SANITATION DISTRICTS OF LOS ANGELES COUNTY

FINAL

Project Report

Montebello Forebay Attenuation and Dilution Studies

Los Angeles County
California

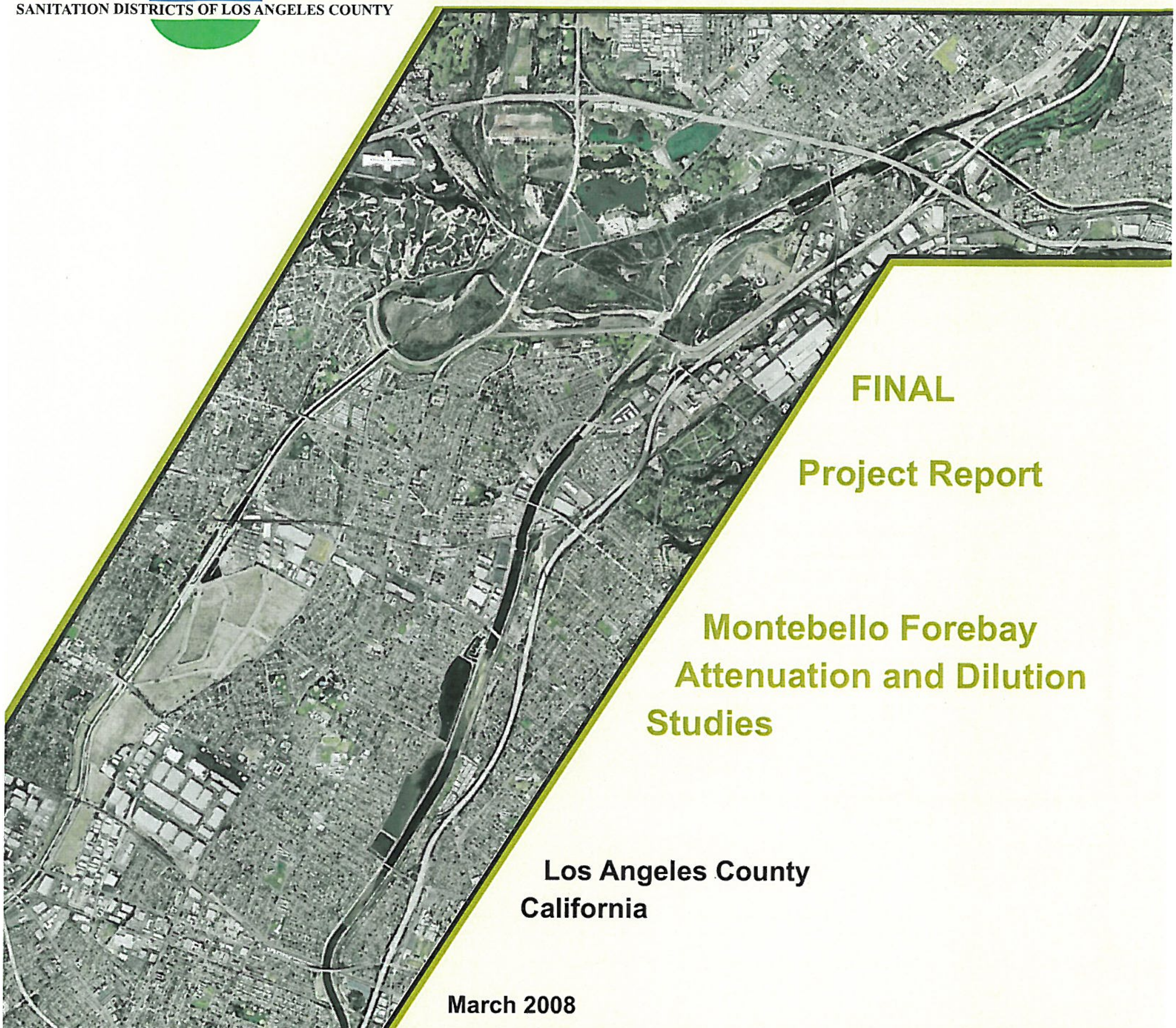
March 2008

Prepared by:

Kennedy/Jenks/Todd LLC
Emeryville, California

Lawrence Berkeley National Laboratory
Berkeley, California

SANITATION DISTRICTS OF LOS ANGELES COUNTY



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County Sanitation Districts of Los Angeles County
Whittier, California

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for

Montebello Forebay
Attenuation and Dilution Studies

Los Angeles County, California

March 2008

Prepared by:

Lawrence Berkeley National Laboratory
Earth Sciences Division
One Cyclotron Rd.
University of California
Berkeley, California 94720

Kennedy/Jenks/Todd LLC
2200 Powell St., Suite 225
Emeryville, California 94608
Ph: 510/595-2120
Fax: 510/595-2112
www.kenndeyjenkstodd.com

Montebello Forebay Attenuation and Dilution Studies

This report was prepared by the staff of Kennedy/Jenks/Todd LLC and Lawrence Berkeley National Laboratory under the supervision of professionals whose signatures appear hereon. The findings or professional opinions were prepared in accordance with generally accepted professional engineering and geologic practice.

CERTIFIED HYDROGEOLOGIST
SALLY McCRAVEN
No. 356
Exp. 12/31/08
STATE OF CALIFORNIA

PROFESSIONAL GEOLOGIST
CHARLES (RUS) PURCELL
No. 4091
STATE OF CALIFORNIA

Sally McCraven, P.G., C.E.G., C.Hg.
Project Manager and Senior Hydrogeologist

Rus Purcell, P.G.
Senior Geologist

Quanlin Zhou, Ph.D.
Senior Modeler and Geological Scientist

Julio Garcia, Ph.D.
Senior Modeler/Hydrogeologist

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List of Acronyms	
AF	acre-foot
AFY	acre-foot per year
API RP	American Petroleum Institute Recommended Practices
ASTM	American Society for Testing and Materials
ATFs	attenuation factors
ATSDR	Agency for Toxic Substances and Disease Registry
avg	average
AWWARF	American Water Works Association Research Foundation
bgs	below ground surface
Bookman-Edmonston	Bookman-Edmonston Engineering, Incorporated
CARB	California Air Resources Board
CBMWD	Central Basin Municipal Water District
CDM	Camp, Dresser, and McKee, Incorporated
cfs	cubic feet per second
CIMIS	California Irrigation Management Information System
cm/s	centimeters per second
CTECH	C Tech Development Corporation
DHS	California Department of Health Services
DMA	dimethylamine
DPH	California Department of Public Health
DWR	California Department of Water Resources
ETIC	ETIC Engineering, Incorporated
ETo	evapotranspiration
EVS	Earth Visualization Software™
ft/d	feet per day
ft/s	feet per second
ft/yr	feet per year
ft^2/d	feet squared per day
FWPP	Revised Final Field Work Project Plan
GeoSyntec	GeoSyntec Consultants
Geosystem	Geosystem Consultants, Incorporated
gpm	gallons per minute
GWAM	Groundwater Augmentation Model
ILO	International Labor Organization
in/yr	inches per year
K/J/Todd	Kennedy/Jenks/Todd, LLC
K_H	Henry's Law Constant
km	kilometer
Koc	organic-carbon to water partition coefficient
Kow	octanol water partition coefficient
LACDPH	Los Angeles County Department of Public Health
LACDPW	Los Angeles County Department of Public Works
Layne	Layne Christensen, Incorporated
LBNL	Earnest Orlando Lawrence Berkeley National Laboratory
LLC	Limited Liability Corporation
m	meter

List of Acronyms	
m/m	vertical meters per horizontal meters
m/s	meters per second
m^2	square meters
m^3/s	cubic meters per second
MCL	Maximum Contaminant Level
meq/L	milli-equivalents per liter
mg/L	milligrams per liter
mL/g	milliliters per gram
ml/min	milliliters per minute
MGD	million gallons per day
MRP	Monitoring and Reporting Program
MSGBW	Main San Gabriel Basin Watermaster
MSL	mean sea level
MWD	Metropolitan Water District of Southern California
N	nitrogen
NDMA	N-nitrosodimethylamine
NDN	nitrification-denitrification
ng/L	nanograms per liter
NL	Notification Level
nm	nanometers
NO	nitrogen oxide
NO_2^-	nitrite
NOAA	National Oceanic & Atmospheric Administration (US)
NPDES	National Pollution Discharge Elimination System
NPL	National Priorities List
OCWD	Orange County Water District
OEHHA	California Office of Environmental Health Hazard Assessment
OU	Operable Unit
P2	Well Pico 2
RFP	request for proposal
PCE	tetrachloroethylene
PG	professional geologist
PRPs	potentially responsible parties
PSI	pounds per square inch
RH1	Well Rio Hondo 1
RHSG	Rio Hondo Spreading Grounds
RWQCB	Regional Water Quality Control Board, Los Angeles Region
Sanitation Districts	County Sanitation Districts of Los Angeles County
SAP	Revised Final Sampling and Analysis Plan
SAT	Soil Aquifer Treatment
SF_6	sulfur hexafluoride
SGSG	San Gabriel Spreading Grounds
SJC	San Jose Creek
SJCE	San Jose Creek East Water Reclamation Plant
SJCW	San Jose Creek West Water Reclamation Plant
SRC	Syracuse Research Corporation

List of Acronyms	
SWAT	Soil and Water Uptake Tool
TCE	Trichloroethylene
TDS	total dissolved solids
THM	trihalomethane
UDMH	unsymmetrical dimethylhydrazine
ug/L	microgram per liter
USBR	United States Bureau of Reclamation
USCOE	United States Army Corps of Engineers
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
UV	Ultraviolet
VOCs	volatile organic compounds
WASP	Water Quality Analysis Simulation Program
WateReuse	WateReuse Foundation
Watershed Council	Los Angeles and San Gabriel Rivers Watershed Council
WHO	World Health Organization
WN	Whittier Narrows Water Reclamation Plant
WRD	Water Replenishment District of Southern California
WRP	Water Reclamation Plant
$(CH_3)_2N\bullet$	dimethylamino radical
1/d	first order decay rate constants
^{11}B	boron-11
^{124}Xe	xenon-124
^{136}Xe	xenon-136

Executive Summary

The County Sanitation Districts of Los Angeles County's Joint Outfall System[1] (Sanitation Districts) operate three water reclamation plants (WRPs) that provide recycled water for active recharge at the Rio Hondo and San Gabriel spreading grounds and incidental recharge within unlined reaches of the San Jose Creek, Rio Hondo, San Gabriel River, and Zone 1 Ditch (see Figure 1-1). The San Jose Creek and Whittier Narrows WRPs provide the majority of the water; some small contributions are provided by the Pomona WRP. While recycled water released from the WRPs is highly treated, it does contain constituents that may affect water beneficial uses if concentrations are above certain thresholds. A constituent found in the WRPs effluent, N-nitrosodimethylamine (NDMA), is both created and destroyed as a result of wastewater treatment processes. While there is currently no enforceable drinking water standard for NDMA, the California Department of Public Health (DPH) has established a Notification Level (NL) of 10 nanograms per liter (ng/L) for NDMA in drinking water. NLs are health-based advisory levels established by DPH for chemicals in drinking water that lack Maximum Contaminant Levels (MCLs). If a chemical is detected above its NL, certain notification requirements and recommendations apply to drinking water purveyors.

Testing of effluent for NDMA with a sensitive analytical method beginning in 2000 found concentrations typically at the hundreds of ng/L level. Monitoring of shallow groundwater wells at the Rio Hondo and San Gabriel spreading grounds for NDMA was also initiated in 2000 and NDMA was typically not detected (2 ng/L reporting limit), indicating that at the observed effluent concentrations, NDMA was being attenuated and diluted to below detectable levels in groundwater near the spreading grounds.

To achieve compliance with ammonia Basin Plan objectives (RWQCB, June 1994), beginning in 1995, the Sanitation Districts initiated a research, design, and construction program to convert the WRPs to activated sludge nitrification-denitrification (NDN). Although the chemistry is not fully understood, WRP monitoring data indicate that NDMA levels in effluent increased after full implementation of NDN treatment. This implementation was completed by 2003 at the WRPs. Effluent NDMA concentrations after NDN implementation were typically in the range of one thousand to several thousand ng/L at the San Jose Creek WRP. At these higher effluent concentrations, NDMA was initially detected above the NL in shallow monitoring wells at the spreading grounds. Once the higher NMDA concentrations at the spreading grounds were discovered, the Sanitation Districts ceased direct deliveries of recycled water to the spreading grounds via the San Jose Creek WRP outfall pipeline and instead began delivering recycled water only via surface flows, to take advantage of photolysis of NDMA during travel. This regime was implemented in mid-2004.

The Montebello Forebay Attenuation and Dilution Studies were undertaken in 2004 to address the initial high NDMA concentrations found in the spreading grounds following conversion of the WRPs to NDN treatment. As part of this investigation, a monitoring well network near the WRP effluent discharge locations upstream of the spreading grounds was established and monitored for low-level NDMA. Results of the testing found elevated levels of NDMA in groundwater immediately downgradient of the San Jose Creek and Whittier Narrows WRPs' effluent

[1]Ownership and operation of the Joint Outfall System is proportionally shared among the signatory parties to the amended Joint Outfall Agreement effective July 1, 1995. These parties include County Sanitation Districts of Los Angeles County Nos. 1, 2, 3, 5, 8, 15, 16,17, 18, 19, 21, 22, 23, 28, 29, and 34, and South Bay Cities Sanitation District of Los Angeles County.

discharge locations. Additionally, the testing indicated that ceasing direct deliveries of recycled water to the spreading grounds had resulted in substantial reductions of subsurface NDMA concentrations at the spreading grounds. Therefore, NDMA concentrations at the spreading grounds were no longer at levels of concern. These results changed the focus of this investigation from the spreading grounds to the upstream areas closer to the effluent discharge locations for the San Jose Creek and Whittier Narrows WRPs.

Following the observed increase in NDMA levels after NDN implementation, the Sanitation Districts began evaluating various treatment system modifications to address NDMA. One such modification is called sequential chlorination whereby wastewater is exposed briefly to free chlorine to destroy NDMA precursors prior to chloramination. Sequential chlorination was implemented at the San Jose Creek and Whittier Narrows WRPs in late 2006 and early 2007. The process reduced effluent NDMA levels at the WRPs, in some cases by as much as an order of magnitude. NDMA levels in effluent are currently at levels in the low hundreds of ng/L.

While the intensive monitoring program conducted during this investigation was scheduled to be terminated in December 2006, sampling continued in a subset of wells into 2007 to evaluate changes in groundwater quality resulting from lower effluent NDMA levels. These recent data show NDMA levels in groundwater have declined significantly and quickly in response to lower NDMA levels in effluent. The Sanitation Districts are currently implementing ultraviolet (UV) treatment at the Whittier Narrows WRP and evaluating the need for UV treatment of effluent at the other WRPs, which, if implemented, would be anticipated to further reduce NDMA levels from current levels.

The Montebello Forebay Attenuation and Dilution Studies were conducted to evaluate the fate and transport of NDMA from the WRP effluent discharge locations to groundwater. For that purpose, a combination of extensive field monitoring of NDMA concentrations and flow conditions and numerical modeling of NDMA transport in the coupled surface water and groundwater system were employed.

The project was based on compilation and review of available literature and data regarding the hydraulics of the surface water system, hydrogeologic conditions in the subsurface, and water quality in the Study Area, as well as NDMA fate and transport processes. The scientific literature indicates that NDMA is removed from surface water by photolysis from exposure to sunlight and can also be removed during transport through the vadose zone and in groundwater by biodegradation. The rate of biodegradation is dependent on the concentration of NDMA in the recharge water, the existence of an adapted biocommunity, and the aerobic and anerobic conditions for microbial degradation. While biodegradation under unsaturated and saturated conditions has been previously demonstrated only through laboratory experiments, these experimental results can be applied to the field characterization of NDMA fate and transport in the unsaturated and saturated groundwater in the Study Area.

Building on review and assessment of the existing data and literature, data gaps were identified and extensive field monitoring was performed. The field monitoring program included installation and testing of shallow borings and monitoring wells, synoptic surface water gauging, and collection of water quality data from a comprehensive network of surface water stations and wells.

Analysis of surface water quality data compiled and collected during this investigation showed that NDMA is significantly attenuated in surface water as it travels downstream from the WRP discharge locations. Removal of NDMA in surface water is judged to be due primarily to photolytic degradation from exposure to sunlight. NDMA in effluent from the Pomona WRP is significantly attenuated as it travels down the lined San Jose Creek, to the extent that no appreciable amount of NDMA reaches downstream unlined river reaches from this plant. Photolysis of NDMA may play a more significant role in the San Gabriel River when water is blocked by hydraulic structures (e.g., dams and rubber dams), leading to longer residence times for photolysis. The significant concentration reduction in NDMA along the pathway from the spreading ground intakes to shallow monitoring wells near the spreading grounds may also be attributed to NDMA photolysis because NDMA concentrations higher than 10 ng/L are rarely detected in groundwater and a long residence time is seen in recharge basins. Dilution with imported and storm water also contribute to reductions in observed surface water concentrations, particularly in the wet season.

While photolysis in the surface water system helps to significantly reduce NDMA concentrations in recharge water, biodegradation plays the key role in attenuating NDMA mass and concentration in the vadose zone and groundwater. While biodegradation in the vadose zone was difficult to quantify based on the observed data, biodegradation in groundwater was clearly demonstrated by: 1) a regional comparison of the mass of NDMA in recharge water and the mass of NDMA in groundwater, and 2) a local mass budget comparison of NDMA in effluent from a discrete release at Effluent Discharge Location WN004 and NDMA in groundwater based on nearby monitoring and production wells. In the first instance, the evidence relies on the fact that the estimated NDMA mass in groundwater changes significantly with time and that the NDMA groundwater mass is much smaller than the NDMA mass entering groundwater through recharge water. In the second instance, the combined NDMA mass in remediation extraction water and groundwater compared with the NDMA mass released during a discrete period of discharge at Effluent Discharge Location WN004 indicates significant NDMA mass is biodegraded. As a result, it is judged that NDMA in groundwater along the rivers near the San Jose Creek and Whittier Narrows WRPs effluent discharge locations can be naturally attenuated with time by biodegradation.

In the Study Area, NDMA in groundwater appears to occur primarily in the upper 200 feet below ground surface (bgs). As a result, most production wells, which are typically screened at greater depths, have not detected NDMA. Nonetheless, NDMA was detected at low levels in a few production wells in the Study Area and was detected once above 10 ng/L in a production well used for domestic supply. The higher concentration at this well was reduced to below 10 ng/L by blending. This lone production well detection above 10 ng/L occurred in 2004 and no NDMA concentrations greater than 10 ng/L have occurred since. Recent production data for wells located near effluent discharge locations show that NDMA has dropped to non-detectable levels following implementation of sequential chlorination at the San Jose Creek and Whittier Narrows WRPs. Based on the quick reductions in NDMA observed in groundwater following implementation of sequential chlorination, it is anticipated that NDMA detected in production wells located further from the effluent discharge locations will also show declining trends in the future as the lower level NDMA recharge water moves through the groundwater system and biodegradation continues.

Additionally, a surface water and groundwater flow and transport model was developed and calibrated to simulate the fate and transport of NDMA and predict future surface water and groundwater concentrations resulting from the lower NDMA effluent concentrations achieved with sequential chlorination, and the even lower NDMA effluent concentrations that may be achieved if UV treatment were implemented in the future at the WRPs. The surface water and groundwater flow and transport model was calibrated using observed groundwater levels, NDMA concentrations, and time-concentration data at a number of key wells. A good match between simulated and observed water levels and NDMA concentrations was achieved. More specifically, the groundwater transport model accurately captured the significant and rapid drop in NDMA groundwater concentrations following the implementation of sequential chlorination.

Model predictions indicate that at the lower NDMA effluent levels now being achieved at the San Jose Creek and Whittier Narrows WRPs, NDMA impacts to groundwater at levels above 10 ng/L will be limited to a narrow shallow band beneath the unlined reaches of the rivers near the two WRPs. Model predictions find that at the lower NDMA effluent concentrations expected with UV treatment, NDMA would still occur at concentrations above 10 ng/L in shallow groundwater immediately beneath the unlined portions of the rivers near the WRPs.

The model has shown that groundwater conditions are rapidly changing and have drastically improved following implementation of sequential chlorination. However, due to the thin vadose zone and limited opportunity for biodegradation prior to reaching groundwater, impacts to a small volume of groundwater are unavoidable. In addition to the Sanitation Districts' commitment to continue operating sequential chlorination at the San Jose Creek and Pomona WRPs and installation of UV treatment at the Whittier Narrows WRP, the Sanitation Districts are dedicated to continuing ongoing efforts to further reduce NDMA concentrations at the WRPs and in the groundwater.

Under the prediction scenarios, NDMA concentrations in groundwater are very limited in magnitude and extent with no predicted impacts to production wells currently located in the Study Area. In terms of impacts to potential new production wells, anyone seeking to drill a well in the area would have to have a water right, satisfy any obligations set by the groundwater basin's Watermaster, and obtain appropriate permits, including a water supply permit from DPH. For this type of situation, DPH would conduct an evaluation pursuant to Policy Memo 97-005, which would address treatment and risks associated with any contaminants present in order for the source to be used for drinking water.

Finally, based on the lack of NDMA detections in groundwater near the San Gabriel Spreading Grounds prior to NDN implementation, it appears that direct deliveries of recycled water to the spreading grounds do not cause unacceptable NDMA concentrations at the spreading grounds when NDMA concentrations in the San Jose Creek WRP effluent are at pre-NDN levels. Therefore, such direct deliveries can be reinstated now that NDMA levels have been decreased with implementation of sequential chlorination.

Section 1: Introduction

1.1 Background

The County Sanitation Districts of Los Angeles County (Sanitation Districts) operate three water reclamation plants (WRPs) that provide recycled water for active recharge at the Rio Hondo and San Gabriel spreading grounds and within unlined reaches of the Zone 1 Ditch, San Jose Creek, Rio Hondo, and San Gabriel River (see Figure 1-1). The WRPs are the Whittier Narrows, San Jose Creek, and Pomona WRPs. The San Jose Creek WRP includes two separate facilities: San Jose Creek East and San Jose Creek West. The San Jose Creek and Whittier Narrows WRPs provide the majority of water; some small contributions are provided by the Pomona WRP. Water recharged in the spreading grounds also includes storm water and water imported from the Metropolitan Water District of Southern California (MWD). The Study Area for the project included the southern portion of the Main San Gabriel Basin (where the San Jose Creek WRP is located), the Whittier Narrows (where the Whittier Narrows WRP is located), the Puente Subbasin and portions of the adjacent Upper Santa Ana Valley Basin (where the Pomona WRP is located), and the Montebello Forebay portion of the Central Basin (where the Rio Hondo and San Gabriel spreading grounds are located).

N-nitrosodimethylamine (NDMA) is both formed and degraded in wastewater treatment processes. The California Regional Water Quality Control Board, Los Angeles Region (RWQCB) issued new Waste Discharge Requirements (WDRs) and National Pollution Discharge Elimination System (NPDES) Orders for the San Jose Creek (East and West) and Pomona WRPs in 2004 (RWQCB, 2004a and 2004b). These orders include NDMA effluent limits based on California surface water objectives for the protection of human health, derived considering the pathway of human consumption of aquatic organisms. The daily maximum NDMA effluent limits for the San Jose Creek and Pomona WRPs were established at a level of 16,000 nanograms per liter (ng/L); the monthly average effluent limit was established at a level of 8,100 ng/L. These effluent limitations were based on the California Toxics Rule human health criteria for organisms only. A monthly average interim limit of 20,000 ng/L was established for the San Jose Creek WRP, which is in effect until May 10, 2009. No interim limit for NDMA was included for the Pomona WRP. No NDMA limits were included in the NPDES permit issued for the Whittier Narrows WRP in 2002.

The California Department of Public Health (DPH), formerly the California Department of Health Services (DHS), has established a Notification Level (NL) for NDMA that is currently set at 10 ng/L. NLs are health-based advisory levels for chemicals in drinking water, which have no established Maximum Contaminant Level (MCL). NLs are not enforceable standards, and are revised as needed by DPH, but do not go through a regulatory process. If a chemical is detected above its NL in a drinking water source, certain notification requirements and recommendations apply to drinking water purveyors.

For the San Jose Creek and Pomona WRPs permits, the RWQCB included re-opener provisions to reevaluate and possibly modify final effluent limits for NDMA, based on the results of studies conducted by the Sanitation Districts to protect the groundwater recharge beneficial use. This Montebello Forebay Attenuation and Dilution Studies project is intended to assess NDMA fate and transport in the environment from the effluent discharge locations to groundwater.

Testing of effluent for NDMA with a sensitive analytical method beginning in 2000 found concentrations typically at the hundreds of ng/L level. Monitoring of shallow groundwater wells at the Rio Hondo and San Gabriel spreading grounds was also initiated in 2000 and NDMA was typically not detected (2 ng/L reporting limit) indicating that at the observed effluent concentrations, NDMA was being attenuated and diluted to below detectable levels in groundwater near the spreading grounds.

To achieve compliance with ammonia Basin Plan objectives (RWQCB, June 1994), beginning in 1995, the Sanitation Districts initiated a research, design, and construction program to convert the WRPs to activated sludge nitrification-denitrification (NDN). Although the chemistry is not fully understood, WRP monitoring data indicate that NDMA levels in effluent increased after full implementation of NDN treatment. This implementation was completed by 2003 at the WRPs. NDMA concentrations after NDN implementation were typically in the range of one thousand to several thousand ng/L at the San Jose Creek WRP. At these higher effluent concentrations, NDMA was initially detected above the NL in shallow monitoring wells at the spreading grounds. Once the higher NMDA concentrations at the spreading grounds were discovered, the Sanitation Districts ceased direct deliveries of recycled water to the spreading grounds via the San Jose Creek WRP outfall pipeline and instead began delivering recycled water only via surface flows, to take advantage of photolysis of NDMA during travel. This regime was implemented in mid-2004.

The Montebello Forebay Attenuation and Dilution Studies were undertaken in 2004 to address the initial high NDMA concentrations found in the spreading grounds following conversion of the WRPs to NDN treatment. As part of this investigation, a monitoring well network near the WRP effluent discharge locations upstream of the spreading grounds was established and monitored for low-level NDMA. Results of the testing found elevated levels of NDMA in groundwater immediately downgradient of the San Jose Creek and Whittier Narrows WRPs' effluent discharge locations. Additionally, ceasing direct deliveries of recycled water to the spreading grounds had resulted in substantial reductions of subsurface NDMA concentrations at the spreading grounds. Therefore, NDMA concentrations at the spreading grounds were no longer at levels of concern. These results changed the focus of this investigation from the spreading grounds to the upstream areas closer to the effluent discharge locations for the San Jose Creek and Whittier Narrows WRPs.

Effluent concentrations of NDMA in the San Jose Creek WRP have varied dramatically over time. This facility contributes the largest volume of recycled water to the Study Area and as such has the greatest influence on NDMA levels in groundwater. The Whittier Narrows and Pomona WRPs have shown less variability. Prior to implementation of NDN treatment in 2003, effluent NDMA concentrations from the San Jose Creek WRP averaged below 400 ng/L. Following NDN implementation, NDMA concentrations rose to an average of about 2,500 ng/L at the San Jose Creek East WRP and about 1,100 ng/L at the San Jose Creek West WRP. The majority of the water quality data collected during this investigation represents conditions during the period of these elevated NDMA effluent concentrations.

As a result of the increased NDMA levels, the Sanitation Districts began evaluating treatment processes to reduce NDMA levels. In late 2006 and early 2007, they implemented sequential chlorination at the San Jose Creek and Whittier Narrows WRPs, wherein wastewater is exposed briefly to free chlorine to destroy NMDA precursors prior to chloramination. This process significantly reduced NDMA levels at the San Jose Creek WRP and moderately reduced levels at the Whittier Narrows WRP. Monitoring was continued beyond the scheduled project end date in December 2006 to evaluated changes in NDMA levels in groundwater following reductions in effluent concentrations. Groundwater quality data collected in 2007 show that there was a quick decline in NDMA levels in response to reduced effluent concentrations. The Sanitation Districts are currently implementing ultraviolet (UV) treatment at the Whittier Narrows and evaluating the feasibility of UV treatment implementation at the other WRPs, which would further reduce NDMA levels in effluent, if implemented.

There are several components of the Montebello Forebay Attenuation and Dilution Studies including: literature review and existing data compilation; collection of data for effluent, surface water, vadose zone, and groundwater characteristics and quality; and development of surface water and groundwater flow and transport models. The models were used to simulate the fate and transport of NDMA (by attenuation and dilution) in the Study Area and predict future groundwater quality conditions based on reduced NDMA levels in effluent achieved by treatment process improvements. This report presents the field work conducted for this project, the conceptual hydrogeologic model of the Study Area developed as input to the surface water and groundwater models, the fate and transport characteristics of NDMA, the water quality results, the surface water and groundwater models, and conclusions.

1.2 Purpose and Objective

The main objective of these studies is to assess the fate and transport of NDMA from WRP effluent discharge locations to groundwater. That characterization is based on review and analysis of existing data, collection of additional data, collection and rigorous analysis of a comprehensive set of water quality data, and development of sound and defensible surface water and groundwater flow and transport models. The goal of the modeling is to provide a tool to simulate the fate and transport of NDMA in the Study Area and predict future groundwater concentrations based on lower NDMA effluent concentrations achieved through implementation of improved treatment technologies.

1.3 Acknowledgements

The project consulting team performing the work on the Montebello Forebay Attenuation and Dilution Studies included staff of Kennedy/Jenks/Todd, LLC (K/J/Todd) and Lawrence Berkeley National Laboratory (LBNL). K/J/Todd provided overall management of the project, conducted the field investigations and water quality monitoring program, developed the conceptual model of the Study Area, and provided analysis of the water quality data. Sally McCraven, P.G., C.Hg., and C.E.G., of K/J/Todd was the overall Project Manager and lead Hydrogeologist. Rus Purcell, P.G., of K/J/Todd was the Project Manager for Field Activities. Julio Garcia, Ph.D., formerly an employee of ETIC Engineering, Inc. (ETIC), performed the surface water flow and transport modeling. Quanlin Zhou, Ph.D. formerly of ETIC and currently of LBNL conducted the groundwater flow and transport modeling. Michael Maley, P.G. and P.E., of K/L/Todd provided review and oversight of surface water and groundwater modeling. William Motzer, Ph.D., of K/J/Todd contributed to the NDMA fate and transport assessment.

The Sanitation Districts supervised and directed the studies, provided low-level NDMA analysis at their laboratory, assisted with additional program monitoring, and supplied required references and data to support the project. Monica Gasca was the Sanitation Districts' Project Manager. Significant support for the project was also provided by other agencies including the Water Replenishment District of Southern California (WRD), the Los Angeles County Department of Public Works (LACDPW), the U.S. Environmental Protection Agency (USEPA), the Los Angeles and San Gabriel Rivers Watershed Council (Watershed Council), and the U.S.

Army Corps of Engineers (USCOE). Ted Johnson of WRD coordinated the transfer of information and data from WRD, helped facilitate sampling of forebay wells and recharge basins, and provided technical review of project work. Ed Gerlits of LACDPW facilitated the transfer of information. Patricia Bowlin of the USEPA assisted in the transfer of references and data. Suzanne Dallman of the Watershed Council applied the Watershed Council's recharge model to the Study Area to develop more accurate recharge values for input to the groundwater model. Gregory Peacock of the USCOE provided monitoring and operational data for the Whittier Narrows Dam.

1.4 Scope of Work

The project scope was initially defined in the Sanitation Districts' request for proposals (RFP) (August 4, 2004). The scope of work was refined by K/J/Todd to fill data gaps identified during the initial review of available data. The main project tasks included:

- Literature Review and Identification of Data Gaps
- Field Activities
- Development of the Hydrogeologic Conceptual Model
- Groundwater and Surface Water Monitoring
- Data Compilation and Analysis
- Surface Water and Groundwater Model Development, Calibration, and Application
- Analysis and Reporting

1.5 Report Structure

The main text of this report provides an overview and summary of the main project components specifically related to the fate and transport of NDMA and impacts to groundwater. All project data and detailed discussion of the procedures, analyses, and results are presented in attached appendices. A comprehensive description of field data collection procedures and results are presented in Appendix A. Appendices B through K include various field work related logs, permits, data, and specifications as described in Appendix A. Appendix L describes the hydrogeologic conceptual model. Appendix M presents a review of the available scientific literature regarding the fate and transport of NDMA. Appendix N discusses NDMA water quality results. Appendix O presents the surface water model and results, while Appendix P presents the groundwater model and results.

Section 2: Study Area Description

The hydrogeologic conceptual model presented in Appendix L provides detailed information on the physical characteristics of the Study Area. This section summarizes key Study Area characteristics.

2.1 Physical Setting

The Study Area encompasses the three WRPs and areas upstream and downstream of the WRP effluent discharge locations necessary to characterize hydrogeologic and hydrologic conditions (Figure 1-1). The Study Area encompasses portions of three groundwater basins; the San Gabriel Basin, the Central Basin, and the Upper Santa Ana Valley Basin. The Puente Narrows defines the boundary between the Puente Subbasin and main portion of the San Gabriel Basin. Similarly, the Whittier Narrows Dam defines the boundary between the San Gabriel and Central basins. The Montebello Forebay is in the northeast area of the Central Basin where substantial infiltration of surface water occurs due to the absence or thinning of aquitards.

The Pomona WRP is located next to the South San Jose Creek in the Upper Santa Ana Valley Basin. Effluent is discharged from the plant into the South San Jose Creek, which drains into the San Jose Creek, which in turn runs through the Puente Subbasin. The creek is concrete lined for approximately 18 miles from the effluent discharge location to just east of the San Jose Creek WRP. The San Jose Creek is the main surface water drainage for the Puente Subbasin.

The San Jose Creek East and West WRPs are located next to the confluence of the San Jose Creek and San Gabriel River. The San Gabriel River and Rio Hondo are the main surface waterways that drain the San Gabriel Basin. The Whittier Narrows WRP is located adjacent to the Rio Hondo in the Whittier Narrows. Groundwater and surface water discharge from the San Gabriel Basin flows predominantly through the Whittier Narrows into the Montebello Forebay area of the Central Basin. The Rio Hondo and San Gabriel spreading grounds are located in the Montebello Forebay area of the Central Basin.

Figure 1-1 illustrates the topographic relief of the Study Area. The San Gabriel Valley is bounded on the north by the San Gabriel Mountains and on the south by a crescent-shaped system of low rolling hills that separate the San Gabriel Valley from the Los Angeles Coastal Plain. The southern bounding hills of the San Gabriel Valley are broken only at the Whittier Narrows, a 1-1/2 miles-wide floodplain. The Puente and San Jose hills bound the Puente Subbasin on the south and north, respectively.

The Montebello Forebay, part of the Central Basin, extends south of the Merced Hills and the Whittier Narrows. The forebay is the area of the Central Basin where substantial infiltration of surface water occurs and is divided from the Central Basin Pressure Area where confining layers restrict the deep percolation of water from the ground surface. The accepted delineation of the transition between these two areas is shown in Figure 1-1.

2.2 Hydrogeology

2.2.1 San Gabriel Basin

The San Gabriel Basin is filled with a thick sequence of alluvial deposits derived from erosion of the surrounding mountains and hills. The deposits reach a thickness of approximately 4,000 feet in the southwestern portion of the basin, while being thinner in the vicinity of the Whittier Narrows. In the vicinity of the Whittier Narrows Dam depth to bedrock is generally less than 400 feet in the western portion and more than 800 feet near the San Gabriel River to the east (USEPA, November 1999). Depth to bedrock is greater than 1,000 feet in the north central portion of the Whittier Narrows and shallows on either side toward the Puente and Merced hills. The Puente Valley makes up the southeastern portion of the San Gabriel Valley and is a horn-shaped valley approximately 12-1/2 miles long and from 2 to 3 miles wide. The valley fill deposits range in thickness from approximately 380 feet at the Puente Narrows to less than 25 feet in the extreme eastern portion and valley perimeter.

The sediments derived from erosion of the San Gabriel Mountains are typically coarse-grained (e.g., sand, gravel, and boulders), whereas the hills that border the basin on the southwest and southeast have contributed sediment to the basin that are distinctly finer-grained (e.g., silts and clays). Alluvial fan and braided stream depositional environments that are characteristic of the Main San Gabriel Basin have resulted in a high degree of vertical and lateral variability in the alluvial deposits of the basin. In general terms, the sediments of the Main San Gabriel Basin are characterized by discontinuous interfingering lenses of alluvial deposits (e.g., cobbles, gravel, sand, silt, and clay). Throughout most of the Main San Gabriel Basin there are no distinct, laterally continuous stratigraphic layers. However, in the southern portion of the basin in the vicinity of South El Monte and the Whittier Narrows, several fairly distinct and laterally continuous layers of fine-grained sediment have been identified dividing the hydrogeologic system into shallow, intermediate, and deep water-bearing zones. Alluvial sediments in the Puente Subbasin tend to be much finer-grained than those from the San Gabriel Mountains and the deposits in the Puente Subbasin exhibit more layering compared with the Main San Gabriel Basin.

Groundwater in the Main San Gabriel Basin occurs under unconfined or semiconfined conditions. Generally, hydraulic conductivity of the alluvial materials in the Main San Gabriel Basin is highest in the gravel of the upstream central portion of the basin. Grain size (and hydraulic conductivity) decreases away from this area, towards the southern and lateral margins of the basin. The flow system in the Puente Valley has been characterized as a confined system (CDM, May 1997). Hydrogeologic layers dip and thicken from the east end of the Puente Subbasin toward the Main San Gabriel Basin. The Puente Valley hydrogeologic system has been divided into a shallow, intermediate, and deep water-bearing zones separated by low conductivity aquitards. Hydraulic conductivities are significantly lower in the Puente Valley compared with those in the Main San Gabriel Valley. Aquifer parameters in the Main San Gabriel Basin and Puente Valley are summarized in Appendix L.

On a regional scale groundwater flow in the San Gabriel Basin is generally away from the perimeter of the basin toward the Whittier Narrows as shown in Figure 2-1, a groundwater elevation contour map prepared for January 2006. Groundwater flows westward through the Puente Subbasin and northwestward into the Main San Gabriel Basin and towards the Whittier Narrows. Pumping depressions around production wells are illustrated in several areas of the basin on Figure 2-1. Vertical gradients are downward in most areas of the Main San Gabriel Basin and Puente Subbasin.

The average regional groundwater velocity through the center of the Main San Gabriel Basin (in vicinity of the Baldwin Park OU) is about 2 feet per day (ft/d) or about 730 feet per year (ft/yr) (GeoSyntec and Todd Engineers, September 1995). CH2M HILL (July 1989) reported that the average regional groundwater flow velocity in the Whittier Narrows appears to be approximately 1,000 ft/yr or about 3 ft/d.

2.2.2 Montebello Forebay

The Montebello Forebay is located in the northeast region of the Coastal Plain in the Central Basin. As outlined by California Department of Water Resources (DWR) (1961) and Montgomery Watson (2001), the Coastal Plain is a northwest-trending structural basin underlain by up to 20,000 feet of sedimentary deposits. The Montebello Forebay is underlain by Quaternary alluvial deposits comprised of gravel, sand, silt, and clay.

Unlike the vertically heterogeneous, unlayered nature of deposition in the Main San Gabriel Basin, the Central Basin is characterized by a multiple, layered aquifer/aquitard system (DWR, 1961 and USGS, 2003). The most prominent hydrogeologic feature of the Montebello Forebay is the absence or thinning of aquitards. As a result of this condition, surface infiltration in the forebay can recharge deeper aquifers. Elsewhere in the Central Basin (Central Basin Pressure Area), these aquifers are confined by intervening aquitards.

Within the shallow stratigraphy, higher hydraulic conductivities are found in the immediate vicinity of the Montebello Forebay, whereas less permeable areas are located on the outskirts of the Montebello Forebay. Vertically, the highest conductivities occur from 50 to 150 feet below ground surface (bgs). The deeper stratigraphy is characterized by higher permeable areas in the immediate vicinity of the spreading grounds. Available hydraulic conductivity data are presented in Appendix L.

Figure 2-2 is a groundwater elevation contour map of the Central and West Coast Basins for Spring 2005 (WRD, March 2006). Groundwater flows in a generally southwesterly direction across the Montebello Forebay. There is radial flow of groundwater away from the Whittier Narrows and Montebello Forebay. In response to pumping from deeper zones, a downward gradient exists between the shallow-intermediate zones and the deep zone in the Montebello Forebay.

2.2.3 Model Input Parameters

As part of this project, data from boring logs in the Study Area were interpreted and input to Earth Visualization Software™ (EVS). EVS is a software program that allows three-dimensional interpolation and visualization of geologic systems (CTECH, 2006). EVS was used to refine the interpretation of hydrogeologic layering and geologic structure in the Study Area and generate a three-dimensional visualization for input to the numerical groundwater model. EVS generated cross sections and a three dimensional depiction of the geology are presented in Appendix L.

Figures showing the hydraulic conductivity, effective porosity, and storativity distribution used for groundwater modeling are presented in Appendix P.

2.3 Surface Water

2.3.1 Rivers and Flood Control

The San Gabriel River drains surface water runoff for most of Main San Gabriel Basin. All runoff not collected by upstream reservoirs or spreading facilities, passes through the Whittier Narrows into the Montebello Forebay. The San Gabriel River and Rio Hondo are the two main components of the surface water system. These rivers in conjunction with the San Jose Creek provide the major conduits for water discharged from the WRPs, local storm water, and imported water from MWD. The Rio Hondo and San Gabriel River and their tributaries are shown in Figure 2-3.

Two channels hydraulically connect the two rivers in the Whittier Narrows: the Zone 1 Ditch and Whittier Narrows Flood Control Cross-Over Channel (Figure 1-1). The Zone 1 Ditch, also known as the Rio Hondo Bypass Channel, is used to actively transport water from the San Gabriel River via a diversion structure to the Rio Hondo upstream of the Whittier Narrows Dam. The Whittier Narrows Flood Control Cross-Over Channel allows for hydraulic communication between the east and west sides of the Whittier Narrows Dam. This channel generally carries additional flood flow from the San Gabriel River, allowing water to be transferred to the west side of the dam and ultimately into the Rio Hondo. This channel is not actively used to transport recycled water. The overall hydraulic communication between the two rivers is dependent on flood conditions, spreading ground objectives, and the operation of the Whittier Narrows Dam facilities by LACDPW and USCOE. The west side of the dam also has a water conservation pool to provide post-storm flow to the Rio Hondo Spreading Grounds.

Within the Study Area, the surface water system consists of a blend of concrete-lined channels, unlined river sections, and the large unlined water conservation pool behind the Whittier Narrows Dam. Figure 1-1 depicts the lined and unlined sections of the key creeks and channels. The San Gabriel River is unlined throughout most of the Study Area. The Rio Hondo is unlined from about four miles north of the Whittier Narrows Dam to the dam. The Zone 1 Ditch and Flood Control Cross-Over Channel are unlined. The San Jose Creek is lined throughout the Puente Subbasin and becomes unlined about two miles before the confluence with the San Gabriel River.

Generally, the unlined portions of streams and rivers within the Study Area are losing reaches. Small portions of the San Gabriel River and Rio Hondo near the Whittier Narrows may receive discharge from groundwater during periods of high groundwater levels. The San Jose Creek does receive discharge from groundwater via weepholes in the lined stretch designed to relieve hydrostatic pressure during high groundwater conditions. Within the Study Area, certain portions of the San Gabriel River have been identified as potential incidental recharge areas and subsequently listed as spreading facilities by LACDPW. Instream recharge areas on the San Gabriel River are shown in Figure 2-3. Infiltration occurs throughout the unlined San Gabriel River and is enhanced significantly by rubber dam facilities that operate in the river.

2.3.2 Recharge Facilities, Lakes, and Reservoirs

With the exception of direct rainfall recharge, the primary sources of groundwater recharge within the Study Area include the Montebello Forebay Spreading Grounds, instream recharge facilities (rubber dams and check dams) on the San Gabriel River, other spreading facilities in the San Gabriel Basin, Legg Lake, and water conservation pools within the Whittier Narrows Flood Control Basin (see Figure 2-3). Legg Lake is a series of small lakes within the Whittier

Narrows Recreation Area. The lakes provide recreation in addition to groundwater recharge. The Whittier Narrows Flood Control Basin provides incidental recharge when the dam facilities are operated to achieve water conservation objectives and supply water to the Rio Hondo and San Gabriel spreading grounds. Spreading facilities including the Montebello Forebay Spreading Grounds are operated to promote the recharge of water to the Central and San Gabriel groundwater basins.

The Rio Hondo and San Gabriel spreading grounds located downstream of the Whittier Narrows Dam recharge significant amounts of water to the Montebello Forebay. The Rio Hondo Spreading Grounds include basins on both the east and west sides of the Rio Hondo. The San Gabriel Spreading Grounds basins are located on the west side of the San Gabriel River. Recharge water in the spreading grounds includes a mix of recycled water from the WRPs, imported water from MWD, and local storm water.

2.3.3 Water Reclamation Plants

The Sanitation Districts operate three WRPs within the Study Area, which introduce a significant volume of flow to surface water. Effluent from these facilities is discharged into the San Jose Creek, San Gabriel River, Rio Hondo, and Zone 1 Ditch. In addition, water from the San Jose Creek WRP can be diverted directly into the San Gabriel Spreading Grounds via a pipeline. The daily flow values for each plant at each discharge point are well documented by the Sanitation Districts. The WRPs and their associated effluent discharge locations are depicted on Figure 2-3.

The San Jose Creek WRP is located east of the confluence of the San Jose Creek and San Gabriel River and consists of an east and west facility dissected by the San Gabriel (605) Freeway. The combined plants have a capacity of 100 million gallons per day (MGD). The treatment processes at both WRPs currently consist of primary sedimentation, NDN activated sludge biological treatment, secondary sedimentation with coagulation, inert media filtration, chlorination and dechlorination, and sequential chlorination. To achieve compliance with ammonia Basin Plan objectives (RWQCB, June 1994), the Sanitation Districts initiated a research program in 1995 and began a conversion of the WRPs to NDN treatment beginning in 2000. As of June 2003, the San Jose Creek East and West WRPs have been in full NDN treatment. Although the chemistry is not fully understood, NDMA levels in effluent from the San Jose Creek WRP significantly increased following implementation of NDN treatment. Following the increase in NDMA levels, the Sanitation Districts began evaluating various treatment system modifications to address NDMA levels. One such modification is called sequential chlorination whereby wastewater is exposed briefly to free chlorine to destroy NMDA precursors prior to chloramination. This process was implemented at the San Jose Creek West WRP in October 2006 and at the San Jose Creek East WRP in January 2007. Sequential chlorination was found to reduce NDMA levels by about an order of magnitude at the San Jose Creek East WRP and by about 70 percent at the San Jose Creek West WRP. Effluent water quality data are discussed in more detail in Appendix N and in Section 4.

Treated effluent from the San Jose Creek East WRP can be discharged into the unlined portion of the San Jose Creek at Effluent Discharge Location SJC002, the lined portion of the San Gabriel River downstream from the San Gabriel Spreading Grounds at Effluent Discharge Location SJC001, the unlined San Gabriel River near the San Gabriel Spreading Grounds at Effluent Discharge Location SJC001A, or diverted directly into San Gabriel Spreading Grounds via a pipeline at Effluent Diversion Location SJCSGSG (Figure 2-3).

Treated effluent from the San Jose Creek West WRP can be discharged directly into the unlined portion of the San Gabriel River upstream of the Whittier Narrows Dam at Effluent Discharge Location SJC003, the lined portion of the San Gabriel River downstream of the San Gabriel Spreading Grounds at Effluent Discharge Location SJC001, the unlined San Gabriel River near the San Gabriel Spreading Grounds at Effluent Discharge Location SJC001A, or diverted directly into the San Gabriel Spreading Grounds via a pipeline at Effluent Diversion Location SJCSGSG. Use of SJCSGSG was discontinued in 2004 following elevated NDMA concentrations detected at the San Gabriel spreading grounds due to an increase in effluent NDMA concentrations at the San Jose Creek WRP following conversion of the plant to NDN treatment.

The Whittier Narrows WRP is a 15 MGD facility located between the Rio Hondo and Rosemead Boulevard, south of the Pomona (60) Freeway. Treatment at the Whittier Narrows WRP consists of primary sedimentation, NDN activated sludge biological treatment, secondary sedimentation with coagulation, inert media filtration, chlorination and dechlorination, and sequential chlorination. Conversion to NDN treatment was completed in 2003. Sequential chlorination was implemented at the Whittier Narrows WRP in late October 2006 to reduce NDMA levels in effluent. Sequential chlorination resulted in about a 60 percent reduction in effluent NDMA concentrations. The Sanitation Districts are currently implementing UV treatment at the Whittier Narrows WRP.

The Whittier Narrows WRP has three active effluent discharge locations in the Study Area, all located upstream of the Whittier Narrows Dam. Effluent from the plant can be discharged directly into the unlined portion of the San Gabriel River upstream of the Whittier Narrows Dam at Effluent Discharge Location WN001, directly into the Rio Hondo upstream of the Whittier Narrows Dam adjacent to the WRP at Effluent Discharge Location WN004, and into the Zone 1 Ditch (Rio Hondo Bypass Channel) to the east of the WRP at Effluent Discharge Location WN002.

The Pomona WRP is located at the far eastern edge of the Study Area. Treatment processes at the Pomona WRP include primary sedimentation, NDN activated sludge biological treatment, secondary sedimentation with coagulation, inert medial filtration, and chlorination and dechlorination. Conversion to NDN treatment was completed in 2003 and sequential chlorination was implemented in September 2007.

The Pomona WRP discharges directly into the South San Jose Creek at Effluent Discharge Location POM001. The plant has the capacity of 15 MGD. During the summer, much of the recycled water from the Pomona WRP is used for non-potable applications in the immediate area, and flows to San Jose Creek are greatly reduced.

The daily WRP flows at each effluent discharge location in conjunction with effluent water quality data are well documented, providing surface discharge and NDMA mass loading values at each effluent discharge location. Effluent flows are presented in charts and tables in Appendix L.

2.3.4 Imported Water

Water is delivered to the Study Area from MWD at three main discharge points. Imported water is generally available nine months of the year and is purchased by various agencies in the Study Area for water supply and groundwater recharge. Imported water is purchased by WRD to augment recharge operations at the Rio Hondo and San Gabriel spreading grounds. These flows enter the Study Area at three major discharge points CEN.B-28, CEN.B-48, and CEN.B-36 as shown on Figure 2-3.

2.3.5 Storm Water

Storm water flows contribute water to the surface water system during the wet season from roughly October to April. Water held in upstream reservoirs can also be released to contribute local water to the surface water system.

Section 3: Fate and Transport of N-Nitrosodimethylamine in the Environment

Scientific literature on the fate and transport of NDMA in the environment were compiled and evaluated to aid in understanding its magnitude and distribution in the Study Area and to provide a basis for the attenuation factors input to the surface water and groundwater transport models. Appendix M provides a detailed discussion of the available literature. Currently, literature on the fate and transport of NDMA is not extensive, but new information is being developed as research focuses on this emerging compound.

In the transport of recycled water from the WRP effluent discharge locations to groundwater beneath the spreading grounds and unlined river reaches, degradation by photolysis due to exposure to sunlight is one of the most important processes reducing NDMA concentrations within the surface water system. Dilution with imported and storm water will also reduce NDMA concentrations in the surface water system. Biological degradation is expected to be the most important process for the removal of NDMA in the vadose zone and groundwater. Dispersion, dilution, and groundwater extraction will further reduce NDMA concentrations observed in groundwater.

It is well established that NDMA is removed by photolysis in water and wastewater treatment facilities. Several studies indicate that NDMA is also removed by photolysis in natural sunlight (Liteplo, et al., 2002; Howard, et al., 1991; Mitch, et al., 2003a; Souroushian, et al., 2001; and Gasca, 2005). The observational data (presented in Section 4 and Appendix N) evaluated as part of this investigation also support the conclusion that NDMA is significantly attenuated in the surface water system.

Based on the literature, the half-life of NDMA in surface water exposed to natural sunlight is expected to range from less than 3 to 24 hours. Based on the observed concentrations and estimated travel times along San Jose Creek during this investigation, the NDMA decay rate constant is estimated to be 0.3153 1/hours corresponding to a half-life of 2.2 hours. Based on distance, the decay rate constant is -7E-5 1/feet corresponding to a half-life of 1.9 miles, for a given travel speed (see Section 4.2.3.1). NDMA half-lives were also estimated during surface water modeling and ranged from 0.6 to 4.8 hours depending on the river segment.

The literature indicates that NDMA may be attenuated in the vadose zone and groundwater by biodegradation, mainly under laboratory conditions (Liteplo, et al., 2002; Gunnison, et al., 2000; Howard, et al., 1991; Bradley, et al., 2005, Drewes, et al., 2006; Yang, et al., 2005; and Kaplan and Kaplan, 1985). There is a significant range of NDMA biodegradation half-lives reported for the vadose zone; from 4.1 to 180 hours. For groundwater, the literature-reported NDMA half-lives range from 1.4 to 39 days for anaerobic conditions and from 11 to 360 days for aerobic conditions. There is some limited reporting on NDMA degradation under field conditions presented in the literature; however, the attenuation process was not determined.

Field observational data collected in the Study Area during this investigation (presented in Section 4.2.7) demonstrates that attenuation of NDMA is occurring in the vadose zone and groundwater, most probably due to biodegradation. Field observation data were inadequate to determine biodegradation rates in the vadose zone. The rate of biodegradation of NDMA in the vadose zone varies for different areas with active recharge depending on thickness of the vadose zone and travel time. Observed data does support NDMA biodegradation in groundwater. Data indicate NDMA was reduced by 82 percent in groundwater over a period of one year in the Whittier Narrows, most probably as a result of biodegradation (see Section 4.2.7). Biodegradation in groundwater was also demonstrated by the fact that the NDMA mass in groundwater changed significantly with time and that the NDMA mass in groundwater is much smaller than the estimated mass in recharge water. For groundwater transport modeling, groundwater biodegradation half-lives of 17 and 69 days were used for different areas of the Study Area as discussed in Section 5. No vadose zone biodegradation was applied in the transport modeling.

Laterally extensive, high concentrations of NDMA in groundwater are observed at several NDMA release sites in California (WateReuse, 2006) indicating that significant attenuation of NDMA in the vadose zone and groundwater does not occur in all environments and is dependent on site-specific conditions. Research indicates that the rate of NDMA biodegradation is affected by the initial NDMA concentration and the presence of an adapted biocommunity. Lower NDMA concentrations in recharge water showed higher degradation rates. Additionally, soil columns that had received NDMA impacted effluent water for a longer period of time ("older") showed higher rates of degradation compared with "younger" soil columns. Most recharge areas of the Study Area are expected to have adapted biocommunities given that recycled water has been actively recharged since the 1960s. Recent work has shown that the microbial populations in experimental systems (batch reactors and batch soil columns) used to measure biodegradable dissolved organic carbon in recycled water can be acclimated in a very short period of time to test activity and removal (Drewes and Dickenson, 2007). Areas near the San Jose Creek WRP where effluent is consistently discharged should have well adapted biocommunities. Recent reductions in NDMA concentrations in WRP effluent due to implementation of sequential chlorination should result in increased biodegradation rates in the vadose zone and groundwater.

Section 4: Water Quality

This section summarizes background detections of NDMA; the levels and distribution of NDMA in effluent, surface water, and groundwater in the vicinity and downstream of the WRPs; and the observed attenuation of NDMA in surface water, the vadose zone, and groundwater. Appendix N presents the water quality data in more detail. The locations of effluent discharge locations, surface water stations, and groundwater wells sampled for NDMA in the Study Area are shown in Figures 4-1 and 4-2. Figure 4-1 shows wells with NDMA monitoring data in the vicinity of recycled water recharge areas. Tables presenting all the NDMA sampling data are provided in Appendix I.

4.1 Background NDMA Contamination in the Study Area

Levels of NDMA from sources other than the WRPs were assessed for these investigations. Figure 4-3 shows regional average NDMA concentrations[2] in groundwater from 1996 to 2006 in the Study Area. In 1999 and 2000, NDMA was detected in the Baldwin Park Operable Unit (OU) of the San Gabriel Basin Superfund site in a shallow monitoring well at an aerospace facility. In addition to being a treatment byproduct in wastewater, NDMA is also associated with the rocket fuel mixture unsymmetrical dimethylhydrazine (UDMH). The Baldwin Park OU appears to be a significant source of NDMA in the Main San Gabriel Basin as shown by the relatively large average NDMA detections in the area and extending downgradient. NDMA detections are also noted in the upgradient Alhambra and South El Monte OU areas. The general areas of the Superfund OUs are shown on Figure 1-1.

Low-level NDMA detections are noted in the Puente Valley OU. The source(s) of these detections have not been documented. Since the San Jose Creek is lined through the Puente Valley, recycled water recharged from the Pomona WRP is not thought to be contributing to these detections. Imported water purchased from the MWD is a significant source of water supply in the Puente Subbasin and imported water for recharge at the spreading grounds is discharged to the San Gabriel Basin at a station upstream of the Pomona WRP (CEN.B-28 in Figure 2-3). Imported water used for recharge is predominantly untreated Colorado River and State Water Project water. Imported water at CEN.B-28 was sampled for low-level NDMA by the Sanitation Districts in a one-time sampling event in December of 2004. NDMA was detected at a concentration of 4.8 ng/L indicating that imported water may be a source of low-level NDMA background concentrations observed in the Study Area.

NDMA detections in the Whittier Narrows and Montebello Forebay are thought to be primarily due to infiltration of recycled water due to discharge from the Whittier Narrows and San Jose Creek WRPs as discussed in more detail in the next section.

Figure 4-4 shows an average NDMA concentration[1] contour map of the Baldwin Park OU NDMA plume. The Baldwin Park OU plume appears to extend into the north Whittier Narrows area. The vertical distribution of NDMA in and downgradient of the Baldwin Park OU is illustrated in the cross section shown on Figure 4-5. The cross section location is shown in Figure 4-4. The NDMA plume extends approximately 13 miles from the source area to the northern Whittier Narrows. Average values are posted beside the well screens. As indicated on the cross section,

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[2] Concentrations represent the average of all detected values and the average of one half the reporting limit for all non-detected values with reporting limits at or below 10 ng/L. Non-detected values with reporting limits greater than 10 ng/L were ignored in order to prevent skewing of the averages.

NDMA has migrated downward as it has moved away from the source area in Baldwin Park. At the USEPA Westbay™ multiple-completion Well EPA-W-410 located in the north Whittier Narrows area, NDMA is detected in the shallowest port above 140 feet bgs, concentrations decline to non-detectable levels with increasing port depth, and then increase at about 600 feet bgs. It appears that the deeper NDMA detections in this well may be associated with the Baldwin Park OU plume, while shallow detections may be associated with releases from the San Jose Creek WRP. Because groundwater shallows in the Whittier Narrows due to a rise in the base of the aquifer as shown in Figure 4-5, the deeper impacted groundwater from the Baldwin Park OU may rise as groundwater moves into the Whittier Narrows, which could result in a commingling of NDMA sources.

4.2 NDMA Water Quality Data

Low-level NDMA has been analyzed in effluent, surface water, spreading ground intake water, groundwater monitoring wells, and production wells in the Study Area. NDMA data collected as part of this investigation as well as data collected by the Sanitation Districts, WRD, USEPA, DPH, and CBMWD have been compiled to assess the fate and transport of NDMA in the Study Area.

4.2.1 Effluent Limits

The RWQCB has issued WDRs for the San Jose Creek and Pomona WRPs that establish NDMA effluent limits. These limits are based on California water quality objectives for surface waters that are not existing or potential drinking water sources. They are derived to be protective of human health for those consuming aquatic organisms from the water body. To date no effluent limits for NDMA have been established for the Whittier Narrows WRP. Table 4-1 summarizes these requirements.

Table 4-1 Effluent Limits for NDMA for Whittier Narrows, San Jose Creek, and Pomona WRPs

WRP	Discharge Limitation		Interim Limitation
	Daily Average (ng/L)	Monthly Average (ng/L)	Monthly Average[1] (ng/L)
Whittier Narrows	NE	NE	NE
San Jose Creek East and West	16,000	8,100	20,000
Pomona	16,000	8,100	NE

ng/L – nanograms per liter
NE – No effluent limit established
[1] - Effective until May 10, 2009

The Sanitation Districts are required to comply with the interim effluent limit for the San Jose Creek WRP until May 10, 2009. The WDRs for the San Jose Creek and Pomona WRPs will be re-evaluated for possible modification of the final NDMA effluent limits following completion of these studies to protect the groundwater recharge beneficial use.

4.2.2 NDMA in Effluent

Figure 4-6 shows time-concentration plots of NDMA in effluent from the San Jose Creek East and West, Whittier Narrows, and Pomona WRPs. As shown in the figure, NDMA is consistently detected in treated effluent from all three WRPs. All samples have been below the 8,100 ng/L monthly effluent limit established for the San Jose Creek and Pomona WRPs. NDMA concentrations in WRPs' effluents are highly variable over time within each WRP as well as from plant to plant.

As of June 2003, all WRPs were upgraded to include full NDN treatment to reduce nitrogen compounds in effluent as discussed in Section 2.3.3. NDMA concentrations in effluent increased following implementation of NDN treatment, particularly at the San Jose Creek WRP. This is believed to be due to increased polymer addition to the return activated sludge to enhance sludge settling. The Mannich™ polymer used has dimethylamine (DMA), an NDMA precursor, as an additive. Increased levels of NDMA formed when chloramines from the disinfection process reacted with increased amounts of DMA from the polymer. To mitigate this, following extensive research, sequential chlorination was implemented by the Sanitation Districts at the San Jose Creek West WRP in October 2006, at the San Jose Creek East WRP in January 2007, at the Whittier Narrows WRP in late October 2006, and at the Pomona WRP in September 2007.

Sequential chlorination is a two-step process that uses free chlorine as the primary disinfectant and chloramines as the secondary disinfectant. First, free chlorine reacts with DMA making it unavailable to react with chloramines to form NDMA. Next, chloramines stop the reaction between free chlorine and trihalomethane (THM) precursors and provide further disinfection. Sequential chlorination was found to reduce NDMA levels dramatically by about an order of magnitude at the San Jose Creek East WRP and by about 70 percent at the San Jose Creek West WRP. The Sanitation Districts are planning to implement UV treatment at the Whittier Narrows WRP, which should further reduce NDMA levels in effluent.

As shown in Figure 4-6, NDMA in effluent from the San Jose Creek East WRP averaged about 333 ng/L prior to NDN implementation and 2,534 ng/L after NDN implementation and prior to sequential chlorination implementation. Since implementation of sequential chlorination, NDMA concentrations have been reduced to an average of 276 ng/L. Similarly, the average NDMA concentration at the San Jose Creek West WRP was 169 ng/L prior to NDN implementation and 1,151 ng/L after NDN implementation and prior to sequential chlorination implementation. Since implementation of sequential chlorination, average NDMA concentrations have been reduced to 371 ng/L.

An increase in NDMA concentrations following implementation of NDN treatment was not evident at the Whittier Narrows and Pomona WRPs. This is believed to be due to better sludge settling at these plants, which requires less polymer addition. Average NDMA concentrations at the Whittier Narrows WRP were about 363 ng/L prior to implementation of sequential chlorination and have shown a moderate decrease to about 140 ng/L following implementation of sequential chlorination. NDMA concentrations at the Pomona WRP have been relatively stable and averaged about 459 ng/L between July 2000 and July 2007. Sequential chlorination was implemented at the Pomona WRP in September 2007; however, data was not collected in time to be included in this report.

4.2.3 Surface Water

Water quality monitoring is conducted by the Sanitation Districts and WRD at various surface water stations in the Study Area. Low-level NDMA monitoring of surface water was conducted as part of this investigation. The WRP effluent discharge locations and surface water monitoring stations are shown in Figure 4-2. Time-concentration plots of NDMA for all surface water stations are included and discussed in Appendix N. Surface water data indicate that NDMA is attenuated as it flows downstream from the WRP effluent discharge locations. Upgradient surface water stations sporadically detect low levels of NDMA (less than 5 ng/L) indicating that there is occasionally some NDMA in background surface water.

Unfortunately, low-level NDMA data are not available for surface water stations for the period following implementation of sequential chlorination. However, it is expected that NDMA levels in surface water have declined in direct correlation with effluent concentrations.

Figure 4-7 shows time-concentration plots of NDMA in surface water stations downstream of the Pomona WRP. Detections are indicated by dots, non-detected results are indicated by boxed dots at the reporting limit, and estimated values, generally below the reporting limit, are indicated by circled dots. NDMA concentrations decline from an average of 355 ng/L in Surface Water Station R-A-POM located 1,200 feet downstream of the Pomona WRP Effluent Discharge Location POM001 to an average of 22 ng/L at Surface Water Station R-C located about 23,100 feet downstream of Effluent Discharge Location POM001. By the time surface water reaches Surface Water Stations R-15 and R-D-POM, located about 56,100 and 71,800 feet downstream from Effluent Discharge Location POM001, respectively, NDMA concentrations are typically not detected or detected at estimated levels below the reporting limit, similar to background concentrations. The data indicate that NDMA is being attenuated and/or diluted in the surface water system and that recycled water from the Pomona WRP contains almost no detectable levels of NDMA by the time it reaches unlined portions of the San Jose Creek in the Study Area.

4.2.3.1 NDMA Decay in Surface Water

To assess the decay of NDMA in surface water, the San Jose Creek surface water samples were selected for periods of time when there was no imported water being delivered and no precipitation had been recorded for several weeks prior to the sampling event. This ensured that there would be minimal dilution of surface water flow. Samples collected in October 2005 and March 2006 were representative of these conditions. The NDMA results for Surface Water Stations R-A-POM, R-C, and R-15 for these two sampling events are plotted on the bottom of Figure 4-7 against both distance and estimated travel time from Effluent Discharge Location POM001. Based on synoptic stream gauging data, it is estimated that it takes about 18 and 20 hours for effluent from the Pomona WRP to reach Surface Water Stations R-D-POM and C-2, respectively. This indicates that surface water will be exposed to sunlight during travel along San Jose Creek, allowing photolysis of NDMA to occur. Surface water sampling data also support the conclusion that photolysis is occurring because NDMA concentrations at Surface Water Station R-D-POM are usually below reporting limits.

A predictable first order decay rate is seen in Figure 4-7. The figure illustrates that NDMA is reduced exponentially with either distance or time. Based on the observed concentrations and estimated travel time, the NDMA decay rate constant is estimated to be 0.3153 1/hours corresponding to a half-life of 2.2 hours. Based on distance, the decay rate constant is 7E-5 1/feet corresponding to a half-life of 1.9 miles. It is noted that the travel time estimations include a significant margin of error, and are based primarily on the velocities measured during synoptic stream gauging conducted for this investigation. The estimated travel times could vary by approximately ± 50 percent. It is also noted that discharge from groundwater and runoff inflow to the creek may be contributing to dilution of NDMA. However, based on this work and information available in the literature, the estimated decay constants appear reasonable.

4.2.4 Spreading Grounds Intake Water

NDMA concentrations at the spreading grounds intakes are highly variable. NDMA averaged 167 ng/L at the Rio Hondo Spreading Grounds intake and 134 ng/L at the San Gabriel Spreading Grounds intake during the study period. The limited number of intake samples collected since initiation of sequential chlorination at the WRPs in late 2006 and early 2007 show NDMA intake concentrations below 100 ng/L.

Average NDMA concentrations at the spreading grounds intakes are lower than in the WRP effluent indicating attenuation and/or dilution along the surface water flow path to the spreading grounds. Because these samples represent water as it is introduced to the spreading grounds at the intakes, they are not believed to represent the levels of NDMA in the water recharged to groundwater. Rather, NDMA concentrations are likely to be further reduced by photolysis from exposure to sunlight as the water spreads out in the basins and slowly percolates. This further attenuation is also supported by the usually non-detectable levels of NDMA observed in shallow monitoring wells near the basins as discussed in the next section.

4.2.5 Groundwater

Low-level NDMA has been analyzed in shallow monitoring wells, production wells, and multi-port monitoring wells in the vicinity of the San Jose Creek and Whittier Narrows WRPs effluent discharge locations, the Whittier Narrows, along the unlined San Gabriel River, and near the spreading grounds.

NDMA in groundwater is discussed and presented in several different ways including summary tables, time-concentration plots, plan views of NDMA concentration contours, and in cross sections presented in Appendix N. This section summarizes results and presents key figures and tables.

4.2.5.1 NDMA Time-Concentration Plots

NDMA time-concentration plots for all wells with available data are presented and discussed in Appendix N. The time-concentration plots show that NDMA is detected at the highest concentrations in groundwater near effluent discharge locations close to the WRPs. Further downstream from the effluent discharge locations, monitoring wells show progressively lower concentrations with distance. This is because NDMA concentrations in recharge water are reduced as the recycled water moves downstream and is attenuated by photolysis due to exposure to sunlight. NDMA is usually not detected and rarely detected above 10 ng/L in groundwater near the spreading grounds.

NDMA concentrations in most monitoring wells are highly variable. Diversion of recycled water from one effluent discharge location to another can result in significant changes in local NDMA loading and resulting NDMA concentrations in groundwater in nearby wells, as demonstrated by the variable discharge at Effluent Discharge Locations WN001, WN002, and WN003. Decreasing NDMA concentrations as recycled water moves through the surface water system and recharges the groundwater system indicate that there is a likely significant amount of dilution with other water, photolytic degradation in surface water, and biodegradation in the vadose zone and groundwater. All wells with recent sampling data show significant decreases in NDMA concentrations in 2007, which correspond to recent reduction in effluent concentration due to implementation of sequential chlorination. This rapid and significant reduction in groundwater concentrations in response to effluent concentration reduction indicates that the NDMA mass that existed in groundwater prior to the NDMA effluent reduction may have been biodegraded, because no significant NDMA mass migration is observed in the downstream boundary of the area of detectable NDMA.

Figure 4-8 identifies all active (pumping within the last two years) production wells within one half mile of recycled water recharge areas. There are 78 production wells in this area. These include 11 wells used for irrigation, and 67 wells used for domestic water supply in the vicinity of the recharge areas. NDMA has not been tested at low levels in all these wells. However, the testing that has been conducted indicates that, with the exception of one detection greater than 10 ng/L in Well EPA-EW-CB1 in December 2004, NDMA is usually not detected or detected at concentrations at or below 10 ng/L in production wells used for domestic supply. Well EPA-EW-CB1 is located just downstream of the Whittier Narrows Dam near Rosemead Blvd. (Figure 4-1). Water from Well EPA-EW-CB1 is treated to remove volatile organic compounds (VOCs) and blended with other waters prior to distribution to customers, thereby ensuring NDMA concentrations were below 10 ng/L in water delivered to customers in December 2004. NDMA was detected at a concentration slightly above10 ng/L in Well EPA-EW-407, prior to use of the well for water supply. Well EPA-EW-407 is located in the Whittier Narrows just north of the Zone 1 Ditch (Figure 4-1). NDMA has been detected at concentrations below 10 ng/L in a few production wells (2947LM, 201-W2, 201-W4, 201-W5, and 201-W6) near the San Gabriel River in the Whittier Narrows; however, recent decreases in NDMA levels in Wells 2947LM, 201-W4, and 201-W5 indicate that impacts to production wells in the area will likely be eliminated with the reduction in NDMA in effluent as a result of the recent implementation of sequential chlorination. NDMA is rarely detected in production wells near and downgradient of the Rio Hondo and San Gabriel spreading grounds.

4.2.5.2 NDMA Concentration Contours

Appendix N contains several NDMA concentration contour maps prepared for different dates. Figure 4-9 and 4-10 are NDMA concentration contours in map view in the area near and downstream of the Whittier Narrows and San Jose Creek WRPs in September 2006 and May/June/July 2007, respectively. All detections and estimated values below the reporting limit are posted in orange on the figures.

Figure 4-9 shows that NDMA detections greater than 100 ng/L were detected in Wells SJC-MW-1 and SJC-MW-2 near the San Jose Creek WRP. NDMA was detected at concentrations greater than 10 ng/L in Well SJC/WN-MW-4 along the San Gabriel River between the Whittier Narrows Dam and the San Gabriel Spreading Grounds; in Wells EPA-MW-423 and EPA-MW-426 in the Whittier Narrows; and in Well WN-1 located along the San Gabriel River near the Whittier Narrows Dam. The 10 ng/L contour is extended to encompass Well 2947LM in the vicinity of the San Gabriel River in the Whittier Narrows. This production well has a relatively long screen compared with shallow monitoring wells. Thus it is assumed that the detected NDMA concentration in this well would be diluted by clean water pulled from deeper portions of the aquifer and that higher than detected concentrations occur in the shallow groundwater depicted in the figures. To be conservative the shallow groundwater concentration in this well is assumed to be higher than the detected well concentration.

Figure 4-10 shows a significant reduction in magnitude and extent of the area with detectable levels of NDMA in May/June/July 2007. This is believed to be directly related to reduced effluent concentrations resulting from implementation of sequential chlorination in late 2006 and early 2007 at the WRPs. Figure 4-10 shows no NDMA detections greater than 100 ng/L, although NDMA was detected at concentrations greater than 10 ng/L in Wells SJC-MW-1 and SJC-MW-2 near the San Jose Creek WRP. To present a conservative depiction of the extent of NDMA in the groundwater, a 10 ng/L contour was extended to encompass Well EPA-EW-CB1, which showed an NDMA detection just at 10 ng/L, and EPA-MW-426, which was not sampled in 2007 but showed a concentration of 90 ng/L in September 2006.

4.2.5.3 NDMA in Cross Section

Cross sections are presented in Appendix N, which illustrate the lateral and vertical distribution of NDMA in the vicinity of the Whittier Narrows, spreading grounds, and rivers. The cross sections imply that concentrations greater than 10 ng/L are generally limited to the upper 200 feet bgs.

4.2.6 Comparison of NDMA Concentrations in Sampled Media

For the NDMA data collected from June 2005 through December 2006, maximum and average concentrations were calculated for each sampling location. For averaging, one half the reporting limits of non-detected values with reporting limits less than 10 ng/L were used. The June 2005 to December 2006 time period was selected because prior to June 2005 and after December 2006, the complete network of surface water stations and wells was not being sampled on a regular basis.

Figure 4-11 is a bar chart showing the maximum and average NDMA concentration in each sampling location. Effluent sampling locations are shown in red, surface water stations are shown in blue, spreading ground intakes are shown in purple, monitoring wells are shown in yellow and orange, and production well are shown in green. Surface water stations are generally presented from upstream to downstream from left to right. NDMA was not detected at stations with yellow highlighted names. The chart shows that NDMA in surface water near the effluent discharge locations shows similar average and maximum NDMA concentrations to effluent. NDMA concentrations decline rapidly with distance downstream of the effluent discharge locations. NDMA average and maximum concentrations in spreading ground intakes are generally lower than in upstream surface water samples. NDMA concentrations in monitoring wells are lower than in nearby surface water and production wells show very low to non-detectable NDMA concentrations. The chart illustrates that NDMA is attenuated and diluted as it moves downstream from the effluent discharge locations, into shallow groundwater, and ultimately into deep groundwater where production well screens are set.

4.2.7 NDMA Degradation in Vadose Zone and Groundwater

Based on review of the literature on the fate and transport of NDMA discussed in Section 3 and the observed water quality data in the Study Area, NDMA is expected to be removed from the surface water and groundwater systems by several degradation processes including sunlight photolysis during surface water transport and biodegradation in the vadose zone and groundwater. Degradation of NDMA in surface water was discussed in Section 4.2.3.1.

In order to assess degradation of NDMA in the vadose zone, data available for Well EPA-MW-424 was evaluated. Well EPA-MW-424 is an ideal well for evaluation of vadose zone attenuation for several reasons. It is located close to Effluent Discharge Location WN004 and NDMA detections in this well can be attributed only to this nearby effluent source. Well EPA-MW-424 is screened at a relatively shallow interval (25 to 45 feet bgs) so it responds quickly to NDMA in effluent discharged at Effluent Discharge Location WN004 and is less likely to show dilution from inflow of groundwater. Finally, effluent discharge at Effluent Discharge Location WN004 has been variable over time, which allows discrete NDMA effluent release impacts to be observed in EPA-MW-424. Other wells in the Study Area are not situated or screened in a manner that allows similar analysis.

Figure 4-12 is a chart illustrating this evaluation. The Whittier Narrows WRP NDMA effluent concentration is shown in black. The blue line represents the calculated diluted NDMA concentration at Effluent Discharge Location WN004 based on the inflow of upstream water, the Whittier Narrows WRP NDMA effluent concentrations, and the time periods when effluent was discharged at Effluent Discharge Location WN004. The red line represents NDMA concentrations in Well EPA-MW-424. Note that there is almost no lag time between surface water concentration peaks and groundwater peaks. The figure shows a general correlation between effluent concentrations and nearby groundwater concentrations. Figure 4-12 shows several spikes in NDMA concentrations at Effluent Discharge Location WN004 when effluent was being discharged at this effluent discharge location. In some cases EPA-MW-424 was not sampled during the surface water spikes and the relationship between surface water and groundwater concentrations cannot be evaluated. Focusing on the surface water spike in September 2004, groundwater concentrations in EPA-MW-424 are higher than the calculated diluted concentration indicating no NDMA attenuation in the vadose zone. During a second surface water spike in November 2005, the correlation shows that NDMA in recharge water (diluted effluent) is attenuated by about 50 percent by the time it reaches nearby groundwater (Well EPA-MW-424). These variable results make it difficult to quantify vadose zone attenuation of NDMA.

Attenuation of NDMA in the vadose zone appears to be taking place at the spreading grounds as NDMA is rarely detected at concentrations above 10 ng/L in shallow monitoring wells in the vicinity of the spreading grounds even given the large quantities of recycled water recharged. An attempt was made to quantify the attenuation by comparing the recharge water NDMA concentrations at the San Gabriel Spreading Grounds from direct deliveries at Effluent Diversion Location SJCSGSG to observed concentrations in Well 1620RR. The percent reduction between the intake water and groundwater at Well 1620RR is between 74 and 98 percent (see Table N-9 in Appendix N). The highest intake concentration correlates to the lowest reduction, which is consistent with the literature, indicating higher attenuation at lower recharge water NDMA concentrations (see Section 3). However, it is noted that the attenuation is not attributed solely to vadose zone biodegradation. Sunlight photolysis that takes place as the water spreads out in the recharge basins and slowly infiltrates is expected to significantly reduce NDMA levels in the recharge water compared with intake concentrations. Therefore, data at the spreading grounds is also not sufficient to quantify vadose zone attenuation of NDMA.

Degradation of NDMA in groundwater was assessed by evaluation of NDMA concentration contour maps. The mass of NDMA in groundwater was estimated based on the concentration contour maps prepared for September 2006 and May/June/July 2007 (Figures 4-9 and 4-10, respectively). Cross sections indicate that NDMA detections extend to a maximum depth of about 200 feet bgs in some portions of the Study Area (see Figures N-30 to N-35 in Appendix N). Therefore, for calculation of the NDMA mass in groundwater, a saturated thickness of 200 feet was used. The representative average groundwater NDMA concentration in the 200-foot interval was assumed to be 50 percent of the contoured levels shown in Figures 4-9 and 4-10.

The contoured NDMA levels represent the concentrations observed in the upper shallow aquifer. A concentration representative of the entire 200-foot thickness will be lower than that observed in shallow monitoring wells. The effective porosity of this interval was assumed to be 20 percent based on values presented in the literature for the mix of fine- and coarse grained materials (USGS, 1983). While there is uncertainty in the selected parameters for estimating the mass of NDMA in the aquifer, the estimates are used to compare the relative difference in mass between time periods rather than provide absolute estimates. Table 4-2 presents the estimated NDMA mass in the groundwater. As shown in the table, the mass of NDMA in the groundwater decreased significantly in May/June/July 2007 to 1.1 kilograms (kg) after implementation of sequential chlorination at the WRPs compared with the estimated 3.1 kg in September 2006.

Table 4-2 Estimated Mass of NDMA in Groundwater

Date	Mass of NDMA (kg)
September 2006	3.1
May/June/July 2007	1.1

kg - kilograms

For comparison, the total mass of NDMA in effluent discharged from the WRPs in the Study Area (excluding flow directly to the spreading grounds and to Effluent Discharge Location SJC001 in the lined San Gabriel River) from January 2000 to July 2007 is estimated to be 437 kg. The estimated mass of NDMA in effluent is calculated based on the daily effluent discharge volume and the monthly effluent concentration. The NDMA mass for the recharge water through river segments into groundwater was estimated using the concentration in surface water (excluding the spreading grounds) and an estimated river recharge rate (see Table L-11 in Appendix L). The estimated recharge water NDMA mass for the period from January 2000 to July 2007 is 19.6 kg. The comparison between the total effluent mass and recharge water mass indicates the following processes: 1) photolytic decay in surface water of the river segments in the Study Area, and 2) a larger fraction of surface water flow out of the Study Area and a smaller fraction of surface water flow recharged into groundwater. The comparison between the recharged mass and the groundwater mass demonstrates that NDMA mass is potentially reduced by several factors including: 1) biodegradation in the vadose zone and groundwater, 2) removal by extraction wells, and 3) downstream migration at a residual concentration. The calculated amount of total NDMA mass pumped through extraction wells is minor and based on the NDMA groundwater contour maps, no significant NDMA mass leaves the Study Area as subsurface flow in groundwater. As a result, the mass balance of NDMA in groundwater indicates significant NDMA has been biodegraded in groundwater, as well as in the vadose zone.

Further evidence of biodegradation in groundwater is the significant reduction in estimated mass of NDMA in the groundwater between September 2006 and May/June/July 2007. This mass reduction indicates that NDMA is likely being removed in the groundwater system due to biodegradation. If NDMA were not removed by biodegradation in groundwater, the size of the area of detectable NDMA and the NDMA mass would increase over time as more NDMA is continually added to the system. Comparison of the September 2006 NDMA concentration contour map (Figures 4-9) representing conditions prior to implementation of sequential chlorination and the May/June/July 2007 NDMA concentration contour map (Figure 4-10) representing conditions after implementation of sequential chlorination shows that the magnitude and extent of NDMA decreased quickly in response to reduction in effluent concentrations and that NDMA mass is being removed from the groundwater system, presumably by biodegradation.

In order to quantify NDMA removal in groundwater, conditions near Effluent Discharge Location WN004 in the Whittier Narrows were evaluated. The variable, temporally discrete discharge of effluent at Effluent Discharge Location WN004 makes this effluent discharge location well suited for evaluation of NDMA attenuation in groundwater. Figure 4-13 shows NDMA concentration contour maps for September 2004 and September 2005 in the vicinity of the Whittier Narrows WRP Effluent Discharge Location WN004. A chart showing NDMA concentrations released at Effluent Discharge Location WN004, diluted effluent concentrations, and Well EPA-MW-424 concentrations is also shown in the figure. The September 2004 NDMA concentration contour map is representative of groundwater impacts during a period of discharge at Effluent Discharge Location WN004 as indicated by the relatively higher NDMA detections and greater areal extent of detections in September 2004 compared with September 2005. The September 2005 NDMA concentration contour map represents the end of a five month period (April to September 2005) when there was no discharge at Effluent Discharge Location WN004. Based on the assumptions discussed above it is estimated that the mass of NDMA in the groundwater in the local area in September 2004 and September 2005 was 394 and 12 grams, respectively. Comparison of the mass in groundwater for the two contour maps allows for an estimation of NDMA attenuation in groundwater. Because there was remedial extraction at Wells EPA-EW-403, EPA-EW-407, EPA-EW-408, EPA-EW-CB1, and EPA-EW-CB2 beginning in late 2004, removal of NDMA mass by extraction was accounted for in the analysis. It is estimated that about 59 grams of NDMA was removed from the system by groundwater extraction between September 2004 and September 2005. Table 4-3 presents the NDMA estimates.

Table 4-3 Estimated Mass of NDMA in Groundwater Near Effluent Discharge Location WN004

Date	Mass of NDMA (g)
Groundwater Mass in September 2004	394
Mass Removed by EPA-EW-403, EPA-EW-407, EPA-EW-408, EPA-EW-CB1, and EPA-EW-CB2 from September 2004 to September 2005	59
Groundwater Mass in September 2005	12
Estimated attenuation by biodegradation in groundwater from September 2004 to September 2005	82%

g - gram

Comparison of the September 2004 and September 2005 NDMA groundwater masses can be used to estimate the amount of NDMA mass removed by biodegradation. Of the 394 grams of NDMA in groundwater in September 2004, 59 grams was subsequently removed by extraction wells, and 12 grams remained in the groundwater in September 2005, leaving 323 grams removed from groundwater, presumably by biodegradation. This represents an 82 percent reduction in NDMA mass over a period of one year.

The findings from this investigation are consistent with those presented in the scientific literature for saturated and unsaturated soil columns under laboratory conditions (Drewes, et al., 2006). For example, Drewes, et al. (2006) suggest that NDMA is more readily biodegraded when NDMA concentrations are lower (in the range of a few hundred ng/L) and when an adapted biocommunity is present. It is expected that the rate of NDMA degradation in the Study Area will increase now that NDMA concentrations have been reduced (to levels in the range of a few hundred ng/L) following implementation of sequential chlorination. In addition, most areas of the Study Area are expected to have adapted biocommunities due to the continuous nature of effluent discharges. This is particularly true near the San Jose Creek WRP.

Section 5: Mathematical Modeling

In order to simulate the fate and transport of NDMA in the Study Area and to predict future groundwater concentrations based on reduced NDMA levels in effluent, surface water and groundwater flow and transport models were developed, calibrated, and applied. The surface water model is discussed in Appendix O and the groundwater model is discussed in Appendix P.

5.1 Model Transport Scenarios

Three transport scenarios were simulated during surface and groundwater modeling. The model scenarios simulated NDMA concentrations under three conditions including: 1) historically observed, 2) currently observed, and 3) potential future. All three scenarios were based on the flow conditions observed during the past six years from October 2000 to September 2006. Flow conditions include observed effluent discharge volumes, stream flows at surface water gauging stations, and estimated groundwater recharge and discharge. The three scenarios varied only in the input NDMA effluent concentrations. Flow calibrations were based on data available through September 2006, as groundwater pumping data for the San Gabriel Basin was not available beyond that date. However, the transport model was based on all data available through July 2007.

Scenario 1 was based on historically observed effluent concentrations for the past six years. Scenario 2 was based on the typical average effluent concentration currently being achieved with the recent implementation of sequential chlorination. Scenario 3 was based on potential future effluent NDMA concentrations assuming NDMA is reduced further with the implementation of UV treatment at the Whittier Narrows and San Jose Creek WRPs. NDMA in effluent releases from the Pomona WRP is not pertinent to the transport analysis because NDMA released from this WRP is removed by photolysis from exposure to sunlight prior to reaching unlined river segments. Table 5-1 presents the input effluent concentrations used for the scenarios.

In order to evaluate the impacts of current reductions in NDMA concentrations since implementation of sequential chlorination and to compare these improvements with potential additional NDMA effluent reductions that could possibly be achieved if UV treatment were implemented at both the San Jose Creek and Whittier Narrows WRPs, the models simulated NDMA in surface water and groundwater in the future (March and September 2008) based on Scenarios 2 and 3 effluent concentrations. Future simulations were generated using the past six years of flow data. Therefore, March and September 2008 reflect flow conditions observed in March and September 2002. 2002 was a relatively low rainfall year and likely represents a conservative representation of NDMA in groundwater since dilution was minimal. March is representative of wetter spring conditions and September is representative of drier fall conditions.

Table 5-1 Modeling Scenarios

Scenario	Flow Conditions	Effluent Concentration (ng/L)		
		San Jose Creek East	San Jose Creek West	Whittier Narrows
Scenario 1	Observed flow conditions over the past six years	Variable effluent concentrations from observed data collected over the past six years		
Scenario 2	Observed flow conditions over the past six years	305	413	168
Scenario 3	Observed flow conditions over the past six years	125	125	92

ng/L – nanograms per liter

5.2 Receptor Wells

For the purpose of assessing model results six key receptor wells were selected (Figure 5-1). The receptor wells represent shallow monitoring wells located in close proximity to effluent discharge locations. Table 5-2 lists the receptor wells and associated effluent discharge locations. These wells represent monitoring points likely most sensitive to impacts from recharge of recycled water.

Table 5-2 Modeling Receptor Wells

Receptor Well	Effluent Discharge Location	Screened Interval (feet bgs)
SJC-MW-1	SJC002	50 – 70
SJC-MW-2	SJC003	40 – 60
SJC/WN-MW-4	WN001	40 – 60
1620RR	SJCSGSG	50 – 80
EPA-MW-426	WN002	27 – 52
EPA-MW-424	WN004	25 – 45

bgs – below ground surface

5.3 Surface Water Modeling

Based on the scientific literature and Study Area observation data, NDMA is removed by photolysis in surface water. Dilution due to mixing with essentially NDMA-free water sources such as imported water and local water also reduces NDMA concentrations in surface water. Specifically, the transport submodel in the surface water model considered advection, dispersion (and molecular diffusion), and mass decay caused by photolysis.

The domain for the surface water model covers the San Gabriel River, Rio Hondo, San Jose Creek, and Zone 1 Ditch into which the recycled water from the WRPs is released at eight effluent discharge locations (Figure 4-2).

The surface water system was modeled using the WASP™ version 7.2 modeling software (USEPA, 2006). NDMA transport was simulated using the TOXI™ program, part of the WASP model package (Wool, et al., 2005).

Surface water modeling indicates that the relative amounts of NDMA attenuation from photolysis and dilution are highly variable based on location within the model and the amount of inflow of effluent, imported water, and storm water. During storms, periods of imported water releases, and periods of upstream reservoir releases, dilution accounts for the majority of the reduction in NDMA observed in surface water. During periods when recycled water accounts for most or all of the water in the surface water system, photolysis is the dominant removal process.

For the period from January to December 2005, surface water modeling shows that from the confluence of the San Gabriel River and San Jose Creek to Surface Water Gauging Station F262C-R (south of the San Gabriel Spreading Grounds), photolytic removal accounts for 70 to 90 percent of the NDMA reduction during dry months. Lower percentages were noted during the high flow months of March, November, and December 2005 when photolysis accounted for about 50 to 60 percent of the reduction in NDMA concentration. During the highest flow month (February 2005), photolytic removal accounted for about 30 percent of the decrease in NDMA concentration. These percentages can change dramatically with location, rainfall, and inflow conditions, depending on the travel time of recycled water from effluent discharge locations to the location of interest.

Scenario 1 simulated the historic NDMA concentrations observed in effluent and surface water. The surface water model was calibrated using the observed NDMA concentration in surface water and was able to achieve a good match to the data (see Appendix O). Scenario 2 simulated NDMA concentrations in surface water resulting from the current lower NDMA levels in effluent. NDMA concentrations in surface water were substantially lower under Scenario 2 compared with historically observed conditions (Scenario 1). For example, at locations near the effluent discharge locations such as Surface Water Station R-11 on the San Gabriel River and Surface Water Station R-D-WN on the Rio Hondo, the mean NDMA concentration showed a nearly fourfold decrease from historical conditions. Downstream surface water stations also showed substantial declines in both the San Gabriel River and Rio Hondo. The results demonstrate that the currently reduced NDMA effluent concentrations have significant impact on NDMA concentrations in the surface water system.

The simulated potential future NDMA concentrations in the surface water are further reduced under Scenario 3. The mean NDMA concentrations in Scenario 3 are less than half of the comparable Scenario 2 results. This indicates the addition of the UV treatment would further reduce NDMA concentrations in the surface water system.

5.4 Groundwater Modeling

Based on the scientific literature and Study Area observation data, NDMA is removed by biodegradation in the vadose zone and groundwater. Within groundwater NDMA concentrations are also reduced due to mixing and spreading mechanisms (e.g., hydrodynamic dispersion, macrodispersion, and diffusive mass transfer). The transport submodel in the groundwater model incorporated biodegradation in groundwater, advection along with mean fluid velocity, local dispersion caused by pore-scale variability in velocity, and macrodispersion caused by field-scale heterogeneity. Vadose zone biodegradation was not applied in the modeling due to variability in vadose zone thickness, uncertainty in vadose zone travel time, and uncertainty in the rate of vadose zone attenuation.

The groundwater model domain consists of the Montebello Forebay, the southern portion of the Main San Gabriel Basin, the entire Puente Subbasin, as well as the northern portion of the Central Basin in contact with the Montebello Forebay. The extent of the model domain reflects the path of potential migration of NDMA away from the WRP effluent discharge locations and is in part based on previous regional groundwater flow models and available data.

The numerical model was constructed using the FEFLOW™ software package for modeling fluid flow and solute transport in the subsurface. FEFLOW is a finite-element numerical model (WASY, 2006).

Representation of the various hydrogeologic layers within the FEFLOW model domain was accomplished through the incorporation of previous published cross sections and historical interpretations of subsurface layering (USGS, 2003; DWR, 1961; DWR, 1966; GeoSystem, 1998; and CH2M HILL, November 1997a). These resources were combined with a new comprehensive interpretation and spatial interpolation of available well logs. The interpretation was performed through use of the EVS three-dimensional interpolation and visualization software environment (CTECH, 2006). Figure 5-2 illustrates representative cross sections through the model domain. The cross sections show the nine model slices representing the principal layers in the model domain. Elevation Slice 1 represents the ground surface.

Simulated NDMA results from the surface water model scenario simulations were input to the groundwater model. The groundwater model was calibrated to observed historical water levels and water quality and achieved a good match as discussed and presented in Appendix P.

5.4.1 Historic and Current Simulations - Scenarios 1 and 2

Figure 5-3 shows the simulated NDMA concentration contours in March 2006, June 2006, September 2006, and July 2007 in the upper shallow aquifer. The upper shallow aquifer is the zone screened by most shallow monitoring wells in the Study Area. March 2006, June 2006, and September 2006 represent historic conditions (Scenario 1), while July 2007 represents the effects of current effluent concentrations (Scenario 2) achieved after implementation of sequential chlorination in late 2006 and early 2007. The simulated Scenario 1 NDMA groundwater concentrations in September 2006 were used as the starting condition for the July 2007 Scenario 2 prediction. The model time period was extended into the future based on representative historical flow conditions. The receptor wells and all active production wells used for domestic supply within ½ mile of the recharge areas are shown in the figure. Active irrigation wells not used for water supply are also shown in the figure. Comparison of these simulated NDMA concentration contour maps with the measured NDMA concentration contour maps (Figures N-24 through N-27 in Appendix N) indicates that the calibrated transport model reasonably reproduces the temporal change in NDMA in groundwater characterized by the measured NDMA concentrations in a number of monitoring and production wells. The simulations for March and June 2006 show two production wells (2947LM and 201-W5) in the contour interval greater than 10 ng/L. The September 2006 simulation shows one production well (2947LM) in the area of NDMA concentrations above 10 ng/L. No production wells used for domestic supply are within the 10 ng/L concentration contour in the Scenario 2, July 2007 simulation. These results are consistent with the observed data. Well 2947LM is screened from 180 to 800 feet bgs and Well 201-W5 is screened from 160 to 520 feet bgs. Historically NDMA migrated to these wells in the shallowest portion of the screens. Concentrations measured in the production wells were lower than the simulated concentrations in the upper shallow aquifer due to dilution through mixing with water from deeper portions of the aquifer. The simulated NDMA concentrations for July 2007 (Figure 5-3) do not show a detection at Well EPA-EW-CB1 while the observed NDMA concentrations in Well EPA-EW-CB1 were 3.3 ng/L in March 2007, 10 ng/L on June 18, 2007, and 6 ng/L on June 26, 2007. It is possible that the detection at 10 ng/L was a short-term impact not represented in the July 2007 model simulation.

In looking at the progression of the simulated NDMA concentration contour maps side by side on Figure 5-3, it is clear that while the accumulated NDMA mass recharged to groundwater monotonically increases with time, no long-term accumulation or increase of NDMA mass is observed in the simulated NDMA concentration contour maps. Furthermore, the size of the July 2007 NDMA area is significantly smaller than in previous maps.

Figure 5-4 shows the simulated NDMA concentration contours in March 2006, June 2006, September 2006, and July 2007, respectively, in the lower shallow aquifer. The lower shallow aquifer is representative of the zone screened by most production wells (with relatively shallow screens) in the Study Area. It can be seen that the simulated NDMA concentrations in this zone are much smaller than those in the upper shallow aquifer, indicating that there is little vertical migration of NDMA into deeper aquifers. Production Well 2947LM is screened in the lower shallow aquifer and the simulations show this well is within the 10 ng/L concentration contour in March, June, and September 2006, which is consistent with the observed data. The simulated area of NDMA concentrations greater than 10 ng/L in the lower shallow aquifer is very limited in July 2007 following implementation of sequential chlorination. The July 2007 contour map shows no NDMA impacts to production wells, which is consistent with the observed data.

5.4.2 Future Simulations - Scenarios 2 and 3

Figure 5-5 shows the predicted NDMA concentrations in March and September 2008 for current treatment conditions (Scenario 2, sequential chlorination) in the upper and lower shallow aquifers. March 2008 represents wet spring conditions during a relatively dry year. September 2008 represents the dry fall conditions during a relatively dry year. For the current scenario, in the upper shallow aquifer, the predicted area of NDMA in groundwater in March 2008 at concentrations higher than 10 ng/L, is limited to a narrow shallow zone along the San Gabriel River and Rio Hondo in the vicinity of WRP effluent discharge locations. For the current scenario, in the lower shallow aquifer, the predicted NDMA in groundwater in March 2008 shows a very small area of NDMA concentrations higher than 10 ng/L along the San Gabriel River.

For the current scenario, in the upper shallow aquifer, the predicted NDMA in groundwater in September 2008 at concentrations higher than 10 ng/L, is limited to a very narrow shallow zone along the San Gabriel River and Rio Hondo in the vicinity of WRP effluent discharge locations. For the current scenario, in the lower shallow aquifer, the predicted NDMA in groundwater in September 2008 shows a very small area of NDMA concentrations higher than 10 ng/L along the San Gabriel River. As a result of reduced effluent concentrations following implementation of sequential chlorination, no production wells currently being operated in the Study Area are within the 10 ng/L contours in the upper or lower shallow aquifer for the March and September 2008 simulations. The 2008 simulations represent conservative (most likely to show high NDMA concentrations in groundwater) conditions because they reflect a relatively dry year with minimal dilution by rainfall infiltration. No production wells used for domestic supply are within the simulated 10 ng/L contour for any of the predicted conditions under Scenario 2 (sequential chlorination).

Figure 5-6 shows the predicted NDMA concentrations in March and September 2008 for potential future conditions (Scenario 3, UV treatment) in the upper and lower shallow aquifers. The figure shows that under Scenario 3 in the upper shallow aquifer there is a narrow band of NDMA at concentrations above 10 ng/L along the San Gabriel River and Rio Hondo. In the lower shallow aquifer, under potential future conditions, NDMA concentrations are less than 10 ng/L everywhere in the Study Area.

The predicted NDMA concentrations under potential future conditions with implementation of UV are lower than those predicted for current conditions and the extent of NDMA is also less extensive. The simulated mass of NDMA in groundwater in March 2008 under Scenarios 2 and 3 is 212 and 101 grams, respectively. In September 2008, the simulated mass of NDMA in groundwater under Scenarios 2 and 3 is 224 and 99 grams, respectively. Thus UV treatment is estimated to result in a 52 to 56 percent reduction in total mass of NDMA in groundwater in 2008 compared with sequential chlorination. No production wells used for domestic supply are within the simulated 10 ng/L contour for any of the predicted conditions under Scenario 3 (UV treatment).

5.4.3 NDMA Mass Recharged

For comparison, the simulated mass of NDMA recharged into groundwater over the six year simulation period was estimated for each of the scenarios. At the historic observed NDMA effluent concentrations (Scenario 1), it is estimated that 19.61 kg of NDMA were recharged to groundwater from October 1, 2000 to September 30, 2006. This is equivalent to 3.8 kg per year. In comparison, under the same discharge conditions with the lower current NDMA effluent concentrations (Scenario 2), it is estimated that 4.04 kg would be recharged. This is equivalent to 0.8 kg per year. With further reduction in NDMA concentrations through potential implementation of UV treatment (Scenario 3), it is estimated that 2.02 kg would be recharged, which is equivalent to 0.4 kg per year.

5.4.4 Groundwater Modeling Results

Model predictions indicate that at the lower NDMA effluent levels now being achieved at the San Jose Creek and Whittier Narrows WRPs, NDMA impacts to groundwater at levels above 10 ng/L will be limited to a narrow shallow band beneath the unlined reaches of the rivers near the WRPs. Model predictions find that at the lower NDMA effluent concentrations expected with UV treatment, NDMA will still occur at concentrations above 10 ng/L in shallow groundwater immediately beneath the unlined portions of the rivers near the WRPs. Due to the thin vadose zone and limited opportunity for biodegradation prior to reaching groundwater, impacts to a small volume of groundwater are unavoidable. Under both the prediction scenarios, impacts to groundwater are very limited in magnitude and extent and no impacts to production wells are predicted as a result of NDMA levels reduced in effluent with implementation of sequential chlorination.

Section 6: Summary of Results

The Montebello Forebay Attenuation and Dilution Studies were conducted to evaluate the fate and transport of NDMA from the WRP effluent discharge locations to groundwater. For that purpose, a combination of extensive field monitoring of NDMA concentrations and flow conditions and numerical modeling of NDMA transport in the coupled surface water and groundwater system was employed. The studies were initially focused on the spreading grounds where the greatest volumes of recycled water are recharged. However, when the Sanitation Districts ceased direct deliveries of recycled water to the spreading grounds in 2004, there were substantial reductions in subsurface NDMA concentrations at the spreading grounds. Additionally, installation and testing of new and existing wells across the Study Area found that the areas with the highest levels of NDMA in groundwater are near the WRPs' effluent discharge locations upstream of the spreading grounds. As a result, the main project focus was redirected to these areas.

Assessment of recycled water quality found that there have been significant changes in NDMA concentrations over the period of available data from 2000 to 2007. Initially from about 2000 to 2003, NDMA concentrations in effluent were typically at levels of several hundred ng/L. Beginning in 2003, with the full implementation of NDN treatment, NDMA concentrations rose significantly to levels of several thousand ng/L at the San Jose Creek WRP. Most of the data collected during this investigation represents impacts to groundwater from these higher effluent NDMA levels. Monitoring results indicate that when recycled water with NDMA concentrations of several thousand ng/L is incidentally recharged near the effluent discharge locations, NDMA is detected in groundwater at concentrations of up to several hundred ng/L and areas of NDMA detections in groundwater extend away from these incidental recharge areas. In contrast, NDMA was rarely detected near the spreading grounds when recycled water containing NDMA at these higher concentrations was recharged at the spreading grounds, as long as direct deliveries of recycled water were not made to the spreading grounds.

Following the observed increase in effluent NDMA levels resulting from NDN implementation, the Sanitation Districts began evaluating various treatment system modifications to address NDMA levels. As a result, sequential chlorination was implemented at the San Jose Creek and Whittier Narrows WRPs in late 2006 and early 2007. The process reduced NDMA levels at the WRPs, in some cases by as much as an order of magnitude. NDMA levels in effluent are currently at levels in the low hundreds of ng/L. While the intensive monitoring program conducted during this investigation was scheduled to be completed in December 2006, sampling continued in a subset of wells into 2007 to evaluate changes in groundwater quality resulting from lower effluent NDMA levels. This additional monitoring found that NDMA levels in groundwater declined quickly in response to lower NDMA levels in effluent. In addition, the magnitude and extent of NDMA in groundwater decreased following implementation of sequential chlorination.

The extensive monitoring network established and monitored for this investigation provided direct observation of photolysis in surface water and biodegradation in the vadose zone and groundwater. This investigation found significant removal of NDMA in surface water systems caused by NDMA photolysis. An NDMA half-life of 2.2 hours was estimated based on sampling along the San Jose Creek during periods when no dilution water was available. When available, dilution with imported and storm water will further reduce NDMA concentrations in surface water. Biodegradation in the vadose zone, while implied by the lack of detections in groundwater near the spreading grounds, could not be quantified based on the available field observation data. In groundwater, NDMA is biodegraded as demonstrated by:

- Significant temporal change in the NDMA mass in groundwater estimated from observed NDMA concentrations and NDMA concentration contour maps;

- Quick and dramatic reduction in NDMA groundwater concentrations in response to the significant reduction in effluent concentration following implementation of sequential chlorination, and

- An approximately 80 percent mass reduction over a period of one year based on evaluation of data near Effluent Discharge Location WN004.

Dispersion, dilution, and groundwater extraction further reduce NDMA concentrations in groundwater.

NDMA in groundwater in the Study Area appears to occur primarily in the upper 200 feet bgs. As a result, most production wells, which are usually screened at greater depths, have not detected NDMA. Nonetheless, NDMA was detected at low levels in a few production wells in the Study Area. NDMA was detected once in a production well used for domestic supply above 10 ng/L. This detection occurred in December 2004. NDMA concentrations in water delivered to customers from this well were below 10 ng/L in December 2004 due to treatment (to remove VOCs) and blending prior to delivery to customers. There have been no detections above 10 ng/L since that time. Based on the rapid reductions in NDMA observed in groundwater following implementation of sequential chlorination, it is anticipated that NDMA detections in production wells will also show declining trends in the future. Groundwater modeling supports this expectation.

The field observations of photolysis in the surface water system and biodegradation in the groundwater system were incorporated into the surface water and groundwater flow and transport models. The surface water model was calibrated using the observed NDMA concentration at surface water stations and the spreading grounds intake points. Specifically, the site-specific first-order decay constant for photolysis was calibrated for the river segments. The calibrated NDMA half-lives for the surface water model ranged from 0.6 to 4.8 hours, depending on river segment characteristics. The groundwater flow and transport model was calibrated against observed groundwater elevations and NDMA concentrations in monitoring and production wells. Biodegradation, the key process required to address the observed behavior of NDMA in groundwater during transport, was calibrated using the first-order decay model. The calibrated decay constant was 0.01 day^{-1}, with a half-life of 69 days for most of the groundwater system. A higher decay constant of 0.04 day^{-1} was used to account for the adapted biocommunity likely present in the San Jose Creek area caused by continuous effluent discharge at Effluent Discharge Location SJC002, and the corresponding biodegradation. A good match was obtained between observed and calibrated time-concentration data in a number of wells. All the biodegradation parameters used in the calibrated groundwater transport model are consistent with laboratory observations reported in the literature.

The calibrated surface water and groundwater models were used to simulate observed NDMA concentration conditions (Scenario 1), to predict future concentrations as a result of lower NDMA effluent concentrations achieved with sequential chlorination (Scenario 2), and to predict the NDMA groundwater concentrations in response to the even lower NDMA effluent concentrations expected to be achieved if UV treatment were implemented at the WRPs

(Scenario 3). Model predictions indicate that at the lower NDMA effluent levels now being achieved at the San Jose Creek and Whittier Narrows WRPs, NDMA in groundwater at levels above 10 ng/L will be limited to a narrow shallow band beneath the unlined reaches of the rivers near the WRPs. Model predictions find that at the lower NDMA effluent concentrations expected with UV treatment, NDMA would still occur at concentrations above 10 ng/L in shallow groundwater immediately beneath the unlined portions of the rivers near the WRPs.

The model has shown that groundwater conditions are rapidly changing and have drastically improved following the implementation of sequential chlorination. However, due to the thin vadose zone and limited opportunity for biodegradation prior to reaching groundwater, impacts to a small volume of groundwater are unavoidable. Although it is uncertain what future treatment technologies will be implemented by the Sanitation Districts, the WRPs will continue, at a minimum, to operate sequential chlorination at the San Jose Creek and Pomona WRPs and to construct and operate UV treatment at the Whittier Narrows WRP. Additionally, the Sanitation Districts are committed to continuing ongoing efforts to further reduce NDMA concentrations at the WRPs and in the groundwater.

Under the prediction scenarios, NDMA concentrations in groundwater are very limited in magnitude and extent with no predicted impacts to production wells currently located in the Study Area. Regarding potential new production wells, anyone seeking to drill a well in the area would have to have a water right, satisfy any obligations set by the groundwater basin's Watermaster, and obtain appropriate permits, including a water supply permit from DPH. For this type of situation, DPH would conduct an evaluation pursuant to Policy Memo 97-005, which would address treatment and risks associated with any contaminants present in order for the source to be used for drinking water.

Section 7: Conclusions

The conclusions presented below were developed from the Montebello Forebay Attenuation and Dilution Studies.

- NDMA is found in effluent from the WRPs operated by the Sanitation Districts that supply recycled water to the Montebello Forebay. Effluent NDMA concentrations have varied over the period of record since low-level sampling was initiated in 2000.

- Implementation of NDN treatment in 2003 caused a significant rise in effluent NDMA concentrations at the San Jose Creek WRP. Effluent NDMA concentrations at the San Jose Creek and Whittier Narrows WRPs decreased when the Sanitation Districts implemented sequential chlorination in late 2006 and early 2007.

- NDMA in effluent from the San Jose Creek East WRP averaged about 333 ng/L prior to NDN implementation and 2,534 ng/L after NDN implementation and prior to sequential chlorination implementation. Since implementation of sequential chlorination, NDMA concentrations have been reduced to an average of 276 ng/L at San Jose Creek East WRP. Similarly, the average NDMA concentration at the San Jose Creek West WRP averaged 169 ng/L prior to NDN implementation and 1,151 ng/L after NDN implementation and prior to sequential chlorination implementation. Since implementation of sequential chlorination, NDMA concentrations have been reduced to an average of 371 ng/L at San Jose Creek West WRP. NDMA concentrations did not increase at the Whittier Narrows and Pomona WRPs following implementation of NDN treatment. Average NDMA concentrations at the Whittier Narrows WRP were about 363 ng/L prior to implementation of sequential chlorination and have shown a moderate decrease to about 140 ng/L following implementation of sequential chlorination. NDMA concentrations at the Pomona WRP have been relatively stable and averaged about 459 ng/L between July 2000 and July 2007.

- Upon implementation of NDN at the San Jose Creek WRPs, NDMA concentrations in groundwater at the Montebello Forebay significantly increased. However, cessation of direct deliveries of recycled water to the Forebay resulted in substantial reductions in subsurface NDMA concentrations.

- NDMA in effluent from the Pomona WRP is removed through photolysis during surface water transport along the lined portion of the San Jose Creek to the extent that this plant does not provide any mass of NDMA above background to groundwater along the unlined rivers in the Study Area. Based on the observed water quality along San Jose Creek, a NDMA half-life of 2.2 hours was estimated.

- NDMA concentrations in surface water and spreading ground intakes are highly variable due to changes in effluent discharge locations, and availability of imported and local water over time.

- NDMA concentrations in surface water near the WRPs are similar to NDMA concentrations in effluent. NDMA concentrations in surface water decline with distance from the WRP effluent discharge locations due to photolysis and dilution (when other sources of water are available).

- Low-level NDMA analysis of surface water has not been conducted since implementation of sequential chlorination. However, surface water modeling predicts that NDMA levels at locations near the effluent discharge locations such as Surface Water Stations R-11 and R-D-WN should show declines of over an order of magnitude with the reductions in effluent concentrations achieved with implementation of sequential chlorination.

- NDMA concentrations in groundwater show significant fluctuations over time primarily related to variability in effluent discharge locations. Changes in effluent NDMA concentrations and the degree of surface water dilution (with imported and storm water) also effect NDMA concentrations.

- NDMA has been detected in shallow groundwater near the WRP effluent discharge locations and along the unlined San Gabriel River between the Whittier Narrows Dam and the San Gabriel Spreading Grounds at concentrations greater than 10 ng/L. NDMA has rarely been detected above 10 ng/L in monitoring wells near the spreading grounds since direct deliveries of recycled water to the spreading grounds was halted in 2004.

- NDMA has been detected in a few production wells in and just downstream of the Whittier Narrows typically at concentrations below 10 ng/L. NDMA was detected above 10 ng/L in only one sample from a production well used for domestic supply (EPA-EW-CB1); however, water delivered to customers was below 10 ng/L due to application of treatment for other constituents and blending.

- NDMA is rarely detected in production wells near the spreading grounds and has not been detected above 10 ng/L.

- Recent groundwater quality data collected since implementation of sequential chlorination have shown a dramatic improvement in groundwater quality. The groundwater system responded quickly to reductions in effluent NDMA levels.

- Based on the lack of NDMA detections in groundwater near the San Gabriel Spreading Grounds prior to NDN implementation, it appears that direct deliveries of recycled water to the spreading grounds do not cause unacceptable NDMA concentrations at the spreading grounds when NDMA concentrations in the San Jose Creek WRP effluent are at pre-NDN levels. Therefore, such direct deliveries can be reinstated now that NDMA levels have been decreased with implementation of sequential chlorination.

- Observed data, particularly near the spreading grounds, indicate that NDMA is likely being biodegraded in the vadose zone. The data were not sufficient to quantify the rate of biodegradation in the vadose zone. Biodegradation of NDMA in the vadose zone is variable across the Study Area and depends on the thickness of the vadose zone and travel time.

- Observed data indicate that NDMA is being degraded in groundwater in the Study Area. Analysis of data near Effluent Discharge Location WN004 in the Whittier Narrows indicate that biodegradation in groundwater accounted for the removal of about 82 percent of the NDMA in groundwater over a period of one year.

- Modeling of NDMA transport following reductions in effluent NDMA levels with implementation of sequential chlorination (Scenario 2) predict that NDMA impacts to groundwater at levels above 10 ng/L will be limited to a narrow shallow band beneath the unlined reaches of the rivers near the WRP effluent discharge locations.

- Model predictions find that at the lower NDMA effluent concentrations expected if UV treatment were to be implemented (Scenario 3), NDMA will still occur at concentrations above 10 ng/L in shallow groundwater immediately beneath the unlined portions of the rivers near the WRP effluent discharge locations. These concentrations are due to the thin vadose zone and limited opportunity for biodegradation prior to recharge water reaching groundwater.

- Based on conservative estimations of vadose zone biodegradation, impacts to a small volume of groundwater directly under the unlined river reaches near the WRP effluent discharge locations are unavoidable. However, impacts to groundwater are very limited in magnitude and extent with no impacts to production wells.

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Figures

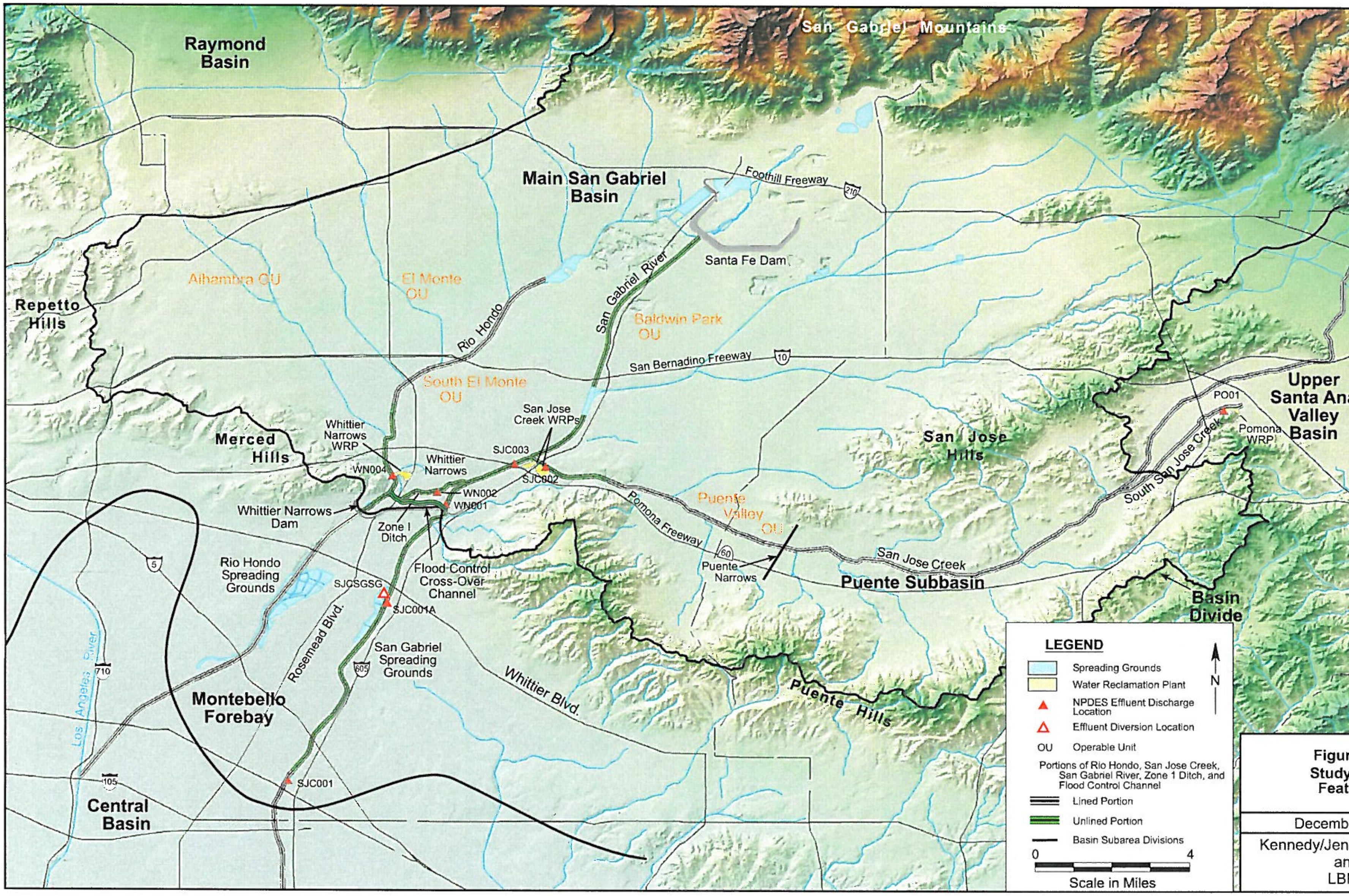
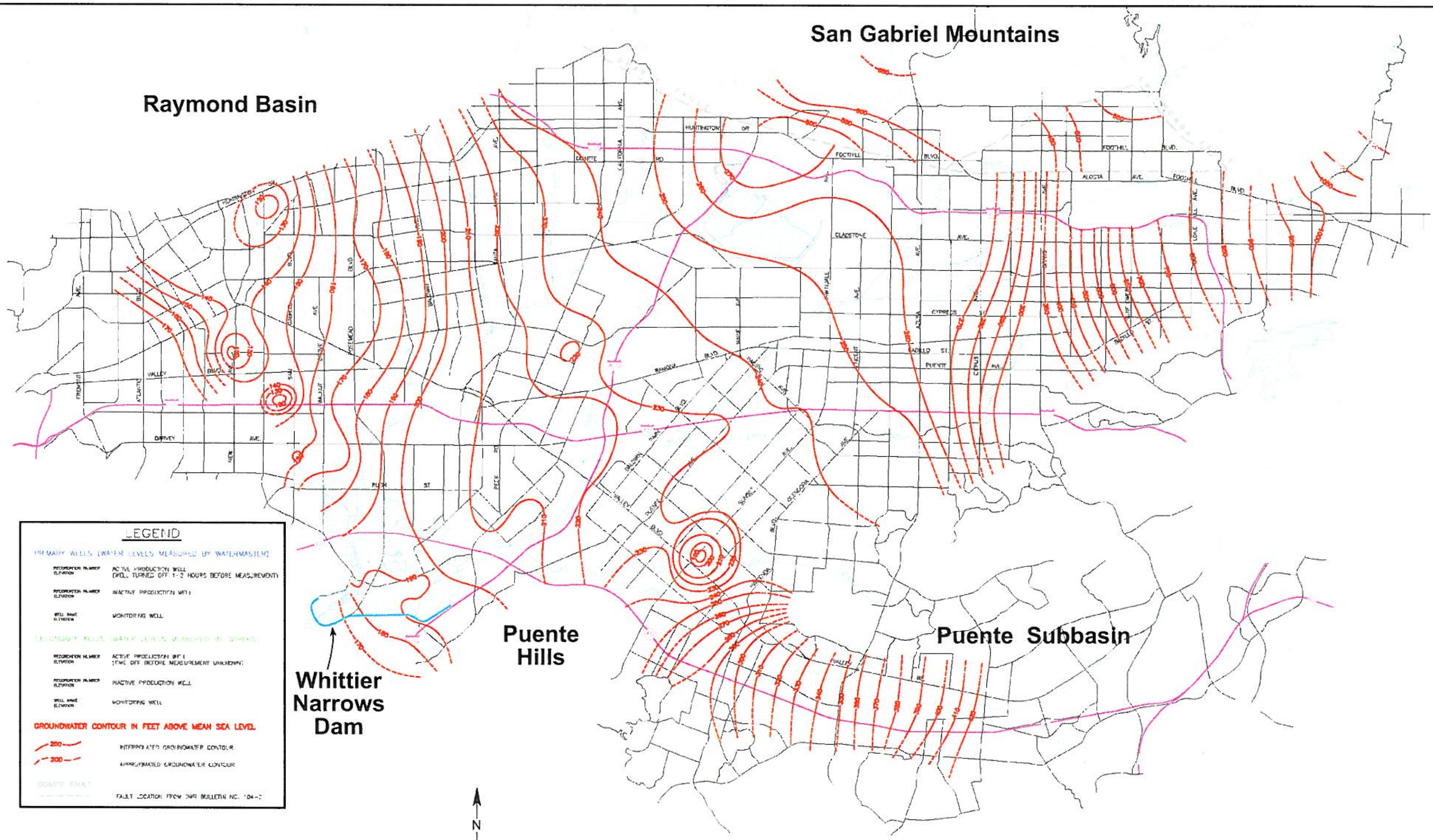


Figure 1-1
Study Area Features

December 2007

Kennedy/Jenks/Todd LLC
and
LBNL



From: Main San Gabriel Basin Watermaster

December 2007	Figure 2-1 Groundwater Elevation Contours in San Gabriel Basin January 2006
Kennedy/Jenks/Todd LLC and LBNL	

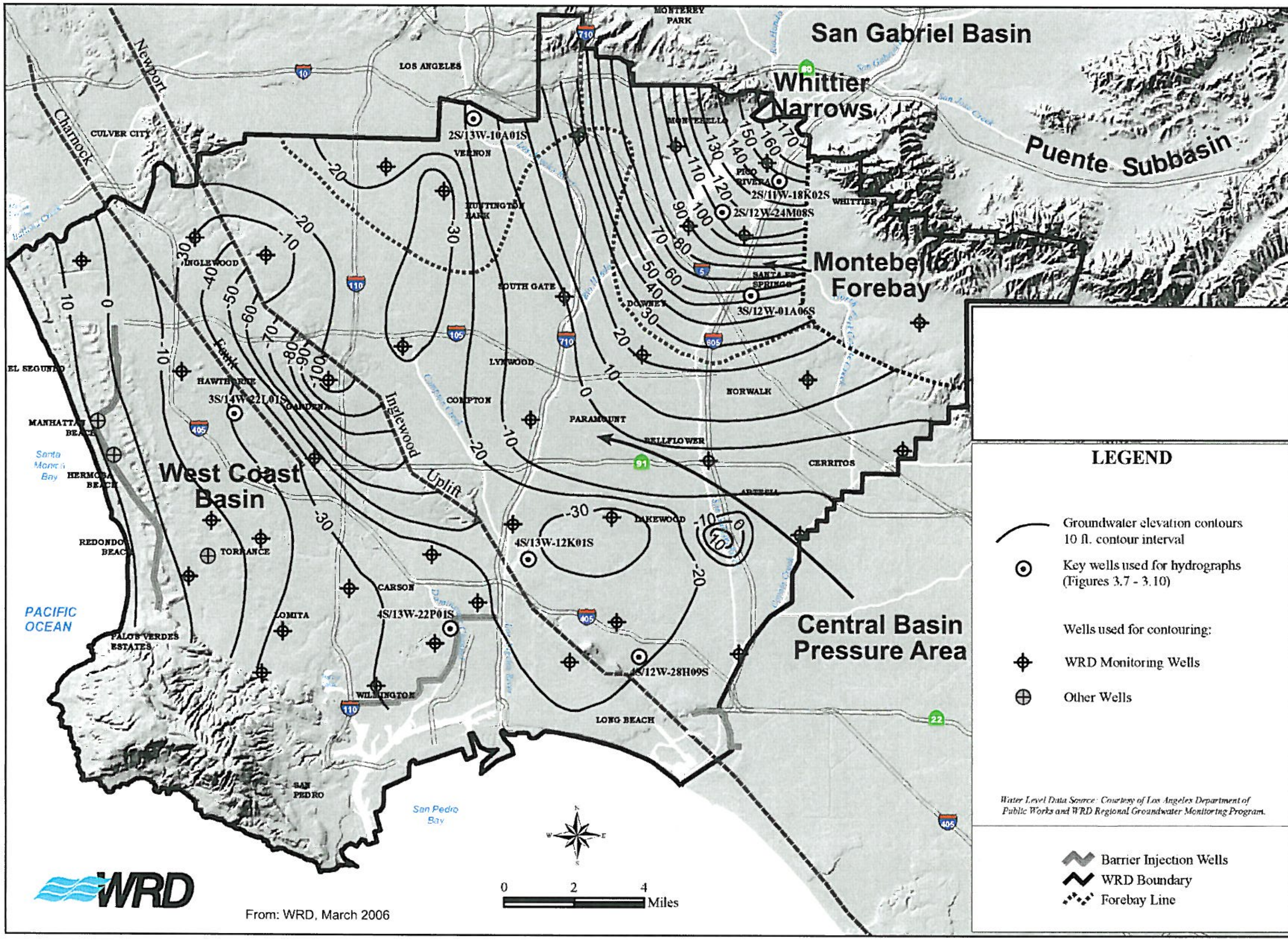


Figure 2-2
Groundwater Elevation Contours in Central Basin Spring 2005

December 2007

Kennedy/Jenks/Todd LLC and LBNL

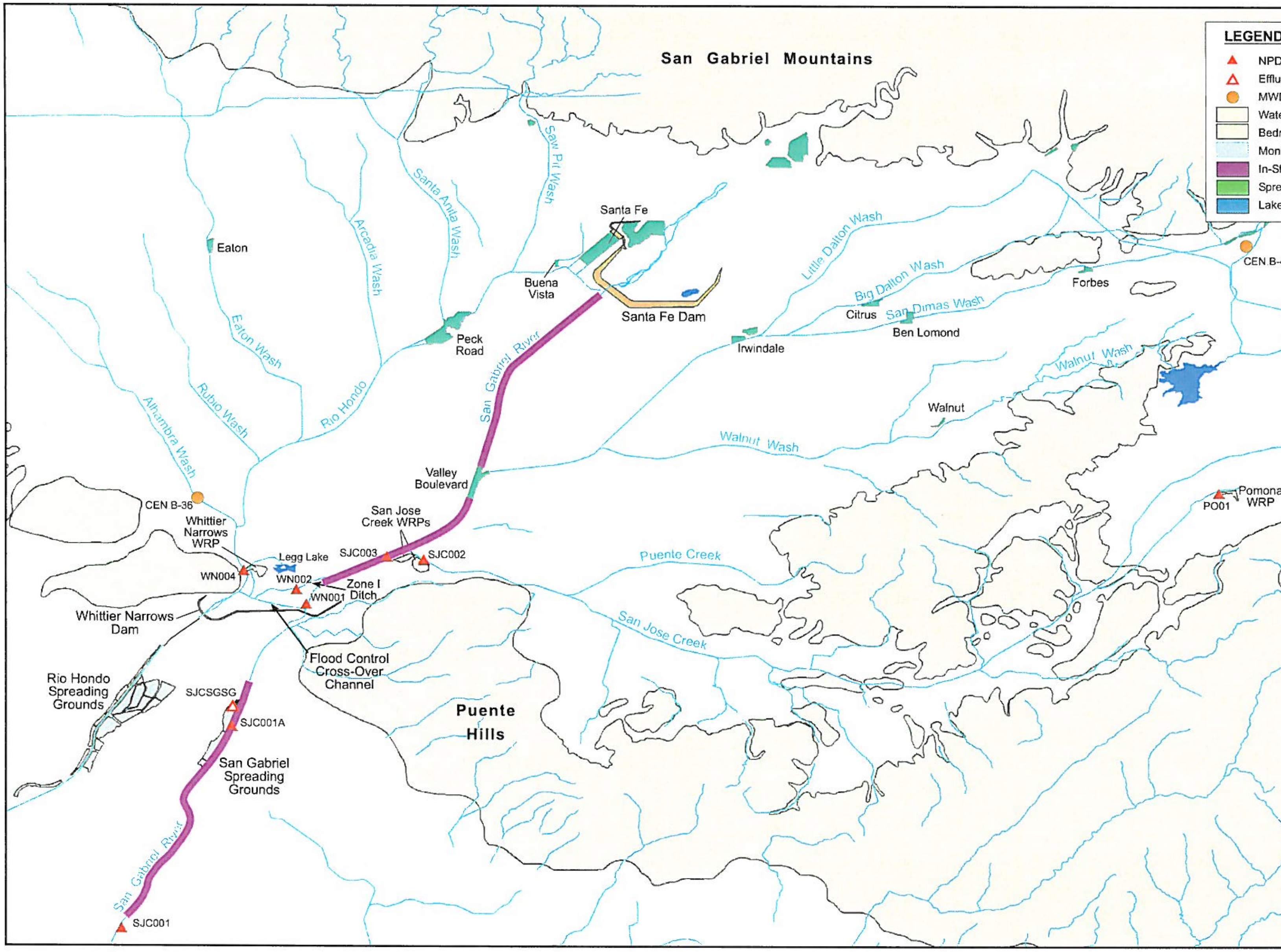
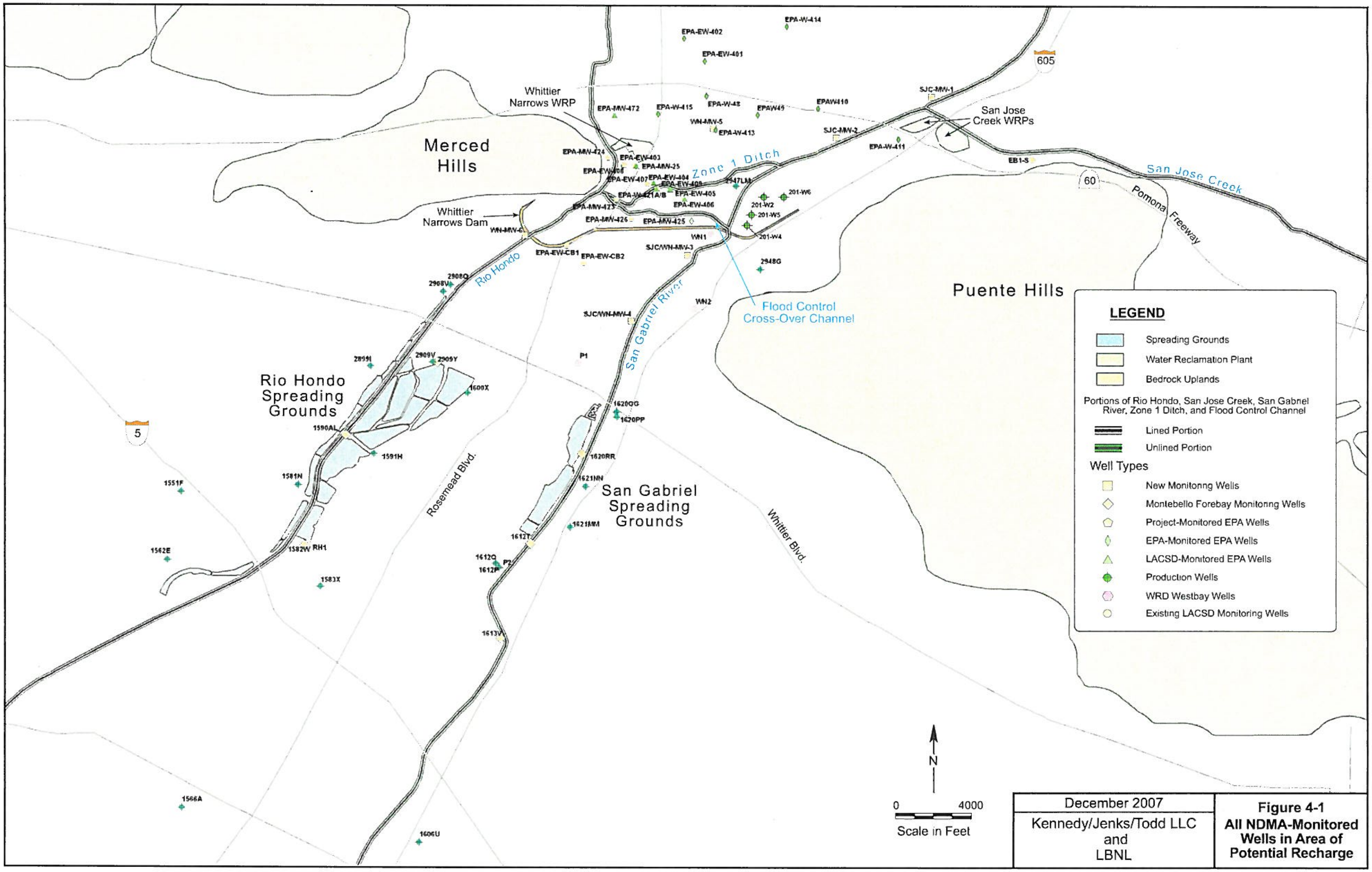


Figure 2-3
Surface Water System and Features within the Study Area

December 2007

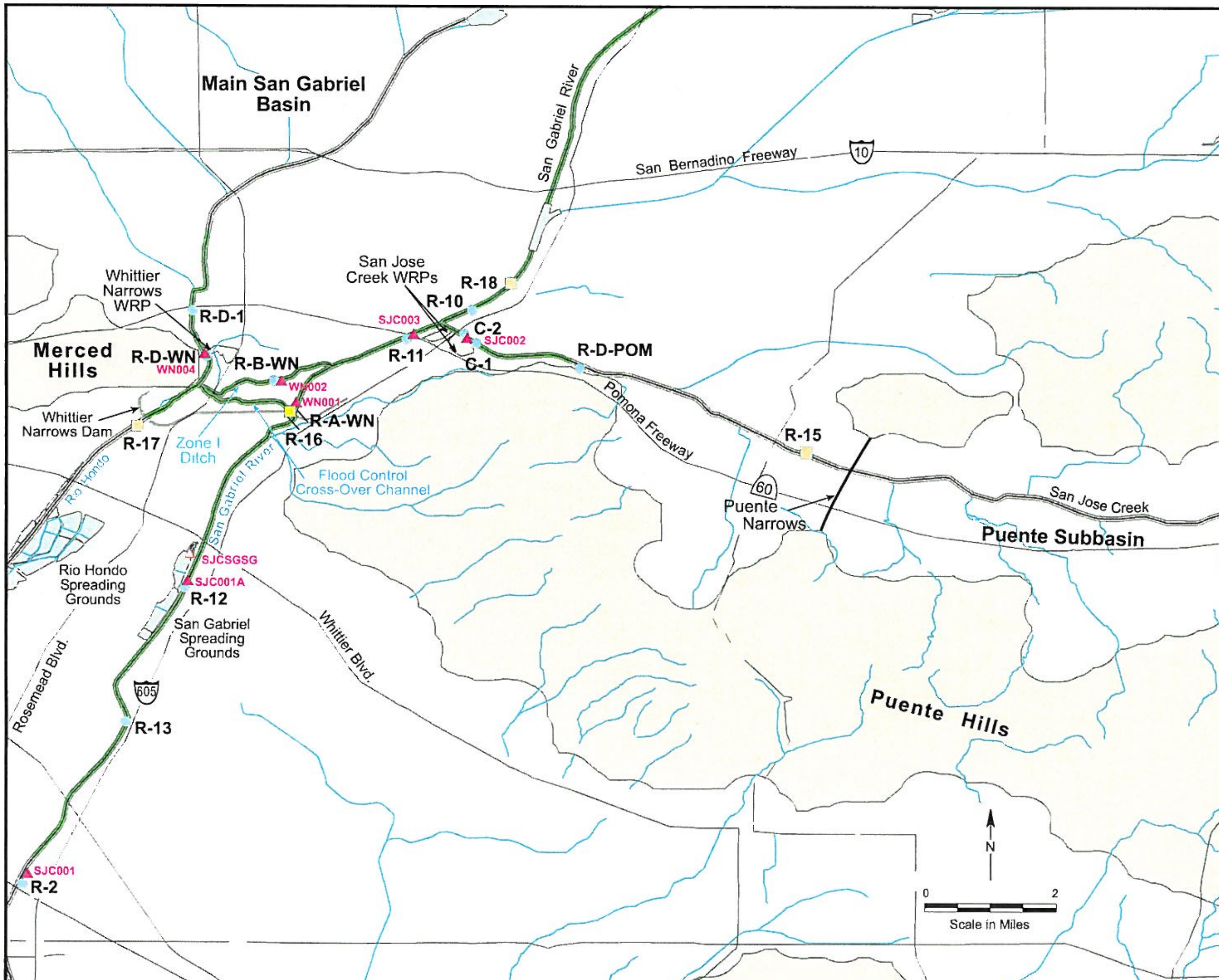
Kennedy/Jenks/Todd LLC and LBNL



December 2007

Kennedy/Jenks/Todd LLC and LBNL

Figure 4-1
All NDMA-Monitored Wells in Area of Potential Recharge



December 2007	Figure 4-2
Kennedy/Jenks/Todd LLC and LBNL	Surface Water Sampling Locations

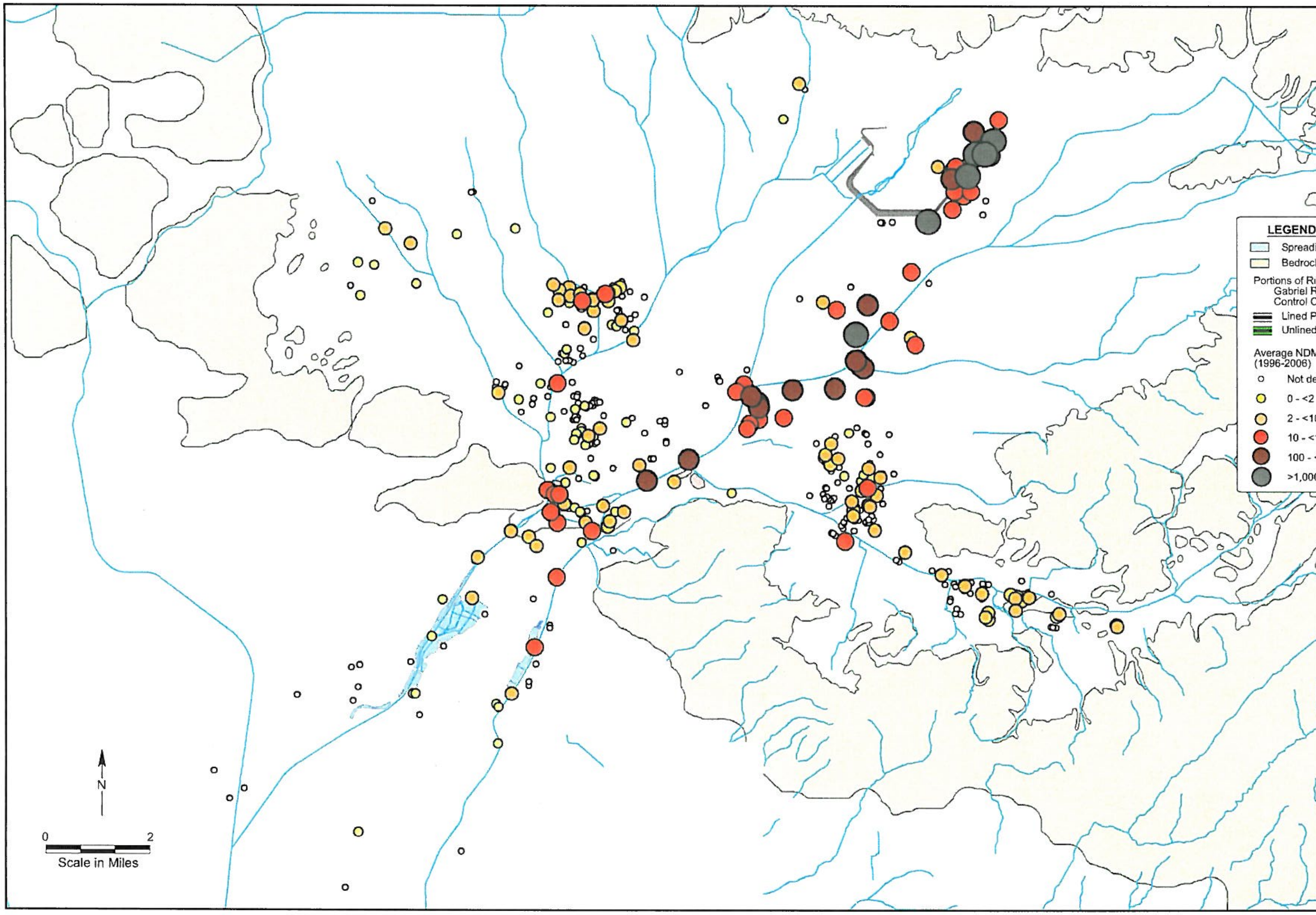
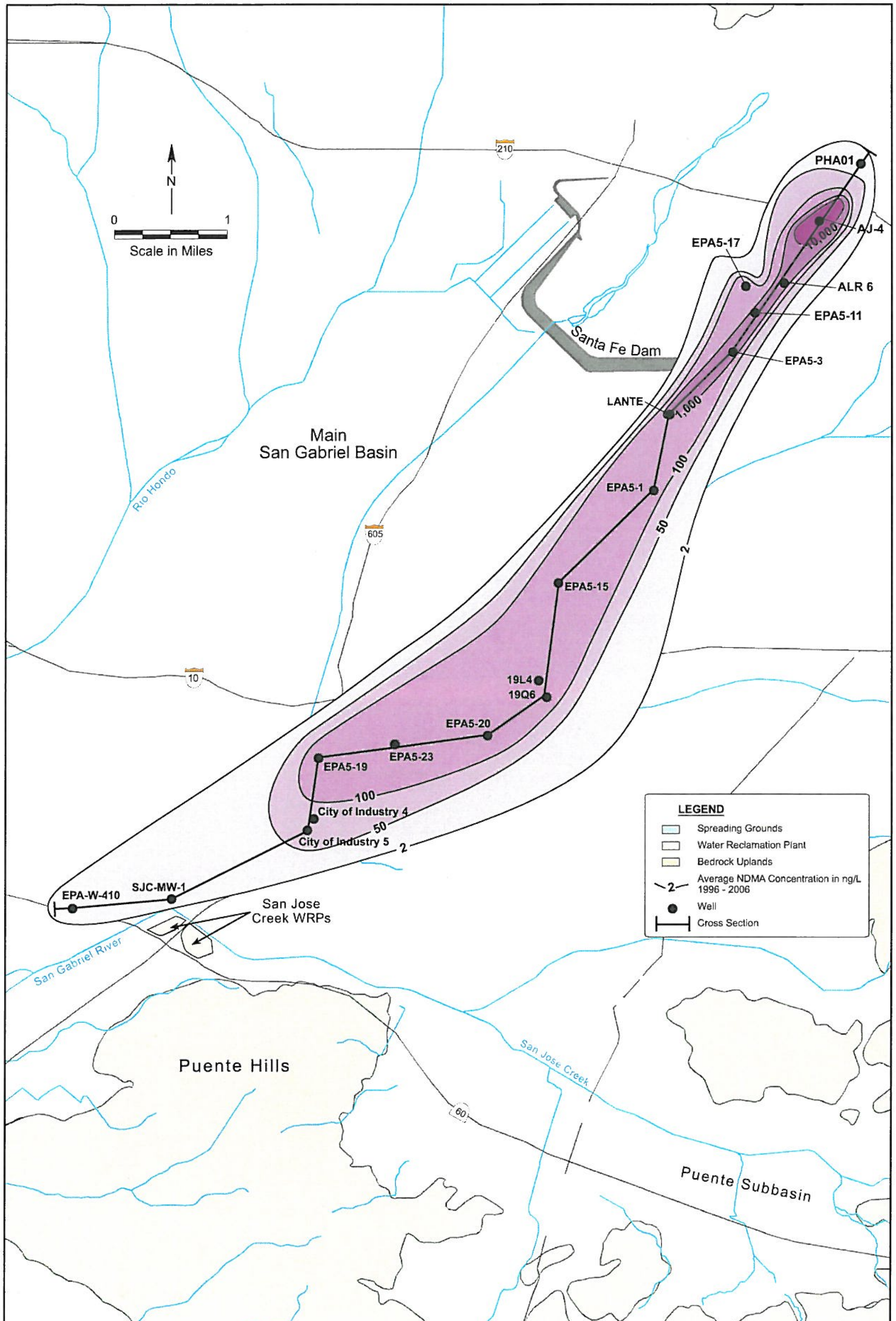


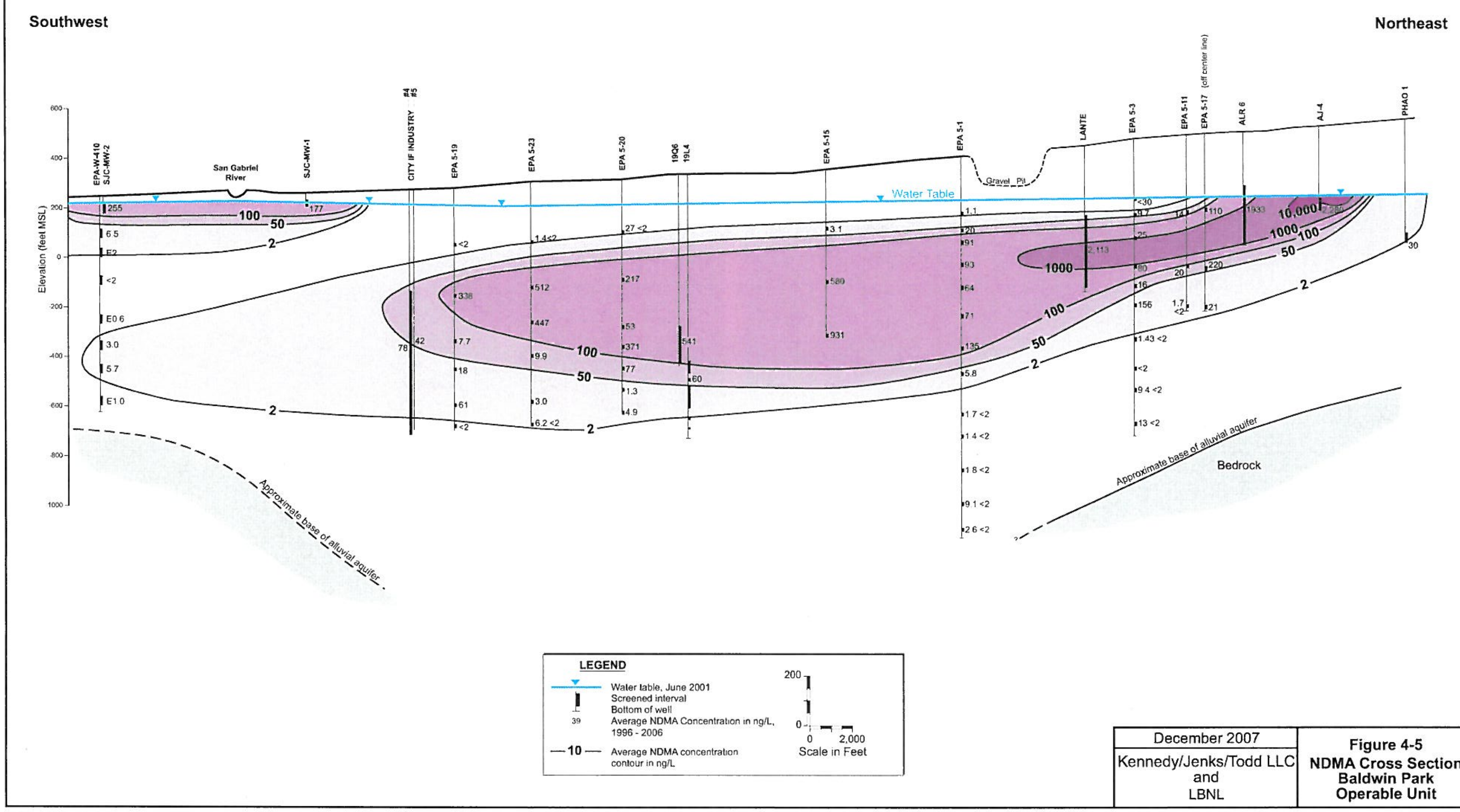
Figure 4-3
Average Regional NDMA Detections in Groundwater

December 2007

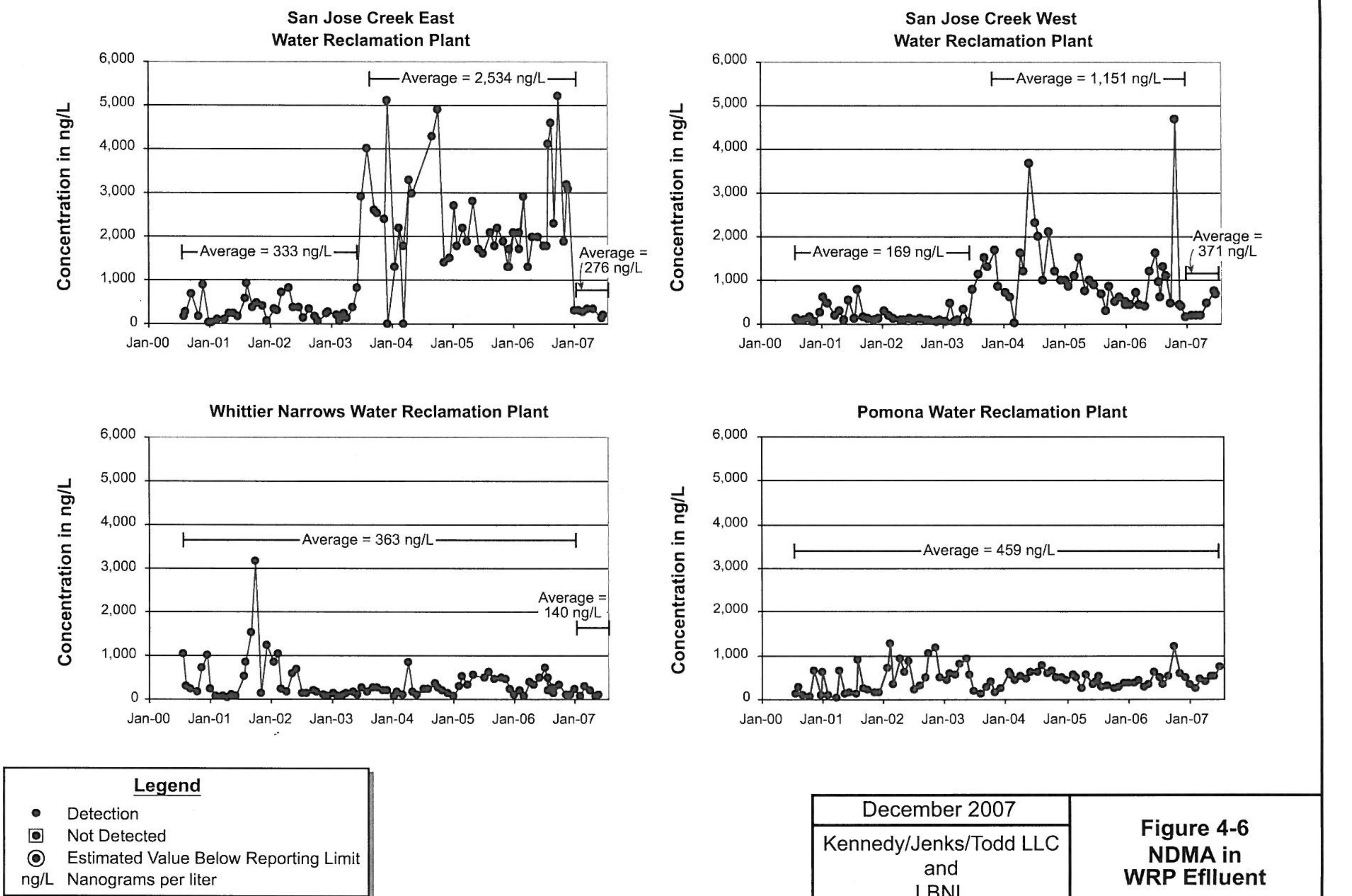
Kennedy/Jenks/Todd LLC and LBNL



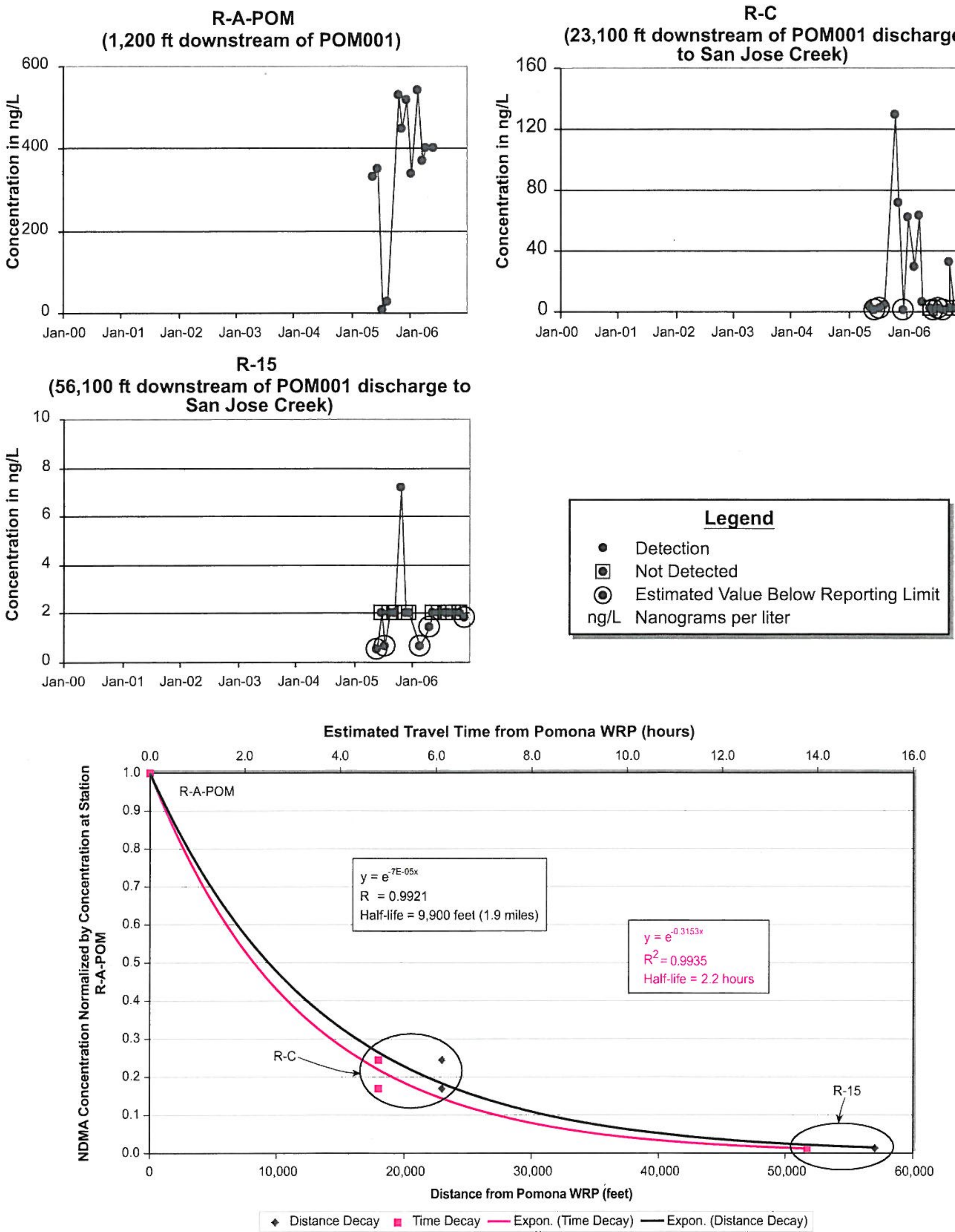
December 2007	Figure 4-4
Kennedy/Jenks/Todd LLC and LBNL	**Baldwin Park Operable Unit NDMA Concentration Contour Map**



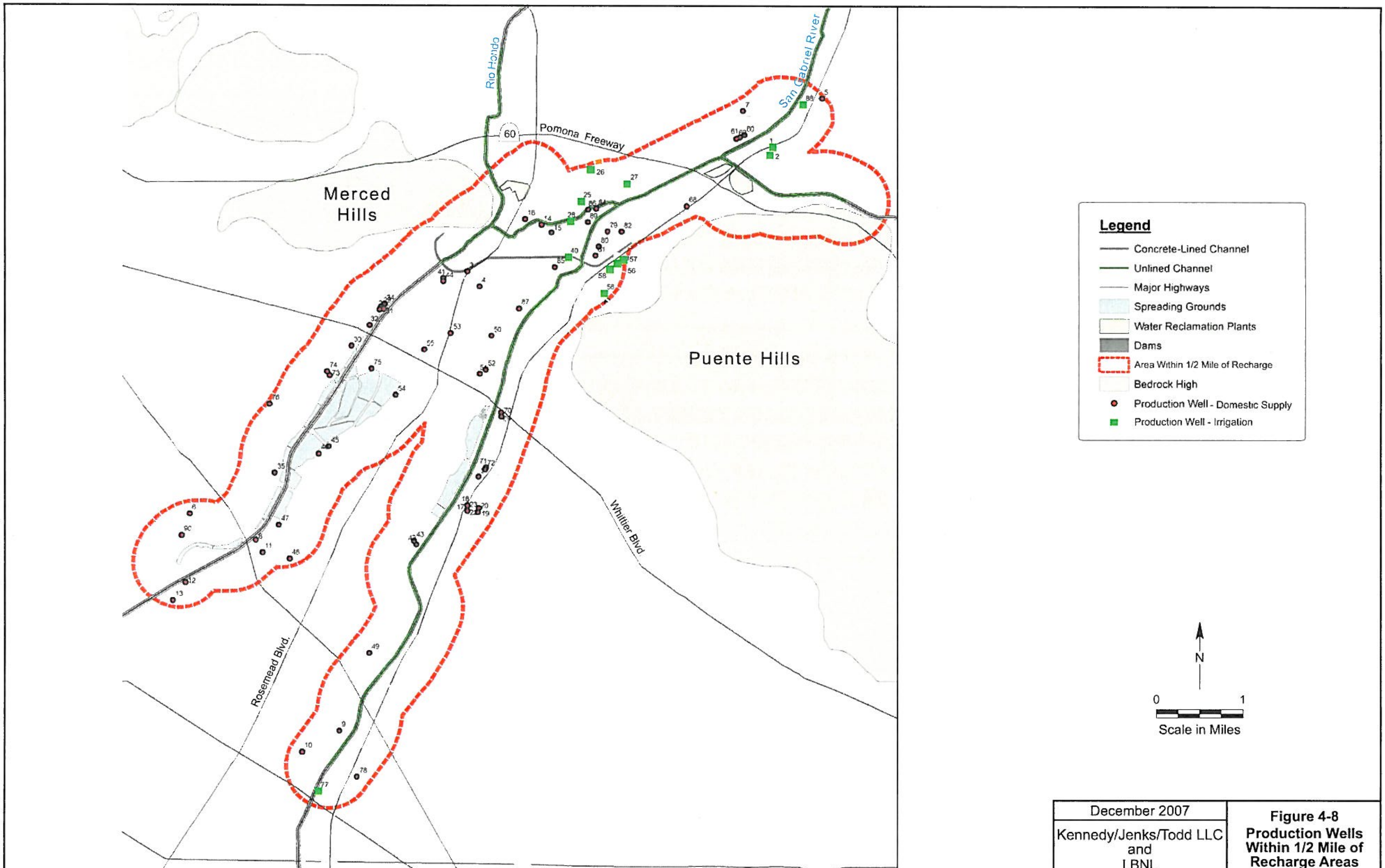
December 2007	Figure 4-5
Kennedy/Jenks/Todd LLC and LBNL	NDMA Cross Section Baldwin Park Operable Unit



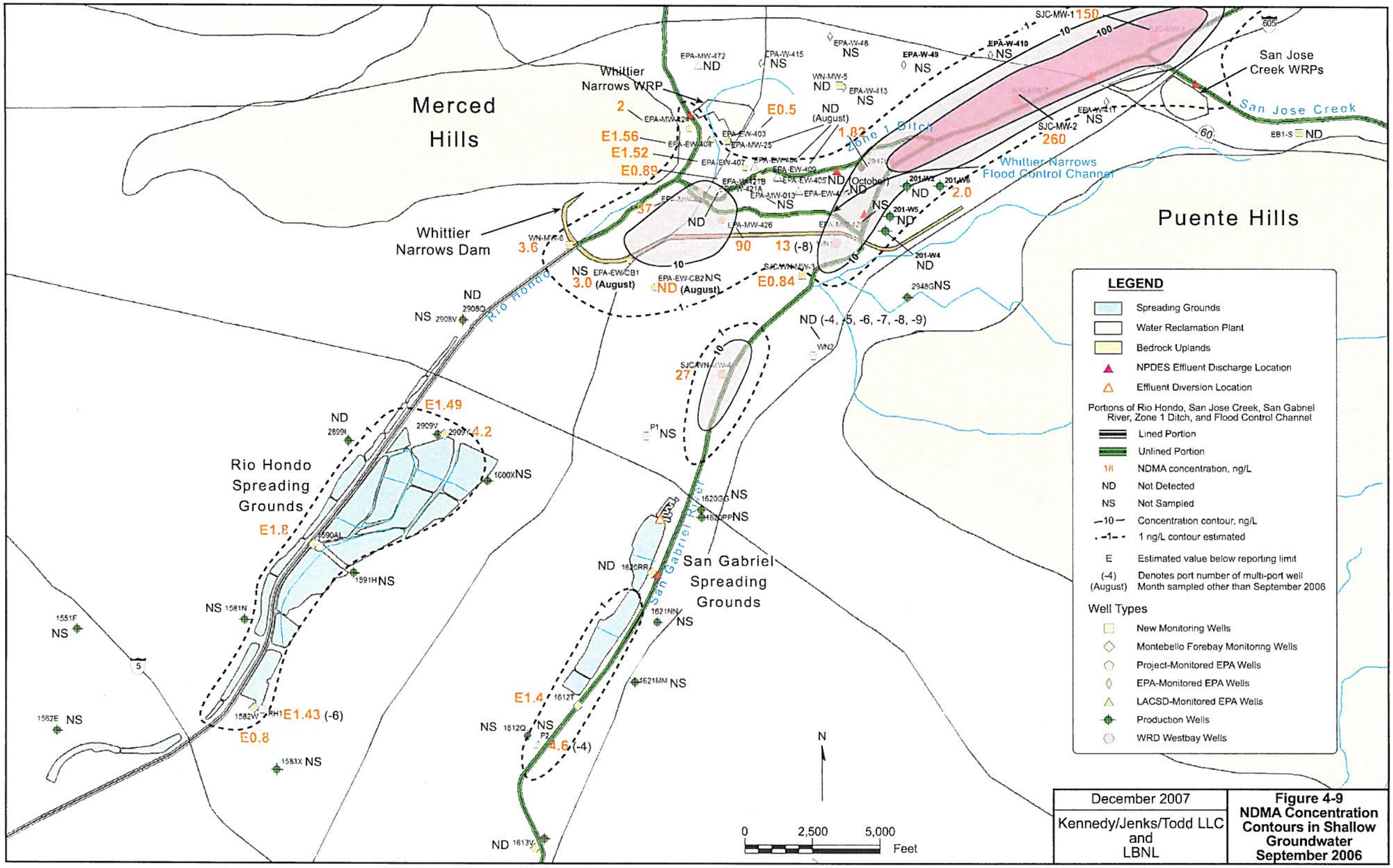
December 2007	**Figure 4-6 NDMA in WRP Effluent**
Kennedy/Jenks/Todd LLC and LBNL	



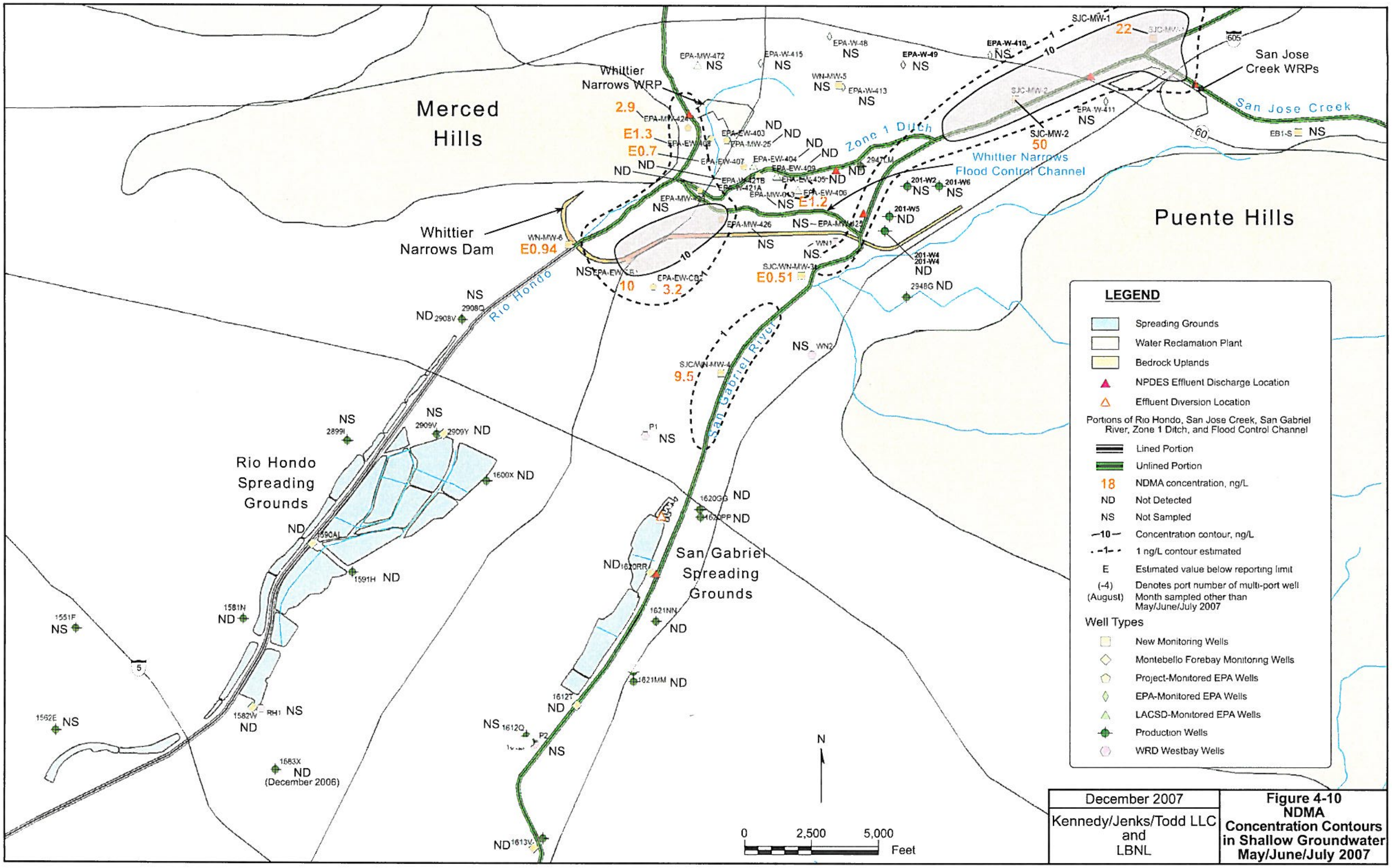
December 2007	**Figure 4-7 NDMA Decay in Surface Water**
Kennedy/Jenks/Todd LLC and LBNL	

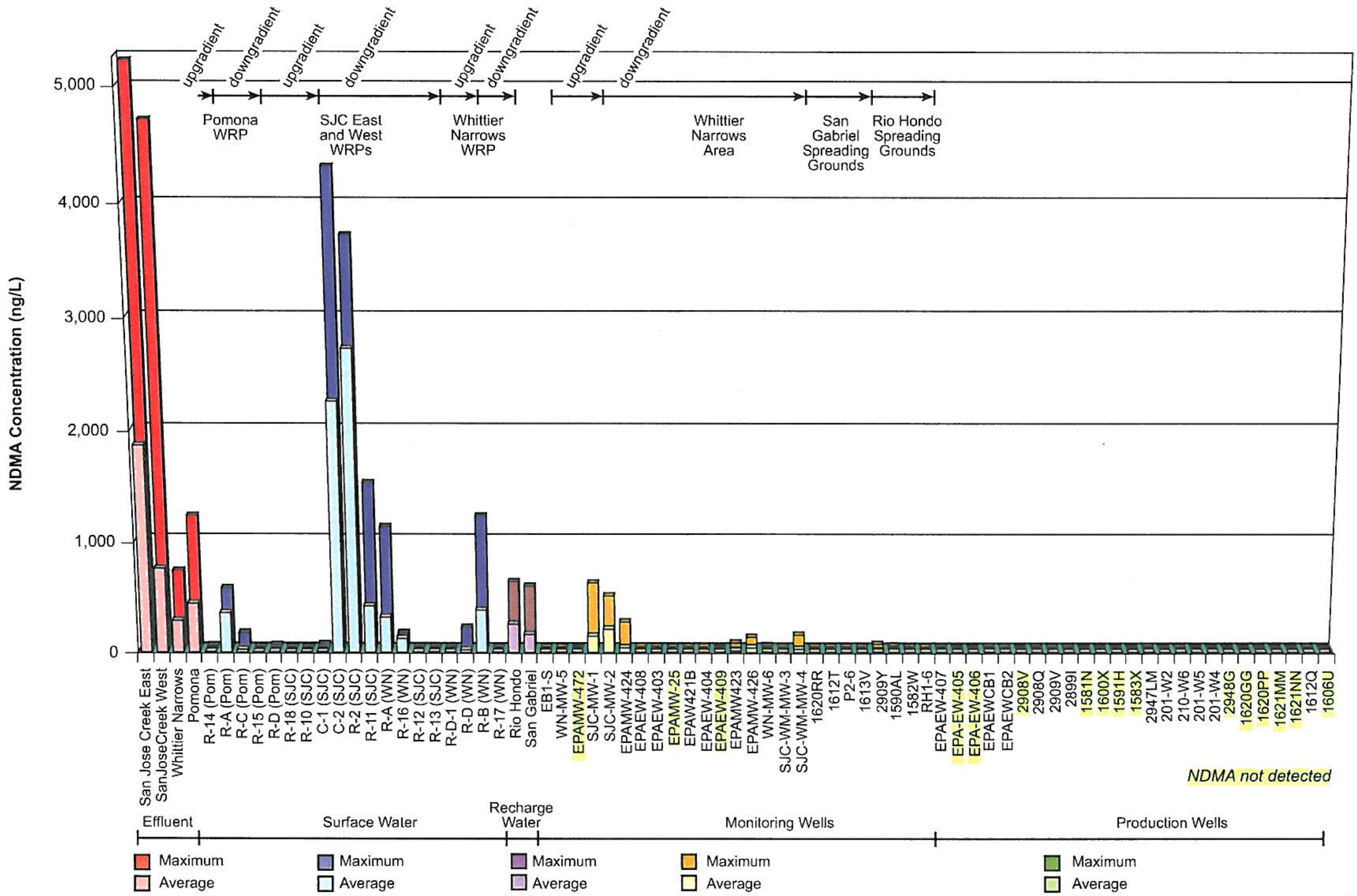


December 2007	Figure 4-8 Production Wells Within 1/2 Mile of Recharge Areas
Kennedy/Jenks/Todd LLC and LBNL	

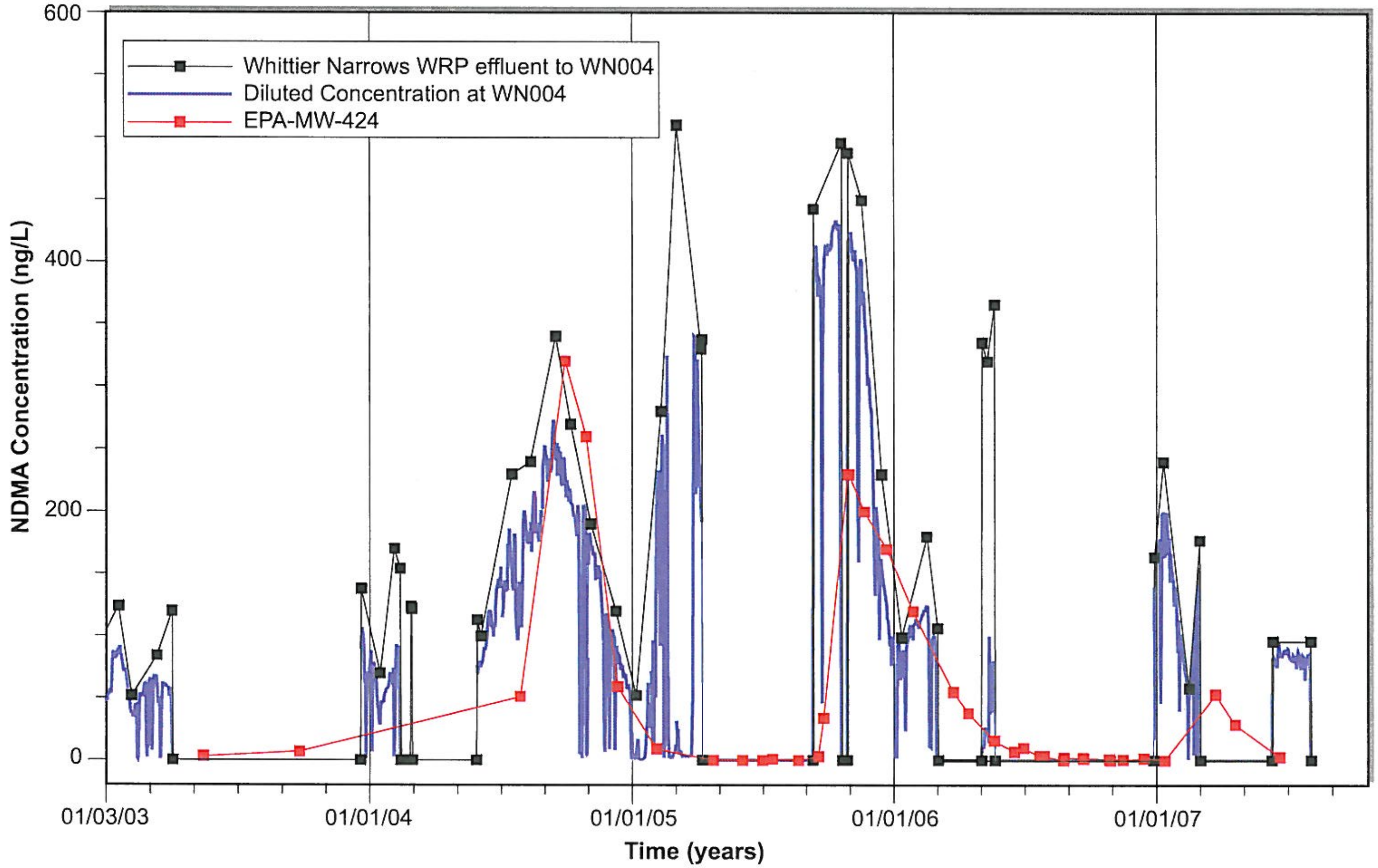


Merced
Hills
Puente Hills
Whittier
Narrows WRP
Whittier
Narrows Dam
San Jose
Creek WRPs
San Jose Creek
Zone 1 Ditch
Whittier Narrows
Flood Control Channel
Rio Hondo
San Gabriel River
Rio Hondo
Spreading
Grounds
San Gabriel
Spreading
Grounds
SJC-MW-1 150
SJC-MW-2
260
100
10
1
2
E1.56
E1.52
E0.89
E0.5
1.82
ND
(August)
ND (October)
37
ND
90
13 (-8)
3.6
NS
3.0 (August)
ND (August)
E0.84
ND (-4, -5, -6, -7, -8, -9)
27
E1.49
4.2
E1.8
E1.43 (-6)
E0.8
E1.4
4.6 (-4)
2.0
LEGEND
Spreading Grounds
Water Reclamation Plant
Bedrock Uplands
NPDES Effluent Discharge Location
Effluent Diversion Location
Portions of Rio Hondo, San Jose Creek, San Gabriel River, Zone 1 Ditch, and Flood Control Channel
Lined Portion
Unlined Portion
18 NDMA concentration, ng/L
ND Not Detected
NS Not Sampled
—10— Concentration contour, ng/L
- -1- - 1 ng/L contour estimated
E Estimated value below reporting limit
(-4) Denotes port number of multi-port well
(August) Month sampled other than September 2006
Well Types
New Monitoring Wells
Montebello Forebay Monitoring Wells
Project-Monitored EPA Wells
EPA-Monitored EPA Wells
LACSD-Monitored EPA Wells
Production Wells
WRD Westbay Wells
N
0
2,500
5,000
Feet
December 2007
Kennedy/Jenks/Todd LLC
and
LBNL
Figure 4-9
NDMA Concentration
Contours in Shallow
Groundwater
September 2006


Merced Hills
Puente Hills
Whittier Narrows WRP
Whittier Narrows Dam
San Jose Creek WRPs
San Jose Creek
Zone 1 Ditch
Whittier Narrows Flood Control Channel
Rio Hondo
San Gabriel River
Rio Hondo Spreading Grounds
San Gabriel Spreading Grounds
SJC-MW-1
22
EPA-W-410
NS
EPA-W-49
NS
EPA-W-48
NS
EPA-MW-472
NS
EPA-W-415
NS
WN-MW-5
NS
EPA-W-413
NS
SJC-MW-2
50
EPA-W-411
NS
EB1-S
NS
2.9
EPA-MW-424
E1.3
E0.7
EPA-EW-403
EPA-MW-25
ND
EPA-EW-407
EPA-EW-404
EPA-EW-409
EPA-EW-405
EPA-EW-406
EPA-W-421B
EPA-W-421A
EPA-MW-426
NS
E1.2
2947LM
201-W2
NS
201-W6
NS
201-W5
ND
201-W4
ND
2948G
ND
WN-MW-6
E0.94
EPA-EW-CB
10
3.2
SJC-WN-MW-3
E0.51
WN1
NS
WN2
NS
SJC-WN-MW-4
9.5
P1
NS
2908Q
NS
2908V
ND
2899I
NS
2909V
NS
2909Y
ND
1600X
ND
1620GG
ND
1620PP
ND
1590AL
ND
1591H
ND
1620RR
ND
1621NN
ND
1621MM
ND
1581N
ND
1551F
NS
1562E
NS
1582W
ND
RH1
NS
1583X
ND
(December 2006)
1612T
ND
1612Q
NS
P2
NS
1613V
ND
5
60
605
N
0
2,500
5,000
Feet
LEGEND
Spreading Grounds
Water Reclamation Plant
Bedrock Uplands
NPDES Effluent Discharge Location
Effluent Diversion Location
Portions of Rio Hondo, San Jose Creek, San Gabriel River, Zone 1 Ditch, and Flood Control Channel
Lined Portion
Unlined Portion
18 NDMA concentration, ng/L
ND Not Detected
NS Not Sampled
—10— Concentration contour, ng/L
- -1- - 1 ng/L contour estimated
E Estimated value below reporting limit
(-4) Denotes port number of multi-port well
(August) Month sampled other than May/June/July 2007
Well Types
New Monitoring Wells
Montebello Forebay Monitoring Wells
Project-Monitored EPA Wells
EPA-Monitored EPA Wells
LACSD-Monitored EPA Wells
Production Wells
WRD Westbay Wells
December 2007
Kennedy/Jenks/Todd LLC
and
LBNL
Figure 4-10
NDMA
Concentration Contours
in Shallow Groundwater
May/June/July 2007



December 2007	**Figure 4-11**
Kennedy/Jenks/Todd LLC and LBNL	**Maximum and Average NDMA (All Media) June 2005 to December 2006**



LEGEND

WRP Water Reclamation Plant

December 2007	**Figure 4-12 Vadose Zone Attenuation at EPA-MW-424**
Kennedy/Jenks/Todd LLC and LBNL	

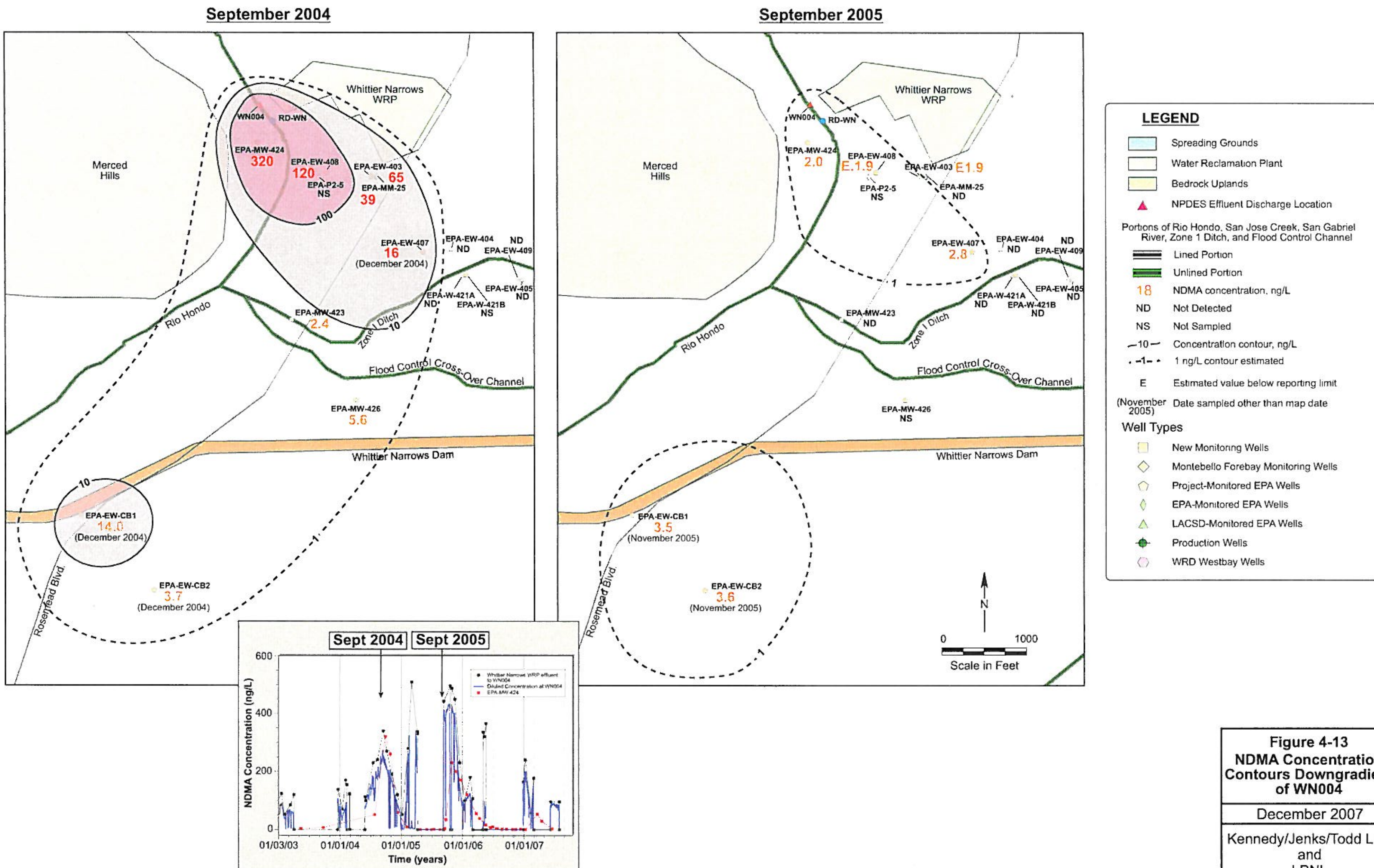
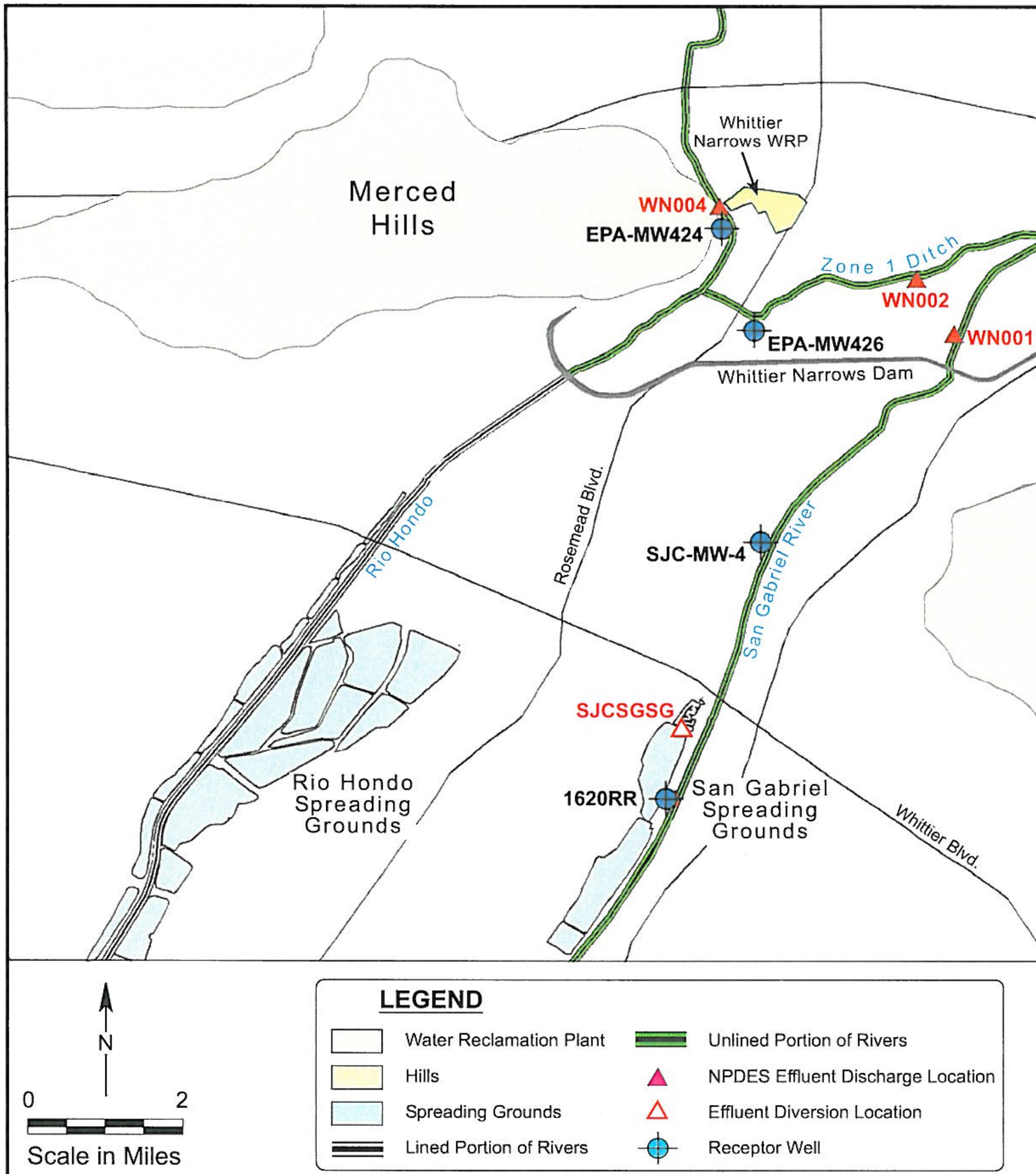


Figure 4-13
NDMA Concentration Contours Downgradient of WN004

December 2007

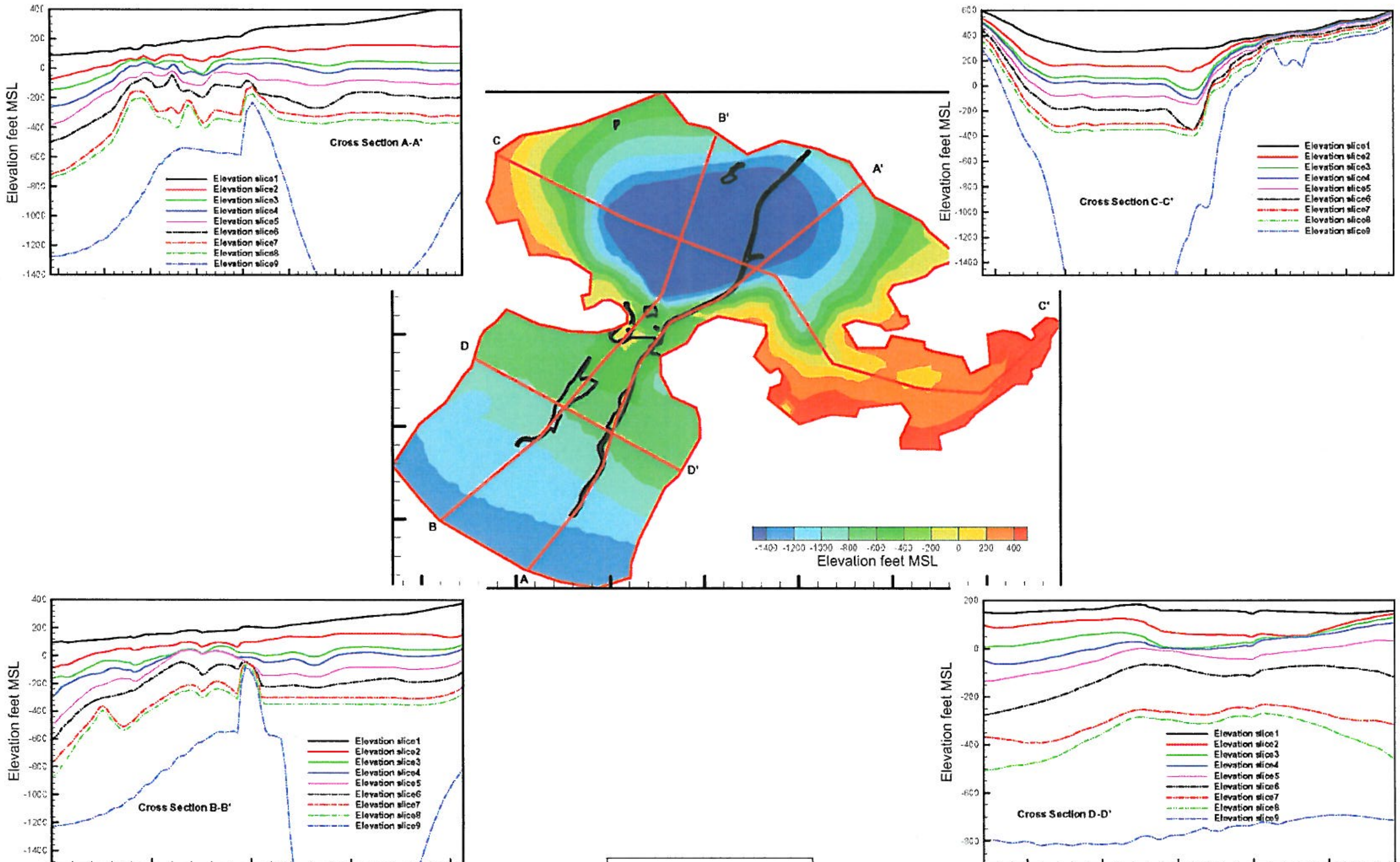
Kennedy/Jenks/Todd LLC
and
LBNL



December 2007

Kennedy/Jenks/Todd LLC
and
LBNL

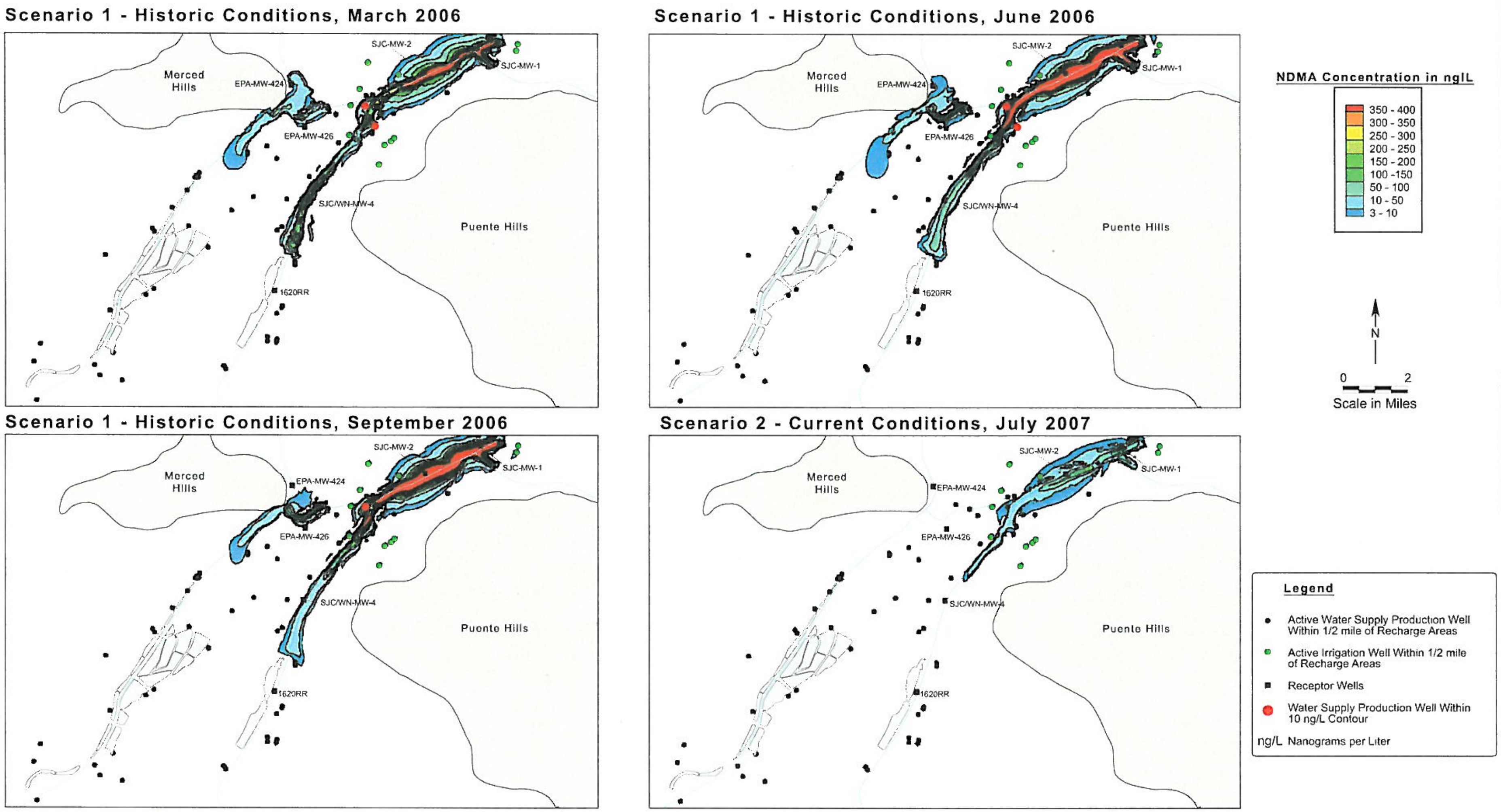
Figure 5-1
Modeling Receptor Wells



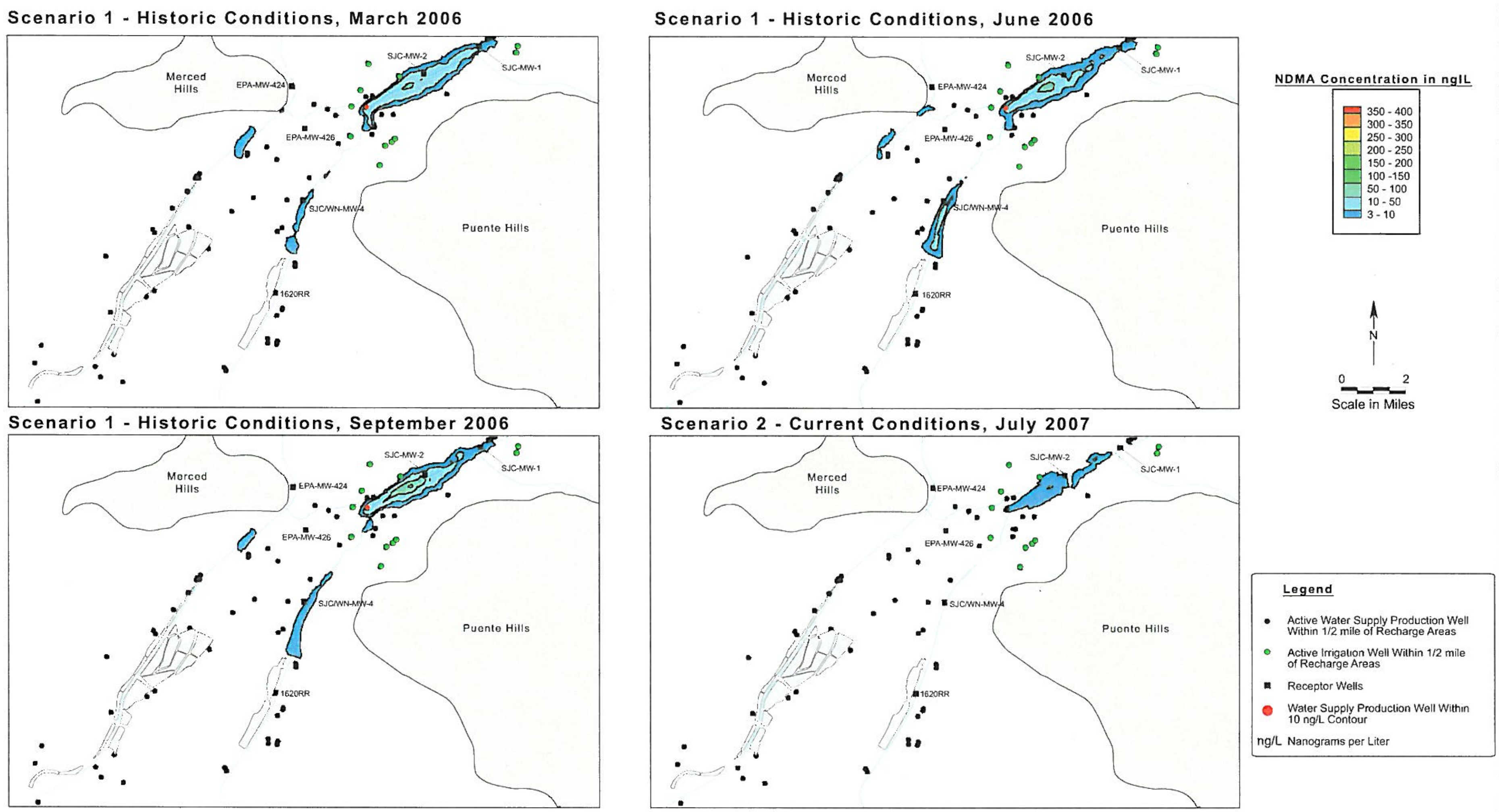
Legend

MSL Mean Sea Level

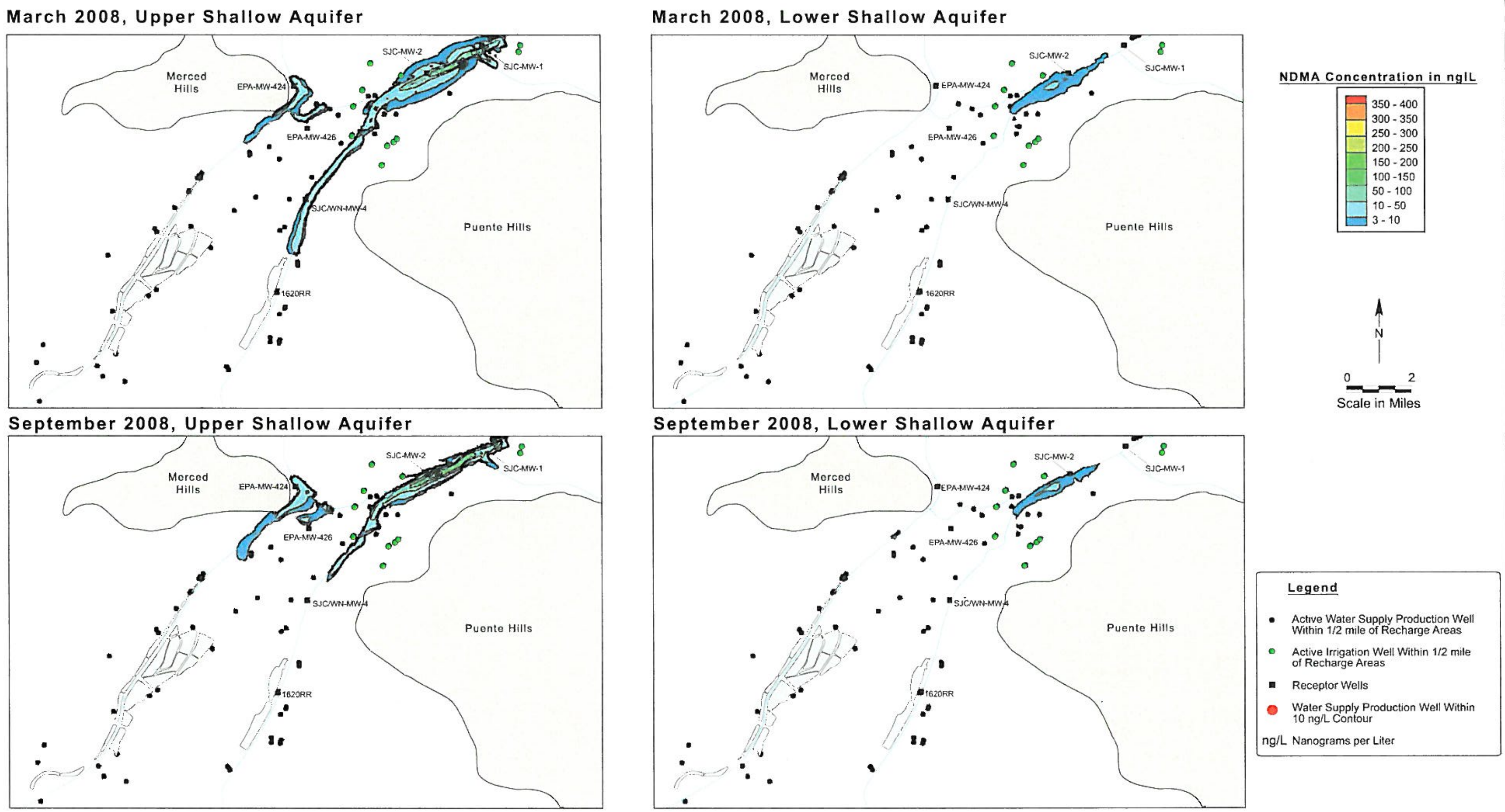
December 2007	Figure 5-2 Cross Sections Through Model Domain
Kennedy/Jenks/Todd LLC and LBNL	



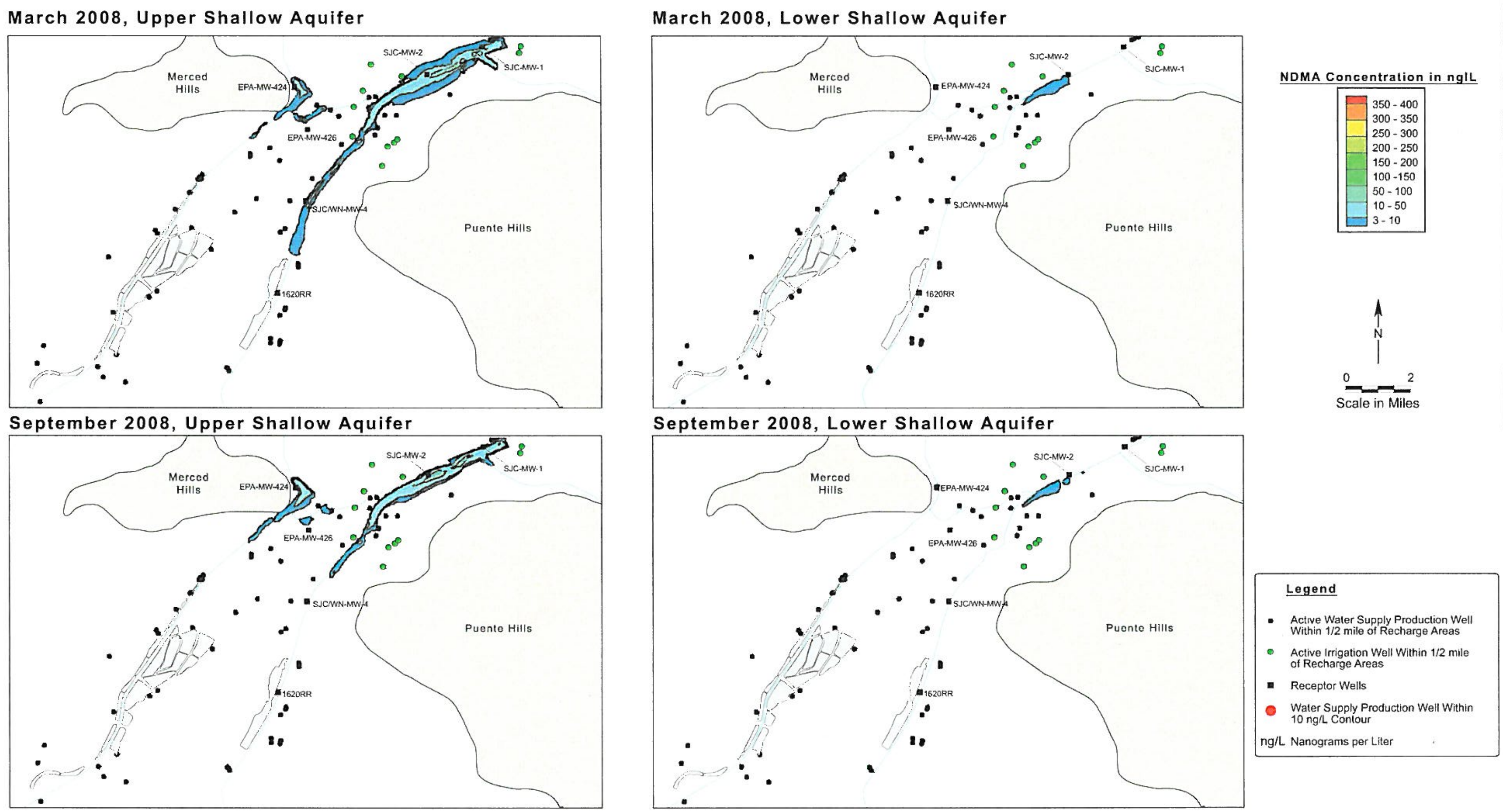
December 2007	Figure 5-3 Simulated NDMA Concentration Contours Upper Shallow Aquifer
Kennedy/Jenks/Todd LLC and LBNL	



December 2007	**Figure 5-4**
Kennedy/Jenks/Todd LLC and LBNL	**Simulated NDMA Concentration Contours Lower Shallow Aquifer**



December 2007	**Figure 5-5**
Kennedy/Jenks/Todd LLC and LBNL	**Scenario 2 Predicted Future NDMA Concentration Contours Upper and Lower Shallow**



December 2007	Figure 5-6 Scenario 3 Predicted Future NDMA Concentration Contours Upper and Lower Shallow
Kennedy/Jenks/Todd LLC and LBNL	