALUES FROM PRIOR TO 2015 HAVE NOT COMPLETED A QUALITY CONTROL PROCESS.
- 2 REGIONAL WELLS WILL BE ADDED OUTSIDE THE STUDY AREA AND WELLS MAY BE CATEGORIZED TO DIFFERENT DEPTH INTERVALS AS ADDITIONAL DATA BECOME AVAILABLE DURING THE RI.

DRAFT

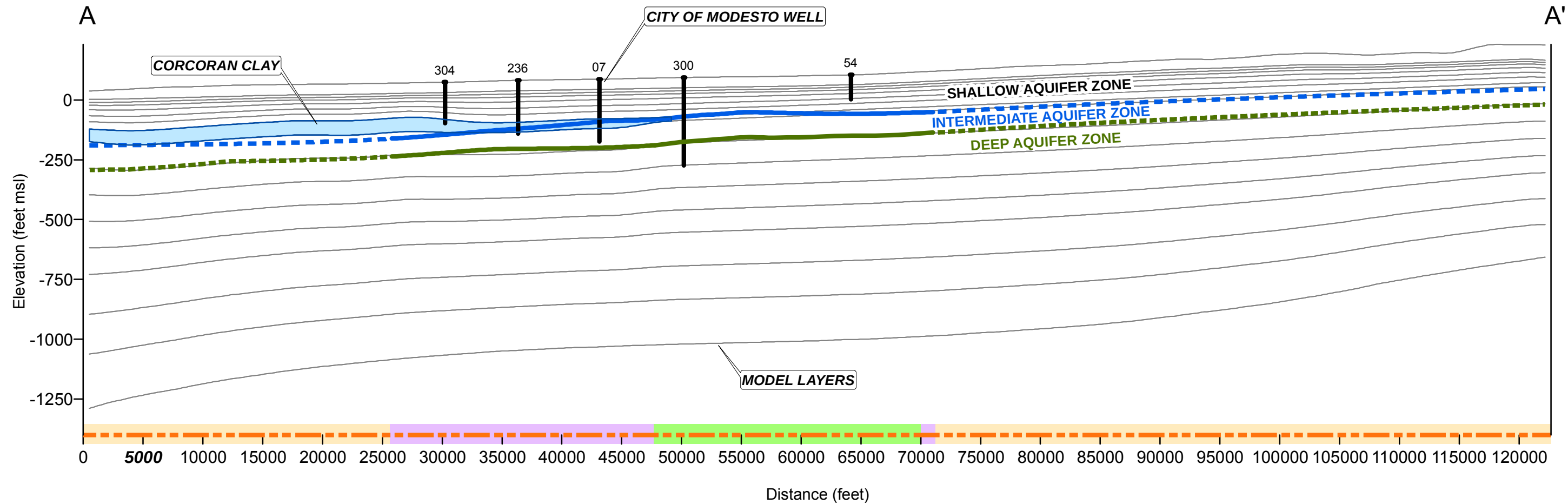


DEEP AQUIFER ZONE WELL MAP
URANIUM CONCENTRATIONS
(2015-2017)¹
CITY OF MODESTO
STANISLAUS COUNTY CALIFORNIA

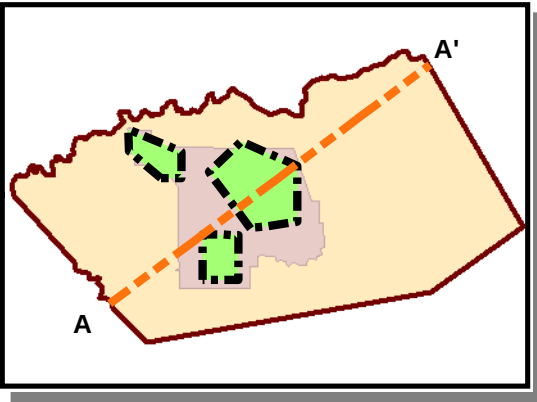
JJA

DRAWN BY DPG	APPROVED BY TH	DATE 4/17/19	FIGURE 2-13
------------------------	--------------------------	------------------------	-----------------------

Path: J:\GIS\Modesto2019\RI\FS\Workplan\Figure 3-1 Cross Section.mxd



SECTION LOCATION



LEGEND

- RIFS REGIONAL MODEL USING THE LRGSS GRID SPACING: 100m x 100m
- CONCEPTUAL RIFS SUBREGIONAL MODEL AREA IDENTIFIED IN GRANT APPLICATION. GRID SPACING: 100ft x 100ft
- STUDY AREA (MODESTO CONTIGUOUS WATER SERVICE AREA)
- TOP OF INTERMEDIATE AQUIFER ZONE (LOWER TURLOCK LAKE FORMATION). DASHED WHERE INFERRED.
- TOP OF DEEP AQUIFER ZONE (LAGUNA FORMATION). DASHED WHERE INFERRED

NOTES

Section A-A' alignment corresponds to regional model LRGSS grid row 154 and RIFS Regional Model grid row 45.

Aquifer zone boundaries were determined based on the local stratigraphy and formation boundary elevations.

The Shallow aquifer zone is defined as the Upper Turlock Lake, Riverbank, Modesto formations (and includes the Corcoran Clay). The Intermediate aquifer zone is defined as the Lower Turlock Lake formation. The Deep aquifer zone is defined as the Laguna and Mehrten formations.

Aquifer zone boundaries inferred outside of the Modesto Contiguous Water Service Area based on regional formation dip and strike.

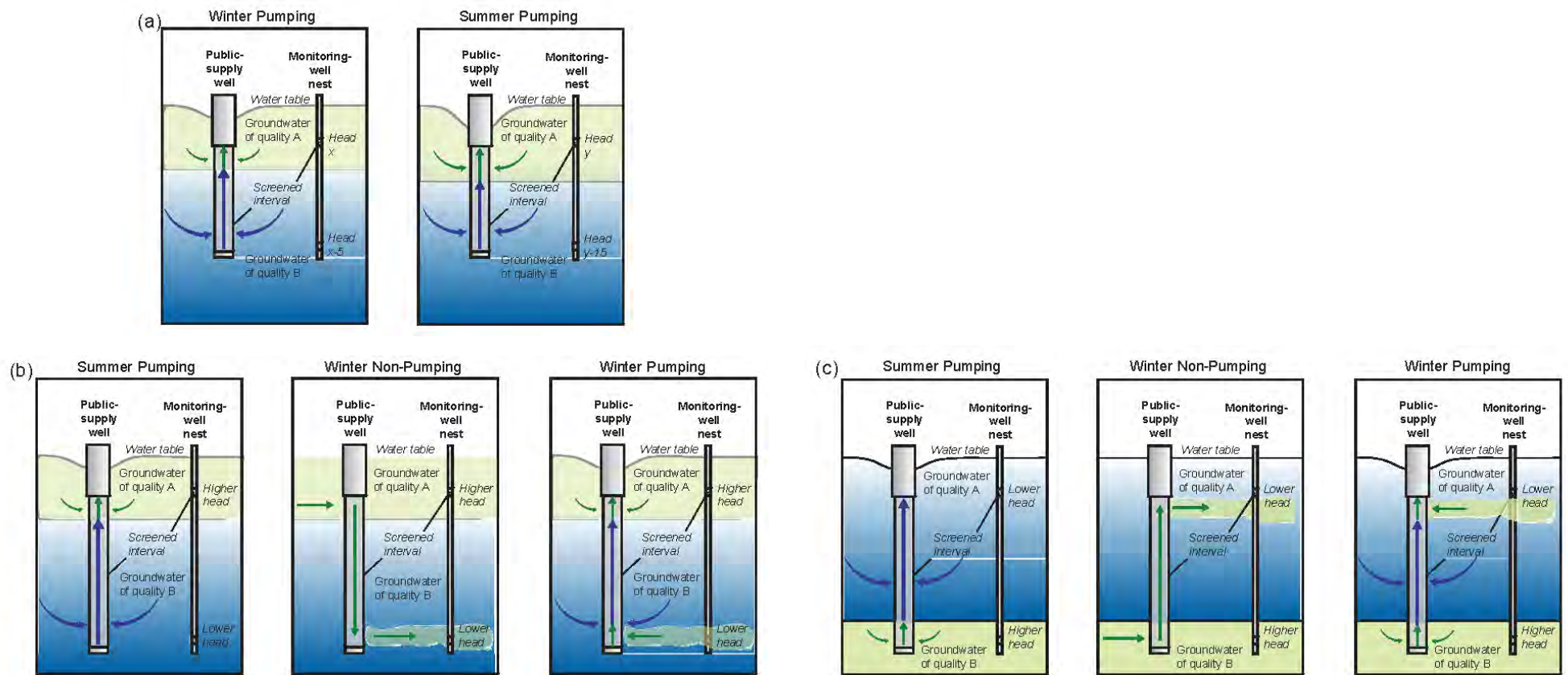
DRAFT

**CITY OF MODESTO RI/FS STUDY AREA
REGIONAL MODEL SECTION VIEW**

CITY OF MODESTO
STANISLAUS COUNTY CALIFORNIA



DRAWN BY DPG	APPROVED BY DJ	DATE 4/23/19	FIGURE 3-1
-----------------	-------------------	-----------------	---------------



Conceptual models of hydrologic processes influencing seasonal variability in the quality of water produced by public-supply wells in the Modesto and Albuquerque study areas, and likely in other alluvial basins with stratified water quality and substantial vertical head gradients. (a) Conceptual model where the dominant process is enhanced downward migration of shallow contaminated groundwater through the aquifer to the screened intervals of supply wells as a result of increased regional pumping during the summer. (b) Conceptual model where the dominant process is downward flow of shallow contaminated groundwater through wellbores of idle supply wells in the winter to greater depths where the water resides until pumping resumes. (c) Conceptual model where the dominant process is upward flow of deep contaminated groundwater through wellbores of idle supply wells in the winter to shallower depths where the water resides until pumping resumes.

Figure adapted from Figure 5, Effects of Seasonal Operation on the Quality of Water Produced by Public-Supply Wells. By Laura M. Bexfield and Bryant C. Jurgens. Groundwater, Vol. 52. Focus Issue 2014 (pages 10-24).



City of Modesto
Stanislaus County, California

DRAFT

FIGURE 3-2

Conceptual Models of Hydrologic Processes

PROJECT NO.

MOD-001-02

DATE

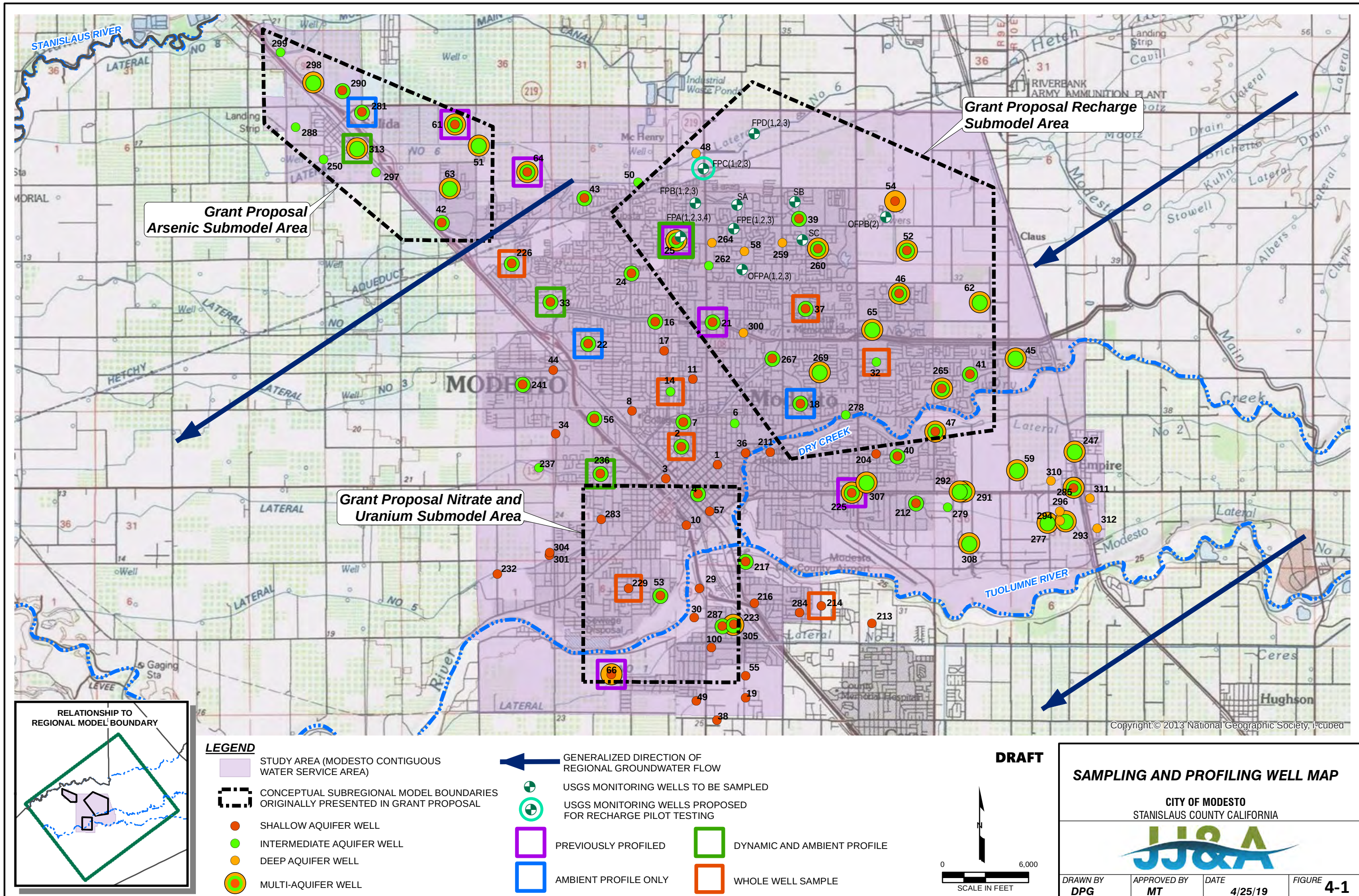
5/4/17

DRAWN BY

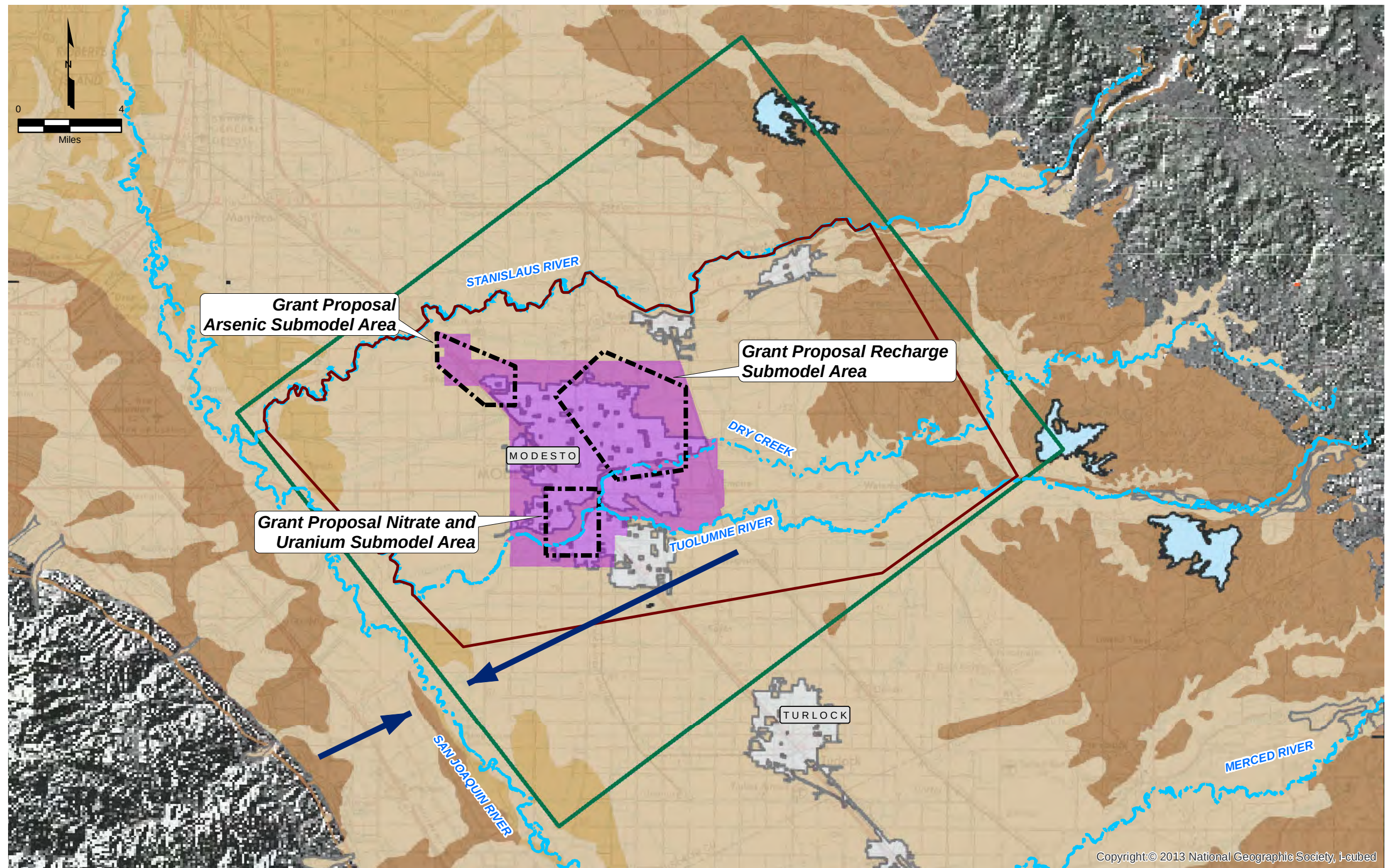
JH

APPR. BY

MT



Path: J:\GIS\Modesto2019\RI\FS\Workplan\Figure 6-1 Study Area and RMB.mxd



LEGEND

- STUDY AREA (MODESTO CONTIGUOUS WATER SERVICE AREA)
- CONCEPTUAL SUBREGIONAL MODEL BOUNDARIES ORIGINALLY PRESENTED IN GRANT PROPOSAL
- GENERALIZED DIRECTION OF REGIONAL GROUNDWATER FLOW
- REGIONAL LGA GRANT MODEL GRID AREA

- ALLUVIAL FAN DEPOSITS
- FLOOD PLAIN DEPOSITS
- MORE CONSOLIDATED DEPOSITS
- AREA OF FLOW AND TRANSPORT SIMULATION (ADOPTED FROM LOCALLY-REFINED GRID MODEL AREA DEVELOPED UNDER THE LGA GRANT)

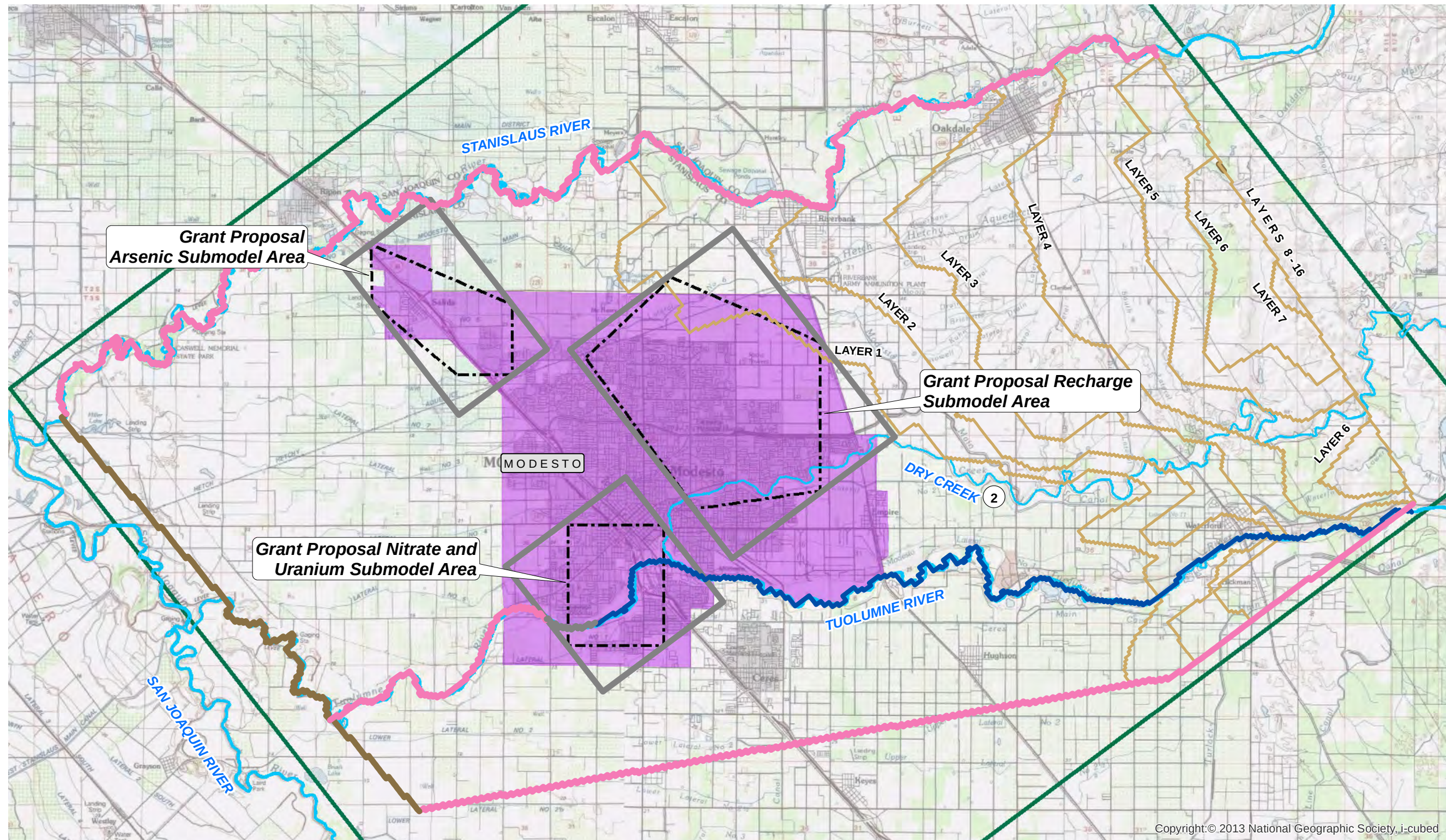
DRAFT

**CITY OF MODESTO RI/FS STUDY AREA
AND REGIONAL MODEL BOUNDARY**

CITY OF MODESTO
STANISLAUS COUNTY CALIFORNIA



DRAWN BY DPG	APPROVED BY DJ	DATE 4/17/19	FIGURE 6-1
-----------------	-------------------	-----------------	---------------



LEGEND

- REGIONAL FLOW AND NITRATE TRANSPORT MODEL USING THE LRGS GRID. GRID SPACING: 100m X 100m
- CONCEPTUAL SUBREGIONAL FLOW AND NITRATE, ARSENIC AND URANIUM TRANSPORT MODEL. GRID SPACING: 100ft X 100ft
- SUB-REGIONAL FOCUS AREA MODEL GRID AREA
- STUDY AREA (MODESTO CONTIGUOUS WATER SERVICE AREA)
- REGIONAL LRGS MODEL GRID AREA.

BOUNDARY CONDITIONS

- REGIONAL CONSTANT HEAD
- SUB-REGIONAL GENERAL HEAD
- REGIONAL GENERAL HEAD
- NO FLOW, LAYER-SPECIFIC
- RIVER (PRESCRIBED FLUX) ①
- ① PRESCRIBED FLUX WILL BE ASSIGNED VIA WELL, RIVER, OR GENERAL HEAD BOUNDARY MODFLOW PACKAGE. FLUX ASSIGNMENT METHODOLOGY WILL BE CONSIDERED DURING FINAL MODEL DEVELOPMENT.
- ② REPRESENTATION OF DRY CREEK IN THE SUB-REGIONAL FOCUS AREA MODEL WILL BE CONSIDERED DURING FINAL MODEL DEVELOPMENT.

DRAFT

CITY OF MODESTO RI/FS STUDY AREA MODEL BOUNDARY CONDITIONS

CITY OF MODESTO
STANISLAUS COUNTY CALIFORNIA



DRAWN BY DPG	APPROVED BY DJ	DATE 4/17/19	FIGURE 6-2
-----------------	-------------------	-----------------	---------------

DRAFT RIFS WORKPLAN

CITY OF MODESTO WELL FIELD RIFS, MODESTO, CALIFORNIA – APRIL 26, 2019

APPENDIX A

MONITORING AND REPORTING PLAN

Appendix A

Draft Monitoring and Reporting Plan

City of Modesto Well Field RIFS
Grant Agreement No. D1712514
Modesto, California

April 26, 2019

Prepared for:

City of Modesto Utilities Department
1010 Tenth Street, Suite 4000
Modesto, California 95353

Prepared by:



9083 Foothills Blvd., Suite 370
Roseville, California 95747
916.367.5111



1631 Alhambra Boulevard, Suite 220
Sacramento, California 95816
916.970-0507

Appendix A

Draft Monitoring and Reporting Plan

City of Modesto Well Field RIFS
Grant Agreement No. D1712514
Modesto, California

April 26, 2019

Prepared By

Juliet Hutchins
Staff Scientist, JJ&A

Terri Herson
Project Manager, JJ&A

Reviewed By

Mike Tietze
Principal Geologist/Hydrogeologist
Formation Environmental

TABLE OF CONTENTS

PAGE II

LIST OF TABLES.....	Page iv
LIST OF APPENDICES.....	Page iv
LIST OF ACRONYMS AND ABBREVIATIONS.....	Page v
1.0 INTRODUCTION	1-1
1.1 OBJECTIVES.....	1-1
1.2 REPORT ORGANIZATION	1-1
1.3 DISCLOSURE.....	1-1
2.0 BACKGROUND AND OVERVIEW	2-1
2.1 SETTING	2-1
3.0 SCOPE OF WORK OVERVIEW.....	3-1
4.0 GROUNDWATER SAMPLING PROCEDURES	4-1
4.1 PURPOSE.....	4-1
4.2 PRE-MOBILIZATION ACTIVITIES.....	4-1
4.3 HEALTH AND SAFETY	4-1
4.4 GROUNDWATER SAMPLING EQUIPMENT	4-1
4.5 MONITORING WELL SAMPLING PROCEDURES	4-2
4.6 SUPPLY WELL SAMPLING PROCEDURES	4-3
4.7 SAMPLE IDENTIFICATION	4-4
4.8 SAMPLING HANDLING AND ANALYSES	4-4
4.9 DECONTAMINATION PROCEDURES	4-5
4.10 QUALITY ASSURANCE / QUALITY CONTROL	4-5
4.10.1 FIELD DUPLICATES.....	4-5
4.10.2 MATRIX SPIKE/MATRIX SPIKE DUPLICATES (MS/MSD)	4-5
4.10.3 FIELD EQUIPMENT BLANKS	4-5
4.10.4 SOURCE WATER BLANKS.....	4-6
4.11 PURGE AND WASH WATER MANAGEMENT.....	4-6
4.12 FIELD DOCUMENTATION PROCEDURES.....	4-6
4.12.1 DAILY FIELD LOG	4-7
4.12.2 FIELD DOCUMENTATION FORMS.....	4-7
4.12.3 CORRECTIONS TO DOCUMENTATION	4-7
4.13 DATA VALIDATION	4-7
4.14 DATA STORAGE	4-8
4.15 RESULTS AND REPORTING	4-8

5.0	FLOW AND CONCENTRATION PROFILING OF PUBLIC SUPPLY WELLS	5-1
5.1	PURPOSE.....	5-1
5.2	PRE-MOBILIZATION ACTIVITIES.....	5-1
5.2.1	CITY COORDINATION	5-1
5.2.2	PERMITS	5-1
5.2.3	SITE RECONNAISSANCE	5-1
5.2.4	HASP.....	5-2
5.3	AMBIENT FLOW PROFILING.....	5-2
5.4	DYNAMIC FLOW PROFILING	5-2
5.5	CONCENTRATION PROFILING	5-3
5.5.1	SAMPLE COLLECTION AND ANALYSIS	5-3
5.6	RESULTS AND REPORTING	5-3
6.0	RECHARGE WATER PILOT TEST.....	6-1
6.1	PURPOSE.....	6-1
6.2	APPROACH	6-1
6.3	PRE-MOBILIZATION AND MOBILIZATION ACTIVITIES.....	6-2
6.3.1	CITY COORDINATION	6-3
6.3.2	RWQCB REVIEW.....	6-3
6.4	TEST PROCEDURES	6-3
6.5	RESULTS AND REPORTING	6-4
7.0	REFERENCES	7-1

LIST OF TABLES

Table 4-1	Sample Collection Requirements
Table 4-2	Groundwater Well Sampling Matrix
Table 5-1	Vertical Profiling Sampling Matrix

LIST OF APPENDICES

Appendix A	Field Form Templates
Appendix B	Standard Operating Procedures

LIST OF ACRONYMS AND ABBREVIATIONS

BESST	Besst, Inc.
City	City of Modesto
COC	Chain-of-custoday
EDF	Electronic Deliverable File
FS	Feasibility Study
Grant Agreement	Grant Agreement No. D1712514 between the city of Modesto and the SWRCB
GAMA	Groundwater Ambient Monitoring and Assessment Program
HASP	Health and Safety Plan
JJ&A	Jacobson James & Associates, Inc.
LGA	Local Groundwater Assistance
Modesto Wellfield RIFS	Modesto Wellfield Remedial Investigation Feasibility Study (the Project)
MRP	Monitoring and Reporting Plan
MS/MSD	matrix spike/matrix spike duplicate
PPE	personal protective equipment
PSW	public supply well
QAPP	Quality Assurance Project Plan
QA	quality assurance
QC	quality control
RI	Remedial Investigation
RIFS	Remedial Investigation Feasibility Study
RWQCB	Regional Water Quality Control Board
SJVGB	San Joaquin Valley Groundwater Basin
SM	Standard Method
SWRCB	California State Water Resources Control Board
TDS	total dissolved solids
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
%	percent

1.0 INTRODUCTION

1.1 OBJECTIVES

This Monitoring and Reporting Plan (MRP) describes the remedial investigation program approach including field services, groundwater sampling, and data management and reporting procedures for the Modesto Wellfield Remedial Investigation Feasibility Study (Modesto Wellfield RIFS; the Project). The Project was developed for the purpose of conducting a RIFS that will identify and evaluate alternatives to help reduce and prevent nitrate, arsenic, and uranium impacts in the City of Modesto’s drinking water aquifers. The Project is being funded under a grant from the State Water Resources Control Board (SWRCB) Proposition 1 Groundwater Sustainability Grant Program. This MRP has been developed in accordance with the Grant Agreement No. D1712514 between the City of Modesto and the SWRCB (Grant Agreement), which was executed on November 30, 2018. The Grant Agreement requires development of a MRP for the purpose of *“providing the information necessary to address data gaps during the remedial investigation and the pre-design data necessary to develop groundwater cleanup alternatives.”* The scope provided here-in is consistent with the Grant Agreement; this MRP presents the plan for sampling and field testing based on prior studies and investigations, data objectives, and data gaps. Additional discussion regarding the RIFS phases of work (post-investigation) is provided in the RIFS Workplan (JJ&A and Formation, 2019).

1.2 REPORT ORGANIZATION

The MRP is organized as follows:

- Introduction;
- Background and Overview;
- Background of Work Overview
- Groundwater Sampling Procedures;
- Flow and Concentration Profiling of Public Supply Wells;
- Recharge Water Pilot Test; and
- References

1.3 DISCLOSURE

The funding for this Project has been provided in full or in part through an agreement with the SWRCB using funds from Proposition 1. The contents of this document do not necessarily reflect the views and policies of the foregoing, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

2.0 BACKGROUND AND OVERVIEW

2.1 SETTING

The City of Modesto (City) is located within Stanislaus County and is underlain by portions of the Modesto and Turlock Subbasins of the San Joaquin Valley Groundwater Basin (SJVGB). The site location is shown on RIFS Workplan Figures 2-1 and 2-2 (JJ&A and Formation, 2019). The subbasins are bounded to the east by relatively impermeable basement rocks of the Sierra Nevada, to the west by the San Joaquin River, and to the north and south by the Stanislaus and Merced Rivers, respectively. The Tuolumne River divides the two subbasins in the southern portion of City. Aquifer systems in the SJVGB comprise continental sediments derived from erosion of the Sierra Nevada to the east and the Coast Ranges to the west, and deposition in the valley. The alluvial aquifer system, much of which occurs as fan deposits, consists of a complex set of interbedded aquifers and aquitards. The aquifers are relatively thick, with the upper 800 feet providing the primary source of groundwater supply in the area. Groundwater flow is generally to the southwest, following the dip of the basement rock and sedimentary units, and toward the San Joaquin River.

Aquifer materials consist of gravel and sand, which become increasingly interbedded with fine-grained silt, clay, and lakebed deposits toward the center of the valley. Regionally, the aquifer system of the SJVGB can be divided into an unconfined to semi-confined aquifer system, a series of geographically extensive confining clay layers toward the center of the basin, and a deep confined aquifer system that occupies the central portions of the basin.

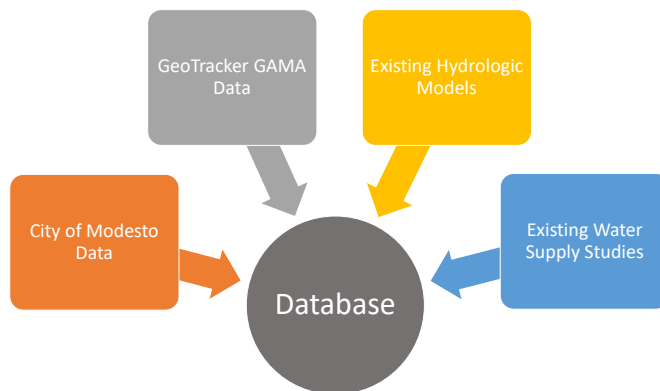
The unconfined aquifer system in the vicinity of the City includes the Modesto, Riverbank, and Upper Turlock Lake formations (Todd et al., 2016). The Corcoran Clay is a well-defined regional confining layer that occurs between the Upper and Lower Turlock Lake Formation, and separates the shallow unconfined and semi-confined aquifers from deeper confined aquifers. In the Modesto area, the eastern extent of the Corcoran Clay roughly parallels State Highway 99 beneath the western portion of the City (Phillips et al., 2015). West of the Modesto area, the Corcoran Clay has a maximum thickness of approximately 120 feet. The Corcoran Clay thins beneath the City, and is not present beneath eastern portions of the City. East of the Corcoran Clay, the aquifer system transitions from unconfined conditions to semiconfined conditions with depth, due to the presence of local clay lenses and extensive paleosols. A semiconfined aquifer occurs at depth in this area, and consists of the Lower Turlock Lake, Laguna, and Upper Mehrten Formations. Additional hydrologic context and project background are provided in the RIFS Workplan (JJ&A and Formation, 2019).

3.0 SCOPE OF WORK OVERVIEW

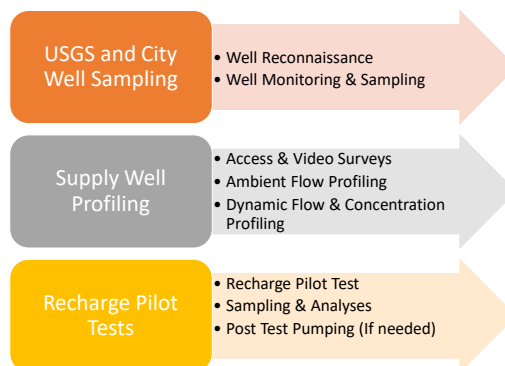
A summary of the major RIFS work steps is presented below to provide a context for the remedial investigation (RI) data tasks. This MRP addresses the field, laboratory, data management and reporting procedures associated with items 2, 3 and 4, below. The broader RIFS Workplan (JJ&A and Formation, 2019) includes additional discussion of items 5, 6, and 7 below.

1. Data Compilation. An extensive dataset of hydrogeologic and contaminant analytical information that exists in various studies has been compiled into a database and is summarized to form the background context for this MRP. This existing data set forms the basis of our initial conceptual understanding of arsenic, nitrate and uranium occurrence behavior in the drinking water aquifers underlying the City, and informs the scope of the data collection activities included in the RI that are the subject of this MRP.

Data Compilation



Remedial Investigation Fieldwork



2. Supplemental Water Quality Data Collection. In order to refine our understanding of contaminant behavior and distribution in the aquifer system, and to develop baseline data for feasibility analysis, additional water quality data will be collected from up to seven public supply wells, and up to 23 monitoring wells installed by the USGS.
3. Flow and Concentration Profiling of Public Supply Study Wells (PSW). Well hydraulic and contaminant concentration data will be collected at vertically-spaced intervals along the screen/perforated intervals of approximately seven PSWs selected for detailed study.
4. Recharge Water Pilot Testing. Pilot testing will be performed using two selected United States Geological Survey (USGS) installed monitoring wells to evaluate the potential for recharge water to change the mobility of arsenic, nitrate and uranium in the aquifer system, otherwise affect the quality of water in the aquifer system, and or cause precipitation or scaling that could adversely affect well operation or aquifer permeability.
5. Remedial Investigation Report. The methods and findings of the above tasks will be summarized in a RI Report that will present an updated and refined understanding of the sources and behavior of contaminants in the aquifer system and serve as the basis for a FS.
6. Solute Transport Modeling. As a key tool to help define implementation projects and evaluate their effectiveness, data gathered in the RI will be used to develop a solute transport model. Analysis will focus on the areas where potential project alternatives are identified during the early stages of the FS.
7. Feasibility Study. A FS will be conducted to identify and screen potential technologies that could be used to prevent or clean up contamination, develop potential implementation project alternatives based on the screened technologies, evaluate and rank the potential implementation projects based on objective performance criteria, and select the top-ranked projects to be refined for future implementation.

For RI data collection steps 2, 3, and 4 (above), the list of wells, sampling program, and rationale are provided on RIFS Workplan Table 5-2 (JJ&A and Formations, 2019). A location map of the proposed wells for sampling is provided on RIFS Workplan Figure 4-1 (JJ&A and Formations, 2019).

4.0 GROUNDWATER SAMPLING PROCEDURES

4.1 PURPOSE

The purpose of the planned groundwater sampling activities is to better understand contaminant behavior and distribution in the aquifer system, and to develop baseline data for the FS.

4.2 PRE-MOBILIZATION ACTIVITIES

Coordination and preparation for monitoring and supply well sampling will include the following activities:

- Prepare of a Project-Specific Health and Safety Plan (HASP);
- Coordinate with the City to schedule sampling activities and arrange for access to wells;
- Work with City to develop a plan to discharge water pumped from wells during sampling, as well as sampling equipment wash water, to flush lines associated with the City's PSWs;
- If required, obtain permission to discharge water to the City's sewer system; and,
- Inspect wells selected for sampling to confirm well can be accessed and evaluate the condition and suitability of the well for sampling.

4.3 HEALTH AND SAFETY

All work will be performed in accordance with the HASP and applicable job hazard analyses. The HASP will contain emergency contact information and procedures, roles and responsibilities, evaluation of potential hazards associated with sampling activities, and personal protective equipment (PPE), medical monitoring and training requirements.

Each work day will begin with a Site safety meeting. Topics discussed during the daily meetings will pertain to the planned work for the day and any site-specific health and safety concerns. Documentation of the safety meeting will be included daily field notes.

4.4 GROUNDWATER SAMPLING EQUIPMENT

The following equipment is required for planned groundwater sampling activities:

- PPE;
- Sample containers;
- Labels;
- Chain-of-custody forms;
- Field sampling forms;
- Coolers;
- Ice;

- Zip-top bags;
- Trash bags;
- Packaging tape;
- Decontamination supplies (distilled or purified water, squirt bottle, non-phosphate detergent, scrub brush);
- Field meters with flow-through cell (pH, oxidation-reduction potential, dissolved oxygen, conductivity, temperature, and turbidity);
- Camera;
- Water level indicator; and,
- Portable tanks or containers to contain purge and sampling rinse water as needed.

4.5 MONITORING WELL SAMPLING PROCEDURES

Monitoring well locations are shown on RIFS Workplan Figure 4-1 (JJA and Formation, 2019). The monitoring wells will be sampled using low flow purge methods (United States Environmental Protection Agency [USEPA], 2017), except for the two monitoring wells designated for implementation for Recharge Water Pilot Testing, which will be sampled by purging a minimum of three casing volumes of groundwater prior to sampling. Field parameters will be measured and recorded on the Groundwater Monitoring Well Field Sampling Form (Appendix A) periodically during purging and at the time of sampling.

For every sample collected, the following water quality parameters will be measured during purging activities in the field:

- Electrical conductivity;
- Oxidation-reduction potential;
- Dissolved oxygen;
- pH;
- Temperature; and,
- Turbidity.

The wells will be purged until water-quality parameters stabilize. Parameters will be considered stable when, for at least three consecutive measurements, the pH remains constant within 0.1 Standard Unit and the specific conductance varies no more than approximately five percent (5%). The final set of water quality measurements (obtained at the completion of purging activities) will be considered representative of the samples collected and submitted to the laboratory.

Field measurements and groundwater samples will be obtained at the closest appropriate point relative to the well head (i.e., from the closest available sampling port or valve. Groundwater samples will be transferred directly into sample containers provided by the laboratory. Prior to being preserved, samples to be analyzed for metals will be filtered in the field using disposable 0.45-micron filters. Samples will be labeled and

immediately placed on ice (water based) in an insulated cooler and submitted under COC control to a California State certified laboratory.

4.6 SUPPLY WELL SAMPLING PROCEDURES

The City supply wells to be sampled for groundwater quality are shown on RIFS Workplan Figure 4-1 (JJA and Formation, 2019). A reconnaissance will be conducted prior to sampling to verify well access and conditions, and if access or other issues affecting the ability to collect representative samples are identified at any wells, alternative wells may be recommended.

This section describes the procedures that will be followed to collect groundwater samples from City supply wells. If a well is not in operation, a City engineer will turn on the well pump. The pump will be allowed to run for at least 10 minutes prior to sample collection. A discharge tube will be connected to a sampling valve near the wellhead and water will be allowed to run through the sampling tube and a flow-through cell into a bucket during the purging process. Field parameters will be measured and recorded on the Groundwater Monitoring Well Field Sampling Form (Appendix A) periodically during purging and at the time of sampling.

For every sample collected, the following water quality parameters will be measured during purging activities in the field:

- Electrical conductivity;
- Oxidation-reduction potential;
- Dissolved oxygen;
- pH;
- Temperature; and
- Turbidity.

The wells and sampling lines will be purged until water-quality parameters stabilize. Parameters will be considered stable when, for at least three consecutive measurements, the pH remains constant within 0.1 Standard Unit and the specific conductance varies no more than approximately five percent (5%). The final set of water quality measurements (obtained at the completion of purging activities) will be considered representative of the samples collected and submitted to the laboratory.

Samples will be collected from the discharge line directly into laboratory-supplied containers. Prior to being placed into sample containers, samples for analysis of metals will be filtered in the field using disposable 0.45-micron filters. Samples will be labeled and immediately placed on ice (water based) in an insulated cooler and submitted under chain-of-custody control to a California State certified laboratory.

4.7 SAMPLE IDENTIFICATION

Samples collected during the groundwater sampling will be given unique identification numbers based on an alpha-numeric code that describes the type and location of each sample (see Appendix A, Sample ID Overview):

A-B-C

Where:

- A = Sample type (W for well, MW for monitoring well; FB for field blank).
- B = Sample location (can contain multiple characters).
- C = Test code (A for primary, B for duplicate, AF for primary – field filtered, BF for duplicate – field filtered, EB for equipment blank).

Identifications for several hypothetical samples are listed below:

- W-MOD025-A = Primary water sample from sample location MOD025
- MW-OFPB-2-BF = Duplicate sample collected from sample location OFPB-2
- SM-03012019-EB = Equipment blank sample collected from a slope meter on March 1, 2019

4.8 SAMPLING HANDLING AND ANALYSES

Water samples will be collected for laboratory analyses in the appropriate container based on the required analysis, as specified in Table 4-1. Containers will be labeled with the sample identification number, date, and time using waterproof labels and indelible ink. Sample containers will be wiped clean and securely packed in a cooler on ice for transport under standard chain-of-custody protocols.

Anticipated analyses are listed below, though not all samples may be subjected to the entire list of analyses. Analytical methods, preservatives, and holding times are summarized on Table 4-2.

- Sulfate, chloride, bromide, and fluoride by USEPA Method 300.0;
- Calcium, iron, magnesium, manganese, sodium, potassium, aluminum, boron, strontium, and orthophosphate/dissolved phosphorus by USEPA Method 200.7;
- Total Kjeldahl Nitrogen by USEPA Method 351.2 (approximately 10% of samples to verify that organic nitrogen is not present);
- Total Alkalinity (as calcium carbonate) with bicarbonate and carbonate by Standard Method (SM) 2320B;
- Title 22 Metals by USEPA Method 6010B;
- Dissolved arsenic, manganese, and iron by USEPA Method 6020;
- Dissolved uranium by USEPA Method 200.8;
- Nitrate by USEPA Method 353.3 or 353.2;
- Total dissolved solids (TDS) by SM 2540C;

- Specific conductance by SM 2510B; and,
- Dissolved organic carbon and total organic carbon by SM 5310.

Chemical analyses will be performed by a laboratory certified by the California Department of Health Services and the National Environmental Laboratory Accreditation Program.

4.9 DECONTAMINATION PROCEDURES

Decontamination procedures will be followed during groundwater sampling to prevent cross contamination by multi-use sampling equipment. Multi-use sampling equipment will be washed in a non-phosphate detergent (such as Liquinox®) and potable water, rinsed in potable water, and then double rinsed in a reagent-free water (such as purified or distilled water). Management of the decontamination fluids is described below.

4.10 QUALITY ASSURANCE / QUALITY CONTROL

Key Quality Assurance/Quality Control (QA/QC) procedures are summarized below. A detailed description of QA/QC procedures is provided in the Quality Assurance Project Plan (QAPP) provided as Appendix B in the RIFS Workplan (JJ&A and Formations, 2019).

4.10.1 FIELD DUPLICATES

Field duplicates are split samples submitted for analysis under a separate identification from the original sample to evaluate laboratory precision. Field duplicate samples will be collected for the groundwater samples. Field duplicate samples are typically collected at a frequency of 10 percent (10%) of the total number of samples, one for every 10 original samples.

4.10.2 MATRIX SPIKE/MATRIX SPIKE DUPLICATES (MS/MSD)

MS/MSDs are extra sample volumes used by the laboratory to test for matrix interference in the analyses. MS/MSD samples are typically collected at a frequency of five percent (5%) of the total number of samples, or one for every 20 original samples. The sampling team may select which samples to use as MS/MSDs. MS/MSD samples require triple the volume of a standard sample, or a quantity specified by the project laboratory.

4.10.3 FIELD EQUIPMENT BLANKS

Field equipment blanks are fluid samples collected by pouring water over multi-use sampling equipment and collecting the water in appropriate sample containers. Analytical results for field blanks are used to evaluate the effectiveness of decontamination procedures and potential cross-contamination by the sampling equipment. Field equipment blanks will be obtained by pouring purified or distilled water over previously decontaminated sampling equipment (such as the water level indicator) and collecting the rinse water in an

appropriate sample container. Field equipment blanks will not be filtered. Field equipment blanks will be collected each day that multi-use sampling equipment is used and analyzed for each constituent type requested for the groundwater samples collected using that piece of equipment on that day. Field equipment blanks are not necessary if sample media do not contact multi-use sampling equipment.

4.10.4 SOURCE WATER BLANKS

Source water blanks are samples of the water used for field equipment blank sampling to determine if the water is a source of contamination. Source water blanks are collected by pouring the source water directly into appropriate sample containers. One source water blank will be collected from each batch or lot of source water used for field equipment blank sampling and analyzed for the full analytical suite. Source water blanks will not be necessary if the water used for field equipment blank sampling is provided by the Project laboratory, or otherwise demonstrated to be free of constituents. Source water blanks may be submitted to the Project laboratory on hold and analyzed only if constituents are detected in the field equipment blanks. Source water blanks are not necessary if field equipment blanks are not collected.

4.11 PURGE AND WASH WATER MANAGEMENT

The groundwater being sampled is considered raw drinking water. Water generated during the groundwater sampling is anticipated to consist of purged groundwater, decontamination fluids, and disposable field supplies (personal protective equipment, product packaging, and any single-use sampling equipment). The subsections below describe the procedures for containing, storing, and disposing of the Investigation Derived Waste.

Purge water and decontamination wash water generated from monitoring well sampling will be containerized and disposed of in a method that is acceptable to the City that may include:

- Discharge to existing flush lines located at nearby City wells; or
- Containerize and transport to the local wastewater treatment plant.

Disposable field supplies (gloves, single-use sampling equipment) and other material such as product packaging will be contained in trash bags and disposed as municipal waste. Labeling will not be necessary for trash bags containing waste.

4.12 FIELD DOCUMENTATION PROCEDURES

Field activities will be recorded on field documentation forms, COC forms, and sample labels. Field personnel will review data documentation at the end of each day to ensure completeness and accuracy. The Project manager or a technically qualified individual will also review the field notes for accuracy and completeness. Blank copies of field forms are provided in Appendix A.

4.12.1 DAILY FIELD LOG

The primary document for recording field information is the Daily Field Log (Appendix A). Entries will be made legibly using ink. If an error is made, corrections will be made by crossing a line through the error and entering the correct information. Changes will be initialed and dated. At no time will entries be obliterated or rendered unreadable. Data on the Daily Field Log will be organized similar to the data required in the field logs.

4.12.2 FIELD DOCUMENTATION FORMS

Field documentation forms include similar information to that contained in the Daily Field Log. However, the information is more readable and specific data can be easily extracted for evaluation. Example forms are identified below with a summary of their contents. All forms require the identification of the field person responsible for the given activity, date, and Site name.

- Groundwater Field Sampling Form (Appendix A) to document well information and field parameters;
- COC forms to identify sample collection and analysis information and to document personnel responsible for sample custody from sample collection to delivery of the sample to the laboratory for analysis; and,
- Photographic Log to document photographs taken during the field investigation.

4.12.3 CORRECTIONS TO DOCUMENTATION

Original data recorded in field paperwork, COC records, and other forms will be written in waterproof ink. None of these documents will be altered, destroyed, or discarded, even if they are illegible or contain inaccuracies that require a replacement document.

If an error is made on a document assigned to one individual, that individual will make corrections by crossing a line through the error, entering the correct information, and initialing and dating the change. The erroneous information will not be obliterated. Subsequent error(s) discovered on a document will be corrected by the person who made the entry. All corrections will be initialed and dated.

4.13 DATA VALIDATION

Data validation evaluates the precision and accuracy of the analytical results. The procedures used for validating the data will be consistent with those referenced in the USEPA National Functional Guidelines for Data Review (USEPA, 2016a and 2016b). This will include the review of analytical results and QC data submitted by the analytical laboratory. Data collected will be checked for the following:

- Data completeness;
- Analytical holding times and sample preservation;
- Blank samples;

- Surrogate recoveries;
- Laboratory control samples/laboratory control sample duplicates;
- Laboratory duplicate sample results;
- Matrix spike/matrix spike duplicate (MS/MSD) and post-digestion spike samples;
- Comparison of field duplicate sample results;
- Compound identification and quantification; and,
- Verification of electronic data deliverable/database.

Through the data validation step, analytical data may be rejected or qualified as appropriate. A data evaluation memorandum will be prepared to present the findings. Waste profile data will not require data validation.

4.14 DATA STORAGE

All records of field operations will be maintained in the project file. This includes field logs, sampling records, COC records, laboratory reports, maps, drawings, and data compilations and statistical evaluations performed as part of any sampling and analysis program. The laboratory is required to maintain all records, calculations, raw data, and backup files for all sample analyses for a period of five years. Samples and extracts will be retained by the laboratory for thirty days after a final report is issued to Jacobson James & Associates, Inc. (JJ&A). Unless otherwise notified, the laboratory will dispose of excess or unused samples in a manner consistent with appropriate government regulations. Validated laboratory and field data will be entered into JJ&A's Site environmental database.

4.15 RESULTS AND REPORTING

JJ&A will prepare and upload all groundwater analytical data collected to the SWRCB Geotracker/Groundwater Ambient Monitoring and Assessment Program system in Electronic Deliverable Format, provide the sampling data, tabulated summaries, and a brief field memorandum. Sampling locations will be submitted using the Geo XY file.

5.0 FLOW AND CONCENTRATION PROFILING OF PUBLIC SUPPLY WELLS

5.1 PURPOSE

JJ&A will oversee the collection of well hydraulic and contaminant concentration data at vertically-spaced intervals along the screen/perforated intervals of approximately seven public supply study wells in the study areas under dynamic (pumping) and ambient (non-pumping) conditions. This includes the public supply study wells listed in Table 5-1. Flow and concentration profiling will be performed by BESST Inc. (BESST). BESST provides groundwater quality and monitoring solutions using miniaturized hydraulic profiling and sampling technologies. Water quality profiling will be conducted under dynamic conditions, and flow profiling will be performed under static and dynamic conditions at the wells designated for dynamic profiling. At wells designated for ambient profiling, hydraulic and water quality profiling will be conducted under ambient conditions only.

Standard Operating Procedures for BESST are included as Appendix B.

5.2 PRE-MOBILIZATION ACTIVITIES

5.2.1 CITY COORDINATION

Flow and concentration profiling of the public supply wells will require coordination with the City for site access, well entry and (if necessary) disinfection procedures, test procedures, and well shut down and restarting procedures. Water pumped from the wells during dynamic testing will be discharged to dedicated flush lines located at the wells, distribution lines or to nearby canals. Equipment wash water will be discharged to dedicated flush lines or containerized and transported to the local wastewater treatment plant with City approval.

5.2.2 PERMITS

In coordination with the City, permission to discharge sampling equipment rinse water to the City's wastewater treatment plant will be obtained as needed.

5.2.3 SITE RECONNAISSANCE

Prior to flow and concentration profiling activities, in coordination with the City, proposed well sites will be observed together by representatives of the City, JJ&A, and BESST to assess well conditions (presence of a flow meter, sample tap and power supply near the discharge head, and pumped water discharge). Wells determined to have adequate access to be profiled will have a down-hole access survey by lowering a "dummy tool" to determine if there are any obstructions to performing the survey. A downhole, miniaturized video survey of each well will also be performed to confirm downhole construction features and access, and to confirm the condition of the well screen or perforated interval. If, based on this reconnaissance evaluation,

a designated well is not adequate for profiling, corrective actions, an alternative approach, or an alternate well will be proposed.

5.2.4 HASP

The Site-Specific HASP will be updated with health and safety procedures associated with flow and concentration profiling.

5.3 AMBIENT FLOW PROFILING

The ambient flow profiling will occur while the pumping system is shut down. As mentioned previously, coordination with the City is required for well shut down and restarting procedures. Ambient flow profile information can be collected after resting the well for at least 24 hours.

- Data to determine hydraulic behavior of each well will be collected using the Tracer Pulse Ambient Flow Profile method, including the following steps:
 - Tracer injection tubing will be inserted to specified depths in the well;
 - Timed pulses of fluorescent (rhodamine) dye will be released at the specified depths. The dye tracer test will use a small amount of a non-toxic, degradable dye manufactured and approved for use in drinking water systems. A Technical Data Bulletin and Safety Data Sheet for this product are included in Appendix B; and,
 - Two fiber-optic sensors vertically situated above and below the injection nozzle will be monitored using a fluorimeter to determine the timing of pulse arrivals and record the values for use in well flow calculations and to determine the velocity, hydraulic gradient and direction of flow within the well.

5.4 DYNAMIC FLOW PROFILING

Dynamic flow profiling will occur while the pumping system is operational. The wells will need to be operated for a least 24 hours prior to the dynamic tests. The dynamic profiling will be conducted using a miniaturized dye tracer and sampling system developed by the USGS and licensed to BESST, as described below:

- Data to determine hydraulic behavior of each well will be collected using the Tracer Pulse Dynamic Flow Profile method, including the following steps:
 - Tracer injection tubing will be inserted to specified depths in the well;
 - Timed pulses of fluorescent (rhodamine) dye will be released at the specified depths; and,
 - Well discharge will be monitored using a fluorimeter to determine the timing of pulse arrivals and record the values for use in well flow dynamics calculations.

5.5 CONCENTRATION PROFILING

Vertically-integrated water quality sampling will be performed using BESST HydroBooster or Panacea Pump Technology to collect samples at select intervals, including the following steps:

- Sampling will be conducted at the same time as flow profiling using a system that bundles the injection and a miniaturized sampling pump to collect samples from select depth intervals in the well;
- The samples will be collected, handled and analyzed using the methods described in Section 4.8; and,
- Purge water and decontamination wash water will be placed into an existing on-site purge water tank.

For every sample collected, the water quality parameters will be measured using water quality sensors in a flow-through cell in accordance with the procedures described in Section 4.6.

Field parameters will be measured and recorded on the Groundwater Monitoring Well Field Sampling Form periodically during purging and at the time of sampling. The sampling lines will be purged until water-quality parameters stabilize. Parameters will be considered stable when, for at least three consecutive measurements, the pH remains constant within 0.1 Standard Unit and the specific conductance varies no more than approximately five percent (5%). The evaluation of parameter stabilization may be modified if sample volume is limited, as needed. The final set of water quality measurements (obtained at the completion of purging activities) will be considered representative of the samples collected and submitted to the laboratory.

5.5.1 SAMPLE COLLECTION AND ANALYSIS

Groundwater samples will be collected from the discharge line directly into laboratory-supplied containers. Prior to being placed into sample containers, samples for analysis of metals will be filtered in the field using disposable 0.45-micron filters. Samples will be labeled and immediately placed on ice (water based) in an insulated cooler and submitted under COC control to a California State certified laboratory. Anticipated analyses will be the same as those listed in Section 4.8, though not all samples may be subjected to the entire list of analyses. Analytical methods, preservatives, and holding times are summarized on Table 4-1.

5.6 RESULTS AND REPORTING

JJ&A will prepare and upload all groundwater analytical data collected during profiling to the SWRCB Groundwater Ambient Monitoring and Assessment Program (GAMA) system in electronic deliverable format (EDF) format. JJ&A will prepare a brief memorandum presenting field and laboratory data, and well flow and concentration profile data figures and tables, and interpretational information.

6.0 RECHARGE WATER PILOT TEST

6.1 PURPOSE

As mentioned, a solute transport model will be constructed to simulate the mobilization and transport of arsenic, nitrate, and uranium under different wellfield operation and managed recharge scenarios. To help support construction of the model, the potential chemical interaction of recharge water with aquifer water will be investigated by conducting Recharge Water Pilot Tests which document chemical changes that occur when recharge water is introduced into the aquifer or migrates into zones that do not yet contain modern recharge water. The results of these tests will be evaluated using a geochemical reaction model that simulates the chemical behavior of solutes in the aquifer system and serve as the basis for calculation of source and transport terms to be applied to the solute transport model. The Recharge Water Pilot Test will evaluate the geochemical interaction of raw river water and modern recharge water with the aquifer, but does not aim to evaluate recharge project feasibility or investigate recharge project design parameters.

6.2 APPROACH

The Recharge Water Pilot Tests will be conducted using monitoring wells that are completed near Modesto Well No. 25, which was previously tested by the USGS and will be further investigated during this study. To conduct the test, a limited amount of Tuolumne River water obtained from the City's Regional Water Treatment Plant will be allowed to flow into two monitoring wells. Each batch water will be prepared for infiltration as follows:

- Test 1 location: raw water will be mixed with a small amount of food-grade bicarbonate and introduced through a monitoring well completed in the shallow aquifer near the water table to simulate the chemistry of modern recharge water that has been influenced by near surface and root zone processes;
- Test 2 location: treated river water would be introduced through monitoring wells completed in the intermediate or deep aquifer zone, similar to the chemistry that would occur if recharge water were directly injected into the aquifer through aquifer storage and recovery wells; and,
- In both cases, a low concentration (approximately 100 milligrams per liter) of bromide ion will be added to the water as a tracer.

The infiltration phase of the test is assumed to occur over the course of one week. Water samples from the two test wells would be withdrawn from the aquifer after approximately one week, one month, two months and three months after the completion of infiltration and analyzed for general minerals, major cations and anions, the target constituents (arsenic, nitrate and uranium), and bromide tracer to assess geochemical changes and percentage of recharge water contained in the withdrawn sample. Following the conclusion of the test, the remaining infiltrated recharge water would be removed from the aquifer system by operating the supply well.

The candidate test wells for Recharge Water Pilot Test include the following, generally listed in order of increasing distance from Modesto Well No. 25:

- FPA (wells 1, 2, 3, 4);
- FPB (wells 1, 2, 3);
- FPC (wells 1, 2, 3);
- OFPA (wells 1, 2, 3); and,
- FPD (wells 1, 2, 3)

At this time, FPC-1 and FPC-2 (RIFS Workplan Figure 4-1) are the preferred wells for recharge testing of the shallow and intermediate aquifer zones, respectively. The status and suitability of these wells will be assessed prior to proceeding with the work. If the wells are not suitable for recharge testing, alternative wells will be recommended.

6.3 PRE-MOBILIZATION AND MOBILIZATION ACTIVITIES

Mobilization for each test location will include the following scope of work:

- As described in Section 4, shortly prior to conducting the Recharge Water Tests, the wells selected for testing will have been purged using the three casing volume method, sampled and (if necessary) re-developed to assure the water in the wells is representative of formation conditions and to establish baseline conditions. Well No. 25 will have been profiled as described in Section 5.
- Two samples of raw surface water and one sample of treated surface water will be collected from the Modesto Regional Water Treatment Plant. Each surface water sample will be analyzed for the following constituents:
 - Samples designated for metals analysis will be field filtered using a 0.45 micron filter;
 - Nitrate by USEPA Method 353.3 or 353.2;
 - Arsenic, uranium, manganese and iron by USEPA Method 6020;
 - Title 22 metals and silica by USEPA Method 6010B;
 - General minerals, dissolved organic carbon, and major cations and anions with ion balance (various methods); and,
 - Dissolved organic carbon and total organic carbon by SM 5310.

The treated water sample will be additionally analyzed for disinfection byproducts.

- If the wells selected for testing are located within ½ mile of an active supply well, prior to conducting the Recharge Tests, the well will be turned off and will not be restarted until after the test is completed.
- Based on the available information, it is highly unlikely that the bromide tracer or any analytes associated with the recharge water would be detected in nearby supply wells; however, prior to starting the test, confirmatory calculations would be performed to assess whether the water is likely

to be captured and if so, evaluate the effect of the recharge water on the water quality of the receptor well so as to assure that unacceptable water quality impacts will not occur.

- Mobilize an approximately 4,900 gallon tank to each location and deploy the tank on plastic sheeting within a temporary containment berm.
- Connect the tanks to the monitoring wells via a 1-inch diameter PVC pipe with a ball valve, propeller flow meter/totalizer and sampling port. Pass the pipe through a well seal or packer into the well.
- Deploy a recording pressure transducer into the well and a barometric logger at the surface.

6.3.1 CITY COORDINATION

It is anticipated that City approvals, and coordination related to this task include the following:

- Active supply wells – shutdown prior to the test and restarting the well after the test, if needed;
- Public Notification - to local residents for testing and deploying tanks within urban areas, if needed;
- Obtaining Treated and Untreated River Water – coordinating with the subcontracted water service truck and the Modesto Regional Water Treatment Plant to allow filling of the water trucks when needed;
- Encroachment Permit – obtaining an Encroachment Permit from the City Public Works Department, as required to allow a temporary water tank to be deployed near the USGS well clusters, if needed; and,
- Purge Water Management – containerizing and disposing of the purge water from monitoring well preparation in a method that is appropriate to the City, likely to the dedicated flush line at Well No. 25.

6.3.2 RWQCB REVIEW

Regional Water Quality Control Board (RWQCB) approvals or permits required for the Recharge Water Pilot Test implementation will be obtained before field work begins. Signed copies of such approvals, entitlements, or permits will be submitted to the Grant Manager. During work planning, the RWQCB has been contacted to discuss and review the pilot test plan. Upon completion of the RWQCB's review, the necessary approvals or permits will be obtained.

6.4 TEST PROCEDURES

The test will introduce approximately up to 36,000 gallons (0.1 acre-foot) of recharge water by gravity flow into the aquifer through each of the two monitoring wells. Assuming a screen interval of approximately 10 feet and an aquifer effective porosity of approximately 0.2, this will result in recharge water infiltrating into the aquifer for a distance of approximately 30 feet from the test well. At each location, the test will be conducted in accordance with the following procedures:

- A tanker truck licensed to transport potable water will be used to pick up raw (untreated) river water from the Modesto Regional Water Treatment Plant and transport it to each test location. The trucks will be filled using a procedure that minimizes agitation and potential entrainment of oxygen;
- Upon arriving at the test site, the water will be pumped into the tanks through a mixing vessel to which the bromide tracer and (for one of the locations) bicarbonate will be added;
 - Sufficient sodium bromide reagent will be added to each batch of water to bring the bromide ion concentration in the infiltrated water to approximately 100 milligrams per liter (Kim et al., 2005);
 - At the bicarbonate test location, sufficient food-grade sodium bicarbonate (baking soda) will be added to each batch to bring the bicarbonate concentration to level that is approximately equivalent to average bicarbonate concentrations expected in recharge water for the project being simulated (e.g., winter percolation of flood waters vs. percolation of normal supply water at other times of the year);
- A sample of the water will be collected from each batch during infiltration for laboratory analysis of bromide and, when applicable, pH and bicarbonate. In addition, during sampling water will be passed through a flow through cell and the sample pH, oxidation-reduction potential, dissolved oxygen, electric conductivity and field bromide concentration will be recorded;
- The infiltration flow rate and total infiltrated volume will be recorded periodically, and pressure measurements will be obtained using a pressure transducer that is placed in the well;
- The wells will be sampled after one week, one month, two months and three months using the conventional three casing volume purge technique as described in Section 4;
- Each sample will be analyzed as specified for the baseline water samples and for bromide using USEPA Method 300 (Table 4-2);
- The samples from the treated water recharge test will be additionally analyzed for disinfection byproducts; and,
- Following completion of the final sampling event, nearby municipal supply wells would be restarted if they have been shut down.

6.5 RESULTS AND REPORTING

The analytical data from the Recharge Water Pilot Tests will be compared to the baseline water samples from the wells to evaluate the extent of chemical changes attributable to mixing within the aquifer and to post-mixing chemical reactions or desorption. A brief technical memorandum will summarize methods, findings, and conclusions of the recharge water pilot tests, including an assessment of the effect of recharge water on the concentrations and mobility of nitrate, arsenic, and uranium. Implications for nitrate, arsenic, and uranium behavior and potential remedial strategies may also be discussed.

7.0 REFERENCES

- CRWQCB, Central Valley Region, 2016. The Water Quality Control Plan (Basin Plan) for the California Regional Water Quality Control Board, Central Valley Region, Fourth Edition, The Sacramento River Basin and the San Joaquin River Basin. Revised July.
- Jacobson James & Associates (JJ&A) and Formation Environmental, 2019. *Draft Remedial Investigation Feasibility Study Workplan*. April.
- Jurgens, et al., 2009. Effects of Groundwater Development on Uranium: Central Valley, California, USA: Groundwater 10.1111/j.1745-6584.2009.00635.x
- Kim, Young, M. Azizian, J. Istok and L. Semprini, 2005. *Field Recharge Test Protocol for Aerobic Cometabolism of Chlorinated Aliphatic Hydrocarbons*. Prepared for the Department of Defense Environmental Security Technology Certification Program.
- Phillips, S.P., Rewis, D.L., and Traum, J.A., 2015. *Hydrologic model of the Modesto Region, California, 1960–2004*: U.S. Geological Survey Scientific Investigations Report, 2015–5045, 69 p., <http://dx.doi.org/10.3133/sir20155045>.
- Smith, Ryan, R. Knight and S. Fendorf, 2018. *Overpumping leads to California groundwater arsenic threat*: in Nature Communications 9(1), December.
- Todd Groundwater and RMC Water and Environment, 2016. *Groundwater Characterization and Recharge Study, Modesto Local Groundwater Assistance (LGA) Project*. June.
- USEPA, 2016a. *National Functional Guidelines for Inorganic Superfund Methods Data Review*. September.
- USEPA, 2016b. *National Functional Guidelines for Superfund Organic Methods Data Review*. September.
- USEPA, 2017. *Low Stress (low flow) Purging and Sampling Procedures for the Collection of Groundwater Samples from Monitoring Wells*. EQASOP-GW4, Region I, Revised September.
- USGS, 2008. *Hydrogeology, Water Chemistry, and Factors Affecting the Transport of Contaminants in the Zone of Contribution of a Public-Supply Well in Modesto, Eastern San Joaquin Valley, California*: Scientific Investigations Report SIR 2008-5156.
- USGS, 2010. *Status and understanding of groundwater quality in the Central–Eastside San Joaquin Basin, 2006: California GAMA Priority Basin project*. Scientific Investigations Report 2009–5266.

TABLES

LIST OF TABLES

Table 4-1	Sample Collection Requirements
Table 4-2	Groundwater Well Sampling Matrix
Table 5-1	Vertical Profiling Sampling Matrix

TABLE 4-1
SAMPLE COLLECTION REQUIREMENTS
RIFS Monitoring Plan
City of Modesto
Modesto, California

Analytical Parameter	Analytical Method	Container Type	Preservation Requirements	Maximum Holding Times	Reporting Units
Calcium, Iron, Magnesium, Manganese, Sodium, Potassium, Aluminum, Boron, Strontium, Orthophosphate/ dissolved phosphorus ^a	USEPA 200.7	250ml HDPE	HNO3	180 days	mg/L
Bromide, Chloride, Sulfate, Fluoride	USEPA 300.0	250ml HDPE	Unpreserved	28 days	mg/L
Total Kjeldahl Nitrogen	USEPA 351.2	1L glass or HDPE	H2SO4	28 days	mg/L
Title 22 Metals + Silicon ^a	USEPA 6010B	250ml HDPE	HNO3	180 days	mg/L
Arsenic, Manganese, Iron ^a	USEPA 6020	250ml HDPE	Omni HNO3	180 days	mg/L
Uranium ^a	USEPA 200.8	250ml HDPE	HNO3	28 days	mg/L
Alkalinity – Total and Bicarbonate	SM 2320B	250ml HDPE	Unpreserved	14 days	mg/L
Specific Conductance	SM 2510B	125ml HDPE	Unpreserved	28 days	mg/L
Total Dissolved Solids	SM 2540C	1L HDPE	Unpreserved	7 days	mg/L
Nitrate	USEPA 353.3	250ml HDPE	Unpreserved	28 days	mg/L
Dissolved Organic Carbon	SM 5310	250ml glass	H2SO4, field filtered	28 days	mg/L
Total Organic Carbon	SM 5310	125ml HDPE/glass	Lab filtered		
		250ml glass	H2SO4	28 days	mg/L
Disinfection Byproducts	Specific analytes, analytical methods, and sampling handling requirements to be determined based on discussions with the laboratory.				

Notes:

^a Field filtered using disposable 0.45 micron filter

HDPE = High-density polyethylene

H2SO4 = sulfuric acid

HNO3 = nitric acid

L = liter

mg/L = milligrams per liter

ml = milliliter

SM = Standard Method

USEPA = U.S. Environmental Protection Agency

Well Owner	Well Identification ^b	Analysis												QA/QC Samples		
		Calcium, Iron, Magnesium, Manganese, Sodium, Potassium, Aluminum, Boron, Strontium, Orthophosphate/ dissolved phosphorus ^a	Bromide, Chloride, Sulfate, Fluoride	Total Kjeldahl Nitrogen	Title 22 Metals + Silicon ^a	Arsenic, Manganese, Iron ^a	Uranium ^a	Alkalinity – Total and Bicarbonate	Specific Conductance	Total Dissolved Solids	Nitrate	Dissolved Organic Carbon	Total Organic Carbon			
		Method														
		USEPA 200.7	USEPA 300.0	USEPA 351.2	USEPA 6010B	USEPA 6020	USEPA 200.8	SM 2320B	SM 2510B	SM 2540C	USEPA 353.3	SM 5310	SM 5310	Duplicate (10% of samples)	MS/MSD (5% of samples)	
		Bottle Type														
		250ml HDPE	250ml HDPE	1L glass or HDPE	250ml HDPE	250ml HDPE	250ml HDPE	250ml HDPE	125ml HDPE	1L HDPE	250ml HDPE	250ml glass or 125ml HDPE/glass	250ml glass			
City of Modesto Public Supply Wells	2	X	X	--	X	X	X	X	X	X	X	X	X	--	--	
	14	X	X	On Duplicate Only	X	X	X	X	X	X	X	X	X	X	--	
	32	X	X	--	X	X	X	X	X	X	X	X	X	--	--	
	37	X	X	--	X	X	X	X	X	X	X	X	X	--	--	
	214	X	X	--	X	X	X	X	X	X	X	X	X	--	--	
	226	X	X	On Duplicate Only	X	X	X	X	X	X	X	X	X	--	X	
229	X	X	--	X	X	X	X	X	X	X	X	X	--	--		
USGS Monitoring Wells	FPA-1	X	X	--	X	X	X	X	X	X	X	X	X	--	--	
	FPA-2	X	X	--	X	X	X	X	X	X	X	X	X	--	--	
	FPA-3	X	X	--	X	X	X	X	X	X	X	X	X	--	--	
	FPA-4	X	X	--	X	X	X	X	X	X	X	X	X	--	--	
	FPB-1	X	X	--	X	X	X	X	X	X	X	X	X	--	--	
	FPB-2	X	X	On Duplicate Only	X	X	X	X	X	X	X	X	X	X	--	
	FPB-3	X	X	--	X	X	X	X	X	X	X	X	X	--	--	
	FPC-1	X	X	--	X	X	X	X	X	X	X	X	X	--	--	
	FPC-2	X	X	--	X	X	X	X	X	X	X	X	X	--	--	
	FPC-3	X	X	--	X	X	X	X	X	X	X	X	X	--	--	
	FPD-1	X	X	On Duplicate Only	X	X	X	X	X	X	X	X	X	--	X	
	FPD-2	X	X	--	X	X	X	X	X	X	X	X	X	--	--	
	FPD-3	X	X	--	X	X	X	X	X	X	X	X	X	--	--	
	FPE-1	X	X	--	X	X	X	X	X	X	X	X	X	--	--	
	FPE-2	X	X	--	X	X	X	X	X	X	X	X	X	--	--	
	FPE-3	X	X	--	X	X	X	X	X	X	X	X	X	--	--	
	OFPA-1	X	X	--	X	X	X	X	X	X	X	X	X	--	--	
	OFPA-2	X	X	On Duplicate Only	X	X	X	X	X	X	X	X	X	X	--	
	OFPA-3	X	X	--	X	X	X	X	X	X	X	X	X	X	--	--
	OFPB-2	X	X	--	X	X	X	X	X	X	X	X	X	X	--	--
	SA	X	X	--	X	X	X	X	X	X	X	X	X	X	--	--
	SB	X	X	--	X	X	X	X	X	X	X	X	X	X	--	--
	SC	X	X	--	X	X	X	X	X	X	X	X	X	X	--	--

Notes:

^a Field filtered using disposable 0.45 micron filter

^b Wells included in the sampling matrix are considered candidate wells for sampling. The actual number and locations of wells to be sampled may change based on field observations (i.e., well conditions) or a determination that investigation objectives can be met with data from fewer wells.

X = to be analyzed

HDPE = High-density polyethylene

L = liter

ml = milliliter

MS/MSD = matrix spike/duplicate sample

SM = Standard Method

USEPA = U.S. Environmental Protection Agency



City of Modesto Well Identification ^a	Analysis												QA/QC Samples	
	Calcium, Iron, Magnesium, Manganese, Sodium, Potassium, Aluminum, Boron, Strontium, Orthophosphate/ dissolved phosphorus ^b	Bromide, Chloride, Sulfate, Fluoride	Total Kjeldahl Nitrogen	Title 22 Metals + Silicon ^b	Arsenic, Manganese, Iron ^b	Uranium ^b	Alkalinity – Total and Bicarbonate	Specific Conductance	Total Dissolved Solids	Nitrate	Dissolved Organic Carbon	Total Organic Carbon		
	Method												Duplicate	MS/MSD
	USEPA 200.7	USEPA 300.0	USEPA 351.2	USEPA 6010B	USEPA 6020	USEPA 200.8	SM 2320B	SM 2510B	SM 2540C	USEPA 353.3	SM 5310	SM 5310		
	Bottle Type													
250ml HDPE	250ml HDPE	1L glass or HDPE	250ml HDPE	250ml HDPE	250ml HDPE	250ml HDPE	250ml HDPE	125ml HDPE	1L HDPE	250ml HDPE	250ml glass or 125ml HDPE/glass	250ml glass		
18	X	X	On Duplicate Only	X	X	X	X	X	X	X	X	X	X	
22	X	X	On Duplicate Only	X	X	X	X	X	X	X	X	X	X	
25	X	X	On Duplicate Only	X	X	X	X	X	X	X	X	X	X	X
33	X	X	On Duplicate Only	X	X	X	X	X	X	X	X	X	X	
236	X	X	On Duplicate Only	X	X	X	X	X	X	X	X	X	X	
281	X	X	On Duplicate Only	X	X	X	X	X	X	X	X	X	X	
313	X	X	On Duplicate Only	X	X	X	X	X	X	X	X	X	X ^b	

Notes:

^a The wells identified are considered candidate wells for vertical profile sampling. This list wells may be changed based on field observations (i.e., well condition) or determination that investigation objectives can be met with vertical profiling data from alternate wells.

^b Field filtered using disposable 0.45 micron filter
HDPE = High-density polyethylene
USEPA = U.S. Environmental Protection Agency
SM = Standard Method
L = liter
ml = milliliter
MS/MSD = matrix spike/duplicate sample



APPENDIX A

FIELD FORM TEMPLATES

SAMPLE IDs CAN NOT BE LONGER THAN 25 CHARACTERS
ITEMS LIKE AOC DESCRIPTIONS, LOCATION ALIAS AND NOTES
CAN BE ASSIGNED IN THE DATABASE AND LEFT OFF THE SAMPLE ID

SOURCE	SAMPLE TYPE
W; MW	WELL-MONITORING
HP; GG; G	GRABWATER
OW; DW	DOMESTIC WELL
SWD	STORMWATER
SW	SURFACE WATER
RO	RUNOFF

TYPICAL WELL MONITORING SAMPLE ID

W-W24A-AF

SOURCE/MEDIA LOCATION/ZONE TEST CODE

TEST CODE	DESCRIPTION
A	PRIMARY
B	DUPLICATE
C	SPLIT
AF	PRIMARY - FIELD FILTERED
BF	DUPLICATE - FIELD FILTERED

S	SEDIMENT
SS	SURFACE SOIL
SV	SOIL VAPOR
RK	ROCK
SB	SOIL BORING
COMP	COMPOSITE

TYPICAL GRAB GROUNDWATER SAMPLE ID

HP-SB-08-10.5-11.5-A

SOURCE/MEDIA LOCATION/ZONE SAMPLE INTERVAL TEST CODE

SOURCE	DESCRIPTION
TB	TRIP BLANK
SB	SOURCE BLANK
FB	FIELD BLANK

TYPICAL QC TRIP BLANK SAMPLE ID

TB021513

SOURCE/MEDIA DATE OF BLANK

SOURCE	DESCRIPTION
SM	SLOPE METER
HA	HAND AUGER
SH	SLIDE HAMMER
CB	CORE BARREL
PMP	PUMP
BAIL	BAILER

TYPICAL QC SLOPE METER EQUIPMENT BLANK SAMPLE ID

SM-W24A-EBF

SOURCE/MEDIA LOCATION/ZONE TEST CODE

TEST CODE	DESCRIPTION
EB	EQUIPMENT BLANK
EBF	EQUIPMENT BLANK - FIELD FILTERED

TYPICAL QC AMBIENT BLANK SAMPLE ID

W-W24A-AB

★ LOCATION NOTES:
LOCATION IDs (LOC ID) ARE SHORTENED
VERSIONS OF THE SAMPLE IDs. THEY TYPICALLY
INCLUDE A LOCATION NUMBER, TYPE AND
SOMETIMES A VERTICAL ZONE OR AOC

SOURCE	DESCRIPTION
IDW	INV. DERIVED WASTE
WL	WASTE LIQUID
WS	WASTE SOLID
WC	WASTE CHARACTERIZATION
COMP	COMPOSITE

TYPICAL WASTE SAMPLE ID

WL-DRUM1-A

SOURCE/MEDIA BIN, DRUM, TNK, PILE TEST CODE

REMCO EXAMPLE: W24A
HILMAR EXAMPLE: MW-24 (NO ZONE)
PAGE EXAMPLE: PPP-03R (PIEZOMETER)
MLPP EXAMPLE: CTF-SV-25 (AOC)

JACOBSON | JAMES
& associates, inc

PROJECT NO.	DATE	DRAWN BY	APPROVED BY
STND	2/15/13	DPG	TJ

FIGURE 1
SAMPLE ID OVERVIEW

JACOBSON | JAMES
 & associates . inc

DAILY FIELD LOG

Personnel:

Date: _____

Client:

Project Name:

Task Number:

Location:

Sub-Contractor:

Weather:	Sun	Cloudy	Rain	Other:
----------	-----	--------	------	--------

[illegible]

Total Hours On-Site:

Equipment Used:

Total Hours in Transit: _____

Employee Signature _____

JACOBSON | JAMES
& a s s o c i a t e s . i n c

FIELD PREPARATION CHECKLIST

Project Name:

FIELD PREPARATION AND FOLLOW-UP		
Telephone Calls		
Client/Site Contact:		
Regulatory Agency:		
USA (48 hr notice) ticket #		
Expires:		
Private Utility Locator		
Other:		
Site Walk Information		
Mark borings/excavations in white for USA		
Obtain utility maps or plans		
Access Issues:		
keys or keypad security code #		
time constraints on work (hours/days)		
limited by power lines, structures, soft ground		
Water or electrical source at site		
Traffic control requirements		
Other:		
Documents to Prepare		
JJA work plan		
JJA Health and Safety Plan		
Subcontractor cost estimates/bids		
Subcontractor work order		
Other:		
Permits		
County Drilling Permit		
Encroachment Permit		
Grading Permit		
Other:		
Analytical Laboratory		
Lab:		
Laboratory Service Request		
Bottle order: sample containers and (circle)		
duplicate or split samples		
trip, atmospheric, or temp blanks		
equipment, pump, or rinsate samples		
cleaning water		
Sample Courier		
Other:		
Waste Generated		
Soil (soil bin, drums, stockpiled on plastic)		
Water (drums, Baker tank)		
Sample for disposal		
Coordinate storage location at site and disposal		
Other:		
Follow-up Tasks		
Surveyor		
DWR Forms for well installations		
Other:		

[illegible]

APPENDIX B

STANDARD OPERATING PROCEDURES

GROUNDWATER SAMPLING

Approval/Date

 2/3/14
Terry James
Health and Safety Manager

1.0 OBJECTIVES

The objective of this standard operating procedure (SOP) is to provide general information regarding the sampling of monitoring wells. The procedures described in this document are designed to reduce the potential variability associated with purging and sampling. These procedures may be changed as required, dependent upon site conditions and/or project requirements.

2.0 APPLICABILITY

This SOP will be used to support groundwater monitoring programs and the field groundwater sampling activities. Groundwater sampling involves two primary operations, purging stagnant water from a well followed by the collection of a sample from the same well. This may be achieved by a number of methods and procedures, and in some cases, a combination of them. These methods and procedures are described in this SOP.

3.0 REQUIRED EQUIPMENT

Equipment required for conducting groundwater monitoring and sampling are variable depending on the method chosen to conduct the sampling. The following list includes equipment generally used during monitoring and sampling activities. Additional specialized equipment may be required based on the sampling method chosen, and will be covered later in the SOP. General equipment that should be considered for monitoring and sampling are as follows:

- Health and Safety Plan
- Personal protection equipment (PPE)
- Health and safety monitoring equipment (e.g., PID)
- Appropriate field paperwork (e.g., water level monitoring forms, well sampling forms, and sample matrix)
- Decontamination equipment

- Water level indicator and weighted tape
- Water quality meters
- Purge equipment (i.e., pumps, controllers, generator, tubing, bailers)
- Calculator
- Appropriate keys for well-cap locks
- Sample containers and labels
- Chain of custody forms
- Shipping coolers
- Ziploc plastic bags
- Ice
- Garbage bags
- Packing Tape
- Shipping documents
- Distilled/De-ionized (DI) water
- Filters (0.45 micron), if appropriate
- General tools (including screwdrivers, ratchet and sockets, hammer, flashlight)

Additional equipment may be required depending on the site, sampling method, and project requirements.

4.0 METHOD SUMMARY

Pre-mobilization communication and project set up will ensure the ultimate success of a groundwater monitoring and sampling project. This includes communication with the project team, client, and analytical laboratory. Prior to beginning any monitoring and sampling event, a field sampling plan, quality assurance plan, scope of work, and laboratory coordination should be completed. These plans will discuss the objectives of the project and describe the procedures necessary to complete the project. The following sections describe the methods and procedures required during a sampling program.

4.1 Equipment Decontamination

Equipment that will be in contact with the sample must be properly decontaminated prior to each use. This is necessary to minimize contamination of the sample and any cross contamination to other sample locations. Use of dedicated or new, disposable purging and sampling equipment

is preferable to decontamination of reusable equipment. Dedicated equipment, and the use of new, disposable equipment, can virtually eliminate cross-contamination between samples. When decontaminating reusable equipment, a four step process is used. First, gross contamination is removed using brushes, sponges, and/or high or low pressure water blasting. Second, a non-phosphate detergent is used to remove trace amounts of contaminants, followed by a tap water rinse and finally a distilled or de-ionized water rinse. The equipment is then allowed to air dry, away from any other contaminated equipment. Decontamination procedures should be documented on the field sampling forms.

4.2 Purging and Sampling

This section describes the procedures to be used for groundwater sampling. These procedures include preparatory field activities, purging, sampling, and post sampling activities.

4.2.1 Preparatory Field Activities

The following procedures should be conducted in the field prior to well purging and sampling.

Well Maintenance Check

A visual inspection of the condition of the well should be conducted prior to purging and sampling activities. The visual inspection should include inspecting the well apron, well box lid and bolts, well cap and lock, and well casing condition. Any damage or problems observed should be documented and addressed.

Determination of Total Depth of Well

A weighted tape or water level indicator may be used to determine the total depth (TD) of the well on an annual basis¹, or as needed to verify well ID. Determining total depth is useful to ensure the well is identified (compare measurement with well log) and evaluate amount of sediment intrusion. The measurement device should be lowered slowly to minimize the suspension of sediment at the bottom of the well or silt trap. In addition to the depth, it should be noted if a hard or soft bottom is encountered.

Preparation of Well Area

A suitable and safe work area should be established around the perimeter of the well. Safety equipment (e.g., cones or caution signs) may be required depending on well location. All sampling equipment should be placed on a clean surface such that it will not become inadvertently contaminated.

¹ May be required more often for extraction wells or if historical record indicates sediment intrusion is an issue.

Water Level Measurements

The depth to water should be measured in all wells to be sampled prior to the initiation of sampling activities. Water levels will be collected from the cleanest well to dirtiest well, if known, to reduce cross contamination. An electronic water level indicator graduated to 0.01-foot increments will be used to measure water levels. If two water meters are used, both will be used on the first well to ensure consistent measurements. Results are documented and any consistent differences are reported to the project manager. Water levels will be monitored twice to ensure an accurate measurement is made. Water levels will be recorded on the well monitoring file sheets and will be referenced to the top of well casing. The water level indicator will be properly decontaminated between each well.

Calculation of Well Purge Volume

Standard purging and sampling methods require at least three well casing volumes to be removed from the well prior to sampling. Purging a well prior to sampling ensures that water that may be stagnant in the well is removed, allowing fresh ground water to enter the well for sampling. The volume of water standing in the well should be calculated using the depth to water measurement, total depth of the well (either measured or from well completion logs), and well diameter. The volume of one well casing volume can be calculated using the following formula:

$$V = \pi d^2 h / 77$$

Where:

V = volume of water in gallons

d = diameter of the well in inches

h = height of the water column in feet

77 = conversion factor to gallon

Alternatively, the following conversion factors can be used for quick calculation of well casing volume:

<u>Well Casing Diameter (inches)</u>	<u>Gallons per foot of water</u>
1.0	0.041
2.0	0.163
3.0	0.367
4.0	0.653
6.0	1.469

Well casing volume calculations should be documented on the field sampling forms.

4.2.2 Well Purging

Monitoring wells may be sampled 48-hours following development. Prior to sampling a monitoring well, the well must be purged to remove water that may have been stagnant in the well as described previously. The most common methods for purging are using a bailer, submersible pump, peristaltic pump, or inertial pump. Each method will be described in the Equipment Instructions section of the SOP.

While the well is being purged, field parameters (e.g., pH, temperature, conductivity, oxidation reduction potential, and turbidity) should be measured and recorded following removal of a set volume of water (e.g. well volume) until the readings stabilize. This is done to assure that fresh ground water is entering the well. Field parameters are stable when there is less than 0.2 pH unit change and 10% change for conductivity and temperature for three consecutive measurements. Depth to water measurements should also be monitored at regular intervals during purging. Ideally purging activity will be done in a manner as to not allow the water level in the well to drop closer than 1-foot from the bottom of the well (to minimize the induced turbidity).

Always follow the manufacturer's instructions when using purging equipment and water quality instruments. All instruments and monitoring equipment must be calibrated and documented prior to use according to the manufacturer's specifications and following the Instrument Calibration SOP.

If purging equipment or monitoring instruments are malfunctioning, or cannot be successfully calibrated, the equipment will need to be repaired immediately. In the event that this occurs during the course of field activities, it will be the field personnel's responsibility to ensure that replacement equipment is obtained as quickly as possible and that the Project Manager, or Site Field Manager, is immediately notified. Under no circumstances should field personnel continue with activities until a replacement is obtained or approval from the Project Manager is obtained. Instances of equipment failure and corrective actions taken will be documented in field notebook.

4.2.3 Groundwater Sampling

It is important that wells be sampled as soon as possible after purging, as long as the well has recovered to 80% of the original water column height. If not, sampling should occur as soon as

the well has recovered sufficiently to provide adequate volume within 24 hours.

As with purging equipment, there are a number of considerations in the selection of sample collection equipment. It is also common to use a different device for purging than for sampling. An example would be to purge with the use of a submersible pump and collect a sample with a disposable bailer.

The type of analysis for which a sample is being collected determines the type of sample container, preservative, holding time, and filtering requirements are used. Refer to the project field sampling plan and/or sample matrix for this information. Consideration should be given to the order in which sample containers for different parameters are filled. The order should be determined based on parameter sensitivity to volatilization, pH change, or oxidation. For example, volatile organic compounds (VOCs) are the most sensitive constituent to volatilization, and should be containerized first.

Samples should be collected directly from the sampling device into the appropriate laboratory supplied containers, labeled (i.e., sample ID, date, time, and analysis), and place in a cooler with ice. Field personnel will then log the sample on a chain of custody, which will accompany the samples to the laboratory.

4.2.4 Equipment Instructions

This section describes the specific instructions for the installation and use of various purging and sampling equipment.

Bailer

Bailers are the simplest purging device used. They generally consist of a rigid length of tube, with a ball-check valve at the bottom. String or twine is used to lower the bailer into the well and retrieve a volume of water. The same bailer can be used for both purging and sample collection. This method of purging is suited for shallow or small-diameter wells.

Purging and Sampling Instructions:

1. Determine the volume of water to be purged based on field observations and notes (Depth to water, Total depth, and well casing diameter) as described previously.
2. Don a pair of gloves and attach the string to a new disposable bailer or decontaminated, re-useable bailer.

3. Slowly lower until the bailer is completely submerged, being careful not to drop the bailer down to the water, causing turbulence and the possible loss of volatile-organic contaminants.
4. Pull the bailer out of the well, ensuring that the line never touches the ground.
5. Empty the bailer into a container of known volume as necessary in order to determine the number of bails necessary to achieve the required purge volume.
6. Samples will be collected periodically to determine if field parameters such as pH, temperature, and electrical conductivity have stabilized.
7. After completion of purging, dispose of the purge water as specified in the site specific sampling plan.
8. Sampling procedure with a bailer is the same as the purging procedure. Fill sample containers slowly, in order of sensitivity to volatilization and oxidation, as discussed above.
9. Filtered samples can be obtained by filling a non-preserved sample container, and then transferring the liquid through an in-line filter (typically a 0.45 micron disposable filter) into a sample container using a peristaltic pump.

Electric Submersible Pump

Submersible pumps can be operated with a wide variety of pumping rates and therefore are versatile for both well purging and sample collection. Collecting groundwater samples from these pumps is only appropriate if approved project-specific planning documents include this technique for collecting samples.

In general, the decontaminated (clean) pump is connected to new or dedicated polyethylene tubing, appropriate for the depth of the well, and operated by a control box. The pump is lowered into the well and the purge rate is adjusted based on well drawdown and/or project protocols.

Purging and Sampling Instructions:

1. Determine the volume of water to be purged based on field observations and notes (Depth to water, Total depth, well casing diameter) as described previously.
2. Assemble pump, tubing, and any safety cables, and lower the pump into the vicinity of the midpoint of the well screen. Make sure the pump is deep enough so that it stays submerged during pumping. Running the pump without water around it may cause damage.

3. Attach flow meter to the outlet hose to measure the volume of water purged or use a graduated container of known volume in order to achieve the required purge volume.
4. Use a ground fault circuit interrupter or ground the generator to avoid possible electric shock.
5. Attach control box, and purge well until specified volume of water has been evacuated (or until field parameters have stabilized). Do not allow the pump to run dry. If the pumping rate exceeds the well-recharge rate, lower the pump farther into the well and/or decrease the pumping rate and continue pumping.
6. Samples will be collected periodically to determine if field parameters such as pH, temperature, and electrical conductivity have stabilized.
7. Collect and dispose of purge waters as specified in the site specific sampling plan.
8. Allow the well to recharge after purging, prior to sampling.
9. Resume pumping and adjust pumping rate to the slowest possible rate.
10. Collect samples by purging directly into the sample containers, in order of sensitivity to volatilization and oxidation, as discussed previously.
11. Filtered samples can be obtained by installing an in-line filter directly onto the pump discharge.

Peristaltic Pumps

A peristaltic pump can be used to purge shallow, small diameter wells. The lift capacity is limited with these pumps and is often exceeded at groundwater depths of greater than 20 feet. This type of pump is normally used with dedicated or new tubing. Peristaltic pumps can also be used for filtering samples through an inline filter.

Purging and Sampling Instructions:

1. Determine the volume of water to be purged based on field observations and notes (Depth to water, Total depth, well casing diameter) as described previously.
2. Replace the silicone tubing in the pump head if the pump will be used for sample collection.
3. Attach new or dedicated polyethylene tubing to the silicone tubing and lower it into the well, being careful not to contact any surface other than the well casing.
4. Start the pump and direct the discharge water into a graduated container to determine the purge rate.
5. Continue pumping until the necessary volume of water has been purged from the well.

-
6. Samples will be collected periodically to determine if field parameters such as pH, temperature, and electrical conductivity have stabilized.
 7. Collect and dispose of purge waters as specified in the site specific sampling plan.
 8. Allow well to recharge after completion of purging, if necessary.
 9. Resume pumping and adjust to a slow pumping rate.
 10. Collect the samples by purging directly into the sample containers, in order of sensitivity to volatilization and oxidation, as discussed previously.
 11. Filtered samples can easily be obtained by installing an in-line filter directly onto the pump discharge.

Inertia Pumps

An inertia pump is a simple device that can be used to purge and sample wells of almost any diameter to a depth of approximately 100 feet. They are appropriate to use when wells are too deep to bail by hand or too narrow (or inaccessible) to warrant a submersible pump. This type of pump uses new or dedicated tubing with a check valve attached to the bottom of the tubing. The tubing is lowered down the well, and the inertial lift of the pump brings groundwater up the tubing.

Purging and Sampling Instructions:

1. Determine the volume of water to be purged based on field observations and notes (Depth to water, Total depth, well casing diameter) as described previously.
2. Don a new pair of gloves and install check valve into bottom of tubing by threading it onto the tubing and securing with a zip-tie or hose clamp.
3. Lower tubing into well, making sure not to contact any surface other than the well casing. Also, make sure you do not place the valve into sediment at the base of the well, clogging the check valve.
4. Place pump above well casing or hang from outside of standpipe. Connect extension cord between pump and generator and turn on generator. Make sure generator is equipped with a Ground Fault Circuit Interrupter (GFCI) and is located as far from the well head as possible in a down-wind direction.
5. Begin pumping, discharging water into a 5-gallon bucket to determine purge rate. Purge until specified volume of water has been evacuated (or until field parameters such as temperature, pH, conductivity, turbidity, and ORP have stabilized).
6. Collect and dispose of purge waters as specified in the site specific sampling plan.

-
7. Allow well to recharge after completion of purging, if necessary.
 8. Resume pumping and adjust to a slow pumping rate.
 9. Collect the samples by purging directly into the sample containers, in order of sensitivity to volatilization and oxidation, as discussed previously.
 10. Filtered samples can easily be obtained by installing an in-line filter directly onto the pump discharge.
 11. Remove check valve from bottom of tubing, again ensuring that the tubing doesn't contact the ground. Replace tubing in the well (if dedicated) and decontaminate the foot-valve before storage.

4.2.5 Low Flow Purging and Sampling

Low flow purging and sampling results in the collection of groundwater samples from monitoring wells that are representative of ground water conditions in the geological formation. This is typically accomplished by limiting the flow rate during purging to the range of 100 to 500 ml/min (0.026 to 0.13 gallons/min). For this procedure, the goal is to induce a steady flow rate while minimizing drawdown in the well casing.

Sampling at the prescribed (low) flow rates has three primary benefits:

1. Minimizes disturbance of sediment in the bottom of the well, thereby producing samples with low turbidity.
2. Minimizes aeration of the groundwater sample during collection, which improves sample quality.
3. Significantly reduces the volume of groundwater purged from a well and the costs associated with its proper treatment and disposal.

Initially, the purge flow rate should start at approximately 200 ml/min (0.053 gallons/min) and water level should be frequently monitored. Flow rate should be adjusted so drawdown will not exceed 0.5 feet, or approximately 2 percent of the saturated thickness of low permeability formations, whichever is greater.

Indicator parameters should be monitored every three to five minutes during low flow purging until measurements indicate stability in water quality (as described above). Once parameters are stable, samples are collected directly into sample containers at the same flow rate as the well was purged.

Follow the same decontamination and equipment operation procedures as discussed in Section

4.2.4.

4.2.6 Post Sampling Activities

After all samples from a well are collected and preserved, the sampling equipment should be decontaminated prior to sampling another well to prevent cross contamination of the equipment and monitoring wells between locations as described above. Typically at the end of the day or sampling event, samples are submitted to a laboratory for analysis. Generally, this is done in the field. Proper sample documentation, handling, and shipping practices will ensure that samples will be received and analyzed by the laboratory within required hold times.

Documentation

Accurate field records must be maintained to document both purging and sampling activities. Specifically, the field sampling records should include, at a minimum, the following:

- Sampling location
- Date and time
- Field Personnel
- Condition of the well
- Static water level
- Depth to the bottom of the well (at least once/year)
- Calculated well casing volume
- Purge equipment and methods
- Actual purge volume
- Sample collection method
- Sample ID
- Water quality measurements

Field forms should be reviewed the Project Manager and/or Field Manager following the sampling event and filed into the appropriate project files. An example of the groundwater sampling field form is included in the attachment of this SOP.

Sample Handling

- Prior to sample collection, a cooler should be filled with water-based wet ice. This is to ensure that the samples are chilled immediately after collection.
- Place sample containers in the cooler in appropriate size Ziploc bags immediately after sampling in the field.
- Surround the samples with sufficient ice to chill to 4°C.
- Check the samples often, making sure there is enough ice to maintain the required temperature. Add more ice when necessary, and drain off water as the ice melts.

Shipping**VOAS:**

- Place all the VOAS for each sampling location in a 1 quart Ziploc bag. Stand all the VOAS in the same direction.
- Place as many small Ziploc bags into a 1 gallon Ziploc bag that can fit into a row, making sure that the VOAS are upright, and ensure the bag is tightly sealed.

Polys, Ambers, other containers:

- Place one bubble wrapped amber in a 1 gallon Ziploc bag, making sure that the amber is upright, and ensure that the bag is tightly sealed.
- Place as many polys in a 1 gallon Ziploc bag, making sure the polys are upright, and ensure that the bag is tightly sealed.

Packing the Cooler:

- Place an open 55 gallon garbage bag inside the cooler.
- Fill the bottom of the cooler with 1 gallon Ziploc bags of ice.
- Place the samples upright and directly on top of the ice. Pack the samples tightly in the cooler, adding 1 gallon Ziploc bags of ice between samples to fill any gaps.
- Add a layer of 1 gallon Ziploc bags of ice on top of the samples.
- If the ice and samples do not completely fill the cooler to the top, pack the remaining space with bubble wrap or packing paper until the cooler is full to prevent the samples from moving during shipment.
- Seal the 55 gallon garbage bag with a zip tie to seal up the samples and ice in case of a leak. Shipping companies will stop shipment of a leaking package and all the samples will be compromised.
- Complete the chain of custody (COC) and check off contents to ensure all samples are accounted for.

-
- Sign and date COC and make sure to retain a copy for the field records.
 - Place a copy of the COC inside the cooler in a 1 gallon Ziploc bag.
 - Seal the top of the cooler shut with packing tape around the whole cooler on both ends to prevent the lid from falling off or opening during shipment.
 - Fill out shipping forms and affix to the top of the cooler.

5.0 FIELD QUALITY ASSURANCE/QUALITY CONTROL SAMPLES

Additional samples should be collected for the specific purpose of documenting the Quality Assurance/Quality Control (QA/QC) of the field sampling procedures. Field QA/QC samples provide technically and legally defensible data regarding the reproducibility and overall quality of the groundwater sample. Descriptions of the type and frequency of QA/QC sampling should be specified in the project-specific planning documents. Field QA/QC samples include trip, field, ambient, rinseate and/or equipment blanks. These samples are collected in addition to the laboratory QA/QC samples which may include method blanks, matrix spikes, and matrix spike duplicates.

6.0 HEALTH AND SAFETY

When working with potentially hazardous materials, follow U.S. Environmental Protection Agency (U.S. EPA), Occupational Safety and Health Administration (OSHA), or corporate health and safety guidelines. More specifically, depending upon the site specific contaminants, various protective programs must be implemented prior to sampling the first well. The site health and safety plan (HASP) should be reviewed with specific emphasis placed on the protection program planned for the well-sampling tasks.

Physical hazards associated with well sampling include, but are not limited to, the following:

- Lifting injuries associated with pump and bailer retrieval, and moving equipment.
- Traffic hazards associated with working in public right of ways.
- Cuts associated with the use of utility knives.
- Heat/cold stress as a result of exposure to extreme temperatures and because of protective clothing.
- Animal and insect injuries, such as spider, wasp, tick, or snake bites.
- Situations conducive to slipping, tripping, or falling as a result of wet or icy conditions.

- Electrical shock associated with use of submersible pumps is possible. Use a ground fault circuit interrupter or a copper grounding stake to avoid this problem.
- Acid burns may occur if acid preservatives are mishandled.
Long-term exposure to hazardous chemicals found at many sites of investigation may pose a health hazard, especially if proper protective clothing is not worn.

7.0 ATTACHMENTS

Groundwater Sampling Form

Approval/Date

**General Waste Management
Standard Operating Procedure (SOP)**

Terry James
Health and Safety Director

Overview

JJ&A employees shall be instructed on proper waste storage and disposal procedures. This general waste management SOP includes instruction on disposal of hazardous, non-hazardous wastes, recyclables, etc. JJ&A employees are to follow the guidance in this document, in addition to receiving client specific training on proper waste handling, to ensure proper disposal of wastes.

Plan for Anticipated Waste Generation

- Prior to beginning field activities, identify anticipated waste streams and quantities. Wastes can include decontamination water, soil, groundwater, contact waste, etc. Notify and seek input from client, project manager, etc., as appropriate regarding potential wastes, the amount to be generated, and the proper disposal.
- Obtain appropriate storage containers and designate waste storage location(s). Ensure there is secondary containment for liquid wastes.
- Use the Waste Screening QA/QC Checklist in the Administrative/Waste Management folder to determine waste type as follows:
 - Is the waste excluded/exempted?
 - Is the waste a CA or RCRA listed waste?
 - Is the waste considered acutely or extremely hazardous in CA?
 - Does the waste exhibit a hazardous waste characteristic?
 - Is the waste a special waste?
- Coordinate with the client to determine if sampling will be necessary or if profile will be based on generator knowledge. (Note that JJ&A is not the generator.)
- If needed, define analysis requirements and coordinate with the laboratory that will complete the analysis.
- Notify the JJ&A waste coordinator of the anticipated waste, and keep them informed throughout process including verbal updates and copying them on or forwarding them emails relevant to waste generation, analysis, and pickup and disposal.

Generation of Waste

Contain Waste

- Once waste is generated at the project site, the waste disposal process is triggered. Hazardous waste must be removed from the site within 90 days of the accumulation start date.
- Proper handling, organization, and storage of waste and recyclables is important in order to minimize potential impacts to the environment.
- Containers must be appropriate for the type of waste generated. Containers must be DOT-approved and may include drums, bins, poly tanks, etc.
- Segregate non-hazardous wastes from hazardous wastes to reduce the amount of hazardous material going to disposal.
- If applicable, separate out materials, such as scrap metals, for recycling. Recyclable waste must still be properly handled, organized, and stored.

Collect Samples for Waste Profiling

- Confirm with waste disposal facility if sampling of waste is required or if waste can be profiled based on generator knowledge.
- If sampling is required for waste characterization and profiling, collect a sample of waste for analysis as designated by the disposal facility.
- Handle and submit waste sample to the analytical laboratory following standard chain-of-custody (COC) procedures.
- Complete a separate COC form for each waste stream for waste characterization samples. Do not include on the same COC used for investigation or monitoring samples.
- Include Database Department contact information on the COC so laboratory reports will be entered into data base once received.

Label Containers

- Keep an ample supply of all label types (e.g., Hazardous, Non-Hazardous, Pending Analyses, etc.) during waste generation.
- Client Specific Programs
 - For PG&E sites:
 - Label waste container per PG&E policy saved on server at J:\Administrative\Waste Management.

- Write “**Remediation Waste**” on top of drum with a paint pen or on a blank label on the side of the container.
- For wastes that are unknown or have the possibility of being hazardous, but are pending analysis:
- Place a “HAZARDOUS WASTE” label on container immediately that includes the following information: Generator Address and Phone Number, EPA ID Number, Accumulation Start Date (date that waste was first placed in container), contents and composition, physical state and hazardous properties.
- Do not fill in EPA or State Waste Codes or proper shipping description block at this time.
- Place a “Pending Analysis” label adjacent to the “Hazardous Waste” label.
- If laboratory results indicate that waste is hazardous, then **WITHIN 10 DAYS OF RECEIVING RESULTS**, remove “Pending Analysis” label and then label in accordance with waste characterization results.
 - If retaining the “Hazardous Waste” label, fill in the remaining information.
 - If removing the “Hazardous Waste” label, replace with a label that includes a description of the waste, contact information (name and phone number) and date when waste was first accumulated.
- Applying Generator Knowledge (per PG&E procedures):
 - Obtain approval from Environmental Remediation EHS Manager or Environmental Operations Hazardous Materials Manager to use generator knowledge.
 - Place label that includes “Generator Knowledge” on the container immediately.
 - Fill out “Hazardous” or “Non-Hazardous” waste label, as appropriate.
 - Do not apply a “Pending Analysis” label even if lab analysis is being performed.

- For Other sites:
 - For wastes that are unknown or have any possibility of being hazardous, but are pending analysis:
 - Place a “Pending Analysis” or “Non-Classified Waste Material” label on the container immediately that includes the following information: Material, Site Address, Accumulation Date, Generator, Generator Contact and Phone and/or Contractor Contact and Phone
 - There is no need to also apply a “Hazardous Waste” label.
 - Once the waste has been characterized, removed “Pending Analysis/Non-Classified Waste Material” label as soon as possible and replace with “Hazardous” or “Non-Hazardous” according to laboratory results.
- Applying Generator Knowledge at non-PGE sites
 - JJ&A is not considered a generator of waste, so JJ&A staff must confer with the client/generator to get approval for waste classification based on generator knowledge.
 - Place label that includes “Generator Knowledge” on the container immediately.
 - Fill out “Hazardous” or “Non-Hazardous” waste label, as appropriate.

Store Waste

- Be aware of 90-day time limit on storage of hazardous waste which starts at the time waste was placed in a container. There is no storage time limit on non-hazardous waste.
- Store contained waste in a designated, secure location.
- Provide secondary containment for liquid hazardous wastes.
- If non-hazardous waste stockpiles are stored outside (without overhead protection), plastic sheeting must be placed over the stockpiled materials to prevent dispersion of waste materials and to control the potential for run-off. Plastic sheeting must be secured with sandbags to prevent the sheeting from blowing off. Straw waddles will also be placed around stockpiles to prevent erosion.

Workplace (Satellite) Accumulation Areas

- Generators may temporarily accumulate small quantities of hazardous wastes at or near the point where wastes are generated if the following conditions are met:
 - Volume limit is 55 gallons of hazardous waste or one quart of acute or extremely hazardous waste.

- Waste is accumulated in containers, not tanks.
- A “Hazardous Waste” label that includes the following must be placed on the container: accumulation start date and date quantity limit is reached, generator’s name and address, composition, physical state, and hazardous properties.
- The Accumulation Area is under the control of the operator of the process that generates waste.
- Initial date of accumulation is marked on each container.
- **Within 3 days after container becomes full or quantity limit is reached**, mark date and move to Hazardous Waste Accumulation Area.
- **Waste must not be held on-site for more than one year from initial date of accumulation or 90 days from the time the quantity limit is reached, whichever occurs first.**
- The container must be in good condition and be made of or lined with material that is compatible with the waste.
- The container is kept closed except when being filled or emptied.
- The Accumulation Area should be inspected weekly for leaks, proper labeling, improperly combined wastes, and volume. A written record of inspections should be maintained at the facility.
- If wastes are transferred into containers at the Hazardous Waste Accumulation Area, the container into which the waste is transferred must be marked with the oldest of the initial accumulation start dates from the various containers being emptied.

Waste Disposal – Coordinate Pick Up

- Confirm JJ&A role; if JJ&A is not contracted to manage waste, client will handle waste management from this point onward.
- If JJ&A is contracted for waste disposal, coordinate with client and waste transport subcontractor to schedule pick-up.
- JJ&A will generally provide oversight during waste pick-ups unless specifically directed otherwise with client project manager.
- Disposal subcontractor will create waste manifest based on profile. **Review manifest before scheduled pick-up.**

- Confirm the following are entered correctly on manifest: hazardous/non-hazardous designation, site information (address, EPA ID, manifest mailing address), disposal facility information (name, address, EPA ID, phone number), description of waste (quantity, profile number).
- Coordinate pick up.
- Client or an authorized representative must sign the manifest. **JJ&A should confirm availability of client or authorized representative when scheduling pickup. JJ&A does not sign the manifest.**
- Following disposal of hazardous waste, send DTSC a notification letter with completed manifest. In some cases, the client may assume responsibility for this task.

Recordkeeping

- Field staff who generate waste (solid or liquid) are required to complete the JJ&A Generated Waste Inventory Form before demobilizing, and provide a copy of the form to the project manager and JJ&A Waste Coordinator.
- Record location, date, type of waste, container type and volume, and take pictures of the stored waste and the labels.
- Keep copies of all field notes, emails, and records of telephone communications.
- Keep records of all phases of waste management including generation, storage, profiling, weekly waste inspections, transport and disposal.
- Notify the JJ&A Waste Coordinator when waste (hazardous or non-hazardous) are generated on a project site and keep them involved with waste management activities including profiling and disposal.
- All projects that generate waste should have a waste tracking spreadsheet filed in a "Waste Management" subfolder. Shortcuts to all tracking sheets will be maintained in the Administrative\Waste Management folder. The JJ&A Waste Coordinator will maintain these tracking sheets with information provided by PMs.

Waste Screening Table(s)

- Follow Waste Screening Table directions and QA/QC Checklist saved in Administrative/Waste Management/Waste Screening folder.
- Based on soil results screening table, determine if additional (leachate) analyses are required.

Complete Waste Summary Memo

- Following disposal, prepare detailed JJ&A internal waste disposal memo.

- Waste Memo should include: lab reports, screening tables, waste profile sheets, disposal coordination records and documents, documentation of weekly waste inspections, and waste manifest signed by disposal facility.
- Arrange for review of memo by the JJ&A Waste Coordinator or designee.
- Generate hardcopy (with lab results on CD) of memo for file and also save as pdf on JJ&A server. Memo author and reviewer should initial the hardcopy in the title block. The initialed page should then be scanned and included in a pdf of the entire memo.
- Use a tracking sheet to document memo author, reviewer, and completion date. When complete, scan the tracking sheet and save with the memo on the server. Top sheet of memo needs to be initialed by memo author and reviewer and then scanned.
- A Waste Memo Template is available at J:/Administrative/Waste Management.

GROUNDWATER SAMPLING

Approval/Date

 2/3/14
Terry James
Health and Safety Manager

1.0 OBJECTIVES

The objective of this standard operating procedure (SOP) is to provide general information regarding the sampling of monitoring wells. The procedures described in this document are designed to reduce the potential variability associated with purging and sampling. These procedures may be changed as required, dependent upon site conditions and/or project requirements.

2.0 APPLICABILITY

This SOP will be used to support groundwater monitoring programs and the field groundwater sampling activities. Groundwater sampling involves two primary operations, purging stagnant water from a well followed by the collection of a sample from the same well. This may be achieved by a number of methods and procedures, and in some cases, a combination of them. These methods and procedures are described in this SOP.

3.0 REQUIRED EQUIPMENT

Equipment required for conducting groundwater monitoring and sampling are variable depending on the method chosen to conduct the sampling. The following list includes equipment generally used during monitoring and sampling activities. Additional specialized equipment may be required based on the sampling method chosen, and will be covered later in the SOP. General equipment that should be considered for monitoring and sampling are as follows:

- Health and Safety Plan
- Personal protection equipment (PPE)
- Health and safety monitoring equipment (e.g., PID)
- Appropriate field paperwork (e.g., water level monitoring forms, well sampling forms, and sample matrix)
- Decontamination equipment

- Water level indicator and weighted tape
- Water quality meters
- Purge equipment (i.e., pumps, controllers, generator, tubing, bailers)
- Calculator
- Appropriate keys for well-cap locks
- Sample containers and labels
- Chain of custody forms
- Shipping coolers
- Ziploc plastic bags
- Ice
- Garbage bags
- Packing Tape
- Shipping documents
- Distilled/De-ionized (DI) water
- Filters (0.45 micron), if appropriate
- General tools (including screwdrivers, ratchet and sockets, hammer, flashlight)

Additional equipment may be required depending on the site, sampling method, and project requirements.

4.0 METHOD SUMMARY

Pre-mobilization communication and project set up will ensure the ultimate success of a groundwater monitoring and sampling project. This includes communication with the project team, client, and analytical laboratory. Prior to beginning any monitoring and sampling event, a field sampling plan, quality assurance plan, scope of work, and laboratory coordination should be completed. These plans will discuss the objectives of the project and describe the procedures necessary to complete the project. The following sections describe the methods and procedures required during a sampling program.

4.1 Equipment Decontamination

Equipment that will be in contact with the sample must be properly decontaminated prior to each use. This is necessary to minimize contamination of the sample and any cross contamination to other sample locations. Use of dedicated or new, disposable purging and sampling equipment

is preferable to decontamination of reusable equipment. Dedicated equipment, and the use of new, disposable equipment, can virtually eliminate cross-contamination between samples. When decontaminating reusable equipment, a four step process is used. First, gross contamination is removed using brushes, sponges, and/or high or low pressure water blasting. Second, a non-phosphate detergent is used to remove trace amounts of contaminants, followed by a tap water rinse and finally a distilled or de-ionized water rinse. The equipment is then allowed to air dry, away from any other contaminated equipment. Decontamination procedures should be documented on the field sampling forms.

4.2 Purging and Sampling

This section describes the procedures to be used for groundwater sampling. These procedures include preparatory field activities, purging, sampling, and post sampling activities.

4.2.1 Preparatory Field Activities

The following procedures should be conducted in the field prior to well purging and sampling.

Well Maintenance Check

A visual inspection of the condition of the well should be conducted prior to purging and sampling activities. The visual inspection should include inspecting the well apron, well box lid and bolts, well cap and lock, and well casing condition. Any damage or problems observed should be documented and addressed.

Determination of Total Depth of Well

A weighted tape or water level indicator may be used to determine the total depth (TD) of the well on an annual basis¹, or as needed to verify well ID. Determining total depth is useful to ensure the well is identified (compare measurement with well log) and evaluate amount of sediment intrusion. The measurement device should be lowered slowly to minimize the suspension of sediment at the bottom of the well or silt trap. In addition to the depth, it should be noted if a hard or soft bottom is encountered.

Preparation of Well Area

A suitable and safe work area should be established around the perimeter of the well. Safety equipment (e.g., cones or caution signs) may be required depending on well location. All sampling equipment should be placed on a clean surface such that it will not become inadvertently contaminated.

¹ May be required more often for extraction wells or if historical record indicates sediment intrusion is an issue.

Water Level Measurements

The depth to water should be measured in all wells to be sampled prior to the initiation of sampling activities. Water levels will be collected from the cleanest well to dirtiest well, if known, to reduce cross contamination. An electronic water level indicator graduated to 0.01-foot increments will be used to measure water levels. If two water meters are used, both will be used on the first well to ensure consistent measurements. Results are documented and any consistent differences are reported to the project manager. Water levels will be monitored twice to ensure an accurate measurement is made. Water levels will be recorded on the well monitoring file sheets and will be referenced to the top of well casing. The water level indicator will be properly decontaminated between each well.

Calculation of Well Purge Volume

Standard purging and sampling methods require at least three well casing volumes to be removed from the well prior to sampling. Purging a well prior to sampling ensures that water that may be stagnant in the well is removed, allowing fresh ground water to enter the well for sampling. The volume of water standing in the well should be calculated using the depth to water measurement, total depth of the well (either measured or from well completion logs), and well diameter. The volume of one well casing volume can be calculated using the following formula:

$$V = \pi d^2 h / 77$$

Where:

V = volume of water in gallons

d = diameter of the well in inches

h = height of the water column in feet

77 = conversion factor to gallon

Alternatively, the following conversion factors can be used for quick calculation of well casing volume:

<u>Well Casing Diameter (inches)</u>	<u>Gallons per foot of water</u>
1.0	0.041
2.0	0.163
3.0	0.367
4.0	0.653
6.0	1.469

Well casing volume calculations should be documented on the field sampling forms.

4.2.2 Well Purging

Monitoring wells may be sampled 48-hours following development. Prior to sampling a monitoring well, the well must be purged to remove water that may have been stagnant in the well as described previously. The most common methods for purging are using a bailer, submersible pump, peristaltic pump, or inertial pump. Each method will be described in the Equipment Instructions section of the SOP.

While the well is being purged, field parameters (e.g., pH, temperature, conductivity, oxidation reduction potential, and turbidity) should be measured and recorded following removal of a set volume of water (e.g. well volume) until the readings stabilize. This is done to assure that fresh ground water is entering the well. Field parameters are stable when there is less than 0.2 pH unit change and 10% change for conductivity and temperature for three consecutive measurements. Depth to water measurements should also be monitored at regular intervals during purging. Ideally purging activity will be done in a manner as to not allow the water level in the well to drop closer than 1-foot from the bottom of the well (to minimize the induced turbidity).

Always follow the manufacturer's instructions when using purging equipment and water quality instruments. All instruments and monitoring equipment must be calibrated and documented prior to use according to the manufacturer's specifications and following the Instrument Calibration SOP.

If purging equipment or monitoring instruments are malfunctioning, or cannot be successfully calibrated, the equipment will need to be repaired immediately. In the event that this occurs during the course of field activities, it will be the field personnel's responsibility to ensure that replacement equipment is obtained as quickly as possible and that the Project Manager, or Site Field Manager, is immediately notified. Under no circumstances should field personnel continue with activities until a replacement is obtained or approval from the Project Manager is obtained. Instances of equipment failure and corrective actions taken will be documented in field notebook.

4.2.3 Groundwater Sampling

It is important that wells be sampled as soon as possible after purging, as long as the well has recovered to 80% of the original water column height. If not, sampling should occur as soon as

the well has recovered sufficiently to provide adequate volume within 24 hours.

As with purging equipment, there are a number of considerations in the selection of sample collection equipment. It is also common to use a different device for purging than for sampling. An example would be to purge with the use of a submersible pump and collect a sample with a disposable bailer.

The type of analysis for which a sample is being collected determines the type of sample container, preservative, holding time, and filtering requirements are used. Refer to the project field sampling plan and/or sample matrix for this information. Consideration should be given to the order in which sample containers for different parameters are filled. The order should be determined based on parameter sensitivity to volatilization, pH change, or oxidation. For example, volatile organic compounds (VOCs) are the most sensitive constituent to volatilization, and should be containerized first.

Samples should be collected directly from the sampling device into the appropriate laboratory supplied containers, labeled (i.e., sample ID, date, time, and analysis), and place in a cooler with ice. Field personnel will then log the sample on a chain of custody, which will accompany the samples to the laboratory.

4.2.4 Equipment Instructions

This section describes the specific instructions for the installation and use of various purging and sampling equipment.

Bailer

Bailers are the simplest purging device used. They generally consist of a rigid length of tube, with a ball-check valve at the bottom. String or twine is used to lower the bailer into the well and retrieve a volume of water. The same bailer can be used for both purging and sample collection. This method of purging is suited for shallow or small-diameter wells.

Purging and Sampling Instructions:

1. Determine the volume of water to be purged based on field observations and notes (Depth to water, Total depth, and well casing diameter) as described previously.
2. Don a pair of gloves and attach the string to a new disposable bailer or decontaminated, re-useable bailer.

3. Slowly lower until the bailer is completely submerged, being careful not to drop the bailer down to the water, causing turbulence and the possible loss of volatile-organic contaminants.
4. Pull the bailer out of the well, ensuring that the line never touches the ground.
5. Empty the bailer into a container of known volume as necessary in order to determine the number of bails necessary to achieve the required purge volume.
6. Samples will be collected periodically to determine if field parameters such as pH, temperature, and electrical conductivity have stabilized.
7. After completion of purging, dispose of the purge water as specified in the site specific sampling plan.
8. Sampling procedure with a bailer is the same as the purging procedure. Fill sample containers slowly, in order of sensitivity to volatilization and oxidation, as discussed above.
9. Filtered samples can be obtained by filling a non-preserved sample container, and then transferring the liquid through an in-line filter (typically a 0.45 micron disposable filter) into a sample container using a peristaltic pump.

Electric Submersible Pump

Submersible pumps can be operated with a wide variety of pumping rates and therefore are versatile for both well purging and sample collection. Collecting groundwater samples from these pumps is only appropriate if approved project-specific planning documents include this technique for collecting samples.

In general, the decontaminated (clean) pump is connected to new or dedicated polyethylene tubing, appropriate for the depth of the well, and operated by a control box. The pump is lowered into the well and the purge rate is adjusted based on well drawdown and/or project protocols.

Purging and Sampling Instructions:

1. Determine the volume of water to be purged based on field observations and notes (Depth to water, Total depth, well casing diameter) as described previously.
2. Assemble pump, tubing, and any safety cables, and lower the pump into the vicinity of the midpoint of the well screen. Make sure the pump is deep enough so that it stays submerged during pumping. Running the pump without water around it may cause damage.

3. Attach flow meter to the outlet hose to measure the volume of water purged or use a graduated container of known volume in order to achieve the required purge volume.
4. Use a ground fault circuit interrupter or ground the generator to avoid possible electric shock.
5. Attach control box, and purge well until specified volume of water has been evacuated (or until field parameters have stabilized). Do not allow the pump to run dry. If the pumping rate exceeds the well-recharge rate, lower the pump farther into the well and/or decrease the pumping rate and continue pumping.
6. Samples will be collected periodically to determine if field parameters such as pH, temperature, and electrical conductivity have stabilized.
7. Collect and dispose of purge waters as specified in the site specific sampling plan.
8. Allow the well to recharge after purging, prior to sampling.
9. Resume pumping and adjust pumping rate to the slowest possible rate.
10. Collect samples by purging directly into the sample containers, in order of sensitivity to volatilization and oxidation, as discussed previously.
11. Filtered samples can be obtained by installing an in-line filter directly onto the pump discharge.

Peristaltic Pumps

A peristaltic pump can be used to purge shallow, small diameter wells. The lift capacity is limited with these pumps and is often exceeded at groundwater depths of greater than 20 feet. This type of pump is normally used with dedicated or new tubing. Peristaltic pumps can also be used for filtering samples through an inline filter.

Purging and Sampling Instructions:

1. Determine the volume of water to be purged based on field observations and notes (Depth to water, Total depth, well casing diameter) as described previously.
2. Replace the silicone tubing in the pump head if the pump will be used for sample collection.
3. Attach new or dedicated polyethylene tubing to the silicone tubing and lower it into the well, being careful not to contact any surface other than the well casing.
4. Start the pump and direct the discharge water into a graduated container to determine the purge rate.
5. Continue pumping until the necessary volume of water has been purged from the well.

-
6. Samples will be collected periodically to determine if field parameters such as pH, temperature, and electrical conductivity have stabilized.
 7. Collect and dispose of purge waters as specified in the site specific sampling plan.
 8. Allow well to recharge after completion of purging, if necessary.
 9. Resume pumping and adjust to a slow pumping rate.
 10. Collect the samples by purging directly into the sample containers, in order of sensitivity to volatilization and oxidation, as discussed previously.
 11. Filtered samples can easily be obtained by installing an in-line filter directly onto the pump discharge.

Inertia Pumps

An inertia pump is a simple device that can be used to purge and sample wells of almost any diameter to a depth of approximately 100 feet. They are appropriate to use when wells are too deep to bail by hand or too narrow (or inaccessible) to warrant a submersible pump. This type of pump uses new or dedicated tubing with a check valve attached to the bottom of the tubing. The tubing is lowered down the well, and the inertial lift of the pump brings groundwater up the tubing.

Purging and Sampling Instructions:

1. Determine the volume of water to be purged based on field observations and notes (Depth to water, Total depth, well casing diameter) as described previously.
2. Don a new pair of gloves and install check valve into bottom of tubing by threading it onto the tubing and securing with a zip-tie or hose clamp.
3. Lower tubing into well, making sure not to contact any surface other than the well casing. Also, make sure you do not place the valve into sediment at the base of the well, clogging the check valve.
4. Place pump above well casing or hang from outside of standpipe. Connect extension cord between pump and generator and turn on generator. Make sure generator is equipped with a Ground Fault Circuit Interrupter (GFCI) and is located as far from the well head as possible in a down-wind direction.
5. Begin pumping, discharging water into a 5-gallon bucket to determine purge rate. Purge until specified volume of water has been evacuated (or until field parameters such as temperature, pH, conductivity, turbidity, and ORP have stabilized).
6. Collect and dispose of purge waters as specified in the site specific sampling plan.

-
7. Allow well to recharge after completion of purging, if necessary.
 8. Resume pumping and adjust to a slow pumping rate.
 9. Collect the samples by purging directly into the sample containers, in order of sensitivity to volatilization and oxidation, as discussed previously.
 10. Filtered samples can easily be obtained by installing an in-line filter directly onto the pump discharge.
 11. Remove check valve from bottom of tubing, again ensuring that the tubing doesn't contact the ground. Replace tubing in the well (if dedicated) and decontaminate the foot-valve before storage.

4.2.5 Low Flow Purging and Sampling

Low flow purging and sampling results in the collection of groundwater samples from monitoring wells that are representative of ground water conditions in the geological formation. This is typically accomplished by limiting the flow rate during purging to the range of 100 to 500 ml/min (0.026 to 0.13 gallons/min). For this procedure, the goal is to induce a steady flow rate while minimizing drawdown in the well casing.

Sampling at the prescribed (low) flow rates has three primary benefits:

1. Minimizes disturbance of sediment in the bottom of the well, thereby producing samples with low turbidity.
2. Minimizes aeration of the groundwater sample during collection, which improves sample quality.
3. Significantly reduces the volume of groundwater purged from a well and the costs associated with its proper treatment and disposal.

Initially, the purge flow rate should start at approximately 200 ml/min (0.053 gallons/min) and water level should be frequently monitored. Flow rate should be adjusted so drawdown will not exceed 0.5 feet, or approximately 2 percent of the saturated thickness of low permeability formations, whichever is greater.

Indicator parameters should be monitored every three to five minutes during low flow purging until measurements indicate stability in water quality (as described above). Once parameters are stable, samples are collected directly into sample containers at the same flow rate as the well was purged.

Follow the same decontamination and equipment operation procedures as discussed in Section

4.2.4.

4.2.6 Post Sampling Activities

After all samples from a well are collected and preserved, the sampling equipment should be decontaminated prior to sampling another well to prevent cross contamination of the equipment and monitoring wells between locations as described above. Typically at the end of the day or sampling event, samples are submitted to a laboratory for analysis. Generally, this is done in the field. Proper sample documentation, handling, and shipping practices will ensure that samples will be received and analyzed by the laboratory within required hold times.

Documentation

Accurate field records must be maintained to document both purging and sampling activities. Specifically, the field sampling records should include, at a minimum, the following:

- Sampling location
- Date and time
- Field Personnel
- Condition of the well
- Static water level
- Depth to the bottom of the well (at least once/year)
- Calculated well casing volume
- Purge equipment and methods
- Actual purge volume
- Sample collection method
- Sample ID
- Water quality measurements

Field forms should be reviewed the Project Manager and/or Field Manager following the sampling event and filed into the appropriate project files. An example of the groundwater sampling field form is included in the attachment of this SOP.

Sample Handling

- Prior to sample collection, a cooler should be filled with water-based wet ice. This is to ensure that the samples are chilled immediately after collection.
- Place sample containers in the cooler in appropriate size Ziploc bags immediately after sampling in the field.
- Surround the samples with sufficient ice to chill to 4°C.
- Check the samples often, making sure there is enough ice to maintain the required temperature. Add more ice when necessary, and drain off water as the ice melts.

Shipping**VOAS:**

- Place all the VOAS for each sampling location in a 1 quart Ziploc bag. Stand all the VOAS in the same direction.
- Place as many small Ziploc bags into a 1 gallon Ziploc bag that can fit into a row, making sure that the VOAS are upright, and ensure the bag is tightly sealed.

Polys, Ambers, other containers:

- Place one bubble wrapped amber in a 1 gallon Ziploc bag, making sure that the amber is upright, and ensure that the bag is tightly sealed.
- Place as many polys in a 1 gallon Ziploc bag, making sure the polys are upright, and ensure that the bag is tightly sealed.

Packing the Cooler:

- Place an open 55 gallon garbage bag inside the cooler.
- Fill the bottom of the cooler with 1 gallon Ziploc bags of ice.
- Place the samples upright and directly on top of the ice. Pack the samples tightly in the cooler, adding 1 gallon Ziploc bags of ice between samples to fill any gaps.
- Add a layer of 1 gallon Ziploc bags of ice on top of the samples.
- If the ice and samples do not completely fill the cooler to the top, pack the remaining space with bubble wrap or packing paper until the cooler is full to prevent the samples from moving during shipment.
- Seal the 55 gallon garbage bag with a zip tie to seal up the samples and ice in case of a leak. Shipping companies will stop shipment of a leaking package and all the samples will be compromised.
- Complete the chain of custody (COC) and check off contents to ensure all samples are accounted for.

-
- Sign and date COC and make sure to retain a copy for the field records.
 - Place a copy of the COC inside the cooler in a 1 gallon Ziploc bag.
 - Seal the top of the cooler shut with packing tape around the whole cooler on both ends to prevent the lid from falling off or opening during shipment.
 - Fill out shipping forms and affix to the top of the cooler.

5.0 FIELD QUALITY ASSURANCE/QUALITY CONTROL SAMPLES

Additional samples should be collected for the specific purpose of documenting the Quality Assurance/Quality Control (QA/QC) of the field sampling procedures. Field QA/QC samples provide technically and legally defensible data regarding the reproducibility and overall quality of the groundwater sample. Descriptions of the type and frequency of QA/QC sampling should be specified in the project-specific planning documents. Field QA/QC samples include trip, field, ambient, rinseate and/or equipment blanks. These samples are collected in addition to the laboratory QA/QC samples which may include method blanks, matrix spikes, and matrix spike duplicates.

6.0 HEALTH AND SAFETY

When working with potentially hazardous materials, follow U.S. Environmental Protection Agency (U.S. EPA), Occupational Safety and Health Administration (OSHA), or corporate health and safety guidelines. More specifically, depending upon the site specific contaminants, various protective programs must be implemented prior to sampling the first well. The site health and safety plan (HASP) should be reviewed with specific emphasis placed on the protection program planned for the well-sampling tasks.

Physical hazards associated with well sampling include, but are not limited to, the following:

- Lifting injuries associated with pump and bailer retrieval, and moving equipment.
- Traffic hazards associated with working in public right of ways.
- Cuts associated with the use of utility knives.
- Heat/cold stress as a result of exposure to extreme temperatures and because of protective clothing.
- Animal and insect injuries, such as spider, wasp, tick, or snake bites.
- Situations conducive to slipping, tripping, or falling as a result of wet or icy conditions.

- Electrical shock associated with use of submersible pumps is possible. Use a ground fault circuit interrupter or a copper grounding stake to avoid this problem.
- Acid burns may occur if acid preservatives are mishandled.
Long-term exposure to hazardous chemicals found at many sites of investigation may pose a health hazard, especially if proper protective clothing is not worn.

7.0 ATTACHMENTS

Groundwater Sampling Form

Approval/Date

**General Waste Management
Standard Operating Procedure (SOP)**

Terry James
Health and Safety Director

Overview

JJ&A employees shall be instructed on proper waste storage and disposal procedures. This general waste management SOP includes instruction on disposal of hazardous, non-hazardous wastes, recyclables, etc. JJ&A employees are to follow the guidance in this document, in addition to receiving client specific training on proper waste handling, to ensure proper disposal of wastes.

Plan for Anticipated Waste Generation

- Prior to beginning field activities, identify anticipated waste streams and quantities. Wastes can include decontamination water, soil, groundwater, contact waste, etc. Notify and seek input from client, project manager, etc., as appropriate regarding potential wastes, the amount to be generated, and the proper disposal.
- Obtain appropriate storage containers and designate waste storage location(s). Ensure there is secondary containment for liquid wastes.
- Use the Waste Screening QA/QC Checklist in the Administrative/Waste Management folder to determine waste type as follows:
 - Is the waste excluded/exempted?
 - Is the waste a CA or RCRA listed waste?
 - Is the waste considered acutely or extremely hazardous in CA?
 - Does the waste exhibit a hazardous waste characteristic?
 - Is the waste a special waste?
- Coordinate with the client to determine if sampling will be necessary or if profile will be based on generator knowledge. (Note that JJ&A is not the generator.)
- If needed, define analysis requirements and coordinate with the laboratory that will complete the analysis.
- Notify the JJ&A waste coordinator of the anticipated waste, and keep them informed throughout process including verbal updates and copying them on or forwarding them emails relevant to waste generation, analysis, and pickup and disposal.

Generation of Waste

Contain Waste

- Once waste is generated at the project site, the waste disposal process is triggered. Hazardous waste must be removed from the site within 90 days of the accumulation start date.
- Proper handling, organization, and storage of waste and recyclables is important in order to minimize potential impacts to the environment.
- Containers must be appropriate for the type of waste generated. Containers must be DOT-approved and may include drums, bins, poly tanks, etc.
- Segregate non-hazardous wastes from hazardous wastes to reduce the amount of hazardous material going to disposal.
- If applicable, separate out materials, such as scrap metals, for recycling. Recyclable waste must still be properly handled, organized, and stored.

Collect Samples for Waste Profiling

- Confirm with waste disposal facility if sampling of waste is required or if waste can be profiled based on generator knowledge.
- If sampling is required for waste characterization and profiling, collect a sample of waste for analysis as designated by the disposal facility.
- Handle and submit waste sample to the analytical laboratory following standard chain-of-custody (COC) procedures.
- Complete a separate COC form for each waste stream for waste characterization samples. Do not include on the same COC used for investigation or monitoring samples.
- Include Database Department contact information on the COC so laboratory reports will be entered into data base once received.

Label Containers

- Keep an ample supply of all label types (e.g., Hazardous, Non-Hazardous, Pending Analyses, etc.) during waste generation.
- Client Specific Programs
 - For PG&E sites:
 - Label waste container per PG&E policy saved on server at J:\Administrative\Waste Management.

- Write “**Remediation Waste**” on top of drum with a paint pen or on a blank label on the side of the container.
- For wastes that are unknown or have the possibility of being hazardous, but are pending analysis:
- Place a “HAZARDOUS WASTE” label on container immediately that includes the following information: Generator Address and Phone Number, EPA ID Number, Accumulation Start Date (date that waste was first placed in container), contents and composition, physical state and hazardous properties.
- Do not fill in EPA or State Waste Codes or proper shipping description block at this time.
- Place a “Pending Analysis” label adjacent to the “Hazardous Waste” label.
- If laboratory results indicate that waste is hazardous, then **WITHIN 10 DAYS OF RECEIVING RESULTS**, remove “Pending Analysis” label and then label in accordance with waste characterization results.
 - If retaining the “Hazardous Waste” label, fill in the remaining information.
 - If removing the “Hazardous Waste” label, replace with a label that includes a description of the waste, contact information (name and phone number) and date when waste was first accumulated.
- Applying Generator Knowledge (per PG&E procedures):
 - Obtain approval from Environmental Remediation EHS Manager or Environmental Operations Hazardous Materials Manager to use generator knowledge.
 - Place label that includes “Generator Knowledge” on the container immediately.
 - Fill out “Hazardous” or “Non-Hazardous” waste label, as appropriate.
 - Do not apply a “Pending Analysis” label even if lab analysis is being performed.

- For Other sites:
 - For wastes that are unknown or have any possibility of being hazardous, but are pending analysis:
 - Place a “Pending Analysis” or “Non-Classified Waste Material” label on the container immediately that includes the following information: Material, Site Address, Accumulation Date, Generator, Generator Contact and Phone and/or Contractor Contact and Phone
 - There is no need to also apply a “Hazardous Waste” label.
 - Once the waste has been characterized, removed “Pending Analysis/Non-Classified Waste Material” label as soon as possible and replace with “Hazardous” or “Non-Hazardous” according to laboratory results.
- Applying Generator Knowledge at non-PGE sites
 - JJ&A is not considered a generator of waste, so JJ&A staff must confer with the client/generator to get approval for waste classification based on generator knowledge.
 - Place label that includes “Generator Knowledge” on the container immediately.
 - Fill out “Hazardous” or “Non-Hazardous” waste label, as appropriate.

Store Waste

- Be aware of 90-day time limit on storage of hazardous waste which starts at the time waste was placed in a container. There is no storage time limit on non-hazardous waste.
- Store contained waste in a designated, secure location.
- Provide secondary containment for liquid hazardous wastes.
- If non-hazardous waste stockpiles are stored outside (without overhead protection), plastic sheeting must be placed over the stockpiled materials to prevent dispersion of waste materials and to control the potential for run-off. Plastic sheeting must be secured with sandbags to prevent the sheeting from blowing off. Straw waddles will also be placed around stockpiles to prevent erosion.

Workplace (Satellite) Accumulation Areas

- Generators may temporarily accumulate small quantities of hazardous wastes at or near the point where wastes are generated if the following conditions are met:
 - Volume limit is 55 gallons of hazardous waste or one quart of acute or extremely hazardous waste.

- Waste is accumulated in containers, not tanks.
- A “Hazardous Waste” label that includes the following must be placed on the container: accumulation start date and date quantity limit is reached, generator’s name and address, composition, physical state, and hazardous properties.
- The Accumulation Area is under the control of the operator of the process that generates waste.
- Initial date of accumulation is marked on each container.
- **Within 3 days after container becomes full or quantity limit is reached**, mark date and move to Hazardous Waste Accumulation Area.
- **Waste must not be held on-site for more than one year from initial date of accumulation or 90 days from the time the quantity limit is reached, whichever occurs first.**
- The container must be in good condition and be made of or lined with material that is compatible with the waste.
- The container is kept closed except when being filled or emptied.
- The Accumulation Area should be inspected weekly for leaks, proper labeling, improperly combined wastes, and volume. A written record of inspections should be maintained at the facility.
- If wastes are transferred into containers at the Hazardous Waste Accumulation Area, the container into which the waste is transferred must be marked with the oldest of the initial accumulation start dates from the various containers being emptied.

Waste Disposal – Coordinate Pick Up

- Confirm JJ&A role; if JJ&A is not contracted to manage waste, client will handle waste management from this point onward.
- If JJ&A is contracted for waste disposal, coordinate with client and waste transport subcontractor to schedule pick-up.
- JJ&A will generally provide oversight during waste pick-ups unless specifically directed otherwise with client project manager.
- Disposal subcontractor will create waste manifest based on profile. **Review manifest before scheduled pick-up.**

- Confirm the following are entered correctly on manifest: hazardous/non-hazardous designation, site information (address, EPA ID, manifest mailing address), disposal facility information (name, address, EPA ID, phone number), description of waste (quantity, profile number).
- Coordinate pick up.
- Client or an authorized representative must sign the manifest. **JJ&A should confirm availability of client or authorized representative when scheduling pickup. JJ&A does not sign the manifest.**
- Following disposal of hazardous waste, send DTSC a notification letter with completed manifest. In some cases, the client may assume responsibility for this task.

Recordkeeping

- Field staff who generate waste (solid or liquid) are required to complete the JJ&A Generated Waste Inventory Form before demobilizing, and provide a copy of the form to the project manager and JJ&A Waste Coordinator.
- Record location, date, type of waste, container type and volume, and take pictures of the stored waste and the labels.
- Keep copies of all field notes, emails, and records of telephone communications.
- Keep records of all phases of waste management including generation, storage, profiling, weekly waste inspections, transport and disposal.
- Notify the JJ&A Waste Coordinator when waste (hazardous or non-hazardous) are generated on a project site and keep them involved with waste management activities including profiling and disposal.
- All projects that generate waste should have a waste tracking spreadsheet filed in a "Waste Management" subfolder. Shortcuts to all tracking sheets will be maintained in the Administrative\Waste Management folder. The JJ&A Waste Coordinator will maintain these tracking sheets with information provided by PMs.

Waste Screening Table(s)

- Follow Waste Screening Table directions and QA/QC Checklist saved in Administrative/Waste Management/Waste Screening folder.
- Based on soil results screening table, determine if additional (leachate) analyses are required.

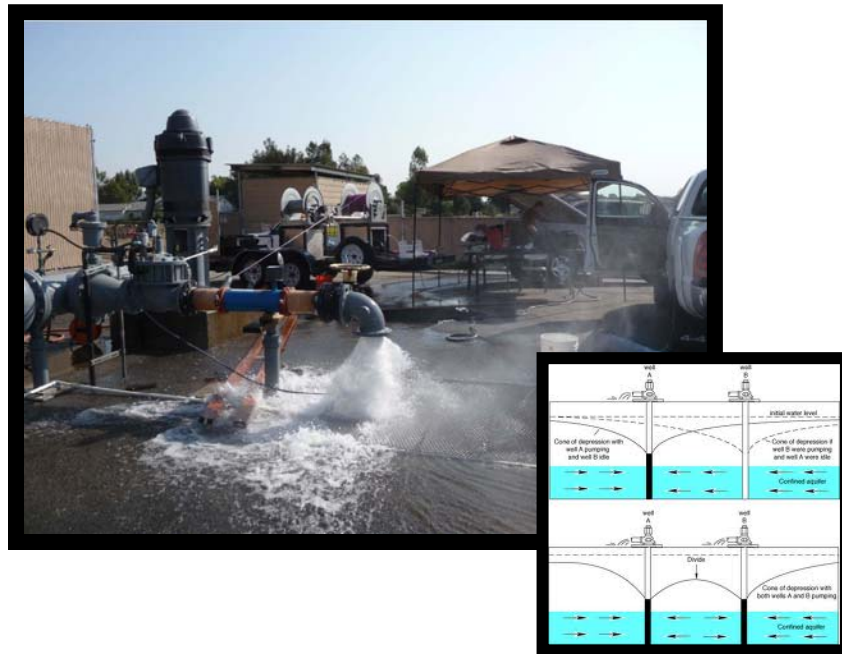
Complete Waste Summary Memo

- Following disposal, prepare detailed JJ&A internal waste disposal memo.

- Waste Memo should include: lab reports, screening tables, waste profile sheets, disposal coordination records and documents, documentation of weekly waste inspections, and waste manifest signed by disposal facility.
- Arrange for review of memo by the JJ&A Waste Coordinator or designee.
- Generate hardcopy (with lab results on CD) of memo for file and also save as pdf on JJ&A server. Memo author and reviewer should initial the hardcopy in the title block. The initialed page should then be scanned and included in a pdf of the entire memo.
- Use a tracking sheet to document memo author, reviewer, and completion date. When complete, scan the tracking sheet and save with the memo on the server. Top sheet of memo needs to be initialed by memo author and reviewer and then scanned.
- A Waste Memo Template is available at J:/Administrative/Waste Management.

Standard Operating Procedures

Dye Tracer Flow Meter Profiling and Depth Dependent Groundwater Sampling



1. Tracer Pulse Ambient Flowmeter and Depth Dependent Sampler Profiling – General Description

The Tracer Pulse Dynamic Flowmeter (TPDF) is profiling system method and apparatus patented by the USGS and is constructed and operated under exclusive commercial license from the USGS. The technology has the ability to provide a dynamic flow velocity profile from virtually any type of production, remediation or monitoring well without first having to remove the pump from the well. The end result of the method produces a quantitative groundwater production profile of zonal water influx along a well screen under steady state pumping conditions. The velocity and production profiles generated by this technology are comparable to profiles generated by spinner logging tools under dynamic flow conditions. The setup for the TPDF consists of the following key components...

- Flow profiling rig with tracer and water sampling system
 - Motorized hose reel for tracer pulse flowmeter
 - Motorized hose reel for groundwater sampling
 - Miniaturized Teflon FEP Bailer for VOC sampling
 - Miniaturized HydroBooster Mini Pump for Inorganic Sampling
 - NSF 60 Approve Tracer for potable drinking water systems: Rhodamine Red FWT 50
 - Injection Control Unit / Injection Motor / Injection Pump / Electrical Panel
 - Fluorometer with connecting hose to well discharge sampling tap
 - Laptop
 - Nitrogen Gas Supply
 - Water level meter. This can also be provided by the water producer or the producer's consultant.

Other requirements for the profiling survey that are typically supplied by the water producer are the following...

- Operational flow meter. BESST can provide a clamp on flow meter if the water producer cannot provide a properly functioning device.
- Water sampling tap on the well's discharge line
- Electrical. A generator can be provided by BESST if there is no electrical.
- Laboratory bottles / Labels / Chain of custody / shipping
- Laboratory contract

2. The First Step – Contract With Water Producer and/or Consultant

Contracting is typically the first step in the profiling process. However, sometimes our clients provide preliminary well information prior to the contracting process in order for BESST to determine the feasibility of profiling the well of concern as well as for quote generation. The contracting process includes...

- Signed purchase order and/or contract
- Insurance documents from BESST including our general, professional and pollution liability, auto and worker's compensation insurances.

3. The Second Step – BESST obtain available information about well

This is another key step in the process. The information that we believe to be useful in achieving a successful outcome to the field work and for providing a comprehensive report to the client is the following:

- Driller's well completion report
- Well schematic or knowledge of well diameter, well depth, pump column diameter, pump diameter, pump depth, pump intake depth, length of suction pipe, presence of engineered suction, length and

depths of well screens, date well constructed, geophysical logs, previous spinner logs and water chemistry results.

- Video log if available
- Photographs of the well head from multiple directions showing vent pipe, locations of bolt holes, pump plate configuration, location and layout of discharge pipe.
- Determine if there is a working flow meter, sample tap and electrical hookup at or in close proximity to the well head.
- Determine if the test is to be run while pumping water into the system or if the water will be pumped to waste.
- Determine if there will be any time constraints in performing the test due to limits on discharge volume, day-time testing, night testing

4. The Third Step – Chain Survey to Determine Well Access

The chain survey is a necessary requirement for project completion. BESST cannot perform any profiling work at the job site until access into the well is confirmed. The chain survey consists of using BESST's assortment of dummy tools which are selected on the basis of the information obtained in **The Second Step**. The chain survey can be performed in one of two ways. Either the water producer or a consultant for the producer performs the test with the BESST chain survey tools, or the chain survey test is performed by BESST. When the operator or the operator's consultant performs the test, BESST will Fed Ex the survey tools to the specified address. BESST will prepare the chain survey tool accordingly, making sure that there is enough cable on the chain survey tool to go at least 50 feet past the pump bowls.

Important information to note during the chain survey test are the following...

- Record the length and diameter of the chain survey tool and record the number of sausage weights that are attached.
- Record points of entry into the well and describe each entry point's characteristics such as entry diameter and angle as well as entry point classification such as vent pipe, sounding tube, bolt hole, angle of pipes at entry point to well reference to the horizontal plane of the pump block.
- Record access problems associated with each entry point around well head. As an example, notate depths where surveyor encountered sticking points. Mention if survey tool loses weight and at approximate depth that this occurs.

BESST can also provide this service but at an extra cost which has to be approved within the signed purchase order or contract.

Communication about the chain survey results between the client and BESST is critical to the successful completion of the project. At this point in the process BESST will provide an opinion to their client as to whether or not the profiling can be performed with the existing well head configuration – meaning that nothing is changed at the well head for the purpose of successful access. On the other hand, a range of recommendations could follow from BESST such as...

- Drilling a 1-inch to 1.25-inch hole in the pump plate
- Removing a section of elongated vent
- Lifting the pump and shifting it to one side
- Coring a hole through the pump block at a steep angle
- Removing existing pump and using a smaller diameter test pump – with or without the installation of a PVC access pipe that extends past the pump bowls and/or extends to the top of an uppermost screen interval or top of screen.

The most common solution to well access when the chain survey demonstrates a tight annulus is to drill a hole through the pump plate. BESST will provide an expansion plug to seal off the hole.

5. The Fourth Step – Tracer Pulse Ambient Flowmeter Survey

The TPDF tubing and injection nozzle typically ranges between ½-inch to ¾-inch in diameter. The small diameter and flexibility of the tubing and nozzle assembly make it possible to bypass the pump column, down-hole impeller bowls and / or electric pump motors in most situations. A key factor in successfully inserting the injection tubing and nozzle is the attachment of a small diameter string of sausage weights or weighted chain attached to a metal loop located and attached just below the injection nozzle.

In typical applications, the TPDF tubing is lowered through a mechanical counter that indicates the depth of the injection nozzle. The injection process is typically started about 20 feet below the bottom of the pump in order to preliminarily confirm that all of the key components of the TPDF system are working down hole. From there, the survey progresses downward toward the bottom of the well. Injection points are typically laid out on 10- to 20-foot vertical depth centers in order to obtain enough data points to vertically profile production along the well screen.

The tracer solution used in the survey consists of 50 ml of Rhodamine Red (RR) (from Bright Dyes, Inc.) mixed with 5-Gallons of tap water. The solution from the RR bottle is then fed by the injection motor/pump assembly through the injection line until the line is completely filled with the RR solution. When released into a well, each second of injection by the Injection Control Unit (ICU) is equivalent to approximately 20 ml of RR released from the injection nozzle. Figure 1 below shows a typical setup for the TPDF system at a production well location in northern Nevada.

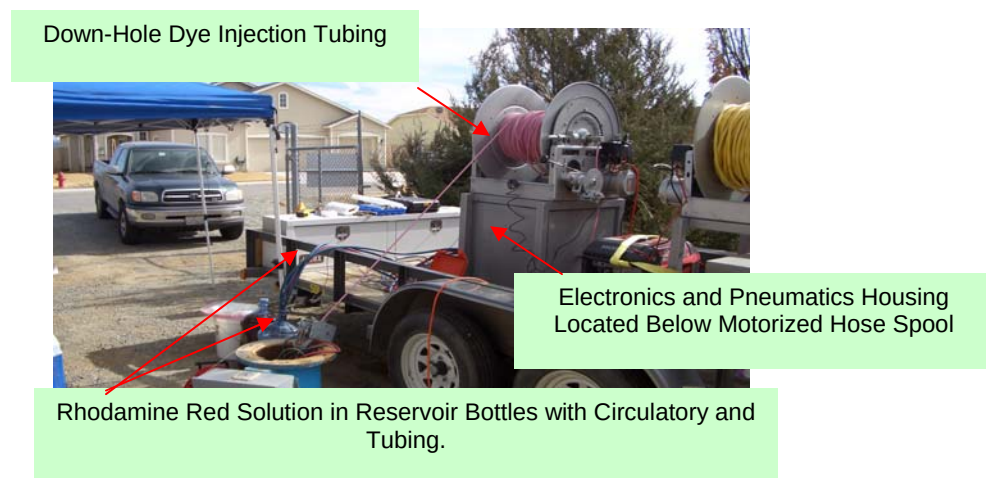


Figure 1: Typical trailer setup TPDF System – at a location in northern, Nevada.

In between injection points the RR solution is circulated in the 5-gallon reservoir bottle to prevent air bubbles from entering the liquid and being injected into the well. Additionally, an electronic float sensor is placed within the reservoir bottle to prevent air from being drawn into the injection line as the solution draws down within the bottle. When the RR solution is drawn down to the lower third of the reservoir, the injection pump automatically shuts off. More RR solution is then added to the bottle before RR injection is continued. Introduction of air into the injection line is undesirable since air bubbles can cause delays in the return time of the RR to the fluorometer.

5.1 General Description of Equipment

The fluorometer used for the velocity profiling is either a Model 10-AU from Turner Designs and is shown in Figure 3 (or the C3 system). The 10-AU Fluorometer measures the concentration of various analytes in samples of interest via fluorescence. In the case of dynamic flow velocity analysis for wells, the analyte of interest is artificially introduced in order to measure the peak concentration return times of rhodamine red from the release point to the fluorometer via the discharge path of the pumping well. The return concentrations are typically in the part per billion range. An excitation light source inside the fluorometer

is passed through a color filter specific to rhodamine red, that transmits light of the chosen wavelength range (color). The wavelength of the exciting light that falls on the sample is set by the choice of the light source and the excitation filter. The emitted light radiates in a sphere from the light source and is directed towards the 10-AU detector through an emission filter. The purpose of the emission filter is to prevent any scattered exciting light from reaching the detector (photomultiplier tube) and to pass the emitted color that is specific to the analyte of interest. The concentration of the RR solution is directly proportional to the signal response received by the fluorescing light emitted by the rhodamine red that is received by the detector. The concentration is typically reported on an analog display panel located on the front of the 10-AU (Turner Designs, 1996). Figure 3 below shows an example of a BESST, Inc. injection control unit for regulating injection pulse times. Figures 4 and 5 provide a more detailed look of the circulatory system of the dye injector.

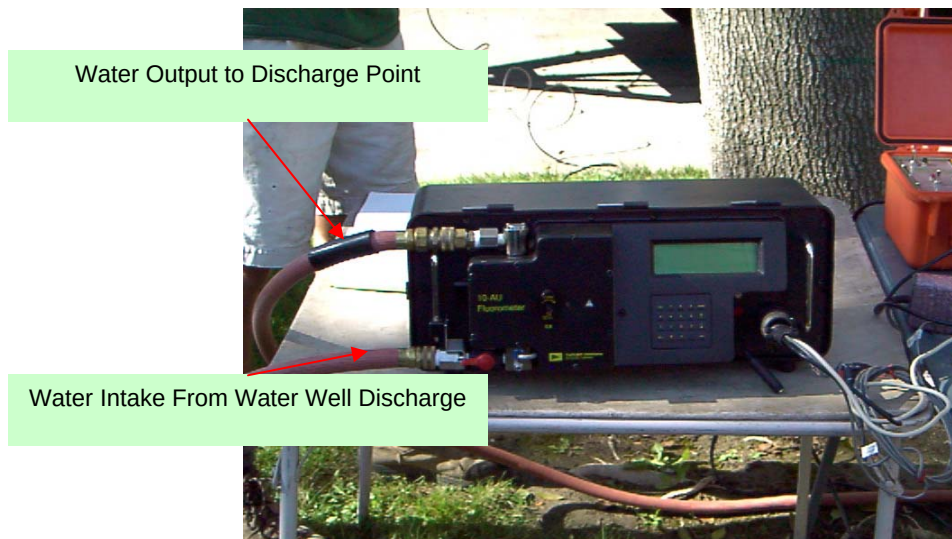


Figure 2: Model 10-AU fluorometer from Turner Designs.



Figure 3: Injection Timer Control Unit used for pulsing tracer into well.



Figure 4: Electrical and Pneumatics components inside housing are controlled by the Dye Injection Control Unit (Figure 4). The housing contains injection pump, injection pressure regulator, pneumatically controlled valve switching solenoid, fuse box, electrical circuits and primary and secondary valve control units.



Figure 5: Bottle to right contains primary RR reservoir. When the large oval red button is depressed on the Dye Injection Control Unit (Figure 4), the RR solution is fed from the red tube, then to the injection pump, and finally through the injection nozzle and into the well. When the injection pump is idling, the RR solution circulates through the blue tube and red tube in the primary RR reservoir bottle. The secondary RR bottle receives excess RR that is not used during an injection pulse.

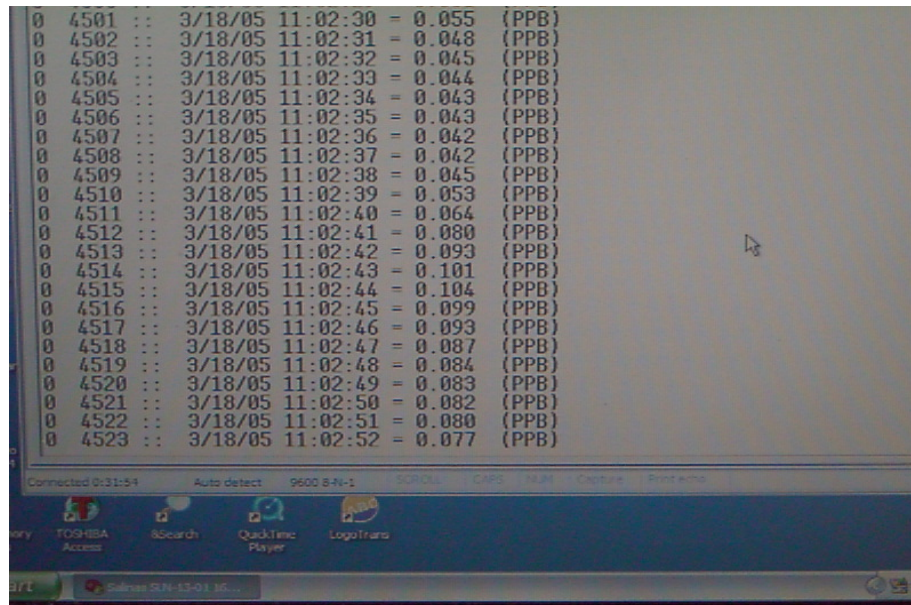


Figure 6: Streaming Laptop Hyperlink Communication Display from AU-10 Fluorometer. Date, time and concentration value are reported and stored in continuous scrolling format.



Figure 7: Laptop connected to 10-AU

5.2 Data Requirements

During the course of completing the vertical dye injection grid, some of the injection points are repeated in order to establish travel time and velocity reproducibility. Once all of the injection points are completed, the data is entered into an Excel spreadsheet with built-in data calculations that facilitate the generation of the flow profile – using the Excel chart function. The basic equation (Izbicki, 2000) used for calculating flow velocity is:

$$Q = (V\pi r^2) \text{ where,}$$
$$V = (d_2 - d_1) / (t_2 - t_1)$$

Q = flow in gallons per minute (gpm)

d = injection depth

d₂ = injection depth # 2

d₁ = injection depth # 1

t = travel time of peak tracer concentration from release point to detector

t₂ = return time for rhodamine red peak to fluorometer detector for d₂ injection point

t₁ = return time for rhodamine red peak to fluorometer detector for d₁ injection point

Other factors that are required for the solution and interpretation of the results are well diameter, pump diameter, pump column diameter and length, depth of pump intake, well screen interval(s), and length of well screen located above the pump. Other pieces of information that can play a role in the interpretation of the results are driller's logs from when the well bore was drilled and any geophysical logs such as resistivity short and long normal, spontaneous potential (SP), gamma ray, neutron, caliper, video surveys and others.

As far as data plotting, there are various types of valid presentation formats. One type of format (presented in Figure 8) plots depth on the y-axis, percent flow on the top x-axis and GPM discharge on the bottom x-axis. Additionally, lithologic and geophysical information are presented in co-plots to the right in order to correlate lithologic and geophysical properties to production.

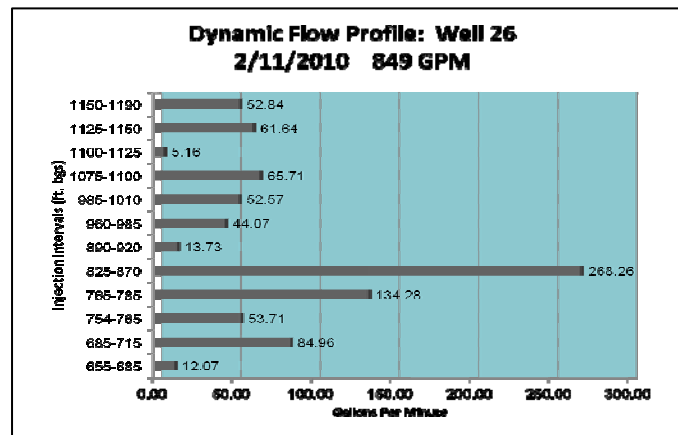


Figure 8: Example of bar graph flow profile showing flow contribution in GPM.

5. The Fifth Step – Depth Dependent Groundwater Sampling Survey

BESST provide categories of groundwater sampling services. Those provided with a pressurized bailer and are primarily used for volatile organic compounds and use of a miniaturized gas displacement pump specifically for inorganic compounds. Prior to deployment in any well the tubing is pressure washed off-site. At the job site, BESST field scientists spray the tubing with a chlorine bleach solution from a Hanson sprayer as a means of killing bacteria on the outside of the tubing.

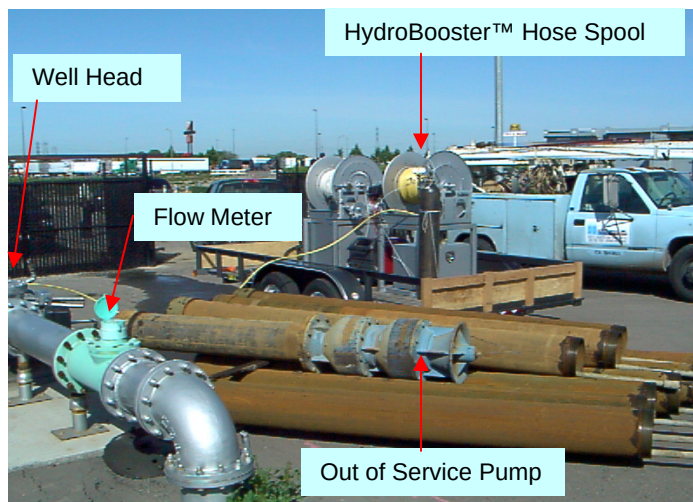
Miniaturized Bailer

The miniaturized bailer is made from Teflon FEP – an inert polymer and broadly accepted by the environmental industry as the preferred polymer type to be used when collecting VOCs. Construction at the bottom of the bailer consists of a miniaturized poppet valve made from 316 stainless steel. Before deployment into the well of interest the bailer is pressurized with an inert gas such as nitrogen (but helium and argon are acceptable as well); the pressure used being in excess of the head pressure between pumping water level and the sample depth. Typically, the sample pressure is set to 10% above theoretical to insure that the valve does not open unintentionally. The mini bailer is lowered through a mechanical counter to the target depth where the pressure is released by an up-hole control valve. A simple bubble detector is used at the ground surface to determine the tubing is close or completely full of water from the target depth. Once the bubbler provides confirmation the bailer is re-pressurized to the pressure setting used during descent for that specific sample. The bailer is then retrieved back to the ground surface. The pressure is slowly bled off. The bottom of the bailer is opened and the water sample drained by gravity into the sample collection vials.

Prior to reuse for the next sampling interval the bailer is thoroughly purged with an inert gas at the ground surface to the point where no observable water droplets exit the bailer. This procedure has been successfully used on many projects sampling for VOCs without any cross contamination issues.

Miniaturized Pump

The HydroBooster™ is a miniaturized displacement pump (not an air-lift pump) for collecting groundwater samples from active production wells without having to remove the pump. The pump can be connected to any type of tubing (i.e. Teflon, polyethylene, nylon, etc.). For high pressure applications, the tubing can consist of regular nylon, or even nylon reinforced with fiber glass or Kevlar for ultra high pressure applications to 3,000+ feet BGS. Figure 9 shows an example of a HydroBooster™ application at a site in the California Central Valley for a production well under study for vertical distribution of nitrate contamination. The HBP measures less than 3/4" OD and about 4-inches long.





Division of Kingscote Chemicals ®

WATER TRACING DYE FWT RED PRODUCTS

TECHNICAL DATA BULLETIN

Bright Dyes FWT Red liquid products are specially formulated versions of Rhodamine WT dye for convenient use in water tracing and leak detection studies. This bright, fluorescent red dye is certified by NSF International to ANSI/NSF Standard 60 for use in drinking water. It may be detected visually, by ultraviolet light and by appropriate fluoremetric equipment. Today it is most often used visually. Visually the dye appears bright pink to red, depending on its concentration and under ultraviolet light as bright orange.

The dye is resistant to absorption on most suspended matter in fresh and salt water. However, compared to Bright Dyes FLT Yellow/Green products it is significantly more resistant to degradation by sunlight and when used in fluoremetry, stands out much more clearly against background fluorescence. As always the suitability of these products for any specific application should be evaluated by a qualified hydrologist or other industry professional. Store product out of sunlight, in a cool and dry location. Shelf life is 4 years from date of purchase.

General Properties	Tablets	Liquids (50)	Powders
Detectability of active ingredient ¹	Visual <100 ppb	Visual <100 ppb	Visual <100 ppb
Maximum absorbance wavelength ²	550/588 nm	550/588 nm	550/588 nm
Appearance	Dark red convex 1.6cm diameter	Clear dark red aqueous solution	Dark red fine powder
NSF (Max use level in potable water)	0.3 ppb	0.4 ppb	0.1 ppb
Weight	1.05 gms $\pm$ 0.05		
Dissolution Time ³	50% < 3 minutes 95% < 6 minutes		50% < 3 minutes 95% < 6 minutes
Specific Gravity		1.03 $\pm$ 0.05 @ 25° C	
Viscosity ⁴		1.3 cps	
pH		8.7 $\pm$ 0.5 @ 25° C	

Coverage of Products	One Tablet	One Pint Liquid	One Pound Powder
Light Visual	604 gallons	62,500 gallons	467,000 gallons
Strong Visual	60 gallons	6,250 gallons	46,700 gallons

Caution: These products may cause irritation and/or staining if allowed to come in contact with the skin. The use of gloves and goggles is recommended when handling this product, as with any other dye or chemical.

To our best knowledge the information and recommendations contained herein are accurate and reliable. However, this information and our recommendations are furnished without warranty, representation, inducement, or license of any kind, including, but not limited to the implied warranties and fitness for a particular use or purpose. Customers are encouraged to conduct their own tests and to read the material safety data sheet carefully before using.

¹ In deionized water in 100 ml flask. Actual detectability and coverage in the field will vary with specific water conditions.

² No significant change in fluorescence between 6 and 11 pH.

³ (One tablet, 1 gram of powder), in flowing deionized water in a 10 gallon tank.

⁴ Measured on a Brookfield viscometer, Model LV, UL adapter, 60 rpm @ 25° C.

Issue Date: 09-Jan-2014

Revision Date: 18-Jan-2019

Version Number: 2.2

1. Identification

Product Identifiers

Product Name: Bright Dyes® FWT Red 50 Liquid

Product Number: 106053

Recommended Use & Restrictions on Use

Water tracing & leak detection dye

Manufacturer/Supplier

Kingscote Chemicals, Inc.
3334 South Tech Blvd.
Miamisburg, OH 45342
U.S.A.

Emergency Telephone Number

Company Telephone Number: (937) 886-9100

Emergency Telephone (24 hr): INFOTRAC (800) 535-5053 (North America)
+1-352-323-3500 (International)

2. Hazards Identification

Classification

This chemical does not meet the hazardous criteria set forth by the 2012 OSHA Hazard Communication Standard (29 CFR 1910.1200). However, this Safety Data Sheet (SDS) contains valuable information critical to the safe handling and proper use of this product. This SDS should be retained and available for employees and other users of this product.

3. Composition/Information on Ingredients

This product is not hazardous according to OSHA 29 CFR 1910.1200. Components not listed are not hazardous or are below reportable limits.

4. First-Aid Measures

First-Aid Measures

Eye Contact	Rinse immediately with plenty of water, also under the eyelids, for at least 15 minutes. If eye irritation persists: Get medical advice/attention.
Skin Contact	Wash thoroughly with plenty of soap and water. If skin irritation occurs: Get medical advice/attention.
Inhalation	Remove to fresh air. If breathing is difficult, administer oxygen; seek medical attention immediately.

Ingestion	Rinse mouth. DO NOT induce vomiting. Drink plenty of water. Never give anything by mouth to an unconscious person. Get medical attention if large quantities were ingested or if nausea occurs.
------------------	---

Most Important Symptoms and Effects

Symptoms	Will cause staining of the skin on contact. May cause eye irritation. Inhalation of dust may cause respiratory irritation. Ingestion may cause urine to be a red color until the dye has been washed through the system.
-----------------	--

Indication of Any Immediate Medical Attention and Special Treatment Needed

Notes to Physician	Treat symptomatically.
---------------------------	------------------------

5. Fire-Fighting Measures**Suitable Extinguishing Media**

Water spray (fog). Carbon dioxide (CO₂). Dry chemical. Regular foam.

Unsuitable Extinguishing Media

Not determined

Specific Hazards Arising from the Chemical

Product is not flammable. Burning/combustion may produce oxides of carbon and nitrogen (NO_x).

Protective Equipment and Precautions for Firefighters

Wear self-contained breathing apparatus pressure-demand, MSHA/NIOSH (approved or equivalent) and full protective gear.

6. Accidental Release Measures**Personal Precautions, Protective Equipment and Emergency Procedures**

Personal Precautions	Use personal protective equipment as recommended in Section 8.
-----------------------------	--

Environmental Precautions	Prevent from entering into soil, ditches, sewers, waterways and/or groundwater. See Section 12 and Section 13.
----------------------------------	--

Methods and Material for Containment and Cleaning Up

Methods for Containment	Prevent further leakage or spillage if safe to do so.
--------------------------------	---

Methods for Cleaning Up	Sweep up and collect into suitable containers for disposal. Flush area with water.
--------------------------------	--

7. Handling and Storage**Precautions for Safe Handling**

Advice on Safe Handling	Handle in accordance with good industrial hygiene and safety practices. Use personal protection recommended in Section 8. Avoid contact with skin, eyes, or clothing. Avoid breathing dusts. Contaminated clothing should be thoroughly washed before reusing.
--------------------------------	--

Conditions for Safe Storage, Including Incompatibilities

Storage Conditions	Keep container tightly closed and store in a cool, dry, and well-ventilated area. Keep from freezing.
Incompatible Materials	No materials to be especially mentioned

8. Exposure Controls / Personal Protection

Exposure Guidelines

This product, as supplied, does not contain any hazardous materials with occupational exposure limits established by the region specific regulatory bodies.

Engineering Controls

Ensure adequate ventilation, especially in confined areas. Eyewash stations. Showers.

Individual Protection Measures, Such as Personal Protective Equipment:

Eye/Face Protection	Goggles.
Skin & Body Protection	Rubber gloves. Suitable protective clothing.
Respiratory Protection	No protection is ordinarily required under normal conditions of use.
Hygiene Measures	Handle in accordance with good industrial hygiene and safety practices.

9. Physical and Chemical Properties
--

Information on Basic Physical and Chemical Properties

Physical State	Liquid	Odor	Mild
Appearance	Dark red liquid	Odor Threshold	Not determined
Color	Dark red		

Property	Values
pH	Not determined
Melting/Freezing Point	Not determined
Boiling Point/Range	Not determined
Flash Point	Not applicable
Evaporation Rate	Not applicable
Flammability (solid, gas)	Liquid – not applicable
Upper Flammability Limits	Not applicable
Lower Flammability Limits	Not applicable
Vapor Pressure	Not applicable
Vapor Density	Not applicable
Relative Density	Not applicable
Specific Gravity	Not determined
Solubility	Highly soluble in water
Partition Coefficient	Not determined
Auto-ignition Temperature	Not determined
Decomposition Temperature	Not determined
Viscosity	Not determined

10. Stability and Reactivity**Reactivity**

Not reactive under normal conditions.

Chemical Stability

Stable under recommended storage conditions.

Possibility of Hazardous Reactions

None under normal processing.

Conditions to Avoid

Keep separated from incompatible substances. Keep out of reach of children.

Incompatible Materials

No materials to be especially mentioned

Hazardous Decomposition Products

Oxides of carbon and nitrogen (NOx).

11: Toxicological Information**Information on Likely Routes of Exposure**

Inhalation	Avoid breathing vapors or mists.
Ingestion	Do not ingest.
Skin Contact	May cause an allergic skin reaction.
Eye Contact	Avoid contact with eyes.

Delayed, Immediate, and Chronic Effects from Short- and Long-Term Exposure

May cause an allergic skin reaction.

Numerical Measures of Toxicity

Not determined

Symptoms Associated with Exposure

See Section 4 of this SDS for symptoms.

Carcinogenicity

NTP	None
IARC	None
OSHA	None

12. Ecological Information**Ecotoxicity**

This product is not classified as environmentally hazardous. However, this does not exclude the possibility that large or frequent spills can have a harmful or damaging effect on the environment.

Component Information

Not available

Persistence/Degradability

Not determined

Bioaccumulation

Not determined

Mobility

Not determined

Other Adverse Effects

Not determined

13. Disposal Considerations**Waste Disposal Methods**

Dispose of in accordance with federal, state, and local regulations.

Contaminated Packaging

Do not re-use empty containers. Dispose of containers in accordance with federal, state, and local regulations.

14. Transport Information**Note**

See current shipping paper for most up-to-date shipping information, including exemptions and special circumstances.

DOT Not regulated

IATA Not regulated

OMDG Not regulated

15: Regulatory Information**International Inventories**

TSCA Listed

U.S. Federal Regulations

CERCLA This material, as supplied, does not contain any substances regulated as hazardous substances under the Comprehensive Environmental Response Compensation and Liability Act (CERCLA) (40 CFR 302) or the Superfund Amendments and Reauthorization Act (SARA) (40 CFR 355).

SARA 313	Section 313 of Title III of the Superfund Amendments and Reauthorization Act of 1986 (SARA). This product does not contain any chemicals which are subject to the reporting requirements of the Act and Title 40 of the Code of Federal Regulations, Part 372.
CWA (Clean Water Act)	This product does not contain any substances regulated as pollutants pursuant to the Clean Water Act (40 CFR 122.21 and 40 CFR 122.42).

U.S. State Regulations

California Proposition 65	This product does not contain any Proposition 65 chemicals.
U.S. State Right-to-Know	This product does not contain any substances regulated under applicable state right-to-know regulations.

16: Other Information**HMIS**

Health Hazards	Flammability	Instability	Special Hazards
1	0	0	Not determined

NFPA

Health Hazards	Flammability	Physical Hazards	Personal Protection
1	0	0	B

Issue Date	09-Jan-2014
Revision Date	18-Jan-2019
Revision Note	Biennial Review

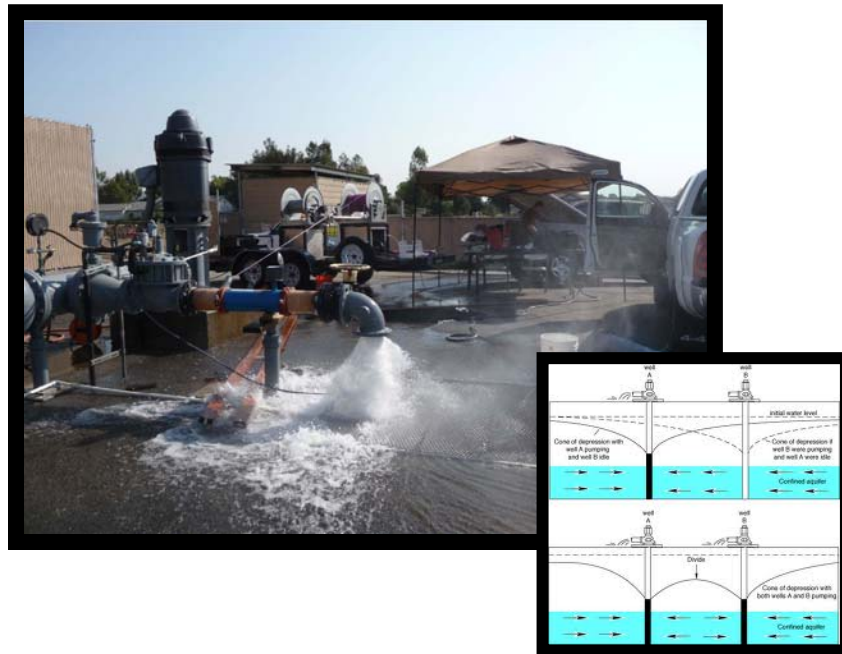
Disclaimer

The information provided in this Safety Data Sheet is correct to the best of our knowledge, information and belief at the date of its publication. The information given is designed only as guidance for safe handling, use, processing, storage, transportation, disposal and release and is not to be considered a warranty or quality specification. The information relates only to the specific material designated and may not be valid for such material used in combination with any other materials or in any process, unless specified in the text.

End of Safety Data Sheet

Standard Operating Procedures

Dye Tracer Flow Meter Profiling and Depth Dependent Groundwater Sampling



1. Tracer Pulse Ambient Flowmeter and Depth Dependent Sampler Profiling – General Description

The Tracer Pulse Dynamic Flowmeter (TPDF) is profiling system method and apparatus patented by the USGS and is constructed and operated under exclusive commercial license from the USGS. The technology has the ability to provide a dynamic flow velocity profile from virtually any type of production, remediation or monitoring well without first having to remove the pump from the well. The end result of the method produces a quantitative groundwater production profile of zonal water influx along a well screen under steady state pumping conditions. The velocity and production profiles generated by this technology are comparable to profiles generated by spinner logging tools under dynamic flow conditions. The setup for the TPDF consists of the following key components...

- Flow profiling rig with tracer and water sampling system
 - Motorized hose reel for tracer pulse flowmeter
 - Motorized hose reel for groundwater sampling
 - Miniaturized Teflon FEP Bailer for VOC sampling
 - Miniaturized HydroBooster Mini Pump for Inorganic Sampling
 - NSF 60 Approve Tracer for potable drinking water systems: Rhodamine Red FWT 50
 - Injection Control Unit / Injection Motor / Injection Pump / Electrical Panel
 - Fluorometer with connecting hose to well discharge sampling tap
 - Laptop
 - Nitrogen Gas Supply
 - Water level meter. This can also be provided by the water producer or the producer's consultant.

Other requirements for the profiling survey that are typically supplied by the water producer are the following...

- Operational flow meter. BESST can provide a clamp on flow meter if the water producer cannot provide a properly functioning device.
- Water sampling tap on the well's discharge line
- Electrical. A generator can be provided by BESST if there is no electrical.
- Laboratory bottles / Labels / Chain of custody / shipping
- Laboratory contract

2. The First Step – Contract With Water Producer and/or Consultant

Contracting is typically the first step in the profiling process. However, sometimes our clients provide preliminary well information prior to the contracting process in order for BESST to determine the feasibility of profiling the well of concern as well as for quote generation. The contracting process includes...

- Signed purchase order and/or contract
- Insurance documents from BESST including our general, professional and pollution liability, auto and worker's compensation insurances.

3. The Second Step – BESST obtain available information about well

This is another key step in the process. The information that we believe to be useful in achieving a successful outcome to the field work and for providing a comprehensive report to the client is the following:

- Driller's well completion report
- Well schematic or knowledge of well diameter, well depth, pump column diameter, pump diameter, pump depth, pump intake depth, length of suction pipe, presence of engineered suction, length and

depths of well screens, date well constructed, geophysical logs, previous spinner logs and water chemistry results.

- Video log if available
- Photographs of the well head from multiple directions showing vent pipe, locations of bolt holes, pump plate configuration, location and layout of discharge pipe.
- Determine if there is a working flow meter, sample tap and electrical hookup at or in close proximity to the well head.
- Determine if the test is to be run while pumping water into the system or if the water will be pumped to waste.
- Determine if there will be any time constraints in performing the test due to limits on discharge volume, day-time testing, night testing

4. The Third Step – Chain Survey to Determine Well Access

The chain survey is a necessary requirement for project completion. BESST cannot perform any profiling work at the job site until access into the well is confirmed. The chain survey consists of using BESST's assortment of dummy tools which are selected on the basis of the information obtained in **The Second Step**. The chain survey can be performed in one of two ways. Either the water producer or a consultant for the producer performs the test with the BESST chain survey tools, or the chain survey test is performed by BESST. When the operator or the operator's consultant performs the test, BESST will Fed Ex the survey tools to the specified address. BESST will prepare the chain survey tool accordingly, making sure that there is enough cable on the chain survey tool to go at least 50 feet past the pump bowls.

Important information to note during the chain survey test are the following...

- Record the length and diameter of the chain survey tool and record the number of sausage weights that are attached.
- Record points of entry into the well and describe each entry point's characteristics such as entry diameter and angle as well as entry point classification such as vent pipe, sounding tube, bolt hole, angle of pipes at entry point to well reference to the horizontal plane of the pump block.
- Record access problems associated with each entry point around well head. As an example, notate depths where surveyor encountered sticking points. Mention if survey tool loses weight and at approximate depth that this occurs.

BESST can also provide this service but at an extra cost which has to be approved within the signed purchase order or contract.

Communication about the chain survey results between the client and BESST is critical to the successful completion of the project. At this point in the process BESST will provide an opinion to their client as to whether or not the profiling can be performed with the existing well head configuration – meaning that nothing is changed at the well head for the purpose of successful access. On the other hand, a range of recommendations could follow from BESST such as...

- Drilling a 1-inch to 1.25-inch hole in the pump plate
- Removing a section of elongated vent
- Lifting the pump and shifting it to one side
- Coring a hole through the pump block at a steep angle
- Removing existing pump and using a smaller diameter test pump – with or without the installation of a PVC access pipe that extends past the pump bowls and/or extends to the top of an uppermost screen interval or top of screen.

The most common solution to well access when the chain survey demonstrates a tight annulus is to drill a hole through the pump plate. BESST will provide an expansion plug to seal off the hole.

5. The Fourth Step – Tracer Pulse Ambient Flowmeter Survey

The TPDF tubing and injection nozzle typically ranges between ½-inch to ¾-inch in diameter. The small diameter and flexibility of the tubing and nozzle assembly make it possible to bypass the pump column, down-hole impeller bowls and / or electric pump motors in most situations. A key factor in successfully inserting the injection tubing and nozzle is the attachment of a small diameter string of sausage weights or weighted chain attached to a metal loop located and attached just below the injection nozzle.

In typical applications, the TPDF tubing is lowered through a mechanical counter that indicates the depth of the injection nozzle. The injection process is typically started about 20 feet below the bottom of the pump in order to preliminarily confirm that all of the key components of the TPDF system are working down hole. From there, the survey progresses downward toward the bottom of the well. Injection points are typically laid out on 10- to 20-foot vertical depth centers in order to obtain enough data points to vertically profile production along the well screen.

The tracer solution used in the survey consists of 50 ml of Rhodamine Red (RR) (from Bright Dyes, Inc.) mixed with 5-Gallons of tap water. The solution from the RR bottle is then fed by the injection motor/pump assembly through the injection line until the line is completely filled with the RR solution. When released into a well, each second of injection by the Injection Control Unit (ICU) is equivalent to approximately 20 ml of RR released from the injection nozzle. Figure 1 below shows a typical setup for the TPDF system at a production well location in northern Nevada.

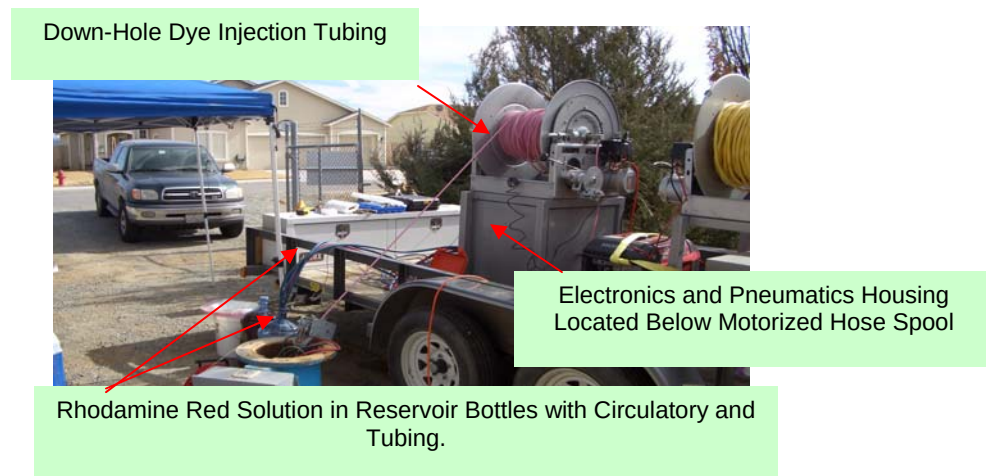


Figure 1: Typical trailer setup TPDF System – at a location in northern, Nevada.

In between injection points the RR solution is circulated in the 5-gallon reservoir bottle to prevent air bubbles from entering the liquid and being injected into the well. Additionally, an electronic float sensor is placed within the reservoir bottle to prevent air from being drawn into the injection line as the solution draws down within the bottle. When the RR solution is drawn down to the lower third of the reservoir, the injection pump automatically shuts off. More RR solution is then added to the bottle before RR injection is continued. Introduction of air into the injection line is undesirable since air bubbles can cause delays in the return time of the RR to the fluorometer.

5.1 General Description of Equipment

The fluorometer used for the velocity profiling is either a Model 10-AU from Turner Designs and is shown in Figure 3 (or the C3 system). The 10-AU Fluorometer measures the concentration of various analytes in samples of interest via fluorescence. In the case of dynamic flow velocity analysis for wells, the analyte of interest is artificially introduced in order to measure the peak concentration return times of rhodamine red from the release point to the fluorometer via the discharge path of the pumping well. The return concentrations are typically in the part per billion range. An excitation light source inside the fluorometer

is passed through a color filter specific to rhodamine red, that transmits light of the chosen wavelength range (color). The wavelength of the exciting light that falls on the sample is set by the choice of the light source and the excitation filter. The emitted light radiates in a sphere from the light source and is directed towards the 10-AU detector through an emission filter. The purpose of the emission filter is to prevent any scattered exciting light from reaching the detector (photomultiplier tube) and to pass the emitted color that is specific to the analyte of interest. The concentration of the RR solution is directly proportional to the signal response received by the fluorescing light emitted by the rhodamine red that is received by the detector. The concentration is typically reported on an analog display panel located on the front of the 10-AU (Turner Designs, 1996). Figure 3 below shows an example of a BESST, Inc. injection control unit for regulating injection pulse times. Figures 4 and 5 provide a more detailed look of the circulatory system of the dye injector.

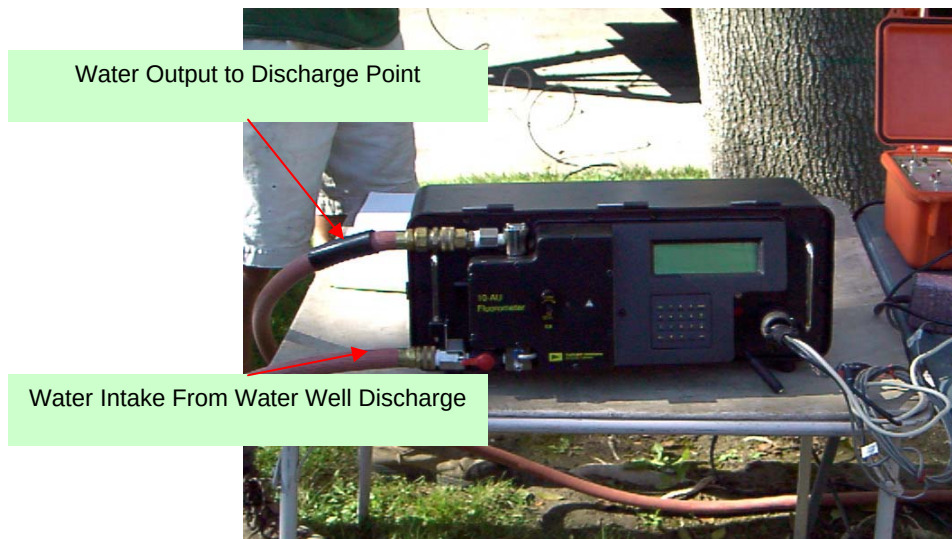


Figure 2: Model 10-AU fluorometer from Turner Designs.



Figure 3: Injection Timer Control Unit used for pulsing tracer into well.



Figure 4: Electrical and Pneumatics components inside housing are controlled by the Dye Injection Control Unit (Figure 4). The housing contains injection pump, injection pressure regulator, pneumatically controlled valve switching solenoid, fuse box, electrical circuits and primary and secondary valve control units.



Figure 5: Bottle to right contains primary RR reservoir. When the large oval red button is depressed on the Dye Injection Control Unit (Figure 4), the RR solution is fed from the red tube, then to the injection pump, and finally through the injection nozzle and into the well. When the injection pump is idling, the RR solution circulates through the blue tube and red tube in the primary RR reservoir bottle. The secondary RR bottle receives excess RR that is not used during an injection pulse.

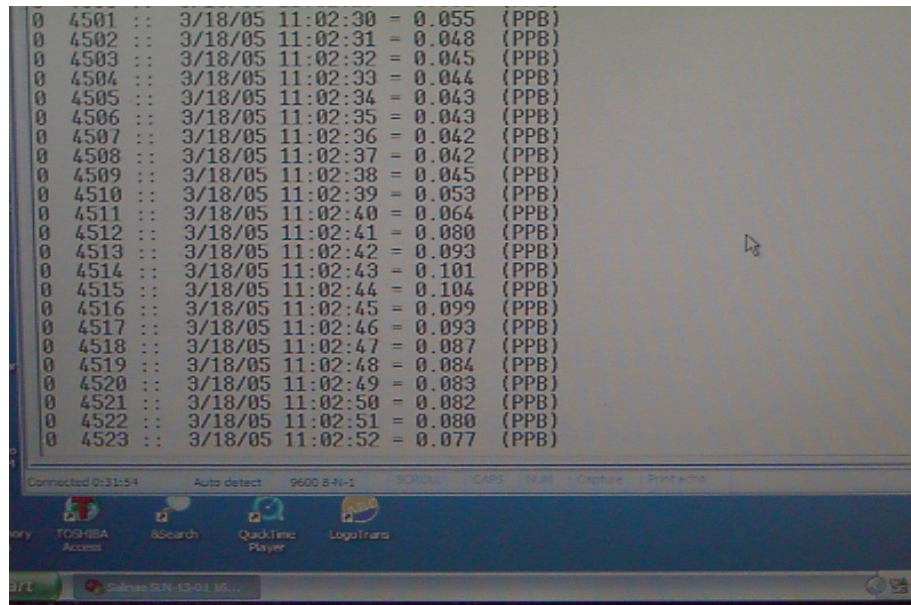


Figure 6: Streaming Laptop Hyperlink Communication Display from AU-10 Fluorometer. Date, time and concentration value are reported and stored in continuous scrolling format.



Figure 7: Laptop connected to 10-AU

5.2 Data Requirements

During the course of completing the vertical dye injection grid, some of the injection points are repeated in order to establish travel time and velocity reproducibility. Once all of the injection points are completed, the data is entered into an Excel spreadsheet with built-in data calculations that facilitate the generation of the flow profile – using the Excel chart function. The basic equation (Izbicki, 2000) used for calculating flow velocity is:

$$Q = (V\pi r^2) \text{ where,}$$

$$V = (d_2 - d_1) / (t_2 - t_1)$$

Q = flow in gallons per minute (gpm)

d = injection depth

d₂ = injection depth # 2

d₁ = injection depth # 1

t = travel time of peak tracer concentration from release point to detector

t₂ = return time for rhodamine red peak to fluorometer detector for d₂ injection point

t₁ = return time for rhodamine red peak to fluorometer detector for d₁ injection point

Other factors that are required for the solution and interpretation of the results are well diameter, pump diameter, pump column diameter and length, depth of pump intake, well screen interval(s), and length of well screen located above the pump. Other pieces of information that can play a role in the interpretation of the results are driller's logs from when the well bore was drilled and any geophysical logs such as resistivity short and long normal, spontaneous potential (SP), gamma ray, neutron, caliper, video surveys and others.

As far as data plotting, there are various types of valid presentation formats. One type of format (presented in Figure 8) plots depth on the y-axis, percent flow on the top x-axis and GPM discharge on the bottom x-axis. Additionally, lithologic and geophysical information are presented in co-plots to the right in order to correlate lithologic and geophysical properties to production.

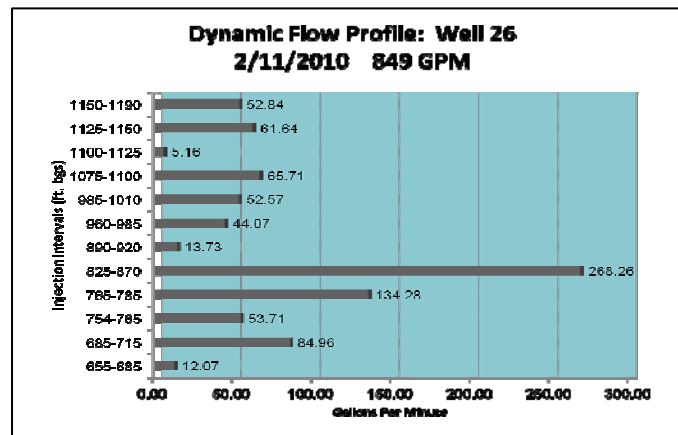


Figure 8: Example of bar graph flow profile showing flow contribution in GPM.

5. The Fifth Step – Depth Dependent Groundwater Sampling Survey

BESST provide categories of groundwater sampling services. Those provided with a pressurized bailer and are primarily used for volatile organic compounds and use of a miniaturized gas displacement pump specifically for inorganic compounds. Prior to deployment in any well the tubing is pressure washed off-site. At the job site, BESST field scientists spray the tubing with a chlorine bleach solution from a Hanson sprayer as a means of killing bacteria on the outside of the tubing.

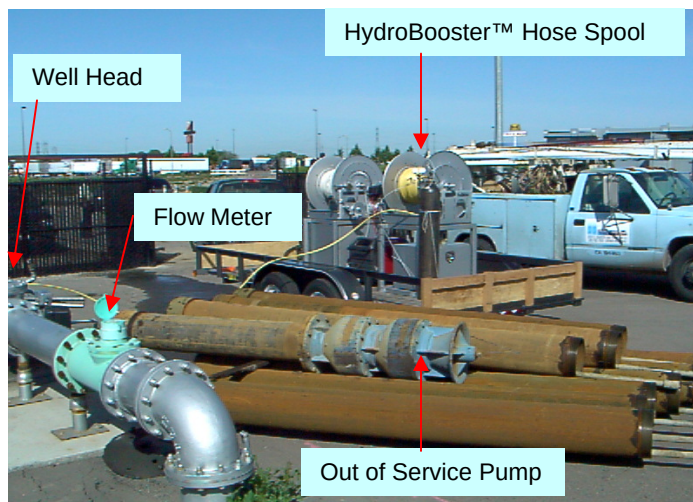
Miniaturized Bailer

The miniaturized bailer is made from Teflon FEP – an inert polymer and broadly accepted by the environmental industry as the preferred polymer type to be used when collecting VOCs. Construction at the bottom of the bailer consists of a miniaturized poppet valve made from 316 stainless steel. Before deployment into the well of interest the bailer is pressurized with an inert gas such as nitrogen (but helium and argon are acceptable as well); the pressure used being in excess of the head pressure between pumping water level and the sample depth. Typically, the sample pressure is set to 10% above theoretical to insure that the valve does not open unintentionally. The mini bailer is lowered through a mechanical counter to the target depth where the pressure is released by an up-hole control valve. A simple bubble detector is used at the ground surface to determine the tubing is close or completely full of water from the target depth. Once the bubbler provides confirmation the bailer is re-pressurized to the pressure setting used during descent for that specific sample. The bailer is then retrieved back to the ground surface. The pressure is slowly bled off. The bottom of the bailer is opened and the water sample drained by gravity into the sample collection vials.

Prior to reuse for the next sampling interval the bailer is thoroughly purged with an inert gas at the ground surface to the point where no observable water droplets exit the bailer. This procedure has been successfully used on many projects sampling for VOCs without any cross contamination issues.

Miniaturized Pump

The HydroBooster™ is a miniaturized displacement pump (not an air-lift pump) for collecting groundwater samples from active production wells without having to remove the pump. The pump can be connected to any type of tubing (i.e. Teflon, polyethylene, nylon, etc.). For high pressure applications, the tubing can consist of regular nylon, or even nylon reinforced with fiber glass or Kevlar for ultra high pressure applications to 3,000+ feet BGS. Figure 9 shows an example of a HydroBooster™ application at a site in the California Central Valley for a production well under study for vertical distribution of nitrate contamination. The HBP measures less than 3/4" OD and about 4-inches long.



Issue Date: 09-Jan-2014

Revision Date: 18-Jan-2019

Version Number: 2.2

1. Identification

Product Identifiers

Product Name: Bright Dyes® FWT Red 50 Liquid

Product Number: 106053

Recommended Use & Restrictions on Use

Water tracing & leak detection dye

Manufacturer/Supplier

Kingscote Chemicals, Inc.
3334 South Tech Blvd.
Miamisburg, OH 45342
U.S.A.

Emergency Telephone Number

Company Telephone Number: (937) 886-9100

Emergency Telephone (24 hr): INFOTRAC (800) 535-5053 (North America)
+1-352-323-3500 (International)

2. Hazards Identification

Classification

This chemical does not meet the hazardous criteria set forth by the 2012 OSHA Hazard Communication Standard (29 CFR 1910.1200). However, this Safety Data Sheet (SDS) contains valuable information critical to the safe handling and proper use of this product. This SDS should be retained and available for employees and other users of this product.

3. Composition/Information on Ingredients

This product is not hazardous according to OSHA 29 CFR 1910.1200. Components not listed are not hazardous or are below reportable limits.

4. First-Aid Measures

First-Aid Measures

Eye Contact	Rinse immediately with plenty of water, also under the eyelids, for at least 15 minutes. If eye irritation persists: Get medical advice/attention.
Skin Contact	Wash thoroughly with plenty of soap and water. If skin irritation occurs: Get medical advice/attention.
Inhalation	Remove to fresh air. If breathing is difficult, administer oxygen; seek medical attention immediately.

Ingestion	Rinse mouth. DO NOT induce vomiting. Drink plenty of water. Never give anything by mouth to an unconscious person. Get medical attention if large quantities were ingested or if nausea occurs.
------------------	---

Most Important Symptoms and Effects

Symptoms	Will cause staining of the skin on contact. May cause eye irritation. Inhalation of dust may cause respiratory irritation. Ingestion may cause urine to be a red color until the dye has been washed through the system.
-----------------	--

Indication of Any Immediate Medical Attention and Special Treatment Needed

Notes to Physician	Treat symptomatically.
---------------------------	------------------------

5. Fire-Fighting Measures**Suitable Extinguishing Media**

Water spray (fog). Carbon dioxide (CO₂). Dry chemical. Regular foam.

Unsuitable Extinguishing Media

Not determined

Specific Hazards Arising from the Chemical

Product is not flammable. Burning/combustion may produce oxides of carbon and nitrogen (NO_x).

Protective Equipment and Precautions for Firefighters

Wear self-contained breathing apparatus pressure-demand, MSHA/NIOSH (approved or equivalent) and full protective gear.

6. Accidental Release Measures**Personal Precautions, Protective Equipment and Emergency Procedures**

Personal Precautions	Use personal protective equipment as recommended in Section 8.
-----------------------------	--

Environmental Precautions	Prevent from entering into soil, ditches, sewers, waterways and/or groundwater. See Section 12 and Section 13.
----------------------------------	--

Methods and Material for Containment and Cleaning Up

Methods for Containment	Prevent further leakage or spillage if safe to do so.
--------------------------------	---

Methods for Cleaning Up	Sweep up and collect into suitable containers for disposal. Flush area with water.
--------------------------------	--

7. Handling and Storage**Precautions for Safe Handling**

Advice on Safe Handling	Handle in accordance with good industrial hygiene and safety practices. Use personal protection recommended in Section 8. Avoid contact with skin, eyes, or clothing. Avoid breathing dusts. Contaminated clothing should be thoroughly washed before reusing.
--------------------------------	--

Conditions for Safe Storage, Including Incompatibilities

Storage Conditions	Keep container tightly closed and store in a cool, dry, and well-ventilated area. Keep from freezing.
Incompatible Materials	No materials to be especially mentioned

8. Exposure Controls / Personal Protection**Exposure Guidelines**

This product, as supplied, does not contain any hazardous materials with occupational exposure limits established by the region specific regulatory bodies.

Engineering Controls

Ensure adequate ventilation, especially in confined areas. Eyewash stations. Showers.

Individual Protection Measures, Such as Personal Protective Equipment:

Eye/Face Protection	Goggles.
Skin & Body Protection	Rubber gloves. Suitable protective clothing.
Respiratory Protection	No protection is ordinarily required under normal conditions of use.
Hygiene Measures	Handle in accordance with good industrial hygiene and safety practices.

9. Physical and Chemical Properties**Information on Basic Physical and Chemical Properties**

Physical State	Liquid	Odor	Mild
Appearance	Dark red liquid	Odor Threshold	Not determined
Color	Dark red		

<u>Property</u>	<u>Values</u>
pH	Not determined
Melting/Freezing Point	Not determined
Boiling Point/Range	Not determined
Flash Point	Not applicable
Evaporation Rate	Not applicable
Flammability (solid, gas)	Liquid – not applicable
Upper Flammability Limits	Not applicable
Lower Flammability Limits	Not applicable
Vapor Pressure	Not applicable
Vapor Density	Not applicable
Relative Density	Not applicable
Specific Gravity	Not determined
Solubility	Highly soluble in water
Partition Coefficient	Not determined
Auto-ignition Temperature	Not determined
Decomposition Temperature	Not determined
Viscosity	Not determined

10. Stability and Reactivity**Reactivity**

Not reactive under normal conditions.

Chemical Stability

Stable under recommended storage conditions.

Possibility of Hazardous Reactions

None under normal processing.

Conditions to Avoid

Keep separated from incompatible substances. Keep out of reach of children.

Incompatible Materials

No materials to be especially mentioned

Hazardous Decomposition Products

Oxides of carbon and nitrogen (NOx).

11: Toxicological Information**Information on Likely Routes of Exposure**

Inhalation	Avoid breathing vapors or mists.
Ingestion	Do not ingest.
Skin Contact	May cause an allergic skin reaction.
Eye Contact	Avoid contact with eyes.

Delayed, Immediate, and Chronic Effects from Short- and Long-Term Exposure

May cause an allergic skin reaction.

Numerical Measures of Toxicity

Not determined

Symptoms Associated with Exposure

See Section 4 of this SDS for symptoms.

Carcinogenicity

NTP	None
IARC	None
OSHA	None

12. Ecological Information**Ecotoxicity**

This product is not classified as environmentally hazardous. However, this does not exclude the possibility that large or frequent spills can have a harmful or damaging effect on the environment.

Component Information

Not available

Persistence/Degradability

Not determined

Bioaccumulation

Not determined

Mobility

Not determined

Other Adverse Effects

Not determined

13. Disposal Considerations**Waste Disposal Methods**

Dispose of in accordance with federal, state, and local regulations.

Contaminated Packaging

Do not re-use empty containers. Dispose of containers in accordance with federal, state, and local regulations.

14. Transport Information**Note**

See current shipping paper for most up-to-date shipping information, including exemptions and special circumstances.

DOT Not regulated

IATA Not regulated

OMDG Not regulated

15: Regulatory Information**International Inventories**

TSCA Listed

U.S. Federal Regulations

CERCLA This material, as supplied, does not contain any substances regulated as hazardous substances under the Comprehensive Environmental Response Compensation and Liability Act (CERCLA) (40 CFR 302) or the Superfund Amendments and Reauthorization Act (SARA) (40 CFR 355).

SARA 313 Section 313 of Title III of the Superfund Amendments and Reauthorization Act of 1986 (SARA). This product does not contain any chemicals which are subject to the reporting requirements of the Act and Title 40 of the Code of Federal Regulations, Part 372.

CWA (Clean Water Act) This product does not contain any substances regulated as pollutants pursuant to the Clean Water Act (40 CFR 122.21 and 40 CFR 122.42).

U.S. State Regulations

California Proposition 65 This product does not contain any Proposition 65 chemicals.

U.S. State Right-to-Know This product does not contain any substances regulated under applicable state right-to-know regulations.

16: Other Information

HMIS

Health Hazards	Flammability	Instability	Special Hazards
1	0	0	Not determined

NFPA

Health Hazards	Flammability	Physical Hazards	Personal Protection
1	0	0	B

Issue Date 09-Jan-2014

Revision Date 18-Jan-2019

Revision Note Biennial Review

Disclaimer

The information provided in this Safety Data Sheet is correct to the best of our knowledge, information and belief at the date of its publication. The information given is designed only as guidance for safe handling, use, processing, storage, transportation, disposal and release and is not to be considered a warranty or quality specification. The information relates only to the specific material designated and may not be valid for such material used in combination with any other materials or in any process, unless specified in the text.

End of Safety Data Sheet



Division of Kingscote Chemicals ®

WATER TRACING DYE FWT RED PRODUCTS

TECHNICAL DATA BULLETIN

Bright Dyes FWT Red liquid products are specially formulated versions of Rhodamine WT dye for convenient use in water tracing and leak detection studies. This bright, fluorescent red dye is certified by NSF International to ANSI/NSF Standard 60 for use in drinking water. It may be detected visually, by ultraviolet light and by appropriate fluoremetric equipment. Today it is most often used visually. Visually the dye appears bright pink to red, depending on its concentration and under ultraviolet light as bright orange.

The dye is resistant to absorption on most suspended matter in fresh and salt water. However, compared to Bright Dyes FLT Yellow/Green products it is significantly more resistant to degradation by sunlight and when used in fluoremetry, stands out much more clearly against background fluorescence. As always the suitability of these products for any specific application should be evaluated by a qualified hydrologist or other industry professional. Store product out of sunlight, in a cool and dry location. Shelf life is 4 years from date of purchase.

General Properties	Tablets	Liquids (50)	Powders
Detectability of active ingredient ¹	Visual <100 ppb	Visual <100 ppb	Visual <100 ppb
Maximum absorbance wavelength ²	550/588 nm	550/588 nm	550/588 nm
Appearance	Dark red convex 1.6cm diameter	Clear dark red aqueous solution	Dark red fine powder
NSF (Max use level in potable water)	0.3 ppb	0.4 ppb	0.1 ppb
Weight	1.05 gms $\pm$ 0.05		
Dissolution Time ³	50% < 3 minutes 95% < 6 minutes		50% < 3 minutes 95% < 6 minutes
Specific Gravity		1.03 $\pm$ 0.05 @ 25° C	
Viscosity ⁴		1.3 cps	
pH		8.7 $\pm$ 0.5 @ 25° C	

Coverage of Products	One Tablet	One Pint Liquid	One Pound Powder
Light Visual	604 gallons	62,500 gallons	467,000 gallons
Strong Visual	60 gallons	6,250 gallons	46,700 gallons

Caution: These products may cause irritation and/or staining if allowed to come in contact with the skin. The use of gloves and goggles is recommended when handling this product, as with any other dye or chemical.

To our best knowledge the information and recommendations contained herein are accurate and reliable. However, this information and our recommendations are furnished without warranty, representation, inducement, or license of any kind, including, but not limited to the implied warranties and fitness for a particular use or purpose. Customers are encouraged to conduct their own tests and to read the material safety data sheet carefully before using.

¹ In deionized water in 100 ml flask. Actual detectability and coverage in the field will vary with specific water conditions.

² No significant change in fluorescence between 6 and 11 pH.

³ (One tablet, 1 gram of powder), in flowing deionized water in a 10 gallon tank.

⁴ Measured on a Brookfield viscometer, Model LV, UL adapter, 60 rpm @ 25° C.

DRAFT RIFS WORKPLAN

CITY OF MODESTO WELL FIELD RIFS, MODESTO, CALIFORNIA – APRIL 26, 2019

APPENDIX B

QUALITY ASSURANCE PROJECT PLAN

Appendix B Draft Quality Assurance Project Plan

City of Modesto Well Field RIFS
Grant Agreement No. D1712514
Modesto, California

April 26, 2019

Prepared for:

City of Modesto Utilities Department
1010 Tenth Street, Suite 4000
Modesto, California 95353

Prepared by:



9083 Foothills Blvd., Suite 370
Roseville, California 95747
916.367.5111

Appendix B

Draft Quality Assurance Project Plan

City of Modesto Well Field RIFS
Grant Agreement No. D1712514
Modesto, California

April 26, 2019

Prepared By

Nick Kehrlein
Associate Scientist

Terri Herson
Principal Project Manager



9083 Foothills Blvd., Suite 370
Roseville, California 95747
(916) 367-5111

	TABLE OF CONTENTS	PAGE
LIST OF ACRONYMS AND ABBREVIATIONS.....		v
1.0 INTRODUCTION		1-1
2.0 BACKGROUND AND PURPOSE.....		2-1
3.0 PROJECT PERSONNEL RESPONSIBILITIES		3-1
3.1 Responsibilities.....		3-1
3.1.1 Project Manager.....		3-1
3.1.2 Field Manager.....		3-1
3.1.3 Site Field Personnel		3-1
3.1.4 Health and Safety Manager		3-1
3.1.5 Laboratory Quality Manager.....		3-1
3.1.6 Laboratory Data Validator.....		3-1
3.2 Training.....		3-2
4.0 DATA QUALITY OBJECTIVES		4-1
4.1 Data Quality Criteria.....		4-3
5.0 QUALITY CONTROL PROCEDURES		5-1
5.1 Analytical Methods		5-1
5.2 Laboratory Quality Control Checks		5-2
5.3 Internal Quality Control Checks		5-2
5.4 Quality Assurance and Quality Control Samples		5-3
5.5 Laboratory Instrument Calibration		5-5
6.0 DATA MANAGEMENT, VALIDATION AND REPORTING.....		6-1
6.1 Field Data Management		6-1
6.2 Laboratory and Analytical Data Management		6-1
6.3 Data Validation.....		6-2
6.4 Data Reporting		6-2
7.0 SAMPLING PROCEDURES		7-1
7.1 Sampling Monitoring Wells.....		7-1
7.2 Sampling Supply Wells		7-1
7.3 Concentration Profiling		7-2
7.4 Sample Collection and Analysis		7-3
7.5 Sampling Containers, Preservatives, and Holding Times		7-4
7.6 Sample Identification		7-4
7.7 Sample Handling and Storage.....		7-4
8.0 SAMPLE CUSTODY PROCEDURES		8-1
8.1 Field Custody Procedures		8-1

8.2	Packaging and Shipping Protocol.....	8-2
8.3	Laboratory Custody Procedures	8-2
9.0	PREVENTIVE MAINTENANCE	9-1
9.1	Laboratory Maintenance	9-1
9.2	Field Maintenance.....	9-1
10.0	CORRECTIVE ACTION MEASURES	10-1
10.1	Field Corrective Action	10-1
10.2	Laboratory Corrective Action	10-1
11.0	REFERENCES	11-1

LIST OF ACRONYMS AND ABBREVIATIONS

APHA	American Public Health Association
COC	Chain-of-custody
DQO	Data quality objectives
DOT	Department of Transportation
Grant Agreement	Proposition 1 – Groundwater Planning Grant Agreement No. D1712514 (November 30, 2018)
HASP	Project-Specific Health and Safety Plan
JJ&A	Jacobson James & Associates, Inc.
MCL	Maximum contaminant level
MDL	Method detection limit
MRP	Grant Agreement Monitoring and Reporting Plan, City of Modesto Wellfield Remedial Investigation/Feasibility Study
MS/MSD	Matrix spike/matrix spike duplicate
Project	City of Modesto Wellfield Remedial Investigation/Feasibility Study
QAPP	Quality Assurance Project Plan
QA	Quality assurance
QC	Quality control
PSW	Public supply well
RL	Reporting limit
Site	City of Modesto Wellfield, Modesto, California
SOP	Standard Operating Procedure
SWRCB	California State Water Resources Control Board
TDS	Total dissolved Solids
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey

1.0 INTRODUCTION

Jacobson James & Associates, Inc. (JJ&A) prepared this *DRAFT Quality Assurance Project Plan* (QAPP) on behalf of the City of Modesto to set forth quality assurance (QA) and quality control (QC) procedures for groundwater monitoring activities associated with the City of Modesto Wellfield Remedial Investigation/Feasibility Study (Project).

The Project is focused on arsenic, nitrate and uranium contamination in City of Modesto groundwater and is funded through the State Water Resources Control Board (SWRCB) Proposition 1 Groundwater Sustainability Grant Program. This QAPP was developed as required in Grant Agreement No. D1712514 between the City of Modesto and the SWRCB, executed on November 30, 2018 (Grant Agreement). As specified in the Grant Agreement, guidelines followed in the preparation of this QAPP are described in the U.S. Environmental Protection Agency (USEPA) *Requirements for Quality Assurance Project Plans, USEPA QA/R-5* (USEPA, 2001) and *Guidance for Quality Assurance Project Plans, USEPA QA/G-5* (USEPA, 2002).

2.0 BACKGROUND AND PURPOSE

The City of Modesto faces ongoing challenges with natural and anthropogenic contamination in its drinking water aquifers. Nitrate, arsenic, and uranium contamination has led to abandonment of a significant number of supply wells, and threatens other wells. Compliance with the Maximum Contaminant Levels (MCL) for drinking water is presently achieved at some supply wells through water blending or above ground treatment.

The purpose of the Project is to identify and evaluate alternatives to reduce nitrate, arsenic and uranium impacts in the City of Modesto's drinking water aquifers through containment and remediation. The purpose of this QAPP is to identify the procedures and criteria required to establish the technical accuracy, precision, and validity of data associated with groundwater sampling and analysis activities.

This QAPP contains general information and specific details regarding field sampling, laboratory, and analytical procedures that apply to the Grant Agreement Monitoring and Reporting Plan (MRP) developed for the City of Modesto Well Field, Modesto, California (Site). The MRP is provided as Appendix A in the RIFS Workplan [JJ&A and Formations, 2019]). The QAPP provides field and laboratory personnel with instructions regarding activities to be performed before, during, and after field investigations. These protocols will ensure data collected for use in project decisions will be of the type and quality needed and expected for their intended purpose.

3.0 PROJECT PERSONNEL RESPONSIBILITIES

3.1 Responsibilities

The specific responsibilities associated with this QAPP assigned to key Project personnel are described in the following QAPP sections.

3.1.1 Project Manager

The Site Project Manager is responsible for overall QA/QC program direction. The Project Manager ensures program objectives are met. The Project Manager will review field documentation and document corrective action resolutions.

3.1.2 Field Manager

The Field Manager is responsible for day-to-day coordination of field activities under the direction of the Project Manager. Other responsibilities include coordination of subcontractors and field personnel to ensure field activities conform to the specifications of the MRP and Health and Safety Plan (HASP). The Field Manager will review and approve field documentation and documentation of field equipment maintenance.

3.1.3 Site Field Personnel

Field Personnel are responsible for field activities and coordination under the direction of the Project Manager or Field Manager. The Field Personnel are responsible for equipment maintenance (e.g., performance, documentation, and calibration) and the use of field notebooks or field forms to document project related field work, including field measurements, observations and field instrument calibrations.

3.1.4 Health and Safety Manager

The Health and Safety Manager is responsible for establishing, implementing, and verifying QA/QC compliance with the project-specific HASP.

3.1.5 Laboratory Quality Manager

The Laboratory Quality Manager is responsible for ensuring that the laboratory implements the requirements of this QAPP. The Laboratory Quality Manager will coordinate with the contract laboratory regarding QA/QC requirements, review the QA/QC report, identify potential problems, and ensure proper use, maintenance and storage of field and analytical equipment.

3.1.6 Laboratory Data Validator

A third party data validation professional will confirm the validity and usability of analytical data and present findings in a data validation report. Data validation will include a review of analytical data and associated data

deliverables. The data will be evaluated for compliance with the QA objectives, QC control limits and QC procedures. Data validation will also include summarizing deviations and its impact on data quality.

3.2 Training

The Site Project Manager or Field Manager will review the capabilities and qualifications of the project personnel assigned to perform the task. If personnel qualifications, including education, experience, or training, do not meet project needs, appropriate training will be performed or other appropriately qualified individuals will be assigned to perform the task.

4.0 DATA QUALITY OBJECTIVES

Data Quality Objectives (DQOs) are qualitative and quantitative statements developed by data users to specify the quality of data needed from a particular data collection activity to support specific decisions or regulatory actions. The process for developing DQOs is described in USEPA Guidance for the Data Quality Objective Process (USEPA, 1994).

The project DQOs developed specifically for the planned sampling and analysis program have been determined based on USEPA's seven-step DQO process (USEPA, 2006). The Project Manager will evaluate the project data against the DQOs to determine if the quantitative and qualitative needs of the sampling and analysis program have been met. The project definition along with each step of the DQO process can be summarized as follows:

Step 1. State the Problem. The City of Modesto's drinking water aquifer is impacted with nitrate, arsenic and uranium.

Step 2. Identify the Goal of the Project. The goal of the RIFS Project is to identify and evaluate alternatives to reduce nitrate, arsenic and uranium impacts in the City of Modesto's drinking water aquifers through containment and remediation.

Step 3. Identify Information Inputs. Inputs to the decision process will include:

- Groundwater elevation and chemistry data from previous investigations;
- Current chemical concentrations in Site groundwater;
- Ambient and dynamic vertical profiling data for select wells;
- Results from an aquifer recharge pilot test, and
- Water quality screening criteria, to evaluate potential risks to human health and the environment.

Step 4. Define the Boundaries of the Project. The project boundaries are presented on Figure 6-2 of the RIFS Workplan (JJ&A and Formations, 2019). The Project includes the Modesto contiguous water service area and the Grant proposal submodel areas:

- Arsenic submodel area
- Nitrate and Uranium submodel area
- Recharge submodel area

Step 5. Develop the Analytical Approach of the Project. The RIFS approach includes the following components as described in the RIFS Workplan:

- *Data Compilation.*
- *Additional Data Gathering (subject of this QAPP):*

- Supplemental Water Quality Data Collection: Additional water quality data will be collected from up to seven public supply wells, and up to 23 monitoring wells installed by the United States Geological Survey (USGS). In addition, samples of untreated surface water that may be used for aquifer storage and recovery projects will be collected and analyzed.
 - Flow and Concentration Profiling of Public Supply Study Wells (PSW): Well hydraulic and contaminant concentration data will be collected at vertically-spaced intervals along the screen/perforated intervals of PSWs selected for detailed study and evaluated together with data from the previous profiling by the City and the USGS (City Well Nos. 25 and 66).
 - Recharge Pilot Testing: Injection pilot testing will be performed using two selected USGS-installed monitoring wells.
- *Remedial Investigation Report*
 - *Contaminant Fate and Transport Modeling*
 - *Feasibility Study*

Chemical analyses will be performed by a laboratory certified by the California Department of Health Services and the National Environmental Laboratory Accreditation Program using the following methods:

- Sulfate, chloride, bromine, and fluorine by USEPA Method 300.0;
- Calcium, iron, magnesium, manganese, sodium, potassium, aluminum, boron, strontium, and orthophosphate/dissolved phosphorus by USEPA Method 200.7;
- Total Kjeldahl Nitrogen by USEPA Method 351.2;
- Total alkalinity (as calcium carbonate [CaCO₃]) with bicarbonate (HCO₃) and carbonate (CO₃) by Standard Method (SM) 2320B;
- Title 22 Metals by USEPA Method 6010B;
- Dissolved arsenic, manganese, and iron by USEPA Method 6020;
- Dissolved uranium by USEPA Method 200.8;
- Chromium VI by USEPA Method 7196A;
- Nitrate and Nitrite by SM 4500;
- Total Dissolved Solids (TDS) by SM 2540C;
- Specific Conductance by SM 2510B; and
- Dissolved Organic Carbon and Total Organic Carbon by SM 5310.

Analytical methods, preservatives, and holding times are summarized on Table 4-1 in Appendix A of the RIFS Workplan (JJ&A and Formations, 2019).

Step 6. Specify Performance or Acceptance Criteria. All analytical testing results will be subjected to data validation. Data are determined to be valid if the specified limits on representativeness and comparability are achieved. If target compounds are detected above analytical reporting limit (RL), then a decision will be made as to the validity of the analytical results.

Step 7. Develop the Plan for Obtaining Data. A detailed groundwater sampling and analysis plan is contained in the MRP.

4.1 Data Quality Criteria

The basis for assessing data quality is presented in the following sections.

4.1.1 Precision

Precision measures the reproducibility of repetitive measurements. Analytical precision is a measurement of the variability associated with duplicate or replicate analyses, and is determined by laboratory quality control samples (e.g., duplicate control samples, matrix spike duplicate (MSD), or sample duplicates). Precision for a single analyte will be expressed as a percentage of the difference between duplicate measurements (relative percent difference). Precision will be determined at a rate of one sample in ten (10%) for field duplicates (replicates) and at a rate of one sample in twenty (5%) for laboratory duplicates.

4.1.2 Accuracy

Accuracy is a statistical measurement of correctness. A measurement is accurate when the value reported agrees with the true value or known concentration of the spike or standard. Accuracy of laboratory analyses may be assessed by laboratory control samples, surrogate standards, matrix spikes (MS), or initial and continuing calibration of instruments. Laboratory accuracy will be expressed as the percent recovery (%R). Accuracy may be determined at a rate of one sample in twenty (5%).

4.1.2.1 Representativeness of Data

The representativeness of the data is the degree to which data accurately and precisely represents selected characteristics of the media sampled. Representativeness of data collection may be addressed by careful preparation of MRP, including a discussion of sample numbers and locations as well as the sampling rationale. The MRP will address representativeness by specifying sufficient and proper number and location of samples, sample collection techniques and procedures, and laboratory analytical methods. The design of any data collection must also consider the representativeness of Site conditions in terms of lithologic, physical and chemical parameters.

4.1.3 Completeness

Completeness is the amount of valid data obtained compared to the amount that was expected under ideal conditions. The number of valid results divided by the number of possible results, expressed as a percentage,

determines the completeness of the data set. The objective for completeness is to recover at least 90% of the planned data to support field efforts.

4.1.4 Comparability

Comparability is an expression of confidence with which one data set can be compared to another. Sample data will be collected and reported consistently, in order to compare data with each other, for similar Site samples and sample conditions. This QAPP addresses comparability by specifying laboratory methods that are consistent with the current standards of practice as approved by the USEPA and California Department of Public Health. Data quality objectives (DQOs) are qualitative and quantitative statements that specify the data needed from a particular data collection activity to support specific decisions or regulatory actions.

5.0 QUALITY CONTROL PROCEDURES

This section presents QC requirements relevant to analysis of environmental samples that will be followed during all project analytical activities. These protocols will include:

- Adherence to strict protocols for field sampling and decontamination procedures and analytical methods;
- Collection and laboratory analysis of appropriate field equipment blanks and trip blanks to monitor for contamination of samples in the field or the laboratory; and
- Collection and laboratory analysis of Matrix Spike/Matrix Spike Duplicates (MS/MSDs) and field duplicate samples to evaluate precision and accuracy.

5.1 Analytical Methods

Laboratories involved in the analysis of samples will have a written QA/QC program that provides criteria and corrective action pathways to ensure reliability and validity of the work conducted by the laboratory. Compliance with the QA/QC program will be coordinated and monitored by a designated laboratory quality assurance person. Laboratories will use USEPA or USEPA-approved methods whenever possible. Analytical procedures will generally be conducted in accordance with the methodology set forth in Methods for Chemical Analysis of Water and Wastes (USEPA, 1983), or Standard Methods for the Analysis of Water and Wastewater (American Public Health Association (APHA), 2006). If the use of alternate analytical methods is deemed necessary, the alternate method(s) will be included in the MRP.

The qualified analytical laboratory will have a written Quality Assurance/Quality Control program that provides rules and guidelines to ensure the reliability and validity of all analytical work conducted in their laboratory.

5.1.1 Method Detection Limit and Reporting Limit

The method detection limit (MDL) is the minimum concentration of an analyte that can be measured and reported with 99 percent confidence that the analyte concentration is greater than zero. The laboratory then develops individual RLs, which represent concentrations that can be consistently obtained by the specific method, and are generally two to five times the applicable MDL.

5.1.2 Method Calibration

At a minimum of once daily, or if the instrument exceeds calibration limits, chemical calibration of each target analyte will be performed to ensure that the analytical instrumentation is functioning within the established sensitivity range. All analytes specified in the MRP must be present in the initial and continuing calibrations, and these calibrations must meet the acceptance criteria specified by the respective method. The laboratories must demonstrate that RLs are routinely and reliably achieved by analyzing a calibration standard

that is at or below the RL for each analyte. Calibration standards and solutions will be of known concentration and purity to achieve the criteria necessary for validation of the analytical results.

5.2 Laboratory Quality Control Checks

Two types of quality checks will be used in the qualified analytical laboratory to ensure the production of analytical data of known and documented quality. These include program quality assurance and analytical method quality control. The QA/QC requirements for the program, instrumentation, data, documentation, and analyses are described below.

5.3 Internal Quality Control Checks

Field quality control checks will include the review and approval of field documentation by the Field Manager or Project Manager. Approval of field documentation will indicate that the provisions outlined in the QAPP and HASP have been properly implemented.

5.3.1 Equipment Decontamination

Decontamination procedures will be followed during groundwater sampling to prevent cross-contamination by multi-use sampling equipment. Multi-use sampling equipment will be washed in a non-phosphate detergent (such as Liquinox®) and potable water, rinsed in potable water, and then double rinsed in a reagent-free water (such as purified or distilled water).

5.3.2 Supplies

All supplies will be inspected prior to their use in the field. An appropriate storage system for these materials will ensure their integrity prior to use. Effectiveness of the system and purity of field supplies may be monitored through the use of blank samples.

5.3.3 Holding Time Compliance

Sample preparation and analysis will be completed within the required method holding time. Holding time begins at the time of sample collection. If holding times are exceeded, and the analyses are performed, the associated results will be qualified in accordance with validation guidelines. The following definitions of extraction and analysis compliance are used to assess holding times:

- *Preparation or extraction completion:* completion of the sample preparation process as described in the applicable method, prior to any necessary extract cleanup.
- *Analysis completion:* completion of all analytical runs, including dilutions, second-column confirmations, and any required re-analyses.

5.3.4 Preventative Maintenance

The JJ&A Field Manager is responsible for documenting the maintenance of all field equipment prescribed in the manufacturer's specifications. Subcontractors are responsible for maintenance of all equipment needed to carry out subcontracted duties.

5.4 Quality Assurance and Quality Control Samples

The purpose of a QA/QC program is to produce data of known quality that satisfy the project objectives and that meet or exceed the requirements of the standard methods of analysis. This program provides a mechanism for ongoing control and evaluation of data quality measurements through the use of QC materials. QA/QC samples will be collected as part of the overall QA/QC program.

The types of QC samples to be collected in the field include field equipment blanks and duplicate samples. Laboratory QC samples include MS samples and laboratory reagent blanks, as explained below.

5.4.1 Field Equipment Blanks

The objective of the field equipment blank is to provide a laboratory analytical check on possible sources of contamination of a sample that may be related to equipment decontamination and sample handling procedures.

Field equipment blank samples will be collected in the field when sample media contact non-dedicated sampling equipment. Field equipment blanks will not be collected if dedicated sampling equipment is used. If non-dedicated sampling equipment is used for water sampling, equipment blanks will be collected and analyzed at a frequency of one per 20 samples or one per day per field crew (whichever is more frequent).

Field equipment blanks will be handled, transported and analyzed in the same manner as the samples acquired that day. The field equipment blank is collected in the field and therefore may also be used to assess ambient conditions that may potentially affect the sample quality.

A field equipment blank is prepared by collecting analyte free deionized water that has been run through or over the sample collection equipment after decontamination. A field equipment blank is collected in the appropriate sample containers for analysis. Although the equipment blank monitors all of the potential sources of contamination, the primary function of these samples is to determine if field decontamination procedures are sufficient.

5.4.2 Trip Blanks

The primary purpose of trip blanks is to detect additional sources of contamination that could influence contaminant values reported in field samples, both quantitatively and qualitatively. Trip blanks serve as a mechanism of control for sample bottle preparation, blank water quality and sample handling. They are generally submitted to the laboratory for analysis of VOCs. The MRP does not call for analysis of VOCs, so trip blanks will not be collected. If VOCs are added to the suite of analyses, this QAPP will be amended accordingly.

5.4.3 Field Duplicates

Field duplicates will be collected and analyzed for groundwater in the same manner as the primary samples. They will be collected at a frequency of one sample in ten percent (10%) of the total primary aqueous samples collected. Agreement between duplicate sample results will indicate sampling and analytical precision. The specific location for collection of field duplicate samples will generally be designated before field activities begin. The precision goal for field duplicate analyses is analyte specific and will generally be plus or minus 50% RPD for aqueous samples.

5.4.4 Matrix Spike/Matrix Spike Duplicates

MS/MSDs are extra sample volumes used by the laboratory to test for matrix interference in the analyses. MS/MSD samples are typically collected at a frequency of five percent (5%) of total samples, or one for every 20 original samples. The sampling team may select which samples to use as MS/MSDs. MS/MSD samples require triple the volume of a standard sample, or as specified by the project laboratory.

Matrix Spikes (MS) are performed by the analytical laboratory to evaluate the efficiency of the sample extraction and analysis procedures, and are necessary because matrix interference (that is, interference from the sample matrix) may have a widely varying effect on the accuracy and precision of the extraction analysis. The MS is prepared adding known quantities of target compounds to a sample. The sample is extracted and analyzed, the results of the analysis are compared with the known additions, and a MS recovery is calculated, giving an evaluation of the accuracy of the extraction and analysis procedures.

MS recoveries are reviewed to check that they are within acceptable range. However, acceptable ranges vary widely with both sample matrix and analytical method.

MSs are performed in duplicate to evaluate the precision of the procedures as well as the accuracy. Precision objectives (represented by agreement between MS/MSD recoveries) and accuracy objectives (represented by MS recovery results) are based on statistically generated limits established annually by the analytical laboratory.

These objectives are to be viewed as goals, not as criteria. If matrix bias is suspected, the associated data will be qualified and the direction of the bias indicated in the data validation report. The laboratory will provide MS/MSD acceptance criteria.

5.4.5 Laboratory Reagent Blanks

A laboratory reagent blank is organic-free de-ionized or distilled water that is extracted by the laboratory and analyzed as a sample. Analysis of the reagent blank indicates potential sources of contamination from laboratory procedures (e.g., contaminated reagents, improperly cleaned laboratory equipment, or persistent contamination due to presence of certain compounds in the ambient laboratory air). A reagent blank will be analyzed at least once per batch for each method utilized by the laboratory for that day.

5.5 Laboratory Instrument Calibration

Calibration and maintenance of analytical instruments are required to ensure that the analytical system is operating correctly and functioning at the proper sensitivity to meet the specified data quality objectives. Each instrument is calibrated with standard solutions or gases appropriate to the type of instrument and the range established for the analytical method.

Maintenance, tuning, calibration and standardization procedures for laboratory instruments will generally follow the frequency and procedures established by the USEPA for Solid Waste 846 Methods (USEPA 1993). Each laboratory will also follow manufacturer's recommended guidelines for maintenance. Detailed records will be maintained in a dedicated logbook for each piece of laboratory equipment.

Certified standard materials will be used for instrument calibrations. Standards used in this program will be prepared and maintained under the normal laboratory standards tracking system, which ensures preparation, checking, documentation, storage, and disposal of standards according to method specified procedures and schedules.

6.0 DATA MANAGEMENT, VALIDATION AND REPORTING

6.1 Field Data Management

JJ&A field personnel will log all field measurements, observations, and field instrument calibrations on field forms provided in Appendix A of the RIFS Workplan (JJ&A and Formations, 2019). Field notebook and field form entries will be dated and signed. Entries will be legible and contain accurate and inclusive documentation of an individual's project activities. Only field observations and data obtained in the field will be posted to the field notebook and/or field form(s).

6.2 Laboratory and Analytical Data Management

A qualified analytical laboratory will perform in-house analytical data reduction and review of chemical analyses under the direction of each laboratory technical staff, QA Officer, and Project Manager for this project. These individuals are responsible for assessing data quality and advising JJ&A of any data which may be rated "preliminary" or "unacceptable" or other notations which would caution the data user of possible unreliability. A case narrative prepared by the analytical laboratory assessing data quality will be submitted to the laboratory Project Manager or designee with every data package prior to transmittal to the client.

The data set report will include laboratory reports and associated data deliverables. Each laboratory report will include, at a minimum, the following information:

- Laboratory ID number;
- Site ID number;
- Sample ID number;
- Date sampled;
- Date analyzed;
- Parameters measured;
- Units in which each parameter is reported;
- Reported estimated value for each parameter detected but below the method reporting limit;
- Analytical methods used; and
- Reporting limits.

The associated data deliverables will include the following:

- Cover sheet listing the samples included in the report and narrative comments describing problems encountered during analysis;
- Copies of signed chain-of-custody records;

- Analytical results for laboratory matrix spike/matrix spike duplicates, laboratory matrix spikes, laboratory duplicates, laboratory control samples, method blanks and surrogate recoveries, with the laboratory control limits listed for each QA/QC sample as applicable for each analytical method; and
- Initial calibration and continuing calibration summaries for each analytical method, including continuing calibration verification results.

Complete data reduction and report procedures will be those specified by each laboratory Quality Assurance/Quality Control Plan.

Each analytical laboratory will prepare and retain full analytical and QC documentation for a minimum of five years. Samples and/or sample extracts will be retained for 30 days after issuance of the final data package, unless otherwise notified.

6.3 Data Validation

Analytical data will be validated by a qualified third party data validation professional. Data validation will include a review of analytical data and associated data deliverables. The data will be evaluated for compliance with the QA objectives, the QC control limits provided by a qualified analytical laboratory for the analytical method, and the QC procedures specified in the methodology. Data validation will also include summarizing deviations and its impact on data quality as described below.

6.3.1 Data Qualifiers

Data validation flags are applied to those sample results that fall outside of specified tolerance limits and, therefore, did not meet the project DQOs. Data validation flags to be used for this project are defined in the National Functional Guidelines (USEPA, 2017a and 2017b). Data validation flags will indicate whether results are considered anomalous, estimated, or rejected. Only rejected data are considered unusable for decision-making purposes.

6.4 Data Reporting

Following completion of fieldwork and the analytical program, a Remedial Investigation report will be prepared. The report will include supporting field forms and documentation, laboratory analytical reports, reviewed QC information, tabulated validated data, and data evaluation. The data will be entered in the project database and uploaded to the Geotracker/GAMA system as described in the Grant Agreement.

7.0 SAMPLING PROCEDURES

Collection of environmental samples of high integrity is important to the quality of chemical data to be generated. To this end, field procedures have been developed as general descriptions of field methods that will be employed at various locations during sampling events. Groundwater samples will be collected from monitoring wells and supply wells as described below. Samples will be collected by staff properly trained and qualified for the task.

7.1 Sampling Monitoring Wells

Monitoring wells will be sampled using low flow methods. Field parameters will be measured and recorded on the Groundwater Monitoring Well Field Sampling Form provided as Appendix A in the RIFS Workplan (JJ&A and Formations, 2019) periodically during purging and at the time of sampling.

For every sample collected, the following water quality parameters will be measured during purging activities in the field:

- Electrical Conductivity;
- Oxidation-Reduction Potential;
- Dissolved Oxygen;
- pH;
- Temperature; and,
- Turbidity.

The wells will be purged until water-quality parameters stabilize. Parameters will be considered stable when, for at least three consecutive measurements, the pH remains constant within 0.1 Standard Unit and the specific conductance varies no more than approximately five percent (5%). The final set of water quality measurements (obtained at the completion of purging activities) will be considered representative of the samples collected and submitted to the laboratory. A monitoring well sampling matrix is provided in Table 4-2 of RIFS Workplan Appendix A (JJ&A and Formations, 2019), and Standard Operating Procedure (SOP) for groundwater sampling is provided as Appendix A in the RIFS Workplan [JJ&A and Formations, 2019]).

7.2 Sampling Supply Wells

This section describes the procedures that will be followed to collect groundwater samples from City supply wells. If a well is not in operation, a City engineer will turn on the well pump. The pump will be allowed to run for at least 10 minutes prior to sample collection. A discharge tube will be connected to a sampling valve near the wellhead and water will be allowed to run through the sampling tube and a flow-through cell into a bucket during the purging process. Field parameters will be measured and recorded on the Groundwater Monitoring Well Field Sampling Form (Appendix A in the RIFS Workplan [JJ&A and Formations, 2019])

periodically during purging and at the time of sampling. A supply well sampling matrix is included in Table 4-2 of Appendix A in the RIFS Workplan (JJ&A and Formations, 2019).

For every sample collected, the following water quality parameters will be measured during purging activities in the field:

- Electrical Conductivity;
- Oxidation-Reduction Potential;
- Dissolved Oxygen;
- pH;
- Temperature; and
- Turbidity.

The wells will be purged until water-quality parameters stabilize. Parameters will be considered stable when, for at least three consecutive measurements, the pH remains constant within 0.1 Standard Unit and the specific conductance varies no more than approximately five percent (5%). The final set of water quality measurements (obtained at the completion of purging activities) will be considered representative of the samples collected and submitted to the laboratory.

Samples will be collected from the discharge line directly into laboratory-supplied containers. Prior to being placed into sample containers, samples for analysis of metals will be filtered in the field using disposable 0.45-micron filters. Samples will be labeled and immediately placed on ice (water based) in an insulated cooler and submitted under chain-of-custody control to a California State certified laboratory.

7.3 Concentration Profiling

JJ&A will oversee the collection of well hydraulic and contaminant concentration data at vertically-spaced intervals along the screen/perforated intervals of approximately six public supply study wells in the study areas under dynamic (pumping) and ambient (non-pumping) conditions. This includes select public supply study wells that have not previously been profiled, and additional wells selected in consultation with the City and the Technical Advisory Committee. Flow and concentration profiling will be performed by BESST Inc. (BESST). BESST provides groundwater quality and monitoring solutions using miniaturized hydraulic profiling and sampling technologies. Water quality profiling will be conducted under dynamic conditions, and flow profiling will be performed under static and dynamic conditions.

Vertically-integrated water quality sampling will be performed using BESST HydroBooster or Panacea Pump Technology to collect samples at select intervals, including the following steps:

- Sampling will be conducted at the same time as flow profiling using a system that bundles the injection and a miniaturized sampling pump to collect samples from select depth intervals in the well; and,

- Purge water and decontamination wash water will be placed into an existing on-site purge water tank.

For every sample collected, the following water quality parameters will be measured using water quality sensors in a flow-through cell:

- Electrical conductivity;
- Oxidation-reduction potential;
- Dissolved oxygen;
- pH;
- Temperature; and,
- Turbidity.

Field parameters will be measured and recorded on the Groundwater Monitoring Well Field Sampling Form periodically during purging and at the time of sampling. The sampling lines will be purged until water-quality parameters stabilize. Parameters will be considered stable when, for at least three consecutive measurements, the pH remains constant within 0.1 Standard Unit and the specific conductance varies no more than approximately five percent (5%). The evaluation of parameter stabilization may be modified if sample volume is limited, as needed. The final set of water quality measurements (obtained at the completion of purging activities) will be considered representative of the samples collected and submitted to the laboratory. A vertical profiling sampling matrix is included in Table 5-1 of the RIFS Workplan Appendix A (JJ&A and Formations, 2019).

7.4 Sample Collection and Analysis

Groundwater samples will be collected from the discharge line directly into laboratory-supplied containers. Prior to being placed into sample containers, samples for analysis of metals will be filtered in the field using disposable 0.45-micron filters. Samples will be labeled and immediately placed on ice (water based) in an insulated cooler and submitted under chain-of-custody control to a California State certified laboratory.

Anticipated analyses are listed below, though not all samples may be subjected to the entire list of analyses. Analytical methods, preservatives, and holding times are summarized on Table 4-1 of Appendix A in the RIFS Workplan (JJ&A and Formations, 2019).

- Anions: sulfate, chloride, bromide, and fluoride by USEPA Method 300.0;
- Cations: calcium, iron, magnesium, manganese, sodium, potassium, aluminum, boron, strontium, and orthophosphate/dissolved phosphorus by USEPA Method 200.7;
- Total Kjeldahl nitrogen by USEPA Method 351.2 (10% of samples);
- Total alkalinity (as calcium carbonate) with bicarbonate and carbonate by SM 2320B;
- Title 22 metals by USEPA Method 6010B;
- Dissolved arsenic, manganese, and iron by USEPA Method 6020;

- Dissolved uranium by USEPA Method 200.8;
- Chromium VI by USEPA Method 7196A;
- Nitrate by USEPA Method 353.3 or 353.2;
- TDS by SM 2540C;
- Specific conductance by SM 2510B; and,
- Dissolved organic carbon and total organic carbon by SM 5310.

Chemical analyses will be performed by a laboratory certified by the California Department of Health Services and the National Environmental Laboratory Accreditation Program. The BESST SOP for depth-dependent groundwater sampling is provided as Appendix A in the RIFS Workplan [JJ&A and Formations, 2019]).

7.5 Sampling Containers, Preservatives, and Holding Times

Table 4-1 of Appendix A in the RIFS Workplan (JJ&A and Formations, 2019) lists the required sample containers, preservatives, and holding times for samples. Sample containers will be provided by the laboratory.

7.6 Sample Identification

Samples collected during the groundwater sampling will be given unique identification numbers based on an alpha-numeric code that describes the type and location of each sample as follows:

A-B-C

Where:

- A = Sample type (W for well, MW for monitoring well; FB for field blank).
- B = Sample location (can contain multiple characters).
- C = Test code (A for primary, B for duplicate, AF for primary – field filtered, BF for duplicate – field filtered, EB for equipment blank).

Identifications for several hypothetical samples are listed below:

- W-MOD025-A = Primary water sample from sample location MOD025
- MW-OFPB-2-BF = Duplicate sample collected from sample location OFPB-2
- SM-03012019-EB = Equipment blank sample collected from a slope meter on March 1, 2019

7.7 Sample Handling and Storage

Water samples will be collected for laboratory analyses in the appropriate container based on the required analysis, as specified in Table 4-1 in Appendix A of the RIFS Workplan (JJ&A and Formations, 2019). Containers will be labeled with the sample identification number, date, and time using waterproof labels and indelible ink. Sample containers will be wiped clean and securely packed in a cooler on ice for transport under standard chain-of-custody protocols.

8.0 SAMPLE CUSTODY PROCEDURES

A sample is the physical evidence collected from a site or the environment. Custody and tracking of the evidence collected shall be controlled by using the procedures presented in this section.

A sample is under custody if it is:

- In the actual physical possession of field personnel or custodian;
- In the view of the field personnel or custodian;
- In a locked area; or
- In a designated, secure storage area.

Each set of sample coolers collected and delivered or shipped to an analytical laboratory will be accompanied by a chain-of-custody (COC) record. The primary purpose of the COC procedure is to document the possession of the samples from collection through storage and analysis to the reporting. COC forms become the permanent record of all sample handling and shipping.

8.1 Field Custody Procedures

The field team is responsible for the care and custody of the samples collected until the samples are transferred to another party, dispatched to a laboratory or disposed. The COC procedures are provided below:

- Prior to sample packaging and shipment, the COC form is completed for the sample collected.
- When the COC is complete or when all samples have been collected, the field team will provide a copy of the COC to the field QA/QC sample manager. The field QA/QC sample manager will check the COC for possible errors. Corrections are made to the record with a single strike mark, initialed, and dated.

When transferring custody of the samples, the individuals relinquishing and receiving custody of the sample shipping container will document the sample shipping container transfer by signing and dating the COC. This process documents sample custody transfer from the sampler, sometimes through an express courier, to the sample custodian in the contracted analytical laboratory. The COC will reflect transfer of the shipping container to the analytical laboratory. If an express courier is used, the bill of lading will serve the purpose of the COC until the shipping container is received by the laboratory.

When multipart COCs are used, a copy of each COC is retained by the sampling team for the project file and the original is sent with the samples. In conjunction with data reporting, the analytical laboratory will return the signed COC or a copy of the signed COC to the Project Manager for inclusion into the central project file.

8.2 Packaging and Shipping Protocol

Shipping procedures will comply with Department of Transportation (DOT) requirements. All samples will be classified as environmental. The following packaging and shipping procedures will be implemented during field investigations:

- Sample containers will be wrapped and packaged to prevent breakage;
- Samples will be packed in ice, if necessary, for shipping;
- The COC documentation will be securely sealed in the shipping container with the samples;
- Coolers being shipped will be properly marked for shipping; and
- A custody seal will be placed on the cooler in a manner to indicate if tampering occurs during shipment and/or delivery.

8.3 Laboratory Custody Procedures

Samples delivered to the approved laboratory will be accepted by the laboratory sample custodian or an appropriate designee during laboratory operating hours, or at alternate times as arranged in advance by the Team Leader. The laboratory sample custodian will be responsible for maintaining custody of the samples and all associated paperwork documenting custody. Laboratory sample management will be initiated using the following sequence of events:

- The carrier and the time of arrival will be documented in the daily receipt log. The number of items on the air bill will be checked with the actual number received to ensure that all coolers arrived;
- Notation will be made as to whether the sample cooler was sealed;
- The cooler will be opened, the internal ambient temperature of the cooler taken and noted on the COC, and the samples itemized. All deviations from the COC form will be noted and reported to the Laboratory QA Manager;
- Samples will be assigned a unique sample laboratory identification number. The laboratory identification number and corresponding field identification number will be logged into a laboratory custody log;
- Once the samples have been transmitted into the laboratory, the following sequence of events will occur;
- The samples will be recorded on the Sample Log-in Form to summarize all the information pertaining to the sample/order and to instruct the laboratory on the proper analysis and reporting of samples;
- After the samples are logged in, they will be assigned to the appropriate secured storage area or refrigerator;

- The laboratory sample custodian will be responsible for ensuring that all transfers of samples into and out of storage will be documented in the sample custody log. The laboratory project coordinator, or appropriate designee, will be responsible for reviewing the sample custody log to ensure that appropriate sample custody procedures have been maintained;
- Samples will remain in secured storage until removed for analysis. Whenever samples are removed for analysis, the names of the individuals who receive the samples will be entered in the sample custody log by the laboratory sample custodian, including the date and time the transfer occurred; and
- To ensure refrigerators are operating at the appropriate temperature, a refrigeration log will be maintained. Refrigerator temperature will be checked daily, seven days per week. The log will indicate the ambient internal temperatures as well as the initials of the person recording the reading and the date. Should the temperature fluctuate outside of the specified temperature range, corrective action will be taken immediately.

9.0 PREVENTIVE MAINTENANCE

To ensure that analytical data generated for the project are reliable, all laboratory equipment and instruments will have a prescribed routine maintenance schedule in addition to a calibration schedule. Preventive maintenance for field instruments will be performed and documented by qualified project personnel.

9.1 Laboratory Maintenance

The qualified analytical laboratory is responsible for the maintenance of its laboratory equipment. Preventive maintenance is completed on a scheduled basis to minimize down time and the potential interruption of analytical work. All instruments will be maintained in accordance with the manufacturer's recommendations, normal approved laboratory practice, and any procedures listed in analytical methodology.

9.2 Field Maintenance

All field instrumentation, sampling equipment and accessories will be maintained in accordance with the manufacturer's recommendations and specifications and established field practice. Lists of field equipment that may be used during the investigations and general maintenance requirements are presented in the MRP.

Equipment that becomes questionable or inoperable during use will be removed from service. Such equipment may be repaired and recalibrated to approved QC standards by the team leader or qualified personnel, as appropriate. Equipment that cannot be repaired will be replaced.

A preventive maintenance plan allows for periodic instrument checks for problems that occur frequently. The objective of a preventive maintenance plan is to rectify equipment problems before they become serious. Preventive maintenance also brings attention to those areas of the instrument susceptible to degradation from aging, toxic/corrosive effects, and malfunction due to environmental factors.

Procedures for preventive maintenance are contained in each instrument's manual under the maintenance/troubleshooting sections. Each piece of equipment will have an associated SOP detailing the calibration/maintenance instructions.

All field equipment will be calibrated according to the manufacturer's schedule, or at a minimum, prior to use in the field. A calibration record for each instrument will be maintained by the Field Manager. Equipment failing calibration specifications will be identified with a red warning label and will not be used for sample analysis.

Equipment requiring calibration will have an assigned record number that is permanently affixed to the instrument. A label will be affixed to each instrument and a record containing the following information will be kept with the equipment:

- Description;
- Manufacturer;

- Model number;
- Serial number;
- Date of last calibration or maintenance;
- Name of person who performed calibration or maintenance; and
- Date of next servicing.

Should the selected subcontractor or laboratory have a more stringent preventive maintenance plan, then the Laboratory QA Manager or the Site Project Manager may approve the use of such plans.

10.0 CORRECTIVE ACTION MEASURES

When errors, deficiencies, or out-of-control situations exist, the QA program provides systematic procedures, called corrective actions, to resolve problems and restore proper functioning to the sampling and/or analytical system

10.1 Field Corrective Action

The Field Manager will review the procedures being implemented in the field for consistency with the established protocols. Sample collection, preservation, documentation, labeling and shipping will be checked for accuracy and completeness.

10.2 Laboratory Corrective Action

The laboratory's Operations Manager or his/her designee will review the data generated to ensure that all quality control samples have been run as specified in the protocol. This review will include calibration procedures, frequency, and results. Instrument maintenance logs also may be checked. Recoveries of laboratory control samples and matrix spike samples will be checked for consistency with method accuracy and precision. Where QC sample results fall outside the acceptable ranges, deficiencies will be reported to the JJ&A Project Manager. Once resolved, full documentation of the corrective action procedure will be documented by the laboratory and provided to the JJ&A Project Manager for inclusion in the project file.

11.0 REFERENCES

American Public Health Association (APHA), 2006. *Standard Methods for the Analysis of Water and Wastewater*.

American Public Health Association (APHA), 2017. *Standard Methods for the Analysis of Water and Wastewater, 23rd Edition*.

California State Water Resources Control Board, 2018. *Proposition 1 Groundwater Planning Grant Agreement No. D1712514 between the City of Modesto and the SWRCB*, November 30.

USEPA, 1983. *Methods for Chemical Analysis of Water and Wastes*. USEPA 600/4-79-020.

USEPA, 1993. *Test Methods for Evaluating Solid Waste: Physical/Chemical Methods*. EPA Publication SW-846, Third Edition, Final Updates I (1993), II (1995), IIA (1994), IIB (1995), III (1997), IIIA (1999), IIIB (2005), IV (2008), and V (2015).

USEPA, 1994. *Guidance for the Data Quality Objective Process*.

USEPA, 2001. *USEPA Requirements for Quality Assurance Project Plans*, USEPA QA/R-5. March.

USEPA, 2002. *Guidance for Quality Assurance Project Plans*, USEPA QA/G-5. December.

USEPA, 2006. *Guidance on Systematic Planning Using the Data Quality Objectives Process*, USEPA QA/G-4. February.

USEPA, 2017a. *National Functional Guidelines for Inorganic Superfund Methods Data Review*. USEPA 540-R-2017-001. January.

USEPA, 2017b. *National Functional Guidelines for Organic Superfund Methods Data Review*. USEPA 540-R-2017-002. January.