FINAL REPORT

Twentynine Palms Salt and Nutrient Management Plan

June 2014

Prepared for

City of Twentynine Palms and Twentynine Palms Water District

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K/J Project No. 1283001*00

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Executive Summary

The primary purpose of the Salt and Nutrient Management Plan (SNMP or Plan) is to develop a strategy for the City of Twentynine Palms (City) and Twentynine Palms Water District (TPWD or District) to monitor and protect the groundwater resources in the Twentynine Palms area in response to an increased need to assess potential groundwater quality impacts from salt and nutrient sources that are derived primarily from septic tanks in the Twentynine Palms area. This analysis is to be used to guide the development of a groundwater monitoring program to collect water quality data that can be evaluated to support informed decisions on wastewater management that protect the beneficial uses of local groundwater resources.

Purpose

The assessment of effects of septic tanks on groundwater quality in the Twentynine Palms area is analyzed within the context of the existing regulatory compliance. This SNMP evaluates the current conditions and whether the continued discharges from septic systems would unreasonably degrade the groundwater quality, resulting in widespread groundwater pollution and compliance issues with the beneficial use of groundwater or water quality objectives for the Colorado River (Region 7) Basin Plan (Basin Plan).

The Colorado River Basin Regional Water Quality Control Board (RWQCB) Basin Plan states that ideally the RWQCB's goal is to maintain the existing water quality of all non-degraded groundwater basins. However, in most cases groundwater that is pumped generally returns to the basin after use with an increase in mineral concentrations such as total dissolved solids (TDS) and nitrate carried by water during its use. Under these circumstances, the RWQCB's objective is to minimize the quantities of contaminants reaching any groundwater basin. This could be achieved by establishing management practices for major discharges to land. As stated in the Basin Plan, a detailed study is needed before establishing specific groundwater quality objectives for a particular basin.

The data from this detailed study are necessary for the development of an effective Local Agency Management Program for Twentynine Palms that complies with Tier 2 of the State Water Resources Control Board Policy for Siting, Design, Operation, and Maintenance of Onsite Wastewater Treatment Systems (OWTS Policy), Resolution No. 2012-0032, which took effect on May 13, 2013. The OWTS Policy covers septic tanks and small package plants for individual disposal systems, community collection and disposal systems, and alternative collection and disposal systems that use subsurface disposal. The intent of the OWTS Policy is to efficiently utilize local programs for the management of OWTS systems through coordination with the RWQCB Basin Plans and state guidelines.

The Policy acknowledges that, because of California's geologic and climatic complexity, local criteria based on site specific data are preferable to broad statewide criteria. Therefore, a Local Agency Management Program may authorize different soil characteristics, usage of seepage pits, and different densities for new developments based on site-specific studies.

The Region 7 RWQCB adopted Resolution R7-2013-0049 on September 19, 2013 that revised the septic system sections of the Colorado River Basin Plan and incorporates by reference the new OWTS Policy into the Basin Plan. The SWRCB approved the amendment to the Region 7 Basin Plan, as adopted under Colorado River Basin Water Board Resolution R7-2013-0049, on December 3, 2013 in SWRCB Resolution 2013-0039.

Overview of Groundwater Analysis

Twentynine Palms is located in the high desert of Southern California. The current population of the area is approximately 18,975, based on the estimate from the 2010 Urban Water Management Plan (UWMP). The population for 2035 is projected to be 30,931 (Kennedy/Jenks, 2011).

The Twentynine Palms area overlies a large alluvial basin that is subdivided into a number of groundwater basins and subbasins due to faulting. The City of Twentynine Palms is underlain by the Mesquite Lake Subbasin (also referred to as the Mesquite Lake subbasin in some references) of Twentynine Palms Basin. South of Twentynine Palms, the Joshua Tree Groundwater Basin is subdivided into the Indian Cove, Fortynine Palms and Eastern Subbasins. Groundwater is compartmentalized due to the complex geology in these individual subbasins in that they are more or less separated from one another by hydrologic barriers, including bedrock ridges, faults, and folds. The degree of separation between these subbasins is dependent upon the character of the barriers separating them.

Groundwater quality data from the TPWD water supply wells were reviewed within the context of the SNMP to help design of a proposed groundwater monitoring plan and to identify data gaps for improving monitoring for water quality. Nitrate (as NO3) concentrations in the TPWD water supply wells range from non-detect to 28 mg/l for nitrate and 100 to 350 mg/l for TDS, all of which are below the nitrate and TDS Maximum Contaminant Levels (MCLs).

In general, nitrate and TDS concentrations in the TPWD wells are stable, except for Well #4 (located in the Fortynine Palms Subbasin) which shows a clear increasing trend with the current nitrate concentration of 28 mg/l. The increasing trend at Well #4 may be attributed to vertical conduits. District staff has identified this facility as an old well and has scheduled it for abandonment. Also, high TDS concentrations in shallow monitoring wells in the Mesquite Lake Subbasin may reflect the concentration of salts associated with buried lake deposits at this location.

The SNMP includes an assessment of current and 2035 conditions using a mass balance model to evaluate groundwater quality resulting from the septic systems in the Twentynine Palms area. A mixed-cell mass balance model was developed to provide a preliminary estimate of the septic loading to the four groundwater subbasins. The mass balance modeling analysis uses simplifying assumptions and provides a conservative, screening-level analysis for the septic loading rate.

Findings

In the TPWD production wells, nitrate and TDS concentrations are relatively stable based on data that extends back up to 50 years. There are no limitations currently on the beneficial use of groundwater because concentrations do not exceed the MCL in the TPWD production wells. Although the existing groundwater quality data provides an initial assessment of the overall trends, additional groundwater monitoring data are needed that include data from monitoring wells to track concentrations and to identify if there are locally-impacted areas or if long-term issues may arise in the future that need to be addressed. The proposed monitoring network is designed to have sufficient spatial distribution to appropriately define the nature and extent of nitrates, TDS and other potential constituents of concern (COC).

The mixed-cell mass balance model results indicate that, among the four subbasins, the southern Mesquite and Eastern Subbasins may ultimately have potential long-term nitrate issues whereas the Indian Cove, Fortynine Palms, and the northern Mesquite Lake Subbasins do not appear to have potential long-term nitrate issues. In evaluating the loading rate from the septic systems within context of the relative size of the groundwater basins, the highest increase in nitrogen concentrations (nitrate as N) is projected in the Eastern and southern portion of the Mesquite Lake Subbasins. For the Indian Cove, Fortynine Palms and northern portion of the Mesquite Lake Subbasins, nitrogen would increase at a lower rate.

The results of the sensitivity analysis indicate that the use of mass conservative assumptions in developing and applying the mixed-cell model may cause the models to overestimate nitrate concentrations in the subbasins. While the mass balance modeling analysis is appropriate as a conservative, screening-level analysis, the complexity of the analysis leads to inherent uncertainty because of the need for simplifying and conservative assumptions. Thus, the modeling analysis results should be viewed as preliminary because of the limited availability of water quality data. Given the limited site specific data required for the model calibration, the current model estimates of nitrogen concentration of the mixed groundwater are preliminary and require further study. Furthermore, these results highlight the need for future data collection and additional study once this new data are available. More data and analysis are necessary to define if there are locally-impacted areas and whether there are long-term issues that need to be addressed. Additional data from future monitoring are also needed to further refine the assumptions used for this analysis.

There are two important considerations that should be noted when comparing the conditions in Twentynine Palms to those in Yucca Valley and the Warren Subbasin. These are:

- the overall septic loading is 20% less in Twentynine Palms (82 tons per year [ton/yr]) compared to Yucca Valley (108 ton/yr), and
- the area that the overall septic loading is distributed over is much larger in Twentynine Palms (90 square miles) compared to Yucca Valley (10 square miles).

These findings are consistent with the observed nitrate and TDS concentrations found in the TPWD production wells that generally show stable conditions over time.

Collaborative Plan Development

The City and the District worked collaboratively to develop the SNMP with input from the public and regulatory agencies. A series of workshops were held with the City and District to discuss the development of the SNMP. A series of five meetings including a public hearing and meeting with local regulatory agencies took place to solicit input and guidance on the development of the SNMP over the period from August 2012 to March 2014.

The Twentynine Palms City Council and the District Board of Directors held a public hearing on November 6, 2013 to solicit public comments. The city council, board of directors and public were given an opportunity to ask questions at the hearing and interested parties were invited to participate in development of the SNMP. The November 6, 2013 public hearing notifications, agenda, and minutes are included in Appendix A.

On March 18, 2014, a presentation of the draft SNMP was given to the Colorado River Basin Region 7 RWQCB in Palm Desert. The purpose of the meeting was to present the overall findings and approach of the SNMP and give an opportunity for RWQCB staff to comment on the SNMP.

Recommended Action

Based on the findings of this study, the recommended action is to: 1) implement measures to improve the overall monitoring of the groundwater, and 2) to implement a Septic System Management Program to limit the further impacts to groundwater. Since the current nitrate concentrations in the TPWD production wells show relatively stable concentrations, it is considered appropriate to take the time to conduct a more detailed assessment. The objective is to better understand groundwater conditions in the Twentynine Palms area so that better decisions on how to address septic tank usage can be developed.

This approach is consistent with the Region 7 Basin Plan which states:

> *"Establishment of numerical objectives for groundwater involves complex considerations since the quality of groundwater varies significantly with depth of well perforations, existing water levels, geology, hydrology and several other factors. Unavailability of adequate historical data compounds this problem. The Regional Board believes that detailed investigation of the groundwater basins should be conducted before establishing specific groundwater quality objectives."*

A long-term groundwater quality monitoring program is recommended to collect data from across the Twentynine Palms area to define the nature and extent of constituents of consern (COCs), primarily nitrates and salts, by regular sampling. This will determine baseline water quality conditions in the area that can be used to establish the basin objectives for each of the groundwater subbasins. These monitoring data are also necessary to fully understand the groundwater quality conditions and trends so that informed management decisions regarding the use and management of septic tanks in the Twentynine Palms area can be derived.

It is also recommended that the District and City adopt a Septic System Management Program to properly manage septic tanks by limiting loading rates as part of an integrated effort to protect groundwater quality. The elements of this Program are designed to provide mechanisms to reduce loading of COCs at the source before entering the groundwater system. A Septic System Management Program is presented to outline the approach for such a program.

The various phases of the SNMP will be documented in annual reports that will be provided to the RWQCB. Monitoring and implementation of the Septic System Management Program will be documented and subsequent groundwater assessments will be conducted to evaluate the impacts of septic systems on the groundwater. The outcome of these evaluations may then be used to support future management of septic systems in the Twentynine Palms area.

After implementing these recommendations, the assessment of the groundwater monitoring data can be updated to better understand the nature and extent of the distribution of nitrogen, salt, and other relevant COCs in groundwater, to better characterize the septic loading, and to improve the mass loading estimates. Model estimates can be also refined with site specific septic loading rates both from residential and non-residential water use sectors.

Recommended Groundwater Monitoring

The recommendation includes a long-term groundwater quality monitoring program that will establish a monitoring well network to define the spatial distribution and temporal trends of COCs, primarily nitrates and salts, by regular sampling over a number of years. The purpose is to collect sufficient groundwater quality data to evaluate the potential impact on groundwater quality from septic tanks. These data will provide the site-specific data needed to establish the technical basis for management criteria in a Tier 2 Local Agency Management Program of the Twentynine Palms area. A summary of the phased approach for the proposed monitoring is as follows:

- **Phase 1 – Increasing Sampling Frequency of Existing District Production Wells** - The District will collect water quality samples from all active and inactive groundwater production wells annually rather than every three years as required by the California Department of Public Health (CDPH).

- **Phase 2 – Establishing a Water Quality Monitoring Well Network using Existing Wells** - In addition to the District wells, additional private wells are present throughout the region. This phase will require coordination with the United States Geological Survey, CDPH and private well owners to be implemented. Available information indicates that more than 400 private wells have also been constructed within the District's service area. The District has located and inspected about 250 of the private wells. Most of these wells are not currently operated and their monitoring status is unknown. The District should assess their viability based on well ownership.

- **Phase 3 – Installing New Monitoring Wells at Key Locations** - The purpose of Phase 3 is to define the vertical extent of nitrates and the effect of the local geology and vertical mixing within the aquifer on COC concentrations. To this end, it is recommended a cluster of monitoring wells be installed in four key areas where elevated concentrations of COCs have been detected.

- **Phase 4 – Conducting a One-Time Existing Conditions Sampling Event** - It is recommended to collect a one-time sample for COCs from as many existing domestic wells as possible. This will require extensive coordination and outreach to local property owners to obtain water quality samples.

The various phases of the SNMP will be documented in concise technical reports, as listed and described below. The reports will succinctly present the project findings as well as recommended actions for the SNMP. TPWD will maintain an electronic library of data and reports.

- A Sampling and Analysis Plan will be developed prior to collecting water quality samples that will provide specific details on sampling procedures and methods for documentation. The Sampling and Analysis Plan will be reviewed after the SNMP and approved by the RWQCB and must be approved prior to conducting field sampling.

- A Groundwater Quality Sampling Report is an interim technical memorandum that will be provided after each sampling event to document the field sampling activities.

- An Annual Report will be submitted to the RWQCB that documents the work completed for the year and will also include consolidated findings and any recommended actions in response to the water quality risk assessment.

- A groundwater review will be prepared after sufficient new data are collected. A comprehensive groundwater study will be conducted to evaluate the findings from the monitoring program. This would include more detailed hydrogeological evaluation and modeling to assess the potential impacts of nitrates and TDS from septic systems on the beneficial use of groundwater in the Twentynine Palms area.

Staff from the TPWD and the City as well as other interested participating stakeholders will be involved at key milestones as the entire Program proceeds with both public meetings and stakeholder workshops. This effort will provide for a broad level of peer review and stakeholder input improving the overall quality of the concepts, assumptions, findings and ultimately the conclusions.

Septic System Management Program

It is recommended that the District and City adopt a system of Septic System Management Program elements in the context of the SNMP to properly manage septic tanks to protect groundwater quality. The Program is designed to reduce COC loading at the source before entering groundwater. The Program is defined as a series of Septic System Management Elements (SSMEs). These SSMEs are grouped into four areas that include administrative measures, operational measures, site-specific studies, and program review. The Septic System Management Program is a precursor of a Local Agency Management Program to be developed for Twentynine Palms under Tier 2 of the OWTS Policy.

Administrative measures are recommended SSMEs that follow a performance based approach. In theory, such measures appear to be both simple and inherently logical and practical. Performance based approaches generally depend heavily on data from research, wastewater characterization processes, site specific evaluations, and expected operation and maintenance activities. Careful monitoring of system performance is strongly recommended as it is an integral part of the administrative measures listed below.

- SSME #1 – Implement a Public Outreach Program

- SSME #2 – Promote Indoor Water Use Reduction to Septic Systems

- SSME #3 – Promote Waste Reduction to Septic Systems
- SSME #4 – Update the Existing Groundwater Management Plan
- SSME #5 – Apply for Grants to Provide Financial Assistance to Low Income Households to Remove Health and Safety Hazards

Operational measures also follow a performance based approach for the Twentynine Palms area. As with the SSMEs involving administrative measures, monitoring of system performance is strongly recommended as it is an integral part of the operational measures listed below.

- SSME #6 – Provide for Regular Inspection, Maintenance and Septic Waste Hauling
- SSME #7 – Develop Local Tracking of Septic Systems
- SSME #8 – Promote Upgrade or Replacement of Failing Septic Systems
- SSME #9 – Identify High-Volume Locations to Implement Advanced Treatment
- SSME #10 – Promote Proper Abandoned Well Destruction

Site-specific studies are recommended to gather site data and fill in data gaps for future evaluation of potential impacts from septic tanks. Site specific evaluations are becoming more refined and comprehensive in the assessment of potential impacts from septic tanks in other areas. Special studies range from a simple mass loading analysis to a more comprehensive analysis of soils and vadose zone, groundwater quality analysis, and numerical modeling of flow and fate and transport of pollutants, e.g., nitrate as an example. Site specific studies listed below are critical in determining the potential impacts from septic tanks.

- SSME #11 – Implement Long-Term Groundwater Monitoring Program
- SSME #12 – Conduct a COC Attenuation Study
- SSME #13 – Perform a Septic Discharge Characterization Study
- SSME #14 – Comprehensive Assessment of Septic System Impacts to Groundwater

Program review provides for mechanism to evaluate and modify the program as necessary based on lessons learned or new information. The following SSMEs outline a general program review process.

- SSME #15 – Annual Progress Report of Septic System Management Program
- SSME #16 – Updated Groundwater Assessment
- SSME #17 – Periodic Program Review and Update

Section 1: Introduction

This Salt and Nutrient Management Plan (SNMP or Plan) was prepared by Kennedy/Jenks Consultants (Kennedy/Jenks) for the City of Twentynine Palms (City) and Twentynine Palms Water District (TPWD or District). The regulatory framework is primarily based on the Regional Water Quality Control Board (RWQCB) Region 7 Basin Plan for the Colorado River Basin.

1.1 Purpose

The main purpose of the SNMP is to develop a strategy to monitor and protect the groundwater resources in the Twentynine Palms area from impacts from salt and nutrient sources. The plan includes an analysis based on the current knowledge of the groundwater and water use in the Twentynine Palms area. This analysis is to be used to guide the development of a groundwater monitoring program to collect water quality data that can be evaluated to support informed decisions on wastewater management that protects the beneficial uses of the groundwater resources. Figure 1-1 shows the general site map for the Twentynine Palms area with the boundaries of the City and District considered in the SNMP.

1.2 Background

The assessment of impacts on groundwater quality from septic tanks in the Twentynine Palms area is analyzed within the context of the existing regulatory compliance. Regulatory and public health agencies are becoming increasingly concerned about groundwater and surface water contamination from wastewater pollutants, especially in areas that currently rely on septic systems and face rapid population growth and development.

In response to recent increased concern for threats to groundwater quality from septic tanks, the City and the District prepared this SNMP to assess the long-term potential impacts to groundwater quality from the use of septic tanks, and proposed a long-term groundwater quality monitoring plan designed to protect groundwater resources and to establish appropriate management practices for wastewater. As population growth continues and more lands are urbanized, groundwater pumping within the District service area is anticipated to increase. Thus, understanding the potential effects of these changes on water use and sewer loading to groundwater is an important aspect of the overall groundwater management. This SNMP evaluates the current conditions and whether the continued discharges from septic systems would unreasonably degrade the groundwater quality and result in widespread groundwater pollution and compliance issues with the beneficial use of groundwater and water quality objectives for the RWQCB Colorado River Basin Plan (Region 7).

1.3 Constituents of Concern

Typical constituents of concern in effluent from onsite wastewater treatment systems (OWTS), like septic tanks include bacteria, nutrients, solids, biochemical oxygen demand, metals, and other potentially toxic organics. Nitrate, TDS, and pathogens (parasites, bacteria, and viruses) are the main constituents of concern (COCs) in septic system effluent. Currently, the release of nitrate and salt found in wastewater is of great concern, not only in the operation of a septic system, but also in the management of groundwater resources. Nitrates and TDS are specifically noted in the Region 7 Basin Plan with the objective of establishing appropriate management practices. The primary MCL for nitrate in a public drinking water system is 45 mg/l, which is equivalent to 10 mg/l nitrate expressed as nitrate-nitrogen (NO3-N). With respect to salt, all surface and groundwater are considered to be suitable, or potentially suitable, for municipal or domestic water supply with the exception of surface or groundwater where TDS exceeds 3,000 mg/l (5,000 us/cm, electrical conductivity). Currently, TDS has a secondary MCL of 500 mg/l, with the upper threshold concentration of 1,000 mg/l and the short-term threshold of 1,500 mg/l.

When properly designed, sited, installed, and maintained, conventional septic tanks are capable of nearly complete removal of suspended solids, biodegradable organic compounds, and fecal coliforms (USEPA, 1980a, 1997). Most traditional systems rely primarily on physical, biological, and chemical processes in the septic tank and unsaturated soil zone below the septic tanks (commonly referred to as a leach field or drain field) to sequester or attenuate pollutants of concern. More recently, however, certain pollutants present in wastewater from septic systems are raising concerns in regulatory compliance, including nutrients (e.g., nitrogen and phosphorus), pathogenic parasites (e.g., Cryptosporidum parvum, Giardia lamblia), bacteria and viruses, toxic organic compounds, and metals.

For the purpose of the SNMP, nitrate and salt were considered as the main COCs to assess the potential impact on groundwater quality from septic tanks. Nitrate (as nitrate-nitrogen) was chosen as the COC for several reasons. Nitrate acts as a conservative chemical in groundwater; it is not adsorbed by aquifer material nor does it enter into most chemical reactions (USEPA, 1980). Although nitrogen may be introduced to groundwater in several dissolved forms, the approach used assumes that all nitrogen in groundwater is converted to nitrate before reaching the groundwater and public supply wells. The principal mechanism by which nitrate is attenuated in groundwater is by dilution. Nitrate, as used hereafter in this report, refers to nitrate as nitrogen (NO3-N); thus, the term nitrogen and nitrate-nitrogen are used interchangeably. With respect to salt, TDS is considered for salt loading assessment.

1.4 Objectives

The main objective of the SNMP is to evaluate the potential groundwater quality issues from the existing septic tanks and if the continued discharges from septic systems would unreasonably degrade groundwater quality and result in widespread groundwater pollution. Key objectives of the SNMP are listed below and described in detail in this Plan.

- Describe the existing groundwater conditions pertinent to salt and nutrient loading assessment, including the current monitoring and measured groundwater quality;
- Identify the primary COCs related to septic system discharge;

- Identify salt and nutrient sources and assess the current and future projected salt and nutrient loading estimates to local groundwater basins;

- Provide a conceptual understanding of the groundwater conditions and historical groundwater quality in the Twentynine Palms area;

- Develop a groundwater monitoring program and management strategies, with a focus on potential areas of concern and COCs to monitor for future data gathering efforts that evaluate the potential impacts to groundwater from septic tanks;

- Develop Septic System Management Elements (SSMEs) for helping reduce the impacts from existing and future septic tank systems; and,

- Document the key findings, data gaps, and recommendations for further site specific studies and data gathering efforts to better manage wastewater and groundwater resources, on a basin-wide level in a manner that is in compliance with the Basin Plan water quality objectives and protection of beneficial uses.

This SNMP was prepared in parallel with a wastewater master plan (WWMP) for the Twentynine Palms area. The SNMP and WWMP are the two major elements of the overall management plan developed by the City and District for assessing the potential impact on groundwater quality from the existing septic systems and anticipated future development. The WWMP, in particular, was prepared to develop a conceptual sewer collection and treatment system that would meet the management objective established by the City and District. The WWMP relies on the SNMP assessment findings for the estimates of current and future projected salt and nutrient loadings from septic tanks to the groundwater basins and potential anticipated groundwater quality issues. The potential impact of septic systems on groundwater quality was considered to derive the necessity of localized sewers/treatment systems under current and future conditions.

1.5 General Approach

The general approach also uses the analysis of measured historical groundwater quality data collected by the District to show the historical conditions of groundwater quality in each subbasin and to look for evidence of increasing trends in salt and nutrient concentrations and related effects on groundwater. Data were discussed for COCs related to septage, primarily for salt (total dissolved solids) and nutrient (nitrate) to evaluate if concentrations exceed or threaten to exceed water quality objectives (or standards) based on the primary and secondary maximum contaminant levels (MCLs) for chemical constituents in drinking water.

As part of this SNMP, the City and District proposed a long-term groundwater monitoring program for the Twentynine Palms area (Section 6). This SNMP and the monitoring program are designed for continued protection of groundwater resources and to improve understanding of the potential effect of septic tanks on groundwater quality, and to establish groundwater and wastewater management practices in compliance with the RWQCB Basin Plan requirements.

1.6 Collaborative Plan Development Summary

The City and the District worked collaboratively to develop the SNMP with input from the public and regulatory agencies. The primary salt and nutrient issue in the area concerns wastewater disposal principally from septic systems. The Twentynine Palms area does not include any significant agricultural areas or other activities that would produce significant salt or nutrient loading that would require other key stakeholders beyond the City and District.

A series of four joint City and District meetings were held to discuss the development of the SNMP and one meeting with the local regulatory agencies. The following discussion summarizes the purpose and results of these meetings:

- On August 6, 2012, a joint meeting between the City, District and consultant team was conducted to outline the overall approach for the development of the SNMP. A review of current water quality data and the technical analysis used for determining the water and salt balance were presented to solicit input and comments. The results of the meeting were coordination with City staff and consultant team on obtaining population numbers and other relevant data needed to complete the technical analysis.

- On December 3, 2012, a joint meeting between the City, District and consultant team was conducted to review the preliminary Monitoring Plan and Septic System Management Program. The meeting resulted in additional guidance for the development of the SNMP.

- On June 25, 2013, a joint meeting between the City, District and consultant team was conducted to discuss the review the initial draft of the SNMP. The results of the meeting included additional comments and guidance for revising the draft SNMP.

- On November 6, 2013, the Twentynine Palms City Council and the District Board of Directors held a joint meeting that included a public hearing. The purpose of the public hearing was to present a Draft SNMP to the public and solicit comments to the plan. The draft SNMP was distributed to key stakeholders prior to the hearing. The city council, board of directors and public were given an opportunity to ask questions at the hearing and interested parties were invited to participate in development of the SNMP. The November 6, 2013 public hearing notifications, agenda, and minutes are included in Appendix A.

- On March 18, 2014, a presentation of the draft SNMP was given to the Colorado River Basin Region 7 RWQCB in Palm Desert. The purpose of the meeting was to present the overall findings and approach of the SNMP and give an opportunity for RWQCB staff to comment on the SNMP.

The collaborative process used for developing the SNMP helped to resolve multiple issues during its development and helped to achieve consensus on the proposed actions included in the SNMP.

1.7 Regulatory Framework

The approach will be consistent with the current regulatory guidelines and compliance related to the operation and management of septic systems and related potential impacts to public health and groundwater quality.

1.7.1 SWRCB Recycled Water Policy

The main purpose of the State Water Resources Control Board (SWRCB) Recycled Water Policy approved in May 2009 is to increase the use of recycled water from municipal wastewater sources in a manner that meets the state and federal water quality laws. The Recycled Water Policy also includes an element for developing a salt and nutrient management plan (SNMP) to address salt and nutrient issues and identify and manage all sources of salts and nutrients on a basin-wide level in a manner that ensures attainment of water quality objectives and protection of beneficial uses. The deadline for preparing SNMPs is May 2014. SNMPs are required for each groundwater basin or subbasin in the State and will be adopted in a Basin Plan Amendment by RWQCB.

Since the District service area does not have a municipal sewer system and is on septic tanks, a recycled water system is not a feasible solution in the near term; thus, the Recycled Water Policy is not directly applicable to the Twentynine Palms area. However, the assessment of salt and nutrient loading to groundwater basins conducted as part of the SNMP focuses on addressing water quality objectives and protection of beneficial uses in each subbasin. While this SNMP does not directly address the salt and nutrient management plan as outlined in the Recycled Water Policy because it is tailored to address issues from the use of septic tanks, as opposed to the use of recycled water in the Recycled Water Policy, this SNMP in conjunction with the proposed monitoring program are considered substantial progress towards identifying salt and nutrient sources basin-wide and demonstrating if concentrations of salt and nutrients, and other constituents of concern related to septic tanks are consistent with applicable water quality objectives. Furthermore, the implementation of the management measures developed as part of this SNMP will address potential groundwater quality issues associated with salt and nitrate in groundwater. Therefore, the results of the SNMP will support the Policy goals and objectives for protection of groundwater quality and beneficial uses from salt and nutrients.

1.7.2 RWQCB Region 7 Basin Plan

The Colorado River Basin Region 7 RWQCB is responsible for protecting water quality within the local groundwater basins in the Twentynine Palms area. The Region 7 Basin Plan provides the basis for the regulatory guidelines and specifies beneficial uses and water quality objectives for groundwater and surface water within its region and provides implementation plans that describe permitting options, waste discharge prohibitions, monitoring and enforcement, salt and nutrient controls, and other control measures necessary to preserve and protect water quality objectives and beneficial uses for groundwater and surface waters.

From the Colorado River Basin Plan, the beneficial use of groundwater in the Twentynine Palms area is municipal, domestic, and industrial water supply. The groundwater pumping is located mainly within Joshua Tree Groundwater Basin. The ultimate build-out extends to areas within the Dale Valley Groundwater Basin.

As stated in the Basin Plan, a detailed study is needed before establishing specific groundwater quality objectives for a particular basin. The specific quotation from the Basin Plan that forms the regulatory driver for this study is provided below:

> *"Establishment of numerical objectives for groundwater involves complex considerations since the quality of groundwater varies significantly with depth of well perforations, existing water levels, geology, hydrology and several other factors. Unavailability of adequate historical data compounds this problem. The Regional Board believes that detailed investigation of the groundwater basins should be conducted before establishing specific groundwater quality objectives."*

The RWQCB's objective is to minimize the quantities of contaminants reaching any groundwater basin and maintain existing water quality where feasible. The Region 7 Basin Plan has narrative groundwater quality objectives with respect to TDS, EC, nitrate, and other constituents of concern. In general, water quality objectives for groundwater are drinking water standards or the maximum contaminant levels (MCLs), as described below:

- Waters designated for use as domestic or municipal supply (MUN) shall not contain concentrations of chemical constituents in excess of the limits specified in California Code of Regulations, Title 22 (Chapter 15, Article 4, Section 64435, Tables 2, 3, and 4) as a result of human activity.
- Groundwater designated for use as domestic or municipal supply (MUN) shall not contain taste or odor-producing substances in concentrations that adversely affect beneficial uses as a result of human activity.
- Groundwater designated for use as domestic or municipal supply (MUN) shall not contain concentration of coliform organisms in excess of the limits specified in California Code of Regulations, Title 22, Chapter 15, Article 3.
- Nitrates and TDS are specifically noted in the Basin Plan and the objective is to establish appropriate management practices. The limit is defined by the MCL of 10 mg/l for nitrate (as nitrogen). With respect to salt, all surface and groundwater are considered to be suitable, or potentially suitable, for municipal or domestic water supply with the exception of surface or groundwater where TDS exceeds 3,000 mg/l (5,000 us/cm, electrical conductivity) and it is not reasonably expected by the RWQCB to supply a public water system.

The Basin Plan also states that ideally the RWQCB's goal is to maintain the existing water quality of all non-degraded groundwater basins. However, in most cases groundwater that is pumped generally returns to the basin after use with an increase in mineral concentrations such as TDS, nitrate etc., picked up by water during the cycle. Under these circumstances, the RWQCB's objective is to minimize the quantities of contaminants reaching any groundwater basin.

This could be achieved by establishing management practices for major discharges to land. Until the RWQCB can complete investigations for the establishment of management practices, the objective will be to maintain the existing water quality where feasible. The results generated from the SNMP and other ongoing groundwater investigations in the Twentynine Palms area will be consistent with the Basin Plan objective of maintaining the existing water quality where feasible. Specific recommended actions developed under this SNMP for implementation will support the RWQCB Basin Plan objectives for protecting groundwater quality within the local groundwater basins. With the implementation of the recommended actions, several management measures will be adopted for improving the overall monitoring of groundwater and limiting potential impacts from septic systems to groundwater.

1.7.3 Region 7 Basin Plan Amendment

The Region 7 Basin Plan includes prohibitions on the use of septic systems in certain areas. The 2008 Basin Plan includes prohibitions in two areas, including Cathedral City Cove, and in areas that overlie the Mission Creek and Desert Hot Springs Aquifers. These prohibitions were adopted in 2002, and 2004, respectively.

In May 2011, the Region 7 Basin Plan was further amended to prohibit the discharge of wastes from septic systems in specific areas in the Town of Yucca Valley to mitigate and eliminate the threat of nitrate contamination to groundwater due to septic tank discharges (RWQCB, 2011). The increase in septic system density in certain areas of Yucca Valley, combined with system failures due to age or inadequate maintenance, presented a significant threat to public health due to increased wastewater loading to the vadose zone and impacts to local groundwater used for municipal supply from nitrates, pathogens, and salts. This Basin Plan Amendment requires the Town of Yucca Valley to construct a wastewater treatment plant and collection system.

The 2003 USGS study that was conducted in support of the 2011 Basin Plan amendment is of particular interest and briefly discussed below, to provide the background studies that led to the Basin Plan amendment on the use of septic systems in the Yucca Valley area. This affects the community of Twentynine Palms; and, the implementation of the actions and measures described in this SNMP will provide critical information on future WWTP scenarios and compliance with RWQCB Basin Plan objectives for protecting groundwater quality and limiting potential effects of septic tanks on groundwater quality.

1.7.4 Statewide Septic Systems Proposed Policy

In 2012, the State Water Resources Control Board adopted the Water Quality Control Policy for Siting, Design, Operation, and Maintenance of Onsite Wastewater Treatment Systems (OWTS Policy) as Resolution No. 2012-0032. The OWTS Policy took effect on May 13, 2013. OWTS is defined to include individual disposal systems (i.e. septic tanks), community collection and disposal systems, and alternative collection and disposal systems that use subsurface disposal.

The policy was developed over a number of years and received input through multiple public workshops, stakeholder comments, and collaboration with RWQCB staff and local government health representatives. The purpose of this Policy is to allow the continued use of OWTS, while protecting water quality and public health. It is the intent of the OWTS Policy to efficiently utilize and improve upon existing local programs and to provide a process for the development of new Local Agency Management Programs.

This OWTS Policy establishes a statewide, risk-based, tiered approach for the regulation and management of OWTS installations and replacements and sets the level of performance and protection expected from OWTS. The OWTS Policy consists of four tiers that include the following.

- Tier 0 – Existing OWTS
- Tier 1 – Low-Risk New or Replacement OWTS
- Tier 2 – Local Agency Management Program for New or Replacement OWTS
- Tier 3 – Impaired Areas
- Tier 4 – OWTS Requiring Corrective Action

Existing OWTS are automatically covered by Tier 0 if they receive only domestic wastewater from residential or commercial buildings and have a projected flow of 10,000 gallons-per-day or less. In areas with no approved Local Management Plan, Tier 1 covers new or replacement OWTS that meet low risk siting and design requirements. Tier 1 requirements include a site evaluation by a qualified professional to determine whether adequate soil depth is present in the dispersal area including percolation tests. Tier 1 specifies setback and design requirements. The average density for any subdivision of property was modified to account for the dispersal effects of rainfall.

Under Tier 2, local agencies may submit management programs for approval by the Region 7 Board to manage the installation of new and replacement OWTS. A Local Agency Management Program may authorize different soil characteristics, usage of seepage pits, and different densities for new developments. The Policy acknowledges that because California is geologically and climatically complex, that site specific criteria are preferable. Once a Tier 2 Local Agency Management Program is approved, it shall supersede Tier 1, and all future OWTS decisions will be governed by the Tier 2 Local Agency Management Program.

If an OWTS is in a designated impaired area, then it would be covered under Tier 3. All existing, new, and replacement OWTS located near impaired surface water bodies may be addressed through the impaired water body's implementation program. According to the Policy, the Twentynine Palms area does not contain any impaired surface water bodies; therefore, Tier 3 does not apply for Twentynine Palms.

If an OWTS is in failing condition or otherwise requires corrective action (for example, to prevent groundwater impairment), then those OWTS would be required to take corrective actions under Tier 4. OWTS included in Tier 4 must continue to meet applicable requirements of Tier 0, 1, 2 or 3 pending completion of the corrective action. The OWTS Policy provides a list of conditions requiring corrective actions. The OWTS Policy provides timelines for implementation.

- The RWQCB has one year from the date the Policy took effect to align the Basin Plans with the Policy, which would be May 2014.
- After the Basin Plan alignment, the local authorities then have two years to develop and submit Local Agency Management Programs to the RWQCB by May 2016.
- The RWQCB then has one year for review and approval of the Programs by May 2017.

- The local agency has a one year adjustment period for implementing the Local Agency Management Program by May 2018.

The Region 7 RWQCB adopted Resolution R7-2013-0049 on September 19, 2013 that revised the septic system sections of the Colorado River Basin Plan and incorporates by reference the new OWTS Policy into the Basin Plan. The SWRCB approved the amendment to the Region 7 Basin Plan, as adopted under Colorado River Basin Water Board Resolution R7-2013-0049, on December 3, 2013 in SWRCB Resolution 2013-0039.

At the statewide level, it is estimated that the new proposed Policy will affect less than two percent of current septic systems or OWTS (as the term used to refer to septic systems or septic tanks in the Policy); thus, more than 98 percent of current OWTS owners will not need to make any changes to their septic systems. If an individual OWTS is currently in good operating condition, and it is not near a stream, river, or lake that the SWRCB has identified in the Policy as possibly contaminated with bacteria and/or nitrogen related compounds from OWTS, then this proposed Policy will have little or no effect on that property owner.

1.7.5 Land Development Sewage Disposal Guidelines

According to the Region 7 guidelines adopted in 1989, the minimum lot size of one-half acre (average gross) per dwelling unit is required for new developments in the region using on-site septic tank systems. Several areas in the City appear to have an average gross lot size of less than one-half acre per dwelling unit. Although these guidelines do not apply to the existing developments, they represent the regulatory standard indicating that the RWQCB considers high-density residential developments as high risk areas. This SNMP and the proposed groundwater monitoring program were prepared to address issues specifically in the high-density areas.

1.7.6 Anti-Degradation Policy Summary

State Water Resources Control Board Resolution 68-16, known as the Anti-Degradation Policy, requires that the CRWQCB regulate the discharge of waste materials to maintain the high quality of waters of the state. Waste Discharge Requirements for facilities must insure that beneficial uses of groundwater are not unreasonably affected. In addition, the facility must meet a standard of Best Practicable Treatment or Control (BPTC) for discharged wastes.

The "Statement of Policy with Respect to Maintaining High Quality of Waters in California," known as the Anti-degradation Policy, adopted in 1968, requires the continued maintenance of existing high quality waters. It provides conditions under which a change in water quality is allowable. A change must:

- Be consistent with maximum benefit to the people of the State,
- Not unreasonably affect present and anticipated potential beneficial uses of water, and
- Not result in water quality less than that prescribed in water quality control plans or policies.

1.8 District Water Planning

The TPWD has developed groundwater management plans, urban water management plans and conducted a comprehensive groundwater study as the basis of the District's water planning responsibilities. A summary of these reports is provided below.

1.8.1 Groundwater Management Plan

The Groundwater Management Plan (GWMP) was updated in 2014 to outline the role of the District in the management of the local groundwater resources and to develop a management plan that can be implemented by the District to protect the quality and quantity of groundwater within its service area. The GWMP also assesses the current status of the groundwater basin and defines how to best manage the basin under local control. The GWMP proposes six Basin Management Objectives (BMOs) to the District, a number of them promoting conservation.

In the context of this SNMP, the District's existing monitoring plan and best management practices were reviewed to identify additional monitoring and management practices required for the proposed monitoring program in this SNMP, consistent with the RWQCB Colorado River Region (Basin Plan). Based on the review of the existing monitoring, areas were identified where additional monitoring may need to be implemented, if necessary, to meet the requirements of the SNMP. Review of the existing monitoring programs will confirm the availability of water quality data parameters required to meet the goals of the Plan to ensure that groundwater quality is protected.

1.8.2 Urban Water Management Plan

The District prepared a 2010 update of the UWMP to evaluate the population, water supply and demand projections over a 25-year period from 2010 through 2035 (Kennedy/Jenks, 2011). The 2010 UWMP Update provides a water use target by 2020 in compliance with the SBX7-7 toward a 20 percent reduction in per capita water use. Water use data from January 1995 to December 2010 were used based on a 10-year average to calculate the baseline daily per capita water use of 147 gallons per capita per day (gpcd) and the District's 2020 compliance water use target of 135 gpcd. Since recycled water is not used in the District service area, it was not accounted for in calculations.

The 2010 UWMP is a key planning document that was used in the development of the SNMP. The UWMP findings for population, water supply and demand projections are pertinent to the SNMP in the context of groundwater management as the District meets water demand solely with groundwater. In addition, projections of domestic wastewater estimates for the salt and nutrient balance rely on water use data from the UWMP projections both for the Current and 2035 Scenarios. Therefore, population and water use projections and corresponding domestic wastewater estimates in the SNMP are consistent with the UWMP projections and meet the 2020 compliance for water conservation.

1.8.3 Groundwater Study

The District took the lead to develop a numerical model for the Mesquite Lake Subbasin and used the model as a useful management tool. Overall, the model is being used to make informed decisions in future management of groundwater resources in a sustainable manner while meeting increased water demand. The model was set up using the USGS MODFLOW-

2000 (Kennedy/Jenks, 2010) and calibrated to the historical data. The main objective of the model was to simulate the long-term changes in groundwater elevation over time. The calibrated model demonstrated that the model is capable of simulating previously observed groundwater trends over time across the entire model domain. The model was used to evaluate the effects on groundwater levels of various potential future groundwater pumping scenarios. The model results indicated that shifting pumping to the Mesquite Lake Subbasin will mitigate the decline in groundwater levels in Indian Cove, Fortynine Palms, and Eastern Subbasins.

During the development of the model, extensive review of background studies on the groundwater basin hydrogeology was conducted. Data from the existing numerical groundwater model were used in the development of the water balance analysis in this SNMP. As described in Section 4, data for recharge, ET, and groundwater flow exchanges between the subbasins were obtained from the calibrated model and incorporated into the water balance by each subbasin.

Section 2: Background and Planning Area

Section 2 presents the background data, including a brief overview of the planning area characteristics based on the previous studies and planning documents prepared in the Twentynine Palms area. Specifically, this section characterizes the service area in relation to climate, land use, current and future projected population, water sources, and service area water demands, as well as the existing wastewater management, groundwater management and monitoring activities in the Twentynine Palms area. Local groundwater basins are introduced in this section and further described in Section 3 as part of the regional and local hydrogeologic settings. This section also provides a brief description of the previous studies that are most pertinent to the development of the SNMP as they provide the basis for the water balance analysis in Section 4 and salt and nutrient analysis in Section 5.

2.1 Planning Area

This Plan is prepared for the City and District and covers the planning area that includes the boundaries of the City and District. The majority of the current land development is within the City and the District. Currently, only small, low-density development is outside of the District and City boundaries but within the City's sphere of influence (SOI). Based on the new land use/zoning of the City's boundary, the City boundary has recently been extended with the approval of the City Council to change the City's SOI to match that of the District. With this change, the City's boundary extends beyond the City limits and more closely matches that of the District and includes the unincorporated areas. The District service area encompasses approximately 86.6 square miles and includes the City. The District is located in the high desert of southern California, approximately 72 miles due east of the City of San Bernardino and 35 miles northeast of the City of Palm Springs, as shown in Figure 1-1.

Throughout this Plan, the District service area and the Twentynine Palms area are used interchangeably to refer to the general study area considered in this SNMP, given that the District's service area matches that of the City closely and covers the unincorporated area considered in this Plan.

2.2 Climate

The climate in the study area is arid, with hot summers and mild winters, with average annual rainfall of less than five inches, most of which occurs during the winter months. Temperatures range from 20 to 60°F during the winter and from 80 to 110°F degrees during the summer. Throughout the area, high temperatures tend to decrease with increasing elevation, while low temperatures do not vary greatly with elevation. Table 2-1 presents the region's annual average climate data, based on the data reported in the 2010 UWMP (Kennedy/Jenks, 2011).

The climate of the Twentynine Palms area, typical of a desert, is characterized by sunny days, low rainfall, hot summers, and relatively cool winters. The Twentynine Palms area is quite dry, with average annual precipitation of about 4.3 inches (Table 2-1), ranging from less than 3 inches per year at the eastern end of the Dale Basin to more than 6 inches per year in the San Bernardino Mountains to the west. Most of this precipitation is lost through evaporation; the total average monthly evaporation rate of a desert area is 57 inches per year (Table 2-1).

Precipitation follows a generally bimodal distribution, with most annual precipitation falling during the summer monsoon and the winter wet season. Summer precipitation occurs in convective storms driven by the import of monsoonal moisture from the Gulf of California and the Gulf of Mexico, while winter precipitation occurs in frontal storms driven by moisture moving east from the Pacific Ocean. Summer storms are intense and of relatively short duration, and may lead to flash floods but are unlikely to contribute to recharge due in large part to the high potential evapotranspiration (ET) during the hot summer months. Winter storms are gentler and of longer duration, and are more likely to contribute to recharge.

The relative importance to the annual total precipitation of each of these two seasons varies with location. In the low-elevation parts of the basin, particularly in the Dale Basin, the months with highest average precipitation occur in the summer, particularly July, August, and September. In the higher-elevation areas, the months with the highest average precipitation occur in the winter, peaking in January and February.

TABLE 2-1
CLIMATE DATA

	Jan	Feb	Mar	Apr	May	Jun
Standard Monthly Average ETo[a] (inches)	1.6	2.2	3.7	5.1	6.8	7.8
Average Rainfall (inches)	0.4	0.3	0.4	0.1	0.1	0.0
Average Max. Temperature (Fahrenheit)	63	68	74	82	91	101
Average Min. Temperature (Fahrenheit)	36	39	43	49	57	65

	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Standard Monthly Average ETo (inches)	8.7	7.8	5.7	4.0	2.1	1.6	57.1
Average Rainfall (inches)	0.7	0.8	0.5	0.3	0.3	0.4	4.3
Average Max. Temperature (Fahrenheit)	105	103	98	86	72	63	84
Average Min. Temperature (Fahrenheit)	72	70	64	53	42	35	52

Note:
(a) Standard Monthly Average ETo determined from CIMIS Station No. 118 Cathedral City.

2.3 Land Use

Residential development in the study area is currently the single largest land use served by the District. Approximately 80 percent of the residential development is single-family homes. The remaining 20 percent is comprised of some multi-family residential units, commercial properties, and minor light industry, with heavy industry. The distribution of land uses in the study area is shown on Figure 2-1. There is no community sewage system and wastewater is disposed through individual septic tank and tile field disposal systems (see Section 2.7).

Figure 2-2 shows the build-out land use map based on the City's General Plan designation. As shown, the majority of land use is designated for residential development and open space residential, with a small portion made up by commercial, institutional, and industrial. Unincorporated area within the District service area currently consists of residential land use and is anticipated to remain the same with the ultimate City build-out.

The current and future projected water demand, and in turn sewer loading, will vary depending on the level of land use changes. Therefore, the land use data and specific water use sectors associated with the land use provide the basis for the water use and sewer loading calculations presented in Section 4 and the salt and nutrient balance analysis in Section 5.

2.4 Population

The current population served by the District is approximately 18,975, based on the estimate from the District 2010 UWMP. The population for 2035 was projected to be 30,931, based on the historic populations and data from the Department of Finance (Kennedy/Jenks, 2011). Tables 2-2 and 2-3 present the historical population from 2006 to 2010 and the 2035 projected population, respectively. As part of this Plan, the build-out population was estimated which included the unincorporated area and the City's SOI population, based on the formula below and population data shown in Table 2-4:

> Build-out population = Total City build-out population - Marine Base population + Unincorporated population (adjusted) + SOI population outside of City boundary

As mentioned above, based on the new land use/zoning of the City boundary, the City SOI boundary has recently been extended beyond the City limits and more closely matches that of the District and includes the unincorporated areas. The build-out population projection accounts for this change.

Based on the discussions with City Staff (refer to Appendix A - email attachment by Matt McCleary, 2014) and General Plan, the City build-out population is 103,275 and the Marine Base population is 22,500. Since the Marine Base is served by sewer systems, based on the discussion with the City Staff the Marine Base population was excluded from the City build-out population calculations. The City's SOI population is 7,586, based on population estimates from the City General Plan. The total unincorporated population is estimated to be 17,253, but a small southern portion of the unincorporated area falls within the City SOI; thus it is adjusted to account for the population of 14,602 that corresponds to the area but outside of the City's SOI. The unincorporated area covers a large area with a very low population density.

TABLE 2-2
HISTORICAL POPULATION ESTIMATES

2006	2007	2008	2009	2010
18,462	18,716	18,736	18,737	18,795

TABLE 2-3
PROJECTED POPULATION ESTIMATES

2015	2020	2025	2030	2035
22,135	25,476	27,339	29,202	30,931

TABLE 2-4
PROJECTED BUILD-OUT POPULATION ESTIMATE

City's Build-out population*	103,275
Marine Base population**	22,500
Total City Population**	80,775
Unincorporated population (adjusted)***	14,602
City Sphere Of Influence population**	7,586
Total build-out population	**102,963**

*Per City Staff Matt McCleary
** Per City of Twentynine Palms General Plan
*** Area included in Twentynine Palms Water District service area. Land use and housing estimates derived from County of San Bernardino planning data. Effective population estimated in accordance with the City of Twentynine Palms Land Use Plan.

2.5 Water Sources

The study area considered in this Plan is mainly served by the District. Groundwater is the sole source of water in the District service area. The District neither receives water from a wholesaler nor supplies water to retail water purveyors. As described in the 2010 UWMP (Kennedy/Jenks, 2011), groundwater will continue to be the sole source in the future and no additional sources of water are anticipated to be available to the District. Connection to imported water from either the Metropolitan Water District of Southern California (MWD) (Colorado River supplies) or the Mojave Water Agency (MWA) (State Water Project supplies) does not appear to be a viable option for the District. MWD's closest facilities are more than 45 miles southwest of the District; MWA's facilities extend no closer than Joshua Tree, approximately 12 miles west of the District. The District Board has voted against extending imported water service to the District on two occasions.

In April 2002, the District completed source water assessments for all active drinking water wells. Wells 4, 14 and 16 are considered most vulnerable to the following activities associated with the contaminants detected in the water supply: septic systems, high density housing, office buildings/complexes, schools and parks. The newest (tenth) well was installed in 2009 and a Source Water Assessment was performed in 2007.

The District recognizes the importance of recycled water and water reliability; however, recycled water is not a feasible solution in the District service area, due to the small size of the system, low annual demand and the use of individual septic systems. The District has considered partnering with other agencies in the region; however, the nearest water agency is 12 miles away and an intertie is cost prohibitive. Therefore, at this time there are no opportunities for water recycling or programs that include recycled water. As an alternative, the District will invest in water conservation approaches to reduce demand and compensate for the lack of recycled water through developing approaches to emphasize outdoor water conservation.

Potable water is scarce in the District for several reasons. As discussed above, the area receives an average of only four inches of annual rainfall. There is negligible infiltration and recharge of direct precipitation in areas where the alluvial deposits are thick. In addition, a substantial amount of runoff is lost to evaporation after flowing into the basin. In addition to the scarce sources, water quality issues in groundwater due to naturally occurring soluble minerals, such as fluoride, make some of the water unsuitable for drinking water prior to treatment. As discussed further in Section 3, water pumped from the Mesquite Lake Subbasin is treated to remove high levels of fluoride before being distributed into the pipeline system.

2.5.1 Groundwater Pumping

Groundwater pumping by the District is a good indication of water use in the study area as the District pumps groundwater as its sole source to meet the residential and non-residential water demand. As the majority of water use is from the residential development and the outdoor water use is generally small, residential indoor water use (and in turn residential wastewater) is considered to be a large contributor to septic systems.

Historical pumping and water deliveries by the District have steadily increased since its formation in the mid-1950s. Annual pumping in the 1990s regularly exceeded 900 million gallons, approximately 2,760 acre-feet per year (afy), with average daily delivery per service connection slightly under 400 gallons. Total water demand in the District was 2,674 acre-feet (af) in 2010, with a projected demand of 5,119 AF in 2035, based on the UWMP (Kennedy/Jenks, 2011).

Water provided by the District is derived from water supply wells located along the southern limit of the service area. The District has been historically pumping from the three subbasins that have high quality of water, but are overdrafted. As of 2010, the District has ten (10) active production wells and pumps from these four different aquifers:

- Fortynine Palms Subbasin has two wells (Well #4 and Well #14)
- Indian Cove Subbasin has five wells (Well #6, Well #9, Well #11, Well #12, and Well #15) and one well on standby
- Eastern Subbasin has one well (Well #16) used for water supply and another well for non-potable use
- Mesquite Lake Subbasin has one well (Well WTP-1).

Figure 2-3 shows the boundaries of the four groundwater subbasins in the Twentynine Palms area and locations of the District active supply wells. Also shown in Figure 2-3 are the District inactive wells. In addition to the District wells, available information indicates that more than 400 private wells have also been constructed within the District service area. Most of these wells are not currently operated. The approximate location of 250 private wells are shown in Figure 2-3 approximately based on the parcel information.

2.5.2 Groundwater Pumping Capacity

The District has a total pumping capacity of approximately 6,985 afy (4,330 gpm) of available future groundwater supply. This includes a pumping capacity of 2,100 gpm (or 3,395 afy) from Mesquite Lake Subbasin and the remaining from the Joshua Tree Basin that consists of 490 gpm (790 afy) from the Eastern Subbasin; 870 gpm (or 1,400 afy) from the Fortynine Palms Subbasin, and 870 gpm (or 1,400 afy) from the Indian Cove Subbasin.

The District's current pumping capacity is well above the current pumping levels and is sufficient to meet the projected 2035 water demand without expansion (see Section 2.6). The current pumping is limited by DWR recommendations to prevent overdraft. There is potential to expand the Mesquite Lake Subbasin facilities to include another well if needed in the future. This additional well would improve reliability by allowing for redundancy in the Mesquite Lake Subbasin by increasing pumping capacity. Future expansion of the treatment plant is considered to provide for an additional 3 mgd of treated water. The District identified the funding (totaling $10 million) for the future expansion of the treatment plan beginning in their fiscal year 2011-12 Capital Budget.

2.6 Water Demand

Currently, the District serves the area solely by groundwater pumping. Water demand in the service area is anticipated to increase in response to population increase and groundwater will continue to be the sole source for meeting future demand, as discussed below.

Water demand data for the study area are described below for the current and 2035 conditions, which provide the basis for water use and sewer loading calculations presented in Section 4 and salt and nutrient balance analysis in Section 5.

2.6.1 Current Water Demand

Based on the 2010 UWMP, the District water demand during 2010 was 2,674 acre-feet (af), serving 7,983 connections, all of which are metered accounts (Kennedy/Jenks, 2011). As discussed above, groundwater is the sole source of water supply and the District does not import from or sell to any other agencies. The principal types of water connections include; residential, commercial/industrial, landscape irrigation, and fire protection/non-potable. Approximately 94 percent of the service connections are residential. Commercial connections account for approximately 4.5 percent, landscape irrigation connections account for less than 1 percent, and fire protection/non-potable connections account for the remaining 1.4 percent of the District's total connections. In addition, unaccounted-for water losses account for about 8 to 17 percent of total water production, based on records between 1990 and 2010 (unaccounted water is defined as the difference between water production and water sales). In 2010, unaccounted-for water loss was 10.9 percent of total District demand.

Based on the most recent water usage data available from the District for March 2010 through February 2012, total annual water use was estimated to be 2,552 afy, as presented in

Table 2-5. For the purpose of the SNMP, the latest water use data in Table 2-5 were considered as a representation of the current annual water use by each land use category. While this is slightly lower than the 2010 water use of 2,674 af presented in the 2010 UWMP, it is more representative of the current conditions; thus considered for estimating the current sewer loading rates for residential and non-residential sectors (see Section 4). In terms of per capita water use, the current residential water use presented in Table 2-5 corresponds to 101 gpcd, based on the current population of 18,795 (Table 2-2). Sewer rate was estimated to be 80 gpcd using water to sewer conversion of 80 percent.

TABLE 2-5
CURRENT ANNUAL WATER DEMAND

Land Use	Annual Water Use (afy)
Single family	1,682
Multifamily	414
Commercial/institutional	278
Industrial	0
Landscape irrigation	115
Other (fire protection/non-potable)	64
Total	**2,552**

Note: Annual water use for each category was calculated based on average monthly water use records provided by the Twentynine Palms Water District for records from March 2010 through February 2012. Similarly, the District UWMP estimates 2010 demands of 2,674 AF (Table 2-4).

Base daily per capita water use is a key indicator commonly used for estimates of wastewater production in the absence of actual wastewater measurements. Since the District service area is on septic systems, actual wastewater production is unavailable. However, as part of the 2010 UWMP, the base daily per capita water use and the future projected per capita water use were calculated and available for the District service area. Calculations are in compliance with the SBX7X7 water reduction by 2020 and applicable for the 2035 future projections. Since recycled water is not used in the District service area, water use data from January 1995 to December 2010, were used based on a 10-year average to calculate the baseline daily per capita water use of 147 gpcd and the District's 2020 compliance water use target of 135 gpcd.

2.6.2 Projected 2035 Water Demand

Water use in the District service area is projected to increase to 5,119 af by 2035, based on the 2010 UWMP (Kennedy/Jenks, 2011). Total residential water demand is projected to be 3,401 af for single family and 839 af for multi-family residential, as presented in Table 2-6.

For the purpose of the SNMP, non-residential water use in Table 2-6 was used as the basis for sewer loading estimates for the 2035 Scenario by converting from water use to wastewater (See Section 4 for details). The approach used to estimate residential sewer loading for the 2035 Scenario relies on the future projected per capita water use. Residential water use (and in turn sewer loading) was assumed to reduce by 2035, proportional to the reduction in the gpcd. As described above, based on the 2010 UWMP, the base daily per capita water use is estimated to be 147 gpcd. Water use is projected to reduce to 135 gpcd by 2020 to meet the 2020 compliance water use target. This represents a reduction of 12 gpcd per capita water use (147 – 135 = 12 gpcd), or 8 percent reduction from the baseline daily per capita water use by 2020. As a reasonable approximation of water use projections beyond 2020, it was assumed that once the 2020 compliance water use target is reached, per capita consumption would remain the same by 2035. For the 2035 sewer loading projections, it was also assumed that sewer loading reduction from the current conditions to 2035 would occur at a similar rate as the water use reduction. In terms of sewer rate, the 2035 projection is estimated to reduce to 73.5 gpcd from the current sewer loading estimate of 80 gpcd. This represents approximately 9 percent reduction in sewer loading by 2035, which is similar to the 8 percent reduction estimated for water use.

TABLE 2-6
2035 PROJECTED ANNUAL WATER DEMAND

Land Use	Annual Water Use (afy)
Single family	3,401
Multifamily	839
Commercial/institutional	561
Industrial	0
Landscape irrigation	151
Other (fire protection/non-potable)	167
Total	**5,119**

Note: Annual water use for each category is based on the District 2010 UWMP projections (Table 2-4).

2.6.3 Build-Out Water Demand

For the purpose of qualitative discussion of the Build-out Scenario, total water demand was estimated following the same methodology developed for the 2035 Scenario. Total water demand based on residential and non-residential usage was estimated to be 12,784 afy. Total water demand includes residential water demand of 10,455 afy and non-residential water demand of 2,329 afy. The residential component of the above demand was based on a build-out population of 102,963 and daily per capita water use of 92 gpcd. The build-out population covers both the District service area and City SOI as described earlier (Table 2-4). The non-residential component was calculated based on area and an 80 percent water to sewer conversion, and as described in detail in Section 4.

The total water use projected for the Build-Out Scenario is significantly higher than the 2035 projections and the District's current pumping capacity of 6,985 afy, presenting issues with long-term water supply and quality. While the maximum pumping capacity is 10,248 afy, pumping at the maximum capacity can be limited due to potential overdraft. In addition, expansion of pumping in the Mesquite Lake Subbasin for future needs would require significant expansion for water treatment to resolve elevated fluoride levels naturally occurring in groundwater.

Section 3: Hydrogeologic Conditions

Hydrogeology, aquifer conditions, and water quality are essential components in designing a successful salt and nutrient groundwater monitoring program appropriate for the physical setting of the groundwater basins. The SNMP includes an overview of hydrogeologic conditions of the groundwater basins including, but not limited to, groundwater flow and ambient groundwater characteristics.

3.1 Physical Setting

The physical setting provides an overview of the key characteristics of the region that influence groundwater conditions in the Twentynine Palms area.

3.1.1 Twentynine Palms Area

The Twentynine Palms area is located in the high desert of Southern California, approximately 70 miles due east of the City of San Bernardino and 35 miles northeast of the City of Palm Springs. TPWD service area encompasses approximately 86.6 square miles and includes the City of Twentynine Palms.

The City of Twentynine Palms lies within a large alluvial basin bounded on all sides by mountain ranges of various sizes (Figure 3-1). The basin floor itself has a gentle and fairly uniform slope to the southeast that is broken up by several bedrock outcrops. The most notable of these is Copper Mountain (3,070 feet) which is located just to the west of the City of Twentynine Palms. Low points within the basin floor are locations of internal drainage, and are occupied by playa lakes, which are almost always dry. Playa lakes within the Mesquite Dry Lake area are small and unnamed south of Mesquite Dry Lake and two small unnamed playas are on the east side of Copper Mountain.

The Twentynine Palms area is located within three groundwater basins, identified as the Twentynine Palms, Dale and Joshua Tree Basins by DWR (2003). The City of Twentynine Palms is underlain on the north by the Mesquite Lake Subbasin (also referred to as the Mesquite Subbasin in some references) of Twentynine Palms Basin. South of Twentynine Palms, the Joshua Tree Groundwater Basin is divided into the Indian Cove, Fortynine Palms and Eastern Subbasins (Figure 3-1).

Groundwater is compartmentalized into these individual subbasins so that they are more or less separated from one another by hydrologic barriers, including bedrock ridges, faults, and folds. The degree of separation between these subbasins is dependent upon the character of the barriers separating them.

3.1.2 Geologic Setting

The Twentynine Palms Basin is in the eastern Mojave Desert geomorphic province. The principal landforms are Cenozoic alluvial fans and alluvial plains bordered by mountains composed of Precambrian and Mesozoic igneous and metamorphic basement rock (Figure 3-2). The geology in the Twentynine Palms area primarily consists of Tertiary to Quaternary alluvium deposits in the basins enclosed by bedrock materials in the surrounding hills and mountains (Riley and Worts, 1953).

The geology of the basin is typical of many extensional basins throughout the western United States. Basin-bounding ranges are fronted by normal faults along which they have risen relative to the basin floor (Riley and Worts, 1952). Over time, the basin has filled with highly heterogeneous deposits. The sediments within the basin have been buried progressively deeper as more sediments have been laid down on top of them; those at the greatest depth are more compacted than are those near the ground surface. The basin geologic system is defined by the bedrock geology, the recent alluvial geology, and the structural features in the basin.

The alluvium is highly variable vertically and horizontally. Riley and Worts (1952) described the makeup of the sediments in the area as being made up of interbedded sand, gravel, and clay. The coarsest alluvium tends to be along the mountain fronts where the depositional energy is highest (Kennedy/Jenks, 2001, 2008, 2010). Typically finer grained sediments are found with distance away from the mountain fronts. The sediment size grades progressively to fine sand at the lower ends of the washes and eventually to silt and clay at the center of the basin forming playa deposits (Riley and Worts, 1952).

3.1.3 Regional Groundwater Flow

Understanding this regional context is important for understanding how groundwater levels within an individual basin may respond to changes in groundwater pumping. A 2008 groundwater elevation map (Figure 3-3) of the entire region is provided to demonstrate the regional groundwater flow and the interconnection between the various groundwater basins in the area (Kennedy/Jenks, 2010). The primary source of groundwater in the study area is runoff from precipitation that falls in the adjacent highland areas. This is reflected on by the highest groundwater levels that occur near to the adjacent highlands. Recharge occurs primarily along the mountain fronts on the western and southern boundaries of the basin. Most of this recharge enters the Pipes Subbasin, with smaller amounts coming into the Pipes, Joshua Tree, Indian Cove, Fortynine Palms, and Eastern Subbasins.

The interconnection between the various groundwater basins is primarily controlled by faults that extend across the basin. These faults act as barriers that limit the volume of groundwater that flows into the adjacent basin. These barriers are reflected on the groundwater elevations map by distinct change in groundwater elevations, in some cases over 100 feet, across some of these faults. For some of these basins that are not adjacent to the highlands, this groundwater flow across the faults is the primary source of recharge.

The largest bounding mountain range is the San Bernardino Mountains to the west. This range is nearly continuous with the Little San Bernardino Mountains, which form the southern boundary of the basin, except for a small notch between the two that contains the towns of Yucca Valley and Morongo Valley and the highway connecting the basin to Interstate 10 to the south.

3.2 Previous Hydrogeological Studies

This report includes an evaluation of previous groundwater investigations of the general hydrogeology for the Twentynine Palms area, mostly performed by the USGS and TPWD.

Below is a brief overview of some of the key previous studies and reports for the area. The results of these studies are incorporated into the discussion in this section.

The earliest studies include Thompson (1921) who included Twentynine Palms in his report on springs and other watering places in the Mojave Desert. Thompson (1929) later produced a more complete assessment of the various hydrological features in the study area, including an assessment on groundwater movement through the basins and potential importance of faults to the hydrologic system.

The DWR (1984) reported on the groundwater hydrology of the four basins in the Twentynine Palms area (the Indian Cove, Fortynine Palms, Eastern, and Mesquite Lake Subbasins), detailing groundwater production, changes in water levels, and geochemistry including the occurrence of fluoride. This was the first report to look at the Twentynine Palms area in isolation from the rest of the region.

In 2010, TPWD completed a comprehensive groundwater study of the subbasins within the District including the development of a numerical groundwater model to evaluate plans to shift pumping from the Indian Cove, Fortynine Palms and Eastern Subbasin to the Mesquite Lake Subbasin for planning purposes (Kennedy/Jenks, 2010). Previously, TPWD updated their Groundwater Management Plan (GWMP) to help plan water resource management (Kennedy/Jenks, 2008). TPWD updated their UWMP to reflect changes in the hydrology and groundwater extraction of the area (Kennedy/Jenks, 2005, 2011). The Mojave Water Agency (MWA) produced a Regional Water Management Plan that includes a GWMP and UWMP in 2004 (MWA, 2004) for its area west of Twentynine Palms.

Recently, Nishikawa *et al* (2004) conducted comprehensive studies of the hydrogeology in the Joshua Tree area to the west of the Twentynine Palms area. The study defined the near-surface primary water-bearing units based on the previous work of Bedford and Miller (1997). Nishikawa *et al* (2003) also included a geochemical study of nitrate concentrations, a hydrogeological analysis of the area, and a numerical groundwater model of the Joshua Tree Subbasin.

Considerable work has been conducted for the military base now operated by the U.S. Marine Corps (USMC) located north of Twentynine Palms. Riley and Worts (1952, 1953) provided the first comprehensive study on the occurrence of groundwater and surface water and included the hydrologic water balance and geochemistry data. Londquist and Martin (1991) described the surface geology and primary water-bearing units following the work of Riley and Worts (1953). Akers (1986) produced a short study on the hydrology of the USMC base quantifying the amount of water in storage. Li and Martin (2011) developed and calibrated a regional groundwater-flow model based on the previous USGS hydrogeologic studies of the USMC base area. The model area included a portion of the Twentynine Palms area.

3.3 Hydrology

In the arid to semiarid environment of the Twentynine Palms area, surface water is generally rare, localized, and short-lived. Exceptions exist, especially during extreme events. Surface water exists in the basin in three different forms: streamflow, playa lakes, and spring flow. The locations of surface water bodies are shown on Figure 3-4.

3.3.1 Springs

Water discharging at springs has historically been an important hydrologic feature as the only easily available source of water. As early as 1921, the USGS mentioned the line of springs at Twentynine Palms known as the Oasis of Mara (Figure 3-4). Thompson (1929) noted that the springs here were about a mile long. Riley and Worts (1953) noted that no water was at the surface at the Oasis of Mara in 1952 and 1953, indicating a great reduction in discharge from the spring here. This location has not been mentioned in more recent reports as a location of surface discharge.

Mesquite Spring (Figure 3-4) once consisted of at least two pools, each 3 to 4 feet across and 2 feet deep, supporting a discharge of water that flowed about 200 feet into the desert (Thompson, 1929). No water level declines are noted in the area (Kennedy/Jenks, 2001, 2008), but discharge is not mentioned at this location in any report other than Thompson (1929), indicating that it likely has not had surface flow for some time.

3.3.2 Streamflow

There are no perennial streams in the Twentynine Palms area. The stream channels are ephemerally flowing streams with runoff originating in the adjoining mountains in response to the largest storms. However, very little surface flow leaves this area (Troxell *et al*, 1954). When runoff is generated by a storm, the streamflow typically either percolates into the alluvial soils in the stream channels near the mountain front or is lost to evaporation (Kennedy/Jenks, 2001, 2008). The several surface water drainage basins in the region ultimately end at a playa lake; therefore, the surface water is confined within the basins. In the event of an extraordinary storm, streamflow may reach Dale Dry Lake (Thompson, 1929).

Nishikawa *et al* (2004) presented streamflow data from several USGS stream gages in the region including the Fortynine Palms Creek in the area (Figure 3-4). Over the period of record, Fortynine Palms Creek had measurable flow on an average of 2.4 days per year, totaling 74.3 afy. These four gauges show streamflow to be highly intermittent, with the duration of surface flows limited to only 1 to 2 days in response to storms (Nishikawa *et al*, 2004).

3.3.3 Playa Lakes

Playa lakes form at the lowest elevations in a number of the surface drainage basins in the study area (Figure 3-4). These dry lakes represent, in some cases, the end of surface water drainages. In other cases, they are topographic low points in their respective basins, where surface water ends up if runoff is high enough. The playa lakes in the study area are rarely sites of surface water collection, as runoff is too ephemeral to reach them.

The Mesquite Dry Lake is about 2.5 miles long, 1 mile wide, and, at an altitude of about 1,760 feet, represents the lowest point in the Twentynine Palms Basin. The southern end of the playa is truncated by a very low fan, which extends across the bottom of the trough between Mesquite Dry Lake and the small unnamed playa to the south that some older maps refer to as Shortz Playa (Figure 3-4). The drainage to Shortz Playa has been captured by recent headward erosion in the wash that drains to Dale Lake so that now Shortz Playa is largely covered with sand dunes. Two lesser playas are just east of Copper Mountain. Both lie near the southern ends of the north-south troughs whose eastern sides are formed by the parallel north-trending ridges. Their small drainage areas limit their size.

3.4 Soils

Three basic types of parent materials exist in the study area: bedrock, alluvium, and playa lakebeds. Thompson (1929) provided general descriptions of the soils in the Mojave Desert on the alluvial slopes and the playa lakes. All soils in this area were typified by having very little organic matter. Soils overlying bedrock are typically thinner than other soils (USDA, 1994, Nishikawa et al., 2004), and are made up mostly of medium- to coarse-grained pieces of the parent material on which they lie.

Alluvial soils have little clay, generally being composed of weathered bits of rock. Some areas contain caliche (layers of concentrated mineral salts), which can prevent downward movement of water, at depths from a few inches to a few feet. Alluvial soils make up most surfaces in the study area. Logs of wells in Riley and Worts (1953) indicate that soil thicknesses vary from 0 to 16 feet throughout the study area north of the Oasis Fault; presumably, similar figures would be found south of the fault.

Playa lake soils are typically very clayey and support little to no vegetation (Thompson, 1929; Nishikawa et al., 2004). There are limited areas of phreatophytic vegetation at the Oasis of Mara and Mesquite Dry Lake. Rough surfaces indicate rising groundwater and active soil moisture evaporation. Playas with discharging groundwater are typified by accumulations of alkali and other mineral salts (Thompson, 1929).

Hydrologic soil groups were mapped for the Twentynine Palms Master Plan of Drainage prepared for the San Bernardino County Flood Control District (NBS/Lowry Engineers & Planners, 1997). Four hydrologic groups were defined in the area, but the majority of the area has Group C soil, including the high density urban area, which have below average infiltration rates of 0.2 to 0.8 inches per hour (DWR, 1984, USDA, 1970). The area west of Twentynine Palms has soil type of group B that has a moderate infiltration rate of 2.5 to 5.0 inches per hour (DWR, 1984, USDA, 1970). Only a small area near the Marine base is designated with Group A that has a high infiltration rate. The general distribution of geologic units that are exposed at the surface is presented in the General Plan based on several geologic maps published for this area (Dibblee, 2008a, 2008b).

3.5 Structural Geology

Structural features are very important to the hydrogeology of the Twentynine Palms area, as they act as flow limiting features that separate the groundwater subbasins from one another. These features are mainly faults, which crisscross this area due to its intense tectonic history. These deep basins are likely strike-slip extensional basins caused by a right slip across a right step from the Mesquite Fault to the Bullion Mountain Fault (Roberts and others, 2002).

There are three sets of faults running through the basin (Riley and Worts, 1952). Several other unnamed faults do not fall into the three fault sets described above, but are visible on geologic maps and may be important to the hydrogeology. The first set consists of normal faults that cross the basin in a generally north-northwest to northwest direction. The easternmost is the

Mesquite Fault (Riley and Worts, 1952). Deadman and Mesquite Dry Lakes are located directly on top of this fault (Figure 3-2).

The second set of faults runs generally north-south, with faults most important in the southern end of the basin and dying out toward the north (Riley and Worts, 1953). These faults include the Elkins and Sand Hill Faults (Figure 3-2).

The third set of faults runs east-west along the southern end of the basin. These include the Pinto, Bagley, and Oasis Faults (Figure 3-2). The Oasis Fault (also known as the Pinto Mountain Fault in many references) was reported by Thompson (1929) as having a scarp 15 to 30 feet high next to the Oasis of Mara. The Bagley Fault is about half a mile north of the Oasis Fault in the area of Twentynine Palms, and intersects with the Oasis Fault west of the City of Twentynine Palms.

Faults make effective barriers for several possible reasons (Riley and Worts, 1952). Sedimentary beds can be tilted near the fault, reducing horizontal conductivity. With movement along the fault, beds of differing permeability can be juxtaposed across the fault, reducing water movement. Clay within the fault zone can be smeared, and other sediments may be ground into a very fine deposit known as fault gouge within the plane of the fault. Finally, groundwater that circulates through the fault zone can deposit calcium carbonate in the fault plane, which acts as a cement. The effectiveness of a fault as a barrier to groundwater flow does not require a great deal of movement along the fault (Riley and Worts, 1952). The fact that faults do act as barriers can be seen by the presence of significant areas of historical groundwater discharge as springs on the upgradient sides of some faults (e.g., Surprise Spring on the Surprise Spring Fault, the Oasis of Mara on the Oasis Fault, and Mesquite Spring on the Mesquite Fault).

The area is seismically active as evidenced by the 7.3 magnitude Landers Earthquake in 1992 which is the largest magnitude earthquake in the lower 48 states since the 1906 San Francisco earthquake. The Landers earthquake was centered on several faults about 20 miles west of Twentynine Palms. Earthquakes have been known to change the location and character of springs, change the flow character of wells, and cause fluctuations in groundwater levels (Roeloffs et. al, 1995). However, the groundwater characteristics of the faults bounding the groundwater subbasins in the Twentynine Palms area have experienced numerous seismic events over their geologic history. It is these events that have defined the hydrogeologic characteristics of the faults that we observe today. Therefore, it is considered unlikely that a single seismic event in the future would significantly change the hydrologic characteristics of the groundwater subbasins.

In addition to the faulting in the area, folding has played a significant role in the geology and hydrology of the basin. The Transverse Arch (Figure 3-2) represents a buried anticlinal fold or structural arch (Riley and Worts, 1952) that brings bedrock to within 500 feet of land surface (Londquist and Martin, 1991), with a cap of fine-grained sediments (Riley and Worts, 1953). There is likely little to no groundwater flow southward across the Transverse Arch between the Surprise Spring and Elkins Faults. Some of the groundwater flow moving east of the Elkins Fault discharges to Deadman Dry Lake. It is assumed that the rest of the water flows south across the Transverse Arch into the Mesquite Lake Subbasin (Riley and Worts, 1953.

The USGS conducted a gravity survey to better understand the structure and thickness of basin fill by mapping the depth to the granitic or volcanic bedrock material (Roberts and others, 2002, Moyle, 1984). Earlier geophysical studies by Woodward-Clyde (1985) and BCI (1990) showed similar trends. The results of the gravity modeling indicate that two basins beneath the Deadman and the Mesquite Lakes (dry) are more than 16,000 ft deep (fig. 5). No wells penetrate the entire thickness of basin fill near these deep depressions; therefore, the depth to the basement complex may be under or overestimated in these areas (Roberts and others, 2002

The estimated depth to bedrock is variable across the region and in other parts of the basin it is relatively shallow. The depth to bedrock decreases to less than 400 feet at the western part of Mesquite Lake subbasin near Copper Mountain. A portion of this extends to the northeast that is related to the Transverse Arch. Another bedrock high exists in the southern part of the Mesquite Lake Subbasin that extends under the City of Twentynine Palms. This area likely represents an extension of Copper Mountain.

3.6 Geologic Units

The geological materials in the study area are grouped into stratigraphic units based on the geologic characteristics. These are consistent with the units used by Nishikawa et al (2004) and Li and Martin (2011) who defined the older sedimentary deposits of Tertiary age (Ts), alluvial fan deposits of Tertiary-Quaternary age (QTf), and younger alluvium (Qa) and playa deposits (Qp) of Quaternary age. The alluvial fan deposits are the principal water-bearing unit in the study area. The combined thickness of alluvial fan deposits ranges from less than 250 to more than 1,000 feet.

The traces of two representative cross sections are shown on Figure 3-5. Cross section A-A' (Figure 3-6) runs from west to east through the Indian Cove, Fortynine Palms and Eastern Subbasins. Cross section B-B' (Figure 3-7) runs from southwest to northeast starting in the Fortynine Palms Subbasins across the Mesquite Lake Subbasin and into the Dale Basin. The Upper and Middle Aquifers shown on the cross sections correlate to subdivisions of the alluvial fan deposits of Tertiary-Quaternary age (QTf) and the Lower Aquifer correlates to the older sedimentary deposits of Tertiary age (Ts). The cross sections show the complex geology of the faulting and depth to bedrock. Groundwater elevations shown are representative of current groundwater levels and illustrate the differences in groundwater levels across the faults that form the boundaries for the various subbasins. Additional hydrologic cross sections across the area are found in Nishikawa et al (2004), Kennedy/Jenks (2010) and Li and Martin (2011).

The hydraulic conductivity of these sediments generally decreases with increasing depth due to the fact that the deeper sediments have experienced greater consolidation, compaction, and cementation. The thicknesses of the lower and upper Quaternary alluvium units are about 400 feet each throughout the study area (except where a shallow depth to bedrock reduces the thickness of one or both units), while the Tertiary alluvium is present from the bottom of the lower Quaternary alluvium to the bedrock surface wherever the depth to bedrock is more than about 800 feet.

3.6.1 Tertiary Alluvium

The Tertiary alluvium directly overlies the bedrock. Riley and Worts (1953) described the sediments as being made up mostly of clayey sand, while Nishikawa *et al* (2004) describe the unit in the Joshua Tree Subbasin as representing somewhat consolidated fanglomerates containing clasts of granite and gneiss. According to Nishikawa *et al* (2004), this unit reaches a saturated thickness of up to 3,000 feet. The maximum saturated thickness of this unit in the Twentynine Palms area is about 1,700 feet along the western edge of the Indian Cove Subbasin.

Sediments that have become deeply buried tend to be more consolidated, compacted, and cemented with depth. Therefore, the deepest sediments tend to be less transmissive of water than are the upper sediments. The hydraulic conductivity, K, is around 0.5 to 1 ft/d, while the transmissivity, T, is on the order of 750 ft^2/d. The specific yield, S_y, of this unit is 0.05, while the specific storage (S_s) is estimated to be 1×10^{-6} ft^{-1}. Because of the low transmissivity and specific storage of this unit, it is generally considered fairly unimportant as a source of water (Londquist and Martin, 1991).

3.6.2 Lower Quaternary Alluvium

The lower Quaternary alluvium overlies the Tertiary alluvium. This unit is mostly (60 percent) made up of beds of coarse sand with little clay, with the rest composed of finer-grained beds made up of very fine silty sand to clay (Riley and Worts, 1953). The older sedimentary deposits (Ts) consist of sand, gravel, and subordinate silt and clay that are commonly indurated with interstitial clay and calcium-carbonate cement (Londquist and Martin, 1991).

The thickness of this unit varies from zero along the basin margins to a maximum of 400 feet in the western Indian Cove and eastern Mesquite Lake Subbasins and throughout much of the Joshua Tree Subbasin. K for this unit varies from 0.5 to 60 ft/d, and T varies from about 200 to 36,000 ft2/d. Sy of these sediments varies from 0.12 to 0.14, while Ss is about 1 × 10-6 ft-1.

3.6.3 Upper Quaternary Alluvium

The alluvial fan deposits (QTf) consist of varying amounts of gravel, sand, silt, and clay (Londquist and Martin, 1991). Li and Martin (2011) divide the upper alluvial fan deposits into two units based on their characteristics. The lower unit (QTf1) consists of silty sand and gravel, which are interbedded with moderate amounts of silt and clay that were deposited on the lower slopes of the alluvial fans. The lower unit is irregularly cemented with calcium carbonate and is moderately consolidated. The upper unit (QTf2) consists of unconsolidated pebbly sand, pebble-cobble gravel, and minor silt and clay that were mainly stream deposits. In general, QTf2 is more permeable than QTf1 because of the predominance of the coarser-grained deposits and the lack of cementation.

The upper Quaternary alluvium is made up of unconsolidated sand and gravel. The thickness of this unit reaches about 400 feet in the Joshua Tree Subbasin, with a saturated thickness of 300 feet. Within the TPWD area, the sediment thickness is assumed to be about 400 feet. K for this unit varies from 5 to 60 ft/d, and T varies from 600 to 56,000 ft2/d. Sy varies from 0.08 to 0.23.

3.6.4 Younger Alluvium and Playa Deposits

Young alluvium (Qa) and playa or dry-lakebed deposits (Qp) overlie the alluvial fan deposits as a thin veneer that is less than 50 ft thick throughout most of the study area. These deposits vary from poorly sorted sand and gravel in the alluvial fans to fine sand, silt, and clay in the playa

(Londquist and Martin, 1991). In general, the young alluvium and playa deposits are above the water table so are more important as part of the vadose zone.

Quaternary playa lake deposits are typically very clayey and support little to no vegetation (Thompson, 1929; Nishikawa *et al*, 2004). The playa clays are known from test borings to be 45 to 50 ft thick beneath Mesquite Dry Lake. The playa soils overlie unconformably the late Tertiary alluvial fan deposits. Because of their very fine-grained texture, the playa lake deposits are nearly impermeable, will permit only very minor infiltration of surface water, and will yield virtually no groundwater to wells. For the same reason, they act as confining beds producing artesian pressure in underlying aquifers.

Playas with discharging groundwater are typified by accumulations of alkali and other mineral salts (Thompson, 1929), left behind by evaporating groundwater. These salts are particularly noteworthy in the area of Dale Dry Lake. A discharging playa surface of this type is present west of the Mesquite Fault on Mesquite Dry Lake.

3.7 Groundwater Subbasins

The Twentynine Palms area includes the Mesquite Lake, Indian Cove, Fortynine Palms, and Eastern Subbasins and a portion of the Dale Basin. This section defines the individual basins within the study area, as well as their bounding barriers and the degree to which they are effective (Figure 3-5).

3.7.1 Indian Cove Subbasin

The Indian Cove Subbasin is located between the Joshua Tree Subbasin on the west and the Fortynine Palms Subbasin on the east (Figure 3-5). The basin is floored by bedrock, which generally slopes northward with depth to bedrock ranging from 100 to 1,200 feet below ground surface (Kennedy/Jenks, 2001, 2008, 2010, BCI, 1988). The Indian Cove Subbasin is defined by the Oasis Fault on the north, an unnamed fault and the Joshua Tree Subbasin on the west, an unnamed fault and the Fortynine Palms Subbasin on the east, and the bedrock of the Little San Bernardino Mountains on the south.

Pumping data are only known for wells operated by TPWD. In this basin, pumping began in 1957, and varied from about 30 afy initially to a peak of 2,075 afy in 1985. Recent discharge totals from this basin have been within a couple hundred afy of 1,000 afy. The production capacity for these eight wells is given as 2,385 afy (Kennedy/Jenks, 2005). The greatest discharge from a single well in the basin was about 620 afy, from TPWD-10 in 1976.

The groundwater levels vary more widely in the Indian Cove Subbasin than in others. Hydrographs of the TPWD wells in the Indian Cove Subbasin are presented in Figure 3-8. The wells with at least a foot per year of groundwater level decline are all located between the Oasis and Pinto Faults. The groundwater elevations in the northern part of the subbasin have declined between 1.5 and 2.5 feet per year from the 1960's to the 2000's. Groundwater elevation dropped most quickly from about 1970 to 1990 before decreasing more slowly to the present time. The Pinto Fault may be an important barrier within the basin.

Wells south of the Pinto Fault do not experience as much decline in the groundwater level, indicating that the Pinto Fault is also (in addition to the Oasis Fault) an effective groundwater barrier, although it is not noted as such by Riley and Worts (1953). The water levels in the southern group wells range from about 2,210 to 2,440 feet asl, but within individual wells the groundwater elevation has not historically seen much decline., Over the past 10 years, water levels in most of these wells generally increased between 0.1 and 0.5 feet per year.

The water level in the Indian Cove Subbasin is more than 250 feet above the water level in the Fortynine Palms Subbasin to the east, indicating that there is some barrier between the two basins, although its character is not defined.

3.7.2 Fortynine Palms Subbasin

The Fortynine Palms Subbasin is located directly east of the Indian Cove Subbasin (Figure 1-1). The known depth to bedrock in the basin is between 170 and 430 feet below ground surface making this the shallowest of the Subbasins (Kennedy/Jenks, 2001, 2008, 2010). The Fortynine Palms Subbasin is defined by the Oasis Fault on the north, an unnamed fault and the Indian Cove Subbasin on the west, an undetermined boundary with the Eastern Subbasin on the east, and the bedrock of the Little San Bernardino Mountains on the south.

Pumping data are only known for six production wells operated by TPWD. In this basin, pumping began before 1953 (when the first records are available), and varied from about 260 afy in 1953 to a peak of 1,620 afy in 2002. Recent discharge totals from this basin have been within a couple hundred afy of 1,000 afy. The production capacity for these six wells is given as 2,466 afy (Kennedy/Jenks, 2005). The greatest discharge from a single well in the basin was about 920 afy, from TPWD-14 in 2007.

Hydrographs of the TPWD wells in the Fortynine Palms Subbasin are presented in Figure 3-9. From the 1940s to about 1970, groundwater levels declined by about 1 foot per year before leveling off until about 1990, coinciding with a steep decline in pumping from this basin. Starting around 1990, water levels declined as pumping again increased in the basin until 2003 when pumping was reduced and water levels again leveled off. Water levels in TPWD-13 and TPWD-14, in the southwestern part of the basin, have experienced a much steadier decline than other TPWD wells in the basin. The recent measured groundwater elevations in the TPWD wells indicate a decrease of at least 100 feet over the 70 years. Pinto Fault also traverses the southern part of this basin, although no wells exist south of it to indicate whether or not it is a barrier to flow. No other significant faults are known within this basin.

3.7.3 Eastern Subbasin

The Eastern Subbasin is located immediately to the east of the Fortynine Palms Subbasin. Groundwater supplies within the basin are limited, with most flow occurring in a shallow zone just above or just in the bedrock surface. The depth to bedrock varies from 160 to 750 feet (Kennedy/Jenks, 2001, 2008, 2010). Test wells drilled in 1987 near the large housing tract encountered bedrock at depths ranging from 327 to 415 feet, and the water table was inferred at depths ranging from160 to 170 feet (BCI, 1988). The Eastern Subbasin is defined by the Oasis Fault on the north, an undetermined boundary with the Fortynine Palms Subbasin on the west; the eastern boundary is undetermined but may be a northward extension of the Pinto Mountains, and the bedrock of the Little San Bernardino Mountains on the south.

Two major drainages enter this basin from the mountains to the south, presumably carrying runoff from the mountains onto the alluvium, where it percolates downward as mountain front recharge. Prior to development, discharge from the basin probably occurred entirely as ET and groundwater discharge at the Oasis of Mara.

TPWD has operated 3 production wells within the basin, with total pumping ranging from about 200 afy in 1953 to a peak of 830 afy in 2002. Discharge amounts are not known from the many other wells located in the basin. Recent discharge totals from this basin have varied from 290 afy in 2003 to 740 afy in 2008. The production capacity for these three wells is given as 1,035 afy (Kennedy/Jenks, 2005). The greatest discharge from a single well in the basin was 580 afy from TPWD-16 in 2002. Woodward-Clyde (1985) noted that groundwater supplies in the Eastern Subbasin appear limited due to most of the flow being confined to a shallow zone above or in the bedrock.

Hydrographs of the TPWD wells in the Eastern Subbasin are presented in Figure 3-10. Groundwater elevations for wells with at least 20 years of record, water levels have mostly declined between 0.2 and 0.8 feet per year, although some wells near the Oasis of Mara have not seen declines as extreme. The most recent water levels reported varied from 1,903 to 1,946 feet asl. The water level in the well just north of the Oasis Fault showed a steady to slightly increasing water level for most of its period of record, with just one water level about 20 feet lower than the others at the end of its record.

3.7.4 Mesquite Lake Subbasin

The Mesquite Lake Subbasin is located south of the Deadman Lake Subbasin (Figure 3-1). The northern boundary is the Transverse Arch, which separates it from the Deadman Lake Subbasin (Riley and Worts, 1952). The eastern boundary is the Mesquite Fault, which separates it from the Bullion Mountains in the northern part of the basin and the Dale Basin in the southern part of the basin. The southern boundary is a combination of the Oasis, Chocolate Drop, and Bagley Faults; although Riley and Worts (1953) state that the southern boundary is not well-defined in the western part of the basin. The western boundary is Copper Mountain and several faults (such as the Elkins and Surprise Spring Faults) and bedrock is close to the surface which severely restricts flow and separates this basin from the Copper Mountain Subbasin to the west.

Hydrographs of the TPWD wells in the Mesquite Lake Subbasin are presented in Figure 3-11. Most water level measurements through the past 60 years are from the eastern part of the basin, near Mesquite Dry Lake, and the southern part of the basin, near the City of Twentynine Palms. Wells in the western half of the basin have only sparsely reported water levels. Riley and Worts (1952) noted that groundwater is confined by playa deposits along the western half of Mesquite Dry Lake. Water levels measured in the 1940s have stayed relatively the same. Most wells with long records have shown either steady water levels or slight decreases of 4 to 5 feet. Most wells with at least 10 years of record have shown between -0.4 and +0.1. The greatest declines have occurred in the east-central and southeastern parts of the basin.

TPWD has one high-capacity supply well in the basin (discharge capacity of 3,395 afy; Kennedy/Jenks, 2005), which came on line in 2003, and has pumped between 610 and 950 afy since then. The static water level in this single well has dropped by about 5 feet over the 6-year period of record. Otherwise, groundwater pumping in this subbasin is limited due to naturally-occurring water quality issues. The only other large water-supply wells are associated with the

USMC base. Riley and Worts (1953) estimate a total withdrawal of about 500 af in 1952, of which 450 af was from the base supply wells. Since then, little reporting has been done on groundwater withdrawals in the basin.

3.7.5 Dale Basin

The Dale Basin is located immediately to the east of the Mesquite Lake Subbasin (Figure 3-1). Little work has been done on the hydrogeology of the Dale Basin, as it is not a host to significant population, nor does it contain many wells. Its western boundary is the Mesquite Fault, which separates it from the Mesquite Lake Subbasin. The northern boundary is the Bullion Mountains. The eastern boundary is the Sheep Hole Mountains. The southern boundary is the Pinto Mountains. The depth to bedrock in this basin is unknown.

Groundwater levels have increased by 0 to 0.7 feet per year in the 7 wells for which records exist, although most of the increases are due to single or few anomalously low water levels at the beginnings of the periods of record. Water levels within this basin have been basically stable since about 1960.

3.8 Groundwater Conditions

The groundwater subbasins are separated from one another by hydrologic barriers that include bedrock ridges, faults, and folds. This section defines the degree of separation and depends a great deal on the permeability of the hydrologic barriers, as well as their continuity.

3.8.1 Depth to Groundwater

The depth to groundwater varies from within 10 to 20 feet of the surface near Mesquite and Shortz Dry Lakes along the Mesquite Fault to more than 400 feet in the western portions of the area (Kennedy/Jenks, 2001, 2008). A bedrock high that extends from Copper Mountain southeastern towards the town of Twentynine Palms is considered an area where the alluvial sediments are relatively thin (between 0 to 300 feet thick) so they are unsaturated. In these areas, the first encountered groundwater is considered to occur in the bedrock rather than in the alluvial sediments. Figure 3-12 shows the depth to groundwater in the alluvial sediments based on the numerical model results in the Kennedy/Jenks (2010) groundwater study.

3.8.2 Groundwater Flow in the Twentynine Palms

Groundwater flow directions are largely determined by the structural geologic framework and the natural processes of recharge and evapotranspiration. The faults act as a barrier that limits the volume of groundwater that flows into adjacent subbasins. These barriers are reflected on the map with distinct changes over small distances across some of the faults. Figure 3-5 shows the general flow direction based on the groundwater model results (Kennedy/Jenks, 2010).

The three basins south of the Oasis Fault (the Indian Cove, Fortynine Palms, and Eastern Subbasins) get recharge at the mountain front of the Little San Bernardino Mountains to the south. Groundwater moves north and east across the basins. Flow between these three subbasins is limited by hydrologic barrier. The water level in the Indian Cove Subbasin is more than 250 feet above the water level in the Fortynine Palms Subbasin to the east, indicating that there is some barrier between the two basins, although its character is not defined. The groundwater elevation is approximately the same in the Fortynine Palms and Eastern Subbasins, reflecting a possibility that significant cross-barrier flow occurs between the basins.

Groundwater outflow from the Indian Cove, Fortynine Palms, and Eastern Subbasins occurs across (or, more likely, overtopping) the Oasis Fault into the Mesquite Lake Subbasin. The Oasis Fault is known to be an effective barrier to groundwater flow. DWR (1984) notes a probable water level difference of at least 100 feet across the Oasis Fault between this basin and the Mesquite Lake Subbasin. Also the presence of the Oasis of Mara indicates a groundwater flow barrier. Riley and Worts (1953) indicated that the southern boundary of the Mesquite Fault includes the Bagley and Chocolate Drop Faults, which are north of the Oasis Fault; the area between these faults and the Oasis Fault may therefore actually be part of the Eastern Subbasin, but the evidence for this is unclear.

Groundwater recharge from high elevations within the basin itself (i.e., Copper Mountain) is considered negligible. Recharge to this basin is primarily from subsurface groundwater flow from adjacent basins including the Deadman Lake Subbasin (across the Transverse Arch), the Copper Mountain Subbasin (around the south end of Copper Mountain; Riley and Worts, 1953), and from the Indian Cove, Fortynine Palms, and Eastern Subbasins to the south (across the Oasis Fault). Additional recharge may occur within the basin, as runoff from the Little San Bernardino Mountains to the south may flow into this basin occasionally (Riley and Worts, 1953). Recharge from percolation of precipitation falling directly on the basin floor is not considered to represent a major source of groundwater recharge (DWR, 1984).

In the southwestern part of the Mesquite Lake Subbasin, bedrock is at or near the land surface, so groundwater may flow around the southern part of this ridge, crossing both the Chocolate Drop and Bagley Faults in the process. Groundwater inflow also occurs from the Joshua Tree to the Indian Cove Subbasin. Nishikawa et al. (2004) showed that no groundwater flows east into the Indian Cove Subbasin, but this may be because they set the conductance of the barrier between the two basins very low. There is a head difference across this barrier of about 34 feet prior to development, and more than 100 feet by 2008. For this study, it is assumed that 10 percent of the groundwater outflow goes into the Indian Cove Subbasin, with the remainder entering the Copper Mountain Subbasin.

Within the Mesquite Lake Subbasin, groundwater flows toward Mesquite Dry Lake from all directions (Riley and Worts, 1953). Discharge from this basin occurs at the area of Mesquite Spring and Mesquite Dry Lake as ET (as shown by the dense vegetation on the western half of Mesquite Dry Lake) and groundwater flow over the Mesquite Fault into the Dale Basin (Riley and Worts, 1953).The Mesquite Fault is considered "highly impervious" by Riley and Worts (1952), with groundwater levels varying by 200 feet over a distance of 100 horizontal feet from the west to the east side of the fault. As noted above, the Mesquite Fault is expressed on the surface by discharge at Mesquite Spring and a sharp delineation in the vegetation on the surface of the Mesquite Dry Lake.

The Dale Basin has no surface outlet, and is ringed by bedrock, indicating that it is a completely closed basin, open only to recharge from the Mesquite Lake Subbasin. Recharge from runoff from the surrounding ranges is likely limited due to their low elevation and overall drier conditions to the east. All groundwater that flows over or through the Mesquite Fault into the Dale Basin continues to flow eastward toward the area of Dale Dry Lake, which is the topographic low point for the entire study area. There is no outlet from this basin; therefore, all water entering this basin must discharge as ET at Dale Dry Lake (Riley and Worts, 1953). There is no record of groundwater discharge from wells in the basin, although a few scattered wells do exist, indicative of potential private pumping for domestic purposes.

3.8.3 Groundwater Storage

Several estimates of groundwater storage have been conducted for the various basins. The estimates vary due to variations in the dimensions of the basins and assumptions on pumping and recharge. The estimated storage in the upper 100 feet of saturated sediments in the Mesquite Lake Subbasin is estimated to be 132,000 af (DWR 2003) and the total estimated volume of groundwater in the basin as 1,420,000 af. DWR (1984) estimated the storage in the upper 100 feet of saturated sediments in the Indian Cove, Fortynine Palms, and Eastern Subbasins as 44,000, 38,000, and 50,000 af, respectively. They further noted that the storage in these basins was being depleted by 1,179, 190, and 145 afy, respectively, based on the average rate of water table elevation decline. Kennedy/Jenks (2001) gives an alternate quantification of storage as 83,000 af for the total of the Indian Cove Subbasin, with 65,000 af in the lower aquifer and 18,000 af in the upper aquifer.

Kennedy/Jenks (2010) developed hydrologic budgets on a subbasin-by-subbasin and year-by-year basis from 1984 to 2008. The result of the water balance equation is the change in storage for a basin. A negative change in storage indicates that the amount of water in the basin is decreasing, which would result in lowered groundwater levels for wells in the basin. The sum of all of the other water budget components is the change in storage. The change in storage was calculated for two separate recharge methodologies. The results of the analysis are summarized below:

- For the Indian Cove Subbasin the average loss was 1,205 to 1,260 afy,
- For the Fortynine Palms Subbasin the average loss was 909 to 1,115 afy,
- The Eastern Subbasin loses 143 to 366 afy, and
- The Mesquite Lake Subbasin loses 442 to 518 afy.

The losses in storage have generally been increasing over time with increasing groundwater pumping.

3.9 Groundwater Quality

Typically, the groundwater served by the TPWD is of good quality. There is no known contamination in the District although there are concerns about naturally-occurring high levels of fluoride, arsenic and TDS.

The historic and current use of septic systems for wastewater disposal has the potential to affect groundwater quality. The review of the groundwater quality data is used to help design of the proposed groundwater monitoring plan. The review of the data also identified data gaps that are critical to the identification of improved monitoring for water quality. The key constituents for monitoring for septic tank influence are nitrates and TDS. Also, changes in the overall character of the cation and anion ratios for groundwater may provide an indication.

The recent groundwater quality data available from the Twentynine Palms area comes from the TPWD water supply wells in the four subbasins and recently installed shallow monitoring wells in the Mesquite Lake Subbasin. TPWD currently conducts water quality monitoring from supply wells per CDPH standards which is sufficient for the purpose of tracking changes in groundwater quality in the basins.

The recent groundwater quality data collected in the Twentynine Palms area was plotted to show trends for nitrate and TDS. Table 3-1 presents the summary of nitrate and TDS from the supply wells and shallow monitoring wells. Groundwater quality data is presented by subbasins on Figures 3-13 through 3-16 for nitrate and on Figures 3-17 through 3-20 for TDS.

3.9.1 Nitrate

From Table 3-1, nitrate (as NO_3) ranges from non-detect to 28 mg/l. Historical and current data are below the MCL of 45 mg/l for nitrate. The maximum contaminant level (MCL) by the CDPH is 45 mg/l for nitrate as NO_3 or 10 mg/l for nitrate as N.

In the Indian Cove Subbasin, historical nitrate data extending back to the early 1960s are available from eight well locations. Most recent data through 2012 are available from five wells. In general, nitrate concentrations for the entire period is well below the MCL and with no apparent increasing trend since the early 1980s (Figure 3-13). Nitrate (as NO_3) concentrations remained less than 13 mg/l during the last ten years (Figure 3-13). The highest nitrate (as NO_3) concentration of 24 mg/l was a single measurement in 1978 that appears to be an outlier.

In the Fortynine Palms Subbasin, historical nitrate data extends back to the early 1970s. Currently, all wells are below the MCL for nitrate. Among the five wells with historical data, only Well #4 shows a clear increasing trend with the current nitrate (as NO_3) concentration of 28 mg/l (Figure 3-14). This is an old well and this increasing trend is attributed to potential vertical conduit. The District is planning to destroy this well but other wells do not show a clear trend. Recent data for Well #14 may show the beginning of an upward trend but it may be skewed by a non-detect measurement in 2002.

In the Eastern Subbasin, historical data from 1970s show low levels of nitrate (as NO_3) generally below 10 mg/l. Recent data for the last ten years are stable and around 7 mg/l (Figure 3-15).

In the Mesquite Lake Subbasin, historical data are available since 2005 from one supply well (WTP-1), which has ranged from non-detect to 5.0. Three monitoring wells were drilled to a total depth of about 70 feet near the treatment plant in 2007 to evaluate shallow groundwater conditions beneath the site. The depth to groundwater at these wells typically ranges from approximately 32 to 36 feet. Nitrate (as NO_3) concentrations from these three shallow monitoring wells (MW-1, MW-2 and MW-3) has been below 5 mg/l (Table 3-2).

In October 2009, a private well located at 4762 Saddlehorn Drive, which is north of WTP-1 and near the golf course was tested and a nitrate concentration of 92 mg/l (as NO3) was reported (Table 3-2). An investigation was conducted by TPWD including sampling other wells in the area. The result of testing on the sample from 4762 Saddlehorn Drive identified the presence of nitrate at levels that are 20 to 40 times (Table 3-2) those detected of two other nearby wells in the golf course area. The well at 4762 Saddlehorn Drive also had detectable levels of Methylene Blue Activated Substances (MBAS) that were not detected in the other wells. These parameters suggest the water at 4762 Saddlehorn Drive is under the influence of waste water from a septic system that has not been completely treated (Kennedy/Jenks, 2009).

Analytical results for two monitoring wells located at Luckie Park were provided by TPWD. Luckie Park is located on Utah Trail about a half mile south of the three shallow monitoring wells near the TPWD evaporation ponds. Two shallow wells were sampled for nitrates in 2009, and analytical results for nitrate (as NO3) were 46 and 91 mg/l which are both above the MCL of 45 mg/l (Table 3-2). Luckie Park is located north and east of a high density housing area. Luckie Park is also one of the few irrigated areas in Twentynine Palms so it is possible that localized areas of nitrate may be associated with fertilizer used at the park.

The location of the shallow wells at the treatment plan, Luckie Park and the golf course are in the vicinity of the Shortz Playa. It is possible that shallow clay layers associated with buried lake deposits may inhibit vertical mixing of the septic tank effluent in the shallow groundwater. The presence of elevated nitrate concentrations in these areas may reflect localized conditions that may not represent significant impact to the regional beneficial use of groundwater in the Mesquite Lake subbasin. Additional work is necessary to evaluate the nature and extent of the nitrates found in the Luckie Park and the golf course areas.

3.9.2 Total Dissolved Solids (TDS)

From Table 3-1, the TDS content of groundwater within the District ranges from about 100 to 350 mg/l from the water supply wells. TDS has a secondary MCL by the CDPH of 500 mg/l. Secondary MCLs regulate contaminant levels based on aesthetics such as taste, color or odor that do not pose a risk to health. These secondary maximum contaminant levels are guidelines, not enforceable limits. Groundwater TDS concentrations are typically expected to increase through recharge of septic effluent (Haley & Aldrich, 2000).

In the Indian Cove, Fortynine Palms and Eastern Subbasins, historical TDS data is relatively stable. Concentrations range from 100 to 304 mg/l which is well below the MCL. In review, the trends for the subbasins on Figures 3-16, 3-17 and 3-18 show no apparent increasing trend since the early 1980s (Figure 3-8). In the Mesquite Lake Subbasin, water supply well WTP-1 has TDS levels ranging between 335 and 350 mg/l (Figure 3-19).

The three shallow monitoring wells installed at the treatment plant in 2007 have higher concentrations of TDS than other wells in the area (Figure 3-19). These high TDS levels are believed to occur naturally and not associated with septic tanks. Similarly, the shallow wells at Luckie Park also have TDS concentrations of 900 and 2,200 mg/l. The location of the shallow wells at the treatment plan and Luckie Park are in the vicinity of the Shortz Playa and may reflect the concentration on salts associated with buried lake deposits at this location.

3.9.3 Piper Diagrams

A Piper diagram (Piper, 1945) shows the relative contribution of major cations and anions, on a charge-equivalent basis, to the ionic content of the water. Percentage scales along the sides of the diagram indicate the relative concentration, in milliequivalents per liter (meq/L), of each major ion. Cations are shown in the left triangle, anions are shown in the right triangle, and the central diamond integrates the data.

Piper diagrams for the Indian Cove, Fortynine Palms, Eastern and Mesquite Lake Subbasins are presented on Figures 3-20, 3-21, 3-22 and 3-23, respectively. A composite of all analyses from each well is shown. No trends in major ion composition were observed in water from wells having more than one analysis.

The major-ion composition of water from wells in the Twentynine Palms area is primarily sodium bicarbonate. These are similar to the compositions from the Joshua Tree Subbasin reported by Nishikawa et al (2004) and appear to be representative of the groundwater composition in the area. The high sodium percentages may be the result of a combination of calcite precipitation and cation exchange occurring over long periods of time as water reacts with aquifer materials. These processes have been shown to cause similar changes in groundwater chemistry in alluvial aquifers elsewhere in the Mojave Desert (Izbicki and others, 1995) and in southern California (Izbicki and Martin, 1997; Izbicki and others, 1997).

Water sampled from MW-1, MW-2 and MW-3 in the Mesquite Lake Subbasin (Figure 3-23) has a sodium sulfate composition with the highest dissolved-solids concentration of all wells sampled. Similar compositions noted by Nishikawa et al (2004) in the Joshua Tree Subbasin were considered to reflect greater contribution of water from the Tertiary-sedimentary and volcanic deposits. However, the location of MW-1, MW-2 and MW-3 is in the vicinity of the Shortz Playa and may reflect the concentration of salts associated with buried lake deposits at this location.

TABLE 3-1
WATER QUALITY SUMMARY FOR TPWD PRODUCTION WELLS

	Nitrate (as NO3) (mg/L) Primary MCL = 45 mg/l			*Total Dissolved Solids (TDS) (mg/L)* Secondary MCL = 500 mg/l			*Years of Well Sampling History*	
Well	**Average**	**Maximum**	**Minimum**	**Average**	**Maximum**	**Minimum**	**Year first sampled[a]**	**Year last sampled[b]**
Indian Cove Subbasin								
TPWD-6	5.9	9.2	1.0	123	157	101	1958	2009
TPWD-7	5.4	8.0	1.0	118	140	102	1962	2003
TPWD-8	9.7	14.1	5.0	163	242	123	1964	1993
TPWD-9	10.0	14.4	2.0	160	257	120	1968	2013
TPWD-10	11.1	13.5	1.0	163	192	140	1968	2006
TPWD-11	12.6	24.0	9.0	171	202	149	1978	2013
TPWD-12	9.6	14.0	7.8	144	180	129	1983	2013
TPWD-15	10.8	12.0	8.8	145	178	126	1987	2013
Summary[c]	**9.4**	**24.0**	**1.0**	**148**	**257**	**101**		
Fortynine Palms Subbasin								
TPWD-3	8.7	13.4	3.0	151	173	135	1953	1992
TPWD-3B	9.2	12.1	6.9	132	151	121	1992	2006
TPWD-4	20.7	36.0	8.0	170	220	135	1951	2013
TPWD-5	10.1	16.0	3.0	149	173	121	1951	1996
TPWD-13	9.2	14.3	5.2	166	215	142	1985	2003
TPWD-14	9.8	14.0	5.5	131	150	100	1993	2013
Summary[c]	**11.3**	**36.0**	**3.0**	**150**	**220**	**100**		
Eastern Subbasin								
TPWD-1	6.1	10.0	1.0	250	304	198	1953	1998
TPWD-2	5.3	9.0	ND	176	190	154	1951	1993
TPWD-16	6.1	8.7	2.9	160	173	145	1991	2013
TPWD-17	8.3	9.0	7.6	n/s	n/s	n/s	2011	2013
Summary[c]	**6.5**	**10.0**	**ND**	**195**	**304**	**145**		

	Nitrate (as NO3) (mg/L)			***Total Dissolved Solids (TDS) (mg/L)***			***Years of Well Sampling History***	
	Primary MCL = 45 mg/l			**Secondary MCL = 500 mg/l**				
Well	**Average**	**Maximum**	**Minimum**	**Average**	**Maximum**	**Minimum**	**Year first sampled[(a)]**	**Year last sampled[(b)]**
Mesquite Lake Subbasin								
MW-1	1.9	2.7	0.4	2,184	3,200	620	2007	2011
MW-2	2.9	4.2	0.4	6,275	6,700	6,000	2007	2011
MW-3	1.6	2.4	0.4	3,400	4,500	1,700	2007	2011
WTP-1	3.5	5.0	ND	340	350	320	2006	2013
All Wells Summary[(c)]	**2.5**	**5.0**	**ND**	**3,050**	**6,700**	**320**		
WTP-1 Only Summary[(c)]	***3.5***	***5.0***	***ND***	***340***	***350***	***320***		

Notes: MCL – maximum contaminant level
(a) Well first sampled is based on TPWD records
(b) Well last sampled is based on TPWD records. Wells marked *"present"* are currently operating.
(c) Summary provides the average, maximum and minimum of all samples in each subbasin.

TABLE 3-2
WATER QUALITY SUMMARY FOR TPWD MONITORING WELLS AND OTHER WELLS

	Nitrate (as NO3) (mg/L)			*Total Dissolved Solids (TDS) (mg/L)*			*Years of Well Sampling History*	
	Primary MCL = 45 mg/l			**Secondary MCL = 500 mg/l**				
Well	**Average**	**Maximum**	**Minimum**	**Average**	**Maximum**	**Minimum**	**Year first sampled**	**Year last sampled**
Mesquite Lake Subbasin								
MW-1	1.9	2.7	ND	2,184	6,200	620	2007	2011
MW-2	2.9	4.2	ND	6,275	6,700	6,000	2007	2009
MW-3	1.6	2.4	ND	3,400	4,500	1,700	2007	2011
4632 Saddlehorn Rd	2.0[(a)]			780[(a)]				2009
4762 Saddlehorn Rd	92[(a)]			3,600[(a)]				2009
Golf Course North	ND[(a)]			370[(a)]				2009
Luckie Park East	46[(a)]			890	900	895	2006	2009
Luckie Park West	91[(a)]			1,100	2,200	1,600	2006	2009

Notes: MCL – maximum contaminant level
(a) Data available from a single sample

Section 4: Water Balance

Understanding the water balance is a key element in evaluating the salt and nutrient balance in groundwater basins. A conceptual water balance model was developed to identify major inflows into and out of the groundwater basins underlying the Twentynine Palms area. The results of the water balance were used as the basis to quantify the volume of water contributing to each basin, including recharge from septic tanks, with the corresponding water quality of water entering the aquifer system. Groundwater outflows were identified to evaluate the resulting mass and concentration of salt and nitrate in groundwater exiting the aquifer system.

4.1 Water Balance Conceptual Model

A simple, analytical water balance conceptual model was developed to quantify the major inflows into and out of the basin. The water balance components were estimated based on various data sources, including the hydrogeologic knowledge of the basins from previous studies, data developed and analyzed from the existing groundwater model, hydrologic data (precipitation and ET), and water use for domestic indoor and outdoor landscape irrigation. The data used from the groundwater model include groundwater inflow and outflow, recharge from precipitation, ET, and groundwater pumping, each based on the long-term average values over 25 years for the period from 1984 to 2008. The long-term average characterizes variations of the groundwater system over various hydrological years.

The overall intent of the water balance is to quantify the long-term effect of the potential salt and nitrate loading to groundwater from septic tanks; thus, using the long-term average values is considered a reasonable approximation. In addition, among the water balance components available from the groundwater model, groundwater pumping is anticipated to change the most over time to reflect an increase in pumping, but this does not have a direct effect on the potential septic loading estimates to groundwater basin as recharge from septic tanks is inflow to the basins while groundwater pumping is outflow from the basins.

The water balance was performed for the areas with septic tanks within the groundwater basins underlying the District service area, including the portions of the Indian Cove, Fortynine Palms, Eastern, and Mesquite Lake Subbasin. The water balance (and the salt and nitrate balance) was developed for these four subbasins separately to account for spatial variations in water balance by subbasins.

The following subsections provide the methodology and assumptions used for quantifying each water balance component. Also described is the background on the various components of the water balance, including the sources of data and how each component was estimated. The septic loading projections associated with the Build-out Scenario is also included for comparison only, but not analyzed quantitatively. A more detailed description of the data sources can be also found in the Groundwater Study for the Mesquite Lake subbasin (Kennedy/Jenks, 2010), in particular for the components estimated from the model.

In Section 5, the water balance model was coupled with the nitrate (and salt) mix-cell model to evaluate the salt and nitrate into and out of the basin corresponding to each component and the resulting mass and concentration of salt and nitrate in groundwater system.

4.2 Approach

The conceptual water balance is defined by the following equation:

Change in Groundwater Storage = R + S – ET- W + GWin – GWout

Where R is recharge from precipitation, S is recharge from septic tanks, ET is outflow due to evapotranspiration, W is well pumping, GWin is groundwater inflow into the basin and GWout is groundwater outflow from the basin.

The general approach used in the SNMP for developing water balance analysis (as well as salt and nutrient assessment) includes the following three scenarios:

- **Current (2010) Scenario** – Based on the current land use and water demand and estimated current septic loading from the existing septic tanks.
- **2035 Scenario** - Based on a future projection for the year 2035, consistent with the water supply planning horizon in the District 2010 UWMP. 2035 Scenario assumes the continued use of septic systems and future septic loading as a result of anticipated increase in population and water demand and evaluates the potential for the continued discharges from septic systems to unreasonably degrade groundwater quality and result in widespread groundwater pollution.
- **Build-Out Scenario** - Based on the City of Twentynine Palms General Plan that represents the ultimate build-out land use and water demand.

The general approach is based on a quantitative and detailed water balance analysis for the Current and 2035 Scenarios and qualitative discussion for the Build-Out Scenario. The water balance model was developed for each subbasin both for the Current and 2035 Scenarios based on the schematic conceptual water balance depicted in Figure 4-1. This representation is on a subbasin level that accounts for spatial variations in land use, water demand, and basin hydrogeologic conditions in each subbasin. The Mesquite Lake Subbasin was further divided into southern and northern portions to account for significant variations in housing density and subsurface hydrogeology. Figure 3-1 shows the southern and northern portions of the Mesquite Lake Subbasin considered in this analysis. The majority of the high density housing is located in the southern portion that covers a smaller area of the subbasin while the housing density is very low in the northern portion that consists of a larger area of the subbasin.

Due to the high uncertainty associated with the ultimate build-out, the Build-out Scenario is limited to a qualitative discussion. While the City's General Plan reflects the anticipated build-out land use designations, it is unknown how the ultimate land use development would occur in the future. A qualitative discussion is used to highlight the issues of water supply and quality surrounding the ultimate build-out land use and water demand projections, as further discussed in Section 4.5.

4.3 Water Balance Model – Current Scenario

A summary of the water balance components for the Current Scenario is presented in Table 4-1. Each component is further described in the following sections, including the methodology and the assumptions used in the development of each component.

The end result of the water balance is the change in groundwater storage, as shown in the formula above. The negative change in storage indicates that the volume of water in the basin is decreasing. Among the water balance components presented in Table 4-1, recharge from septic tanks and well pumping are the two major components. Recharge from septic tanks also contributes to groundwater inflow exchanges among the subbasins. During the evaluation of each component, some of the components shown in Figure 4-1 were found negligible and not included in Table 4-1.

TABLE 4-1
WATER BALANCE SUMMARY BY GROUNDWATER SUBBASINS – CURRENT SCENARIO

Subbasin Name	Septic Tank Return Flow (afy)	GW Inflow (afy)	Precip Recharge (afy)	GW Pumping (afy)	ET (afy)	GW Outflow (afy)	Net Change (afy)
Indian Cove Subbasin	153	466	1.7	1,286	0	199	-864
Fortynine Palms Subbasin	157	482	2.1	1,235	0	259	-853
Eastern Subbasin	200	211	4.6	509	20	322	-435
Mesquite Lake - South	1038	1,578	0.0	0	0	3951	-1,335
Mesquite Lake - North	342	4,152	0.0	705	1,631	2,505	-347
Dale Valley	27	0	-	-	-	-	-
Total	1,916	6,889	8.4	3,734	1,651	7,236	-3,808

Note: Groundwater pumping projection by each subbasin is based on the District's 2010 UWMP projections (Table 3-5).

4.3.1 Recharge from Septic Tanks

There are two major categories of onsite wastewater treatment systems in the Twentynine Palms area – residential and non-residential, where residential includes both Single family and multifamily households. A variety of commercial (e.g., restaurants and hotels) and institutional (e.g., school) establishments and facilities fall into the non-residential wastewater category.

Potable water consumption data for each land use category were available from the District and used to predict wastewater flow rates with adjustment for potable water uses that do not return to the sewer. The amount of water estimated to return to the sewer was assumed to recharge to groundwater basin. This is a reasonable and commonly used approach to estimate recharge from septic tanks from other areas, such as the Yucca Valley area.

For the Current Scenario, total residential and non-residential sewer loading was estimated to be 1,899 afy (Table 4-2) within the District service area and 19 afy outside of the District service area, but within the City SOI. The methodology and assumptions used are described below:

TABLE 4-2
SUMMARY OF ESTIMATED CURRENT SEPTIC LOADING RATES

	Water Use (afy)[(a)]	Water to Sewer Factor (%)	Septic Loading (afy)[(b)]	Septic Loading Rate[(c)]
Residential	2,120	80	1,696	80
Non-Residential	278		222	
Commercial – High Density	164	80	131	900
Commercial – Low Density	55	80	44	320
Institutions	59	80	48	320
Total	**2,398**	-	**1,918**	-

Note:
(a) Total residential water use includes 2,096 afy within District and 24 afy outside of District. All non-residential water use is within District.
(b) Total sewer loading includes 1,677 afy within District and 19 afy outside of District. All non-residential sewer loading is within District.
(c) Septic loading rates are in gal/day/person for residential; gal/day/acre for non-residential

4.3.1.1 Residential Sewer Loading

Generally, the characteristic of wastes generated by a typical residential dwelling can be estimated from the flow rate and the mass loading. Since the study area is not currently sewered, actual per capita wastewater flow production information is not available. Potable water consumption data, however, can be used to predict wastewater flow rates when adjusted for potable water uses that do not return to the sewer (MWH, 2009a; MWH, 2009b). In most communities, summer irrigation is the main use of potable water that does not return to the sewer. For many residential areas, wastewater flow rates are commonly determined on population and the average per capita contribution of wastewater. A similar approach was developed for estimating septic loading based on the land use, housing density, water use records, and average per capita sewer loading.

When using water usage, wastewater from residential dwellings can be estimated from indoor water use in the home and outdoor water use should be subtracted to develop wastewater flow estimates. In the absence of measured data for wastewater production and contribution to septic tanks, the annual potable demand was used as a reasonable indicator of annual wastewater production. The amount of water flowing into septic tanks was conservatively estimated based on the average indoor usage of water. Water usage was defined on a per person basis for residential dwellings, as done typically.

The second parameter used is the number of persons living in each residence. Based on the most recent available data, the average household size was assumed to be 2.68 people in the calculation of total residential water use associated with land use classified as single and multi-family residential. Water use during winter months was analyzed to verify that the 80 percent water to sewer conversion is a good indicator for the average indoor water usage as an average sewer loading rate.

Total residential sewer loading was calculated to be 1,677 afy for the Current Scenario (Table 4-2). This was derived based on the total residential water use of 2,096 afy (Table 2-5) and the 80 percent water to sewer conversion factor. The quantity of septic tank wastewater potentially recharging the underlying groundwater at any given time at a household was estimated by assuming an average per capita septic tank discharge of 80 gpcd based on the current water use and population of 18,795 (Table 2-2).

The 80 gpcd sewer loading rate used for the Twentynine Palms area for the Current Scenario is comparable with sewer loading rate from the communities in the vicinity. For comparison, a per-capita waste water flow rate of 83 gpcd was considered for the Yucca Valley area (MWH, 2009a; MWH, 2009b) and 80 gpcd for the Hi-Desert Water District. The 80 gpcd is considered relatively conservative compared to findings of several other studies that evaluated the residential indoor water use in detail. Based on the results of the study funded by AWWARF that involved the largest number of residential water users ever characterized (1,188 homes in 12 metropolitan areas in North America) indicated average gpcd ranging from 57 to 83.5 with the average of about 69 gpcd in all 12 study sites (Mayer and DeOrea, 1999). This study also included detailed indoor water use characteristics of approximately 100 homes in each of the 12 study area with continuous data loggers and computer software that quantified the end uses of water. These data were derived from some 1 million measured indoor water use events in 1,188 homes in 12 suburban areas.

One of the more important wastewater generating flows identified in this study was water leakage from plumbing fixtures. Leakage accounts for about 13.7% of total indoor usage for 1,188 data logged homes. The 80 gpcd corresponds to the upper end of this range and above the average estimate; thus, is considered a conservative estimate for sewer loading. The previous studies estimated average daily wastewater flows are approximately 50 to 70 gpcd, typical for residential dwellings built before 1994. With the energy use standards that went into effect since 1994, indoor retrofits are expected to reduce water use in indoor appliances. Home built after 1994 or retrofitted with energy and water–efficient appliances would have typical average daily wastewater flows in the 40 to 60 gpcd. Energy and water–efficient clothes washers may reduce the per capita flow rate by up to 5 gpcd (DeOrea et al., 2001).

4.3.1.2 Non-Residential Sewer Loading

For non-residential land uses such as commercial and institutional, flow rates are generally expressed in terms of quantity of flow per unit area. The results of previous studies have demonstrated that in many cases nonresidential wastewater is considerably different from residential wastewater.

Total non-residential sewer loading was calculated to be 222 afy (Table 4-2), based on the non-residential water use of 278 afy (Table 2-5) and 80 percent water to sewer conversion factor. Similar to the residential, the 80 percent conversion factor was used to represent indoor water use and the portion of water use returning to sewer tanks. Average winter water usage was compared with 80 percent of annual water usage to verify that the 80 percent water to sewer conversion factor is reasonable for non-residential sector.

It is anticipated that non-residential sewer loading varies depending on the land use density and types of activities. Site specific data from different water use sectors are unavailable to differentiate sewer loading for high and low density non-residential sectors. Sewer loading rates for the high density commercial, low density commercial, and institutions were assumed to be 900, 320, and 320 gal/day/acre, respectively, based on data available from nearby communities and simplifying and conservative assumptions. A sewer loading rate used for the communities in the vicinity ranged from 800 gal/day/acre for the Hi-Desert Water District to 1,000 gal/day/acre for the Yucca Valley area (Nishikawa et al., 2003). For the Twentynine Palms area, high density commercial sewer loading rate was assumed to be 900 gal/day/acre as an average of the ranges used for the nearby communities.

Based on the GIS aerial image, the acreages of non-residential land use were identified and high and low density areas were estimated. Using the GIS based acreages and the assumed sewer rates (gal/day/acre); the total sewer rate for high density commercial was calculated. The remaining sewer loading was distributed between the low density commercial and institutions based on the acreages estimated from land use data and the assumed sewer loading rate of 320 gal/day/acre.

4.3.2 Groundwater Inflow and Outflow

Groundwater inflow and outflow was estimated based on the existing groundwater model and the long-term average values over 25 years for the period from 1984 to 2008 (Table 4-2). This component accounts for the movement of groundwater between different groundwater subbasins based on groundwater fluxes across the basin boundaries. In the District service area, groundwater inflow is the main source of water to the subbasins, compared to the natural recharge from precipitation. During the development of the groundwater model, groundwater flow in the model was estimated based on local hydrogeologic knowledge of the hydrologic system and flow estimates from Darcy's Law. A detailed discussion of the approach used is presented in the groundwater study (Kennedy/Jenks, 2010). The following is a brief description of the groundwater inflow and outflow conditions among the adjacent subbasins, based on the groundwater model study:

- Indian Cove Subbasin receives inflow from the Joshua Tree Subbasin to the west and discharges groundwater to the Mesquite Lake Subbasin.
- Fortynine Palms Subbasin does not receive groundwater inflow from an adjacent basin, but discharges groundwater to the Mesquite Lake Subbasin to the north.
- Eastern Subbasin does not receive groundwater inflow from an adjacent basin, but discharges groundwater to the Mesquite Lake Subbasin to the north.
- Mesquite Lake Subbasin receives groundwater inflow from the Indian Cove, Fortynine Palms, and Eastern Subbasins to the south, Surprise Spring and Deadman Lake Subbasins to the north, and the Copper Mountain Subbasin to the west and discharges groundwater to the Dale Basin to the east.

In the water balance model, the amount of sewer loading estimated for each subbasin based on the land use designation and housing density was assumed to recharge to the underlying groundwater subbasin. As mentioned above, this is a reasonable and commonly used approach to estimate recharge from septic tanks.

The underlying assumption is that recharge from septic tanks is completely mixed with groundwater flow and flows in the general groundwater flow direction and contributes to groundwater flow exchanges among the adjacent subbasins. In this water balance analysis, recharge from septic tanks in a subbasin was assumed to leave the subbasin as groundwater outflow and to enter an adjacent subbasin as groundwater inflow according to the groundwater flow directions described above. Following this conceptual model, the southern portion of the Mesquite Lake Subbasin receives groundwater inflow from the three adjacent subbasins, and as expected, shows the largest groundwater flow component in Table 4-1.

4.3.3 Recharge from Precipitation

Potential recharge to groundwater from precipitation was represented as recharge based on estimates from the existing groundwater model. As mentioned above, the values represent the long-term average values over 25 years for the period from 1984 to 2008. As described earlier, due to limited precipitation (4.3 inches per year, Table 2-1), the model estimated recharge is very small, ranging from 2 afy to 5 afy (Table 4-1) and zero for the Mesquite Lake Subbasin.

In comparison to the other components, recharge from precipitation is considered insignificant and included in this water balance analysis for the completeness. The overall findings are not expected to change with the exclusion of this component.

4.3.4 Groundwater Pumping

Well pumping is the dominant outflow of the groundwater basin in the District service area. Well pumping in the water balance was estimated based on the existing groundwater model to represent the long-term average pumping over 25 years for the period from 1984 to 2008.

As presented in Table 4-1, total pumping from the four subbasins averages to 3,734 afy, including 1,286 afy in the Indian Cove, 1,235 afy in the Fortynine Palms, 509 afy in the Eastern Subbasin, and 705 afy in the Mesquite Lake Subbasin northern portion (i.e., no pumping in the southern portion). Historically, the District has been pumping from the other three subbasins and started pumping from the Mesquite Lake Subbasin in 2003.

Currently, the exact number of domestic wells in the basin is unknown; thus, domestic pumping is unquantifiable. Consistent with the approach in the existing groundwater model, pumping from the domestic wells are considered relatively small on the basin scale and not accounted in the water balance (and salt/nitrate) analysis.

4.3.5 Recharge from Irrigation

Potential recharge to groundwater from irrigation was evaluated based on irrigation records for green spaces (golf course and schools) (Table 2-5), and a simple water balance analysis for turfgrass based on precipitation records and estimated ET for turfgrass. The approach is based on two main steps: 1) estimate actual ET for turfgrass and 2) estimate soil water storage and potential for percolation, each described below.

Based on the results of the analysis, the potential for percolation below the root zone is remote and assumed to be negligible. Total irrigation and precipitation are significantly smaller than actual ET requirements and estimated soil water storage in the turfgrass root zone was estimated to zero. This indicates water is used to meet plant uptake and evaporation and no excess water available for percolation below the root zone.

ET for turfgrass was estimated and compared with the amount of irrigation and precipitation. ET for turfgrass that is close to or higher than the combined irrigation and precipitation is a good indicator for the lack of percolation from irrigation.

ET from turf grass was estimated by adjusting reference ET into turf water use (Brown and Kopec, 2000). Conversion of ET to turfgrass ET was performed based on the formula below and consists of three steps: 1) obtain a local ET value, 2) select an appropriate crop coefficient (K_c) and 3) multiply the ET by K_c to obtain ET turfgrass:

$$ET_T = K_c \times ET_o$$

Records of monthly reference ET values were obtained from the CIMIS station 118 (Cathedral City/Imperial/Coachella Valley) based on the period from January 1996 to December 2011. Average annual reference ET was calculated to be 57.1 inches, with monthly average ET ranging from 1.6 inches in January and December to 8.8 inches in July, and this calculated ET rate is compared with current irrigation records. Appropriate values for monthly crop coefficients for use with ETo were obtained from a previous research conducted for California with CIMIS data for warm season turfgrass (Brown and Kopec, 2000). This calculation resulted in annual actual ET of 49.5 inches for the Twentynine Palms area.

Monthly soil water storage over a 2-foot turfgrass root zone was calculated based on the formula below to evaluate the potential for percolation:

Soil Water Storage = Precipitation + Irrigation – ET

Annual precipitation is 4.3 inches, based on monthly precipitation records obtained from Western Regional Climate Center Station 049099 for the Twentynine Palms area. Monthly irrigation in inches was estimated based on the irrigation water delivery records by the District and the acreages of turfgrass areas. Based on the GIS aerial photo, green spaces cover about 102 acres. Based on the District records, the water delivery for irrigation is 115 afy. Monthly irrigation was assumed to be distributed uniformly over the entire green space to derive monthly and total annual irrigation in inches. This resulted in total annual irrigation of 13.7 inches. Total annual irrigation and precipitation add up to only 18 inches, compared to 49.5 inches of ET requirements. Based on this approach, percolation occurs when the root zone is filled above the maximum storage value. Based on the results, soil water storage was estimated to be zero, suggesting a lack of percolation from irrigation below the root zone.

4.3.6 Evapotranspiration

Evapotranspiration values were taken from the existing groundwater model based on the long-term average values over 25 years for the period from 1984 to 2008. In the context of the water balance for the groundwater basins, ET accounts for loss of water from groundwater due to vegetation. ET only occurs in a couple of places in the District service area: Mesquite Dry lake, Mesquite Springs, and the Oasis of Mara. Mesquite, which dominates the plant community of the area, has a maximum rooting depth of 6 meters. The model estimated ET loss is 1,631 afy for Mesquite and only 20 afy from the Oasis of Mara in the Eastern Subbasin.

Because of the arid climate in the basin and the generally very deep water tables, ET loss from groundwater is small in the region. While ET of surface soil moisture can occur throughout the basin when the soil is moistened by precipitation, this does not have a direct impact on groundwater.

The model represents ET loss from deep rooted vegetation since ET from turfgrass occurs over a 2-foot root zone and does not have a direct effect on groundwater. As reported in the groundwater study completed for the Mesquite Lake Subbasin (Kennedy/Jenks, 2010), the groundwater model assumed decrease of water over the 6 meter rooting depth.

4.3.7 Recharge from Evaporation Ponds

As part of the water balance, potential recharge from evaporation ponds in the Mainside WWTP and corresponding salt and nitrate loading into groundwater underlying the ponds was evaluated. Based on the previous investigations and the recent hydrogeologic study submitted by the Mainside WWTP to the RWQCB in 2011 (RWQCB, 2006, 2011), the potential for wastewater to migrate to groundwater from the treatment ponds is unlikely. Therefore, for the purpose of the water balance analysis in the SNMP, potential recharge from the evaporation ponds in the Mainside WWTP is assumed to be negligible and excluded in the water balance.

As discussed earlier, the Mainside WWTP treats domestic wastewater with primary and secondary treatment systems and disposal through four evaporation ponds. The Mainside WWTP presently discharges approximately 0.928 mgd of secondary effluent into four (4) evaporation basins and 0.419 mgd of disinfected secondary-23 (as defined in Title 22 California Code of Regulations Section 60301.225) treated recycled water for golf course irrigation, according to the RWQCB Order No. R7-2012-0002.

A thick impermeable clayey soil is present underlying the bottom surface of the treatment plant ponds, acting as an extremely effective barrier against the migration of wastewater from the ponds and into the aquifer underlying the treatment plant. There is no evidence suggesting that wastewater from the treatment ponds has migrated, or has the potential to migrate through clayey soils underlying the evaporation ponds. This clayey soil is greater than 25 feet in thickness and continuous beneath the ponds within the treatment plant. Clayey soil layers separated by silts, silty fine sands, and fine sands are present between 25 and 100 feet below ground surface (bgs). These clayey layers would assist in reducing potential wastewater migration from the surface and into the underlying aquifer. The rate of wastewater flow through these upper clayey materials was estimated to be very small, ranging from approximately 0.026 to 2.5 cm/year, or 0.01 to one (1) inch per year.

In addition to the thick clay layer, the main aquifer underlying the treatment plant is reportedly located at greater depths, approximately 215 feet bgs. Based on data collected during the recent hydrogeologic study, the perched groundwater encountered at 188 bgs is the closest groundwater located beneath the treatment ponds.

4.4 Water Balance Model – 2035 Scenario

The conceptual water balance model applied to the 2035 Scenario is essentially the same as the model used to evaluate the Current Scenario (Figure 4-1). However, the values for water balance components were modified to reflect changes in population, water demand, and groundwater pumping projections for 2035. The major differences are due to an increase in sewer loading and groundwater pumping for the 2035 Scenario as a result of increase in population and water demand. A summary of each of the water balance components for 2035 projection is presented in Table 4-3 on a subbasin basis.

In the context of this SNMP, the assessment of salt and nutrient issues in groundwater based on the 2035 projections is considered the most relevant and realistic representation for future projections as the data available for 2035 cover a long period appropriate for evaluating the potential impact from future land development and is consistent with the long-term water supply planning horizon reported in the District's UWMP.

This section describes the major model assumptions for the 2035 Scenario with a focus on the water balance components that are modified from the Current Scenario. Among the water components evaluated for the 2035 Scenario, the following components uses the same approach and model assumptions as in the Current Scenario; thus, they are covered in detail in Section 3 and not described again in this section.

- Recharge from irrigation and evaporation ponds from the Main Side WWTP is assumed to be negligible.
- Recharge from precipitation is assumed to be negligible. Data used in the analysis are available from the groundwater model and represent the long-term averages based on 25-year hydrological data and are considered reasonable representation of the long-term response of the hydrologic conditions.
- ET loss from groundwater through vegetation is assumed to remain the same as in the Current Scenario, based on the assumption that data used in the analysis represent long-term averages and are considered reasonable representation of the long-term response of the hydrologic conditions.

While these components remain the same, recharge from septic tanks and groundwater pumping for the 2035 Scenario are the two major components that were modified from the Current Scenario, as described below in detail.

TABLE 4-3
WATER BALANCE SUMMARY BY GROUNDWATER SUBBASINS – 2035 SCENARIO

Subbasin Name	Recharge from Septic Tanks (afy)	Ground-water Inflow (afy)	Recharge from Precipitation (afy)	Ground-water Pumping (afy)	ET (afy)	Ground-water Outflow (afy)	Net Change (afy)
Indian Cove Subbasin	228	466	1.7	1,044	0	274	-622
Fortynine Palms Subbasin	245	521	2.1	1,619	0	384	-1,235
Eastern Subbasin	309	279	4.6	869	20	494	-790
Mesquite Lake - South	1,633	1,859	0.0	0	0	4,818	-1,326
Mesquite Lake - North	526	4,814	0.0	1,588	1,631	2,505	-384
Dale Valley	41	-	-	-	-	-	-
Total	2,981	7,938	8.4	5,119	1,651	8,475	-4,318

Notes:
(a) Calculated based on indoor water use (total water use multiplied by 80 percent water to sewer conversion).
(b) Based on the existing groundwater flow model and additional inflow incorporated to account for the contribution of septic loading to groundwater flow exchanges among the subbasins.
(c) Based on the existing groundwater flow model, long-term average over 25 years.
(d) Based on the District's 2010 UWMP projections (Table 3-5).
(e) Calculated as inflows minus outflows.

4.4.1 Recharge from Septic Tanks

The water balance 2035 projection uses higher sewer loading both for the residential and non-residential land use than the current condition to account for increased water demand in the future as a result of increased population projected for the 2035 Scenario (Table 4-4). As discussed earlier, the population within the District service boundary is projected to be 30,931 by 2035, compared to 18,795 in 2010. As the population increases, water use is projected to increase accordingly to meet the population demand, resulting in increased wastewater. Within the District service area, increased water demand is projected to affect both residential and non-residential land use sectors.

Future land development (residential and non-residential) associated with the 2035 Scenario is anticipated to occur to accommodate the increased population projection. While the 2035 population projection was previously estimated within the District service area and readily available to use in this study, the exact locations of future land development and land use density are uncertain at this time. For the purpose of this assessment, the spatial distribution of sewer loading by each subbasin is needed to assess the potential impact of future septic loading. Therefore, for the water balance analysis, a reasonable assumption was made to distribute the total future projected septic loading among the subbasins proportional to the Current Scenario septic loading in each subbasin. The same approach was used both for residential and non-residential land uses. While the future land development may vary from the current modeling assumption, this approach allows for subbasin specific septic loading assessment while accounting for the total sewer loading across the District service area.

4.4.1.1 Residential Sewer Loading

The approach used to estimate residential sewer loading for the 2035 Scenario relies on the future projected population and projected per capita sewer loading rate. Total residential sewer loading for the 2035 Scenario within the District service area was calculated to be 2,513 afy, compared to 1,677 afy for the current conditions (Table 4-4). Per capita sewer loading rate was calculated to be 73.5 gpcd for 2035 compared to 80 gpcd for the current condition. This accounts for a reduction in sewer loading rate proportional to the reduction in the per capita water use. As reported in the 2010 UWMP and discussed above, per capita water use is estimated to be 147 gpcd and is projected to reduce to 135 gpcd to meet the water reduction compliance by 2020 by water conservation. This is equivalent to 8 percent reduction in the gpcd. As described above, the sewer loading rate for the Current Scenario is 80 gpcd. With the 8 percent reduction, sewer loading rate with water conservation is projected to be 73.5 gpcd. It was assumed that once the water use target by 2020 is achieved, the intent is to keep it at that level. Therefore, the 73.5 gpcd is considered applicable for projecting sewer loading beyond 2020 and used as a reasonable approximation for the 2035 Scenario. The 73.5 gpcd for the 2035 Scenario is considered reasonable for future projections.

Beginning in recent years, greater attention is being given to water conservation and the installation of water-conserving devices and appliances, including in the District service area. With the energy use standards that have gone into effect since 1994, indoor retrofits are expected to reduce water use in indoor appliances. Homes built after 1994 or retrofitted with energy and water–efficient appliances would have typical average daily wastewater flows in the 40 to 60 gpcd (DeOreo et al., 2001). The reduced 73.5 gpcd results in reduced wastewater flows, thus decreasing the quantity of contaminants of emerging concern (CECs) discharged to the waste stream. Reducing water use in a residence can decrease hydraulic loading to the treatment system and generally improve system performance. Indoor residential water use and resulting wastewater flows are attributed mainly to toilet flushing, bathing, and clothes washing. Toilets, showers, and faucets in combination can represent more than 70 percent of all indoor use. Residential wastewater flow reduction can therefore be achieved most dramatically by addressing these primary indoor uses. Installing indoor plumbing fixtures that reduce water use and replacing existing plumbing fixtures or appliances with units that use less water are successful practices that reduce wastewater flows.

Similar to the Current Scenario, the water to sewer conversion is assumed to remain at 80 percent. With the population projection of 30,931 and the 80 percent water to sewer conversion, this results in total residential water use of 3,141 afy. This projection is lower than the 2010 UWMP water demand estimate presented in Table 2-6 (total water demand of 4,240 afy, including 3,401 afy for single family and 839 afy for multifamily) because the UWMP was based on very conservative water demand assumptions in the context of the long-term water supply planning requirements. For the purpose of the septic loading assessment, total residential sewer loading is considered more representative and reflective of recent legislative impacts and overall declining trends in per capita water use.

4.4.1.2 Non-Residential Sewer Loading

Similar with the Current Scenario, non-residential sewer loading for 2035 constitutes a small portion of the total sewer loading in the District service area, due to the limited size and type of outdoor landscaping throughout the Twentynine Palms area. Total non-residential sewer loading for the 2035 Scenario was calculated to be 449 afy, compared to 222 afy for the current condition (Table 4-4). This estimate relies on the total water use of 561 afy, based on the conservative projection in the UWMP (Table 2-6) and the 80 percent water to sewer factor. Sewer loading for the high density commercial, low density commercial, and institutions are 264, 89, and 96 afy, respectively. Sewer loading rate is 900, 320, and 320 gal/day/acre for the high density commercial, low density commercial, and institutions respectively, based on the same assumption developed for the current conditions.

TABLE 4-4
SUMMARY OF ESTIMATED 2035 PROJECTED SEPTIC LOADING RATES

	Water Use (afy)[(a)]	Water to Sewer Factor (%)	Septic Loading (afy)[(b)]	Septic Loading Rate[(c)]
Residential	3,165	80	2,532	73.5
Non-Residential	561		449	
Commercial – High Density	330	80	264	900
Commercial – Low Density	111	80	89	320
Institutions	120	80	96	320
Total	**3,726**	-	**2,981**	-

Notes:
(a) Total residential water use includes 3,141 afy within District and 24 afy outside of District. All non-residential water use is within District.
(b) Total sewer loading includes 2,513 afy within District and 19 afy outside of District. All non-residential sewer loading is within District.
(c) Septic loading rates are in gal/day/person for residential and gal/day/acre for non-residential.

4.4.2 Groundwater Pumping

The UWMP 2035 projections for groundwater pumping were used as the basis for 2035. Similar to water use, due to increase in water demand, groundwater pumping is assumed to be higher for 2035 than the current conditions. Table 4-3 presents a total pumping projection of 5,119 afy and pumping distribution among the subbasins, based on the UWMP projections. As expected, this amount is higher than groundwater pumping of 3,735 afy used for the current condition, but it is within the District's current total pumping capacity of approximately 6,985 afy.

4.5 Build-Out Scenario

Build-Out Scenario and associated sewer loading are described qualitatively in the context of the SNMP, given the high uncertainty and timeline of the ultimate build-out land development in the Twentynine Palms area. The City build-out based on the General Plan is anticipated to take place over several decades to a century. In general, uncertainties associated with impact analysis increase as projections move further into the future. The period required for the ultimate build-out is well beyond a practical engineering planning horizon that is typically less than 50 years. Growth rate in the area has historically been relatively slow and further slowed down due to economic down turn conditions in recent years, compared to a more conservative population projection for 2035.

Similar to the Current and 2035 Scenarios, sewer loading and pumping assumptions are the two major components as part of the water balance analysis. The following qualitative discussion highlights the uncertainties associated with sewer loading estimates in the context of water demand, water supply and water quality issues anticipated with the build-out. This qualitative discussion is intended to serve as a useful guidance for future planning studies conducted by the District and the City.

4.5.1 Total Sewer Loading

The Build-out Scenario requires assumptions for the population projections and sewer loading rate per capita, following the same approach for the 2035 Scenario. As previously discussed, water demand for the Build-out Scenario was estimated to be approximately 12,784 afy based on residential and non-residential water usage. Based on the 80 percent water to sewer conversion, total build-out sewer loading corresponding to the above water usage is estimated at approximately 10,227 afy. This value incorporates the projected population and land use values as well as the 73.5 gpcd of sewer loading rate used for the 2035 Scenario. Using the same sewer loading rate of 73.5 gpcd for the 2035 and the build-out Scenarios is reasonable in the absence of a more definitive parameter beyond 2035, but the rate is likely to vary over time.

Since Build-out water demand is significantly higher than the 2035 projections, it presents issues with respect to water supply and water quality. A couple of options could be made available to meet projected water demand, but each presents constraints and makes it difficult to address the build-out quantitatively.

- **Groundwater Pumping at Current Capacity with Alternative Water Supply** – If the current pumping capacity from the subbasins is assumed to remain the same given overdraft concerns, the rest of water supply would have be met from other sources (i.e., imported water). The current planning within the District service area is that groundwater would be the sole source and no additional source is anticipated to become available in the future.

- **Groundwater Pumping Increase To Meet Build-Out Water Demand** – While this option would be consistent with the District's overall future intent to have the groundwater as the sole source, it presents both water supply and water quality constraints, as summarized below.

4.5.2 Water Supply Constraints

Currently the District pumping capacity is approximately 6,985 afy. This is well below the projected build-out water demand. While the maximum pumping capacity is 10,248 afy, pumping at the maximum capacity can be limited due to potential overdraft. The three small subbasins have good water quality, but the current pumping capacity from the Fortynine Palms and Indian Cove Subbasins are limited by DWR's recommendations to prevent overdraft. While there is potential to expand pumping in the Mesquite Lake Subbasin for future needs, this would require significant expansion and water treatment to resolve elevated fluoride levels naturally occurring in groundwater. Currently, the pumping capacity is 2,100 afy from Mesquite Lake Subbasin. The amount of additional pumping has not been investigated and future studies would be required to determine sustainable production rates.

Future expansion in the Mesquite Lake Subbasin presents cost and water quality issues (see below). While future expansion of the treatment plant for an additional 3 mgd is being considered by the District, it would cost about $10 million to meet only a portion of the build-out water demand.

4.5.3 Water Quality Constraints

The District has been historically pumping from the smaller subbasins in the south because these portions of the groundwater have good water quality. However, pumping in these subbasins is limited by DWR's recommendation to prevent overdraft. The District recently began pumping from the Mesquite Lake Subbasin; however, this portion of the groundwater has water quality issues due to naturally occurring constituents. Additional pumping from the Mesquite Lake Subbasin to meet the water demand would require significant expansion of the treatment plant. Even if future studies show evidence of greater pumping capacity from the Mesquite Lake Subbasin, further expansion to meet the total build-out demand would be costly due to water quality treatment for fluoride.

Section 5: Salt and Nutrient Balance

The primary objective of salt and nitrate balance models is to estimate the mass loading into groundwater subbasins underlying septic tanks and the resulting concentration in groundwater with the mixing of septic recharge with existing groundwater. Salt and nitrate balances were performed at the subbasin scale using a simple, spreadsheet-based mixed-cell model. Currently, the release of nitrate and salt found in wastewater is of great concern within the regulatory framework not only in the operation of a septic system but also regarding the protection and management of groundwater resources.

In this SNMP, nitrate (nitrate as nitrogen) and TDS were chosen as the primary COCs to assess the potential loading from septic tanks and other major sources contributing to the system. Nitrate balance components and related assumptions are presented first followed by the discussion of salt balance components.

5.1 Septic Tank Effluent

The potential mechanism for migration of septic tank effluent is briefly described in general terms to provide the background for the potential fate of nitrate in septic tanks, within the leach field and the vadose zone before reaching groundwater.

Septic tanks provide primary treatment of wastewater, removing most of the settlable solids, greases, oils, and other floatable matter and anaerobic liquefaction of the retained organic solids. Conventional systems work well if they are installed properly and maintained to ensure long-term performance. In areas with appropriate soils and hydraulic capacities, they are designed to treat the incoming waste load to meet public health, groundwater, and surface water performance standards. Nitrate, phosphorus, pathogens, and other contaminants are present in significant concentrations in most wastewaters treated by onsite systems. Although most can be removed to acceptable levels under optimal system operational and performance conditions, some may remain in the effluent exiting the system.

When the effluent from a septic tank is applied over a disposal field, the liquid travels through the vadose zone and further treatment continues in the field through biological mechanisms as well as adsorption, filtration, and infiltration into underlying soils. The degree of the additional treatment in the vadose zone depends on a host of factors (e.g., soil mineralogy, particle sizes, residence time, depth to groundwater). Nitrogen removal occurs in the adsorption field in the vadose zone if the wastewater loading is intermittent and environmental conditions develop for nitrification and denitrification. In soils with excessive permeability or shallow water tables, inadequate treatment in the unsaturated soil zone might allow pathogenic bacteria and viruses to enter the groundwater if no mitigating measures are taken. When nitrate reaches the groundwater, it moves freely with little retardation.

Nitrogen in raw wastewater is primarily in the form of organic matter and ammonia. After the septic tank, it is primarily (more than 85 percent) ammonia. After discharge of the effluent to the infiltrative surface, aerobic bacteria in the biomat and upper vadose zone convert the ammonia in the effluent almost entirely to nitrite and then to nitrate. Nitrogen in its nitrate form is a significant groundwater pollutant. It has been detected in urban and rural groundwater nationwide, sometimes at levels exceeding the USEPA drinking water standard of 10 mg/l (USGS, 1999).

5.2 Approach

A simplified mixed-cell model was developed to illustrate the major mechanisms of the aquifer system and to estimate the potential impacts of septic systems on groundwater. The model is spreadsheet based and accounts for the major nitrate and salt mass loading into and loss of nitrate and salt out of the groundwater system. A separate spreadsheet model was developed for each subbasin, similar to the approach used for the water balance analysis. Figure 5-1 presents a schematic conceptual mass balance model developed for salt and nitrate for each subbasin. Figure 5-1 shows nitrogen components but the conceptual salt balance is essentially the same using the same water balance accounting of inflows and outflows with TDS mass accounting.

The simple model presented here makes it possible (with the limited data available) to obtain a first approximation of the potential impacts of septic system nitrate on groundwater quality and demonstrate if the aquifer system can adequately dilute septic system nitrate with the current and future development without impacting groundwater quality. Results of this modeling analysis also serve to gain useful information and data gaps to fill into future studies to improve the understanding of the current conditions and long-term effects. This model is not intended to accurately predict groundwater salt and nitrate levels locally or for a specific time period, but rather to show average long-term effects on the groundwater system. The model incorporates a geographically broad and complex system into a single mixed-cell, with an underlying assumption that the system is in a steady state condition with long-term average inflows and outflows. This is consistent with the conceptual water balance model. As described in Section 4, water balance components from the groundwater model represent the 25-year long-term average

A similar, simple approach has been used widely by previous studies, including the USGS study for the Yucca Valley (Nishikawa et al, 2003). Some studies applied this concept as a decision-making process to predict nitrate in groundwater from different levels of development schemes and to plan land development accordingly (Bauman and Schafer, 1985; Taylor, 2003; RWQCB, 2011; USEPA, 1980). Such models included a mass-balance accounting for nitrate concentrations and flow volumes and were used for planning development through land use management to keep nitrate concentrations below a given threshold. These models provided guidance to the management of septic system to control the degradation of groundwater quality in aquifers that contribute water to public supply wells. More complex numerical models have been also developed to predict aquifer vulnerability to contaminants in other areas, such as the USGS study for the Yucca Valley, but they generally demand high levels of detailed and site specific data. A more complex model application for the Twentynine Palms area should be supported with more detailed, future site specific data (see Section 6).

5.3 Data Sources for Salt and Nitrate Water Quality Data

During the development of the salt and nitrate balance models, existing reports, manuals, investigations, and regulatory guidelines were reviewed to identify salt and nitrate concentrations and assessment of the fate of constituents in the subsurface. Sources of data include, but are not limited to the followings:

- 2010 Urban Water Management Plan
- Groundwater Study for the Mesquite Lake Subbasin
- Groundwater Management Plan
- Drinking Water Source Assessment Plans
- Water quality data from water supply wells
- Consumer Confidence Reports with water quality data
- Other applicable reports relevant to this Plan, including the USGS study for the Yucca Valley, Colorado River RWQCB, and USEPA.

5.4 Potential Sources of Nitrate

Potential sources of nitrate in the groundwater basins underlying the Twentynine Palms area include nitrogen loading from septic tanks, groundwater inflows, and recharge. There are no potential sources of nitrogen associated with agricultural land activities within the District service area. Each of the nitrogen sources is described below along with the modeling assumptions. In the context of septic loading assessment, the potential nitrogen loading from septic tanks is the primary concern and described in detail while the other components are briefly summarized.

5.4.1 Nitrate Balance Conceptual Model

Figure 5-1 presents the schematic conceptual nitrate mass balance model developed for each subbasin with the potential sources and losses of nitrate in a given subbasin. With the potential nitrate sources entering into the groundwater system, nitrate (or nitrate-nitrogen) concentration of the mixture in groundwater is predicted based on the nitrate concentration that results from the total mass of nitrate loading and total volume of water entering the aquifer system. As mentioned above, the model is a simplified characterization of a geographically broad, regional, and complex system into a single mixed-cell model; thus, it is not intended to accurately predict groundwater nitrogen levels locally or for a specific time period, but rather to show the average long-term effects on groundwater system.

Similar to the water balance, the nitrogen balance was developed for the Current and 2035 Scenarios. The Build-out Scenario is discussed qualitatively in Section 4 and not covered below.

5.4.2 Nitrate Loading from Septic Tanks

Wastewater from homes and businesses is disposed of using septic tanks that separate the floating and settlable solids from the wastewater and discharge clarified wastewater through leach lines. The wastewater percolates from the leach lines through the unsaturated zone and eventually recharges the underlying groundwater. Septic tanks are the primary method of wastewater disposal in the Twentynine Palms area; therefore, septage is the primary source of nitrate to the groundwater. Total mass loading was calculated by the volume of septic loading and nitrate concentrations for wastewater. The potential quantity of septic tank seepage recharging the underlying groundwater for different land-use categories is presented in

Table 4-2 for the Current Scenario and Table 4-4 for the 2035 Scenario. As described in Section 4, the current land use map and water use were used to quantify the spatial distribution of potential leakage from septage by each subbasin. The quantity of septic tank wastewater potentially recharging the underlying groundwater at any given time at a household was estimated by assuming an average per capita septic tank discharge of 80 gpcd for the Current Scenario and 73.5 gpcd for the 2035 Scenario. These sewer rates compare well with the values estimated from other studies, as discussed in Section 4.

Land use classified as commercial and industrial was assumed to have a per acre septic-tank discharge ranging from 920 to 320 gallons/day/acre both for the Current and 2035 Scenarios. For the non-residential, nitrate concentrations were derived using the wastewater quality data in a typical residential establishment.

Samples of nitrate in septic systems are not available in the Twentynine Palms area; therefore published representative estimates were used to evaluate the water quality characteristics of residential and non-residential wastewater flows. For the nitrate balance, nitrate concentration in septage was assumed to be 40 mg/l, both for residential and non-residential establishments. The same concentration was used for the Current and 2035 Scenarios. Data from various existing studies, as summarized below, were reviewed when applying the average representative value of 40 mg/l that was also used in estimates of nitrate loading from septic tanks in the Yucca Valley area.

- Nitrogen concentration in septage ranging from 40 to 80 mg/l (Bouwer, 1978).
- A sample of septage collected from residential septic tanks in the Yucca Valley, California, had a nitrate concentration of about 154 mg/l (Nishikawa et al., 2003). This is equivalent to about 34 mg/l as nitrate-nitrogen.
- Samples of septage from five different septic tanks in Victorville, California, had nitrate concentrations ranging from 97 to 280 mg/l and averaged 208 mg/l (Umari et al., 1995). This corresponds to a range of 21 to 62 mg/l as nitrate-nitrogen, with an average of about 46 mg/l.
- Total nitrogen concentrations ranging from 26 to 75 mg/l, based on the US EPA onsite wastewater treatment systems manual (USEPA, 2002).
- Total nitrogen in septic system effluent typically ranging from 20 to 85 mg/l, averaging around 40 mg/l (Metcalf & Eddy, 1991).
- In estimates of nitrogen loading to groundwater from septic tanks in Yucca Valley, the Colorado River Basin Regional Water Quality Control Board (RWQCB) staff used total nitrogen concentration of 40 mg/l in wastewater based on the reported values by Metcalf & Eddy (1991).

For the Twentynine Palms area, nitrate mass loading from septic systems was calculated based on the total septic loading multiplied by nitrogen concentration of 40 mg/l in septage.

5.4.3 Groundwater Inflows

When considering recharge from septage into groundwater, it is important to evaluate and address other sources of water such as groundwater inflows that would be introduced into the system and nitrogen entering the system along with groundwater inflow. Groundwater inflows entering the subbasins are based on the estimates from the existing groundwater model, as described in Section 4 (Table 4-1 for the Current Scenario and Table 4-3 for the 2035 Scenario). Groundwater inflows were assumed to remain the same for the Current and 2035 Scenarios, given that the model represents the long-term conditions.

Total nitrogen mass loading from groundwater inflows are estimated based on the volume of groundwater inflows and nitrogen concentration of 2 mg/l for groundwater inflow. For the Yucca Valley study, the USGS used NO3 concentration of 10 mg/l, which corresponds to approximately 2.2 mg/l as nitrate-nitrogen. Given the similarities and proximity of the two areas, nitrate-nitrogen concentration of approximately 2 mg/l was considered as a reasonable assumption to represent the native groundwater quality both for the Current and 2035 Scenarios. Review of previous documents indicate that at the nationwide level, nitrate-nitrogen concentrations of less than 0.2 mg/l generally represent natural conditions, whereas values greater than 3 mg/l may indicate the effects of human activities (USGS, March 1996).

5.4.4 Recharge

Reduction of nitrate concentrations in groundwater occurs with recharge of groundwater supplies by precipitation; but in the Twentynine Palms area, natural recharge from precipitation is relatively small based on the groundwater model and assumed to remain the same for the Current and 2035 Scenarios (Tables 4-1 and 4-3).

5.5 Potential Losses of Nitrate

Potential losses of nitrate include nitrate loss through denitrification, groundwater pumping, groundwater outflows, and nitrate loss through vegetation uptake (i.e., ET). In the context of septic loading assessment, the potential loss of nitrate from denitrification is the primary concern and described in detail while the other components are briefly summarized below.

5.5.1 Denitrification Potential

For the nitrate balance and loading assessment in the Twentynine Palms area, 20 percent reduction in nitrogen was assumed to account for potential loss of nitrogen from septage through denitrification. This is consistent with the previous study findings discussed below (Jenssen and Siegrist, 1990) and the value used for the Yucca Valley. In light of previous studies, the large depth to water in groundwater subbasins in the study area (100-200 feet in the east and 200-300 feet in the west) could potentially induce additional denitrification, but 20 percent denitrification rate in the vadose zone is considered reasonable in the absence of site specific data.

Nitrogen can undergo several transformations in and below a septic tank, including adsorption, volatilization, mineralization, nitrification, and denitrification. Nitrification, the conversion of ammonium nitrogen to nitrite and then nitrate by bacteria under aerobic conditions, is the predominant transformation that occurs immediately below the infiltration zone. The negatively charged nitrate ion is very soluble and moves readily with the percolating soil water.

Biological denitrification, which converts nitrate to gaseous forms of nitrogen, can remove nitrate from percolating wastewater. Denitrification is a complex process, which makes it difficult to predict soil nitrogen removal rates for wastewater-borne nitrate or other nitrogen compounds in the soil matrix. Denitrification occurs under anaerobic conditions where available electron donors such as carbon or sulfur are present. Denitrifying bacteria use nitrate as a substitute for oxygen when accepting electrons. It has been generally thought that anaerobic conditions with organic matter seldom occur below soil infiltration fields. Therefore, it has been assumed that all the nitrogen applied to infiltration fields ultimately leaches to groundwater (Brown et al., 1978; Walker et al., 1973a, b). However, several studies indicate that denitrification can be significant. Jenssen and Siegrist (1990) found in their review of several laboratory and field studies that approximately 20 percent of nitrogen is lost from wastewater percolating through soil. Factors found to favor denitrification are fine-grained soils (silts and clays) and layered soils (alternating fine-grained and coarser-grained soils with distinct boundaries between the texturally different layers), particularly if the fine-grained soil layers contain organic material. Jenssen and Siegrist concluded that nitrogen removal below the infiltration field can be enhanced by placing the system high in the soil profile, where organic matter in the soil is more likely to be present, and by dosing septic tank effluent onto the infiltrative surface to create alternating wetting and drying cycles. Denitrification can also occur if groundwater enters surface water bodies through organic-rich bottom sediments, but this is not a potential loss in the Twentynine Palms area. Nitrogen concentrations in groundwater were shown to decrease to less than 0.5 mg/l after passage through sediments in one Canadian study (Robertson et al., 1989, 1990).

5.5.2 Groundwater Pumping

A significant loss of nitrogen in the system is to removal of nitrate with well pumping. Nitrate mass removal from groundwater pumping was estimated based on the volume of groundwater pumping and the average nitrate-nitrogen concentration measured in water supply wells. Groundwater pumping is projected to increase by 2035 to reflect the increasing water demand with population increase (Tables 4-1 and 4-3). The average nitrate concentrations were calculated for each subbasin based on measured data from the water supply wells located in each subbasin. For the subbasins that show stable nitrate levels, such as the Indian Cove and the Eastern Subbasins, data available since 1999 were considered reasonable to show the general trends in the average nitrate levels. For the Fortynine Palms Subbasin, data tend to show slight increasing trends in recent years; thus, most recent data since 2006 were included to characterize the current conditions of the subbasin. The Mesquite Lake Subbasin has nitrate data measured only from one location (WTP-1) based on three sampling events (one in 2006 and two in 2009), but all three sampling events showed non-detect. For the purpose of this analysis, the laboratory reporting limit of 0.5 mg/l was assigned for the Mesquite Lake Subbasin. The resulting average nitrate concentrations for each subbasin were as follows: 10 mg/l for the Indian Cove, 20 mg/l for the Fortynine Palms, 7 mg/l for the Eastern, and about 1 mg/l for the Mesquite Lake Subbasin. They were converted to nitrogen as 2.1, 4.3, 1.5, and 0.1 mg/l, respectively, and used to account for the nitrogen removal from pumping.

5.5.3 Groundwater Outflows

Total nitrogen mass removed through groundwater outflows was estimated based on the volume of groundwater outflows estimated by the groundwater model (Tables 4-1 and 4-3) combined with additional recharge from septic tanks and nitrogen concentration estimated for the mixed groundwater.

5.5.4 Evapotranspiration

Total nitrogen mass removal by ET was estimated roughly based on the volume of ET from the groundwater model and nitrogen concentration of the background groundwater (i.e., 2 mg/l). Site specific measurements for nitrogen uptake by vegetation are unavailable. This approach was developed to provide a rough estimate to account the potential loss of nitrogen uptake by ET. Overall, nitrogen removal by ET is considered small as ET can potentially occur only in two subbasins (Eastern and Mesquite Lake Subbasins), as shown in Tables 4-1 and 4-3.

5.5.5 Atmospheric Losses of Nitrogen

Atmospheric losses of nitrogen, or volatilization, can be significant in fertilized areas when fertilizer is exposed to sunlight and air. In the Twentynine Palms area, green spaces fertilized are limited; thus, atmospheric losses of nitrogen is anticipated to be very small and assumed negligible (not shown in Figure 5-1).

5.6 Nitrate Model Results

The results of the mixed-cell model to evaluate the potential nitrate loading are discussed below for both current and 2035 conditions for each of the groundwater subbasins

5.6.1 Nitrate Model Results for Current Scenario

The Current Scenario model results are presented below and the results are summarized in Table 5-1. For the Current Scenario, the nitrogen mass loading from septic tanks is approximately 82 ton/yr. Contribution from other sources, such as recharge and groundwater inflow, is relatively small (about 12 ton/yr) compared to septic system sources. Among the four subbasins, the southern portion of the Mesquite Lake Subbasin shows the highest septic nitrogen loading (45 ton/yr), consistent with the highest population and density in this area. The northern portion of the Mesquite Lake Subbasin is about 15 ton/yr, representing one third of the loading estimated for the southern portion. The areas overlying the Indian Cove, Fortynine Palms and Eastern Subbasins are less populated; thus, nitrogen loading from septic tanks in these subbasins is less, ranging from 7 ton/yr to 9 ton/yr.

Removal of nitrogen (nitrate as N) from groundwater occurs primarily through groundwater pumping but evapotranspiration may occur near the Oasis of Mara, Shortz Playa and Mesquite Lake. Other losses include groundwater flow out of the basin and between subbasins that are not included in Table 5-1. Removal of nitrogen (nitrate as N) from groundwater is highest in the Fortynine Palms, Indian Cove and the northern portion of the Mesquite Lake Subbasins where groundwater pumping is highest. Removal rates range from 4 to 6 tons/per year in each of these subbasins. No groundwater extraction is included in the southern portion of the Mesquite Lake Subbasin as a conservative assumption. Overall, losses remove the equivalent of about

18 percent of the total septic load. In cases such as the Fortynine Palms Subbasin, the losses remove the equivalent of about 80 percent of the total septic load.

To put the loading rate into context to the relative size of the groundwater basins, we divided the annual nitrogen loading rate by an assumed volume of the aquifer. For the aquifer volume, we assumed 100 foot thickness under only the developed portions of the basin and a specific storage of 0.18 (Kennedy/Jenks, 2009). The developed portions of the basin are based on the land use in Figure 2-1. Based on this approximation, nitrogen (nitrate as N) would increase from 0.05 to 0.25 mg/l per year. The highest increase would be in the Eastern and southern portion of the Mesquite Lake Subbasin. For these areas, nitrogen (nitrate as N) would increase by 1.0 mg/l in 4 to 5 years. For the Indian Cove, Fortynine Palms and northern portion of the Mesquite Lake Subbasin, nitrogen (nitrate as N) would increase at a lower rate ranging from 0.05 to 0.082 mg/l per year. An increase of 1.0 mg/l would range from 12 to 20 years.

5.6.2 Sensitivity Analysis of Nitrate Model

These estimates are based on the mass balance model using simplifying and conservative assumptions. Several parameters have a potentially high degree of uncertainty such as the septic loading assumptions, losses due to natural attenuation and the change in concentration due to the migration of groundwater between groundwater subbasins.

A sensitivity analysis was conducted under current conditions to "bracket" the modeled findings. For the sensitivity analysis, the septic loading parameters were varied to develop a high and low loading case. The parameters selected for the sensitivity are associated with the source loading parameters and include the septic effluent concentration and the percentage loss in nitrogen from the septic system. These are two parameters which have a wide range in the published literature; therefore, the ranges used for the sensitivity analysis are within that range and are also plausible parameter values.

First, the septic effluent concentration was varied plus or minus 25%. The assumed septic tank effluent concentration was assumed to be 40 mg/l Nitrate as N. However, data show that this parameter can be highly variable. For the sensitivity analysis, the septic effluent concentration applied was 30 and 50 mg/l for the low and high case respectively.

Second, the percentage loss in nitrogen from the septic system to the groundwater was varied because this is also a highly uncertain parameter without site-specific data. The assumed percentage loss in nitrogen from the septic system was a 20% loss factor. For the sensitivity analysis, the percentage loss in nitrogen from the septic system was 10% and 30% for the low and high case, respectively.

As anticipated, the total nitrogen mass loading to the four groundwater subbasins ranged essentially plus or minus 25%. Table 5-1 provides a summary of the sensitivity analysis results. For the standard case, the nitrate loading from septic systems was approximately 82 ton/yr. For the high-loading case, the nitrate loading was approximately 103 ton/yr, and for the low-loading case, the nitrate loading was approximately 60 ton/yr. Looking at the subbasins, the septic nitrogen loading rate for the southern portion ranged from 32 to 56 ton/yr. The northern portion of the Mesquite Lake Subbasin ranged from 11 to 19 ton/yr, representing one third of the loading estimated for the southern portion. The areas overlying the Indian Cove, Fortynine

Palms and Eastern Subbasins are less populated; thus, nitrogen loading from septic tanks in these subbasins is less, ranging from 5 ton/yr to 11 ton/yr.

The potential rate of increase in nitrogen loading rate was evaluated similar to the process discussed in Section 5.6.1. Based on this the rate of change, nitrogen (nitrate as N) would increase from 0.33 to 0.03 mg/l per year. The highest increase would be in the Eastern and southern portion of the Mesquite Lake Subbasin. For these areas, nitrogen (nitrate as N) would increase by 1.0 mg/l in 3 to 7 years. For the Indian Cove, Fortynine Palms and northern portion of the Mesquite Lake Subbasin, nitrogen (nitrate as N) would increase similar to the current conditions with an increase of 1.0 mg/l taking from 12 to 33 years.

The sensitivity analysis demonstrates that the uncertainty associated with the source terms can have a significant influence on the results. The results indicate that the use of mass conservative assumptions in developing and applying the mixing cell model may cause the models to overestimate nitrate concentrations in the subbasins. Other parameters with the water balance and the losses at wells would also influence the results, but a sensitivity analysis has not been conducted on these parameters. More site-specific data will be needed to conduct more comprehensive hydrogeochemical analysis and to develop more detailed models of nitrate and TDS loading prior to the implementation of any remediation-related improvements.

5.6.3 Nitrate Model Results for 2035 Projections

The simple mixed-cell model results for the 2035 Scenario are presented below with a focus on the future projected nitrogen loading and estimated nitrogen concentrations in the mixed groundwater system. Table 5-1 presents the nitrogen contribution from the major sources in each subbasin separately and total loading into the four subbasins. The total nitrogen mass loading from septic tanks is approximately 128 ton/yr, representing about 62 percent of the total estimated loading (Figure 5-4). Contribution from other sources is relatively small.

Among the four subbasins, the southern portion of the Mesquite Lake Subbasin shows the highest septic nitrogen loading (71 ton/yr), compared to 23 ton/yr for the northern portion of the Mesquite Lake Subbasin. Nitrogen loading from septic tanks in the three subbasins (the Indian Cove, Fortynine Palms and Eastern Subbasins) is smaller, ranging from 10 ton/yr to 13 ton/yr.

The potential rate of increase in nitrogen loading rate was evaluated similar to the process discussed in Section 5.6.1. Based on this the rate of change, nitrogen (nitrate as N) would increase from 0.28 to 0.05 mg/l per year. The highest increase would be in the Eastern and southern portion of the Mesquite Lake Subbasin. For these areas, nitrogen (nitrate as N) would increase by 1.0 mg/l in 4 to 5 years. For the Indian Cove, Fortynine Palms and northern portion of the Mesquite Lake Subbasin, nitrogen (nitrate as N) would increase similar to the current conditions with an increase of 1.0 mg/l taking from 14 to 20 years. Similar to the Current Scenario, losses remove the equivalent of about 14 percent of the total septic load. In cases such as the Fortynine Palms Subbasin, the losses remove the equivalent about 65 percent of the total septic load.

With the assumed continued land development for the 2035 Scenario and resulting septic tanks added to the system, nitrogen loading from septic tanks would increase proportional to the increase in septic loading. The model estimates that increasing loading would lead to nitrogen concentrations exceeding the basins' capacity to adequately dilute the incoming nitrates, potentially resulting in concentrations exceeding the MCL for nitrate in portions of the groundwater subbasins and most likely in the Eastern and southern portion of the Mesquite Lake Subbasins. However, the simple mixed-model results do not account for the capacity of the subsurface to assimilate wastewater flows. Therefore, the model estimates should be considered in light of the model assumptions and the current interpretation that the model findings are considered inconclusive and highlight the need for further site specific data collection from future groundwater monitoring.

TABLE 5-1
NITROGREN MASS BALANCE MODEL RESULTS SUMMARY

Subbasin Name	Nitrogen Loading from Septic Systems (tons/year)	Nitrogen Loading from Other Sources (tons/year)	Nitrogen Losses (tons/year)	Average Annual Increase in Nitrogen (mg/L)
Current Scenario				
Indian Cove Subbasin	7	1	4	0.05
Fortynine Palms Subbasin	7	1	6	0.08
Eastern Subbasin	9	<1	1	0.20
Mesquite Lake - South	45	3	0	0.25
Mesquite Lake - North	15	7	5	0.05
Total	82	12	15	
Sensitivity Analysis for Current Scenario with Higher Loading Rates				
Indian Cove Subbasin	8	1	4	0.07
Fortynine Palms Subbasin	9	1	6	0.07
Eastern Subbasin	11	<1	1	0.26
Mesquite Lake - South	56	3	0	0.33
Mesquite Lake - North	19	7	5	0.05
Total	103	12	15	
Sensitivity Analysis for Current Scenario with Lower Loading Rates				
Indian Cove Subbasin	5	1	4	.03
Fortynine Palms Subbasin	5	1	6	<0
Eastern Subbasin	7	<1	1	0.15
Mesquite Lake - South	32	3	0	0.15
Mesquite Lake - North	11	7	5	0.04
Total	60	12	15	
2035 Scenario				
Indian Cove Subbasin	10	1	3	0.07
Fortynine Palms Subbasin	11	1	7	0.12
Eastern Subbasin	13	<1	2	0.21
Mesquite Lake - South	71	3	<1	0.28
Mesquite Lake - North	23	7	5	0.05
Total	128	12	17	

5.7 Potential Sources of TDS

Potential sources of salt in the groundwater basins underlying the Twentynine Palms area include TDS loading from septic tanks, groundwater inflows, and recharge. There are no potential sources of TDS associated with agricultural land activities within the District service area. In the context of septic loading assessment, the potential TDS loading from septic tanks is the primary concern and described in detail while the other components are briefly summarized below. In addition, because of the similarities with the nitrate balance model assumptions, potential sources of TDS are described only for the assumptions different from the nitrate mass balance.

5.7.1 TDS Conceptual Model

The conceptual salt balance model is essentially the same as the approach developed and used for nitrate balance presented in Section 5.7 and shown in Figure 5-1. The results of water balance presented in Tables 4-1 and 4-3 apply to both salt and nitrate balance analyses with the underlying assumption that salt and nitrate are carried in the subsurface with water flow. The major difference is that salt balance uses TDS as a surrogate to represent salt loading to groundwater subbasins while the nitrate balance uses nitrate-nitrogen to assess the nitrate loading to groundwater subbasins. Because of the similarities in the conceptual model, the salt balance model components are described in this section briefly and references are made to the detailed description provided in Section 5.7.

5.7.2 TDS Loading from Septic Tanks

Total TDS mass loading was calculated by the volume of septic loading and TDS concentrations for wastewater. The potential quantity of septic tank seepage recharging the underlying groundwater for different land-use categories is the same for the TDS and nitrate loading assessment, as presented in Table 4-2 for the Current Scenario and Table 4-4 for the 2035 Scenario. Septic loading assumes an average per capita septic tank discharge of 80 gpcd for the Current Scenario and 73.5 gpcd for the 2035 Scenario for the residential setting. Non-residential (commercial and industrial) assumes a per acre septic-tank discharge ranging from 920 to 320 gallons/day/acre both for the Current and 2035 Scenarios.

Currently, site specific data for TDS in septic tanks are unavailable. For the purpose of salt balance analysis, TDS concentration of septic was assumed to be 500 mg/l, based on review of the literature values reported for typical composition of domestic waste water. The following two commonly used references were reviewed and considered in determining the average representative TDS concentration of 500 mg/l for domestic wastewater. In the absence of site specific data, the same concentration was assumed for the non-residential TDS loading.

- Metcalf & Eddy (2004) Wastewater Engineering Treatment and Reuse reports average TDS of 500 mg/l with a range of 270-860 mg/l, for a typical composition of untreated domestic wastewater.

- USEPA Onsite Wastewater Treatment Systems Manual (2002, Table 25-2) reports a range of TDS concentration of 680-1,000 mg/l for typical residential dwellings equipped with standard water-using fixtures and appliances (or mass loading of 115-200 grams/person/day).

For the Twentynine Palms area, TDS mass loading from septic systems was calculated based on the total septic loading multiplied by TDS concentration of 500 mg/l in septage.

5.7.3 Other Sources of TDS Mass Loading

The other sources of TDS loading to groundwater include groundwater inflows and recharge, as described below.

- **Groundwater Inflows –** Similar to the nitrate balance, groundwater inflows entering the subbasins are based on the estimates from the existing groundwater model and were assumed to remain the same for the Current and 2035 Scenarios (Tables 4-1 and 4-3). Total TDS mass loading from groundwater inflows were calculated based on the volume of groundwater inflows and the average TDS concentration measured from water supply wells. The average measured TDS values were calculated as 140 mg/l for the Indian Cove, 159 for the Fortynine Palms, 179 mg/l for the Eastern, and 340 mg/l for the Mesquite Lake Subbasin. The TDS concentrations are a simplification in the absence of measured data and may not reflect the boundary conditions for TDS between the subbasins.

- **Recharge –** The overall TDS contribution from recharge is assumed zero for the purpose of the TDS assessment, given that the recharge constitutes a negligible volume of water entering the system. Site specific data on TDS concentration of recharge are unavailable, but anticipated to be much smaller than the ranges measured in groundwater.

5.8 Potential Losses of TDS

Potential losses of salt include groundwater pumping, groundwater outflows, and salt uptake by vegetation (i.e., ET), as described below.

- **Groundwater Pumping –** A significant loss of TDS in the system is anticipated from groundwater pumping, calculated based on the volume of groundwater pumping and average TDS concentration measured in water supply wells. Similar with the nitrate balance, groundwater pumping is projected to increase by 2035 to reflect the increasing water demand with population increase.

- **Groundwater Outflows –** Total TDS mass removed through groundwater outflows was estimated based on the volume of groundwater outflows estimated by the groundwater model (Tables 4-1 and 4-3) combined with additional recharge from septic tanks and nitrogen concentration estimated for the mixed groundwater.

- **Evapotranspiration –** Total TDS mass removal by ET is a rough estimate based on the volume of ET from the groundwater model and the average TDS concentration of groundwater measured in water supply wells.

Atmospheric losses of TDS were assumed to be zero. In the context of septic loading assessment, TDS was assumed to be conservative with no loss of salt in the subsurface. This is different than the nitrate mass balance where the potential loss of nitrate from denitrification (20 percent loss) was accounted.

5.9 TDS Model Results

The results of the mixed-cell model to evaluate the potential nitrate loading are discussed below for both current and 2035 conditions for each of the groundwater subbasins

5.9.1 TDS Model Results for Current Scenario

The Current Scenario model results are presented below for the TDS loading and estimated TDS concentrations in the mixed groundwater system. Table 5-2 presents the TDS contribution from the major sources in each subbasin separately and total loading into the four subbasins. For the Current Scenario, the total TDS mass loading from septic tanks is approximately 1,120 ton/yr whereas loading from other sources, primarily groundwater inflow, is about 3,970 ton/yr. For TDS, the contribution from septic systems is significantly less than from other sources.

Removal of TDS from groundwater occurs primarily through groundwater pumping but limited removal may occur by evapotranspiration near the Oasis of Mara, Shortz Playa and Mesquite Lake. Other losses include groundwater flow out of the basin and between subbasins that are not included in Table 5-2. Removal of TDS from groundwater is highest in the Fortynine Palms, Indian Cove and the northern portion of the Mesquite Lake Subbasins where groundwater pumping is highest. Removal rates range from 245 to 1,080 tons/per year in each of these subbasins. No groundwater extraction is included in the southern portion of the Mesquite Lake Subbasin as a conservative assumption. For the Current Scenario, the removal by groundwater pumping exceeds the loading rate so there would be a net removal of TDS from groundwater relative to the natural loading prior to development.

The spatial distribution of septic loading among the four subbasins follows similar trends as seen in the nitrogen mass loading. The southern portion of the Mesquite Lake Subbasin shows the highest septic TDS loading (564 ton/yr). This is expected as the subbasin underlies the downtown area with the longest history of development and the highest population and density. The northern portion of the Mesquite Lake Subbasin is about 232 ton/yr, smaller than the estimate from the southern portion, reflecting the lower housing density. The smaller three subbasins that are less populated show smaller septic TDS loading of around 100 ton/yr. TDS contribution through exchange flows is the highest for the northern Mesquite Lake Subbasin. This is consistent with the trend for the nitrogen loading and accounts for groundwater flowing toward the northern Mesquite Lake Subbasin from the three smaller subbasins and the southern Mesquite Lake Subbasin.

5.9.2 TDS Model Results for 2035 Projections

The simple mass balance model results for the 2035 Scenario are presented below with a focus on the future projected TDS loading and estimated TDS concentrations in the mixed groundwater system. Table 5-2 presents the TDS contribution from the major sources in each subbasin separately and total loading into the four subbasins. The total TDS mass loading from septic tanks is approximately 2,178 ton/yr whereas loading from other sources, primarily groundwater inflow, is estimated to be 3,974 ton/yr. Similar with the Current Scenario, TDS mass from the groundwater flow still constitutes a significant portion of the total mass.

Removal of TDS mass from groundwater is shown on Table 5-2 for the 2035 Scenario. Similar to the Current Scenario, the removal by groundwater pumping exceeds the loading rate so there would be a net removal of TDS from groundwater relative to the natural loading prior to development.

The spatial distribution of septic loading among the four subbasins follows similar trends with the nitrate mass loading. The southern portion of the Mesquite Lake Subbasin shows the highest septic TDS loading (1,110 ton/yr), as a result of highest population and housing density in the downtown area located in this subbasin. The northern portion of the Mesquite Lake Subbasin is about 537 ton/yr, compared to lower TDS loading of 155 ton/yr to 210 ton/yr from the from the three smaller subbasins.

Based on the continued land development assumption for the 2035 Scenario, future projected salt loading from septic tanks added to the system is anticipate to increase proportional to the increase in septic loading. The model estimates that increase in loading from the current conditions to 2035 would lead to increase in TDS, but concentrations would remain below the secondary MCL of 500 mg/l for TDS. While the model appears to suggest the basin capacity to assimilate the incoming salt from septage and dilute TDS concentration well below the septage concentration of 500 mg/l, the same mixed-model was used both for the nitrate and TDS mass loading assessment. The model results should be considered in light of the model assumptions and the need for model calibration with further site specific data collection from future groundwater monitoring.

TABLE 5-2
TDS MASS BALANCE MODEL RESULTS SUMMARY

Subbasin Name	TDS Loading from Septic Systems (tons/year)	TDS Loading from Other Sources (tons/year)	TDS Losses (tons/year)
Current Scenario			
Indian Cove Subbasin	104	89	245
Fortynine Palms Subbasin	106	88	267
Eastern Subbasin	109	23	122
Mesquite Lake - South	564	2,265	0
Mesquite Lake - North	232	1,509	1,080
Total	1,115	3,974	1,714
2035 Scenario			
Indian Cove Subbasin	155	89	200
Fortynine Palms Subbasin	166	88	350
Eastern Subbasin	210	23	205
Mesquite Lake - South	1,110	2,265	0
Mesquite Lake - North	537	1,509	1,488
Total	2,178	3,974	2,243

Section 6: Assessment of Data and Analysis

This section provides an overview of the data and analysis used to evaluate the potential impacts to groundwater from the use of septic tanks in the Twentynine Palms area including a comparison to the conditions in Yucca Valley.

6.1 Conditions in Twentynine Palms

The Twentynine Palms area is a complex geologic setting. The City of Twentynine Palms overlies a large alluvial basin that is subdivided into a number of groundwater basins and subbasins due to faulting. The alluvium is highly variable vertically and horizontally being made up of interbedded sand, gravel, and clay. The sediments tend to be coarsest along the mountain fronts and progressively finer grained with distance away from the mountain fronts. The sediment at the center of the basin tends to be silt and clay that grades into playa deposits (Riley and Worts, 1952). The soils under much of Twentynine Palms are noted for having below average infiltration rates (DWR, 1984, USDA, 1970). These factors could influence the chemical attenuation, especially of nitrate, in groundwater.

The groundwater in the Twentynine Palms area is compartmentalized into these individual subbasins so that they are more or less separated from one another by hydrologic barriers, including bedrock ridges, faults, and folds. The interconnection between the various groundwater basins is primarily controlled by faults that extend across the basin. These faults act as barriers that limit the volume of groundwater that flows into the adjacent basin. However, the volume of groundwater flow between basins is difficult to quantify. This compartmentalism of the basins influences the flow and transport of COCs in groundwater. Therefore, loading in one area does not necessarily affect the other.

Nitrate (as NO_3) concentrations in the TPWD water supply wells are generally stable and range from non-detect to 15 mg/l. Historical and current data are below the maximum contaminant level (MCL) by the CDPH is 45 mg/l for nitrate as NO_3 or 10 mg/l for nitrate as N. The exception is TPWD Well #4 that shows an increasing trend with the current nitrate concentration of 28 mg/l (Figure 3-14). Other wells in the same subbasin do not show this trend, so the trends in Well #4 maybe an isolated occurrence.

Elevated levels of nitrate found in shallow wells located at Luckie Park and the golf course (Figure 1-1) are in the vicinity of the Shortz Playa. As noted, the presence of shallow clay layers associated with buried lake deposits may inhibit vertical mixing of the septic tank effluent in the shallow groundwater. The presence of elevated nitrate concentrations in these areas may reflect localized conditions that may not represent significant impact to the regional beneficial use of groundwater in the Mesquite Lake Subbasin. Additional work is necessary to evaluate the nature and extent of the nitrates found in the Luckie Park and the golf course areas.

TDS in groundwater in the TPWD water supply wells ranges from about 100 to 350 mg/l. TDS has a secondary MCL by the CDPH of 500 mg/l. Secondary MCLs regulate contaminant levels based on aesthetics such as taste, color or odor that do not pose a risk to health. However, groundwater TDS concentrations are typically expected to increase through recharge of septic effluent (Haley and Aldrich, 2000). Similar to nitrate, TDS concentrations in the TPWD wells are generally stable. Several shallow groundwater monitoring wells in the Mesquite Lake Subbasin have significantly higher concentrations of TDS than other wells in the area. These high TDS levels are believed to occur naturally and may reflect the concentration of salts associated with buried lake deposits at these locations.

Data from measured groundwater quality suggest that under the current conditions, elevated nitrates in groundwater appear to be isolated to a localized area, but conditions in the TPWD production wells are within limits acceptable by the Basin Plan (10 mg/l as N or 45 mg/l as NO_3). The average nitrate as NO_3 concentrations for the subbasins are 6 mg/l for the Eastern, 9 mg/l for the Indian Cove, 12 mg/l for the Fortynine Palms, and non-detect for the Mesquite Lake Subbasin. The measured data suggest that with the current septic loading, the groundwater subbasins may have sufficient dilution capacity to mitigate the impact of nitrate loading from septic tanks before it reaches the deep aquifer system used as drinking water supply.

Based on the nitrate and TDS data, there does not appear to be a regional water quality issue that has impacted beneficial use because the TPWD production wells have relatively low levels. More data and analysis are necessary to define if there are locally-impacted areas and whether there are long-term issues that need to be addressed.

6.1.1 Mass Balance Model Results

The mass balance model is a simple analytical tool used for the representation of a complex regional groundwater system. Two scenarios were developed. One based on the current population of approximately 18,975, and the second based on the projected 2035 population of 30,931 based on the 2010 UWMP (Kennedy/Jenks, 2011).

In evaluating the loading rate within context of the relative size of the groundwater basins, the highest increase in nitrogen concentrations is projected in the Eastern and southern portion of the Mesquite Lake Subbasin. For the Indian Cove, Fortynine Palms and northern portion of the Mesquite Lake Subbasin, nitrogen (nitrate as N) would increase at a lower rate. Addressing each subbasin separately, the following are the overview of the mass balance model estimates with respect to nitrogen loading rates:

- For the Indian Cove Subbasin, the mass balance model projects a relatively low loading rate based on the smaller population and density in this area. This appears consistent with current nitrate concentrations in the TPWD production wells which are relatively low, so the model results are considered as representative for this subbasin.

- For the Fortynine Palms Subbasin, the mass balance model projects a relatively low loading rate based on the smaller population and the high level of groundwater pumping in this subbasin. The nitrate removal rate through the pumping wells is comparable to the septic system loading rate. The current nitrate concentrations in the TPWD production wells which are higher than other areas may reflect this condition. The groundwater pumping may be pulling the nitrate towards the wells and not allowing it to build up in the overall basin. Therefore, the model results are considered as representative for this subbasin.

- For the Eastern Subbasin, the mass balance model projects a higher loading rate based on the smaller overall aquifer volume; however, this is not reflected in current nitrate concentrations in the TPWD production wells which are relatively low, so the model results are considered as conservative for this subbasin.

- For the southern portion of the Mesquite Lake Subbasin, the mass balance model projects a higher loading rate, which is consistent with the highest population and density in this area. The mass balance model may not adequately address natural attenuation due to the thick vadose zone and losses due to outflow, so the model results are considered as conservative for this subbasin.

- For the northern portion of the Mesquite Lake Subbasin, the mass balance model projects a relatively low loading rate based on the large aquifer volume and groundwater pumping from TPWD well WTP-1 located in this area. The mass balance model may not adequately account losses due to outflow, so the model results are considered as conservative for this subbasin.

As presented as part of the model development, the model is based on numerous assumptions, because of gaps in the available data or limited data availability. The model results should be viewed in the context of the model assumptions. The model is intended to provide a preliminary assessment of the overall trends of the system and system response to changes in septic loading. After the collection of additional data, the modeling approach can be updated to better characterize the septic discharge for nitrogen, salt, and other relevant COCs from septic tanks to better understand the nature and extent of septic loading and to improve the mass loading estimates. Model estimates can be also refined with site specific septic loading rates both from residential and non-residential water use sectors.

6.1.2 Assimilative Capacity

The assimilative capacity of each groundwater subbasin is presented below based on the average nitrate (as NO3) and TDS concentrations for wells completed in the respective subbasin. The historical usage of septic tanks has in general accounted for 5 to 25 percent of the assimilative capacity for nitrate with the Mesquite Lake Subbasin having the highest available assimilative capacity and the Fortynine Palms Subbasin the lowest.

For TDS, the analysis is complicated by the high levels of naturally occurring salts especially near the playa lake deposits in the Mesquite Lake Subbasin. In general, the TDS concentrations are consistent with naturally occurring levels in the region. Therefore, the nitrate capacity is considered the stronger assessment for septic tank usage.

This analysis indicates that the subbasins have considerable assimilative capacity for handling the current septic tank usage. In accordance with the Recycled Water Policy, permitting of recycled water projects can be streamlined by demonstrating through a salt and nutrient mass balance or similar analysis that the project uses less than 10% of the available assimilative capacity (or multiple projects use less than 20% of the available assimilative capacity. Accordingly, the continued use of septic tanks in the near future considered to meet this criteria and that ongoing use will remain within the assimilative capacity of each of the subbasins for the near term. New sources of salt and nutrient loading would need to be assessed within the context of the existing septic tank loading.

TABLE 6-1
ASSIMILATIVE CAPACITY OF GROUNDWATER BASINS

Subbasin Name	Average Nitrate conc. (mg/L)	Available Nitrate Assimilative Capacity (mg/L)	Percent of Nitrate Capacity Used	Average TDS conc. (mg/L)	Available TDS Assimilative Capacity (mg/L)	Percent of TDS Capacity Used
Indian Cove	9.4	35.6	21%	148	352	30%
Fortynine Palms	11.3	33.7	25%	150	350	30%
Eastern	6.5	38.5	14%	195	305	39%
Mesquite Lake	2.5	42.5	5%	340	160	68%

Note: Average nitrate and TDS concentrations based on District monitoring and production wells, except for TDS for Mesquite Lake Subbasin where shallow wells are influenced by playa deposits and not representative of entire basin.

6.2 Comparison to Yucca Valley Case

A comprehensive USGS modeling study was conducted for the Town of Yucca Valley (Town) to evaluate the sources of high nitrate concentrations in groundwater. The USGS study started in 1997 and was completed in 2003, in coordination with the Hi-Desert Water District and the Mojave Water Agency. The study results provided substantial evidence leading to the Region 7 Basin Plan Amendment in 2011.

Comparison of the Twentynine Palms to the Yucca Valley conditions is provided below. As described further below, certain conditions are common to both the Yucca Valley and Twentynine Palms areas while there are apparent differences that would significantly affect the fate of nitrate from septic tanks, as further described below.

6.2.1 Overview of USGS Studies on Yucca Valley

In response to the regulatory concerns about groundwater contamination from septic systems, a series of comprehensive studies were conducted for the Town of Yucca Valley to evaluate the sources of high nitrate concentrations in groundwater.

As a result of the artificial recharge program that started in 1995 by Hi-Desert WD using imported water from SWP for recharging groundwater subbasins through surface spreading, water levels recovered by as much as 250 feet from 1995 to 2001. Associated with the water level recovery has been an increase in nitrate concentrations in some wells of Yucca Valley from a background level of about 10 mg/l to in excess of the USEPA MCL of 45 mg/l.

The USGS study investigated two possible conceptual models to explain how high nitrate septage reaches the water table:

1) the continued downward migration of septage through the unsaturated zone to the water table, and

2) rising water levels as a result the artificial recharge program, entraining septage in the unsaturated zone.

The observations indicated that nitrate concentrations increased in groundwater samples from wells soon after the start of the artificial recharge program in 1995 by Hi-Desert WD and the largest increase in concentrations occurred where the largest increase in water levels were. Water quality data combined with isotope data, collected after the start of the artificial recharge program, indicated that mixing occurs between imported water and native groundwater and the increase in nitrate concentrations are related to the artificial recharge program that was initiated in 1995. These findings provided the validity of the second conceptual model that rising water levels and increase in nitrate was as a result of artificial recharge. The USGS report (2003) concluded that septage from septic tanks was the primary source of the high nitrate concentrations to the groundwater system and the increase in nitrate concentrations are related to the artificial recharge that started in 1995.

The USGS study showed different lines of substantial evidence to indicate the cause for elevated nitrate concentrations in groundwater, including a simple mixing-cell model, a calibrated groundwater flow and solute transport model, measured data for nitrate as well as isotope data. A simple mixing-cell model was used to evaluate the potential nitrate concentrations resulting from a water-table rise. The USGS study also included the development of the calibrated groundwater flow and solute transport model to better understand the source and transport of nitrate in the aquifer system. Nitrate-to-chloride and nitrogen isotope data were also used to provide evidence that septage is the source of the measured increase in nitrate concentrations. Samples analyzed for caffeine and selected human pharmaceutical products also suggested that septage is reaching the water table. In addition to the observations, a high number of system failures (total of 798 from September 2002 to March 2010) both for residential and commercial sectors was shown in Yucca Valley.

6.2.2 Comparison of Twentynine Palms and Yucca Valley

For comparison, nitrogen loading from septic systems in the Yucca Valley was calculated to be 108 tons per year (ton/yr), based on the sewer flow rate of 83 gpcd, and the nitrogen concentration of 40 mg/l in septic system. Whereas the per capita sewer rate of 80 gpcd and 83 gpcd are comparable, lower nitrogen loading for the Twentynine Palms area reflects lower population (18,975 for the Twentynine Palms versus 25,500 for the Yucca Valley) and lower water use (approximately 2,550 afy for the Twentynine Palms versus 3,000 afy for the Yucca Valley). Although certain conditions are common to both the Yucca Valley and Twentynine Palms areas, there are apparent differences that would significantly affect the fate of nitrate from septic tanks. Both the communities are on septic systems and groundwater has been historically the sole source of water supply.

The current nitrogen loading from septic systems in the Twentynine Palms area is estimated to be 82 ton/yr. Historical nitrate (as NO_3) concentrations from the TPWD production wells generally remains below 10 to 15 mg/l, with an increasing trend only locally, but still within acceptable range, compared to data from Yucca Valley that showed exceeding MCL of 45 mg/l.

The nitrogen loading from septic systems is distributed over a larger area and multiple groundwater basins in the Twentynine Palms area compared to the Warren Valley Groundwater Basin for Yucca Valley that underlies a smaller area. The Warren Valley Groundwater Basin is approximately 27 square miles (DWR 2003) whereas the area of the Mesquite Lake, Indian Cove, Fortynine Palms and Eastern groundwater subbasins is about 140 square miles (DWR, 2003,. The distribution of nitrate loading over a larger area would result in lower concentrations and require more time for nitrate levels to increase. The portion of the groundwater basins overlain by TPWD is approximately 90 square miles. This is nearly ten times larger than the Town of Yucca Valley that covers about 10 square miles.

In Yucca Valley, the largest changes and increase in groundwater nitrate coincide with the areas of the artificial recharge, as described above. Unlike Yucca Valley, Twentynine Palms area does not have artificial recharge operations and has no plans to implement artificial recharge in the near future. Therefore, there is a lack of mechanism to remobilize nitrate or salt residing in the upper soil and vadose zone as a result of artificial recharge.

6.3 Recommendations

The mass balance modeling analysis is appropriate as a conservative, screening-level analysis; however, the complexity leads to inherent uncertainty because of the use of these simplifying and conservative assumptions. Additional data are needed to further refine the assumptions used for this analysis. This is consistent with the statement in the Region 7 Basin Plan which states:

> *"Establishment of numerical objectives for groundwater involves complex considerations since the quality of groundwater varies significantly with depth of well perforations, existing water levels, geology, hydrology and several other factors. Unavailability of adequate historical data compounds this problem. The Regional Board believes that detailed investigation of the groundwater basins should be conducted before establishing specific groundwater quality objectives."*

Given the need to further predict the potential impact of septic tanks on groundwater quality with respect to COCs, the recommendation of the SNMP is to propose to collect additional data to better define the groundwater conditions in the area. The availability of groundwater quality data for inflows is limited and additional data on nitrate and TDS concentrations would improve the understanding of the groundwater system. A comprehensive groundwater monitoring plan is presented in Section 7 to outline the approach for additional data collection.

In addition to collecting data, there are measures that can be taken now to help reduce loading from septic systems through improvements in administrative and operational measures. A Septic System Management Program is presented in Section 8 to outline the approach for such a program.

Section 7: SNMP Groundwater Monitoring Plan

This groundwater monitoring plan is designed as part of the Salt and Nutrient Management Plan to provide water quality data to help determine if a sewer system would be required to protect public health and water quality in the District. This may also reduce the significant hardship that residents would have to face given the prohibitive cost associated with design, financing, and constructing a sanitary sewer system.

7.1 Proposed Monitoring Plan Objectives

A recommendation for the SNMP is to conduct long-term groundwater quality monitoring to establish the spatial distribution and temporal trends of COCs, primarily nitrates and salts, by regular sampling over a number of years. From the Basin Plan water quality objectives, detailed study is needed before establishing specific groundwater quality objectives for a particular basin. Accordingly, a groundwater monitoring program will be necessary to demonstrate that the City and District intend to fully understand groundwater quality conditions and trends.

The SNMP proposes to collect groundwater quality data to evaluate if the existing septic tank systems are degrading groundwater quality in the area and quantify the nature and extent of any COCs found. The results of the proposed monitoring data and evaluation will help in making more informed decisions with respect to wastewater management, and will provide the site-specific data needed to establish the technical basis for management criteria in a Tier 2 Local Agency Management Program of the Twentynine Palms area.

7.2 General Approach

The proposed monitoring plan recognizes the time required to collect sufficient data and analysis based on scientific evidence if groundwater pollution and degradation in the area are caused by septic tanks. This monitoring plan provides an adaptive approach for data collection efforts needed to make more informed decisions on the effects of septic tanks on groundwater supply.

The monitoring locations will focus on high-density areas with potentially greater impact on potable water supply wells. Existing wells will be used for sampling when the well is known to be in good condition and sufficient information on well construction and depth of perforations is available. If adequate existing wells are not available, installation of new monitoring wells may be warranted, in key areas.

In general, groundwater conditions in the basins are stable and are not subject to significant seasonal variations. Therefore, once sufficient sampling has been conducted to establish the conditions in a well, the frequency of long-term groundwater quality monitoring should not need to account for seasonality.

Annual reports will summarize the monitoring data each year along with a brief data assessment to described groundwater conditions in each of the subbasins. The annual reports will note any issues regarding the effectiveness of the monitoring plan. Revisions to the plan will be reported to the RWQCB as needed to adequately characterize the groundwater quality conditions in the basins.

7.3 Constituents of Concern

The primary COCs related to septic system discharge are nitrate and salts which are related to sewage. Salts can be monitored as individual constituents and as total dissolved solids (TDS) and general minerals. Other COCs are included that will help identify potential septic system influences from residential and commercial/industrial areas. Wells are to be sampled for the COCs listed on Table 3-1. Below is an overview of the key COCs.

7.3.1 Nitrates

Anthropogenic groundwater nitrate sources can come from a number of sources but are typically related to agriculture and wastewater. The California Department of Public Health (CDPH) has set the maximum contaminant level (MCL) for nitrate in drinking water at 45 mg/l for nitrate as nitrate (as NO3) or 10 mg/l for nitrate as nitrogen (as N). These values are stoichiometrically equivalent. Nitrate concentrations in public drinking water supplies exceeding the MCL require water system actions to provide safe drinking water.

7.3.2 General Mineral Analysis

The general mineral analysis provides a means of characterizing the groundwater within each production zone and comparing the groundwater in each of the production zones in which a particular well is screened. The data gained in this analysis can also be used to compare wells and infer whether the study wells are producing water from the same subbasins.

7.3.3 Coliforms

Total coliform is a measurement of general coliform bacteria, the presence of which indicates that the water has had contact with plant or animal life. General coliforms are universally present and can be found in soil, animals, insects, etc. At high levels, coliforms indicate the presence of some type of waste which could include pathogens. Fecal coliforms indicate that the water has had contact with mammal or bird feces. The presence of total and fecal coliforms is an indication of human or animal waste; however, this does not conclusively indicate infiltration from septic tanks. For the purposes of this study, the presence of coliforms could indicate septic influence on the groundwater.

7.3.4 Anthropogenic Analytes

Analytes of anthropogenic origins, such as sucralose and caffeine, are not found naturally in groundwater, and their positive detection can provide strong evidence of an anthropogenic sewage source. The analytes listed are consistent with the OWTS Policy for groundwater monitoring which recommends using the Requirements for Monitoring Constituents of Emerging Concern for Recycled Water as a guideline. These analytes were selected because they are consistently present in septic samples (Oppenheimer et al, 2011), water soluble and/or do not degrade quickly in groundwater. The six analytes listed in Table 7-1 are those listed in the Monitoring Requirements for subsurface application which is consistent with septic tank discharge.

TABLE 7-1
SAMPLING AND ANALYSIS PLAN – LIST OF PARAMETERS

Analyte	Units	EPA Test Method	Typical Lab PQL
General Minerals, Cautions, and Anions:			
Boron	mg/L	200.7	0.3
Calcium	mg/L	200.7	0.3
Total Iron	mg/L	200.7	0.05
Manganese	mg/L	200.7	0.1
Magnesium	mg/L	200.7	0.2
Potassium	mg/L	200.7	0.3
Total Alkalinity	mg/L	310.1	10
Bicarbonate	mg/L	310.1	10
Carbonate	mg/L	310.1	10
Hydroxide	mg/L	310.1	10
Bromide	mg/L	300	1
Chloride	mg/L	300	50
Fluoride	mg/L	340.2	0.1
Nitrate	mg/L	300	0.1
Nitrite	mg/L	354.1	0.01
Orthophosphate	mg/L	365.2	0.2
pH	s.u.	150.1	0.01
Sodium	mg/L	200.7	1
Specific Conductivity	µmhos/cm	120.1	1
Sulfate	mg/l	300	50
TDS	mg/l	160.1	40
Total organic carbon	mg/l		
Field Sampling:			
Dissolved Oxygen	mg/L	Field Probe 1	
Temperature	F	Field Probe	
Microbiological Analysis:			
Total Coliform	MPN/100 ml	SM9223B	2
Fecal Coliform	MPN/100 ml	SM9223B	2
Anthropogenic Analytes:			
Sucralose	µg/L	Non-standard	0.01
Caffeine	µg/L	8270M/SIMS	0.01
17β-estradiol	µg/L	Non-standard	0.001
NDMA	µg/L	Non-standard	0.002
Triclosan	µg/L	Non-standard	0.05
DEET	µg/L	Non-standard	0.05

7.4 Phased Approach to Monitoring Plan

To methodically assess and potentially develop additional monitoring information, Kennedy/Jenks recommends a phased approach. This approach should optimize the use of existing District groundwater quality data, validate the opportunity to capitalize on other local groundwater production well information, and quantify the need for new monitoring wells and facilities. It will also provide an opportunity to seek grant funding for the recommended monitoring program. A discussion of the phased approach follows.

7.4.1 Phase 1 – Increasing Sampling Frequency of Existing District Production Wells

The District has collected water quality samples from the active groundwater production wells at least every three years as required by the California Department of Public Health (CDPH). These samples provide the extent of the data on water quality in the Twentynine Palms area at this time. It is recommended that the sampling frequency for the analytes listed in Table 3-1 be increased to annually for all active and inactive District owned production wells.

The District has been historically monitoring for groundwater levels and quality within the groundwater basins underlying the District service area. Table 3-2 lists the current monitoring activities from the water supply and monitoring wells. The ten water supply wells are monitored for water levels on a monthly basis and water quality at various sampling schedule. Inactive wells listed are not currently monitored.

The District currently conducts water quality monitoring from supply wells per CDPH standards which is sufficient for the purpose of tracking changes in groundwater quality in the basins. In order to provide and maintain the highest standard of healthful drinking water possible, the District employs a stringent testing schedule for all local water sources, based upon state and federal monitoring and quality regulations. This testing is conducted weekly for bacteria and fluoride, annually for radioactivity, and every three years for pesticides, minerals, inorganic substances, clarity, taste and odor. There is no known contamination in the District although there are concerns about high levels of fluoride, arsenic, and TDS in certain areas of the District, as discussed further in Section 3. Historical nitrate data from the water supply wells show no evidence of water quality exceeding the water quality objectives of the Basin Plan.

TABLE 7-2
EXISTING GROUNDWATER MONITORING BY TWENTYNINE PALMS WATER DISTRICT

Well Name	Well Type	Water Levels	Water Quality - Other Constituents	Proposed SNMP Sampling Plan
4	Active water supply	Monthly	Every 3 years	Annually
6	Active water supply	Monthly	Every 3 years	Annually
9	Active water supply	Monthly	Every 3 years	Annually
11	Active water supply	Monthly	Every 3 years	Annually
12	Active water supply	Monthly	Every 3 years	Annually
14	Active water supply	Monthly	Every 3 years	Annually
15	Active water supply	Monthly	Every 3 years	Annually
16	Active water supply	Monthly	Every 3 years	Annually
17	Active water supply	Monthly	Every 3 years; quarterly for VOCs	Annually
WTP-1	Active water supply	Monthly	Every 3 years	Annually
7	Inactive	Monthly	Not Sampled	Annually
10	Inactive	Monthly	Not Sampled	Annually

7.4.2 Phase 2 – Establishing a Water Quality Monitoring Well Network using Existing Wells

Phase 2 of the groundwater monitoring program consists of a network of monitoring wells located throughout the Twentynine Palms area with appropriate spatial distribution to be able to define the nature and extent of COCs related to septic systems discharges. The purpose is to define existing conditions and to collect long-term monitoring data to assess the potential future impacts to the beneficial use of groundwater. The objectives of the monitoring well network include the following:

- Establish background conditions for COCs. The monitoring network should include sufficient wells upgradient of Twentynine Palms to establish COC concentrations relatively unaffected by higher density septic density areas.

- Monitor COC concentrations in high-density areas. The monitoring network should include sufficient wells to establish concentrations for the high density areas.

- Define downgradient concentrations especially for high-density areas. The monitoring network should include sufficient wells to establish downgradient COC concentrations especially for the high density areas.

Each of the different groundwater subbasins should have a separate monitoring well network to establish the distribution of COCs. This should include wells from the following areas:

- Indian Cove Subbasin

- Fortynine Palms Subbasin

- Eastern Subbasin

- Mesquite Lake subbasin (including sufficient distribution to define distribution in the higher and lower density areas)

The groundwater monitoring network should preferably consist of wells that have either a sufficient well construction record or have a long-term monitoring history. Currently, groundwater level monitoring is currently performed by the United States Geological Survey (USGS) primarily associated with the Marine Base but includes several wells in the Twentynine Palms area. Figures 7-1 and 7-2 show the locations of the USGS monitored wells. Using wells with a history of groundwater level measurements is highly desirable, as measurements from these facilities provide a means to evaluate water quality in context with overall groundwater basin conditions. Of the recently monitored (within last five years) USGS wells, three are in the Indian Cove Subbasin, one is in the Fortynine Palms Subbasin, eight are in the Eastern Subbasin, nineteen are in the Mesquite Lake subbasin, and three are in the Dale Basin.

Available information indicates that more than 400 private wells have also been constructed within the District's service area. The District has located and inspected about 250 private wells. Figure 7-1 shows the locations of the inspected private wells. Most of these wells are not operated and their condition is currently unknown. It is assumed the District will assess their viability and well ownership.

It is recommended that water quality samples be collected from a representative number of these wells in the appropriate areas. Coordination with the USGS and private well owners will be required to access these wells for this study. The access issues will be addressed in a detailed Sampling Plan for this phase once the SNMP is approved for implementation.

7.4.3 Phase 3 – Installing New Monitoring Wells at Key Locations

Phase 3 consists of a more focused monitoring network located in a limited number of areas where elevated nitrates have been detected. The purpose of Phase 3 is to define the vertical extent of nitrates and how the local geology and vertical mixing within the aquifer may affect COC concentrations. It is also recommended to install a cluster of monitoring wells in key areas where elevated concentrations of COCs have been detected. The purpose of these monitoring well clusters is to provide more detailed geology, groundwater and water quality data in these areas.

This data will be used to support additional analysis of the influence of the geology and other factors on the movement and attenuation of COCs in the Twentynine Palms area. For example, the underlying geology includes former lake deposits that may form barriers to vertical flow through the vadose zone and the presence of organics and other constituents may lead to denitrification and losses that may potentially limit the transport of COCs to the groundwater. This could also create stratification within the aquifer so that COCs may be found in the shallow groundwater but not be able to reach deeper portions of the groundwater aquifer. The objective is to collect data to improve our understanding of the fate and transport of COCs through the vadose zone and groundwater aquifers.

Four areas have been identified as potentially having elevated COCs for further assessment. These include the following:

- Luckie Park is located along Utah Trail in the eastern part of Twentynine Palms. Existing shallow monitoring wells show elevated COC concentrations. This area is located near the former Shortz Playa and may have elevated naturally occurring TDS. Purpose is to evaluate vertical and horizontal mixing and possible influence of geologic layering. Two monitoring well locations are planned with one near the Luckie Park well and another about 1,000 feet downgradient.

- Saddlehorn Drive area is located along Utah Trail near the golf course. Elevated COC concentrations in a single well were attributed to poor well construction. This area is also near the former Shortz Playa. Purpose is to evaluate vertical and horizontal distribution of COCs and possible influence of geologic layering from lake deposits. A single well cluster is planned.

- TPWD Well #4 has had elevated COC concentrations relative to other TPWD wells. It is unclear if this is a regional or well specific issue. Purpose is to evaluate vertical and horizontal distribution of COCs near Well #4. A single well cluster is planned.

- The high-density residential area located near 2 Mile Road and Mesquite Springs Road is located in an area of thick vadose zone and potentially thin saturated interval of alluvial sediments. Purpose is to evaluate the potential for attenuation of COCs in these areas. Two monitoring well locations are needed, one near the edge of the residential area and a second about 1,000 feet downgradient.

Monitoring will require one or more wells at each of the targeted areas. An initial deep pilot borehole will be drilled that will be geologically logged by a California licensed geologist and have a suite of borehole geophysical logs run to provide detailed geologic data for each of these locations. Based on this information, the number of potential monitoring wells in the cluster at each location will be determined. A downgradient monitoring well cluster will be added as appropriate. Downgradient locations are anticipated for the Luckie Park and the 2 Mile Road and Mesquite Springs Road locations. The monitoring wells will be constructed in a manner consistent with obtaining regular high-quality water quality data. A detailed Sampling Plan for this phase will be developed once the SNMP is approved for implementation.

7.4.4 Phase 4 – Conducting a One-Time Existing Conditions Sampling Event

Collecting a one-time sample for COCs from as many existing domestic wells as possible will require coordination and outreach to local property owners to obtain water quality samples.

It is recommended that a single event sampling program be conducted that will obtain data from a large number of private wells from various parts of the study area to establish what is the areal extent of COCs and potential impact to beneficial uses. The purpose of this is to collect a one-time sample for COCs from as many existing domestic wells as possible to establish the areal extent of COCs and assess the potential impact to beneficial uses.

This will require coordination and outreach to local property owners to obtain water quality samples. It is requested that the District facilitate the procurement of these data, based on local knowledge and receptivity of private land owners to allow their wells to be inspected and sampled for water quality.

In addition, this outreach program would provide a mechanism to evaluate the condition and well construction of existing wells. This provides a means to evaluate whether wells are acting as vertical conduits that may allow septage to flow down the well annulus due to poor well construction, causing areas of locally high nitrate and TDS concentrations.

Well construction of older existing wells may provide a conduit for septic tank effluent to reach the groundwater by flowing down the well rather than percolating through the unsaturated zone, which is up to 300 feet thick in much of the Twentynine Palms area. Therefore, a component of a SNMP will be to identify older wells that may pose a risk of being a vertical conduit and should be considered for destruction in the future.

7.5 Reporting

The various phases of the SNMP will be documented in concise technical reports. The reports will succinctly present the project findings as well as recommended actions for the Salt and Nutrient Management Plan. TPWD will maintain an electronic library of data and reports.

7.5.1 Sampling and Analysis Plan

After the SNMP has been reviewed and approved by the RWQCB, a Sampling and Analysis Plan will be developed prior to collecting water quality samples that will provide specific details on sampling procedures and methods for documentation. The Sampling and Analysis Plan will also be reviewed and approved by RWQCB prior to conducting field sampling.

The Sampling and Analysis plan will identify the final wells that will be sampled for each of the proposed phases of sampling. The final list of parameters will be identified along with the proper analytical technique to incorporate any updates from the RWQCB review of the SNMP.

The overall field procedures will be defined for each of the proposed phases of sampling. Production wells can be sampled following existing protocols that TPWD uses for collecting

CDPH samples. Samples from monitoring wells or unused production or domestic wells will be done in accordance with the Standard Operating Guidelines for Groundwater Sampling. Typically, groundwater will be purged from the monitoring wells prior to sampling to obtain samples representative of aquifer conditions. Field parameters pH, temperature, and electrical conductivity will be measured and recorded during purging to document stabilization. Purge water from the sampled wells will either be distributed on the ground at the well site or transported to the evaporation ponds for disposal. The plan will describe quality assurance/quality control (QA/QC) on sample collection and analysis. QA/QC is described is described in more detail below.

7.5.2 Groundwater Quality Sampling Report

An interim technical memorandum will be provided after each sampling event to document the field sampling activities. This will be a concise report to document field procedures performed during the event, provide field data sheets to verify stabilization parameters and other key sampling parameters, and provide the laboratory results.

7.5.3 Annual Report

This task includes preparation of a draft technical report to document the work completed. The report will also include consolidated findings and any recommended actions in response to the water quality risk assessment.

7.5.4 Groundwater Review

After sufficient new data are collected, a comprehensive groundwater study will be conducted to evaluate the findings from the monitoring program. This would include more detailed hydrogeological evaluation and modeling to assess the potential impacts of COCs on the beneficial use of groundwater in the Twentynine Palms area. TPWD will maintain an electronic library of the report, mapping, shape-files and groundwater model data input and output sets for use by interested parties moving forward.

7.6 Quality Assurance

Quality assurance and quality control is a required element of each technical team's scope of work. Several project requirements are identified below regarding the proposed scope of work in order to assure that the project is technically sound, thoroughly reviewed and of a high quality prior to proceeding with each phase and prior to distribution for stakeholder review.

Field QA/QC will include collection of one field duplicate sample during the first sampling event. The results of the duplicate sample will be compared to the primary sample for consistency. The laboratory will follow their standard internal QA/QC procedures during sample analysis, including elements such as analyzing method blanks and control spikes where appropriate.

Groundwater samples will be collected into containers provided by a state-certified laboratory, labeled, kept in a chilled cooler, and delivered to the laboratory under chain-of-custody procedures. The laboratory will follow their normal turnaround time and internal quality assurance/quality control (QA/QC) procedures during the analysis.

An interim technical memorandum will be provided after each sampling event to document the field sampling activities. This will be a concise report to document field procedures performed during the event, provide field data sheets to verify stabilization parameters and other key sampling parameters, and provide the laboratory results.

Each document and deliverable produced will be reviewed by a technical reviewer to ensure adequate analyses have been completed. In addition, the TPWD project manager and the consultant will coordinate and communicate regularly during the entire project to ensure that the data included in the modeling component reflects the known information about the project area, including water quality, demands and supplies.

7.7 Peer Review

The TPWD staff and interested participating stakeholders will be involved at key milestones as the project proceeds including both public meetings and stakeholder workshops. This effort will provide for a broad level of peer review and stakeholder input improving the overall quality of the concepts, assumptions, findings and ultimately the conclusions of this project.

Section 8: Septic System Management Program

This section outlines recommendations for implementation of a Septic System Management Program to provide measures to manage septic systems in the Twentynine Palms area to protect groundwater quality. The Program described below is considered an initial approach recommendation. The objective for the SNMP is to outline the various elements for the Program. Once a Program is approved, it is anticipated that a more detailed plan will be developed for the implementation of each of the various measures.

8.1 Overview

Implementation of the Septic System Management Program, including measures for proper operation, monitoring, and maintenance of septic systems, can reduce the COC loading from septic systems. If properly implemented, the management program can provide a means to identify and address key issues for maintaining groundwater quality allowing for the long-term, sustainable use of groundwater for beneficial uses.

If proven to be successful, the Septic System Management Program can reduce the financial hardship to local residents who would have to face the relatively significant cost associated with designing, financing, and constructing a sanitary sewer system for the Twentynine Palms area. Therefore, it is recommended that the District and City adopt a Septic System Management Program in the context of the SNMP to properly manage septic tanks and protect groundwater quality.

The recommended Septic System Management Program is composed of a number of Septic System Management Elements (SSMEs). The SSMEs include administrative and operational measures to provide mechanisms to properly manage septic tanks and protect groundwater quality. The SSMEs also include a series of site-specific studies to collect additional data to better understand the composition of septic effluent and evaluate the fate of effluent as it is released into the natural system. The effectiveness of the SSMEs will be reviewed by the City and District to provide a mechanism to assess the implementation of the Program to ensure that the SSMEs are properly implemented.

The Septic System Management Program provides interim actions that can be initiated immediately as Twentynine Palms begins the process to assess the viability of development a Local Agency Management Program under Tier 2 of the OWTS Policy. The actions of the SSMEs are consistent with the OWTS Policy for promoting proper usage of OWTS to protect water quality and public health. Data collected as Site-Specific Studies will be used develop appropriate management criteria for Twentynine Palms.

The following provides a description of the recommended SSMEs for implementation as part of the SNMP. The following SSMEs describe practical techniques, including both administrative and operational measures, designed to reduce the loading from septic tanks to groundwater.

8.2 Administrative Elements

The administrative elements provide mechanisms for the City and District to promote planning, funding, and public involvement in reducing loading from septic tanks to groundwater.

8.2.1 SSME #1 – Implement a Public Outreach Program

The City and District will establish an ongoing public outreach program to raise public awareness of the seriousness of the environmental and financial consequences of the septic tank issue and to educate the public on the merits of proper septic system conditions, practices, and maintenance. The goal is to increase public understanding of the septic tank issue that will lead to public participation in private septic tank maintenance and overall waste reduction. The primary themes of the Program should consist of the followings:

- Develop an understanding of the interaction between where our drinking water comes from and where our septic tank effluent goes.
- Take a more proactive stance on overseeing that waste disposal systems are properly installed and maintained.
- Provide information for the public on how they can properly maintain and reduce the volume of waste.

A number of mechanisms can help accomplish these, including direct mailing, signs, web pages, and presentations to community groups and schools. The Program should provide information for the public on how it can be accomplished. The City and/or District should designate personnel to coordinate and promote the Program and provide that personnel with the administrative and financial support necessary to conduct the Program. The Program should also include direct contact with commercial and industrial users who generate large volumes of effluent and may have special waste handling needs.

8.2.2 SSME #2 – Promote Indoor Water Use Reduction to Septic Systems

Water conservation can reduce total in-house water use which will result in a reduction in the amount of effluent discharged from septic tanks. The City and District will continue to focus on water conservation measures including retrofitting the existing and new development with high-efficiency, low-volume plumbing fixtures. The City and/or District may consider financial incentives with grant funding for residents to promote conversion to high-efficiency, low-volume plumbing fixtures. The Public Outreach Program (SSME #1) can be used to promote financial incentives and provide residents with information on how to implement these measures.

8.2.3 SSME #3 – Promote Waste Reduction to Septic Systems

Septic tanks are designed for handling sewage; public awareness should be increased on what not to put down the drain that leads to the septic tank. The use of garbage disposals can double the amount of solids added to the septic tank (Miller, 2007). Items including cooking greases, oils, and fats can harden in the septic tank and reduce its efficiency. The result of increased waste loading is a decrease in septic tank efficiency that results in increased nitrate concentrations in the effluent discharged from the septic tank into the natural system.

As part of the Public Outreach Program, the City and/or District will provide printed materials to home owners to encourage limiting or eliminating the use of garbage disposals. The printed materials should also include information on other chemicals that should not be put down drain that leads to the septic tank, such as medicines, pesticides, paints, paint thinners, solvents, disinfectants, poisons, and other household chemicals (Hoover and Konsler, 2004).

Special consideration should be given to commercial and industrial users and their septic systems that may generate large volumes of effluent. The Program should identify special waste handling needs of these user categories to understand key issues related to septic tank management and operation and work collaboratively to reduce waste loading.

Administrative measures that the City and/or District may consider to promote waste reduction to septic tanks may include:

- Explore financial incentives for removing garbage disposals and potential requirements for not including garbage disposals in new developments with septic tanks.

- Promote waste disposal options for disposal of food waste. This may include coordination with the local sanitary waste hauler to include a "green can" option for food waste, outreach/education on composting and the consequences of fats, oils and greases to septic systems.

- Provide residents with readily available options for disposing of medicinal and hazardous waste rather than pouring them down a drain that leads into a septic tank.

8.2.4 SSME #4 – Update the Existing Groundwater Management Plan

The District will update the current Groundwater Management Plan for the Twentynine Palms area. With respect to the SNMP, the update will focus on updating water quality monitoring procedures and include basin management objectives (BMOs) to provide a mechanism for long-term groundwater quality for maintaining sustainable beneficial uses of groundwater. The plan update should include an updated hydrologic water balance to account for the current septic system loading data based on the analysis conducted as part of this SNMP. The basin-wide MODFLOW groundwater model should be updated to include updated geologic and hydrologic balance data to keep it current as a quantitative tool that can support the groundwater management activities.

8.2.5 SSME #5 – Apply for Grants to Provide Financial Assistance to Low-Income Households to Remove Health and Safety Hazards

A limitation for the implementation of maintenance and upgrade of septic systems is the cost. This is especially true for low-income residences and small business interests. State and federal loans and grants are available to provide financial assistance to low-income homeowners to repair, improve, or modernize their dwellings or to remove health and safety hazards. The City and/or District should investigate the types of grant and funding programs available to determine which ones will be useful for Twentynine Palms. The information should be disseminated through the Public Outreach Program to promote the use of this financial assistance. The objective is to help residents and businesses in Twentynine Palms upgrade septic tank systems to support groundwater protection.

8.3 Operational Elements

The operational elements focus on actions that can be taken by the City and District to improve septic tank performance and limit potential impacts to groundwater quality.

8.3.1 SSME #6 – Provide Regular Inspection, Maintenance, and Septic Waste Hauling

The objective of this SSME is to establish inspection and maintenance of septic systems on a regular basis. Properly managed onsite treatment systems can be a cost-effective and long-term option for protecting public health and water quality goals, particularly for small towns and rural areas with low housing density. The District and City will prepare educational materials to assist home owners in monitoring their systems. Printed materials will be mailed out to home owners to inform them about the importance of regular septic waste removal and also to remind them that inspection, maintenance, and septic waste removal is critical for their systems. This SSME is most effective when used as part of the Public Outreach Program (SSME #1).

Proper installation and maintenance of septic systems will maximize the system's usefulness by preventing failures and reducing the risk of contaminating the water supply. Increasing the load of solids into the tank decreases the capacity and shortens the interval requiring maintenance. Regular inspection and maintenance of septic systems is necessary as there is potential for system failure given that as many as 75 percent of all system failures have been attributed to hydraulic overloading (Jarrett et al., 1985). Septic tanks generally need to be pumped every two to five years, depending on use. If the tank gets too full, particles of scum or sludge will flush out of the tank. This material will clog the drain tiles and cause the septic system to fail (Miller, 2007; Hoover and Konsler, 2004; Mancl and Slater, 2001). Septic tanks may work without regular scheduled pumping; however, failure to remove sludge periodically will result in reduced tank settling capacity and eventual overloading of the soil absorption system, which is more expensive to remedy and causes service disruption. For instance, replacing a disposal field could cost thousands of dollars.

The frequency of septic waste pumping depends on three variables: the size of the tank, the volume of wastewater, and the solids content of wastewater. In general, the tank should be pumped if the sludge layer has built up to within 25 to 33 percent of the liquid capacity of the tank. For example, a typical 1,000 gallon tank with a 4-foot liquid capacity should be pumped when the solids are 1-foot thick in the bottom of the tank. Table 8-1 provides general frequency guidelines for septic tank pumping (Mancl, 1984; Mancl and Slater, 2001).

TABLE 8-1
ESTIMATED SEPTIC TANK INSPECTION AND PUMPING FREQUENCY IN YEARS

Tank Size (gallons)	Number of People Using the System				
	1	**2**	**4**	**6**	**8**
500	6	3	1	<1	<1
750	9	4	2	1	<1
1,000	12	6	3	2	1
1,250	16	8	3	2	1
1,500	19	9	4	3	2
2,000	25	12	6	4	3
2,500	32	16	7	5	4

Note: More frequent pumping needed if garbage disposal is used.

8.3.2 SSME #7 – Develop Local Tracking of Septic Systems

A tracking system is recommended to provide the City and/or District a mechanism to collect data on the current condition of septic tanks in the area and to track maintenance and upgrades over time. There are currently records of septage removal from tanks in the Twentynine Palms area. With the implementation of this Program, septage removal records will be maintained on a regular basis. The City and/or District should review current practices adopted by other cities and counties within California for permitting and monitoring septic tank conditions of new systems beyond the required percolation test.

It is recommended that the City and/or District include reporting of inspection, maintenance and waste hauling of septic tanks in the tracking system. The reporting should be tracked in a database that captures the relevant information. The objective is to get complete participation to gain information on conditions of the septic tank systems in the area and track progress on maintenance and upgrades. The process should be made simple and little to no cost should be tied to the reporting to encourage residents and businesses participation. The merits of the tracking systems should be promoted as part of the Public Outreach Program.

As part of the Public Outreach Program, a public meeting should be held, an information packet and voluntary questionnaire will be prepared and mailed out in the service area to develop an inventory of the existing septic systems with information on septic tank pumping schedule, replacement of existing septic systems, construction of new septic systems, and any signs or occurrences of septic system failures. Information collected will be reviewed and reported in the context of groundwater monitoring program proposed in the SNMP.

8.3.3 SSME #8 – Promote Upgrade or Replacement of Failing Septic Systems

Replacement of old, inadequate systems and repair of failing ones is an integral part of an onsite wastewater management program. Just like the house roof, driveway, and furnace, septic systems require upgrades and possibly replacement. Upgrading a properly designed and installed septic system is expected to occur every 20 to 30 years (Mancl and Slater, 2001). Common repairs include refitting the onsite system with new inflows and outlets, creating an alternative drainfield, or the use of other alternative technologies. Replacement of the entire system may be required where the original one was inadequate, improperly constructed or installed, or where the system does not respond to corrective measures. Standards have changed and research has developed new and better approaches to treating sewage onsite to protect the health of the residents, the community, and the environment. While some older systems may have met standards when they were installed, upgrades and replacements will take advantage of recent advances to improve wastewater treatment (Mancl and Slater, 2001).

Upgrading or replacement is more effective when used as part of a SSME system which involves public outreach as well as mitigating SSMEs such as inspection and maintenance. The Public Outreach Program will need to include educational information on the benefits to the homeowner as well as the groundwater supply of upgrading or replacing a failing septic system. The District and City can further promote and facilitate remedial measures on an ongoing basis by seeking grants to provide technical assistance to home owners, including financial assistance to low income households for performing the necessary repairs.

8.3.4 SSME #9 – Identify High-Volume Locations to Implement Advanced Treatment

The RWQCB Region 7 Basin Plan includes the policy adopted in 1989 that a minimum lot size of one-half acre (average gross) per dwelling unit is required for new developments in the region to use on-site septic tank systems. Developments with less than one-half acre (average gross) per dwelling unit are expected to implement a more advanced wastewater treatment method. The City is applying this policy for new developments. A permit is required for all new construction and replacement of septic tanks.

Even when functioning properly, septic systems only remove a portion of the nitrogen. Therefore, it is recommended that existing locations where a high volume of wastewater is generated be evaluated for the practicality and the benefit to groundwater quality by retrofitting or replacing an existing septic system with an advanced treatment system that will provide more effective nitrogen removal. Systems such as sand filters have been shown to remove over 50 percent of the total nitrogen from septic tank effluent (USEPA, 1993). Nitrogen may be removed from septic tanks and leach fields through denitrification before it is transported to groundwater. Each site should be assessed individually with respect to the volume and general content of the wastewater generated and any potential threat to beneficial use based on the sites' location with the groundwater basin.

This objective of this SSME is to establish a practical long-term solution to upgrade wastewater treatment systems for the larger or high volume waste producers as a method to limit the overall loading of COCs from septic systems to the groundwater. By redesigning and replacing part or all of it, the construction and maintenance costs of onsite/decentralized systems can be significantly lowered, making them an attractive alternative. Onsite/decentralized systems can protect public health and the environment and can lower capital and maintenance costs in low-density communities.

8.3.5 SSME #10 – Promote Proper Abandoned Well Destruction

The objective of this SSME is to reduce the potential for vertical conduits in the basin by identifying abandoned wells and properly abandoning them to reduce the potential threat to groundwater. Older wells may have been installed with improper surface sanitary seals or have degraded such that they provide a vertical conduit that has the potential to allow septic system effluent to bypass transport through the vadose zone and quickly reach the groundwater.

The District will help to identify abandoned wells that are located in critical areas with respect to water quality. A key element of this SSME will be incorporated into the Public Outreach Program to alert people to the presence and dangers of abandoned wells, and to publicize the AWDP to identify and inventory old wells. The District will provide local well owners with information on how to obtain the proper well destruction permits from San Bernardino County and provide a list of licensed contractors in the area who have the appropriate state contractor license to provide this service. To help facilitate implementation property owners may be provided cost-share assistance from outside funding sources to properly destroy wells to assure they no longer pose a danger to drinking water quality or serve as conduits for potential contamination.

8.4 Site-Specific Studies

Performance based approaches generally depend heavily on data from research, wastewater characterization processes, site specific evaluations, and expected operation and maintenance activities. Careful monitoring of septic system performance is strongly recommended as it is an integral part of the administrative measures.

As stated in the Basin Plan, a detailed study is needed before establishing specific groundwater quality objectives for a particular basin. The specific quotation from the Basin Plan that forms the regulatory driver for this study is provided below:

> *"Establishment of numerical objectives for groundwater involves complex considerations since the quality of groundwater varies significantly with depth of well perforations, existing water levels, geology, hydrology and several other factors. Unavailability of adequate historical data compounds this problem. The Regional Board believes that detailed investigation of the groundwater basins should be conducted before establishing specific groundwater quality objectives."*

The objective of the following SSMEs is to develop and conduct a series of site specific studies to gather site data and fill in data gaps for future evaluation of potential impacts from septic tanks. Site specific evaluations are becoming more refined and comprehensive in the assessment of potential impacts from septic tanks. Special studies include from a simple mass loading analysis to a more comprehensive analysis of soils and vadose zone, groundwater quality analysis, and numerical modeling of flow and fate and transport of pollutants, e.g., nitrate as an example. Site specific studies are critical in determining the potential impacts from septic tanks, as described below in detail.

8.4.1 SSME #11 – Implement Long-Term Groundwater Monitoring Program

The SNMP monitoring program described in Section 7 is designed to obtain better water quality data in the Twentynine Palms area to improve our understanding the nature and extent of the loading of COC concentrations, primarily nitrates and salts, in groundwater. The groundwater monitoring program is presented in this report to establish a long-term groundwater monitoring network to define both the spatial distribution of COCs in the area, and track the long-term temporal trends by sampling over a number of years. This groundwater monitoring plan is designed to provide water quality data to evaluate the potential impacts to groundwater from septic system use in the Twentynine Palms area and use the data to make management decisions regarding the septic tank usage.

8.4.2 SSME #12 – Conduct a COC Attenuation Study

The objective of this SSME is to improve our understanding of the fate and transport of COCs through the vadose zone and groundwater aquifers to better manage groundwater quality. The SNMP monitoring program will provide the majority of the data needed for the COC Attenuation Study (See Section 7). One important objective of this study is to determine the allowable housing density for new subdivisions specific to Twentynine Palms. A work plan will be prepared to develop a site-specific plan on the type of instrumentation and methodology to be applied.

The vadose zone provides potential for denitrification and other reactions to occur. The thickness of the unsaturated soil above the water table (i.e., vadose zone) ranges from 100 to 400 feet thick across the Twentynine Palms area. The underlying geology includes former lake deposits that may form barriers to vertical flow through the vadose zone and the presence of organics and other constituents may lead to denitrification and losses that may potentially limit the transport of COCs to the groundwater. This could also create stratification within the aquifer so that COCs may be found in the shallow groundwater but not be able to reach deeper portions of the groundwater aquifer.

8.4.3 SSME #13 – Perform a Septic Discharge Characterization Study

The objective of this study is to obtain better site specific data characterizing the septic systems in the Twentynine Palms area to improve our understanding the nature and extent of the loading of COCs to better characterize septic system loading for the Twentynine Palms area. Assumptions used for the mass loading estimates in this report are based on literature values or based on data from outside of the area. Some of the types of data to be collected for the Septic Discharge Characterization Study include:

- Characterization of nitrogen, salts and other relevant COCs from septic tanks in Twentynine Palms to obtain site-specific data of local septic effluent concentrations.

- Characterization of household, commercial, and institutional water usage to determine the volume of water discharging to the septic versus outdoor or other losses to develop more reliable water to sewer ratios for estimating septic loading.

- Determine occupancy levels specific to groundwater subbasins, particularly the southern portion of the Mesquite Lake Subbasin for better estimating septic loading.

It is anticipated that this study would be done in conjunction with SSME #6 – Provide Regular Inspection, Maintenance, and Septic Waste Hauling. The first step for this SSME is to develop a detailed work plan to lay out the approach and methodologies to be used. The general approach is to obtain samples from septic systems of various land use types (single family residential, multi-family residential, commercial, etc.), age, and locations, to characterize the volume of septic system discharge generated and the concentrations of COCs. Based on this data, an assessment of the historical loading rates can be determined.

8.4.4 SSME #14 – Comprehensive Assessment of Septic System Impacts to Groundwater

This site-specific study consists of updating the recent groundwater study and MODFLOW model of the Twentynine Palms area to address water quality issues primarily associated with septic system discharge to the basin. The collection of additional monitoring data and the results from the preceding site-specific studies will provide new data to improve the conceptual understanding of septic loading to the basin. The MODFLOW model should be upgraded to include a transport model to simulate the fate and transport of COCs, in particular nitrate, through the groundwater aquifer. The results of the updated groundwater study and model update would be to evaluate the potential impacts of septic system discharge to the beneficial uses of groundwater in the basin (municipal and private water supply). The results of the comprehensive assessment will be documented in a report that will be presented to the City and District and shared with local and regulatory stakeholders.

The Comprehensive Assessment of Septic System Impacts to Groundwater should be conducted after the implementation of the SNMP and the Septic System Management Program. This assessment should be conducted after sufficient time is provided to collect new data from the implementation of the SNMP and evaluate the results.

8.5 SSME Program Review

A successful program should include a review process to verify that progress is made and to evaluate and modify the program as necessary based on lessons learned or new information. The following SSMEs outline a general program review process.

8.5.1 SSME #15 – Annual Progress Report of Septic System Management Program

It is recommended that an annual report be developed that documents any activities of the previous year and summarizes the data collected. The annual report should be written in the style of a management review rather than a technical report. The technical report is recommended periodically and is outlined in the following SSME. The report should be presented and discussed at the appropriate board or committee meeting for both the City and District.

8.5.2 SSME #16 – Updated Groundwater Assessment

The Updated Groundwater Assessment is a technical report that compiles the data collected under the SNMP and the Septic System Management Program. After sufficient new data are collected, an updated groundwater assessment will be conducted to evaluate the findings from the monitoring program. The emphasis is to evaluate the water quality conditions in the groundwater basins.

The first Groundwater Assessment will be SSME#14 and subsequent updates to the Comprehensive Assessment of Septic System Impacts to Groundwater will be more cost-efficient and avoid repeating previously reported information. In this manner, the updates will build upon each other. The Updated Groundwater Assessment would include new evaluation of hydrogeological data and modeling to assess the potential future impacts of COCs on the beneficial use of groundwater in the Twentynine Palms area. This report is anticipated to provide the technical evaluation for making informed management decisions. The City and/or District will maintain an electronic library of the report including monitoring databases, mapping, shape-files and groundwater model data input and output sets for use by interested parties.

8.5.3 SSME #17 – Periodic Program Review and Update

The proposed SSMEs are based on our current understanding and currently available data. As new data are acquired, modifications to the SSMEs may be necessary. It is recommended that the Program should include a review of progress on SSMEs and to make changes in the future that take further actions to reduce risks and specify management measures, reducing the likelihood of drinking water contamination from septic systems. Information collected through the implementation of the SSMEs will be used in the assessments to develop plans to protect wellhead recharge areas and groundwater as drinking water supply. Improving the performance and management of onsite septic systems can be an important component of source water protection.

Section 9: Conclusions

The purpose of the SNMP is to develop a strategy for the City and District to monitor and protect the groundwater resources in the Twentynine Palms area in response to an increased need to assess groundwater quality impacts from septic tanks. This report presents a guide for the development of a groundwater monitoring program to collect water quality data that can be evaluated to support informed decisions on wastewater management that protect the beneficial uses of the groundwater resources.

9.1 Summary

The City of Twentynine Palms overlies a large alluvial basin that is subdivided into a number of groundwater basins and subbasins due to faulting, making for a complex area geology. The Joshua Tree groundwater basin is divided into the Indian Cove, Fortynine Palms and Eastern Subbasins. Groundwater is compartmentalized due to the complex geology in these individual subbasins in that they are more or less separated from one another by hydrologic barriers, including bedrock ridges, faults, and folds. The degree of separation between these subbasins is dependent upon the character of the barriers separating them.

Nitrate (as NO_3) concentrations in the TPWD water supply wells range from non-detect to 28 mg/l for nitrate and 100 to 350 mg/l for TDS, all of which are below the nitrate and TDS MCL. In general, nitrate and TDS concentrations in the TPWD wells are stable, expect for Well #4 which shows a clear increasing trend with the current nitrate concentration of 28 mg/l (Figure 3-14). District staff has identified this facility as an old well, has scheduled it for abandonment, and suggests this increasing trend may be attributed to vertical conduits. Also, high TDS concentrations in shallow groundwater monitoring wells in the Mesquite Lake Subbasin may reflect the concentration of salts associated with buried lake deposits at this location.

A simplified mixed-cell model was developed to provide a preliminary estimate of the septic loading to the various groundwater subbasins. Among the five subbasins, the results of the mixing cell models indicate that the southern Mesquite and Eastern Subbasin may ultimately have potential long-term nitrate issues whereas the Indian Cove, Fortynine Palms northern Mesquite and Dale Subbasins do not appear to have potential long-term nitrate issues.

The results of the sensitivity analysis indicate that the use of mass conservative assumptions in developing and applying the mixed-cell model may cause the models to overestimate nitrate concentrations in the subbasins. These results highlight the need for future data collection and additional study once this new data is available. Given the limited site specific data required for the model calibration, the current model estimates of nitrogen concentration in the groundwater are preliminary and considered inconclusive.

9.2 Recommendations

The regulatory driver for this analysis is the Region 7 Basin Plan which states that ideally the RWQCB's goal is to maintain the existing water quality of all non-degraded groundwater basins. However, the RWQCB's objective is to minimize the quantities of contaminants reaching any groundwater basin by establishing management practices. As stated in the Basin Plan, a detailed study is needed before establishing specific groundwater quality objectives for a particular basin.

Since the current nitrate concentrations in the TPWD production wells show relatively stable concentrations, there does not appear to be a short-term limitation on the beneficial use of groundwater because of nitrate concentrations that exceed the MCL. Therefore, the recommended action is to implement measures to improve the overall monitoring of the groundwater and to implement a Septic System Management Program to limit the potential impacts to groundwater, possibly leading to the development of a Tier 2 Local Agency Management Program for Twentynine Palms.

The recommendation includes a long-term groundwater quality monitoring program that will establish a monitoring well network to define the spatial distribution and temporal trends of COCs, primarily nitrates and salts, by regular sampling over a number of years. This monitoring data are necessary to fully understand groundwater quality conditions and trends to make informed management decisions regarding the use of septic tanks in the Twentynine Palms area and for developing site-specific criteria for Twentynine Palms for a possible Tier 2 Local Agency Management Program.

It is also recommended that the District and City adopt a Septic System Management Program to properly manage septic tanks by limiting loading rates as part of an integrated effort to protect groundwater quality. The elements of this Program are designed to provide mechanisms to reduce loading of COCs at the source before entering the groundwater system. The Septic System Management Program is a precursor of a Local Agency Management Program to potentially be developed for Twentynine Palms under Tier 2 of the OWTS Policy. The actions of the SSMEs are consistent with the OWTS Policy for promoting proper usage of septic systems to protect water quality and public health. Data collected as Site-Specific Studies will be used to develop appropriate management criteria for Twentynine Palms and a Local Agency Management Program. Any later approved Local Agency Management Program would supersede the Septic System Management Program.

The various phases of the SNMP will be documented in annual reports that will be provided to the RWQCB. The process will include a Public Outreach Program component so that participating stakeholders will be involved at key milestones as the Program proceeds with both public meetings and stakeholder workshops. This effort will provide for a broad level of peer review and stakeholder input improving the overall quality of the concepts, assumptions, findings and ultimately the conclusions.

After sufficient new data are collected from the monitoring and implementation of the Septic System Management Program, a comprehensive assessment should be conducted to evaluate the impacts of septic systems on the groundwater. Based on this evaluation, an assessment on the future policy regarding septic systems in the Twentynine Palms area can be established.

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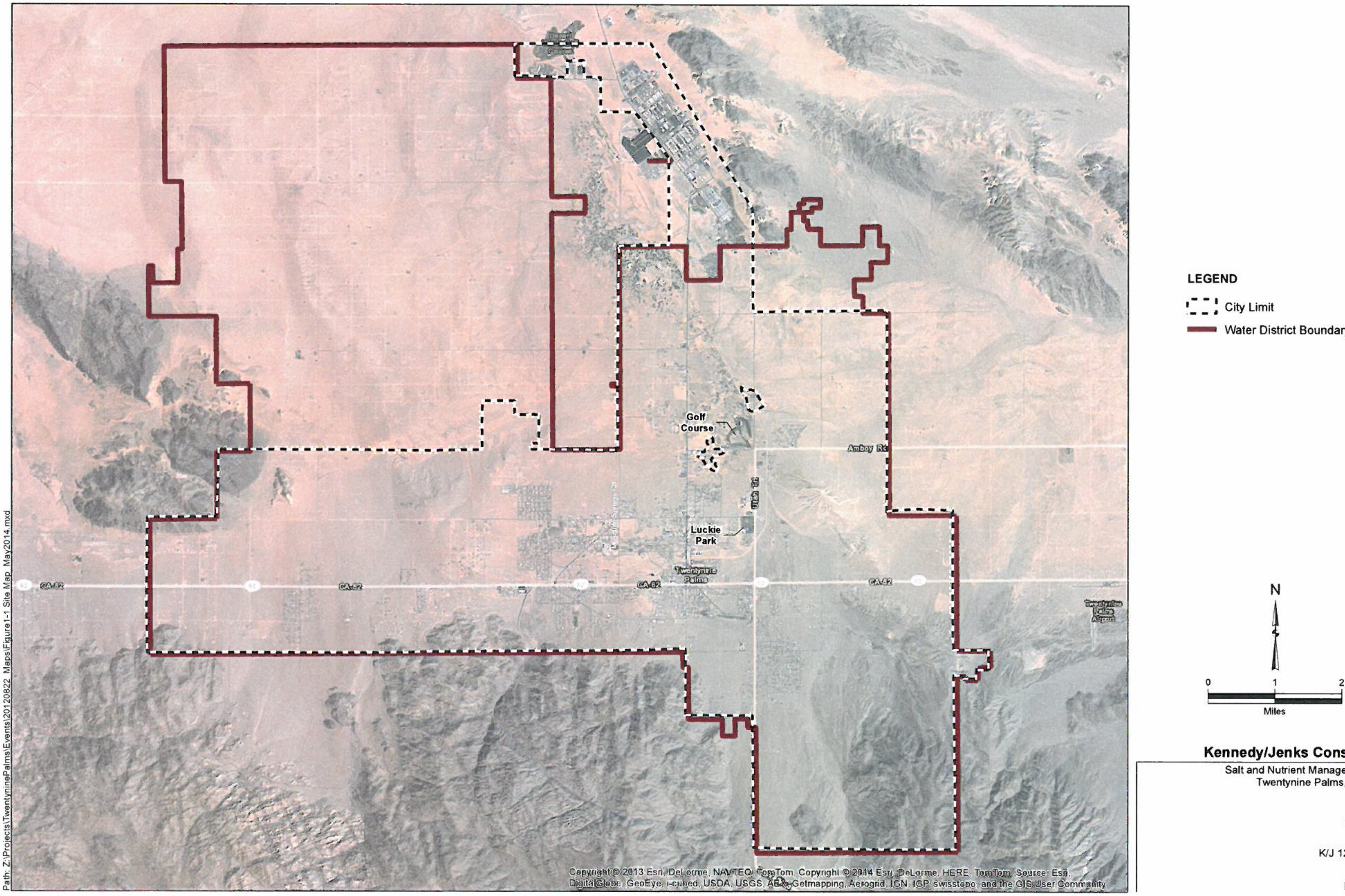
Figures



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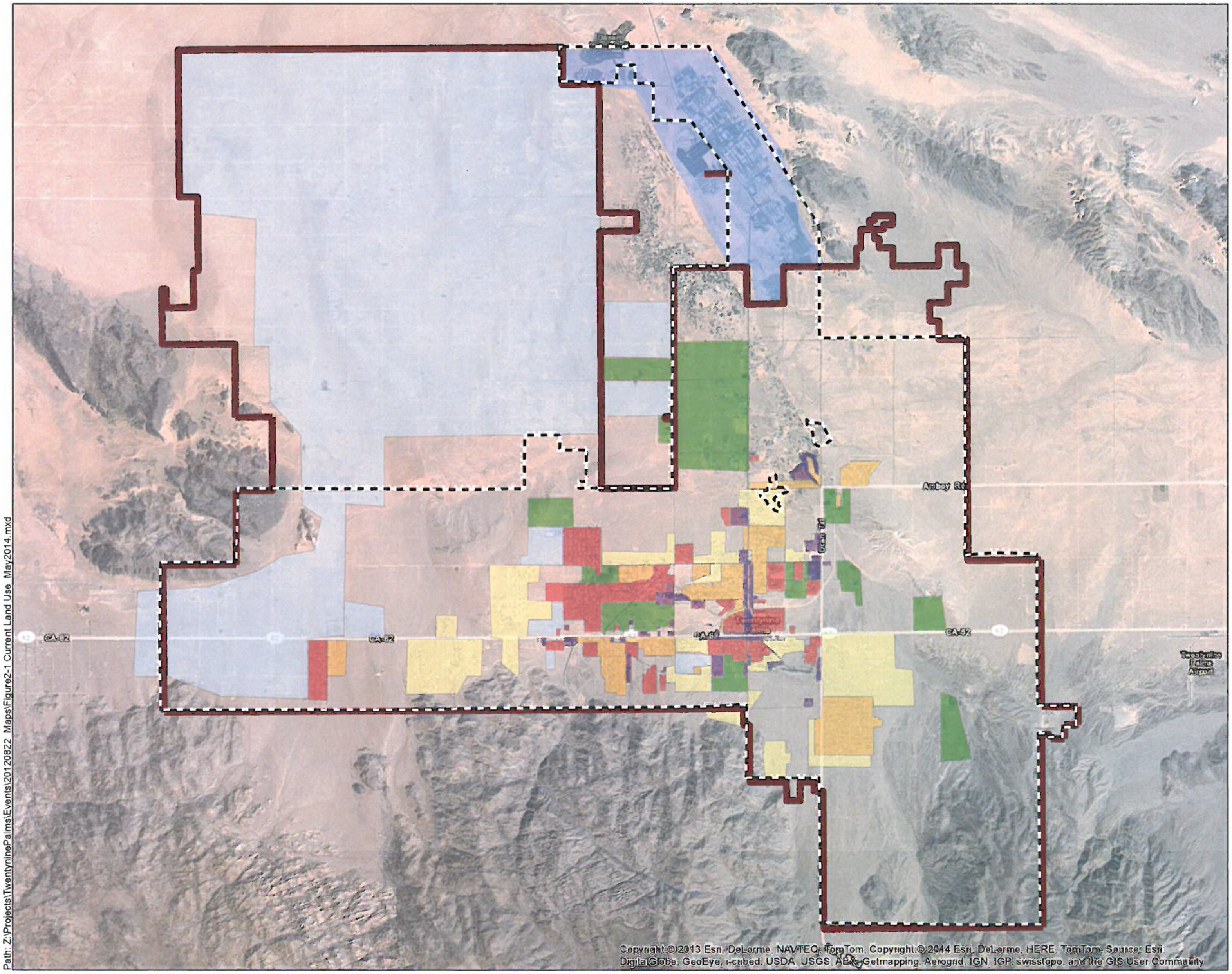
Salt and Nutrient Management Plan
Twentynine Palms, California

Site Map

K/J 1283001*00
June 2014

Figure 1-1



LEGEND

City Limit

Water District Boundary

Current Land Use

Zone A

Zone B

Zone C

Zone D

Zone E

Commercial Area

Military Base

Zone A = High Density Residential (> 2 du/acre)
Zone B = High Density Residential (1 - 2 du/acre)
Zone C = Moderate Density Residential (0.5 - 1 du/acre)
Zone D = Low Density Residential (0.1 - 0.5 de/acre)
Zone E = Low Density Residential (< 0.1 du/acre)

Note: Data compiled from 2012 air photo anaysis

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Salt and Nutrient Management Plan
Twentynine Palms, California

Current Land Use

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Figure 2-1

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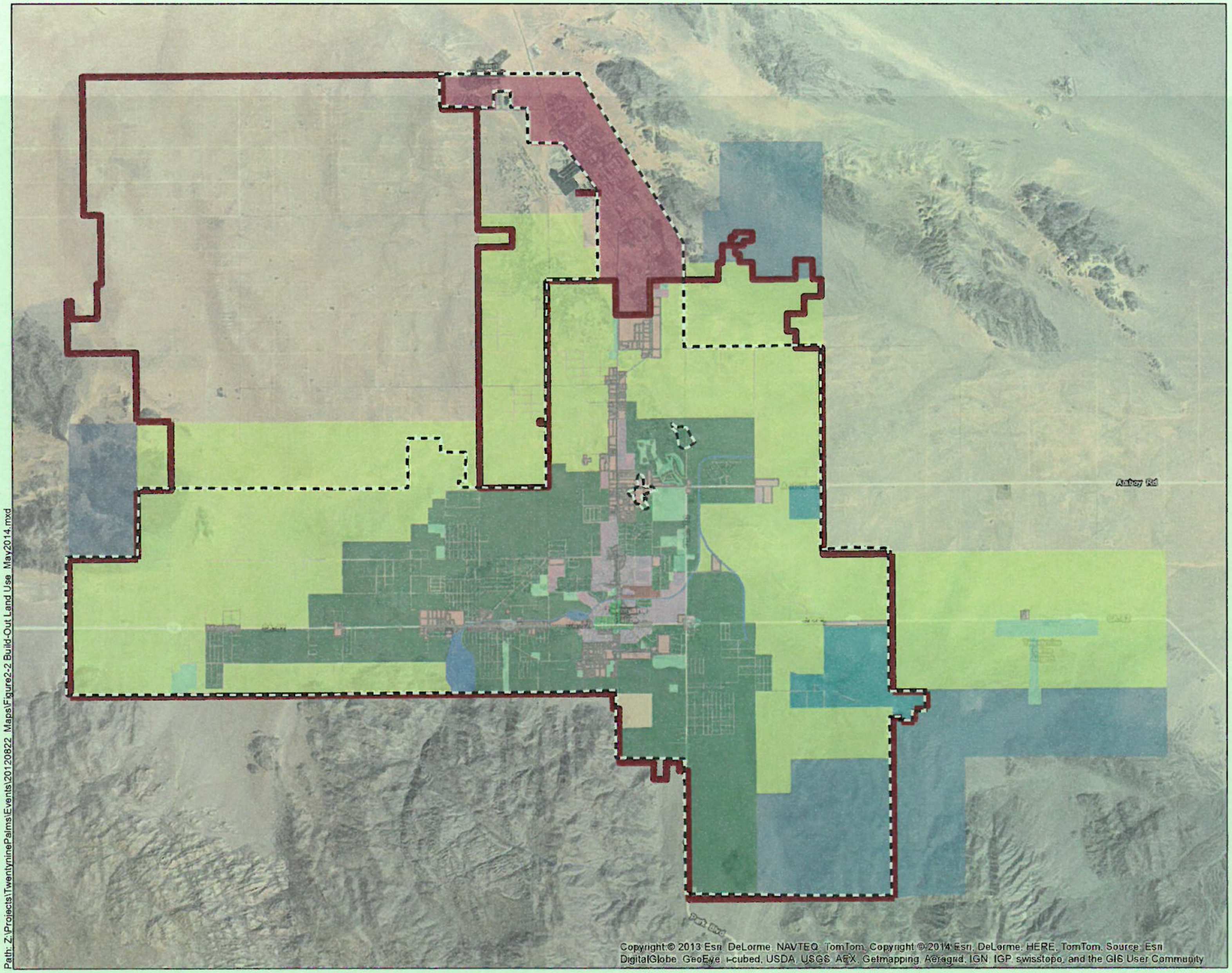

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Salt and Nutrient Management Plan
Twentynine Palms, California

Build-Out Land Use

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Figure 2-2

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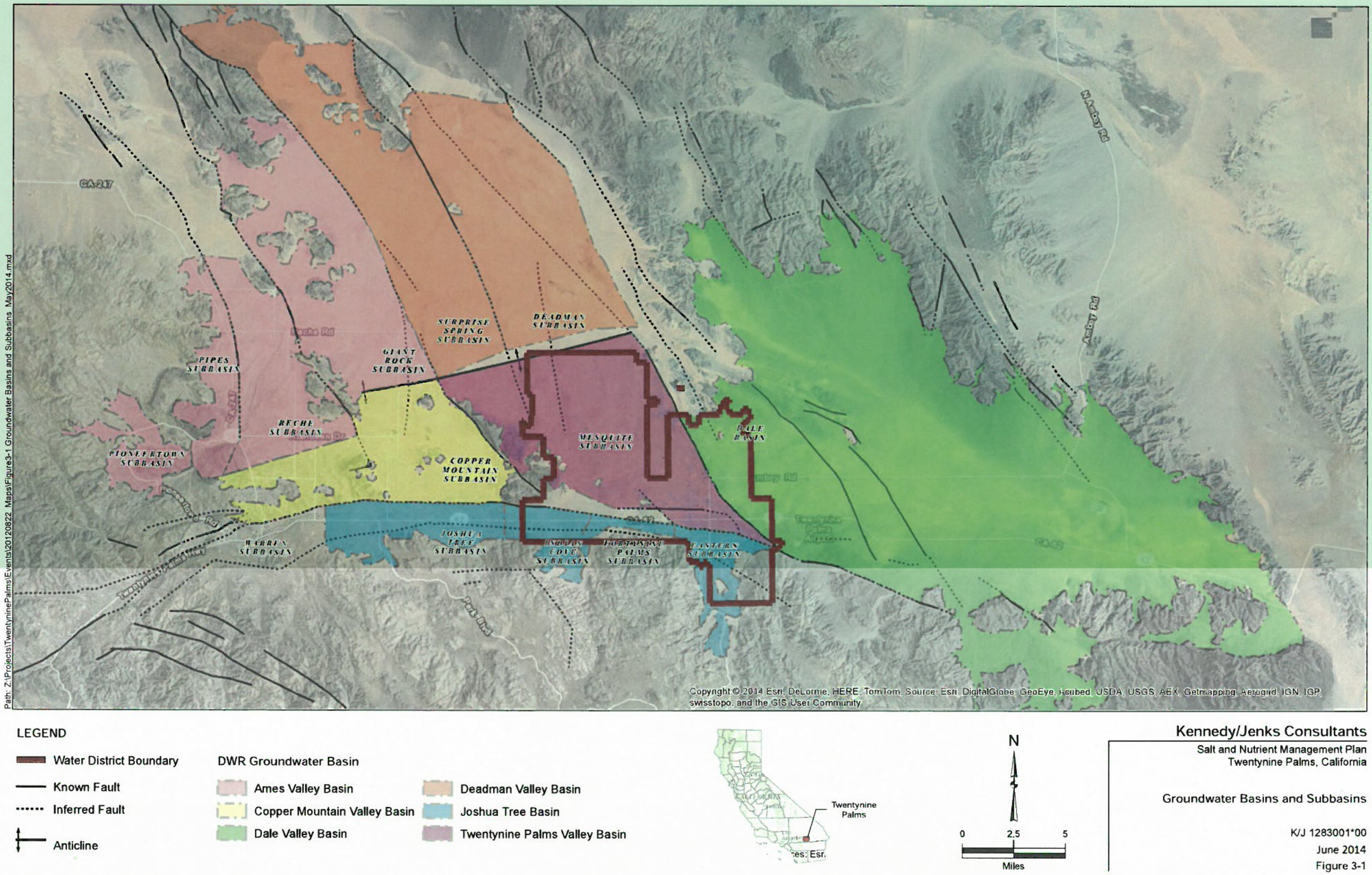

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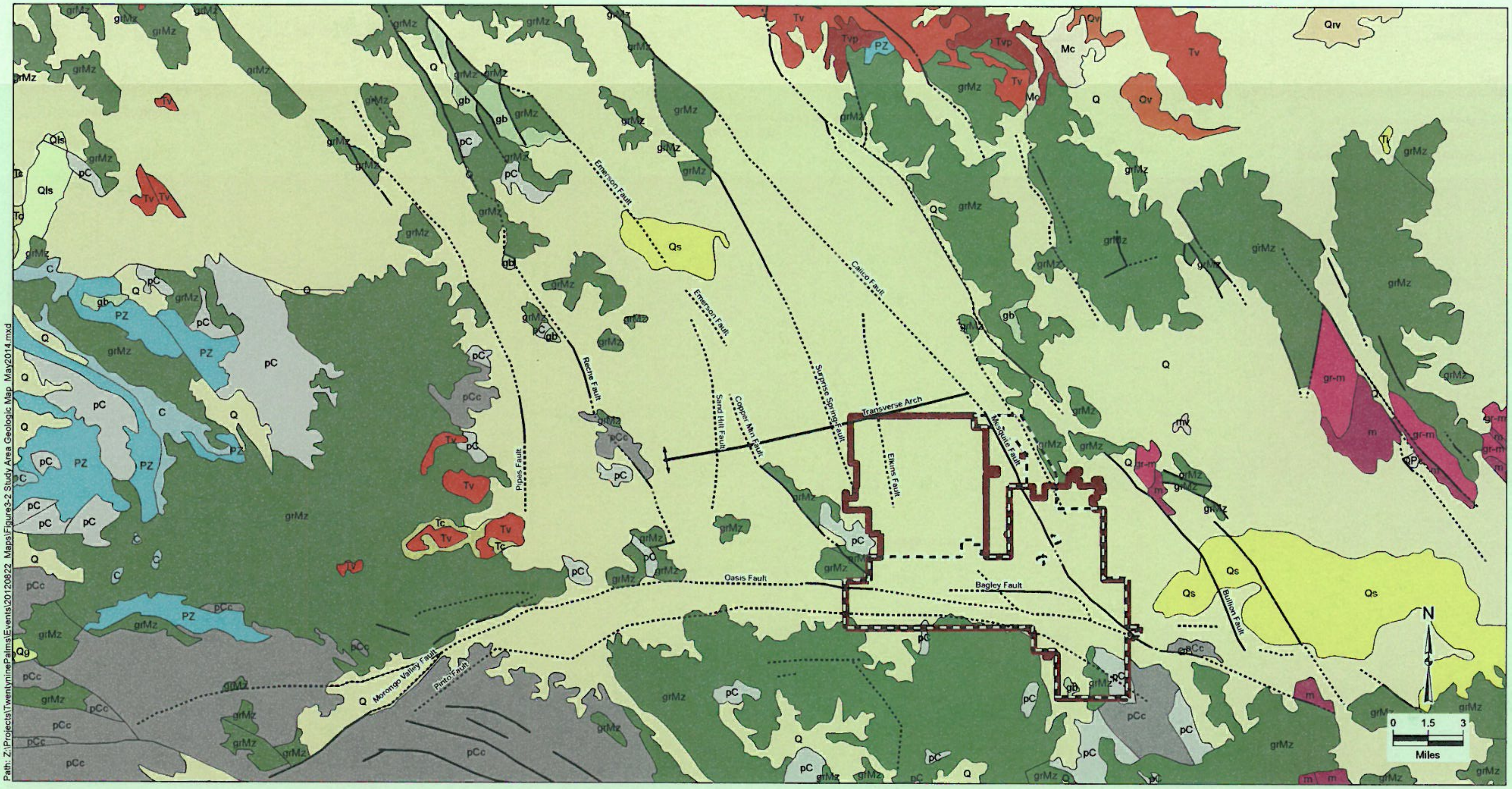
Salt and Nutrient Management Plan
Twentynine Palms, California

Groundwater Basins and Subbasins

K/J 1283001*00
June 2014
Figure 3-1



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LEGEND

- City Limit
- Water District Boundary
- Known Fault
- Inferred Fault
- Anticline

Geologic Units

- Qrv: Recent volcanics
- Qls: Quaternary landslide deposits
- Qs: Quaternary sand deposits
- Qv: Quaternary volcanics
- Q: Quaternary alluvium
- Qg: Quaternary glacial deposits
- QPc: Plio-Pleistocene alluvium
- Mc: Miocene nonmarine rocks
- Tv: Tertiary volcanics
- Tvp: Tertiary pyroclastics
- Tc: Tertiary nonmarine rocks
- Ti: Tertiary intrusive rocks
- gb: Mesozoic gabbroic rocks
- grMz: Mesozoic granitic rocks
- C: Carboniferous marine rocks
- PZ: Paleozoic marine rocks
- mv: Pre-Cenozoic metavolcanic rocks
- gr-m: Pre-Cenozoic granitic and metamorphic rocks
- m: Pre-Cenozoic metasedimentary and metavolcanic rocks
- pC: Precambrian undivided rocks
- pCc: Precambrian igneous and metamorphic rocks

Notes:
See Section 2.7.3 for geologic unit descriptions
The Oasis Fault is also known as the Pinto Mountain Fault.

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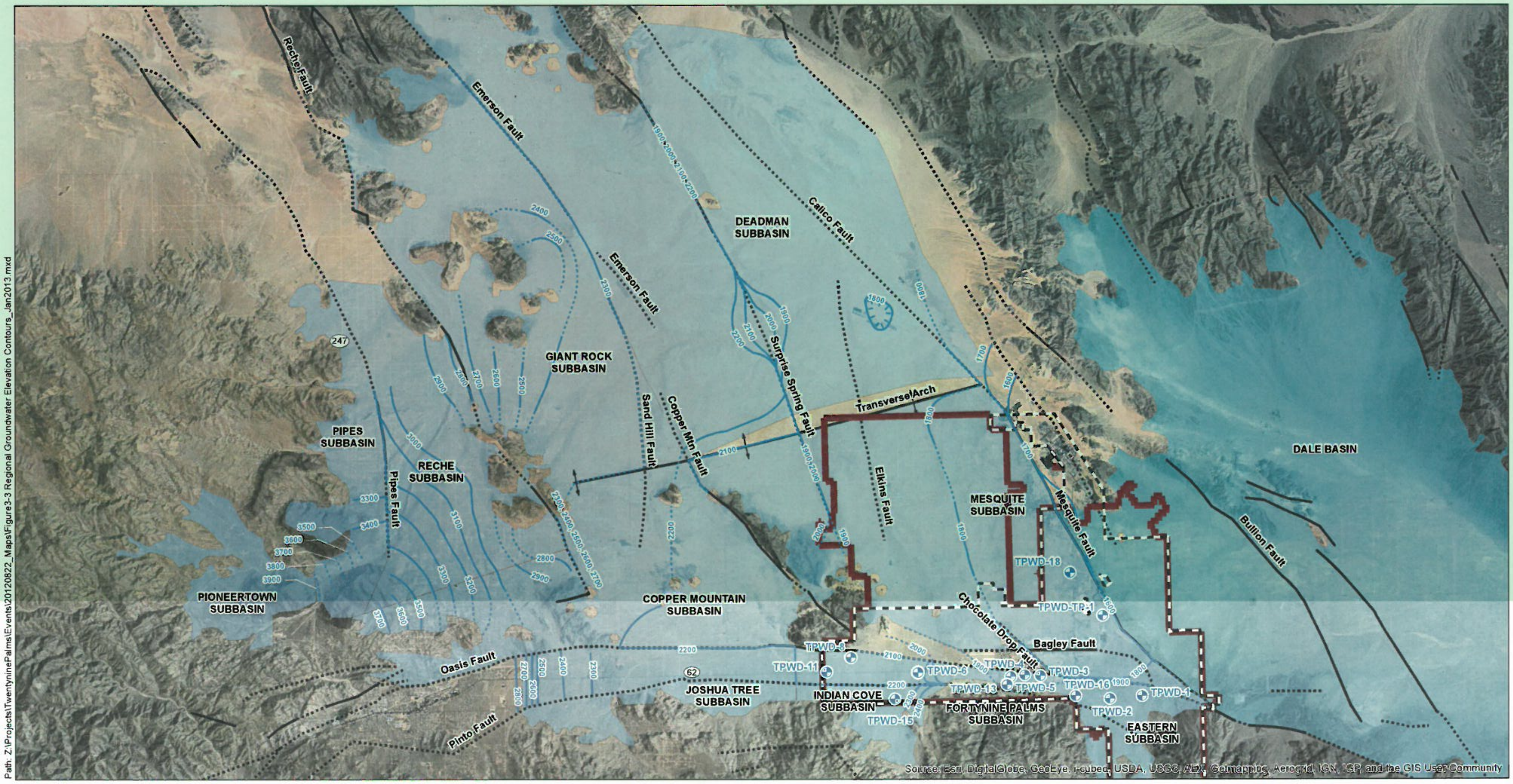
Salt and Nutrient Management Plan
Twentynine Palms, California

Study Area Geologic Map

K/J 1283001*00

June 2014

Figure 3-2



Path: Z:\Projects\TwentyninePalms\Events\20120822_Maps\Figure3-3 Regional Groundwater Elevation Contours_Jan2013.mxd

Source: 2012 ESRI

Explanation

Groundwater Subbasins

Groundwater Elevation (ft AMSL)

Known

Inferred

Faults

Known

Inferred

Anticline

TPWD Wells

City Limit

Water District Boundary

Notes:
Contour Interval = 100 feet.
The Oasis Fault is also known as the Pinto Mountain Fault.

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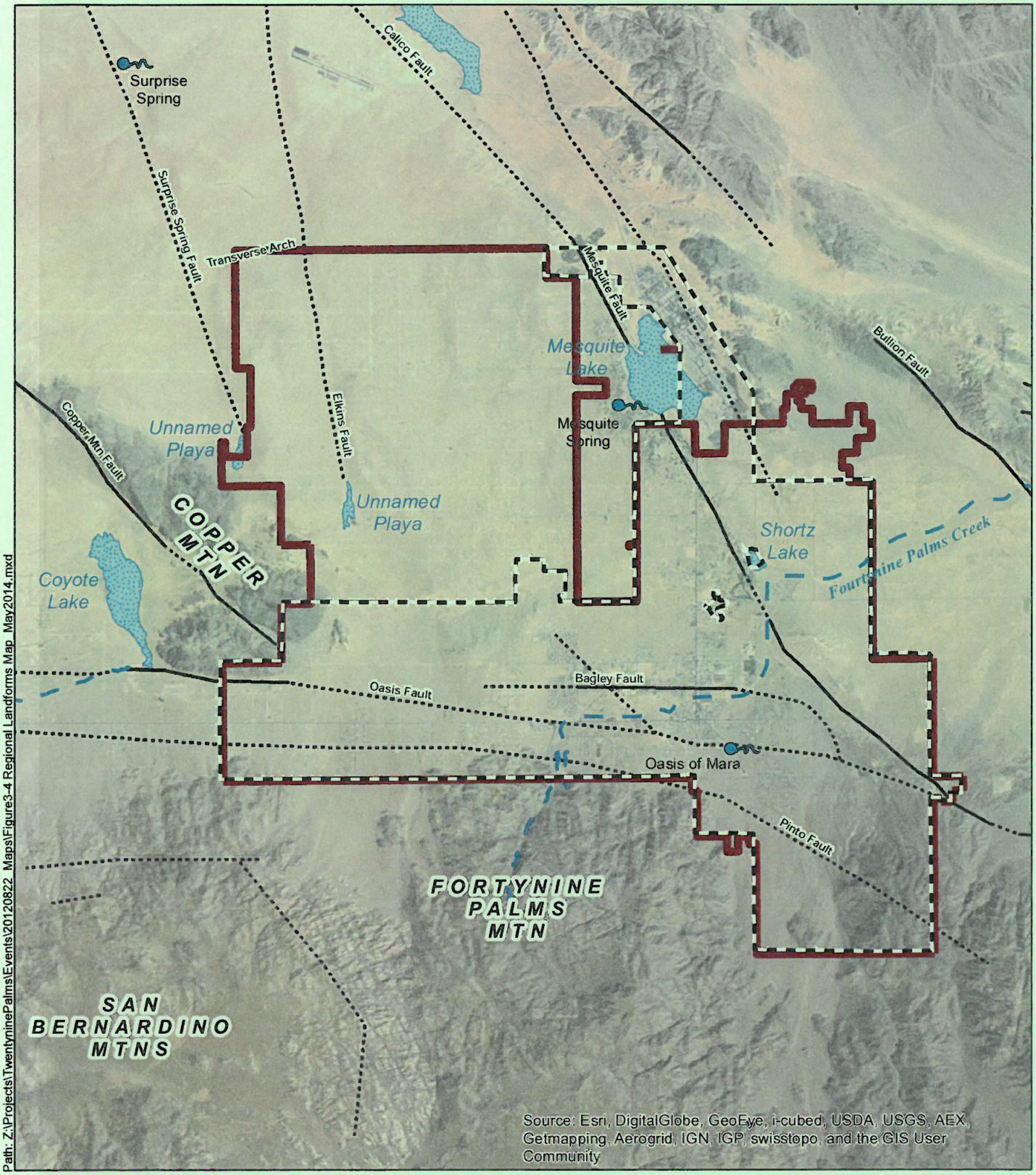
Twentynine Palms
San Bernardino County, California

Regional Groundwater Elevation Contours 2008

K/J 1283001*00

June 2014

Figure 3-3



LEGEND

- City Limit
- Water District Boundary
- Known Fault
- Inferred Fault
- Spring
- Stream
- Playa

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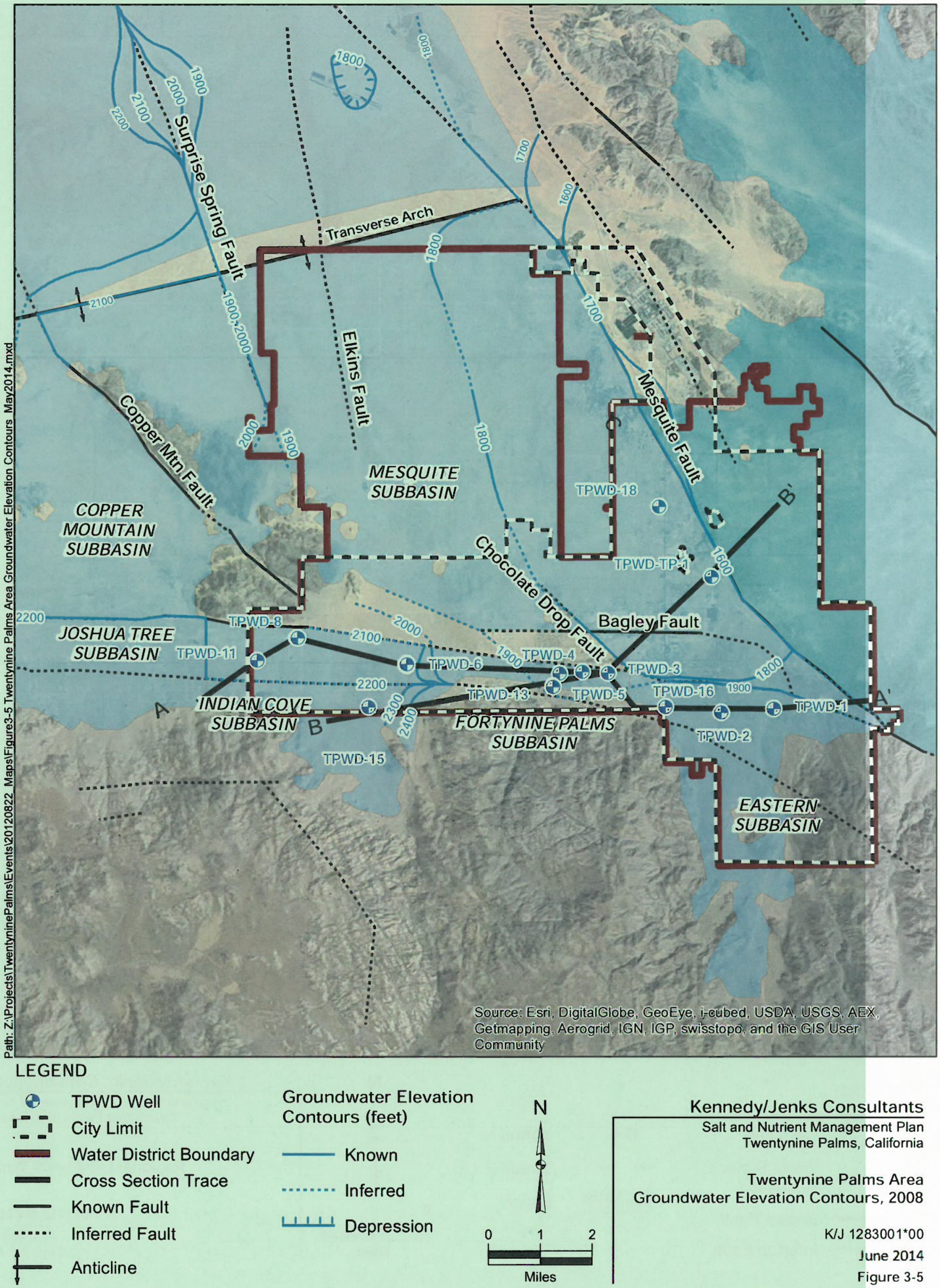
Salt and Nutrient Management Plan
Twentynine Palms, California

Regional Landforms Map

K/J 1283001*00
June 2014
Figure 3-4



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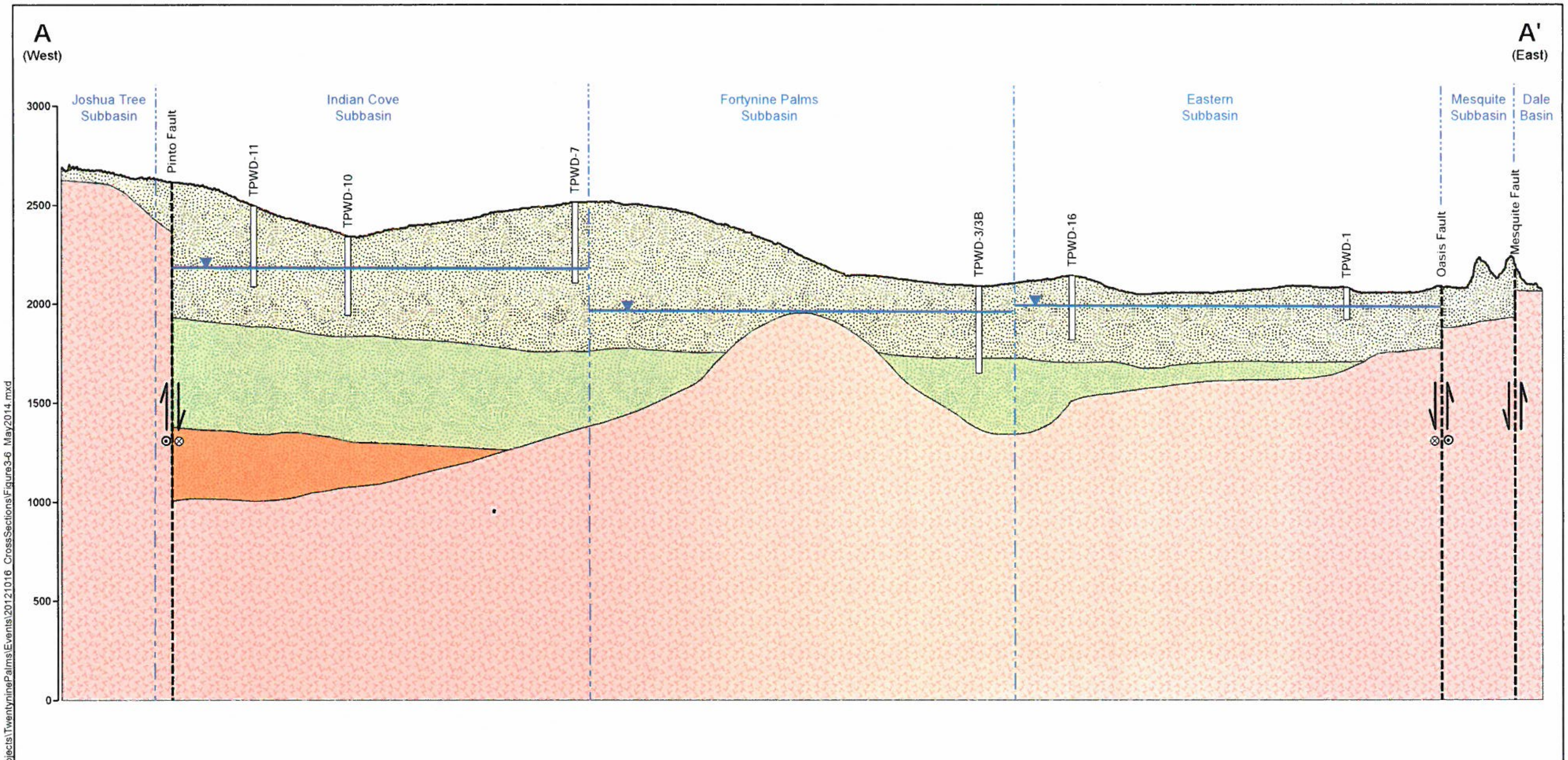
Salt and Nutrient Management Plan
Twentynine Palms, California

Twentynine Palms Area
Groundwater Elevation Contours, 2008

K/J 1283001*00

June 2014

Figure 3-5



Note: The Oasis Fault is also known as the Pinto Mountain Fault.

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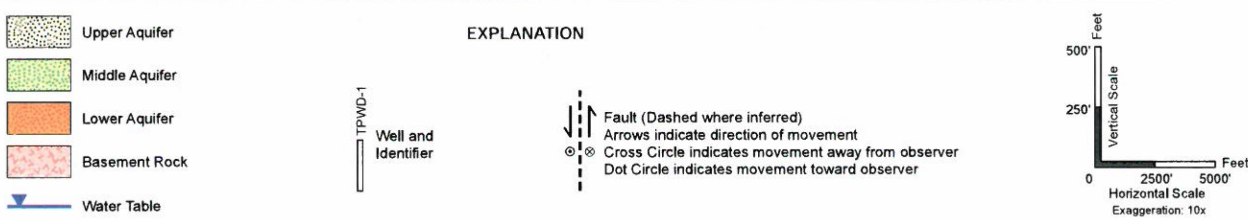

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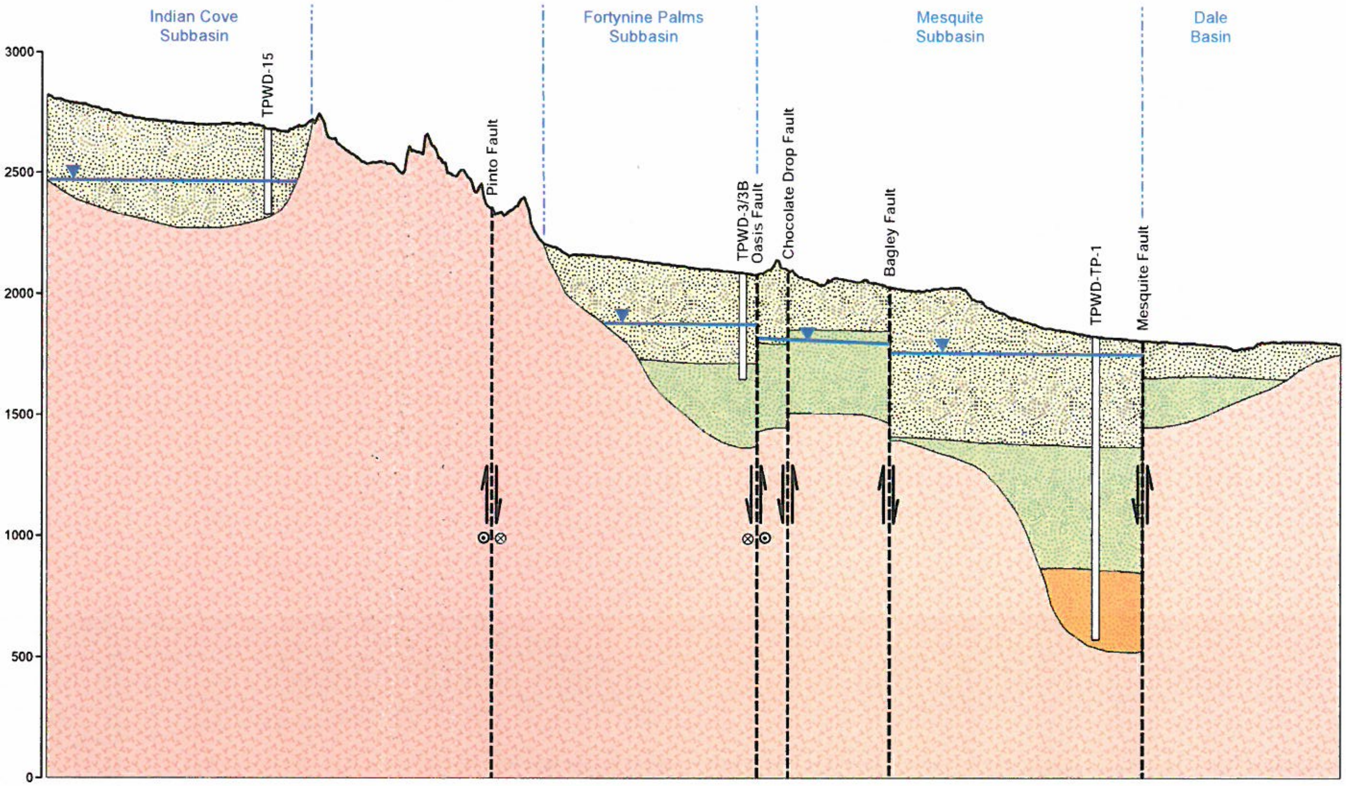
Salt and Nutrient Management Plan
Twentynine Palms, California

Geologic Cross Section A-A'

K/J 1283001*00
June 2014
Figure 3-6



Note: The Oasis Fault is also known as the Pinto Mountain Fault.

EXPLANATION

- Upper Aquifer
- Middle Aquifer
- Lower Aquifer
- Basement Rock
- Water Table
- TPWD-1 Well and Identifier
- Fault (Dashed where inferred)
  Arrows indicate direction of movement
  Cross Circle indicates movement away from observer
  Dot Circle indicates movement toward observer

Vertical Scale: 0, 250', 500' Feet
Horizontal Scale: 0, 2500', 5000' Feet
Exaggeration: 10x

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Salt and Nutrient Management Plan
Twentynine Palms, California

Geologic Cross Section B-B'

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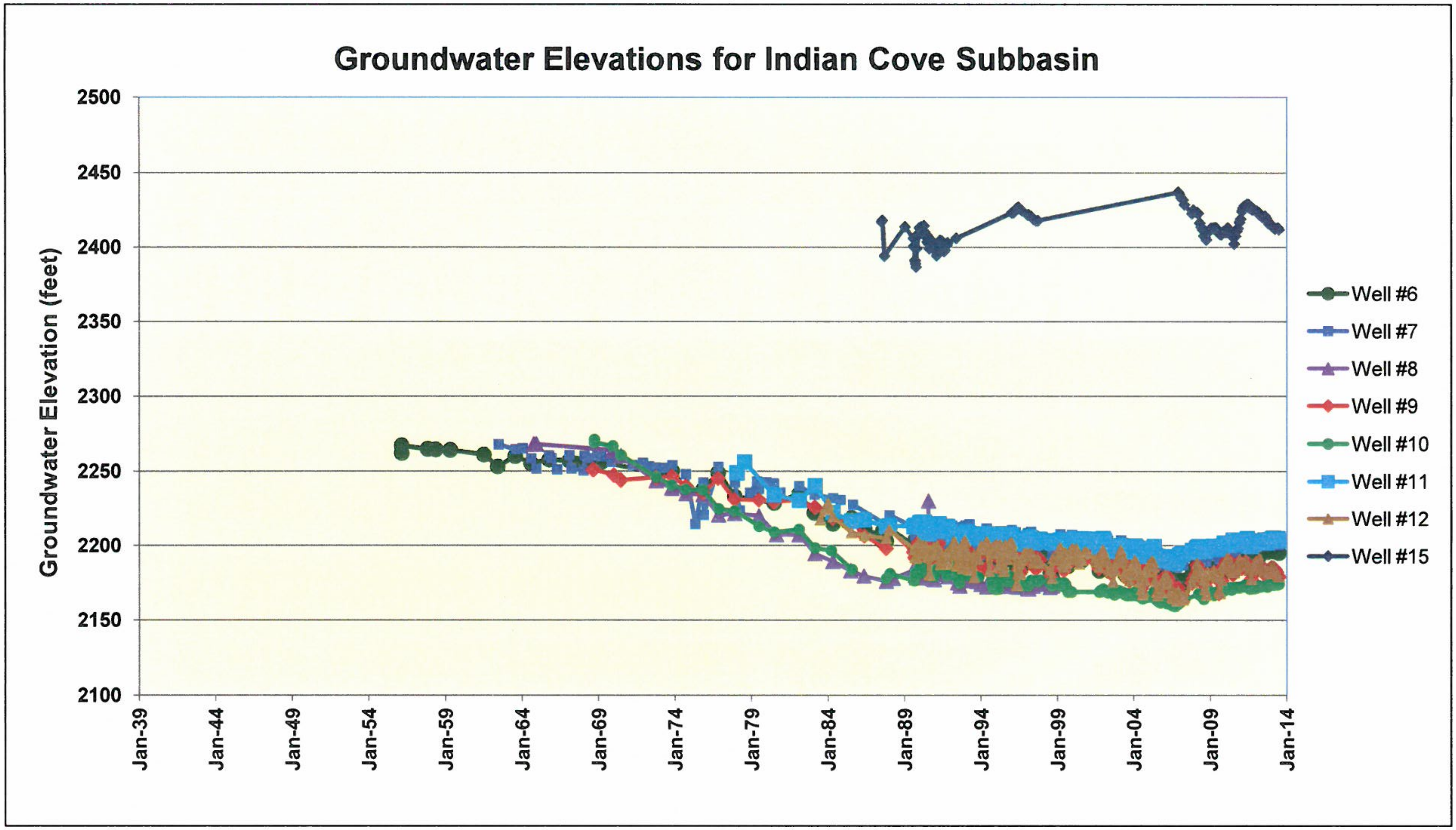
Figure 3-7



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Twentynine Palms, California

Groundwater Elevation History for Indian Cove Subbasin

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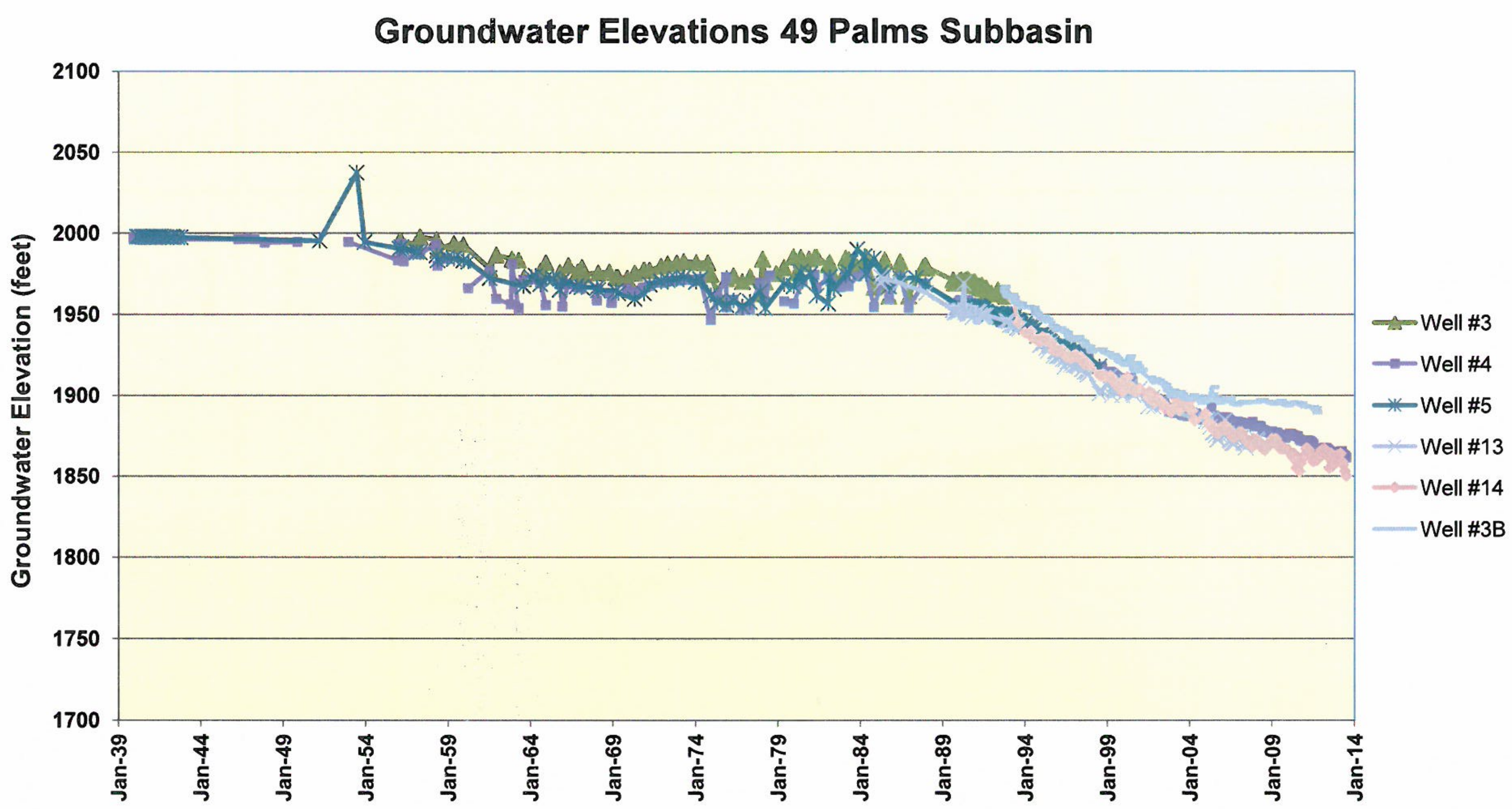
Figure 3-8



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Twentynine Palms, California

Groundwater Elevation History for 49 Palms Subbasin

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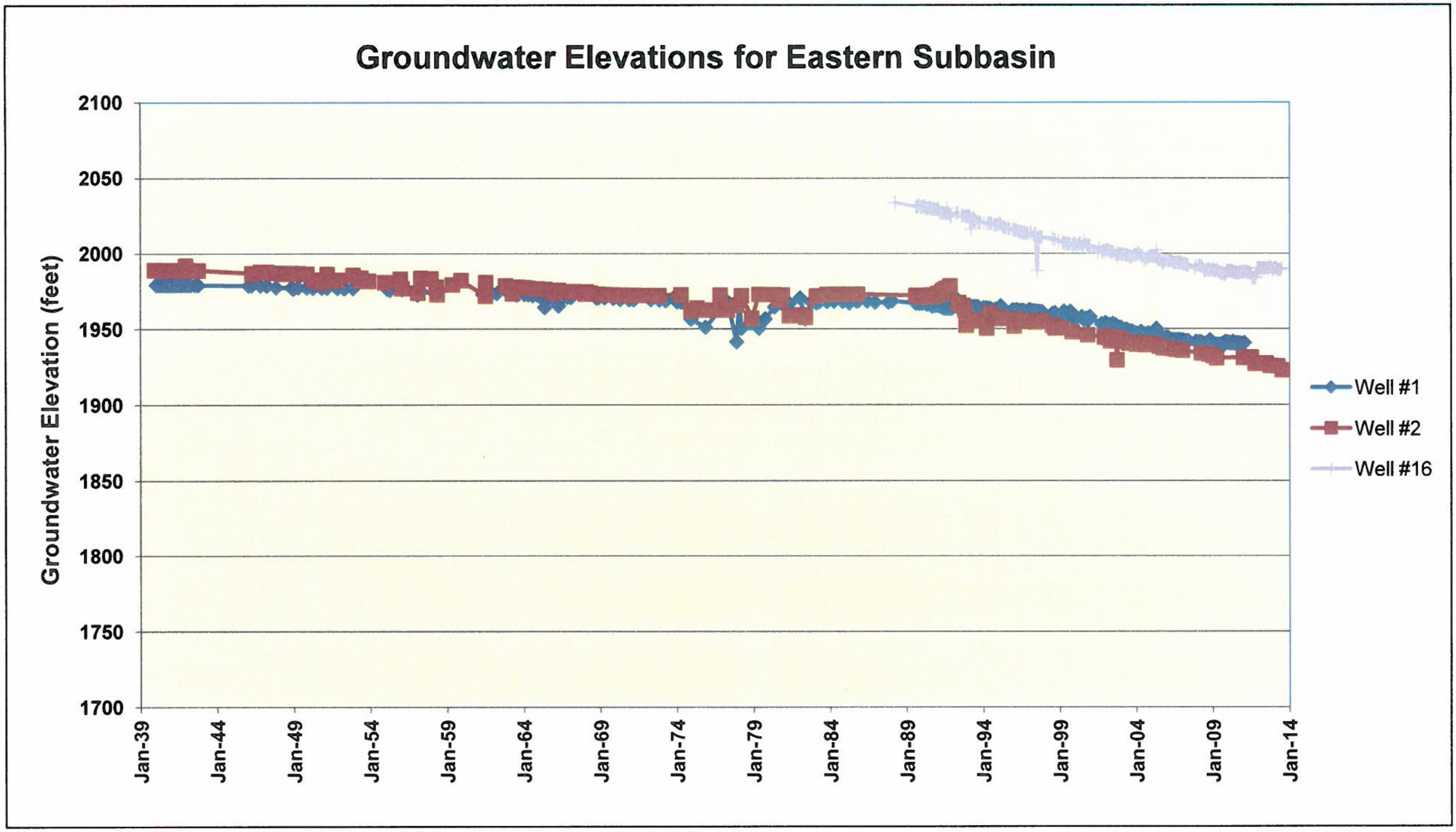
Figure 3-9



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Twentynine Palms, California

Groundwater Elevation History for Eastern Subbasin

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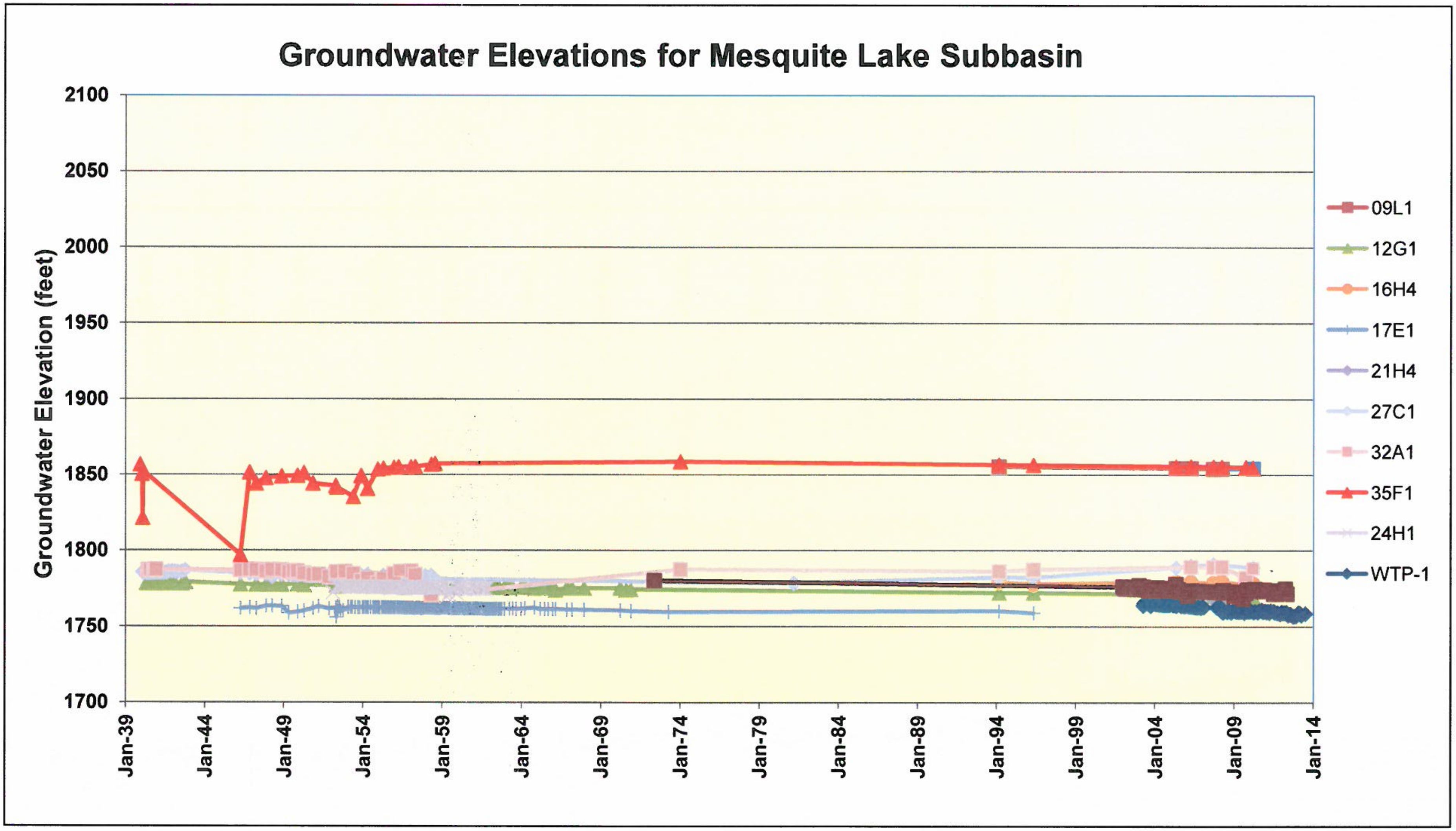
Figure 3-10



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Twentynine Palms, California

Groundwater Elevation History for Mesquite Lake Subbasin

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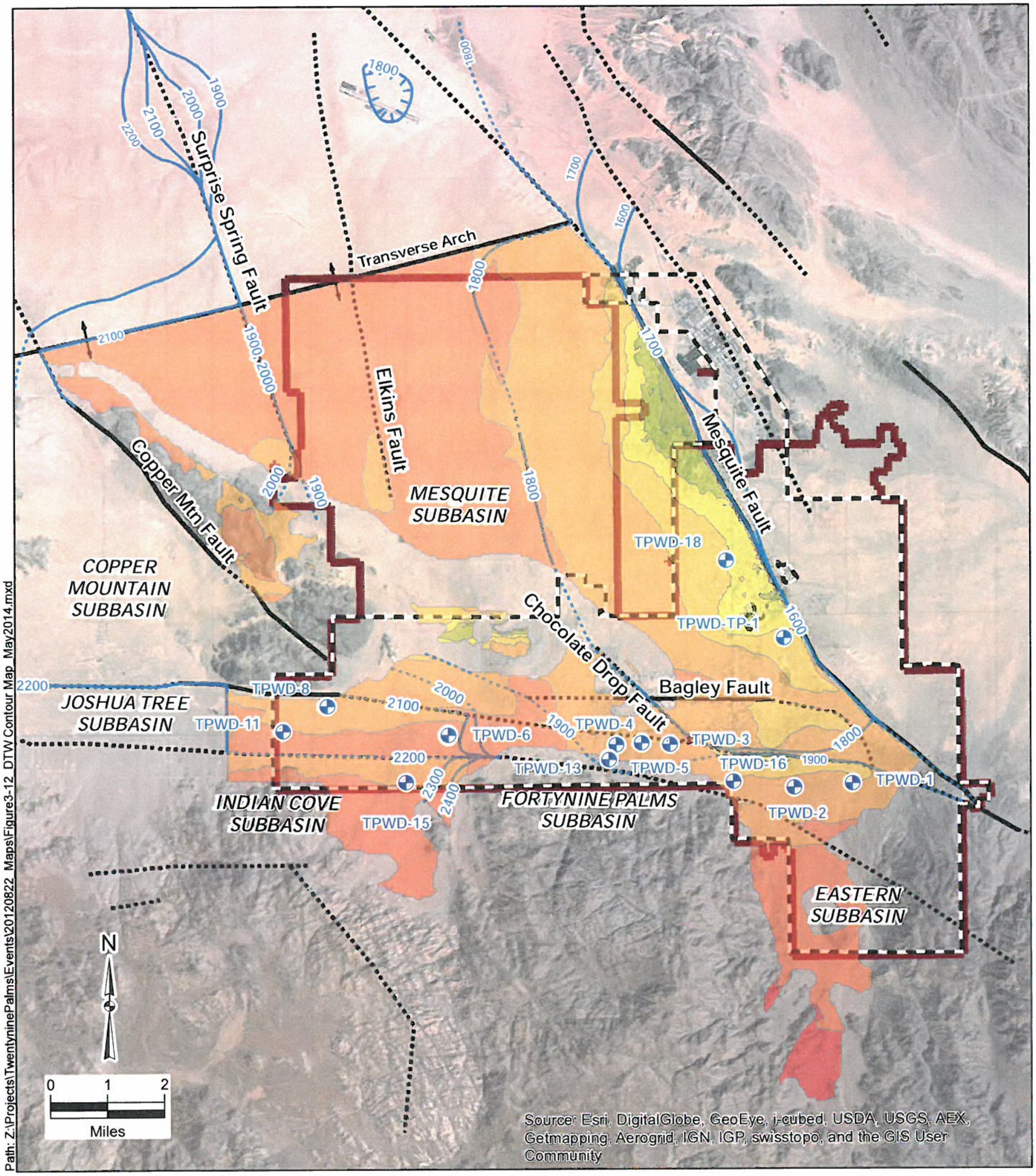
Figure 3-11



LEGEND

- TPWD Well
- City Limit
- Water District Boundary
- Known Fault
- Inferred Fault
- Anticline

Groundwater Elevation Contours (feet)

- Known
- Inferred
- Depression

Depth to Groundwater Contours (feet)

0, 10, 30, 50, 100, 200, 300, 400

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Twentynine Palms, California

Groundwater Model Estimated Depth to Groundwater Contour Map

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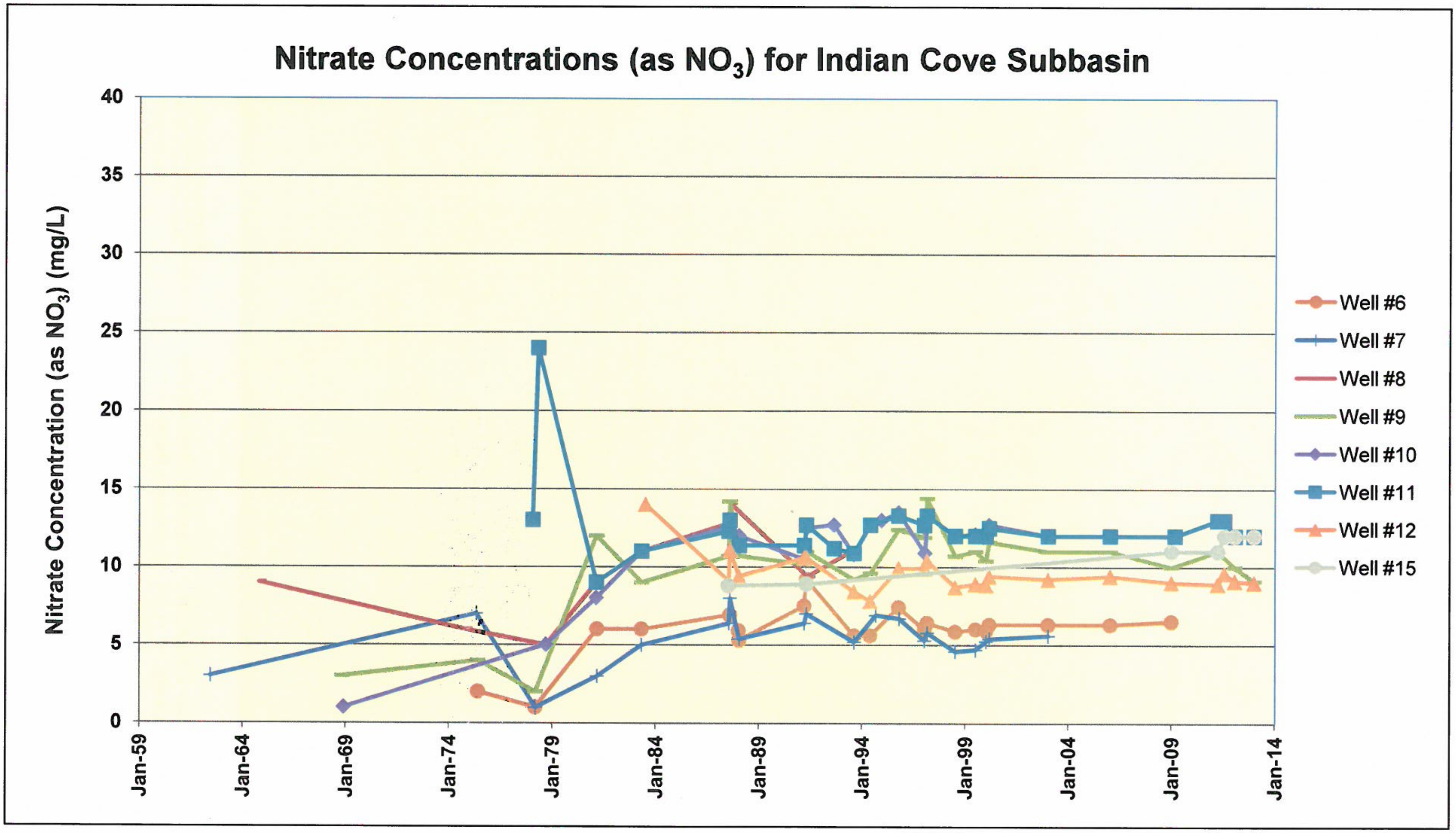
Figure 3-12



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Twentynine Palms, California

Nitrate Concentrations as (NO_3) for Indian Cove Subbasin

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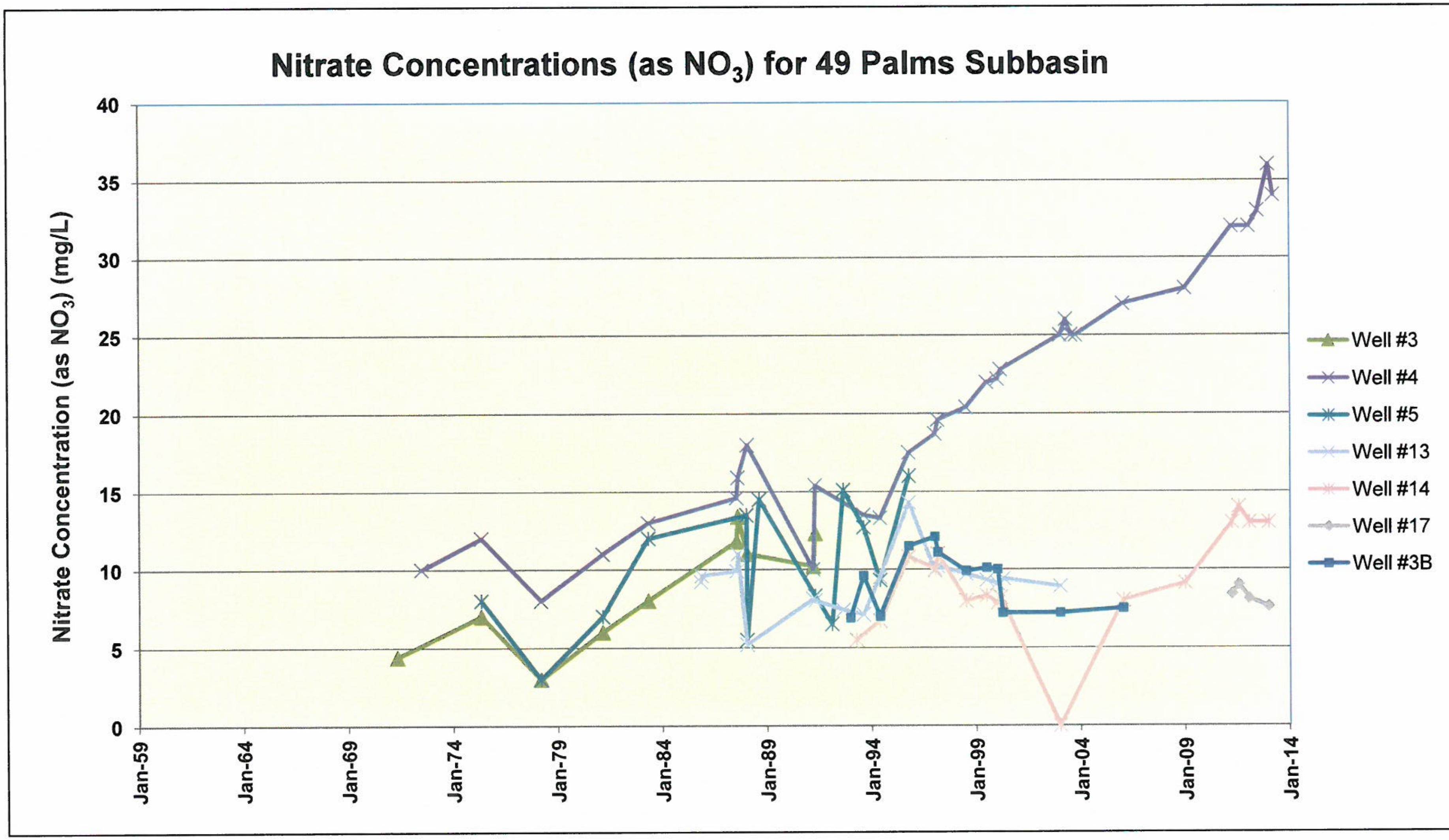
Figure 3-13



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Nitrate Concentrations as (NO_3) for 49 Palms Subbasin

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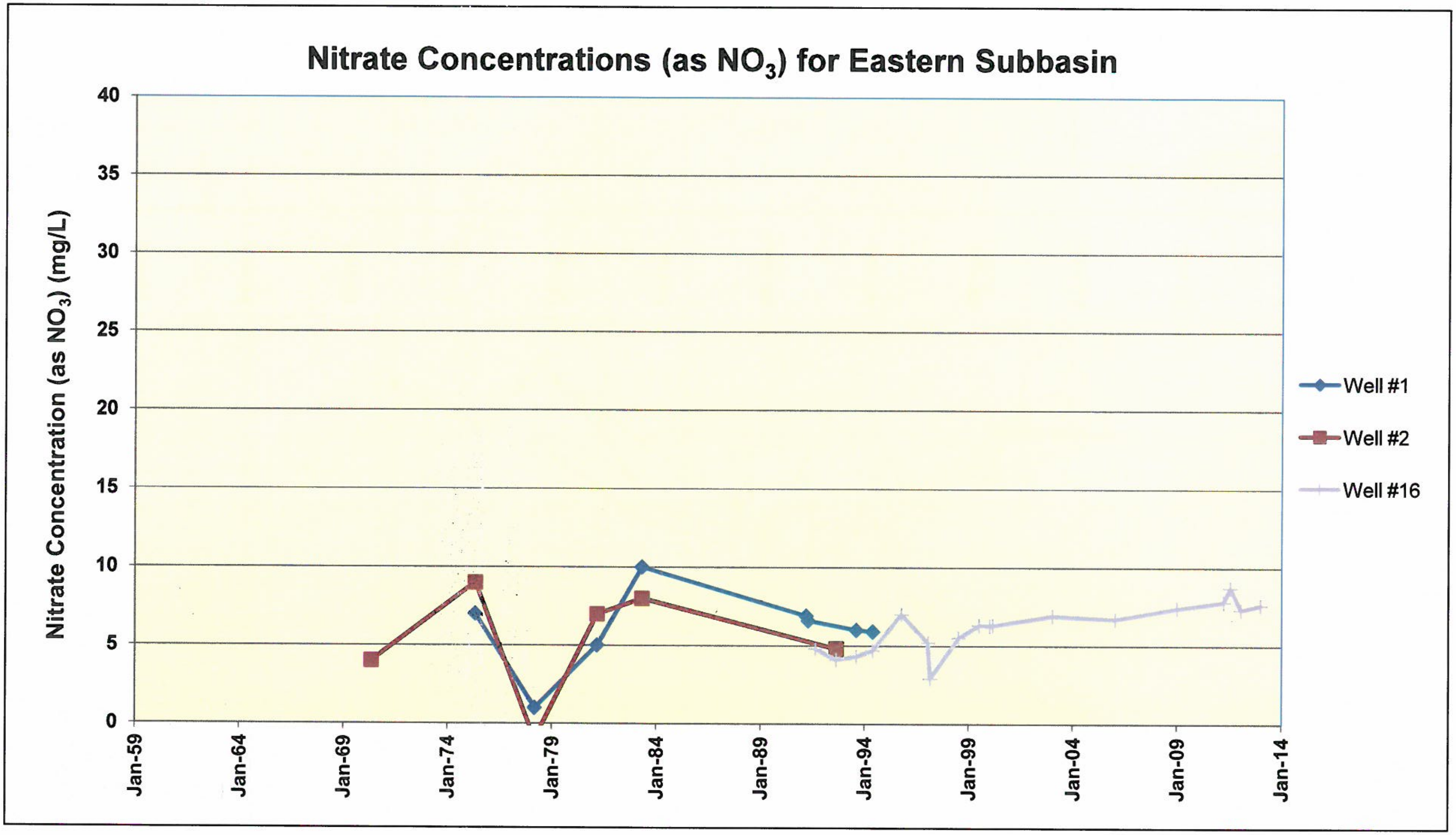
Figure 3-14



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Twentynine Palms, California

Nitrate Concentrations as (NO_3) for Eastern Subbasin

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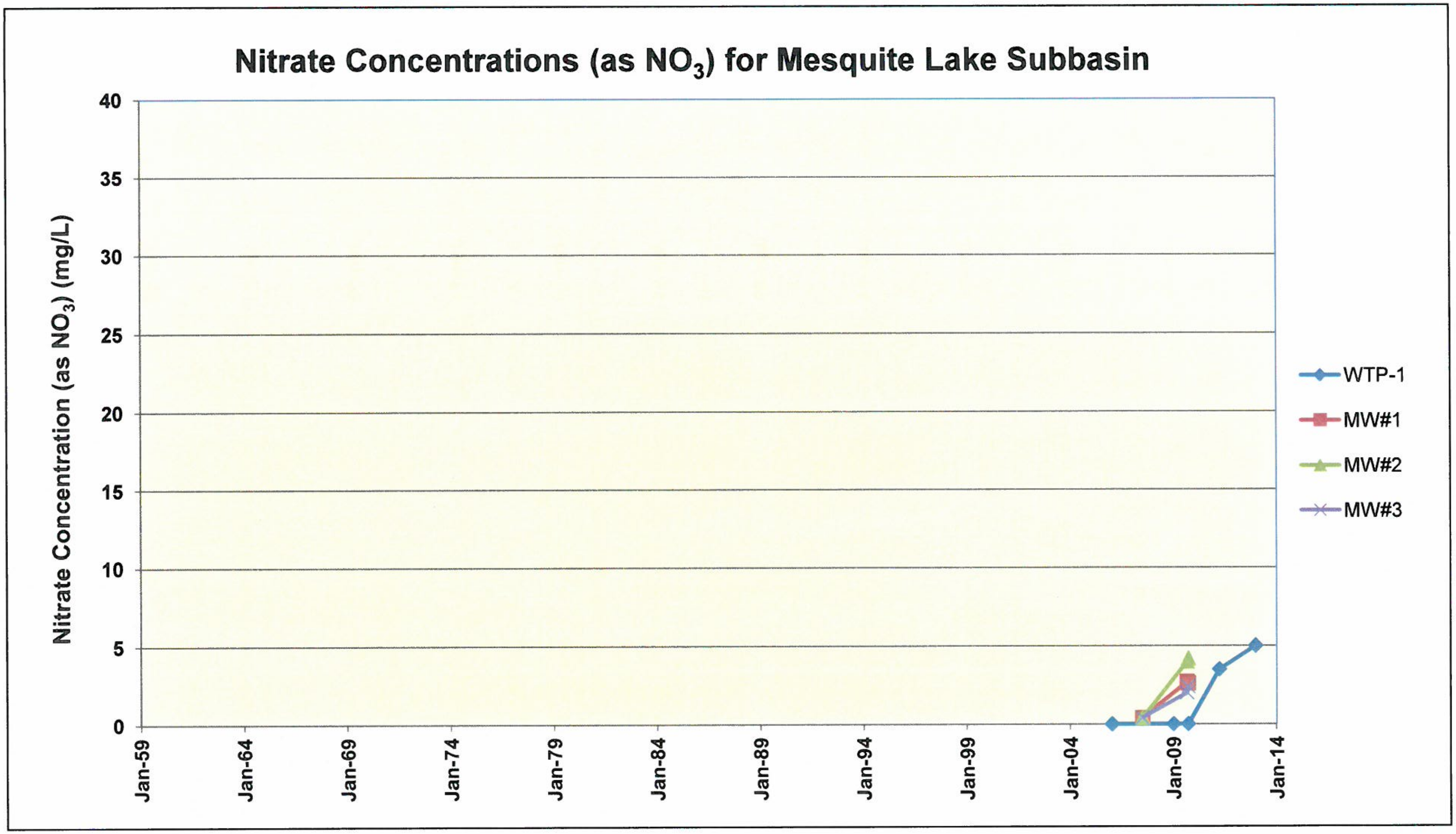
Figure 3-15



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Twentynine Palms, California

Nitrate Concentrations as (NO_3) for Mesquite Lake Subbasin

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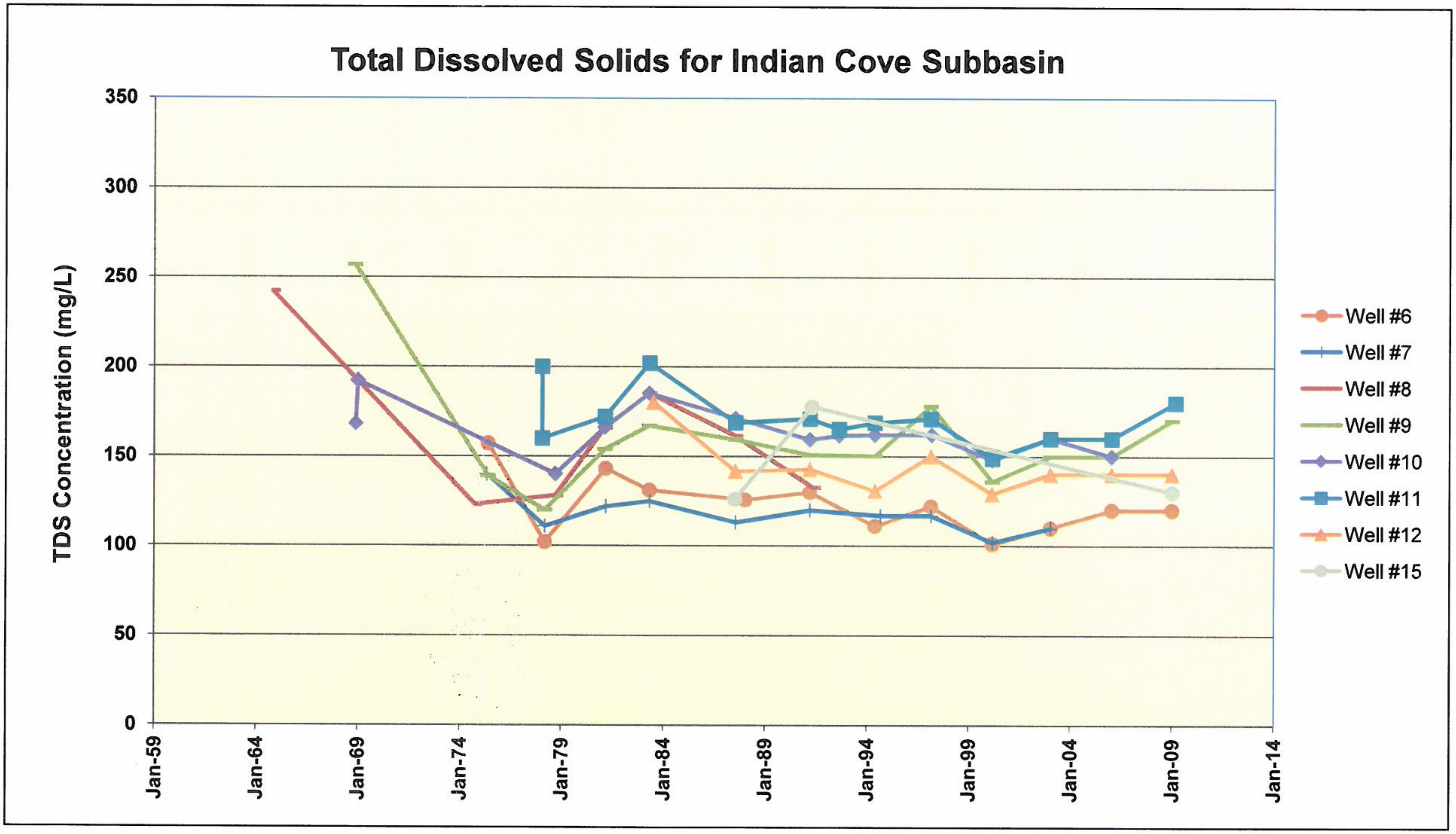
Figure 3-16



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Total Dissolved Solids (TDS) Concentrations for Indian Cove Subbasin

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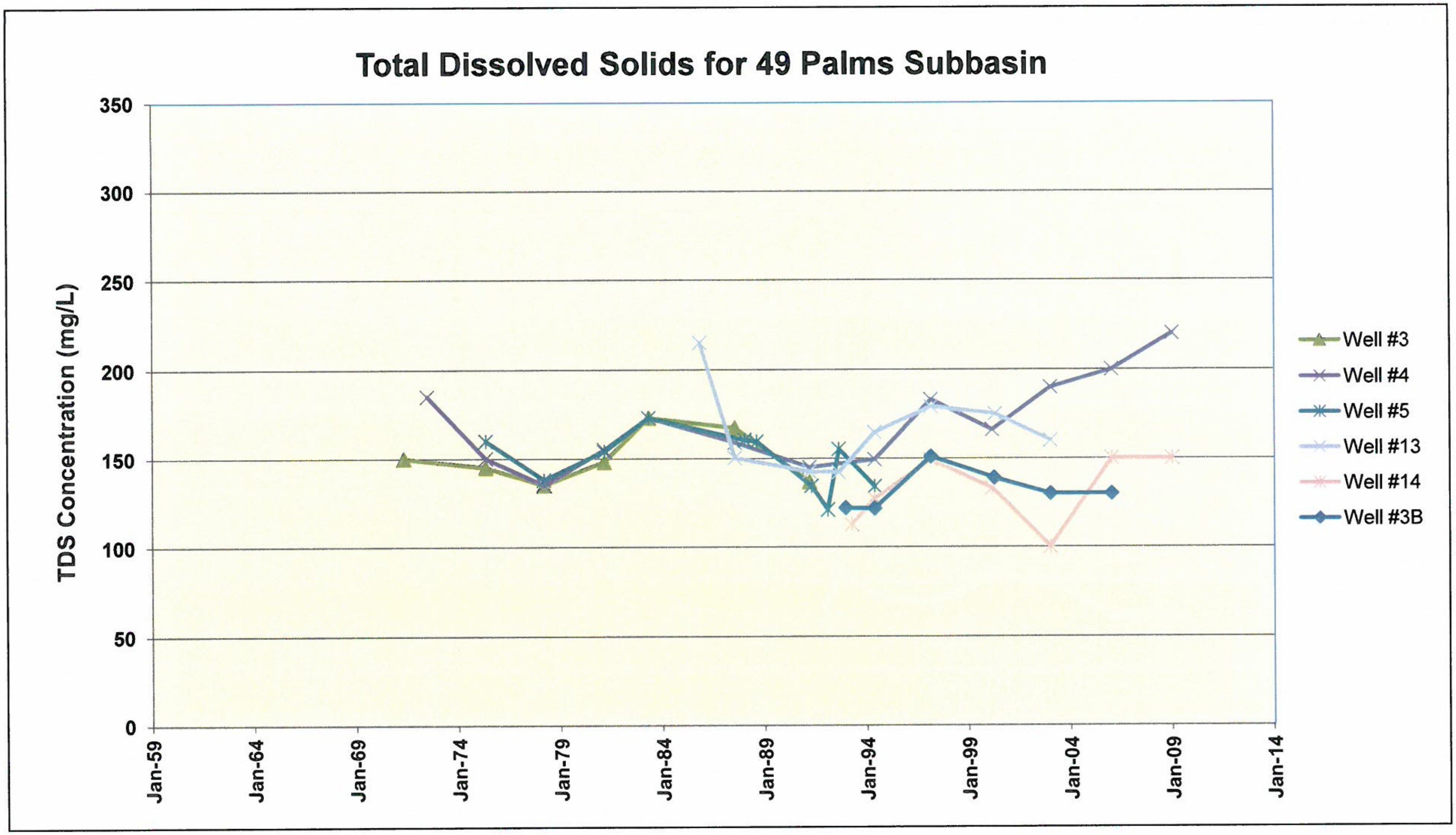
Figure 3-17



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Total Dissolved Solids (TDS) Concentrations for 49 Palms Subbasin

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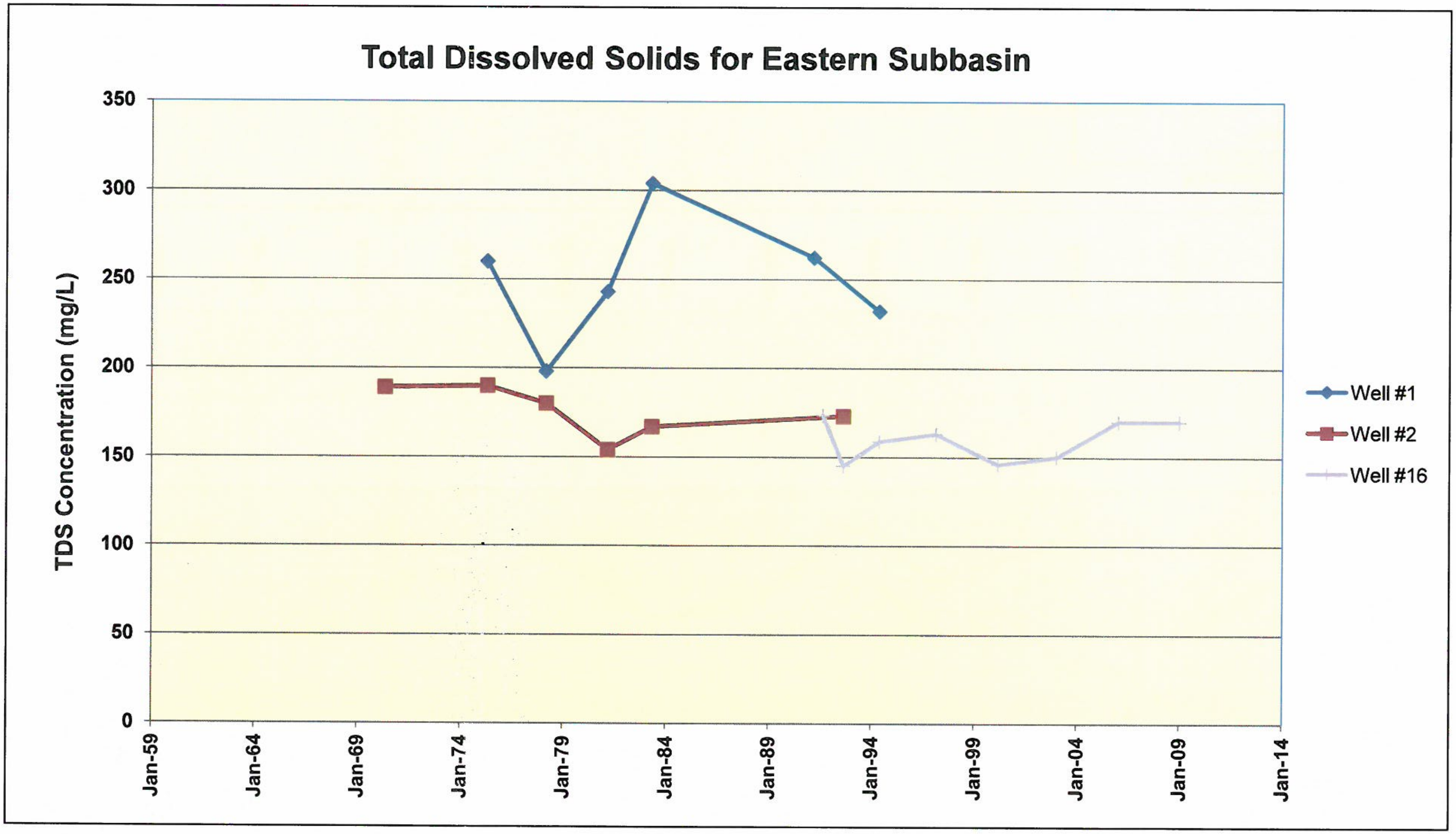
Figure 3-18



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Twentynine Palms, California

Total Dissolved Solids (TDS) Concentrations for Eastern Subbasin

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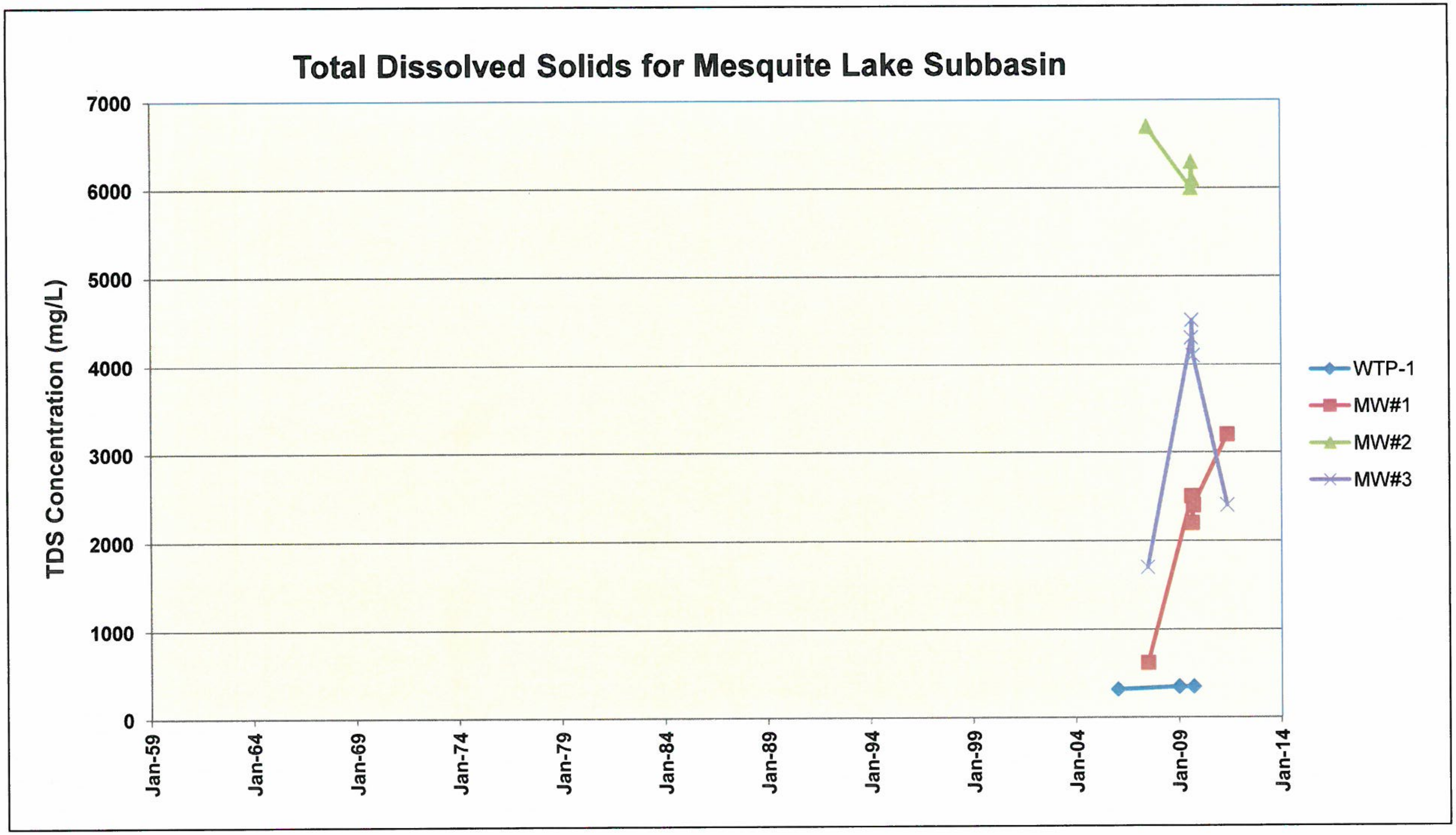
Figure 3-19



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Total Dissolved Solids (TDS) Concentrations for Mesquite Lake Subbasin

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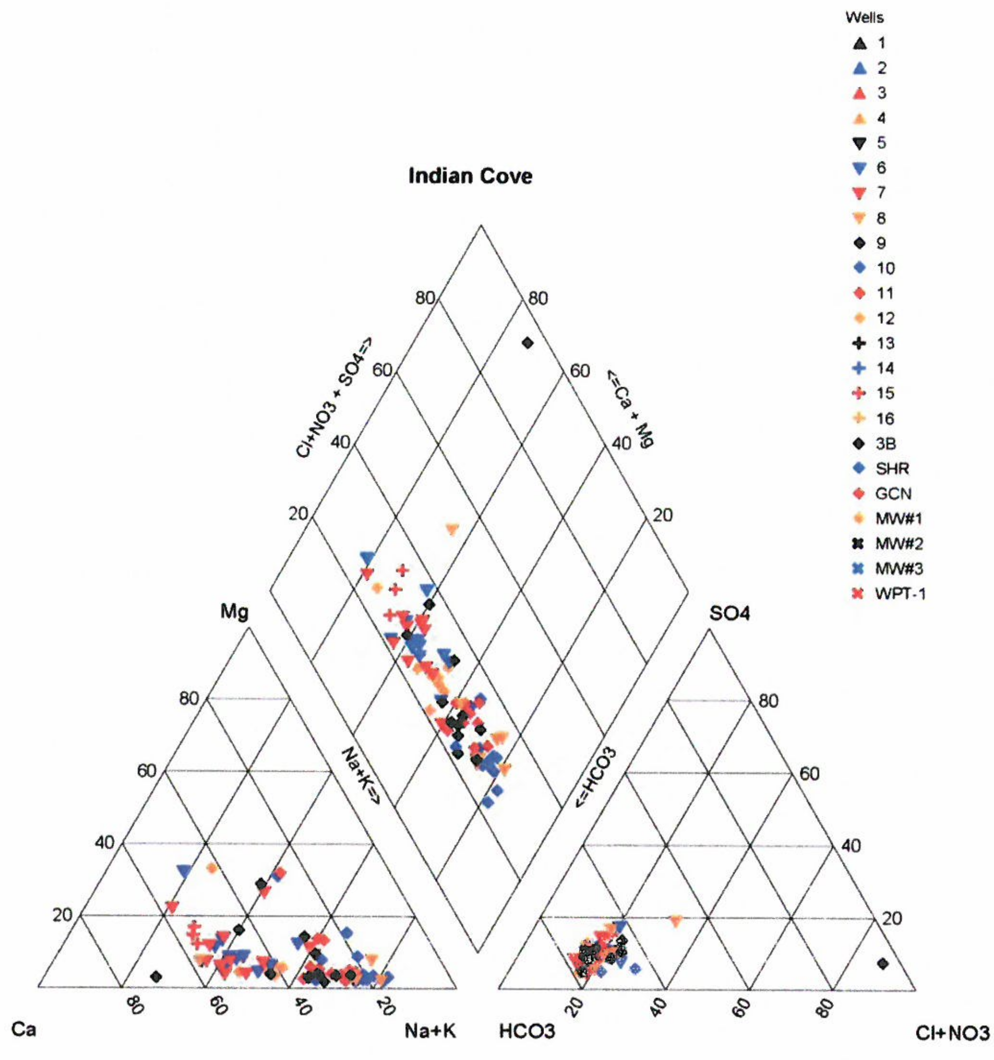
Figure 3-20



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Piper Diagram for Indian Cove Subbasin

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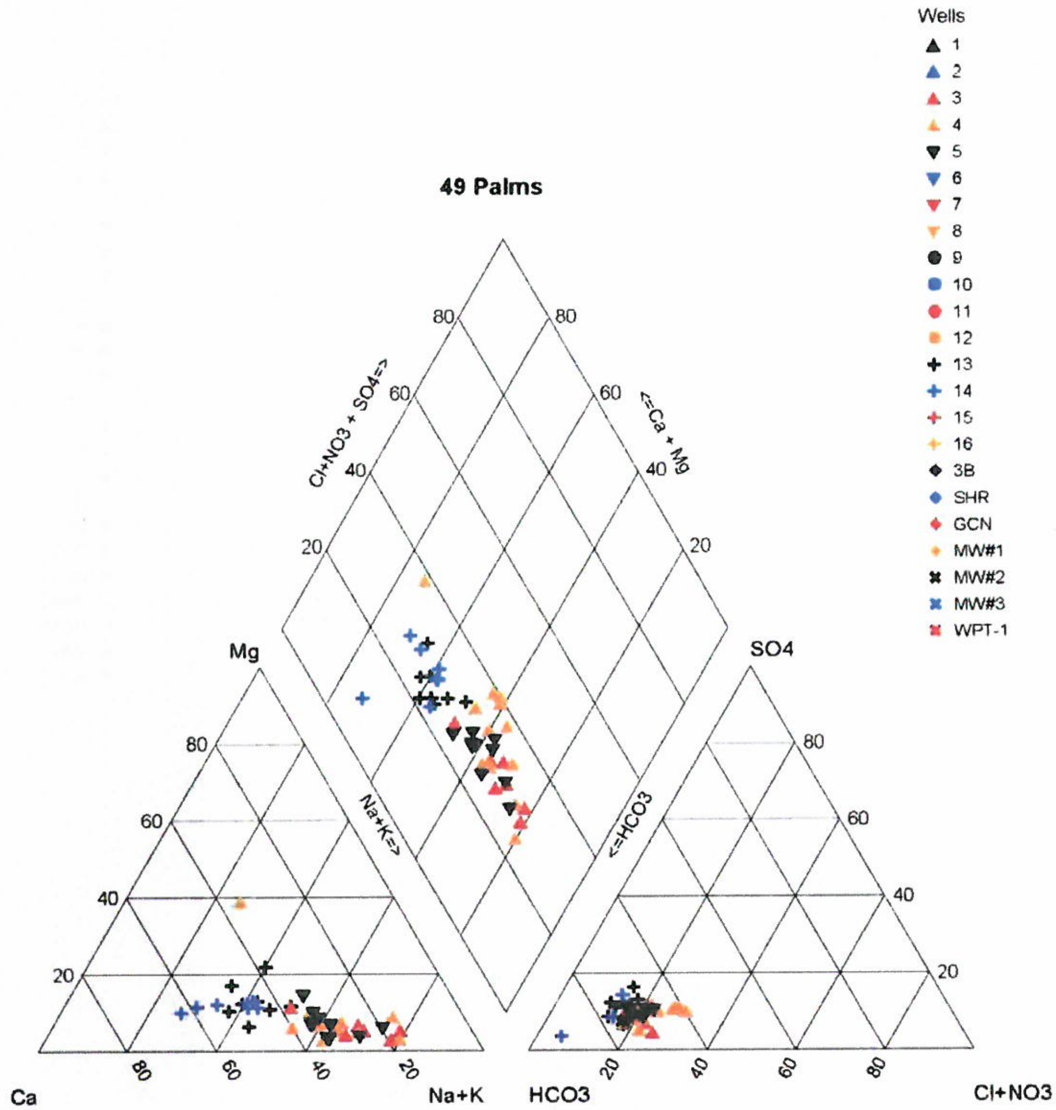
Figure 3-21



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Twentynine Palms, California

Piper Diagram for 49 Palms Subbasin

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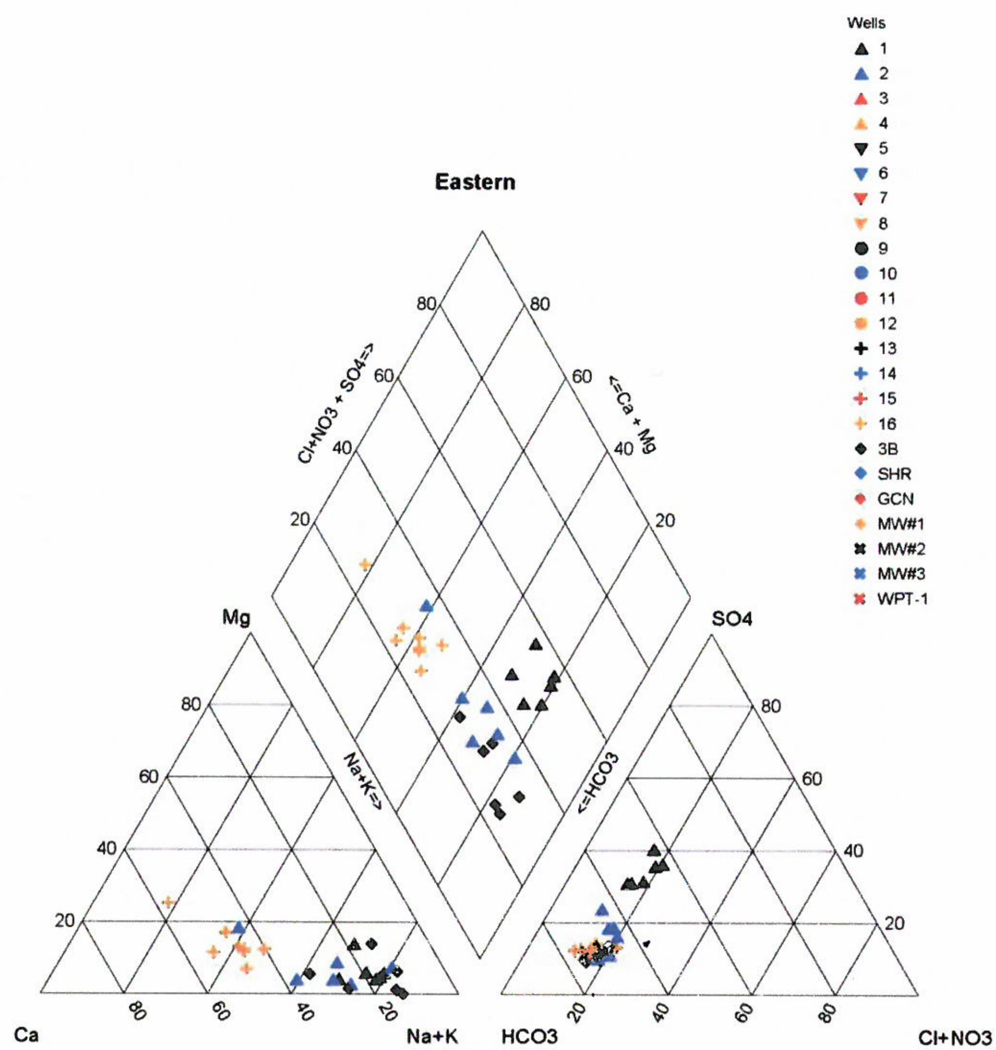
Figure 3-22



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Twentynine Palms, California

Piper Diagram for Eastern Subbasin

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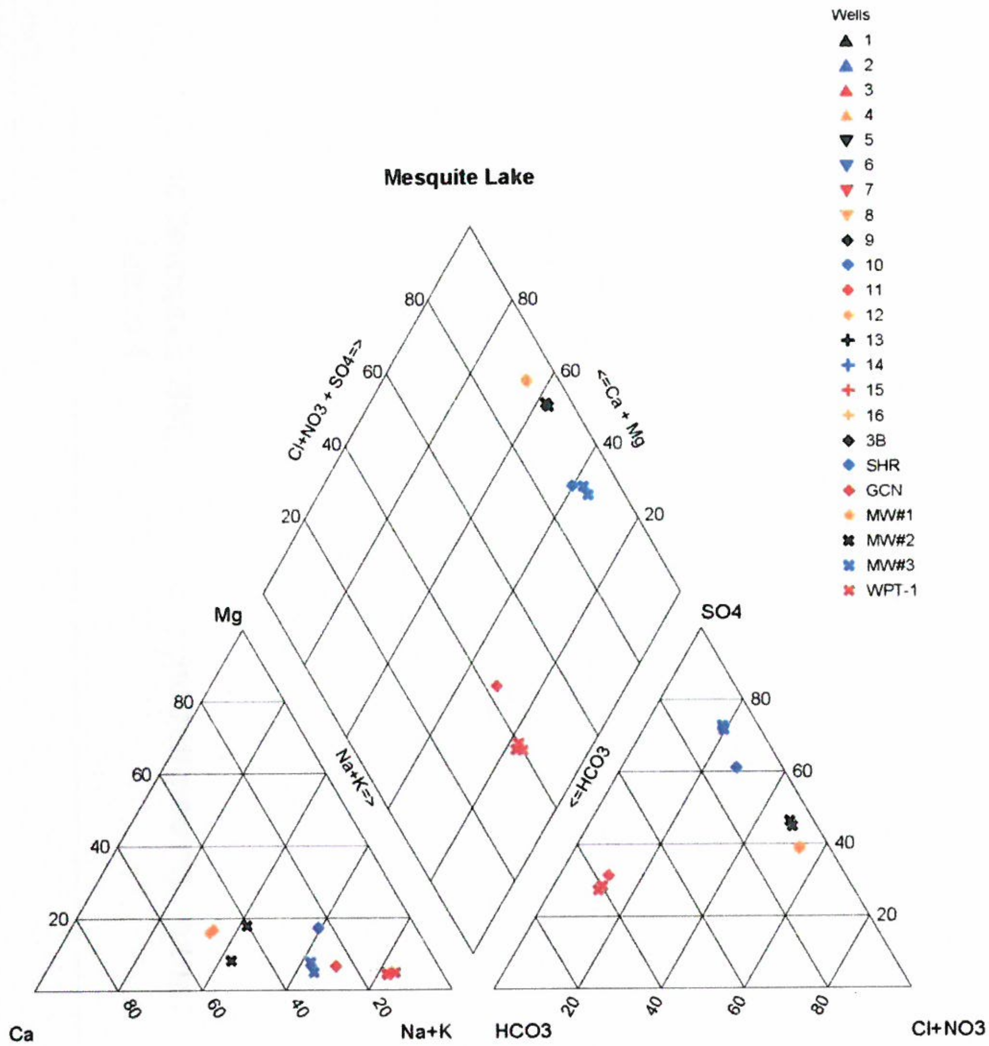
Figure 3-23



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Salt and Nutrient Management Plan
Twentynine Palms, California

Piper Diagram for Mesquite Lake Subbasin

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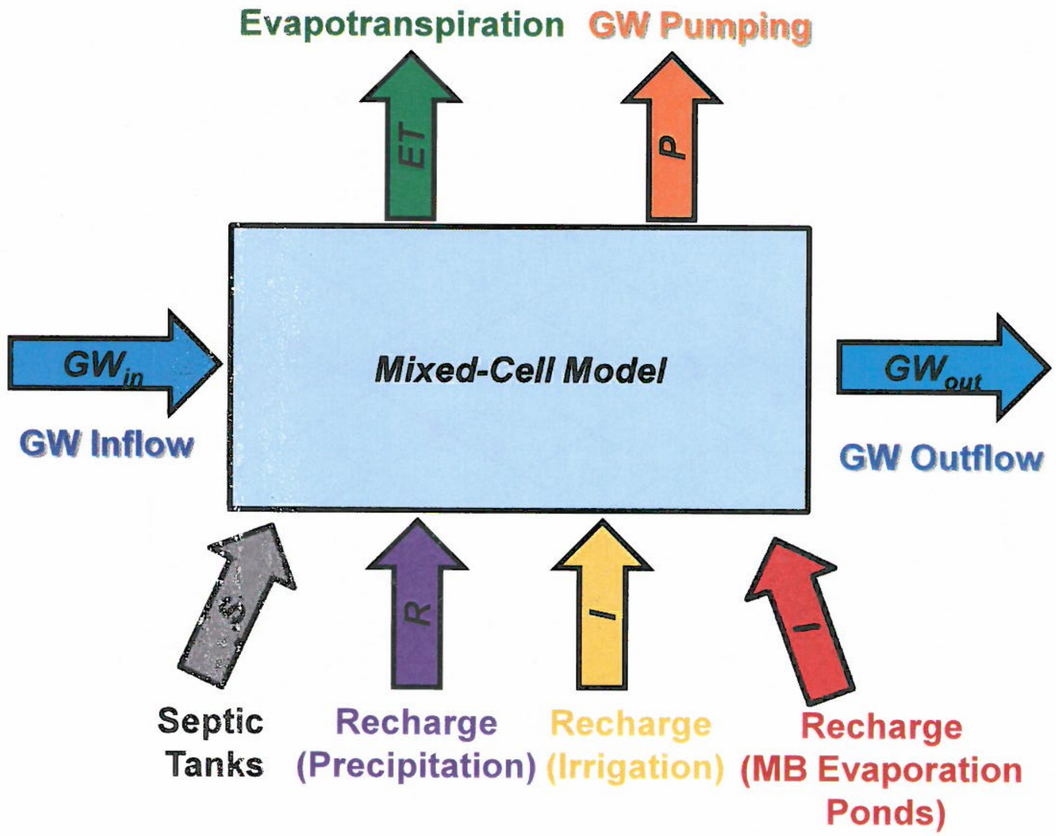
Figure 3-24

Conceptual Water Balance Model Constructed for Each Groundwater Subbasin



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Salt and Nutrient Management Plan
Twentynine Palms, California

Schematic Representation of Conceptual Water Balance Model

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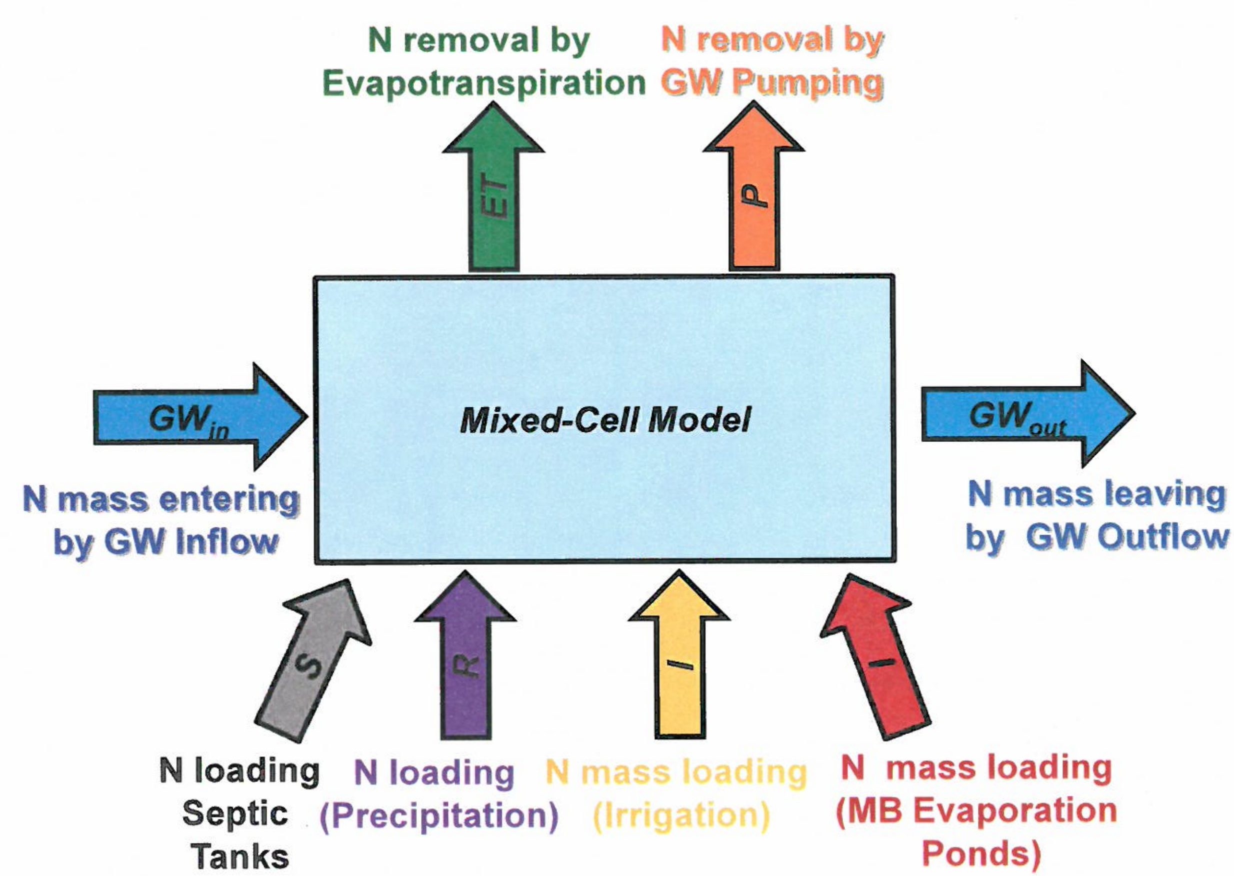
Figure 4-1

Conceptual Mass Balance Model Constructed for Each Groundwater Subbasin



Note: Nitrogen (N) is used to demonstrate the conceptual mass balance model.
Salt balance model is essentially the same and keeps track of salt (TDS) inflows and outflows.

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Salt and Nutrient Management Plan
Twentynine Palms, California

Schematic Representation of Conceptual Salt/Nitrate Mass Balance Model

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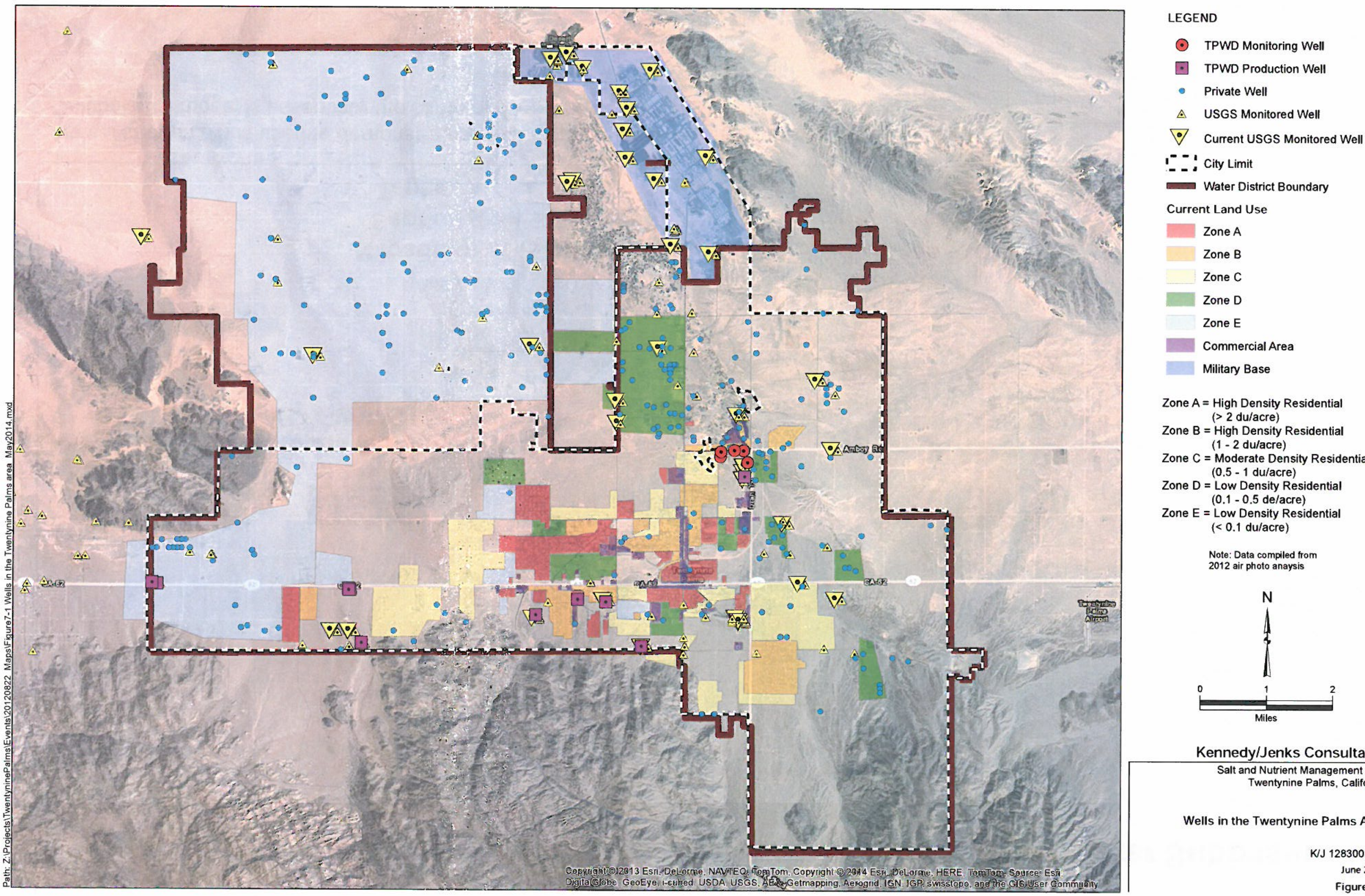
Figure 5-1



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Salt and Nutrient Management Plan
Twentynine Palms, California

Wells in the Twentynine Palms Area

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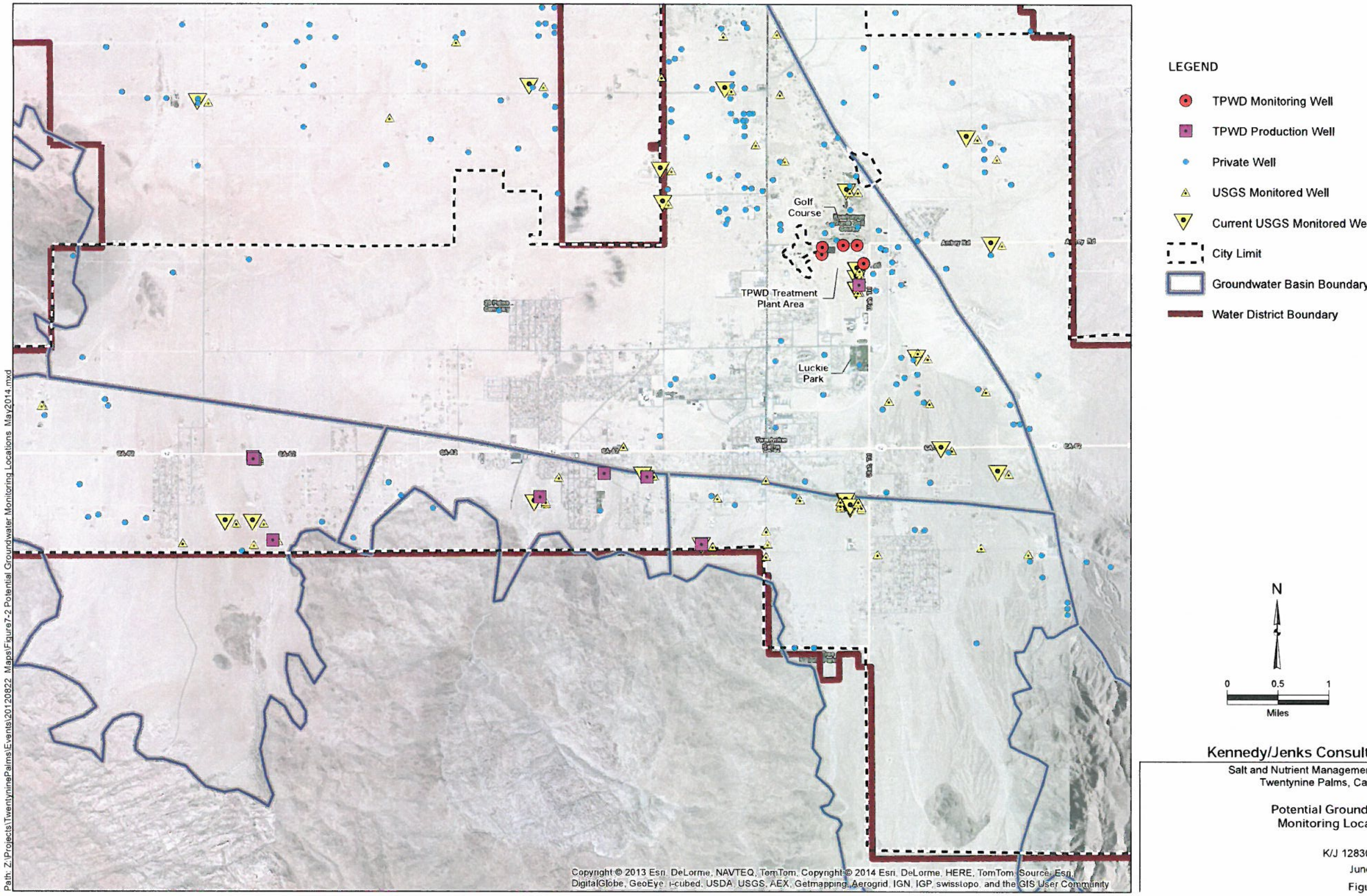
Figure 7-1



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Salt and Nutrient Management Plan
Twentynine Palms, California

Potential Groundwater Monitoring Locations

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Figure 7-2