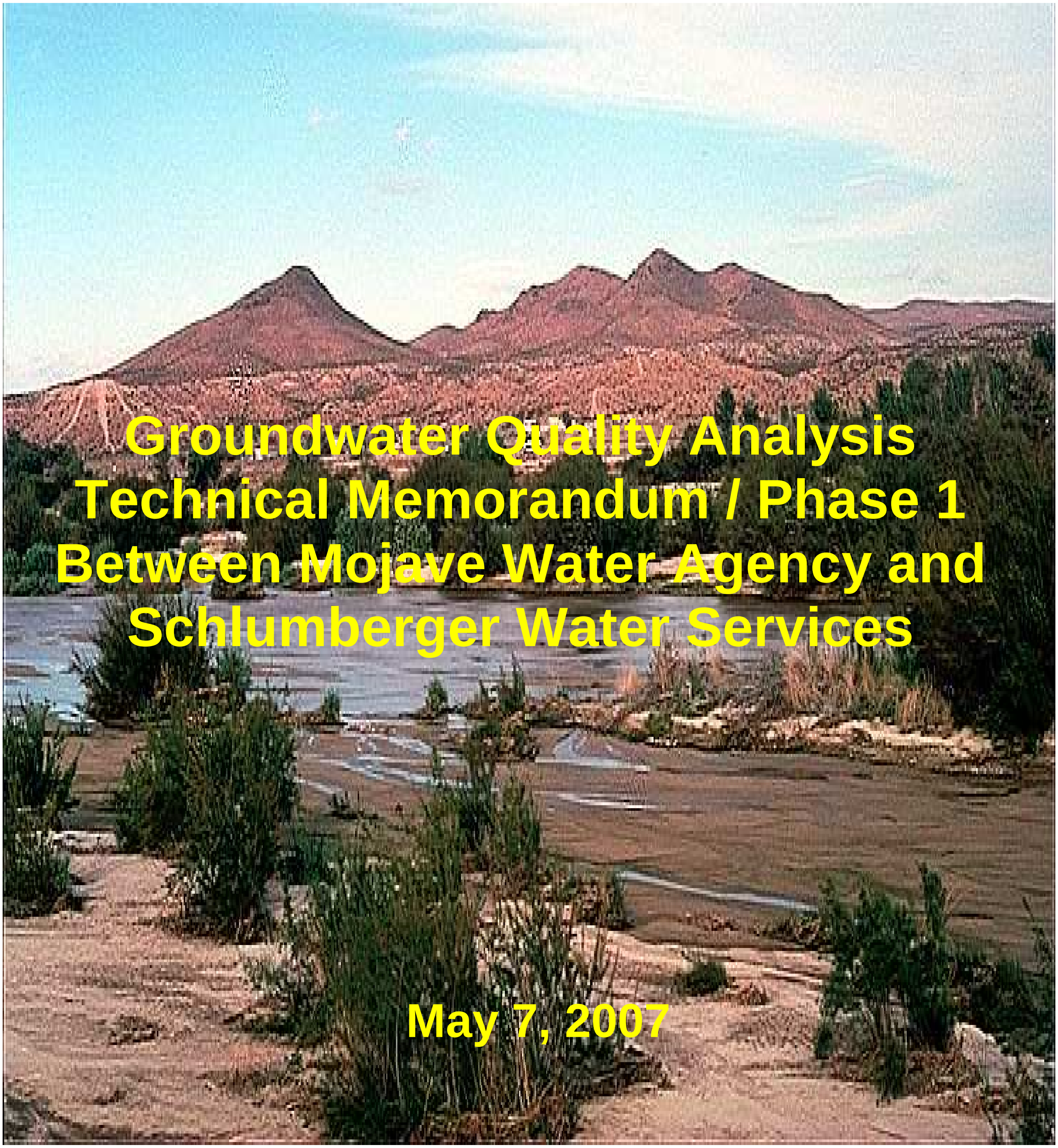


Groundwater Quality Analysis Technical Memorandum / Phase 1 Between Mojave Water Agency and Schlumberger Water Services

May 7, 2007

Mojave
Water
Agency

Schlumberger
WATER SERVICES

Table of Contents

Task 1 - Water Quality Data Compilation, Reconciliation, and Analysis

Task 2 - Requirements and Recommendations for the Initial Groundwater Quality Planning Model Platform

Table of Contents

Task 3 - Model User Reference Documentation: *Water Quality Planning Model User Reference Manual*

Task 4 - Water Quality Alternative Evaluation

Executive Summary

This report presents the results and recommendations of a technical study undertaken by the Mojave Water Agency (MWA), Lahontan Regional Water Quality Control Board (LRWQCB), a water quality technical advisory committee (WQTAC) made up of local stakeholders/water management professionals and professional staff from Schlumberger Water Services (SWS). The purpose of the study was to collect all of the viable historic water quality data for the MWA service area, determine the current native water quality within the many groundwater basins within the study area and develop a tool to forecast the regional effects of land use and water management practices within the groundwater basins with respect to salt concentrations or total dissolved solids (TDS). Over time, the use of water results in the introduction and concentration of salts within a groundwater basin. This is commonly referred to as "salt loading". Examples of sources of TDS introduction and concentration include wastewater, agriculture return flow and industrial uses. Imported water can also introduce salt mass into a groundwater basin because a certain amount of salt is dissolved in all natural waters. Therefore, any water brought into a basin from either the natural watershed or imported sources will introduce some salt mass into that basin.

One of the primary objectives of the study was to collect and assimilate all historic, reasonably available, water quality data for the region into one comprehensive relational database. The data collection effort resulted in 595,000 records spanning 1908 through October 2004. Data sources included MWA, United States Geological Survey (USGS), California Department of Water Resources, California Department of Health Services and the Environmental Protection Agency. These data were reviewed for quality assurance/quality control and carefully screened using both statistical and geochemical screening criteria. Following screening, approximately 474,000 records (approximately 23,700 individual samples) were accepted into the database. As part of the study, protocols were established with entities who continue to collect contemporary water quality data in the region and the MWA has developed a program to request and assimilate these data into the water quality database on a scheduled reoccurring basis.

The MWA, Lahontan and the WQTAC consulted other water management organizations who had undertaken similar regional water quality assessment programs. Based on a review of similar projects and the advice from other water resource management entities, the group chose the ISEE Systems Stella (Stella) modeling environment as the modeling platform. The Stella modeling platform was used during the MWA's regional water management planning process to predict the effectiveness of water management scenarios with regards to water supply. The hydraulic relationships in MWA's existing Stella model were built upon the calibrated USGS regional MODFLOW model and the Stella model could be expanded to accommodate regional water quality scenarios. The model was divided into 22 distinct management zones (aquifer sub-units). Each of the aquifer sub-units carried all of the natural water balance elements such as groundwater levels, groundwater flow direction and interbasin flow. Land and water use practices developed during the RWMP process such as population, land use, waste water management, groundwater pumping, water imports and conservation predictions were also included in the model.

All screened water quality records in the database were relegated to particular aquifer sub-units based on geographic location. The distribution and concentrations of TDS or total salt in groundwater was reviewed to determine the native concentration of TDS in groundwater within each of the sub-units. Of the 22 total modeled sub-units within the study area, 9 sub-units had average TDS values greater than the State Recommended Secondary Standard of 500 mg/L and 2 sub-units had average TDS values greater than the Upper Secondary Standard of 1,000 mg/L. In general, sub-units near sources of recharge such as the Mojave River or the San Bernardino and San Gabriel Mountains have average TDS concentrations lower that those basins located away from sources of appreciable natural recharge.

Once the Stella model was modified to accept water quality and aquifer sub-unit water quality baselines were established, MWA, Lahontan and the WQTAC developed distinct water management scenarios to test long term regional TDS changes and their relation to specific water management practices. The scenarios were chosen in order to estimate the effects of water use/water management actions and their associated TDS changes in individual basins. Each of the model scenarios used all of the land use, population, wastewater and other associated management assumptions developed in the MWA's RWMP.

A total of five scenarios were developed by MWA, Lahontan and the WQTAC and tested with the model. The five scenarios consisted of a no SWP import case along with four other water management scenarios which included the importation of SWP water. The four scenarios that included SWP imports modeled a combination of power plant, centralized and satellite wastewater treatment plants, water reclamation and focused recharge and pumping. Each of the tested scenarios was run for 25, 50 and 70 years. All of the scenarios, with the exception of the no SWP scenario, were developed based on projects that were either in the conceptual phase or design phase and had a strong potential of being implemented at some future date. All of the modeled scenarios maintained population projections and land use assumptions as outlined in the RWMP. These assumptions were modified and carried forward for the 50 and 70 year modeled scenarios

Modeled results of the scenario testing indicate that most sub-aquifer units maintained a steady TDS trend over time (continuous increase or decrease in TDS). TDS concentrations generally increased over time in the sub-aquifer units which is to be expected. Man made sources/concentrations of TDS (domestic use, septic tank discharges, industrial discharges, agricultural return flow, etc.) are the primary factors for water quality degradation and increases in TDS concentration. As water is used and reused, salts are added or concentrated in the water and these salts will accumulate in the basin as wastewater and return flow is recharged back into the aquifer sub-units. Model results showed that SWP generally acts a diluting agent which slows the TDS increases in the sub-aquifer units. In general, without the importation of SWP, the majority of sub-aquifer units would increase in TDS concentration at a faster rate. TDS concentrations in groundwater basins are expected to change over time. The assimilative capacity of each individual basin "the ability of the surface and groundwater system to sustain long term influx of TDS from internal and external anthropogenic sources" will vary depending on the native water quality of each basin, the degree of utilization of the basin and yet to be determined regulatory policy. This model will be important in assisting with the determination of the assimilative capacity of each basin. Model findings would suggest that basin(s) assimilative capacity may be managed through monitoring, modeling and management actions. The results of all modeled scenarios are presented and discussed in Sections 4 and 5 of Task 4.

More extensive modeling can be performed in the future as regional resource management entities coordinate long term data collection efforts. The purpose of the model as it is currently configured is to be used as a regional tool to predict long term changes based on large scale and long term resource management actions. More refined and project specific modeling would benefit from continued collection of water quality data from multiple sources into one data repository. Furthermore, efforts should first be made to fill data gap areas identified during the modeling process with appropriate monitoring wells. A more formal and robust centralized data collection program supported by multiple regional resource management entities will facilitate more comprehensive and discrete potential future modeling efforts.

Mojave Water Agency

Groundwater Quality Analysis

Phase 1 / Task 1

Water Quality Data Compilation, Reconciliation, and Analysis

Technical Memorandum

March 21, 2005

Schlumberger
WATER SERVICES

List of Figures

List of Tables

1

Introduction

This draft technical memorandum fulfills Task 1g of Phase 1 of the Mojave Water Agency (MWA) Groundwater Quality Analysis project. The objectives of project Phase 1 are:

- To assess and characterize the current and historical concentration of salinity in groundwater throughout the basin.
- Identify and describe areas of historically poor quality and areas exhibiting notable changes in salinity concentrations over time.
- Analysis of the overall sufficiency of available data towards the development of water quality planning model.
- Make recommendations for data collection procedure and identify sources of water quality data for ongoing data collection.

This memorandum documents the process undertaken to reconcile and compile all water quality data in the MWA service area, discusses historical water quality trends, and assesses the overall sufficiency of available data towards the development of a water quality planning model. Specific objectives, deliverables, and results for each project sub-task are described in the following sections. Section 7 of this memorandum contains our overall findings with regard to the suitability of the current database for salt balance analysis, as well as recommended procedures for further data collection.

2

Task 1a: Potential Sources of Water Quality Data

2.1 Objectives

Identify and investigate potential sources of water quality data. Identify a list of potential sources that may possess water quality data pertinent to the MWA service area. Investigate each potential source of water quality data and determine the usefulness of the data provided by each potential source.

2.2 Deliverable

A list of regulatory agencies and contacts with applicable water quality data in the MWA service area.

2.3 Results

This task was accomplished through a combination of the following methods:

- Review of existing datasets.
- Web based search.
- Email queries and phone communication with relevant agencies.

We believe that the resulting compilation of data sources represents the vast bulk of water quality data resources currently available. Some but not all of these data resources are periodically updated. Some resources are accessible online, facilitating easy update of a consolidated Mojave Water Agency database. In the case of data from the Department of

Health Services, geo-referencing information is not available to the general public. Efforts to obtain this information are ongoing.

USGS

Online System:	NWIS information server
Link	http://waterdata.usgs.gov/nwis

Contact:

Tom Haltom – Public Relations Officer (Sacramento)
Julia Huff – San Diego office
Ph: (858) 637-6823
Email: jahuff@usgs.gov

Comments:

- Online NWIS data only current to beginning of year.
- Up-to-date data in electronic format may be requested from the USGS.
- Special data requests will receive newer data with "preliminary" status.
- Cooperating agencies will get more data than available to the public.
- Future data updates in electronic format may be requested from Julia Huff at the USGS San Diego office.

CalEPA

The State Regional Water Quality Control Boards and the Department of Toxic Substance Control fall within the purview of CalEPA. The CalEPA also administers the GeoTracker system, an on-line database of LUFT (Leaky Underground Fuel Tank) and LUST (Leaky Underground Storage Tank) monitoring data.

Lahontan Region Water Quality Control Board (Region 6b)

Primary URL:	http://www.swrcb.ca.gov/rwqcb6/
Online System:	None

Contact:

California Regional Water Quality Control Board, Lahontan Region
15428 Civic Dr., Suite 100
Victorville, CA 92392
Phone: (760) 241-6583
Fax: (760) 241-7308
Attn: Hisam Baqai, (760) 241-7325
Mike Plaziak, (760) 241-7404
mplaziak@waterbaords.ca.gov

Comments:

- Lahontan RWQCB database developed as part of the Mojave Watershed water quality study.
- No samples or database updates after November 2001.
- No further water quality data available and no currently ongoing sampling program.

Colorado River Water Quality Control Board (Region 7)

Primary URL: http://www.swrcb.ca.gov/rwqcb7/
Online System: None

Contact:

California Water Quality Control Board, Colorado River Region
73-720 Fred Waring Drive, Suite 100
Palm Desert, CA 92260
(760) 346-7491
fax (760) 341-6820
Attn: Sheila Ault (760) 776-8960
Leanne Chavez (760) 776-8945

Comments:

- Colorado River RWQCB does not have any formal ongoing water quality sampling program.
- Landfill sites are monitored. Contact Leanne Chavez.
- Obtained 20 paper record water quality analysis records from Leanne Chavez.

GeoTracker

http://www.geotracker.swrcb.ca.gov/

Comments:

- Public wells removed from public access.
- Contains many MTBE's as well as TDS, Hardness, and some other inorganic constituents.
- Does not contain state well numbers. Need to be cross-referenced.

Department of Toxic Substances Control

No water quality monitoring.

Department of Water Resources (DWR)

Online System:	Water Data Library
Link:	http://wdl.water.ca.gov/wq/gst/water_quality_report1_gst.asp

Contact:

State Water Project Water Quality Program
P.O. Box 942836
Sacramento, CA 91236
(916) 653-9978
Attn: Dan Peterson – Chief, email: danp@water.ca.gov
Bruce Agee – On-line database support
(916) 375-6008

Eric Senter – WDIS database support
(916) 651-9648
esenter@water.ca.gov
Bob Pierotti – Southern Region
(818) 543-4621

Comments:

- Online data is approximately 1 month old, focused on surface water.
- Legacy DWR dataset is WDIS (Water Data Information System). No on-line link available. WDIS database for San Bernadino County received on CD ROM from Eric Senter, free of charge.
- No ongoing Mojave ground water quality sampling program according to Bob Pierotti.

California Health and Human Services Agency (DHS)

Contact:
Department of Health Services (DOHS)
Division of Drinking Water and Environmental Management
Drinking Water Program
PO Box 997413, MS 7416
Sacramento, CA 95899-7413

Dr. Steven Book	(916) 449-5556
Anthony Meeks	(916) 449-5568
Leah Walker	(707) 576-2295

Comments:

- Water Quality Monitoring Database available on CD ROM, Cost: $100.00.
- Data available from 1980s to current (2 weeks old).

- Water agencies’ data. Drinking water only.
- No coordinates or Township/Range indicators for reasons of public safety and security, per A. Meeks.
- Data set through 10/2004 received from DHS. Many of the records in this dump were usable through cross-indexing against 2001 station list received from DHS prior to moratorium on distributing station information. Refer to section 3 of this memorandum for details.

United States EPA

Online System:	STORET
Link:	http://www.epa.gov/storet/dbtop.html

Eric Wilson (415) 972-3454
wilson.eric@epa.gov

Comments:

- Batch downloads using flexible query engine.
- Mutually exclusive with USGS.
- Common code conventions with USGS.
- “Legacy” database contains data through 1999
- “Modernized” database contains data after 1999
- Legacy database has extensive WQ data for Mojave, but without sample depths.
- Modernized database has no data from the Mojave area. No agencies contributing data in this area.
- District 9 (including California) STORET Coordinator is Eric Wilson.

3

Task 1b: Data Compilation

3.1 Objectives

Compile available existing water quality data from agencies possessing relevant data that is not currently in the possession of SWS or MWA.

3.2 Deliverable

N/A

3.3 Results

Database Software – Raw water quality data files from contributing agencies were pre-processed using Microsoft Access, and then stored in an SQL database. Preprocessing of input datasets included the outlier exclusion and redundancy checks described in the following sections. Access was selected as the software platform for data pre-processing because of its flexibility in editing and modifying databases. However, the final water quality data table was very large, resulting in performance problems for Access. Further, once the water quality table was constructed, the editing capabilities of Access were not required on a routine basis. Microsoft SQL Server was selected as the final database platform for the following reasons:

- Schlumberger-Waterloo Hydrogeologic has developed a specialized interface to SQL Server for hydrogeologic and water quality applications. This interface has extensive querying and mapping capabilities which will be very useful during Task 2 of this study.

- Other hydrogeological data compilation efforts currently being conducted for MWA are based on SQL Server. The use of SQL Server for the water quality database will greatly facilitate future integration of these efforts.

Raw Input Data Summary – The following datasets were compiled into the water quality database:

- DHS – A recent comprehensive collection of water quality data through October 2004 was obtained from DHS. No associated georeferencing data or state well numbers were provided, nor is such information forthcoming. The only station reference field available with this data is the DHS internal station reference code (FDRS). However, in 2001 Schlumberger Water Services (SWS) received a similar data set from DHS. Since this earlier data set was received before the current moratorium on providing georeferencing information, that data set both the DHS FDRS number and state well numbers. This 2001 information was used to develop a cross index between FDRS and state well number which was applied to the 2004 dataset. In this way it was possible to extract data through October 2004 for all wells that were in existence at the time of the 2001 data set. This results in the omission of only data from wells brought into operation after that time.
- NWIS – A dataset was received from the USGS San Diego office in January of 2005 and incorporated into the water quality database.
- STORET - Data were downloaded from the legacy on-line STORET database using a latitude-longitude limited geographic query. The area used was slightly larger than the maximum extents of the MWA area. Wells outside the MWA area are filtered out prior to database analysis. As discussed above in Section 2, the post-2000 “modified” STORET system has no water quality data for the MWA area.
- WDIS – Legacy data received from DWR for all of San Bernadino County. Wells outside the MWA area are filtered out prior to database analysis. No more current groundwater quality data is available from DWR.

Input Dataset File Structures – All data sets were received in ASCII text file format. The term "record" is used here to describe one line of a data file. A record of an input data file may contain station or sample descriptive information, or the result of the laboratory analysis or computation for an individual constituent. All data sources conformed to the USGS/STORET standard five digit numerical parameter code convention. Most parameter codes correspond to constituents, although some correspond to sampling event parameters or well descriptive information. Each record of each input dataset has an associated parameter code. Approximately 400 parameter codes are included in the combined dataset. A complete list of parameter codes and their descriptions is located in Attachment 1.

A single water quality sampling event may provide multiple water quality records corresponding to multiple water quality constituents and associated sample event and well description information. Multiple records for a single sampling event were correlated through a unique sample event code in each record. All input records also contained the sample time and date.

Quality Assessment Data – The input datasets contained various types and quantities of quality assessment information associated with each parameter code record. These are:

- Constituent analysis *remarks*, available for NWIS, DHS, and STORET data and which follow common conventions. This field serves as a modifier to the analytical or computational result for the constituent. The NWIS, DHS, and STORET and STORET remark field conventions have many similarities, but not entirely identical.
- Composite sampling statistic code, available as a separate field in the STORET dataset and included in the cumulative water quality database as a separate field. However, this field is only populated for the records input from the STORET data source.
- Selected non-constituent parameter codes such as sampling agency, sampling method, QA method. These are present to differing degrees in all input datasets. These parameter codes are included as separate records in the database with the appropriate associated parameter codes. These codes are included in Attachment 1.

The cumulative water quality database contains two fields for quality control indicators. One field carries the remark field which is common to NWIS, DHS, and STORET databases. The second field carries the composite statistic field which is unique to STORET data.

***Data Import* -** All data from all sources were imported into Microsoft Access using standard external data import functions. Once imported into Access, all individual water quality tables were reformatted to a common format with State Well Number as the primary key. As part of this reformat, an additional field was added to each table for use in later data redundancy elimination steps. This field carried information used to rank the quality control information contained in each input dataset. The value of this field was determined by the number of quality control fields in each input data source. DWR data, having no data quality fields, was ranked 3. DHS data having 1 data quality field, was ranked 2. USGS and STORET data, having 2 data quality fields, were ranked 1. The role of this field in redundancy elimination will be described in a later section.

After standardization of format, all input tables were appended together into a single table. This appended table contained some wells outside the MWA operational boundary resulting from limitations in the source dataset query capabilities, and redundant instances of water quality constituent result values caused by duplication between the input datasets from contributing agencies. These extra and redundant data were filtered out using the methods described in the following sections.

***Elimination of Data Outside of the MWA Operational Boundary* –** Wells outside the MWA operational boundary were eliminated on the basis of township, range, and section. A master table of all township, range, and section numbers within the MWA operational area, plus a five mile surrounding buffer, was created using a Graphical Information System (GIS). Within the appended water quality table, township, range, and section were extracted from the state well number field and fields created for these values. An SQL query was performed on the water quality database to select only records having township, range, and sections found in the master table. This method did not use a pre-determined station list and did not presume any prior knowledge of stations in the MWA area. Prior to elimination of redundant samples, the resulting water quality data table contained approximately 595,000 records.

Redundancy Check – Manual inspection revealed that redundancies existed between raw input datasets resulting in multiple instances of the same data sample. In light of the vast amount of data at hand, manual elimination of such redundancies was impractical. A scheme was devised in which a unique identifier field was created for each record in the water quality database. This field was created by appending together state well number, sample date, and parameter code for each record. Using this identifier, instances in which two separate records existed for the same parameter code at the same well on the same date were easily identified using the "find duplicate" query capability in Access. This facilitated the creation of a unique water quality sample table. The find duplicate query was further constrained to select the record with the best quality indicator field as described in an earlier section, resulting in selection of the record containing the greatest amount of information in the data quality fields. Table 3.1 lists the contributions of the different data sources to the final water quality data table.

Table 3.1 – Raw input data summary after elimination of stations outside the MWA area and redundant records.

Data Source	Approx. Total Records
DHS	193,000
NWIS	163,000
STORET	38,000
WDIS	80,000
TOTAL	474,000

4

Task 1c: Data QA/QC

4.1 Objectives

Perform QA/QC and reconcile to promote data integrity. After the compilation of all water quality data received, conduct a rigorous quality assurance/quality control of all water quality data received pertaining to the MWA service area. This primarily entails the removal of data that is duplicated, erroneous, and questionable. Review water quality naming conventions and reporting units to identify inconsistencies.

4.2 Deliverable

Documentation of the QA/QC process including all assumptions and methods used to evaluate the water quality data received, and recommendation of a composite list of water quality parameters with naming conventions and standard reporting units.

4.3 Results

Global QA/QC was performed using a combination of statistical and graphical tools. Statistics were calculated for the total sample population as well as on subsets of the population sorted by both data source as well as hydrological sub-area.

Ideal Sampling Characteristics – Global QA/QC was performed on the water quality database for two primary purposes. First, the QA/QC process was necessary to purge inconsistent, redundant, and erroneous data as stated in the task objectives. Second, the QA/QC process was the first step in defining the sampling characteristics of the dataset with respect to those required for future predictive water quality modeling activities. The concept of an ideal set of sampling characteristics was introduced in order to provide a framework for evaluating the suitability of the database for different types or levels of modeling. The spectrum of models which might be employed range from a simple steady state mass balance model to a calibrated transient mass transport model. Water quality data is only one component of the full dataset required for these models. Modeling options and their respective data requirements will be discussed in Section 7 of this memorandum. Table 4.1 lists key water quality sampling characteristics selected for this assessment along with respective worst and best case conditions.

Table 4.1 – Worst and best case sampling parameter characteristics

Parameter	Worst Case	Best Case
Station Location	Not surveyed, only estimated from Township-Range-Section and centroid of a sixteenth section	Exact surveyed location
Sample Frequency	Single sample or sampling station	Systematic repetitive sampling depending on variability and seasonality. Should be adequate to capture variability for model calibration
Period of Record	Single, old sample	Long duration, including recent
Sample Depth	Depth of hole, no explicit sample depth	Known measured sample depth and perforated interval
Sample QC	Only sample value, no QC indicators	Analysis method, Method Detection Limit, and quality remark code
Spatial Distribution	Clustered	Generally even and widely distributed, also depth specific with data adequate to characterize deep zones
Water Level	Non-existent	Adequately sampled hydrographs for all wells. Sampling frequency dependent on magnitude and frequency of water level fluctuations

Quality Control Data – A realistic expectation for sample quality control would be a report of analysis method, detection limit, and how non-detection is reported. Quality control data may be specified for the entire sample, or for individual constituent result values. Quality control data at the sample level is carried in various special parameter codes. These data are present as individual records in the database, and are related with the constituent result value records through the State Well Number and unique sample identifier. Quality control information at the individual constituent result level, where it exists, is carried in separate fields of the water quality constituent record in the database. The following is a brief review of the availability of quality control information by data source:

- WDIS – The WDIS data received from the DWR contains records with standard parameter codes for quality control data at the sample level, but has no additional fields for quality control data at the individual constituent level We are advised by the DWR that this information is not in the WDIS database and, if exists at all, is in hard copy form in laboratory test reports. Collection and manual entry of this large body of information to the database is beyond the scope of this study. The redundancy check described in Section 3.3 was designed to minimize the DWR contribution to the database whenever possible without losing unique sample data.
- NWIS – The USGS NWIS database has records with sample quality control parameter codes, and an additional *remark* field which carries modifier to the value in the result field of individual constituent records. Valid values for the *remark* field are listed in Table 4.2.
- STORET – The EPA STORET database has records with sample quality parameter codes, and two fields with constituent level quality control data. One of these fields is a remark sharing a more or less common convention with the NWIS database remark. The other is a composite statistic code for each constituent.
- DHS – The DHS dataset carries records with sample quality control parameter codes and a remark field using a convention in common with the NWIS and STORET datasets.

Table 4.2 - Valid NWIS remark field codes

Code	**Description**
<	Actual value is known to be less than the value shown
>	Actual value is known to be greater than the value shown.
A	Average value
E	Estimated value
M	Presence of material verified but not quantified
N	Presumptive evidence of presence of material
S	Most probable value
V	Value affected by contamination
U	Analyzed for, not detected

There are a total of 23,700 unique samples in the database. The database may contain several individual constituent records related to each of these samples. Since the database contains approximately 474,000 individual constituent records, the average number of constituents per sample is approximately 16.5. Table 4.3 below contains a summary of key sample quality control parameter code records in the cumulative database. Note in Table 4.3 that a relatively small proportion of samples have quality control parameter codes. The remark and composite statistic fields are not reported in this table because the absence of a value in these field in not in itself indicative of any condition.

Table 4.3 – Summary of sample quality assurance records

Parameter	USGS Code	No. Records
Water Level	70019	479
Collecting agency code	00027	4501
Top of sample interval	72015	27
Bottom of sample interval	72016	36
Analyzing agency code	00028	2175
Sampling method code	82398	247
Sample depth	00003	17

***Well Construction Data* –** The input datasets contained very limited information about well construction other than latitude and longitude. This available information is summarized in Table 4.4 below.

Table 4.4 – Summary of well construction data

Parameter	USGS Code	No. Wells (of 7422)
Georeference	N/A	7422
Elevation	72020	12
Depth of Hole	72001	387
Depth of Well	72008	164

Some additional information is available for wells in the NWIS database available upon request from the USGS through a separate query. These additional data have been reviewed and considered for entry to the database. However, it is felt that the SQL database being prepared for MWA through other projects[1] will be the most reliable source for well construction information. Linking of the water quality database with this other source of well construction will be facilitated by the common use of the SQL Server platform. In most

---

[1] See Section 3.3

cases it will be necessary to estimate sample depth from perforation intervals described in the well construction database.

Spatial Data Distribution (TDS Only) – Figures 4.1 to 4.3 show the distribution of TDS samples within the MWA area. The size of the symbol in Figures 4.1 to 4.3 are proportional to average, standard deviation, and average period of record respectively for available samples at each station. Period of record is the time in days from the first to the last TDS sample inclusive for each station. These figures show fairly good coverage in the principal aquifer units with the exception of parts of the Centro and Transition Zone sub-areas, and Morongo Basin. The vast majority of all TDS data is concentrated along the Mojave River and around main population centers.

Drinking Water Standards – The California Department of Public Health has established recommended and upper secondary drinking water standards for TDS of 500 mg/L and 1,000 mg/L respectively.

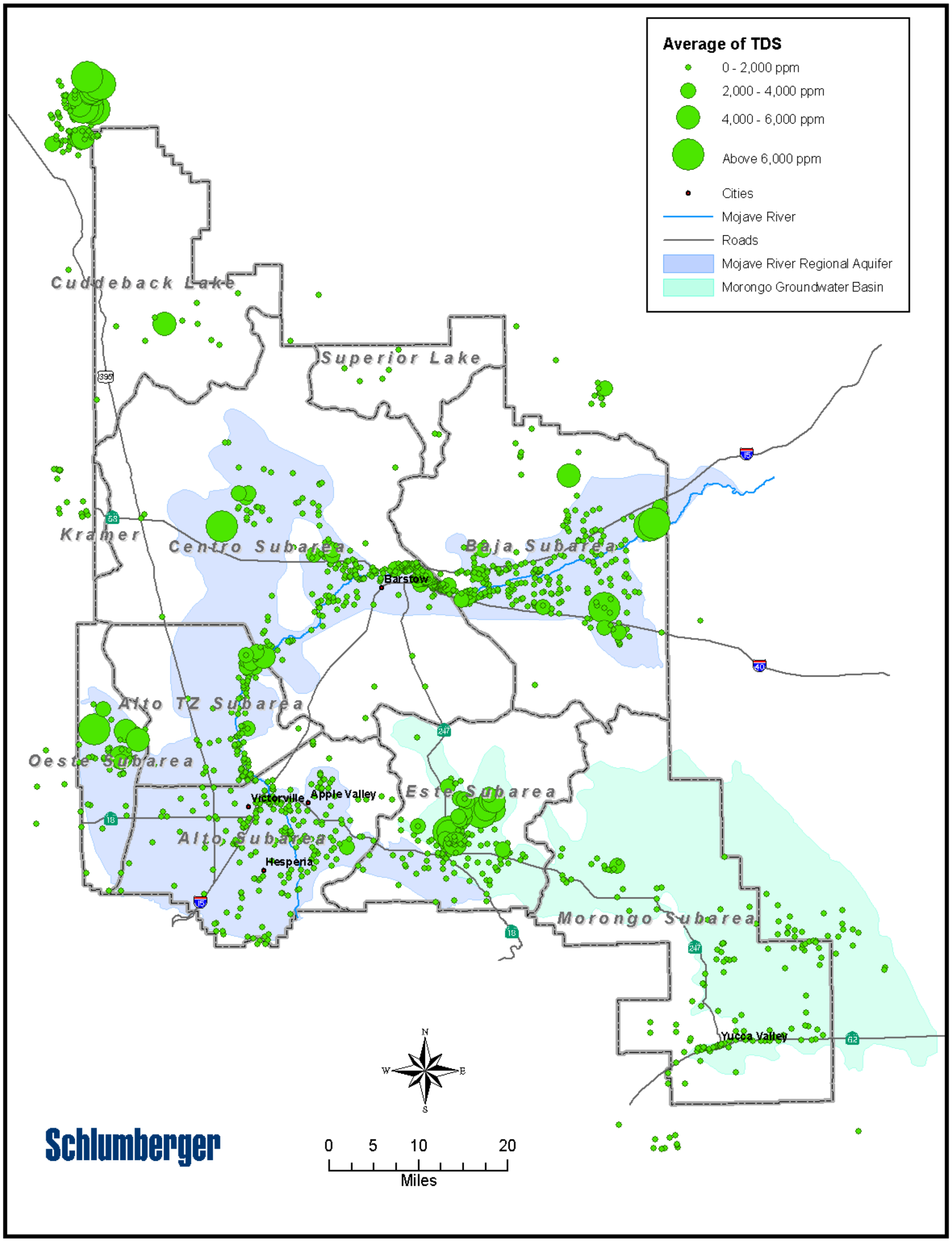


Figure 4.1 – Well locations with TDS samples. Symbol radius is proportional average TDS (ppm).

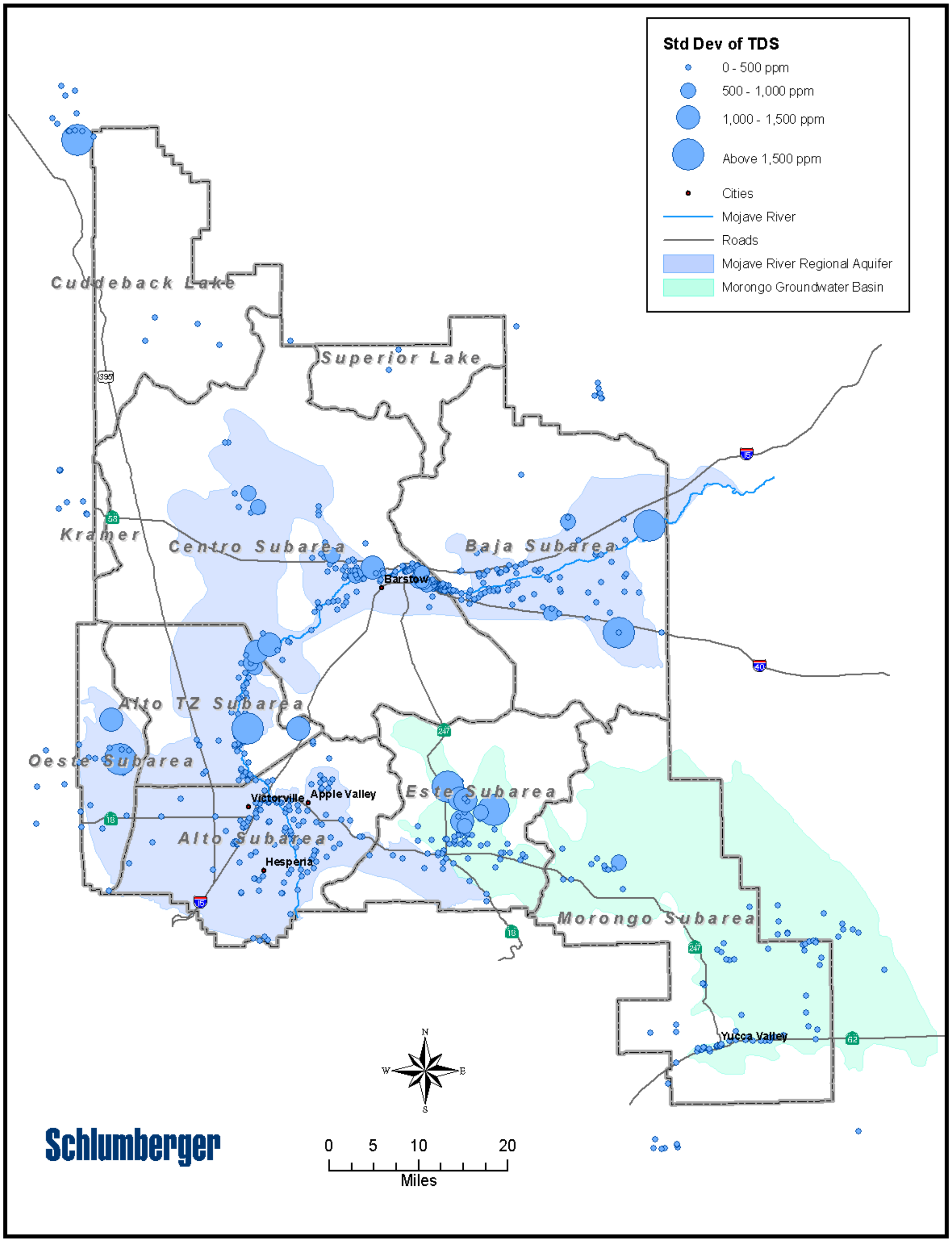


Figure 4.2 – Well locations with TDS samples. Symbol radius is proportional to standard deviation of TDS (ppm).

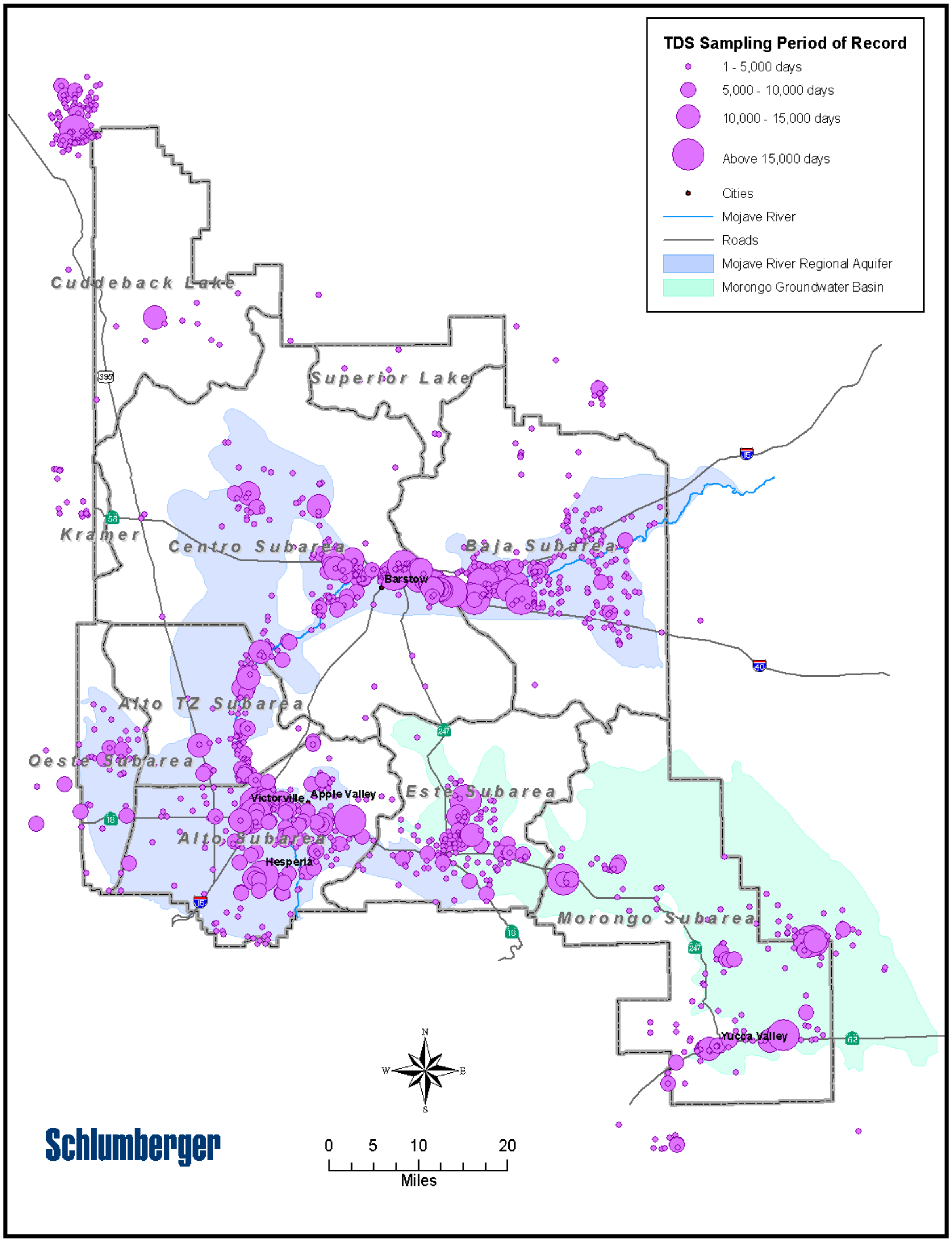


Figure 4.3 – Period of record period of record for TDS samples (Days).

***TDS Sample Population Statistics by Data Source* –** Table 4.5 lists the statistical summary of raw TDS samples by data source. The STORET legacy database was the largest single data source, followed by the NWIS and legacy DHS databases. The WDIS database from the DWR made only a small contribution, because of a high degree of redundancy with the NWIS database and because of the exclusion of DWR water quality records in favor of other sources due to lack of associated quality assurance data. It is notable that the lowest average TDS level is seen in the DHS samples. This is expected as a result of that agency's preferential sampling of drinking water wells. None of these averages exceeds the Department of Public Health upper secondary drinking water standard of 1000 mg/l.

Figure 4.4 shows a TDS exceedance plot for all data sources. Exceedance plots show the percentage of the dataset (horizontal axis) which exceeds a given value (vertical axis). While both NWIS and DWR datasets exhibit high TDS samples at low exceedance percentages, the DWR dataset shows persistently high values up to an anomalous drop at approximately 35 percent exceedance. Errors in units and data import have been eliminated as potential reasons for this anomaly. This anomaly may be caused by a true sampling bias and further amplified by the relatively small number of data points in the WDIS dataset. TDS levels in the NWIS dataset drop off quickly to levels equal to other datasets at exceedance of less than 5 percent. This may be interpreted as the effect of a limited number of anomalously high data points in the NWIS dataset, possibly sampled in the vicinity of dry lakes. These anomalies will be further investigated during Task 2 of this study.

Table 4.5 – TDS Sample statistics by data source

Source	Total Samples	First Date	Last Date	Average Period of Record (days)	Average TDS (mg/l)	StDev (mg/l)	% Exceeding 1000 mg/l
DHS	1,991	7/11/1956	7/19/2004	5,259	305	236	4
NWIS	2,934	7/21/1908	10/18/2004	2,078	709	1,340	15
STORET	4,186	5/7/1951	11/24/1986	2,733	580	510	9
WDIS	113	7/6/1932	1/12/1990	3,842	660	782	15
All	9,224	7/21/1908	10/18/2004	3,087	624	993	13

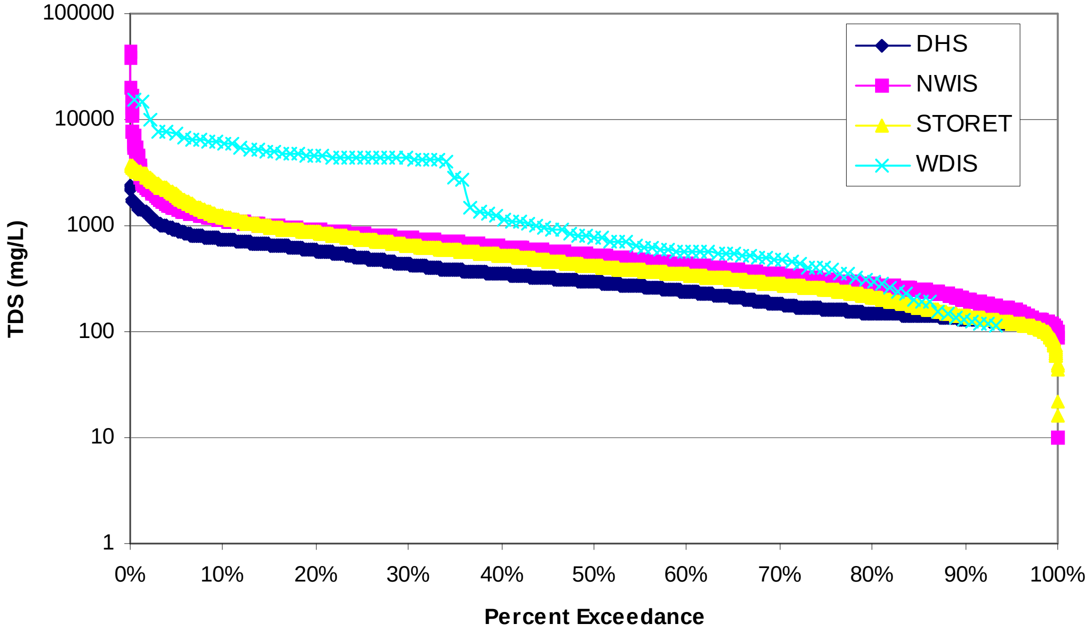


Figure 4.4 – TDS exceedance plot by data source

TDS Sample Population Statistics by Sub-area – Table 4.6 lists the statistical summary of TDS samples sorted by sub-area. The Alto sub-area exhibits the lowest overall average TDS level and is also closest to recharge sources such as mountain fronts and the Mojave River headwaters. The Este sub-area has the highest TDS and greatest variability. Figure 4.5 shows the exceedance plot for TDS by sub-area. The highest isolated levels are observed in the Baja sub-area, dropping off quickly at less than 5% exceedance. The persistently high levels are observed in the Este data, while persistent lowest values are observed in the Alto data. Although the TDS level in Centro is higher than in Este at high exceedance levels, the variability of the Este data is greater than that of the Centro data.

Table 4.6 – TDS sample statistics by sub-area

Sub-area	Total Samples	First Date	Last Date	Avg of Period of Record (days)	Avg of Result (ppm)	StDev of Result (ppm)	% Exceeding 1000 ppm
Alto	1,829	9/21/1942	10/18/2004	2,703	291	2,323	3
Baja	1,215	8/20/1916	10/13/2004	1,804	627	294	9
Centro	2,142	7/21/1908	10/14/2004	2,557	713	436	18
Este	1,048	2/28/1952	5/10/2004	2,137	969	1,104	26
Morongo	910	3/19/1951	7/14/2004	1,903	387	403	5
Oeste	165	5/17/1951	5/17/2004	2,214	725	1,436	10
Transition Zone	575	3/7/1942	10/14/2004	1,798	801	835	20
ALL	7,884	7/21/1908	10/18/2004	3,087	624	993	13

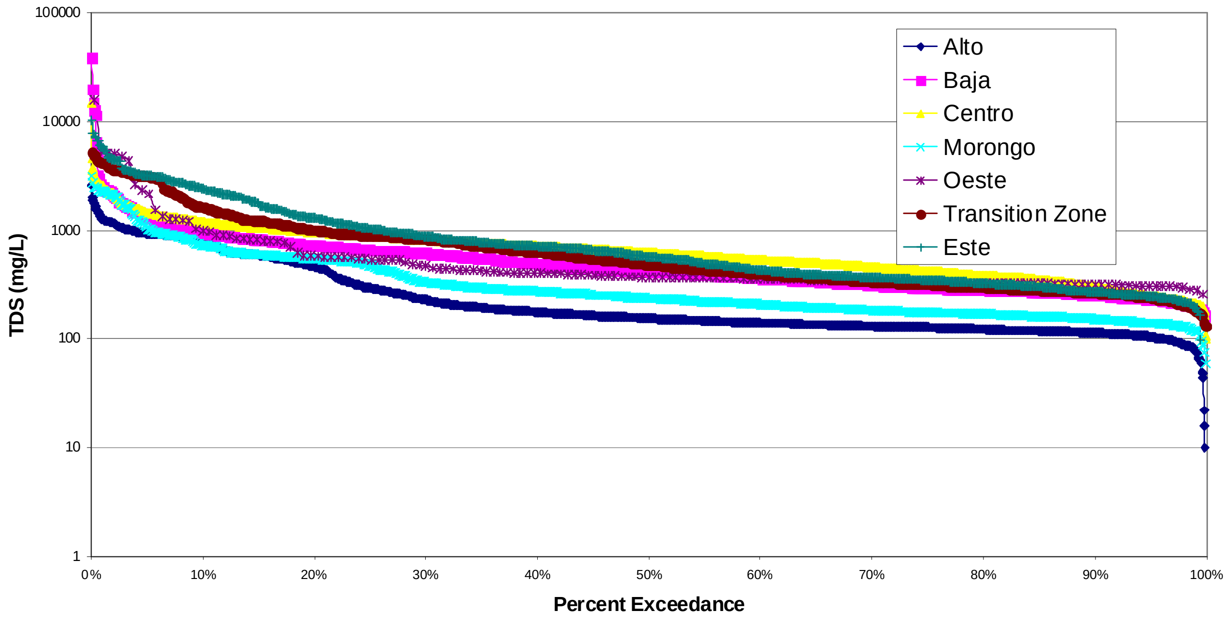


Figure 4.5 – TDS exceedance plot by sub-area

Regional Water Management Plan Sub-areas – The delineation of sub-areas within the Mojave Basin were further refined as part of the MWA Regional Water Management Plan (RWMP) prepared by MWA. These refinements were based upon additional hydrogeological considerations such as the proximity to boundaries with adjacent sub-areas, major aquifer unit, and the inclusion of non-adjudicated sub-basins. Table 4.7 describes the distribution of stations and overall statistics for TDS in the database by RWMP area.

Table 4.7 – Number of stations ad TDS statistics by RWMP sub-area.

RWMP Area	Number of Stations in Database	Number TDS Records	Average TDS (mg/l)	TDS Std Dev (mg/l)
Alto Floodplain	320	278	168.6	62.2
Alto Left Regional	93	93	352.5	128.3
Alto Mid Regional	357	796	140.1	33.2
Alto Right Regional	393	410	616.7	345.4
Baja Floodplain	556	847	650.4	1667
Baja Regional	459	346	548.9	592.5
Centro Floodplain	992	1737	705.9	378.6
Centro Regional	501	286	641.9	984.3
Copper Mountain Valley Subbasin	152	264	227.2	123.8
Este Regional	156	189	495.3	328
Harper Lake Regional	185	98	1175.5	728.7
Johnson Valley Subbasin	81	208	900.5	563.8
Lucerne Basin	495	819	1095	1212
Means/Ames Valley Subbasin	110	77	269.2	92.4
Narrows Floodplain	105	194	191.3	117.6
Oeste Regional	295	138	747.1	1566.5
Transition Zone Floodplain	482	364	891.7	851.8
Transition Zone Regional	245	205	620.3	758.5
Warren Valley Subbasin	83	291	217.8	80.1
Other	1361	725	848	1910.3
Total	7422	8365	626.2	1005.3

5

Task 1d: Data Integration

5.1 Objectives

Integrate all data into standard format with MWA staff to incorporate in MWA database. Work closely with MWA staff to develop a standardized format for archiving and accessing water quality information that is compatible with the current MWA database.

5.2 Deliverable

Digital water quality data reconciled and compiled in Tasks 1b and 1c.

5.3 Discussion

After pre-processing of raw input data as described in Section 3, all station, sample events, and constituent result values were imported into an SQL database using Waterloo HydroGeo Analyst (HGA) software. HGA is a flexible interface for management, query, and mapping of extensive hydrogeological and environmental data. Several pre-defined data structure templates are available in HGA. These structures may be modified by the user. For the water quality database the environmental data template was selected.

The HGA environmental template contains several tables for well construction data, soil types, lithology, etc. However, data is not at this time available to fully populate all tables. In its current form, only three tables of the water quality database are partially populated. These are:

- Station table
- Samples table

- Results table

This data structure template was modified to include special fields for the water quality database. These are:

- Fields for state well number, adjudicated sub-area, and RWMP sub-area were added to the station table.
- A field for data source identifier was added to the sample results table

These modifications facilitated the data queries used for the analyses presented in this memorandum. These tables will be more fully populated, and additional tables will be populated as necessary to meet the objectives of the water quality study. The data structures of these three tables, and their inter-relationships area shown in Figure 5.1 and discussed in the following sections.

Station Table

This table contains the master list of stations in the database. The Station table is related to the Samples table by the Station ID field. The data table fields currently populated are:

- Station ID – Unique integer and primary key
- SWN – State Well Number
- Station Name – Local well names or unique names assigned by other agencies such as the USGS, DWR, or DHS.
- X – Longitude in decimal degrees
- Y – Latitude in decimal degrees
- Adjudication Area – Alto, Baja, Centro, Este, Morongo, Oeste, Transition Zone
- RWMP Area – Name of the sub-aquifer unit as defined in the RWMP (listed in Table 4.7)

Samples Table

This table contains the master list of samples. It is related to the Station table list through the Station ID field, and to the Results table through the System Sample Code. The data table fields currently populated are:

- Station ID – Primary key
- System Sample Code – Unique identifier composed of SWN, data source identifier, and sample date.
- Date – Date of sample

Results Table

This table contains quality records and associated quality assurance information. It is related to Samples table by the System Sample Code field. The data table fields currently populated are:

- Sample_ID – Computed ASCII string composed of SWN, data source identifier, and sample date. Serves as the primary key for the Results table.
- Sample Date – Sampling date from the input dataset
- Source – Data source (i.e. NWIS, WDIS, STORET,DHS)
- Chemical Name – USGS/STORET parameter code for the record
- Result – Analytical or computational result for the constituent
- Remark – Result modifier
- Composite_Statistic_Code – Only available for Legacy STORET data. Statistical qualifier for the reported constituent value. Use of this field is discontinued by STORET.

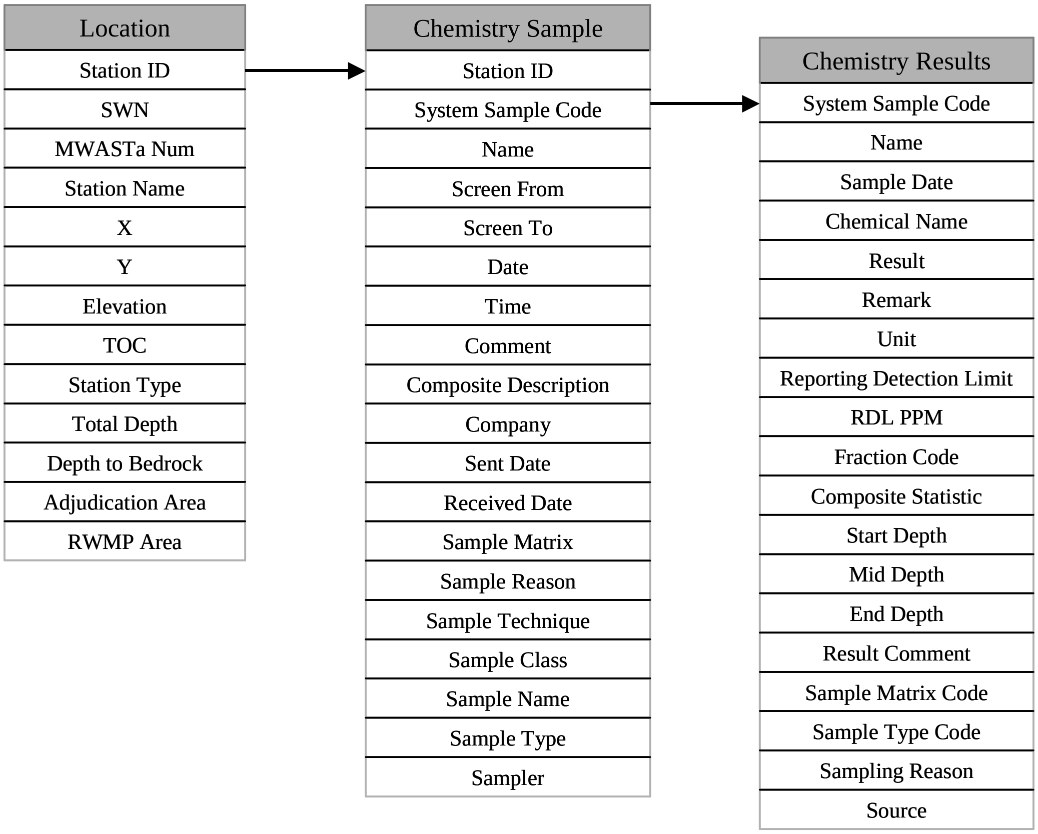


Figure 5.1 - Database tables and relationships

6

Task 1e: Historic Water Quality Analysis

6.1 Objectives

Perform historic water quality trend analysis pertaining to salinity. Assess the current and historical concentration of salinity in groundwater throughout the basin. The objective of this task is to identify areas of historically poor quality and areas exhibiting notable changes in the concentration of salts. Look for recognizable trends of quality degradation through time and attempt to identify causes for any degradation identified.

6.2. Deliverable

N/A

6.3 Discussion

Historical analysis of total dissolved solids content of groundwater in the MWA area was performed using the following analysis tools:

- Global sampling rate cross-plot
- Time series on data from individual wells
- Contour plots

Each of these methods provides different views and insights into the dataset.

Global sampling rate cross plot – A cross-plot method was utilized in an effort to understand the overall sampling frequency characteristics for the dataset. Figure 6.1 shows a cross-plot of the number of TDS samples versus period of record for each station. This cross-plot is used to evaluate the quality of historical sampling with respect to an ideal sampling frequency criteria. The method is as follows:

- Select criteria for the minimum number of samples and the minimum desired sample rate (samples per year) for a good historical sample set.
- Draw a line with a slope equal to the minimum sample rate criterion and passing through the minimum number of samples criterion.
- Draw a vertical line passing through the x axis at the time equal to minimum sample rate x minimum number of samples.
- Stations falling within the area above the sloping line and to the right of the vertical line meet minimum sampling criteria. Stations falling outside this area are under-sampled by the selected criteria.

The red line in Figure 6.1 represents a rate of 1 sample per year. The vertical line represents a minimum 3 year period of record. The area within the green dashed outline represents the good sample domain for yearly sample rate. This tool is meant only as a guideline, to be used along with other spatial and temporal data analysis tools in evaluating the quality of the database. For areas with stable long-term water quality, a sampling frequency of every 3 to 5 years might be more appropriate (orange line). For areas with highly variable water quality, multiple annual samples (blue line) might be required to adequately characterize water quality. It can be seen that the majority of stations meet a three year average sampling frequency requirement while very few meet a 6 month average sampling requirement. This analysis tool will be used in Task 2 of this project to evaluate geographically delimited subsets of stations.

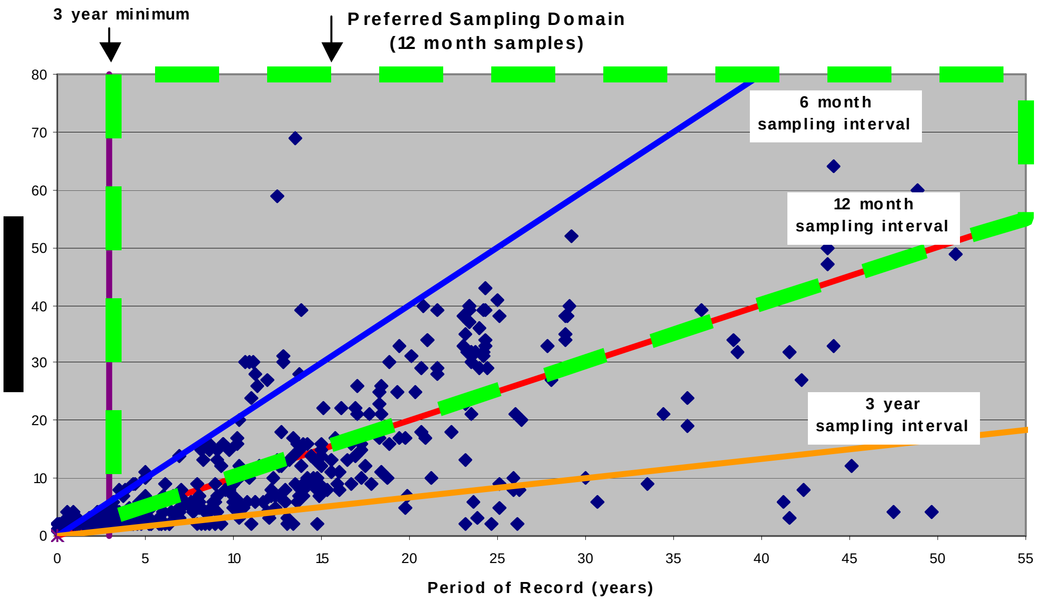


Figure 6.1 – Global TDS sample rate cross-plot for all stations

Time Series **–** Three wells having good period of record and large number of samples were selected from each sub-area for time series display. Figure 6.2 shows the location of the selected stations. Figures 6.3 to 6.9 show the time series for these stations with all three stations for each sub-area on a single plot. These data exhibit a variety of trends.

Stations in the Alto sub-area (Figure 6.3) have the lowest values, as also seen in the histograms for this sub-area. These wells are all in close proximity to one another and show erratic 3-5 year variations reaching approximately 100 mg/l peak-to-peak magnitude until an apparent reduction in the sampling effort occurring in the late 1970s. The most recent data from two of these wells suggests the same erratic behavior may exist today.

In the Baja sub-area (Figure 6.4) two wells in close proximity exhibit fundamentally different trends with one well showing relatively constant levels and the other a distinct increasing trend. The third well approximately five miles away exhibits a similar increasing trend with a possible drop before cessation of sampling.

In the Centro sub-area (Figure 6.5) wells in the vicinity of Barstow show interesting trends. Two wells nearer to Barstow have erratic short-term behavior but relatively stable long-term trends while another well further away from Barstow downstream along the Mojave River has a definite increasing trend before cessation of sampling in the mid 1980s.

In the Este sub-area (Figure 6.6) all three wells show stable concentrations. However, two wells in which are in close proximity to one another have similar levels that are nearly an order of magnitude lower than those observed in the third well approximately two miles away.

In the Oeste sub-area (Figure 6.7) sampling is not uniform throughout the period of record. A sampling gap exists for all three wells between 1973 and 1978. Prior to this gap all wells had similar TDS levels and slowly increasing trends. During the 1978-1979 time period, after the sampling gap, samples from two wells showed levels and trends consistent with prior history while one well (6N7WW10P02S) shows two successive anomalously high values (over 1,200 mg/l). One possible explanation of this anomaly is that during the period from 1978 to 1980 the Mojave Basin experienced extreme fluctuations in precipitation which may have mobilized TDS from El Mirage Lake, effecting samples locally due to the location or other attributes of the one well.

In the Transition Zone sub-area (Figure 6.8) all three wells show distinctively different characteristics. The off channel well (06N05W08F01S) shows low and stable values throughout the period of record. Well 08N04W31R01S within the floodplain aquifer shows a significant increase between 1952 and 1958, followed by a downward trend until approximately 1972, and then stabilizing for the remainder of the period of record. Well 08N04W20A01S, also in the floodplain aquifer tracks well 08N04W20A01S until approximately 1967, at which time TDS levels begin an erratic but persistent rise.

In the Morongo Basin (Figure 6.9) wells in the Yucca Valley and Copper Mountain Valley sub-basins exhibit stable TDS values well within the 500 mg/l drinking water limit. During the same time period a well in the Johnson Valley sub-basin exhibits large fluctuation in TDS with a sharp peak near 3000 mg/l in the early 1960’s followed by a steady decline to approximately 800 mg/l before cessation of sampling activity in the mid 1970s.

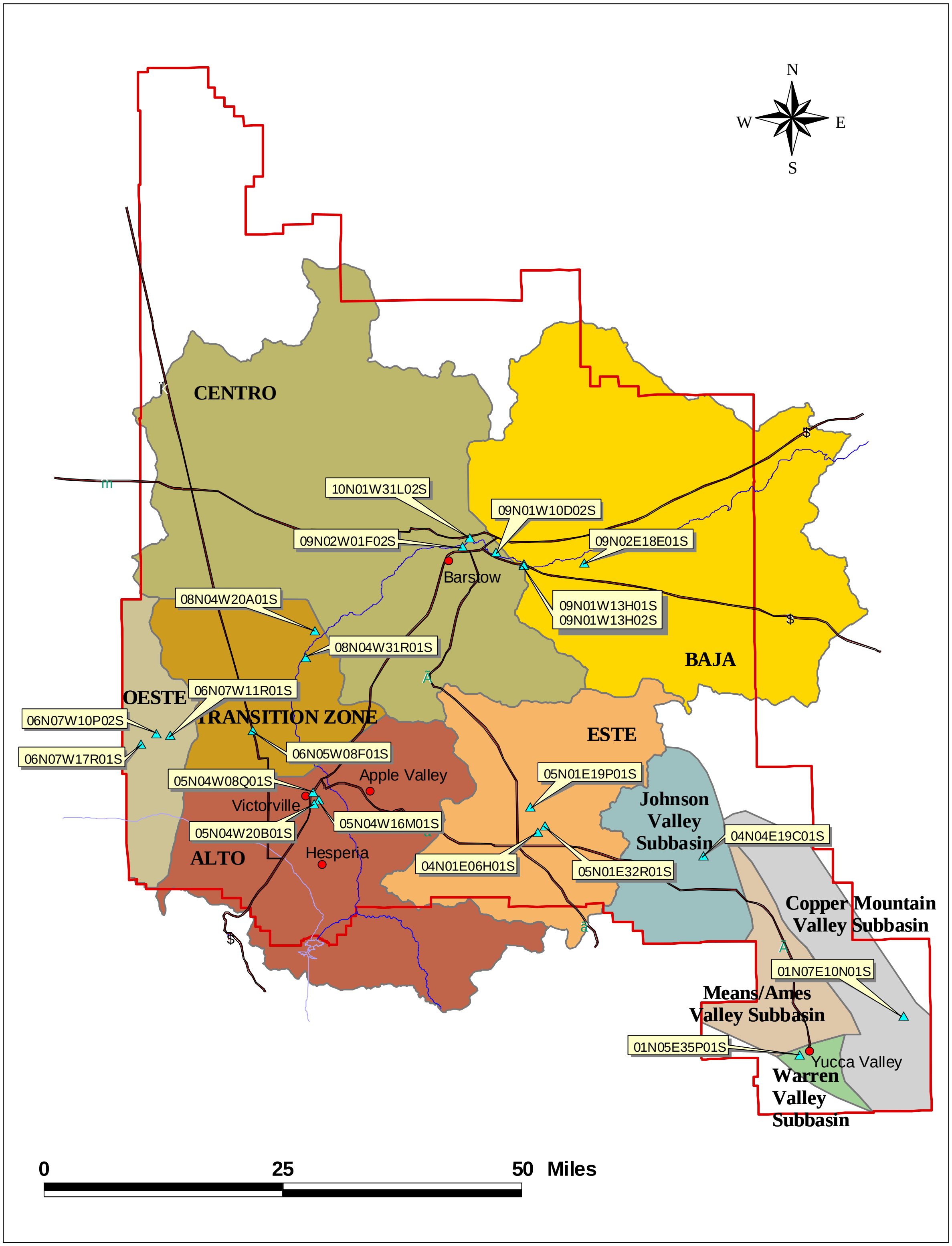


Figure 6.2 – Location of wells used for time series plots

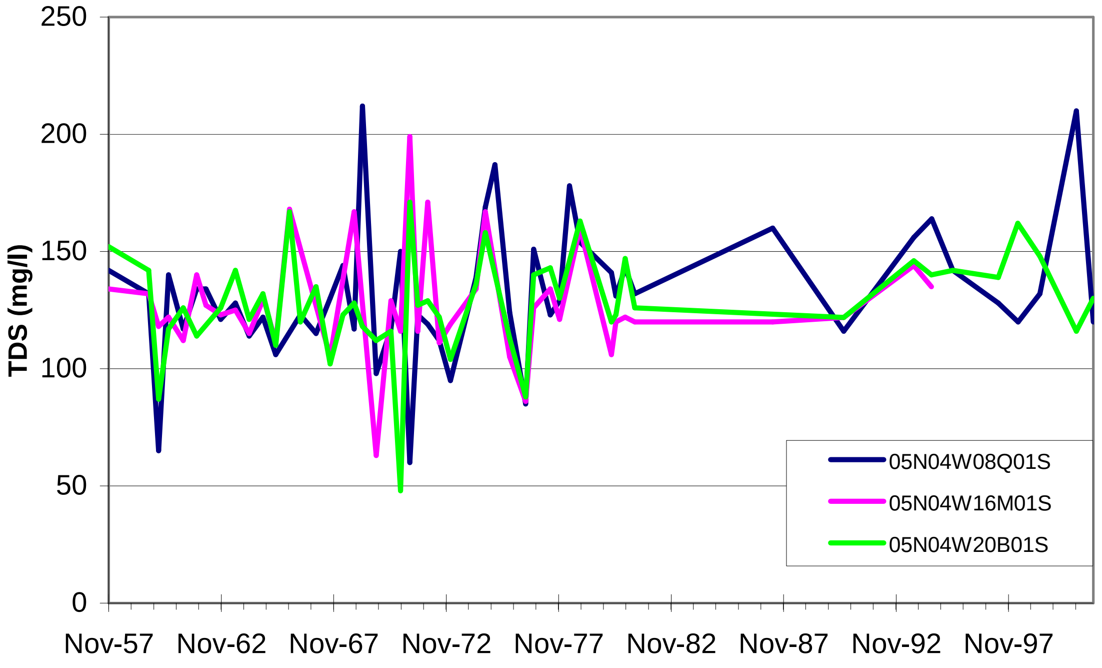


Figure 6.3 – TDS data time series display for wells in Alto sub-area

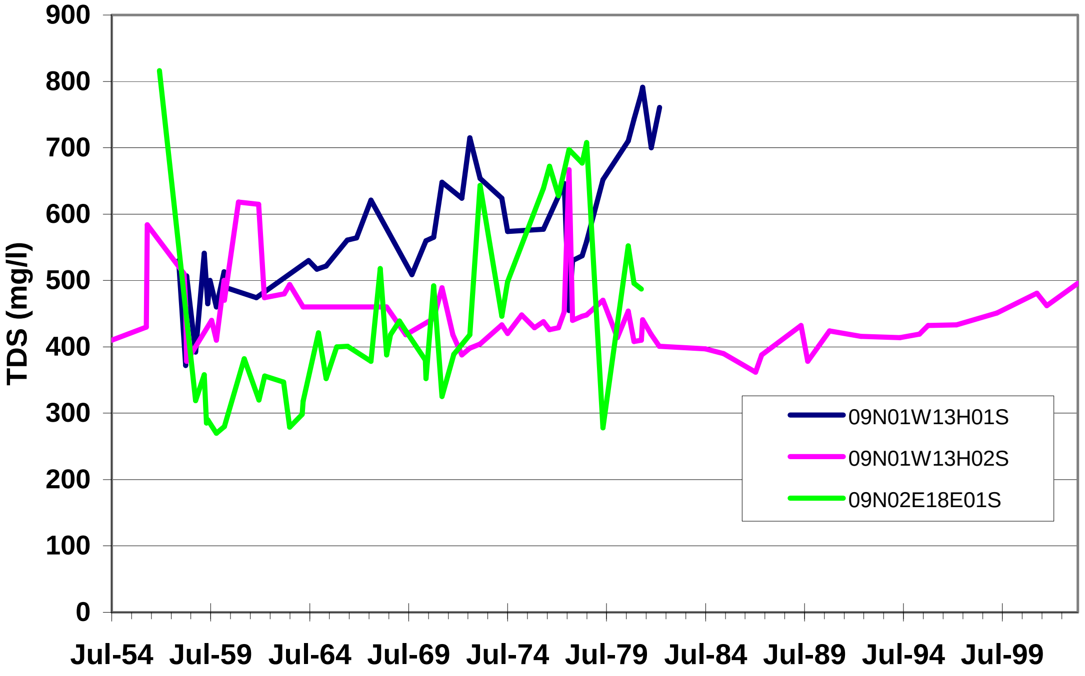


Figure 6.4 – TDS data time series display for wells in Baja sub-area

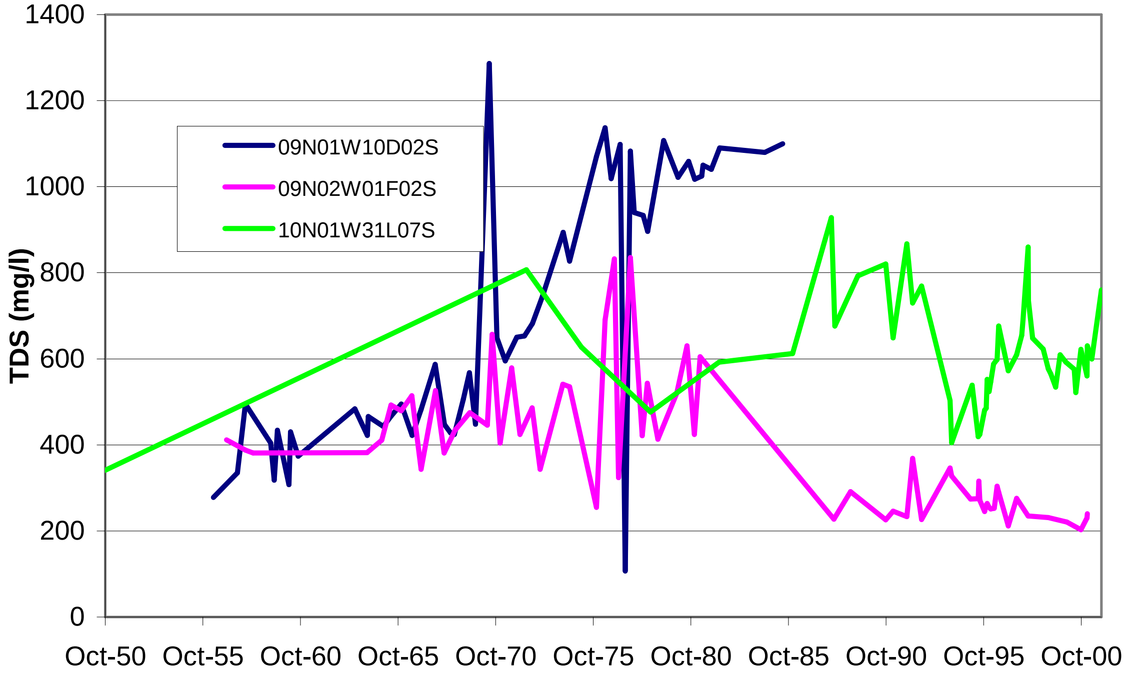


Figure 6.5 – TDS data time series display for wells in Centro sub-area

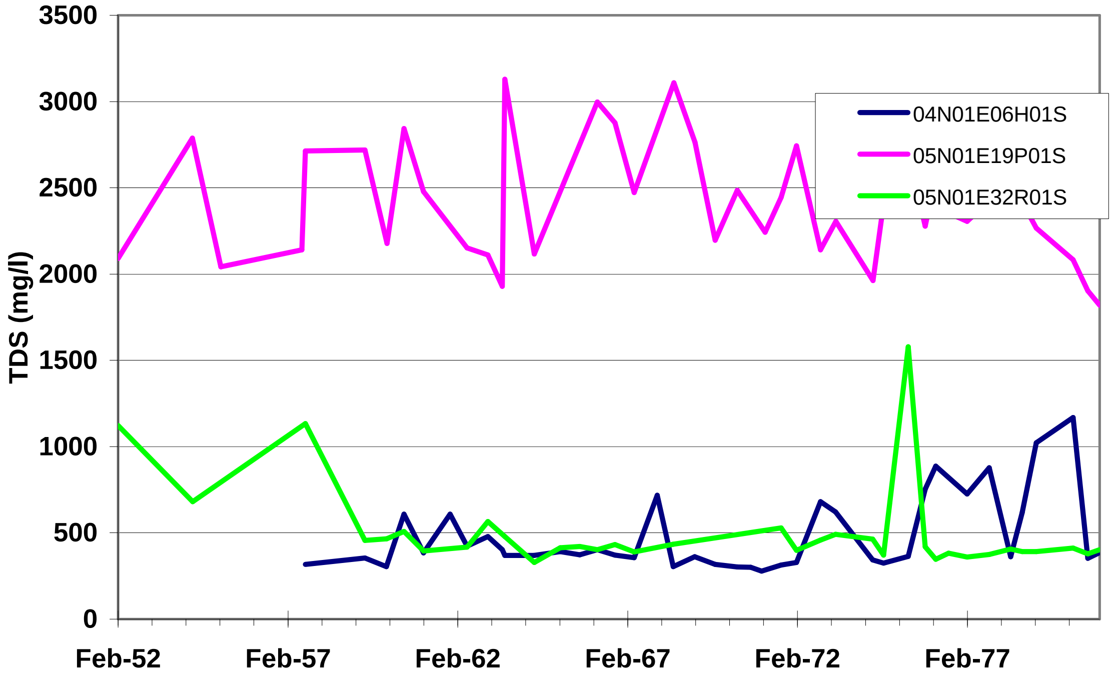


Figure 6.6 – TDS data time series display for wells in Este sub-area

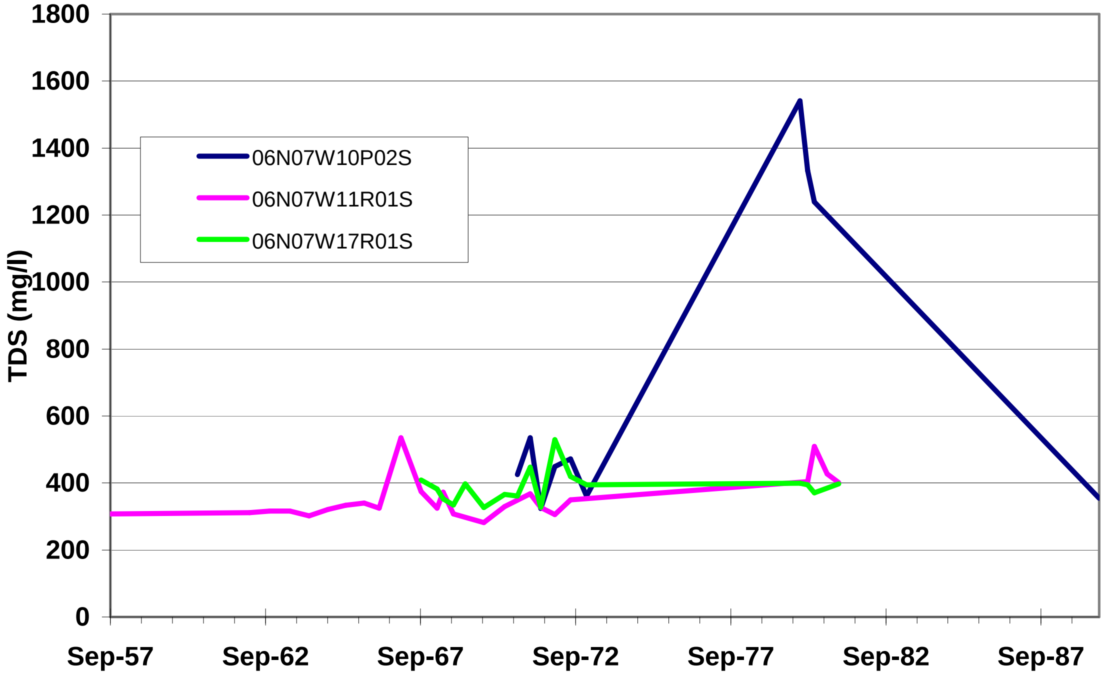


Figure 6.7 – TDS data time series display for wells in Oeste sub-area

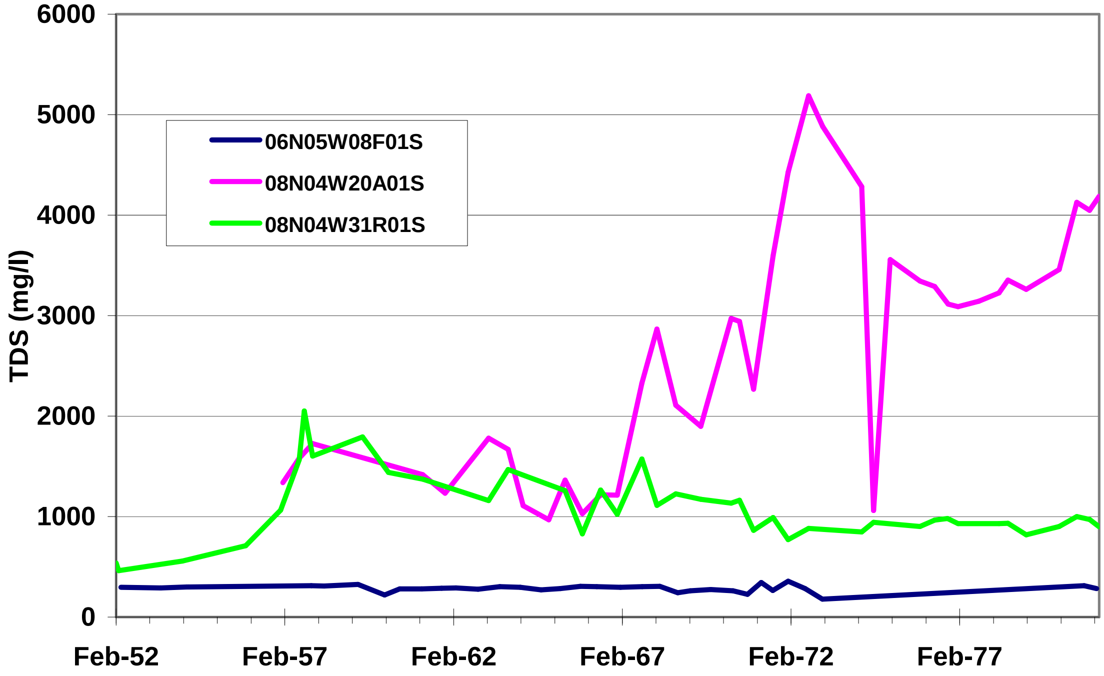


Figure 6.8 – TDS data time series display for wells in Transition Zone sub-area

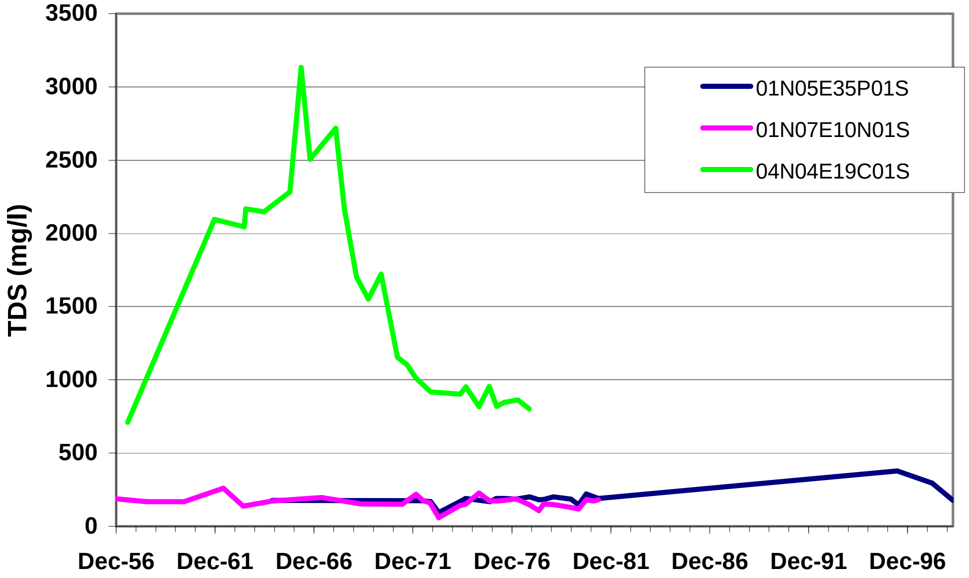


Figure 6.9 – TDS data time series display for wells in Morongo Zone sub-area

Contour "Time Slice" Plots **–** TDS data were sorted into time-limited groups listed in Table 6.1 for contour plotting. These data show relatively uniform sampling after 1950 with the exception of an apparent increase in activity between 1985 and 1995. Contours of these data groups created in Schlumberger's PETREL 3D geological modeling system using a convergent interpolation algorithm are shown in Figures 6.10 to 6.14. These contours are constrained by the limits of the regional aquifer and Morongo Basin but do not account for other features such as faults that might cause abrupt water quality transitions. For the time period between 1925 and 1950 there were no samples in the Morongo Basin. These plots show localized increases in TDS through the 1975-1985 time period, followed by a decrease in those areas during the time period from 1985 to 2004. These localized contour anomalies could be induced by individual wells and will be closely investigated during Phase 2 of this study.

Table 6.1 – TDS contour data group sample characteristics

Date Range	Number of Stations
1925-1950	51
1950-1975	941
1975-1985	284
1985-1995	446
1995-2004	367

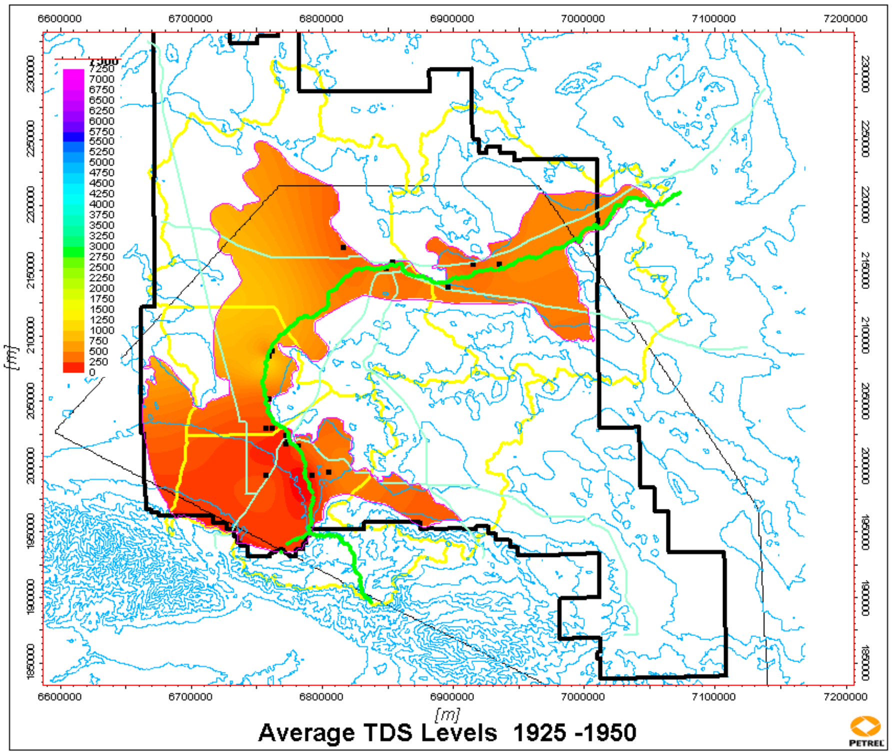


Figure 6.10 – Contour of average TDS level for data grouped between years 1925 and 1950

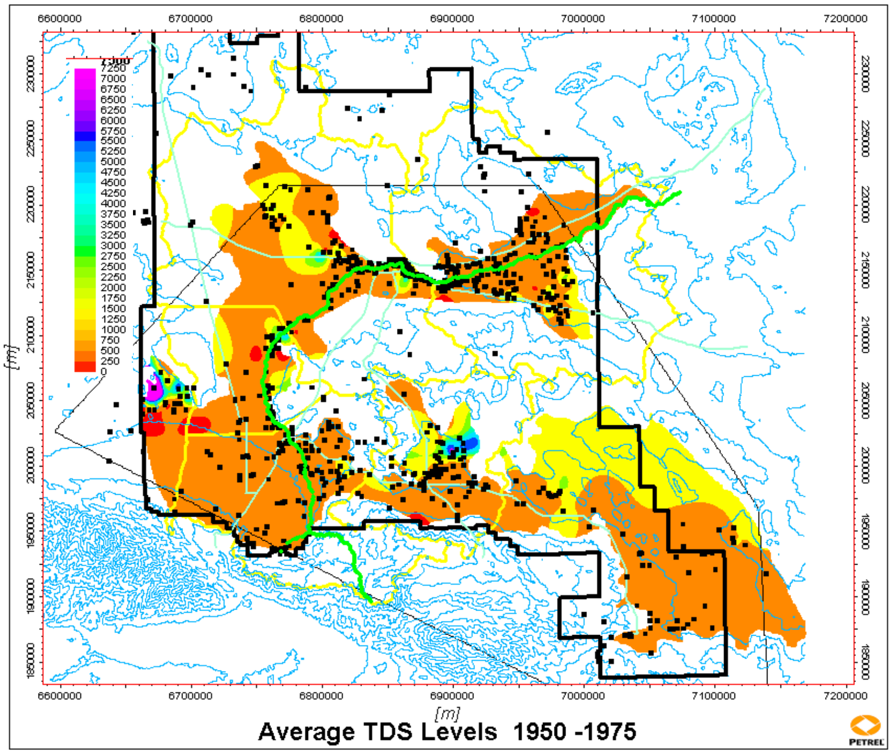


Figure 6.11 – Contour of average TDS level for data grouped between years 1950 and 1975

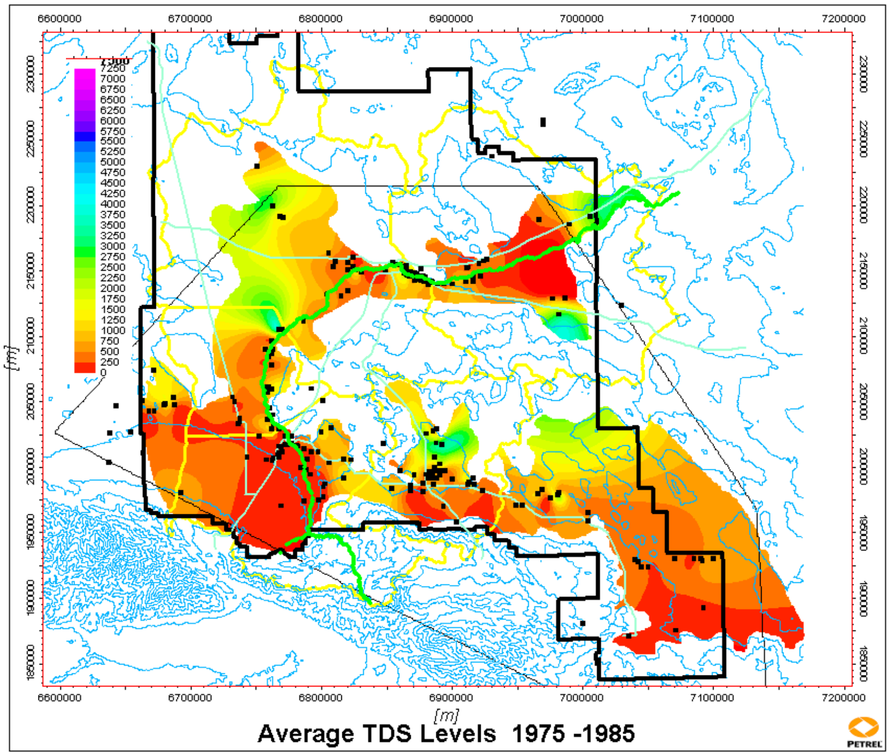


Figure 6.12 – Contour of average TDS level for data grouped between years 1975 and 1985

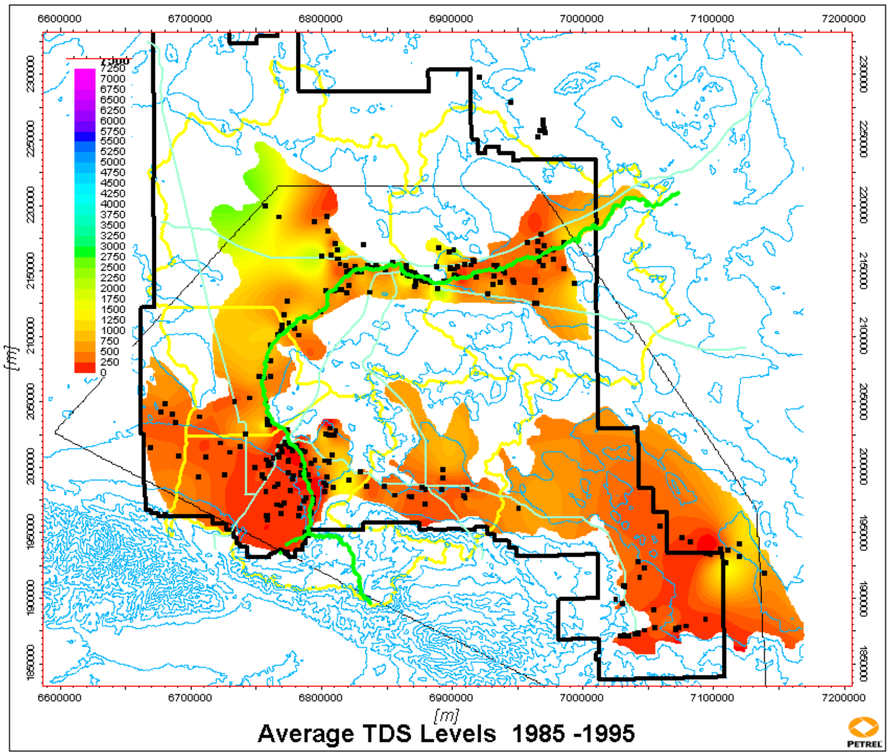


Figure 6.13 – Contour of average TDS level for data grouped between years 1985 and 1995

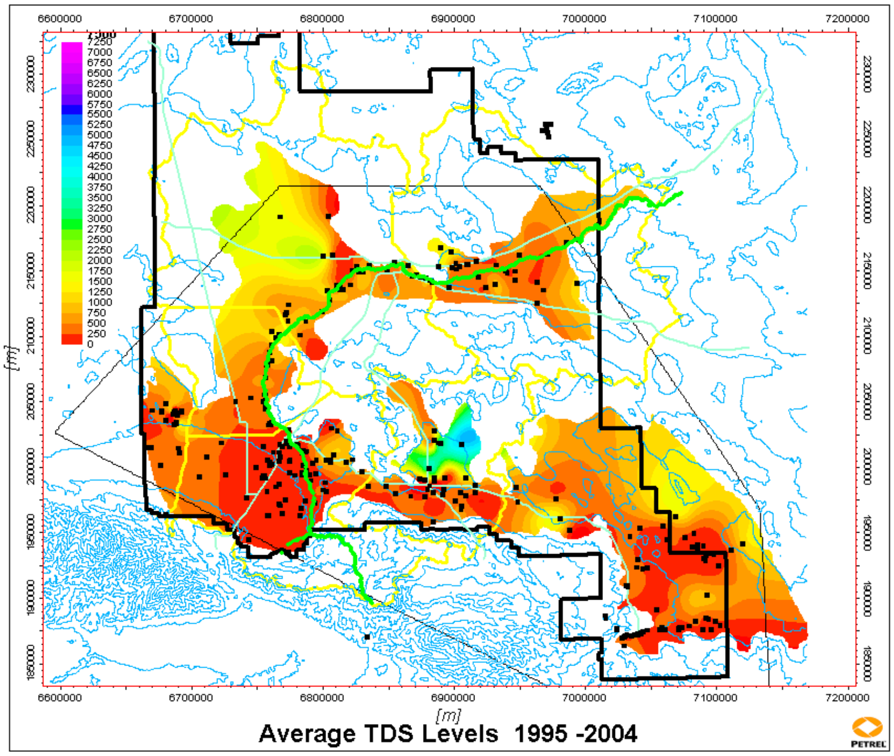


Figure 6.14 – Contour of average TDS level for data grouped between years 1995 and 2004

7

Task 1f: Assessment of Modeling Needs

7.1 Objectives

Assess data needs for computational modeling of salinity balance. Provide recommendations outlining additional data collection activities and any additional analyses necessary. Data collection recommendations are focused primarily on quantifying potential long-term changes in the salinity balance of the basin.

7.2. Deliverable

Recommendations outlining additional data collection activities and any additional analyses necessary.

7.3 Discussion

Recommendations for further data collection must be based upon a realistic assessment of the current database and the modeling objectives, both short and long term. Table 7.1 contains a list of the various types of models which may be used for predicting long-term changes in the salinity balance of the Mojave Basin, along with brief descriptions and pros and cons of each.

The models in Table 7.1 are listed in order of increasing complexity. This increase in model complexity results from increased discretization of the system in one or more of the key model parameters. Table 7.2 describes discretization methods for some of the key model parameters. Increased model complexity and discretization carries with it a corresponding increase in the number of types of data as well as the quantity and quality of data. These requirements put practical limits on water quality modeling using the available database. Referring to Table 4.1, given a worst case or near worst case water quality sampling scenario only the more simplistic modeling techniques would be possible. Poor spatial and temporal sampling with uncertain data quality would support only simple mass balance modeling. At the other end of the spectrum, a best case water quality sampling scenario *in addition to* comprehensive hydrogeological characterization would be required to support complex 3-D transport modeling.

Table 7.1 – Various models under consideration for prediction of the long-term salt balance of the Mojave Basin

Model Type	Description	Recommended Modeling Environment	Pro	Con
Steady State Salt Balance	Bucket model with constant inflow/outflows and initial condition based on snap shot of aquifer salinity state.	Spreadsheet	Simple, inexpensive. No special software required.	Coarse, static, not suitable for heterogeneous transient systems.
Non-Linear System Model	Nodal model with transient inflow/outflow and inter-basin process calibrated against historical data and the available Modflow hydrodynamic model.	System Analysis Software (e.g. Stella)	Inexpensive option for first order modeling of transient, non-linear system behavior.	Increased complexity. Requires explicit characterization of transient processes.
Numerical Advective TDS Transport	Transient numerical hydrodynamic model with TDS treated as a tracer transported through advective flow only.	Numerical simulator (e.g. Modflow)	More accurately predicts heterogeneous and transient hydrodynamic system behavior.	Complex, requires special software, skills, and additional geological and hydrologic input data.
Numerical Transport Model with Dispersion	Transient numerical hydrodynamic/transport model with TDS transported by advection with calibrated dispersion.	Numerical simulator (e.g. Schlumberger Eclipse, MODFLOW RT3D, FEFLOW)	Dispersion can be significant in hydrodynamically transient systems depending on lithology.	Requires calibration and specialized software and skills and additional geological and hydrologic input data. Dispersion often 2nd order effect depending on lithology and hydrodynamic conditions.
Numerical Transport Model with Dispersion and diffusion	Numerical hydrodynamic/transport model with TDS transported by advection, calibrated dispersion, and diffusion.	Numerical simulator (e.g. Schlumberger Eclipse, MODFLOW RT3D, FEFLOW)	Useful in systems which are close to hydrodynamic steady state but transient with respect to concentration state.	Calibration sensitive. Requires specialized software and skills and additional geological and hydrologic input data. Diffusion often 2nd order effect in hydrodynamically transient systems.

Table 7.2 – Model Discretization

Category	Less Discrete	More Discrete
Areal Discretization	Sub-area	Sub-aquifer
Vertical Discretization	Single layer	Multiple layer
Model State	Steady-state	Transient
Transport Process	Advection	Dispersive/Diffusive
Unsaturated (vadose) Zone	Water table	Multi-phase

The spatial distribution of samples shown in Figure 4.1 highlights the spatial non-uniformity of well coverage in the MWA area with clustering corresponding to population centers and along the Mojave River. Some outlying regions are poorly sampled. Although this sampling non-uniformity is undesirable, it is also likely that increased sampling density corresponds to areas where TDS transport is more transient. Conversely, in the absence of other TDS sources or sinks, areas with sparse well coverage may be expected to be closer to steady state transport conditions. As such, recommendations for additional drilling must be based not only on spatial density, but on the spatially variable dynamics of the overall system.

The temporal distribution of TDS sampling was investigated in Section 6 for selected wells from each sub-area. These data show that wells in close proximity to one another can exhibit vastly different levels and trends. This behavior can be attributed to the direct influence of man-made surface inflows or to localized geological phenomena such as faults and lake beds subject to periodic inundation. Data from wells in the Este sub-area displayed in Figure 6.6 highlight the fact that large variations in steady state concentrations may occur over short distances. Ideally, the mechanisms for such variations will be comprehended in future modeling activities.

7.4 Recommendations

Although the current database is clearly not sufficient for sophisticated transport modeling, the trends observed in QA/QC and historical data analysis support the conclusion that the TDS distributions in the area are spatially variable with a mix of transient and near steady-state conditions. Selection of the appropriate model and modeling platform are objectives of Phase 2 of this project. Based on recent studies performed as part of the MWA RWMP we anticipate that simple mass balance techniques will adequately model *short-term* TDS behavior in the area of interest under various water management scenarios. However, a spatially discrete transient transport model will be required to adequately capture and predict the spatial variability and long-term trends observed in the data. The first modeling option that would begin to capture these attributes would be a spatially refined non-linear system model.

Whether the final recommendation from Phase 2 of this study is a non-linear system model or a full transport model, fundamental improvements in the water quality database will be required. While development of an ideal water quality database may not be a realistic near-term objective, such a database should be used as the standard for future sampling activities. If performed rationally, these activities will entail only those short-term cost expenditures necessary and sufficient to support realistic near-term modeling objectives, while at the same time forming the building blocks for more complex modeling efforts in the future.

Based upon our evaluation of the currently available data and in consideration of the modeling alternatives discussed above, we recommend the following actions:

1. ***Assess sampling efficiency*** - Trends in existing data should be evaluated and the efficiency of the current sampling program should be assessed. Water quality sampling taking place in the MWA monitoring network well study may be optimized through analysis of spatial and temporal trends in nearby wells as observed in the water quality database. For example, we suggest sampling once every three to five years in areas with stable water quality, and one to two times per year in areas with variable water quality. This will both assure that significant trends are being captured and minimize unnecessary costs associated with over-sampling in areas exhibiting slowly varying TDS levels.

2. ***Resumption of sampling in selected wells*** - Identify wells exhibiting significant historical variability but for which sampling has ceased and investigate the potential benefit of including these in the monitoring well program. One specific example is well 09N01W10D02S shown in Figure 6.5 and discussed in Section 6.

3. ***DHS data* –** In light of the fact that the DHS is one of only three agencies conducting extensive ongoing regional groundwater sampling programs it is critical that all legacy *and* future DHS data be incorporated into the water quality database. Efforts to obtain critical well number and location information are under way with the cooperation of the Lahontan RWQCB.

4. ***Surface water inflows* –** The available data strongly suggest significant localized effects of cultural activity on groundwater TDS levels. Historical rate and concentrations for all major inflows of surface water should be quantified, including waste streams.

5. ***Conceptual geologic controls* –** Spatial TDS anomalies in the Este and Alto sub-areas suggest that discrete geologic features such as bedrock outcrops, dry lakes, and faults may be having a direct and significant impact on TDS distributions. MWA continuously strives to improve its conceptual models for their operational area through ongoing acquisition of geospatial (GIS), hydrogeological, and geochemical data. These efforts have natural synergy with the water quality study. The water quality planning model will serve as a useful tool in planning of future data acquisition efforts. The combined efforts of conceptual model development and the water quality planning model hold tremendous potential future benefits for MWA in terms of optimizing the long term management of water resources in the Mojave Basin.

6. ***Infill drilling and sampling* –** Ideally a systematic infill drilling and sampling program would be desirable with the long term goal of developing a minimum well density 1 well per 10 square miles. This may not be achievable due to the high cost

of drilling. However, effective use of the available hydrogeological data, up-to-date conceptual model(s), and the water quality planning model, will help to prioritize the drilling program and optimize the benefit of each well drilled.

7. ***Water quality data source interface* –** Utilities for periodic retrieval and integration of data updates from primary water quality data sources should be created.

Attachment 1

USGS/STORET Parameter Codes

Constituent Code	Description
00027	Agency collecting sample, code
00028	Agency analyzing sample, code
72001	Depth of hole, feet below land surface datum
72008	Depth of well, feet below land surface datum
81903	Depth to bottom at sample location, feet
72016	Depth to bottom of sample interval, feet below land surface datum
72015	Depth to top of sample interval, feet below land surface datum
72019	Depth to water level, feet below land surface
72020	Elevation above NGVD 1929, feet
72000	Altitude of land surface, feet
00058	Flow rate of well, gallons per minute
00059	Flow rate, instantaneous, gallons per minute
72004	Pump or flow period prior to sampling, minutes
00061	Discharge, instantaneous, cubic feet per second
00080	Color, water, filtered, platinum cobalt units
81024	Drainage area, square miles
00086	Odor at 60 degrees Celsius, threshold number
00085	Odor at room temperature, threshold number
01330	Odor, atmospheric, severity, code
46529	Precipitation, inches
00003	Sampling depth, feet
82398	Sampling method, code
84143	Well purging condition, code
00070	Turbidity, water, unfiltered, Jackson turbidity units
00025	Barometric pressure, millimeters of mercury
00405	Carbon dioxide, water, unfiltered, milligrams per liter
00300	Dissolved oxygen, water, unfiltered, milligrams per liter
00301	Dissolved oxygen, water, unfiltered, percent of saturation
00400	pH, water, unfiltered, field, standard units
00403	pH, water, unfiltered, laboratory, standard units
00094	Specific conductance, water, unfiltered, field, microsiemens per centimeter at 25 degrees
90095	Specific conductance, water, unfiltered, laboratory, microsiemens per centimeter at 25 degrees
00095	Specific conductance, water, unfiltered, microsiemens per centimeter at 25 degrees Celsius
00020	Temperature, air, degrees Celsius
00010	Temperature, water, degrees Celsius

Constituent Code	Description
00900	Hardness, water, unfiltered, milligrams per liter as calcium carbonate
00904	Noncarbonate hardness, water, filtered, field, milligrams per liter as calcium carbonate
00905	Noncarbonate hardness, water, filtered, lab, milligrams per liter as calcium carbonate
00902	Noncarbonate hardness, water, unfiltered, field, milligrams per liter as calcium carbonate
00903	Noncarbonate hardness, water, unfiltered, lab, milligrams per liter as calcium carbonate
95902	Noncarbonate hardness, water, unfiltered, milligrams per liter as calcium carbonate
00915	Calcium, water, filtered, milligrams per liter
00925	Magnesium, water, filtered, milligrams per liter
00935	Potassium, water, filtered, milligrams per liter
00937	Potassium, water, unfiltered, recoverable, milligrams per liter
00931	Sodium adsorption ratio, water, number
00933	Sodium plus potassium, water, filtered, milligrams per liter as sodium
00930	Sodium, water, filtered, milligrams per liter
00932	Sodium, water, percent in equivalents of major cations
00410	Acid neutralizing capacity, water, unfiltered, fixed endpoint (pH 4.5) titration, field,
00417	Acid neutralizing capacity, water, unfiltered, fixed endpoint (pH 4.5) titration, laboratory
90410	Acid neutralizing capacity, water, unfiltered, fixed endpoint (pH 4.5) titration, laboratory
95410	Acid neutralizing capacity, water, unfiltered, fixed endpoint (pH 4.5) titration, laboratory
00419	Acid neutralizing capacity, water, unfiltered, incremental titration, field, milligrams per liter
71825	Acidity, water, unfiltered, heated, milligrams per liter as hydrogen ion
00435	Acidity, water, unfiltered, milligrams per liter as calcium carbonate
39036	Alkalinity, water, filtered, fixed endpoint (pH 4.5) titration, field, milligrams per liter
29801	Alkalinity, water, filtered, fixed endpoint (pH 4.5) titration, laboratory, milligrams per liter
39086	Alkalinity, water, filtered, incremental titration, field, milligrams per liter as calcium
00453	Bicarbonate, water, filtered, incremental titration, field, milligrams per liter
00440	Bicarbonate, water, unfiltered, fixed endpoint (pH 4.5) titration, field, milligrams per liter
00450	Bicarbonate, water, unfiltered, incremental titration, field, milligrams per liter
29807	Carbonate, water, filtered, fixed endpoint (pH 8.3) titration, field, milligrams per liter
00452	Carbonate, water, filtered, incremental titration, field, milligrams per liter
00445	Carbonate, water, unfiltered, fixed endpoint (pH 8.3) titration, field, milligrams per liter
00447	Carbonate, water, unfiltered, incremental titration, field, milligrams per liter
71830	Hydroxide, water, unfiltered, fixed endpoint (pH 10.4) titration, field, milligrams per liter
71870	Bromide, water, filtered, milligrams per liter
00940	Chloride, water, filtered, milligrams per liter
00950	Fluoride, water, filtered, milligrams per liter
71865	Iodide, water, filtered, milligrams per liter
00955	Silica, water, filtered, milligrams per liter
00945	Sulfate, water, filtered, milligrams per liter
99890	Sulfate, water, filtered, uncorrected, milligrams per liter
00946	Sulfate, water, unfiltered, milligrams per liter
70301	Residue, water, filtered, sum of constituents, milligrams per liter
70303	Residue, water, filtered, tons per acre-foot

Constituent Code	Description
70302	Residue, water, filtered, tons per day
00520	Loss on ignition, from residue on evaporation, water, filtered, milligrams per liter
70300	Residue on evaporation, dried at 180 degrees Celsius, water, filtered, milligrams per liter
00540	Residue, fixed nonfilterable, milligrams per liter
00623	Ammonia plus organic nitrogen, water, filtered, milligrams per liter as nitrogen
00625	Ammonia plus organic nitrogen, water, unfiltered, milligrams per liter as nitrogen
71846	Ammonia, water, filtered, milligrams per liter as NH4
00608	Ammonia, water, filtered, milligrams per liter as nitrogen
71845	Ammonia, water, unfiltered, milligrams per liter as NH4
00610	Ammonia, water, unfiltered, milligrams per liter as nitrogen
00672	Hydrolyzable phosphorus, water, filtered, milligrams per liter
00669	Hydrolyzable phosphorus, water, unfiltered, milligrams per liter
71851	Nitrate, water, filtered, milligrams per liter
00618	Nitrate, water, filtered, milligrams per liter as nitrogen
71850	Nitrate, water, unfiltered, milligrams per liter
00620	Nitrate, water, unfiltered, milligrams per liter as nitrogen
00631	Nitrite plus nitrate, water, filtered, milligrams per liter as nitrogen
00630	Nitrite plus nitrate, water, unfiltered, milligrams per liter as nitrogen
71856	Nitrite, water, filtered, milligrams per liter
00613	Nitrite, water, filtered, milligrams per liter as nitrogen
00615	Nitrite, water, unfiltered, milligrams per liter as nitrogen
00607	Organic nitrogen, water, filtered, milligrams per liter
00605	Organic nitrogen, water, unfiltered, milligrams per liter
00673	Organic phosphorus, water, filtered, milligrams per liter
00670	Organic phosphorus, water, unfiltered, milligrams per liter
00660	Orthophosphate, water, filtered, milligrams per liter
00671	Orthophosphate, water, filtered, milligrams per liter as phosphorus
00650	Phosphate, water, unfiltered, milligrams per liter
00666	Phosphorus, water, filtered, milligrams per liter
00602	Total nitrogen, water, filtered, milligrams per liter
00600	Total nitrogen, water, unfiltered, milligrams per liter
71887	Total nitrogen, water, unfiltered, milligrams per liter as nitrate
00621	Nitrate, bed sediment, total, dry weight, milligrams per kilogram as nitrogen
00690	Carbon (inorganic plus organic), water, unfiltered, milligrams per liter
00681	Organic carbon, water, filtered, milligrams per liter
00680	Organic carbon, water, unfiltered, milligrams per liter
00687	Organic carbon, bed sediment, total, dry weight, grams per kilogram
00340	Chemical oxygen demand, high level, water, unfiltered, milligrams per liter
00335	Chemical oxygen demand, low level, water, unfiltered, milligrams per liter
49954	Biomass, periphyton, ash free dry mass, grams per square meter
70950	Biomass/chlorophyll ratio, periphyton, number
70949	Biomass/chlorophyll ratio, plankton, number

Constituent Code	Description
01106	Aluminum, water, filtered, micrograms per liter
01095	Antimony, water, filtered, micrograms per liter
01000	Arsenic, water, filtered, micrograms per liter
01002	Arsenic, water, unfiltered, micrograms per liter
62452	Arsenite (H_3AsO_3), water, filtered, micrograms per liter as arsenic
01005	Barium, water, filtered, micrograms per liter
01010	Beryllium, water, filtered, micrograms per liter
01020	Boron, water, filtered, micrograms per liter
01025	Cadmium, water, filtered, micrograms per liter
01032	Chromium(VI), water, filtered, micrograms per liter
01030	Chromium, water, filtered, micrograms per liter
01035	Cobalt, water, filtered, micrograms per liter
01040	Copper, water, filtered, micrograms per liter
01046	Iron, water, filtered, micrograms per liter
01045	Iron, water, unfiltered, recoverable, micrograms per liter
01049	Lead, water, filtered, micrograms per liter
01130	Lithium, water, filtered, micrograms per liter
01056	Manganese, water, filtered, micrograms per liter
71900	Mercury, water, unfiltered, recoverable, micrograms per liter
01060	Molybdenum, water, filtered, micrograms per liter
01065	Nickel, water, filtered, micrograms per liter
01145	Selenium, water, filtered, micrograms per liter
01075	Silver, water, filtered, micrograms per liter
01080	Strontium, water, filtered, micrograms per liter
01057	Thallium, water, filtered, micrograms per liter
01085	Vanadium, water, filtered, micrograms per liter
01090	Zinc, water, filtered, micrograms per liter
00550	Oil and grease, water, unfiltered, recoverable, milligrams per liter
34561	1,3-Dichloropropene, water, unfiltered, recoverable, micrograms per liter
34621	2,4,6-Trichlorophenol, water, unfiltered, recoverable, micrograms per liter
34601	2,4-Dichlorophenol, water, unfiltered, recoverable, micrograms per liter
34606	2,4-Dimethylphenol, water, unfiltered, recoverable, micrograms per liter
34616	2,4-Dinitrophenol, water, unfiltered, recoverable, micrograms per liter
34611	2,4-Dinitrotoluene, water, unfiltered, recoverable, micrograms per liter
34626	2,6-Dinitrotoluene, water, unfiltered, recoverable, micrograms per liter
34576	2-Chloroethyl vinyl ether, water, unfiltered, recoverable, micrograms per liter
34581	2-Chloronaphthalene, water, unfiltered, recoverable, micrograms per liter
34586	2-Chlorophenol, water, unfiltered, recoverable, micrograms per liter
34657	2-Methyl-4,6-dinitrophenol, water, unfiltered, recoverable, micrograms per liter
34591	2-Nitrophenol, water, unfiltered, recoverable, micrograms per liter
34636	4-Bromophenyl phenyl ether, water, unfiltered, recoverable, micrograms per liter
34452	4-Chloro-3-methylphenol, water, unfiltered, recoverable, micrograms per liter

Constituent Code	Description
34641	4-Chlorophenyl phenyl ether, water, unfiltered, recoverable, micrograms per liter
34646	4-Nitrophenol, water, unfiltered, recoverable, micrograms per liter
34381	9H-Fluorene, water, unfiltered, recoverable, micrograms per liter
34205	Acenaphthene, water, unfiltered, recoverable, micrograms per liter
34200	Acenaphthylene, water, unfiltered, recoverable, micrograms per liter
39330	Aldrin, water, unfiltered, recoverable, micrograms per liter
39388	alpha-Endosulfan, water, unfiltered, recoverable, micrograms per liter
34220	Anthracene, water, unfiltered, recoverable, micrograms per liter
34526	Benzo[a]anthracene, water, unfiltered, recoverable, micrograms per liter
34247	Benzo[a]pyrene, water, unfiltered, recoverable, micrograms per liter
34230	Benzo[b]fluoranthene, water, unfiltered, recoverable, micrograms per liter
34521	Benzo[g,h,i]perylene, water, unfiltered, recoverable, micrograms per liter
34242	Benzo[k]fluoranthene, water, unfiltered, recoverable, micrograms per liter
34292	Benzyl n-butyl phthalate, water, unfiltered, recoverable, micrograms per liter
34278	Bis(2-chloroethoxy)methane, water, unfiltered, recoverable, micrograms per liter
34273	Bis(2-chloroethyl) ether, water, unfiltered, recoverable, micrograms per liter
34283	Bis(2-chloroisopropyl) ether, water, unfiltered, recoverable, micrograms per liter
39100	Bis(2-ethylhexyl) phthalate, water, unfiltered, recoverable, micrograms per liter
39350	Chlordane (technical), water, unfiltered, recoverable, micrograms per liter
34320	Chrysene, water, unfiltered, recoverable, micrograms per liter
34556	Dibenzo[a,h]anthracene, water, unfiltered, recoverable, micrograms per liter
39380	Dieldrin, water, unfiltered, recoverable, micrograms per liter
34336	Diethyl phthalate, water, unfiltered, recoverable, micrograms per liter
34341	Dimethyl phthalate, water, unfiltered, recoverable, micrograms per liter
39110	Di-n-butyl phthalate, water, unfiltered, recoverable, micrograms per liter
34596	Di-n-octyl phthalate, water, unfiltered, recoverable, micrograms per liter
39390	Endrin, water, unfiltered, recoverable, micrograms per liter
34376	Fluoranthene, water, unfiltered, recoverable, micrograms per liter
39420	Heptachlor epoxide, water, unfiltered, recoverable, micrograms per liter
39410	Heptachlor, water, unfiltered, recoverable, micrograms per liter
39700	Hexachlorobenzene, water, unfiltered, recoverable, micrograms per liter
34386	Hexachlorocyclopentadiene, water, unfiltered, recoverable, micrograms per liter
34403	Indeno[1,2,3-cd]pyrene, water, unfiltered, recoverable, micrograms per liter
34408	Isophorone, water, unfiltered, recoverable, micrograms per liter
39340	Lindane, water, unfiltered, recoverable, micrograms per liter
38260	Methylene blue active substances, water, unfiltered, recoverable, milligrams per liter
39755	Mirex, water, unfiltered, recoverable, micrograms per liter
34447	Nitrobenzene, water, unfiltered, recoverable, micrograms per liter
34438	N-Nitrosodimethylamine, water, unfiltered, recoverable, micrograms per liter
34428	N-Nitrosodi-n-propylamine, water, unfiltered, recoverable, micrograms per liter
34433	N-Nitrosodiphenylamine, water, unfiltered, recoverable, micrograms per liter
39360	p,p'-DDD, water, unfiltered, recoverable, micrograms per liter

Constituent Code	Description
39365	p,p'-DDE, water, unfiltered, recoverable, micrograms per liter
39370	p,p'-DDT, water, unfiltered, recoverable, micrograms per liter
39034	p,p'-Ethyl-DDD, water, unfiltered, recoverable, micrograms per liter
39480	p,p'-Methoxychlor, water, unfiltered, recoverable, micrograms per liter
39516	PCBs, water, unfiltered, recoverable, micrograms per liter
39032	Pentachlorophenol, water, unfiltered, recoverable, micrograms per liter
34461	Phenanthrene, water, unfiltered, recoverable, micrograms per liter
34694	Phenol, water, unfiltered, recoverable, micrograms per liter
32730	Phenolic compounds, water, unfiltered, recoverable, micrograms per liter
39250	Polychlorinated naphthalenes, water, unfiltered, recoverable, micrograms per liter
34469	Pyrene, water, unfiltered, recoverable, micrograms per liter
39400	Toxaphene, water, unfiltered, recoverable, micrograms per liter
81551	Xylenes, water, unfiltered, recoverable, micrograms per liter
77562	1,1,1,2-Tetrachloroethane, water, unfiltered, recoverable, micrograms per liter
34506	1,1,1-Trichloroethane, water, unfiltered, recoverable, micrograms per liter
34516	1,1,2,2-Tetrachloroethane, water, unfiltered, recoverable, micrograms per liter
77652	1,1,2-Trichloro-1,2,2-trifluoroethane, water, unfiltered, recoverable, micrograms per liter
34511	1,1,2-Trichloroethane, water, unfiltered, recoverable, micrograms per liter
34496	1,1-Dichloroethane, water, unfiltered, recoverable, micrograms per liter
34501	1,1-Dichloroethene, water, unfiltered, recoverable, micrograms per liter
77168	1,1-Dichloropropene, water, unfiltered, recoverable, micrograms per liter
49999	1,2,3,4-Tetramethylbenzene, water, unfiltered, recoverable, micrograms per liter
50000	1,2,3,5-Tetramethylbenzene, water, unfiltered, recoverable, micrograms per liter
77613	1,2,3-Trichlorobenzene, water, unfiltered, recoverable, micrograms per liter
77443	1,2,3-Trichloropropane, water, unfiltered, recoverable, micrograms per liter
77221	1,2,3-Trimethylbenzene, water, unfiltered, recoverable, micrograms per liter
34551	1,2,4-Trichlorobenzene, water, unfiltered, recoverable, micrograms per liter
77222	1,2,4-Trimethylbenzene, water, unfiltered, recoverable, micrograms per liter
82625	1,2-Dibromo-3-chloropropane, water, unfiltered, recoverable, micrograms per liter
77651	1,2-Dibromoethane, water, unfiltered, recoverable, micrograms per liter
34536	1,2-Dichlorobenzene, water, unfiltered, recoverable, micrograms per liter
32103	1,2-Dichloroethane, water, unfiltered, recoverable, micrograms per liter
99832	1,2-Dichloroethane-d4, surrogate, Schedule 2090, water, unfiltered, percent recovery
34541	1,2-Dichloropropane, water, unfiltered, recoverable, micrograms per liter
77226	1,3,5-Trimethylbenzene, water, unfiltered, recoverable, micrograms per liter
34566	1,3-Dichlorobenzene, water, unfiltered, recoverable, micrograms per liter
77173	1,3-Dichloropropane, water, unfiltered, recoverable, micrograms per liter
34571	1,4-Dichlorobenzene, water, unfiltered, recoverable, micrograms per liter
99834	1-Bromo-4-fluorobenzene, surrogate, VOC schedules, water, unfiltered, percent recovery
77170	2,2-Dichloropropane, water, unfiltered, recoverable, micrograms per liter
77275	2-Chlorotoluene, water, unfiltered, recoverable, micrograms per liter
77220	2-Ethyltoluene, water, unfiltered, recoverable, micrograms per liter

Constituent Code	Description
78109	3-Chloropropene, water, unfiltered, recoverable, micrograms per liter
77277	4-Chlorotoluene, water, unfiltered, recoverable, micrograms per liter
77356	4-Isopropyltoluene, water, unfiltered, recoverable, micrograms per liter
81552	Acetone, water, unfiltered, recoverable, micrograms per liter
34215	Acrylonitrile, water, unfiltered, recoverable, micrograms per liter
34030	Benzene, water, unfiltered, recoverable, micrograms per liter
81555	Bromobenzene, water, unfiltered, recoverable, micrograms per liter
77297	Bromochloromethane, water, unfiltered, recoverable, micrograms per liter
32101	Bromodichloromethane, water, unfiltered, recoverable, micrograms per liter
50002	Bromoethene, water, unfiltered, recoverable, micrograms per liter
34413	Bromomethane, water, unfiltered, recoverable, micrograms per liter
77041	Carbon disulfide, water, unfiltered, micrograms per liter
34301	Chlorobenzene, water, unfiltered, recoverable, micrograms per liter
34311	Chloroethane, water, unfiltered, recoverable, micrograms per liter
34418	Chloromethane, water, unfiltered, recoverable, micrograms per liter
77093	cis-1,2-Dichloroethene, water, unfiltered, recoverable, micrograms per liter
34704	cis-1,3-Dichloropropene, water, unfiltered, recoverable, micrograms per liter
32105	Dibromochloromethane, water, unfiltered, recoverable, micrograms per liter
30217	Dibromomethane, water, unfiltered, recoverable, micrograms per liter
34668	Dichlorodifluoromethane, water, unfiltered, recoverable, micrograms per liter
34423	Dichloromethane, water, unfiltered, recoverable, micrograms per liter
81576	Diethyl ether, water, unfiltered, recoverable, micrograms per liter
81577	Diisopropyl ether, water, unfiltered, recoverable, micrograms per liter
73570	Ethyl methacrylate, water, unfiltered, recoverable, micrograms per liter
81595	Ethyl methyl ketone, water, unfiltered, recoverable, micrograms per liter
34371	Ethylbenzene, water, unfiltered, recoverable, micrograms per liter
39702	Hexachlorobutadiene, water, unfiltered, recoverable, micrograms per liter
34396	Hexachloroethane, water, unfiltered, recoverable, micrograms per liter
77424	Iodomethane, water, unfiltered, recoverable, micrograms per liter
78133	Isobutyl methyl ketone, water, unfiltered, recoverable, micrograms per liter
77223	Isopropylbenzene, water, unfiltered, recoverable, micrograms per liter
81593	Methyl acrylonitrile, water, unfiltered, recoverable, micrograms per liter
49991	Methyl acrylate, water, unfiltered, recoverable, micrograms per liter
81597	Methyl methacrylate, water, unfiltered, recoverable, micrograms per liter
50005	Methyl tert-pentyl ether, water, unfiltered, recoverable, micrograms per liter
85795	m-Xylene plus p-xylene, water, unfiltered, recoverable, micrograms per liter
34696	Naphthalene, water, unfiltered, recoverable, micrograms per liter
77103	n-Butyl methyl ketone, water, unfiltered, recoverable, micrograms per liter
77342	n-Butylbenzene, water, unfiltered, recoverable, micrograms per liter
77224	n-Propylbenzene, water, unfiltered, recoverable, micrograms per liter
77135	o-Xylene, water, unfiltered, recoverable, micrograms per liter
77350	sec-Butylbenzene, water, unfiltered, recoverable, micrograms per liter

Constituent Code	Description
77128	Styrene, water, unfiltered, recoverable, micrograms per liter
50004	tert-Butyl ethyl ether, water, unfiltered, recoverable, micrograms per liter
78032	Methyl tert-butyl ether, water, unfiltered, recoverable, micrograms per liter
77353	tert-Butylbenzene, water, unfiltered, recoverable, micrograms per liter
34475	Tetrachloroethene, water, unfiltered, recoverable, micrograms per liter
32102	Tetrachloromethane, water, unfiltered, recoverable, micrograms per liter
81607	Tetrahydrofuran, water, unfiltered, recoverable, micrograms per liter
34010	Toluene, water, unfiltered, recoverable, micrograms per liter
99833	Toluene-d8, surrogate, Schedule 2090, water, unfiltered, percent recovery
34546	trans-1,2-Dichloroethene, water, unfiltered, recoverable, micrograms per liter
34699	trans-1,3-Dichloropropene, water, unfiltered, recoverable, micrograms per liter
73547	trans-1,4-Dichloro-2-butene, water, unfiltered, recoverable, micrograms per liter
32104	Tribromomethane, water, unfiltered, recoverable, micrograms per liter
39180	Trichloroethene, water, unfiltered, recoverable, micrograms per liter
34488	Trichlorofluoromethane, water, unfiltered, recoverable, micrograms per liter
32106	Trichloromethane, water, unfiltered, recoverable, micrograms per liter
39175	Vinyl chloride, water, unfiltered, recoverable, micrograms per liter
34554	1,2,4-Trichlorobenzene, bed sediment, recoverable, dry weight, micrograms per kilogram
34539	1,2-Dichlorobenzene, bed sediment, recoverable, dry weight, micrograms per kilogram
34569	1,3-Dichlorobenzene, bed sediment, recoverable, dry weight, micrograms per kilogram
34574	1,4-Dichlorobenzene, bed sediment, recoverable, dry weight, micrograms per kilogram
34624	2,4,6-Trichlorophenol, bed sediment, recoverable, dry weight, micrograms per kilogram
34604	2,4-Dichlorophenol, bed sediment, recoverable, dry weight, micrograms per kilogram
34609	2,4-Dimethylphenol, bed sediment, recoverable, dry weight, micrograms per kilogram
34619	2,4-Dinitrophenol, bed sediment, recoverable, dry weight, micrograms per kilogram
34614	2,4-Dinitrotoluene, bed sediment, recoverable, dry weight, micrograms per kilogram
34629	2,6-Dinitrotoluene, bed sediment, recoverable, dry weight, micrograms per kilogram
34584	2-Chloronaphthalene, bed sediment, recoverable, dry weight, micrograms per kilogram
34589	2-Chlorophenol, bed sediment, recoverable, dry weight, micrograms per kilogram
34660	2-Methyl-4,6-dinitrophenol, bed sediment, recoverable, dry weight, micrograms per kilogram
34594	2-Nitrophenol, bed sediment, recoverable, dry weight, micrograms per kilogram
34639	4-Bromophenyl phenyl ether, bed sediment, recoverable, dry weight, micrograms per kilogram
34455	4-Chloro-3-methylphenol, bed sediment, recoverable, dry weight, micrograms per kilogram
34649	4-Nitrophenol, bed sediment, recoverable, dry weight, micrograms per kilogram
34384	9H-Fluorene, bed sediment, recoverable, dry weight, micrograms per kilogram
34208	Acenaphthene, bed sediment, recoverable, dry weight, micrograms per kilogram
34203	Acenaphthylene, bed sediment, recoverable, dry weight, micrograms per kilogram
34223	Anthracene, bed sediment, recoverable, dry weight, micrograms per kilogram
34529	Benzo[a]anthracene, bed sediment, recoverable, dry weight, micrograms per kilogram
34250	Benzo[a]pyrene, bed sediment, recoverable, dry weight, micrograms per kilogram

Constituent Code	Description
34233	Benzo[b]fluoranthene, bed sediment, recoverable, dry weight, micrograms per kilogram
34524	Benzo[g,h,i]perylene, bed sediment, recoverable, dry weight, micrograms per kilogram
34245	Benzo[k]fluoranthene, bed sediment, recoverable, dry weight, micrograms per kilogram
34295	Benzyl n-butyl phthalate, bed sediment, recoverable, dry weight, micrograms per kilogram
34281	Bis(2-chloroethoxy)methane, bed sediment, recoverable, dry weight, micrograms per kilogram
34276	Bis(2-chloroethyl) ether, bed sediment, recoverable, dry weight, micrograms per kilogram
34286	Bis(2-chloroisopropyl) ether, bed sediment, recoverable, dry weight, micrograms per kilogram
39102	Bis(2-ethylhexyl) phthalate, bed sediment, recoverable, dry weight, micrograms per kilogram
34323	Chrysene, bed sediment, recoverable, dry weight, micrograms per kilogram
34559	Dibenzo[a,h]anthracene, bed sediment, recoverable, dry weight, micrograms per kilogram
34339	Diethyl phthalate, bed sediment, recoverable, dry weight, micrograms per kilogram
34344	Dimethyl phthalate, bed sediment, recoverable, dry weight, micrograms per kilogram
39112	Di-n-butyl phthalate, bed sediment, recoverable, dry weight, micrograms per kilogram
34599	Di-n-octyl phthalate, bed sediment, recoverable, dry weight, micrograms per kilogram
34379	Fluoranthene, bed sediment, recoverable, dry weight, micrograms per kilogram
39701	Hexachlorobenzene, bed sediment, recoverable, dry weight, micrograms per kilogram
39705	Hexachlorobutadiene, bed sediment, recoverable, dry weight, micrograms per kilogram
34389	Hexachlorocyclopentadiene, bed sediment, recoverable, dry weight, micrograms per kilogram
34399	Hexachloroethane, bed sediment, recoverable, dry weight, micrograms per kilogram
34406	Indeno[1,2,3-cd]pyrene, bed sediment, recoverable, dry weight, micrograms per kilogram
34411	Isophorone, bed sediment, recoverable, dry weight, micrograms per kilogram
34445	Naphthalene, bed sediment, recoverable, dry weight, micrograms per kilogram
34450	Nitrobenzene, bed sediment, recoverable, dry weight, micrograms per kilogram
34441	N-Nitrosodimethylamine, bed sediment, recoverable, dry weight, micrograms per kilogram
34431	N-Nitrosodi-n-propylamine, bed sediment, recoverable, dry weight, micrograms per kilogram
34436	N-Nitrosodiphenylamine, bed sediment, recoverable, dry weight, micrograms per kilogram
39061	Pentachlorophenol, bed sediment, recoverable, dry weight, micrograms per kilogram
34464	Phenanthrene, bed sediment, recoverable, dry weight, micrograms per kilogram
34695	Phenol, bed sediment, recoverable, dry weight, micrograms per kilogram
34472	Pyrene, bed sediment, recoverable, dry weight, micrograms per kilogram
07052	Calcium-45, suspended sediment, picocuries per liter
82081	Carbon-13/Carbon-12 ratio, water, unfiltered, per mil
49934	Carbon-14 counting error, water, filtered, percent modern
82172	Carbon-14, percent modern
49933	Carbon-14, water, filtered, percent modern

Constituent Code	Description
82082	Deuterium/Protium ratio, water, unfiltered, per mil
82690	Nitrogen-15/Nitrogen-14 ratio in nitrate fraction, water, filtered, per mil
82085	Oxygen-18/Oxygen-16 ratio, water, unfiltered, per mil
82068	Potassium-40, water, filtered, picocuries per liter
82086	Sulfur-34/Sulfur-32 ratio, water, unfiltered, per mil
75985	Tritium 2-sigma combined uncertainty, water, unfiltered, picocuries per liter
07013	Tritium in water molecules counting error, tritium units
07012	Tritium in water molecules, tritium units
07000	Tritium, water, unfiltered, picocuries per liter
22703	Uranium (natural), water, filtered, micrograms per liter
80155	Suspended sediment load, tons per day
80156	Total sediment load, tons per day
81352	Filter pore size, micrometers
99871	Number of tentatively identified compounds (TICS) from VOC analysis by GCMS, number
50280	Purpose, site visit, code
71999	Sample purpose, code
72005	Sample source, code
84164	Sampler type, code
72006	Sampling condition, code
99931	Set number, VOC analysis
62340	Specimen length, average of composite, biota, millimeters
62342	Specimen weight, average of composite, biota, grams
62344	Standard fish length, average of composite, biota, millimeters
99111	Type of quality assurance data associated with sample, code

Mojave Water Agency

Groundwater Quality Analysis

Phase 1 / Task 2

Requirements and Recommendations for the Initial Groundwater Quality Planning Model Platform

Technical Memorandum

September 29, 2005

Schlumberger
WATER SERVICES

List of Figures

List of Tables

1

Introduction

This technical memorandum summarizes the results of Task 2 of the Groundwater Quality Analysis being performed by Schlumberger Water Services (SWS) for the Mojave Water Agency (MWA). The water quality analysis is part of a regional modeling and analysis program to evaluate and predict changes in groundwater quality based on different management scenarios being considered in the 2004 Regional Water Management Plan (RWMP).

1.1 Scope of Services – Phase 1

The Groundwater Quality Analysis scope of work addresses two main goals:

1. Assemble, reconcile and analyze all available data that is pertinent to help understand water quality issues throughout the MWA service area. Identify any data gaps that need to be addressed while working towards a long-term water quality modeling and analysis system.
2. Design and develop a water quality planning model, appropriate for the data available, that can be used to predict long-term regional changes in water quality. Apply this model to evaluate expected changes in salinity associated with the alternatives being analyzed in the RWMP.

The scope of work consists of four main tasks.

Task 1 – Water Quality Data Compilation, Reconciliation, and Analysis. All available historic water quality information pertinent to the MWA service area has been located, gathered, reconciled, and compiled in a format compatible with current MWA databases. SWS has assessed and characterized the current and historical concentration of salinity in groundwater throughout the basin. A technical memo has been prepared describing the findings from our analysis focusing on areas of historically poor quality and areas exhibiting notable changes in salinity concentrations over time. The technical memo evaluates the overall sufficiency of available data towards the development of a water quality planning model.

Task 2 – Establish Requirements for the Initial Water Quality Planning Model and Select Model Environment. In this current technical memorandum, based on findings from Task 1, SWS has developed recommended requirements and design for the water quality planning model. Given the data currently available, we recommend that the existing Stella node-link system model developed for the MWA 2004 RWMP be enhanced to include a mass balance approach for salinity. The salinity balance will track salt fluxes by accounting for such factors as imported SWP water, natural inflow, natural outflow, existing salinity concentrations, changes in the quantity and location of reclaimed water discharge, evapotranspiration and return flow, deep percolation of precipitation, and other significant factors.

Task 3 – Develop Water Quality Planning Model. Based on the modeling environment selected in Task 2, SWS will develop and calibrate a water quality planning model from historical data.

Task 4 – Apply the Water Quality Planning Model. The model will be used to simulate RWMP alternatives. The results from each alternative will be analyzed and to determine the expected changes of regional water quality to at least 2020. Other operational scenarios may also be evaluated.

1.2 Task 2 Structure

Task 2 includes the following sub-tasks:

- Task 2a – Determine role of model.
- Task 2b – Develop modeling requirements document.
- Task 2c – Determine all necessary inputs and outputs for a salt budget.
- Task 2d – Develop and/or refine physical information needed.
    - Task 2d.1 – Refine aquifer units into smaller management zones - as needed and as data allows.
    - Task 2d.2 – Refine management zone interactions - as needed and data allows.
    - Task 2d.3 – Develop estimates where needed for groundwater in storage by management zone.
    - Task 2d.4 – Develop estimates of TDS by management zone.
    - Task 2d.5 – Define surface and groundwater interactions associated with salt flux mechanisms
    - Task 2d.6 – Refine evapotranspiration and return flow quantities.
- Task 2e – Select applicable modeling platform.

The results of each sub-task are included in this technical memorandum.

2

Task 2a: Role of the Model

2.1 Scope

The Water Quality Workgroup met once to define the objectives of the water quality planning model. The workgroup is made up of representatives from MWA, Schlumberger Water Services (SWS), the Lahontan Regional Water Quality Control Board (LRWQCB), and the MWA Technical Advisory Committee (TAC). The following sections summarize the result and findings of this meeting.

2.2 Introduction

Mojave Water Agency has developed its Regional Water Management Plan to guide water resource management through year 2020. A model to assist in planning of water quality-related activities was identified as a key Management Action for improving understanding of the groundwater basins. MWA has committed to the development of a regional scale water quality planning model and has initiated a comprehensive water quality study. This multi-phase project includes evaluation of the available water quality and hydrogeological data, recommendation of the appropriate platform for the water quality planning model, and model development and implementation. Under the scope of Task 2a of the water quality study, the Water Quality Workgroup met to discuss the role of the water quality planning model.

The purpose of Task 2a is to document the intended role of the water quality planning model. The two primary sources of input considered were the actions proposed in the RWMP, and input from the Water Quality Workgroup. Key aspects of the role of the water quality planning model are summarized below and elaborated in later sections of this memorandum:

- **RWMP Implementation** - The water quality planning model will serve as a valuable tool and a common analytical basis for many of the technical and economic analyses carried out under the RWMP.

- **Water Quality Standards and Metrics -** The water quality planning model will be used to establish water quality standards for MWA projects, and the metrics by which compliance to standards may be monitored and evaluated.

- **Decision Support Tool -** The water quality planning model will be used to evaluate recharge project alternatives and operational scenarios.

- **Data Acquisition Planning -** The water quality planning model will be used to optimize the design and implementation of future water quality sampling and related hydrogeological data acquisition programs.

- **Public Outreach -** The water quality planning model will serve as a valuable tool for collaboration and communication between MWA, its major stakeholders, and the general public.

2.3 Stakeholder Input

RWMP Feedback

Water quality is one of four main elements in the Department of Water Resources (DWR) specification for an Integrated Regional Water Management Plan. MWA has regional management authority for the rapidly growing and strategically located Mojave and Morongo basins and has developed its Regional Water Management Plan (RWMP) to guide water resource management through year 2020. MWA’s responsibility, and the overall objective of the RWMP, is to develop strategies to balance future demands and to maximize overall beneficial use of water. Water quality is one of six key water management issues identified in the RWMP.

Development of the RWMP involved extensive outreach to the public, cooperating agencies, and other stakeholders. Concern over water quality was a consistent theme in the responses to these outreach efforts. The following points summarize outreach responses specifically relating to water quality issues:

- MWA needs to mitigate significant long term increased salt levels due to import of SWP water and effectively manage recharge of imported water.
- The Lahontan RWQCB sees the need for a water quality model to evaluate proposed projects especially those involving recycled water.
- The wastewater infrastructure within the MWA area should be effectively monitored and managed.
- Water quality planning efforts must consider the interaction between subareas or other management zone delineations.
- Important natural recharge sites should be identified and such knowledge incorporated into decisions pertaining to land-use planning and recharge facility siting.
- MWA should take steps necessary to limit migration of water of poor quality.
- Water quality monitoring should be an important objective of the MWA monitoring network programs.

As a result of extensive investigations into the environmental, cultural, technical, and economic aspects, and incorporating the responses to outreach programs, the RWMP contains a menu of proposed projects and management actions to be initiated in the next three to five years. These actions are grouped as follows:

- Monitoring
- Improved characterization of the basin
- Continued long-term planning
- Groundwater protection
- Construction and implementation
- Financing
- Public participation

A total of 60 specific actions were recommended. Approximately 20 of these actions will require or will indirectly but materially benefit from a comprehensive regional water quality planning model. The water quality planning model will complement other management, engineering, and technical tools to be employed in support of these actions.

Water Quality Workgroup Input

On February 15, 2005 a meeting of the Water Quality Workgroup was held at MWA headquarters in Apple Valley, California. The Water Quality Workgroup is composed of staff from MWA, the Lahontan RWQCB, SWS, and TAC. In attendance were:

- MWA representatives Kirby Brill, Norm Caouette, Lance Eckhart, Curt James, and Anna Garcia
- Lahontan RWQCB representative Hisam Baqai
- Schlumberger representatives Mark Williamson, Bob Will, and Alge Merry
- Technical Advisory Committee member Scott Weldy

The meeting was led by Bob Will, who made a presentation covering the following topics:

- Overall water quality project tasks and objectives
- Task 1 findings
- Hydrodynamic and transport modeling fundamentals
- Modeling techniques under consideration
- Suggested roles of the water quality planning model

This presentation stimulated much discussion concerning the data and calibration requirements for the different modeling options, and the suitability of each option with respect to the water quality study. SWS suggestions regarding the role of the water quality planning model were formulated from the vantage of extensive involvement with MWA during preparation of the 2004 Regional Water Management Plan and earlier phases of the water quality project. These suggestions, outlined in the introduction to this section, were well received by the Water Quality Work group.

Discussions during the Water Quality Workgroup meeting yielded several important points for consideration in determining the role of the water quality planning model and selecting the appropriate modeling platform.

- **Model Simplicity –** It was agreed that the complexity of the water quality planning model will be constrained by limitations in both the current water quality dataset and the regional scale conceptual hydrogeological model for the area.
- **Use of a Proxy Hydrodynamic Model –** The technical review included the hydrodynamic proxy model using the Stella model platform used in the 2004 RWMP using proxy head-flow relationships derived from the 2001 USGS ModFlow model. The method of developing the proxy relationships was discussed by the Workgroup. It was agreed that this procedure would be acceptable for the water quality planning model.
- **Proxy Transport Model –** The technical review included a discussion of the distinct data requirements for hydrodynamic and transport process modeling. The need for a transport proxy model was acknowledged and discussed by the Workgroup. The different options for using the 2001 USGS MODFLOW model for this purpose were discussed.
- **Transient vs. Steady State Model –** The technical review included a brief discussion of methods available for modeling steady state and transient systems. The method used for “pseudo-transient” modeling for the 2004 RWMP was discussed. The Workgroup agreed that this method would be deemed adequate for use in the water quality planning model.
- **Model Calibration –** It was understood and agreed by the Water Quality Workgroup that transport processes of the water quality planning model could not be rigorously calibrated against historical data. The initial conditions for constituent distributions in

the model will be based upon available data. Once water quality sample data has been interpolated into the discretized water quality planning model framework, the interpolated data will be checked against raw input data for spatial consistency.

- **Decision Support** – Strong emphasis was placed on decision support aspects of the water quality planning model. Alternative evaluation and operational scenario modeling were highlighted as important capabilities. The ramifications of these activities with respect to model input data requirements, flexibility, and usability were discussed. The ability to easily define and model the performance of multiple operational scenarios will be a key requirement in the water quality planning model.

2.4 Role of the Water Quality Planning Model

Although not specifically defined, the role of the water quality planning model is implicit in the RWMP. Key elements of this role can be inferred from MWA’s responsibility with respect to water quality. Further, some important requirements and objectives of the planning model are effectively articulated in the stakeholders’ responses which are summarized above. Many of these considerations were incorporated into the recommendations included in the Water Quality Workgroup presentation, discussed by the Workgroup, and are summarized earlier in this memorandum. The following sections elaborate on the role of the water quality planning model:

RWMP Implementation

The management and assurance of a reliable supply of water of good quality is a key aspect of the RWMP. Implementation of the RWMP will require a wide variety of tools for engineering, geotechnical assessment, land use, and economic analysis, design, and management. Effective and efficient execution of this plan will require a great deal of cross-disciplinary integration. Such integration requires well-defined standards within each discipline. The water quality planning model will serve as the standard tool for cross-disciplinary integration between water quality related efforts, and other work conducted under the RWMP.

Water Quality Standards and Performance Metrics

Stakeholder response, especially that of LRWQCB, calls for MWA to be involved in the evaluation of proposed recharge projects and comparison of alternatives. These activities require a set of metrics by which such comparisons are to be made. Drinking water quality standards have been established by both state and federal agencies. However, performance metrics for monitoring compliance to these standards have not been specified. Such guidelines are needed in order for MWA to achieve their water quality objectives. The water quality planning model will serve as the basis for technical evaluation of proposed projects and comparison of alternatives related to water quality. The model will also be used to develop the performance metrics for these activities.

Decision Support Tool

The water quality planning model will be used to simulate various RWMP alternatives and operational scenarios. The results will be analyzed for indications of expected changes in regional water quality over time. The analyses will be considered by MWA as decisions are made regarding the details (i.e. general subregional location and timing) of how the RWMP alternatives and operational scenarios are implemented. In cases where water quality characteristics are the primary consideration, the water quality planning model itself will be a key decision support tool. It is anticipated that in some cases the output from water quality planning model alternatives will be input to other geotechnical, environmental, and economic decision support processes.

Data Acquisition Planning

Data acquisition is a major cost to MWA. Data requirements for effective water quality planning include geological, hydrological, and geochemical characteristics of the aquifer system as well as operational characteristics of pumping and recharge facilities. Implementation of the water quality related activities laid out in the RWMP will require an ongoing data acquisition program. Although the burden for such data acquisition is shared with MWA by other cooperating agencies and local purveyors, cost effective data acquisition planning will be critical to optimizing limited funds. The water quality planning model will play a central role in this process. The form of the planning model itself will help to determine what type of data is required. The planning model will be used for sensitivity testing to determine the relative importance of different types of data, and to evaluate trade-offs between different data types. The model will help MWA to select optimal data acquisition locations, sampling frequencies, and techniques. It will also serve as a common basis for coordination of data acquisition activities between the various cooperating agencies. Another important aspect of the water quality planning model is that it will be the mechanism for realizing the value of data. The water quality planning model will facilitate greater routine utilization of geological, hydrological, geochemical, and operational performance data.

Public Outreach

The importance of effective public outreach is clearly evidenced in the recent successful and smooth passage of the 2004 RWMP. This success can be attributed in large part to effective communication and transparency of the process and plan to stakeholders. Continuation and enhancement of this public outreach effort should be adopted as a key element in the role of the water quality planning model. The existence of the water quality model should allow transparency and effective communication of the process and results. Many aspects of the water quality planning process are both interesting and intuitive. Presentation of the model and its results to stakeholders should include extensive use of graphical visualization and animation techniques to convey an understanding of the aquifer system and the important processes related to water quality. The water quality planning model can be used as an educational tool.

2.5 Additional Model Considerations

The role of the model as outlined in the previous section defines the high level objectives of the water quality planning model. These objectives will serve as the key conceptual guidelines in the process of selecting the best modeling platform. In addition to these high level objectives there are additional, more specific model requirements. The following additional modeling considerations were presented to the Water Quality Workgroup for consideration and discussion:

- The water quality planning model must adequately capture the key hydrodynamic and mass transport processes. Despite the desire for simplicity, the model must be compatible with accepted hydrogeologic conceptual models in use or in development for the area.

- The water quality planning model must be easy to update. It must be relatively simple to incorporate new hydrogeological, geochemical, or operational data into the model without complete model reconstruction.
- The modeling platform selected should facilitate routine transfer and incorporation of data elements to and from common GIS and data management systems.
- Although the selection of the modeling platform will be largely dictated by the currently available data and limited regional scale hydrogeological framework, the model should be implemented inasmuch as possible in a manner which provides or allows an upgrade path as the available database grows and the conceptual hydrogeologic model for the area evolves.

2.6 Summary

The water quality planning model will serve a key role in the implementation of the RWMP, supporting several of the recommended management actions. This memorandum summarizes MWA’s motivation for development of a water quality planning model and elaborates the role of the model. The role of the model described in this section will serve as a primary reference throughout this current Task, and during future tasks aimed at design and implementation of the water quality planning model.

3

Task 2b: Modeling Requirements

3.1 Scope

The inputs and model parameters necessary to satisfy the objectives developed in Task 2a have been documented in this task.

The primary motivation for the water quality planning model is to understand long term "salt loading" in the MWA service area. The term salt in this context refers to dissolved minerals. One way to determine the total amount of dissolved minerals in water is to perform laboratory analysis for individual mineral constituents, and then sum these constituents. The more common technique is to evaporate the water from a filtered sample and measure the weight of the remaining solid. The result of the latter method is *called residual on evaporation.* Both analyses result in a measure of the total dissolved minerals, commonly referred to as *total dissolved solids (TDS).* Dissolved solids in the water are non-aqueous mass constituents. The movement of mass in water is called *mass transport.* Modeling of the mass transport process imposes additional requirements on the modeling environment beyond those required for modeling of only water movement. The following sections provide an overview of hydrodynamic and mass (TDS) transport modeling fundamentals, the inputs and output parameters required to model these processes, and the modeling platforms under consideration for use in development of the water quality planning model. The suitability of each of these modeling platforms given the available data will be discussed.

3.2 Hydrodynamic and Mass Transport Modeling Overview

This section contains an overview of groundwater modeling and mass (TDS) transport modeling fundamentals. The objective of this material is to identify and differentiate the key processes at work in the movement of TDS within and between the various hydrogeologic units of the Mojave and Morongo basins. The important distinction between hydrodynamic (water movement) and transport (TDS movement) processes is high-lighted.

Hydrodynamic Inputs and Outputs

Figure 3.1 shows a schematic of a complex hydrogeologic environment illustrating the key hydrodynamic inputs and outputs present in the Mojave Basin. Inputs and outputs of water in the system are also known as "sources" and "sinks" in hydrodynamic modeling and can be either natural or man made. Sources and sinks include rainfall, mountain front runoff, streamflow, recharge ponds and injection wells, production wells, and various plant-related sub-systems such as irrigated crops, phreatophytes, and marshes. Each of these types of sources and sinks are active in the Mojave Basin and will be discussed in detail in Section 4 of this memorandum.

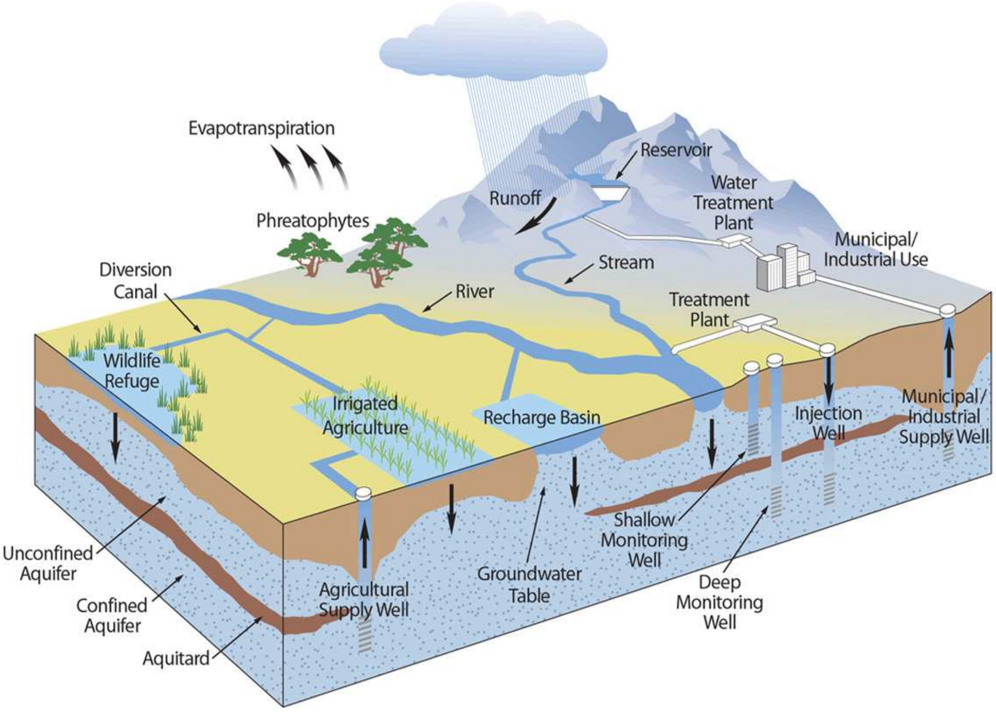


Figure 3.1 - Surface/Groundwater System Components

Sources

- ***Rainfall / runoff***
- ***River / tributary flow***
- ***Reclaimed wastewater injection, infiltration***
- ***SWP water***
- ***Septic systems***
- ***Irrigation, landscape watering***

Sinks

- ***Public water systems***
- ***Domestic wells***
- ***Agricultural supply***
- ***Evapotranspiration***
- ***Industry***
- ***River outflow/base flow***

Hydrodynamic Mechanisms

Each of these hydrodynamic sources and sinks has an associated mechanism or driving force. By far the most prevalent natural mechanism acting in the movement of both surface and groundwater is gravity. Gravity drives river flow from high elevations to lower elevations, infiltration from lakes and streams into the earth, and the flow of subsurface water movement downslope along impermeable bedrock basin margins toward a flat water table. All of these are cases in which the potential energy (or head) of the water is released through downward flow toward equilibrium with its surroundings. Another significant natural driving mechanism is evapotranspiration. Evapotranspiration is the process by which water is given up to the atmosphere through the leaves of plants. This water may originate from the surface (marshes, irrigation, and shallow water table) or deeper groundwater depending upon the type of plant and the local hydrological conditions.

Man made hydrodynamic flow is induced by the creation of an artificial head differential. Potential energy is transferred into or out of the system through pumping or injection, thereby disturbing hydrodynamic equilibrium. Extraction of water from a well causes an artificial reduction in head at that location. This non-equilibrium condition is alleviated by the influx of water from adjacent portions of the aquifer. Conversely, injection of water in a well results in an artificial increase in head, which will be compensated by flow of water away from the well.

Transport Mechanisms

There are three mechanisms by which water-born mass (TDS) may be transported within a hydrodynamic system. These are:

Advection – Constituents are transported by fluid motion alone. Speed of transport is equal to the average speed of fluid movement. If advection is the only active mass transport mechanism then without fluid movement mass concentrations would remain unchanged. In systems with groundwater movement, advection is the dominant mass transport process.

Physical Dispersion – Physical dispersion of mass is caused by mixing action resulting from small scale heterogeneities in aquifer hydrodynamic properties. Physical dispersion therefore requires groundwater flux. Modeling of physical dispersion requires knowledge of the "dispersivity" property of the aquifer material. Although dispersion may be significant in some systems, it is secondary in magnitude with respect to the advection process.

Numerical Dispersion – Numerical dispersion is an artifact of the computational method used to model transient mass transport. Each time step in a spatially discretized model advances the mass concentration front by a complete spatial unit. In coarsely discretized models the length of a spatial unit may easily exceed the distance that mass would actually travel in the true physical system. This results in artificial acceleration in the advancement of the modeled mass concentration front.

Diffusion – A chemical process driven by the tendency toward equilibrium of concentrations. A locally high concentration of a mass will diffuse or mix with lower concentrations in the absence of fluid movement. Diffusion is often considered a significant transport mechanism in modeling of localized studies. However, diffusion will be assumed to be insignificant as a regional scale TDS transport mechanism.

Key Groundwater System Parameters

The actual groundwater and TDS flux resulting from any source or sink will be determined by the combined effect of many aquifer and model properties and parameters. Parameters and properties may describe the source or sink, the aquifer, or the driving mechanism.

Key aquifer hydrodynamic and transport properties:

- **Specific Storage (S_s) –** The volume of water released from or taken in by a unit volume of a confined aquifer per unit change in head. This is the tendency for an aquifer to take on or release water under injection or extraction pumping, and is primarily a characteristic of the compressibility of the aquifer material.
- **Specific Yield (S_y) –** The volume of water released from or taken in by a unit area of an unconfined aquifer per unit change in head. This is the tendency for an unconfined unsaturated aquifer to take on or release water under injection or extraction pumping. Specific yield is strongly related to capillary forces and is primarily a characteristic of grain size, sorting, and aquifer material type.
- **Hydraulic Conductivity (K) –** The ability of an aquifer material to transmit water under an imposed head differential. This is primarily a function of the grain size and connectivity of void space (porosity) of the aquifer material.
- **Anisotropy** – The dependency of hydraulic conductivity on direction of flow. Vertical hydraulic conductivity anisotropy is a common characteristic in confined aquifers. In this case the vertical hydraulic conductivity is lower than the lateral hydraulic conductivity. This is usually the result of thin layers of impermeable (evaporite) materials, or alignment of lens-shaped clay materials during deposition or overburden compression.
- **Effective Porosity –** Porosity or some estimate of connected pore volume is a requirement for rigorous transport modeling because it is necessary to know the initial distribution of mass. Since effective porosity in not a requirement for normal hydrodynamic modeling this property is often poorly defined for the model region and must be estimated from Specific Capacity and Specific Yield.

- **Dispersivity (α) –** An empirical property of the aquifer material and describes the tendency for mixing and spreading during the movement of water through the aquifer. Dispersivity is primarily dependent upon on soil texture (grain size and sorting).
- **Diffusion coefficient (D_d)** – A measure of the tendency of the mass concentrations to seek chemical equilibrium in the absence of mechanical forces.

Other important hydrodynamic system parameters describing the model and its various components include:

- **Boundary conditions** – Describe the hydrodynamic characteristics of the outer boundaries of the system being modeled. For example, an impermeable bedrock basin margin would be described as a “no flow” boundary. The edge of the model adjoining a very large aquifer with strong recharge would be described as a “constant head” boundary. A boundary representing infiltration from a constant flux source such as a perennial river could be described as a “constant flux” boundary. It is important to understand the characteristics of areas adjacent to the model region, and the nature of their interactions with the modeled region so that the appropriate boundary conditions can be implemented.
- **Pumping rates and times –** Man-made stresses on the aquifer through pumping have first order impact on the state of the aquifer at any given time. The times, locations, and rates of pumping also are the primary variables for many of the scenario analyses which will be performed.
- **Streamflow/tributary Flows –** Surface water can be a significant component of the overall hydrogeological system. Unfortunately flow in streams and tributaries can be poorly documented. In addition, streams which flow only sporadically in response to storm surges are difficult to accurately describe using long time step modeling tools. It is therefore often necessary to both estimate the flow in rivers and contributions from tributaries, and to approximate the input mechanism and boundary condition associated with the stream.
- **Evapotranspiration (ET) –** The process of ET associated with riparian growth, phreatophytes, or agriculture may be a significant hydrological factor and should be

measured or estimated. ET is measured in units of volume of water lost per unit area per day. Methods for estimating ET include water balance computations, lysimeter measurements, gravimetric and neutron probe measurements, and advanced satellite imagery combined with meteorological measurements. The latter technique has been recently applied to the MWA service area, the results of which will be discussed in Section 5 of this memorandum.

- **Other surface water discharges** – Other surface water discharges such as State Water Project water and treated waste water may have a significant impact on the hydrodynamic system. Accurate locations, times, and rates of such discharges must be determined.

Unsaturated Zone Modeling

Infiltration of precipitation or other recharge sources through the unsaturated zone above the water table is caused by gravitational forces and the density difference between water and air. Rigorous modeling of infiltration through the unsaturated zone requires knowledge of soil properties that describe its tendency to retain water and inhibit flow. This tendency to retain water is called *capillary action* or *capillary force*. Electrochemical interactions between the air, water, and the soil matrix in the unsaturated zone combine to create capillary forces. In the presence of capillary forces water will not flow vertically under gravity potential until a critical saturation is reached. The failure of occasional precipitation to recharge aquifers in arid regions is the result of capillary forces inhibiting infiltration, and subsequent evaporation of the water trapped in the near surface. Capillary force is dependent upon soil type, sorting, and, to a lesser extent, water chemistry. Capillary force is lowest in high porosity, well-sorted soils and highest in low porosity poorly sorted soils. Determination of the capillary forces in a particular soil requires experimental testing on soil samples. Capillary forces are the cause of deviation between the porosity (void space) and the Specific Yield of a soil. Specific yield approaches porosity as a limit in well-sorted soils.

3.3 Modeling Options

This section provides discussions of key modeling concepts to be considered in development of the water quality planning model, and brief overviews of the modeling options under consideration.

Steady State vs. Transient Models

Hydrodynamic models may be either steady state or transient. The key aspects of these different types of models are:

Steady State – A steady state model is one in which the distribution of heads in the system is assumed to be time-invariant. A steady state condition will result from a lack of any kind of stresses, such as pumping, on a closed system. More commonly, a steady state condition is approximated by the application of *constant* stresses on a system. For example, distribution of heads in a region under constant pumping stress but with strong recharge will be invariant. A steady state assumption is most often applied to the pre-development period of an aquifer system to facilitate calibration of aquifer properties for subsequent transient modeling. However, the steady state condition may also adequately approximate many real hydrodynamic systems with few variable stresses. For a steady state model the heads need only be computed one time. In the case of constant stresses, the resulting fluxes will also be constant.

Transient – A transient model is one that includes the variations of head distributions through time in response to variable stresses. Since most real aquifer systems do not have constant pumping stresses and/or infinite recharge the transient condition is usually the most representative and therefore the preferred model condition. Transient modeling requires repetitive computations of heads in order to represent the time variant nature of the system. The frequency at which heads are recomputed depends on the frequency and magnitude of variations of the stresses imposed. Transient systems with slow variations in stresses and where only infrequent long term estimates of heads are required may sometimes be approximated by series of steady state models with representative stresses and boundary conditions.

Pseudo Steady State - A "pseudo" steady state condition is one in which the head or mass concentration in the system are changing everywhere at the same rate. This occurs when the system boundaries have been reached by the flow or mass transport.

"Proxy" Models

The term "proxy" model is used in this memorandum to describe the approximation and simplification of complex modeling process for the purpose of using this approximation of that process within a model. This type of model substitution is typically used in complex system models involving many inter-related (coupled) processes. In such systems it is often either impractical or impossible to rigorously model the inter-relationships between all processes. However, it is often possible to approximate the relationship for use in the larger system model through an empirically derived substitute or proxy model. This technique was used in development of the system model of the MWA service area used to evaluate 2004 RWMP management alternatives. In that application Mojave Basin ModFlow model was used to develop proxy models for the head dependent flux of groundwater between management zones. Using this method it was possible to implement an approximation of the calibrated groundwater flow model as part of a very complex system model.

3.4 Modeling Options

Three modeling environments have been considered for implementation of the water quality planning model. These models represent progressive degrees of complexity. Key considerations of these modeling options are discussed here and summarized in Table 3.1.

Option 1: "Bucket" Model

The term "bucket" model is used to describe a model in which the groundwater and other aquifer sub-units are treated as simple buckets or tanks. The following are key aspects of bucket models:

- Steady state. Inputs, outputs, stress, and boundary conditions are assumed to be constant and head is assumed to be invariant.

- Instantaneous mixing is assumed. Water entering the sub-unit at any location is assumed immediately distributed throughout the entire sub-unit.
- Hydrogeologic properties are lumped within discretized units.
- Mass balance is maintained. Influxes balance outfluxes.
- Can be performed using a spreadsheet computation.
- Steady state assumptions may be varied to reflect variable stresses in an effort to approximate transient behavior.

Figure 3.2 shows an example of a spreadsheet water balance using a “bucket” model from the 2004 RWMP.

	Este	**Oeste**	**Alto**	**Centro**	**Baja**	**Entire Basin**
WATER SUPPLY						
Surface Water Inflow						
Gaged	0	0	71,300[a]	0	0	71,300
Ungaged	1,700	1,500	3,600	34,700[1]	14,400[2]	7,200[3]
Subsurface Inflow	0	0	1,200	2,000	1,200	0[4]
Deep Percolation of Precipitation	0	0	3,500	0	100	3,600[5]
Import Wastewater						
Lake Arrowhead CSD	0	0	1,900	0	0	1,900[6]
Big Bear ARWWA	2,600	0	0	0	0	2,600[6]
Crestline Sanitation District	0	0	900	0	0	900[6]
Total:	**4,300**	**1,500**	**82,400**	**36,700**	**15,700**	**87,500**
OUTFLOW AND LOSSES						
Surface Water Outflow						
Gaged	0	0	0	0	8,100[b]	8,100
Ungaged	0	0	34,700[1]	14,000[7]	0	0
Subsurface Outflow	800	400	2,000	1,200	0	0
Phreatophyte Consumption	0	0	11,000	3,000	2,000	16,000
Total:	**800**	**400**	**47,700**	**18,200**	**10,100**	**24,100**
NET AVERAGE ANNUAL WATER SUPPLY:						**63,400**

Figure 3.2 - Example of a spreadsheet water balance using a “bucket” model showing inputs, outputs, and mass balance computations. From Schlumberger Water Services (2004)

Option 2: Node-Link System Model

A node-link system model is a model in which the elements of the system are represented as connected nodes. Connections between nodes may be described as simple analytical linear or non-linear relationships between system variables. The entire model forms a system of equations. The instantaneous state of the entire system is determined by solving the system of equations using non-linear solution techniques. Node-link system software, such as Stella, provide the functionality to automatically perform repetitive "time stepped" solutions based upon sequential input data allowing simulation of time variant processes.   The following are key aspects of non-linear system modeling with respect to the water quality planning model:

- Node-link system modeling software packages, such as Stella, have flexible user interfaces providing the utilities and graphical functionality required to build, troubleshoot, and evaluate the results of complex systems.
- The solution technique does not require the same degree of spatial resolution as that required to solve hydrodynamic equations.
- Nodal inflows and outflow links may be either analytical or discrete.
- Can be used to approximate pseudo-steady state processes through automated time stepping.
- Hydrogeologic properties are lumped within discretized units.
- Instantaneous mixing is assumed. TDS entering a zone through any boundary instantaneously impacts the concentrations throughout the zone.

Figure 3.3 below shows an example of the non-linear system model for a portion of the MWA service area from the 2004 RWMP Stella model.

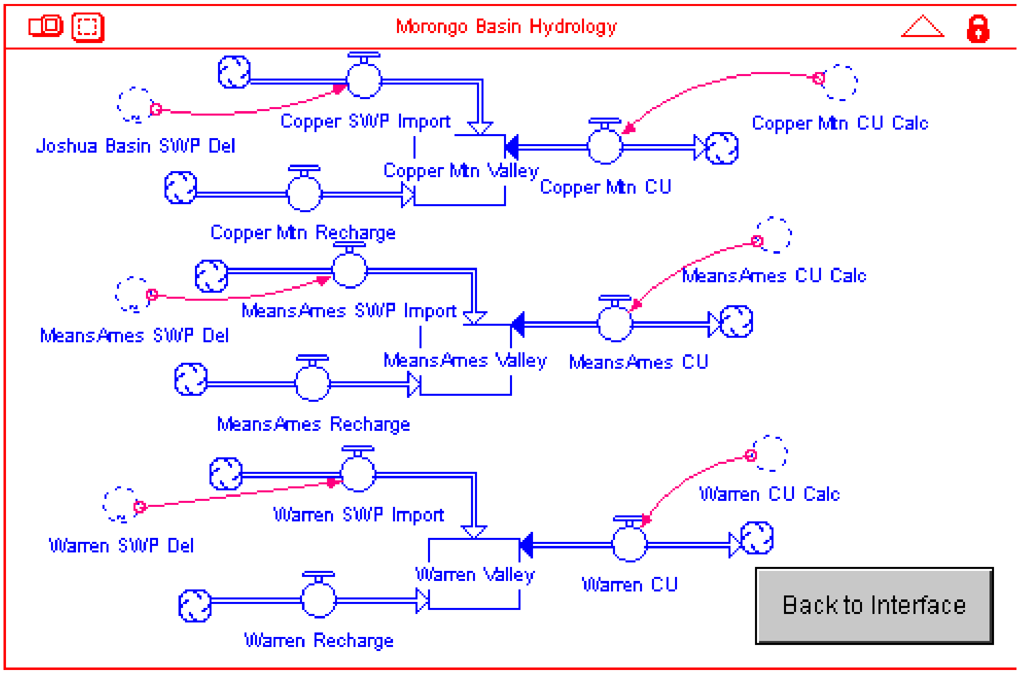


Figure 3.3 - Example of a node-link system model.

Option 3: Numerical Models

Numerical water quality modeling systems can perform rigorous solution of the groundwater flow and mass transport equations. As such, these models more closely honor the actual physics of fluid flow and mass transport. However, the advanced solution process demands additional model parameterization. The additional complexity and possible improved result obtained from these techniques must be supported by good quality and spatially refined hydrogeologic properties as well as reliable estimates of properties describing the driving mechanism. The following are key aspects of numerical modeling methods with respect to the water quality planning model:

- Numerical models will likely be more highly discretized both horizontally and vertically.
- Transport processes may include advection, dispersion, and diffusion.
- Additional parameterization is required for rigorous transport process modeling.

- Software options include Finite Difference (e.g. ModFlow, Eclipse) and Finite Element (e.g. FEFLOW) methods.

Figure 3.4 below shows a cutaway view of the hydraulic conductivity distribution from the 2001 USGS Mojave Basin regional ModFlow hydrodynamic model.

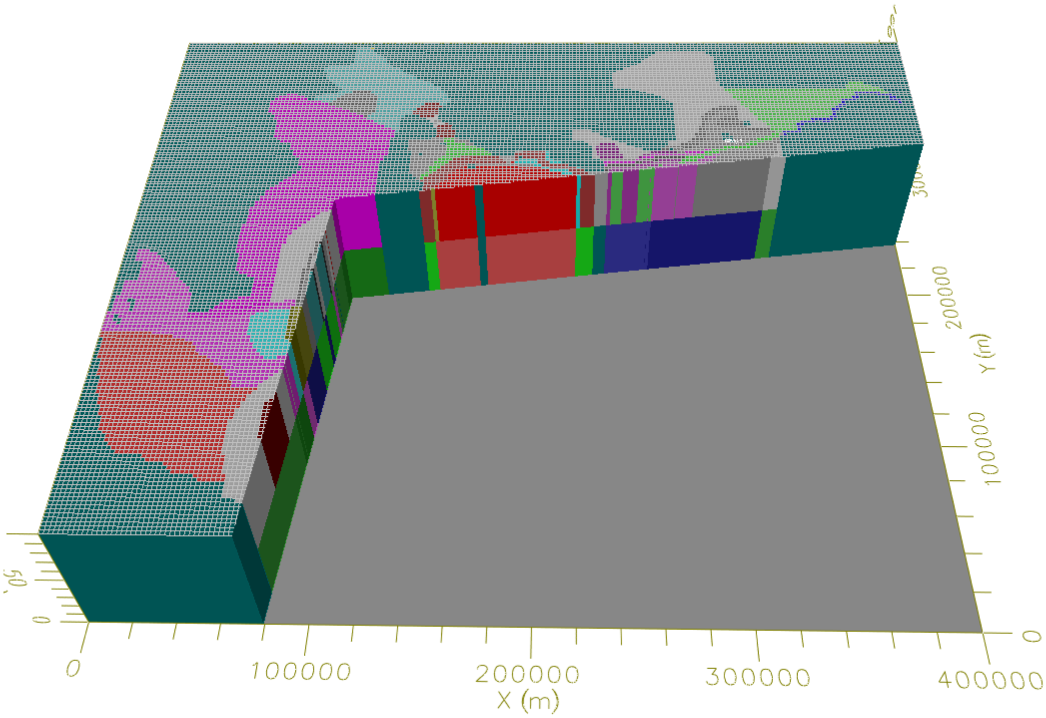


Figure 3.4 - Example of finite difference numerical model grid showing cutaway view of hydraulic conductivity distribution showing the 2000’ x 2000’ grid.

3.5 Summary

This section provided a review of important fundamental considerations in groundwater and mass transport modeling. The three primary modeling options available for use in the water quality planning model were reviewed. Table 3.1 below contains a summary of this and other related information which has been used in the selection of the most appropriate modeling platform for the water quality planning model. The selection process will be discussed in Section 6 of this memorandum.

Table 3.1 - Summary of key considerations for hydrodynamic and transport modeling.

Model Type	Description	Recommended Modeling Environment	Pro	Con
Steady State Salt Balance	Bucket model with constant inflow/outflows and initial condition based on snap shot of aquifer salinity state.	Spreadsheet	Simple, inexpensive. No special software required.	Coarse, static, not suitable for heterogeneous transient systems.
Non-Linear System Model	Nodal model with transient inflow/outflow and inter-basin process calibrated against historical data and the available Modflow hydrodynamic model.	System Analysis Software (e.g. Stella)	Inexpensive option for first order modeling of transient, non-linear system behavior.	Increased complexity. Requires explicit characterization of transient processes.
Numerical Advective TDS Transport	Transient numerical hydrodynamic model with TDS treated as a tracer transported through advective flow only.	Numerical simulator (e.g. Modflow)	More accurately predicts heterogeneous and transient hydrodynamic system behavior.	Complex, requires special software, skills, and additional geological and hydrologic input data.
Numerical Transport Model with Dispersion	Transient numerical hydrodynamic/transport model with TDS transported by advection with calibrated dispersion.	Numerical simulator (e.g. Schlumberger Eclipse, MODFLOW RT3D, FEFLOW)	Dispersion can be significant in hydrodynamically transient systems depending on lithology.	Requires calibration and specialized software and skills and additional geological and hydrologic input data. Dispersion often 2nd order effect depending on lithology and hydrodynamic conditions.
Numerical Transport Model with Dispersion and diffusion	Numerical hydrodynamic/transport model with TDS transported by advection, calibrated dispersion, and diffusion.	Numerical simulator (e.g. Schlumberger Eclipse, MODFLOW RT3D, FEFLOW)	Useful in systems which are close to hydrodynamic steady state but transient with respect to concentration state.	Calibration sensitive. Requires specialized software and skills and additional geological and hydrologic input data. Diffusion often 2nd order effect in hydrodynamically transient systems.

4

Task 2c: Salt Budget Inputs/Outputs

4.1 Scope

A list of TDS sources in the MWA service area with potential direct impact to the quality of the overall groundwater supply has been compiled. This section provides an assessment of each of these sources for incorporation into the water quality planning model. This assessment is based upon quantitative data for each source where available, literature research, and by inference using the water quality database developed in Task 1 of this study. Data availability is discussed for each significant source. All TDS sources to be included in the water quality planning model will be quantified in Section 5 of this memorandum.

4.2 Introduction - Water Quality Sampling in the Mojave Basin

Groundwater quality sampling in the region commenced in the early part of the 20th century. Over time the number and distribution of wells being sampled has greatly increased, but has fluctuated. Figure 4.1 shows a histogram of the number of wells being sampled for TDS between the year 1900 to present in 10 year increments. Figures 4.2 (a-d) show the distribution of wells in the Mojave Basin being sampled for TDS during the time periods 1900-1925, 1925-1950, 1950-1975, and 1975-present. As reported in the Phase 1 Technical Memorandum, sampling throughout the MWA area identified areas in which TDS concentrations have increased over time, and in some cases concentrations have exceeded drinking water standards. Some of these anomalies and trends were high-lighted in the Task 1 technical memorandum of this study. Figure 4.3 shows average TDS levels by well for all available data in the MWA area. Figures 4.4 (a-d) show wells with average TDS levels below 500 mg/L, above 500 mg/L, above 1000 mg/L, and above 1500 mg/L respectively computed from data from 1975 to present. Persistent high TDS anomalies are visible on Figure 4.3 (d) in the vicinities of Barstow, Helendale, and in some of the dry lakes. The significance of these anomalies will be discussed in this and later sections of this memorandum.

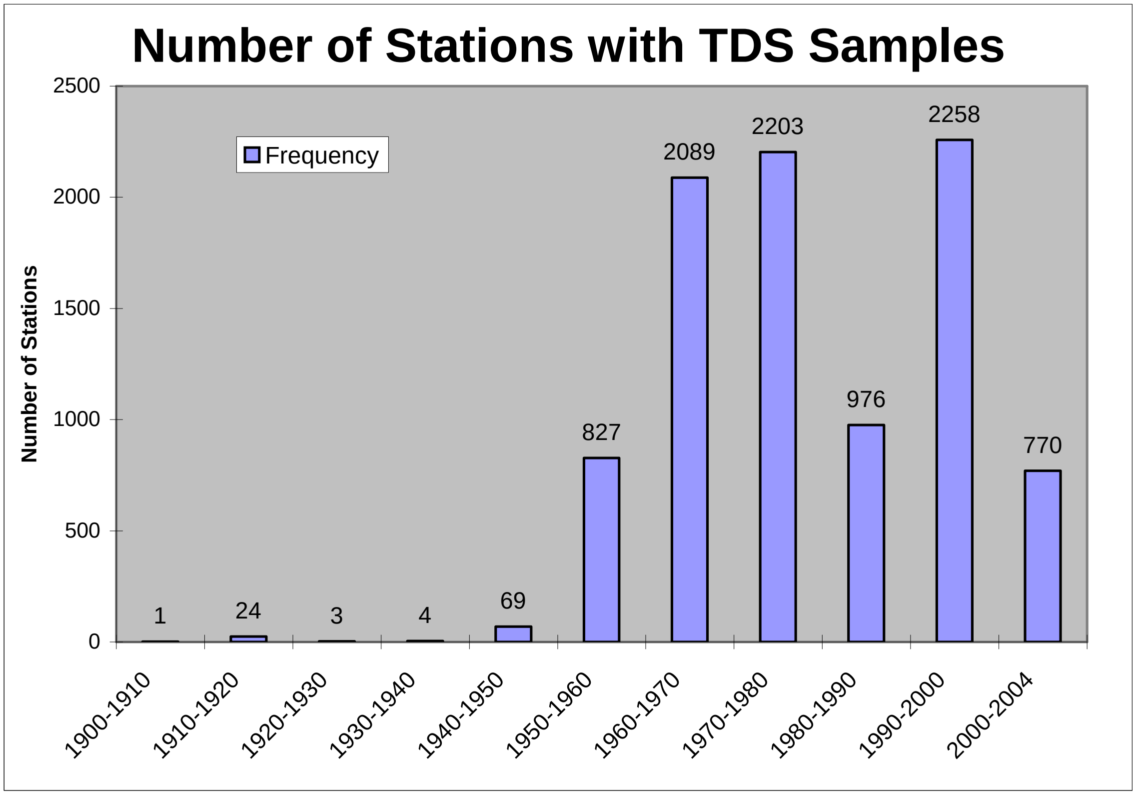


Figure 4.1 - Number of stations sampled for TDS in 10 year intervals through year 2000, and for the 4 year period from 2001-2004.

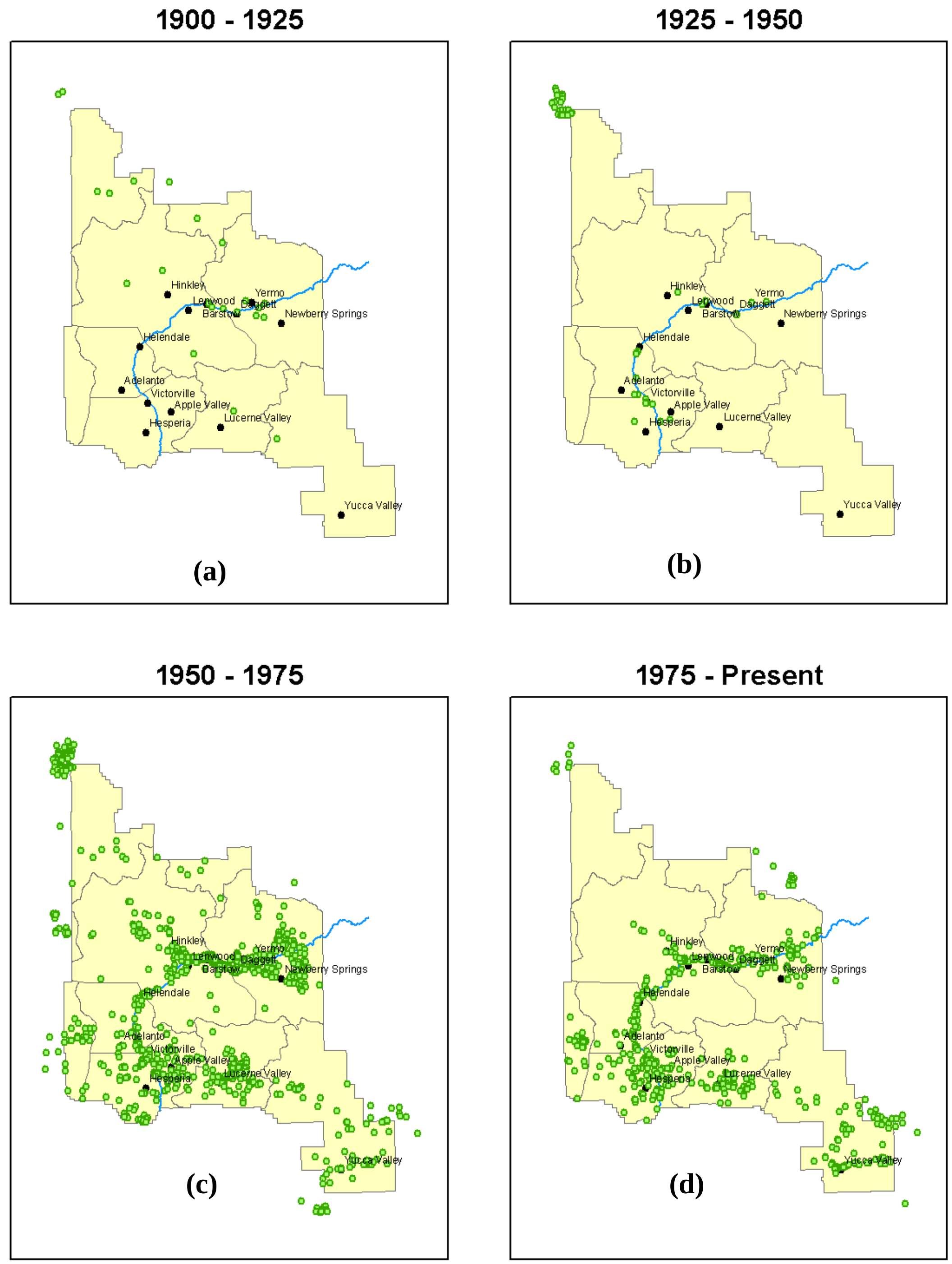


Figure 4.2 - Locations of stations sampled for TDS in time periods (a) 1900 - 1925, (b) 1925-1950, (c) 1950-1975, and (d) 1975 to present. Black squares are cities and towns, green circles are station locations.

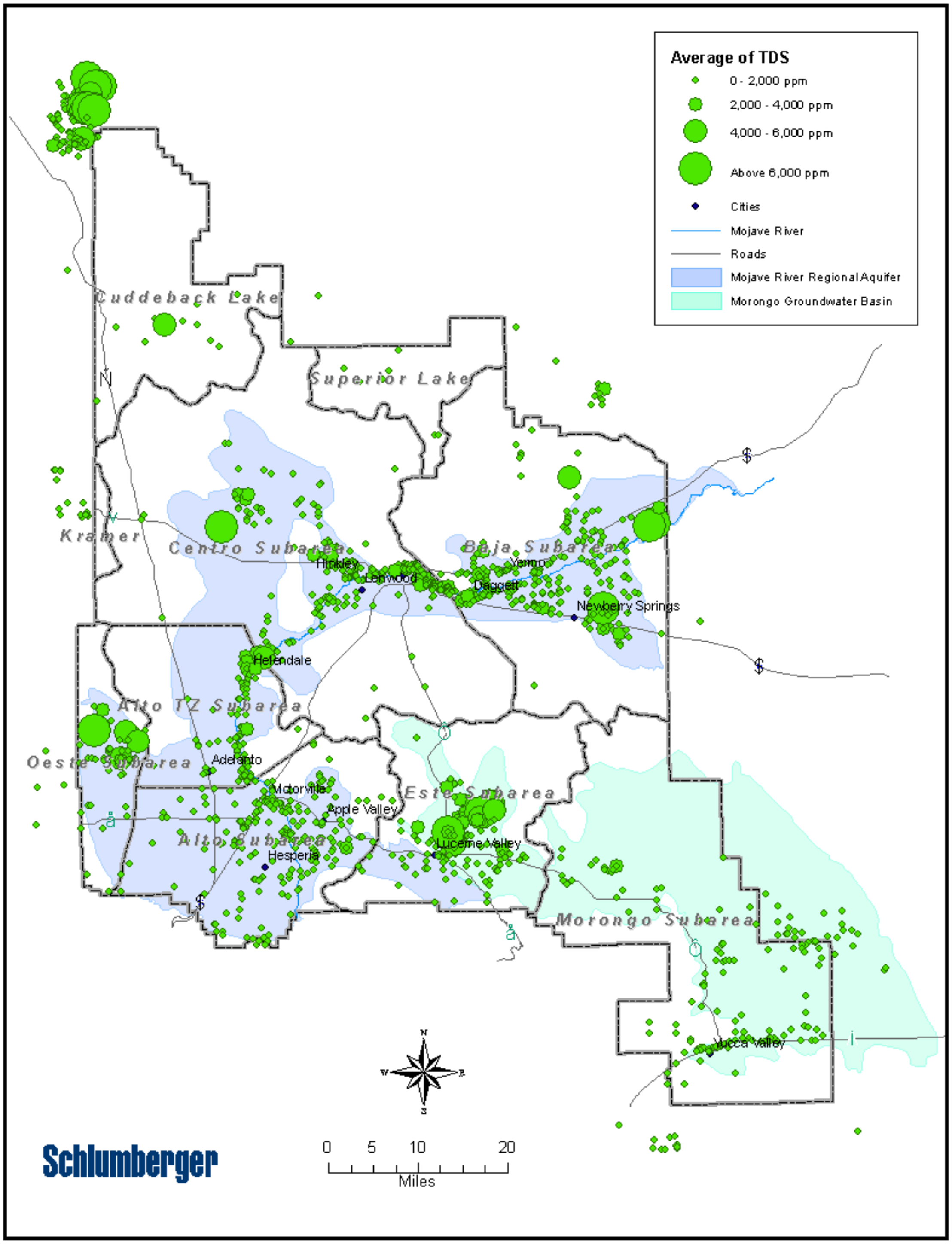


Figure 4.3 - Average TDS levels in the MWA service area by well. Radius of the symbol is proportional to the average value.

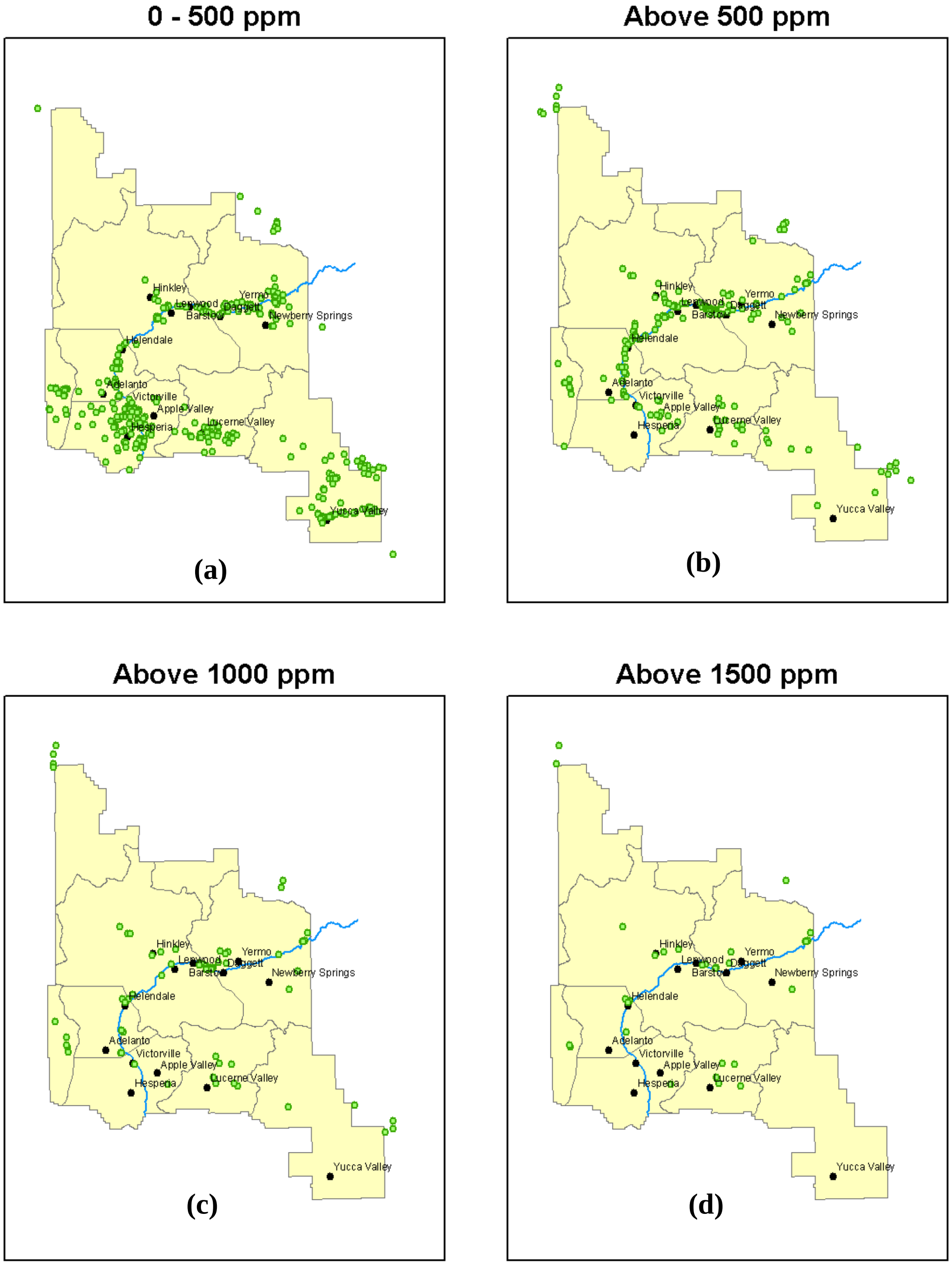


Figure 4.4 - Wells with average TDS levels (a) 0-500 ppm, (b) above 500 ppm, (c) above 1000 ppm, and (d) above 1500 ppm from 1975 to present. Black squares are cities and towns, green circles are station locations.

4.3 Factors Influencing TDS Concentrations

Factors influencing the distribution of TDS concentrations include not only sources and sinks through which TDS crosses the boundaries into and out of the area of interest, but also the mechanisms by which TDS is redistributed within the area. The main objective of the water quality planning model is to predict overall salt loading in the Mojave and Morongo basins. For this purpose alone only TDS sources and sinks would be required. However, the water quality planning model will also be used to evaluate RWMP alternatives. This additional objective requires modeling of the movements of TDS within the area. This additional objective requires modeling of the major transport mechanisms influencing the distribution of TDS in the MWA service area. TDS sources and mechanisms resulting in redistribution of TDS may be either naturally occurring or anthropogenic (man-made). The following lists of potential sources and redistribution mechanisms were compiled:

Anthropogenic TDS Sources and Mechanisms

- Artificially recharged state water project water
- Treated wastewater recharge
- Irrigation return flow
- Railyards
- Septic systems
- Fish hatcheries
- Mining and Landfills

Natural TDS Sources and Mechanisms

- Mojave River and tributary inflow
- Groundwater inflow
- Storm Flows and precipitation
- Evapotranspiration
- Geology and Dry Lakes

Locations of the known TDS sources are shown in Figure 4.5. These may act purely as sources (or sinks) to the area affecting the net TDS budget, or as mechanisms to redistribute TDS within the MWA area, or both. The State Water Project is an example of a source of

TDS from outside the area. The combined effect of Victor Valley Waste-water Authority (VVWRA) sewer system and its wastewater treatment facility act to redistribute effluent from large municipal areas to localized recharge facilities.

Some of the point sources in Figure 4.5 correlate directly with TDS anomalies observed in Figures 4.3. The following sections of this document contain background information on each of these potential TDS sources, assessment of the impact of each on the long-term salt balance in the MWA service area, the redistribution mechanisms at work, and a discussion of whether or not each should be incorporated into the water quality planning model. The assessment will be based upon available quantitative data, prior studies, and observations in the available water quality data.

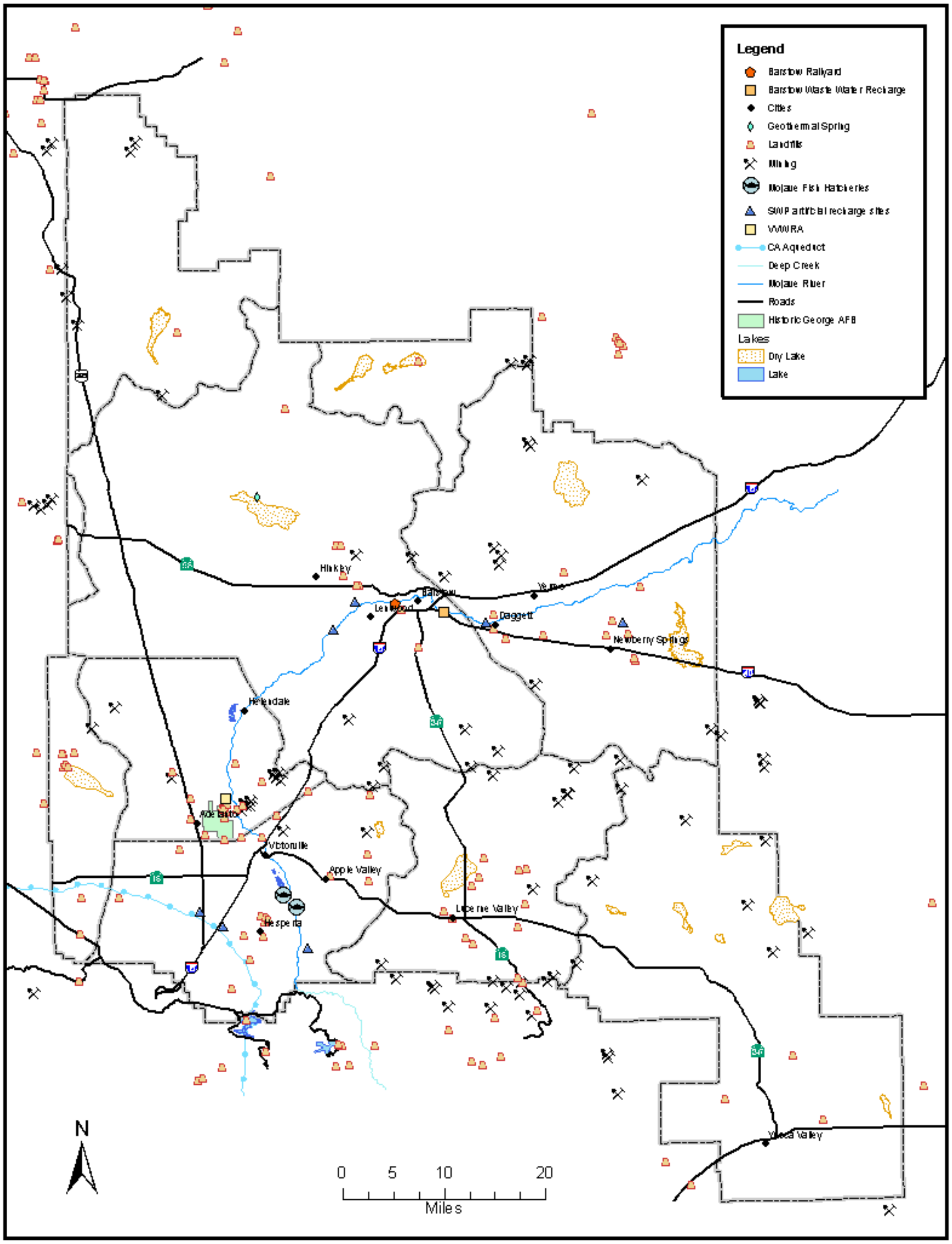


Figure 4.5 - Locations of known point sources of TDS in the MWA service area.

4.4 Anthropogenic Sources of TDS

Artificially Recharged State Water Project Water

Background – The Mojave River Pipeline takes State Water Project (SWP) water from a siphon on the California Aqueduct. Currently, MWA imports approximately 8,400 acre-feet per year of SWP water and is planning to increase its SWP utilization to 75,800 acre-feet per year (SWS, 2004). SWP water is conveyed through the Mojave Pipeline to the Hodge, Lenwood, Daggett, and Newberry Springs recharge facilities located in the Centro and Baja Subareas. The Morongo Basin pipeline delivers SWP water to the Mojave River area, Hesperia, and to the Yucca Valley (Warren Valley Basin).

Assessment – Since SWP water imports to the basin will be persistent, long term, and increasing, these imports are deemed to be a significant factor in the long term salt balance in the Mojave Basin. Data regarding the quantity and quality of SWP water delivered to the MWA service area readily available from the California Department of Water Resources (DWR). The Mojave Regional Water Management Plan (RWMP) contains estimates of anticipated imports through year 2020. Influx of TDS through SWP imports will be included in the water quality planning model. Although the quality of SWP water varies seasonally, the average TDS concentration is approximately 280 ppm.

Treated Wastewater Recharge

Background – Treated wastewater effluent from several sources contributes to groundwater recharge in the MWA. This source contains TDS associated with the consumption of foods and beverages, and personal hygiene. Treated wastewater is discharge to the Mojave River floodplain aquifer in several locations within the MWA service area. Local authorities currently discharging treated effluent include:

- Victor Valley Wastewater Reclamation Authority (VVWRA)
- City of Barstow
- United States Marine Corps Nebo Base and Yerbo Annexes
- Community of Silver Lakes

- City of Adelanto
- Rancho Los Flores
- Lake Arrowhead Community Services District
- Big Bear ARWWA
- Crestline Sanitation District

TDS levels in these discharges range from approximately 370 mg/l to 1000 mg/l. The high TDS anomaly located in the vicinity of Barstow and visible in Figure 4.3 may be, in part, the result of early undocumented wastewater discharges by the City of Barstow and discharges by the USMC at the Nebo and Yerbo Annexes.

Notwithstanding the TDS anomalies mentioned above, these wastewater discharge volumes represent only minute fractions of the active groundwater volume in the basin as estimated in the 2004 RWMP. For example, by 2020 VVWRA plans to discharge as approximately 18.6 million gallons per day (20,000 acre-ft) per year into the regional and floodplain aquifers in various sub-regional treatment facilities. In the scenario described above approximately 1% of the active water volume of the Alto and Transition Zone sub-areas would be redistributed over a 20 year period. For the most part, wastewater treatment and discharge results in *redistribution* of dissolved solids within the basin. Although such internal redistribution of TDS may not significantly increase the overall salt load within the basin over the long term, the concentration and selective reintroduction of such large quantities of TDS resulting from wastewater management could have a significant impact if not managed properly.

Assessment – It is our recommendation that wastewater discharges be included as a mechanism for introduction and redistribution of TDS in the water quality planning model.

Agriculture/Irrigation - Return Flow

Background – Irrigation return flow is the excess water that is applied as agricultural irrigation that is neither used consumptively by plants nor is evaporated, and which is returned to the groundwater supply via percolation. It has been estimated that 29 to 46 percent of the water pumped for agriculture becomes irrigation return flow in the Mojave area (Stamos, 2001). Because of evaporation, leaching of minerals, and introduction of imported fertilizer salts, TDS concentrations in irrigation return water can be more than twice the concentration of the applied water (Densmore, 1997). Since the return flow water is typically poorer in quality than the produced source water, the repeated use of this water can have adverse effects on groundwater and salt concentration may limit perpetual reuse (URS, 2003). It should be noted that the crops grown in the MWA area are largely fodder crops that are primarily consumed within the basin. Therefore, it can be considered that any salts absorbed by the crops stay within the basin. RWMP estimates for agricultural water demand show a significant (approximately 60 percent) decrease by the year 2020.

Commercial dairies may also present significant sources of TDS flux into the groundwater system. TDS content of effluent from dairy cattle may be highly variable and will depend upon factors such as the feed used and whether or not salt supplement is provided. The degree to which the effluent affects groundwater quality will also depend upon other practices such as collection and redistribution of manure as fertilizer. Greater than twofold increases in electrical conductivity (TDS) above background levels have been observed in groundwater below dairy feedlots (Harter, 2005). This phenomenon is currently under study by the Region 5 Water Quality Control Board in cooperation with the University of California.

Assessment – Irrigation return flow does not represent significant net inflow or outflow to or from the Mojave Basin. Irrigation water is typically pumped at the point of use. However, since TDS concentration may be significantly increased through irrigation, this TDS influx mechanism should be included in the water quality planning model. Although the specific information pertaining to the quality of dairy effluent is not currently available, an attempt should be made to include dairies as potential TDS sources in the planning model for sensitivity analysis and for future parameterization when such data becomes available.

Rail Yards

Background – Starting in approximately 1910, the Atchison, Topeka, and Santa Fe Railway began discharging industrial waste through a drain system from the shop and yards into the Mojave River near Barstow. Beginning in 1968, the industrial railyard waste was conveyed to the current city sewage treatment plant Densmore, 1997). Prior to its conveyance to the local sewage treatment plant, the discharged waste, which contained dissolved-solids concentrations between 311 and 2,700 mg/L locally contaminated the floodplain aquifer. The waste consists of petroleum products, solvents, coolants containing chromium, and synthetic detergents (Densmore, 1997).

Water quality degradation near the Community of Barstow has resulted in a plume of contaminants commonly referred to as the “Barstow Slug.” This plume of largely TDS has been attributed in part to industrial discharges made by the railroad industry (Maxwell, 1996). This TDS plume has been observed (Figure 4.3) in several wells down-gradient from Barstow. Available data suggests that the plume is migrating down-gradient and dispersing with time. Figure 4.6 shows the locations of wells used to analyze this plume. Two of the wells shown in Figure 4.7 (09N01W09D01 and 09N01W05J03) in the vicinity of but slightly down-gradient from Barstow have early periods of record. These wells show sharp increases in TDS levels followed by stable decline. A group of monitoring wells located further down-gradient show lower but gradually increasing TDS levels. Map views of TDS data for the area also suggest the down-gradient migration and dissipation of this plume.

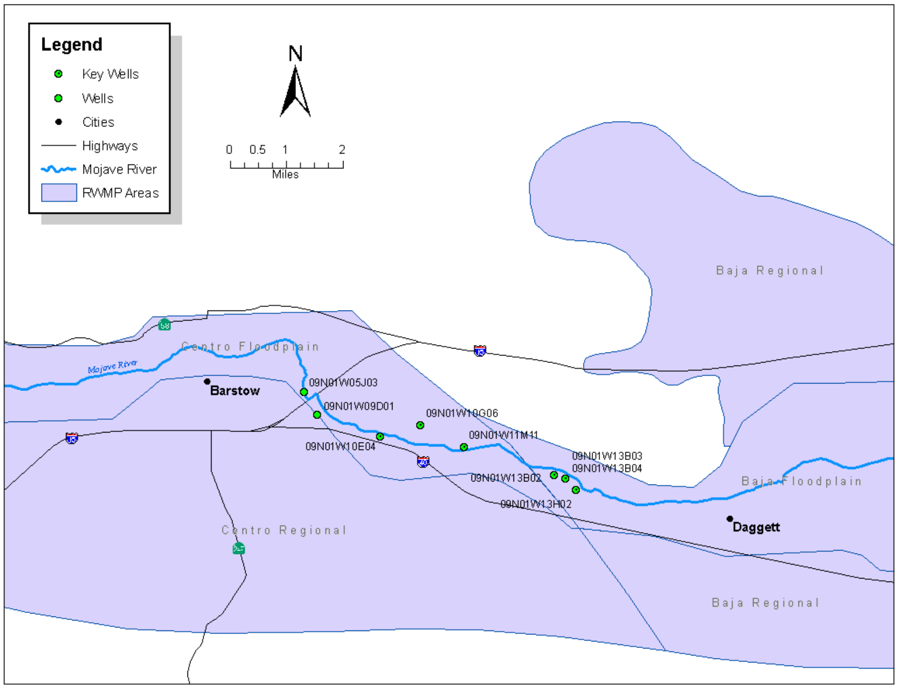


Figure 4.6 - Locations of wells down gradient from Barstow used to analyze the Barstow slug.

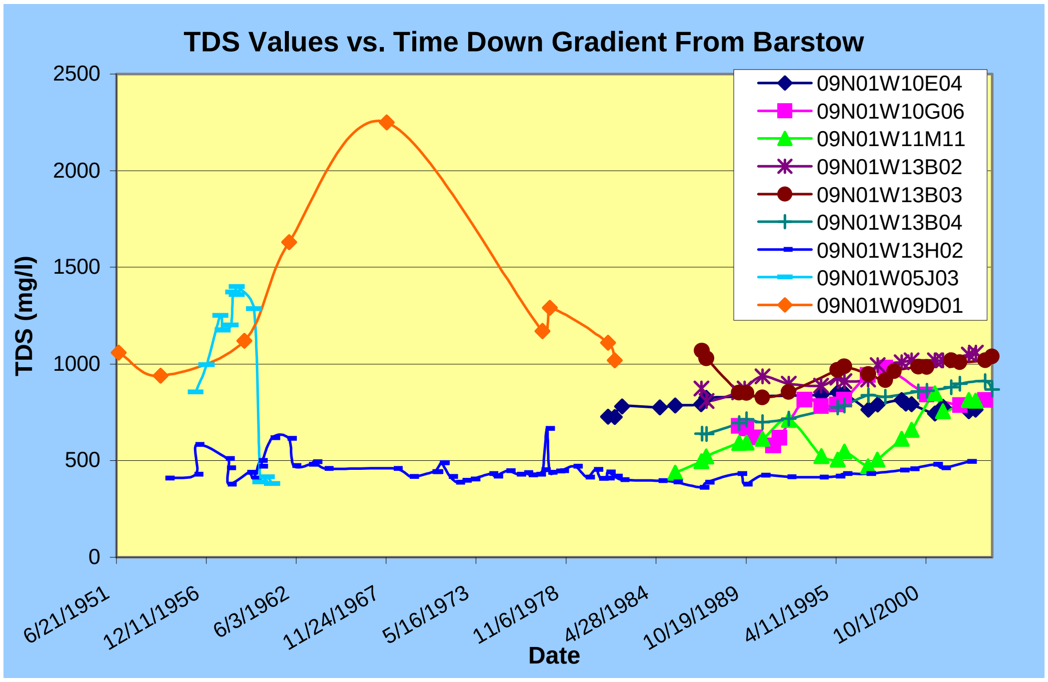


Figure 4.7 - TDS in wells down gradient from Barstow suggesting onset, dissipation, and migration of the TDS plume.

Assessment – The TDS anomaly observed in the water quality database is believed to be the plume of industrial waste referred to as the “Barstow Slug”. Data suggests that this plume is migrating and dissipating. Migration of the plume is problematic with regard to spatial refinement of the model. If the plume were static it would be possible to define an additional management zone describing the anomalous TDS region and include the movement and dissipation of the plume in the water quality planning model. Since the plume is not static, a fixed management zone may not be appropriate to capture this process. However, it is recommended that the high TDS values be included in initial water quality estimates for the water quality planning model.

Septic Systems

Background – Even though a sewage treatment plant has been in operation since 1981, the main method of domestic wastewater disposal in the Alto subarea is still septic systems. Figure 4.6 from Stamos (2003) shows the proliferation of septic systems in the Alto sub-area estimated from census records. Hundreds of residential septic systems operate east of the Mojave River in fractured bedrock. The estimated recharge from septic systems in the Alto subarea in 1990 is 9,980 acre-feet per year (Stamos, 2001). These septic leaching systems have been identified as the main source of TDS in the Floodplain Aquifer within the Alto subarea because flows in the fractured bedrock recharge the Floodplain Aquifer (Maxwell, 1996). Septic recharge has been considered insignificant in other MWA areas because housing density has been low or because sewage-treatment plants have been operational (Stamos, 2003). Bookman-Edmonston (1991) estimated average consumption of approximately 70 gallons per day per person in residential households in Victor Valley. This value was used along with census data by Stamos (2001) to estimate recharge from septic systems in the Alto subarea. Umari (1993) performed field investigation to determine the water quality from septic systems. He found significantly elevated TDS levels in septic system discharge as compared to the water entering the household. Water quality characteristics of septic tank effluent reported by Umari (1993) are listed in Attachment 3.

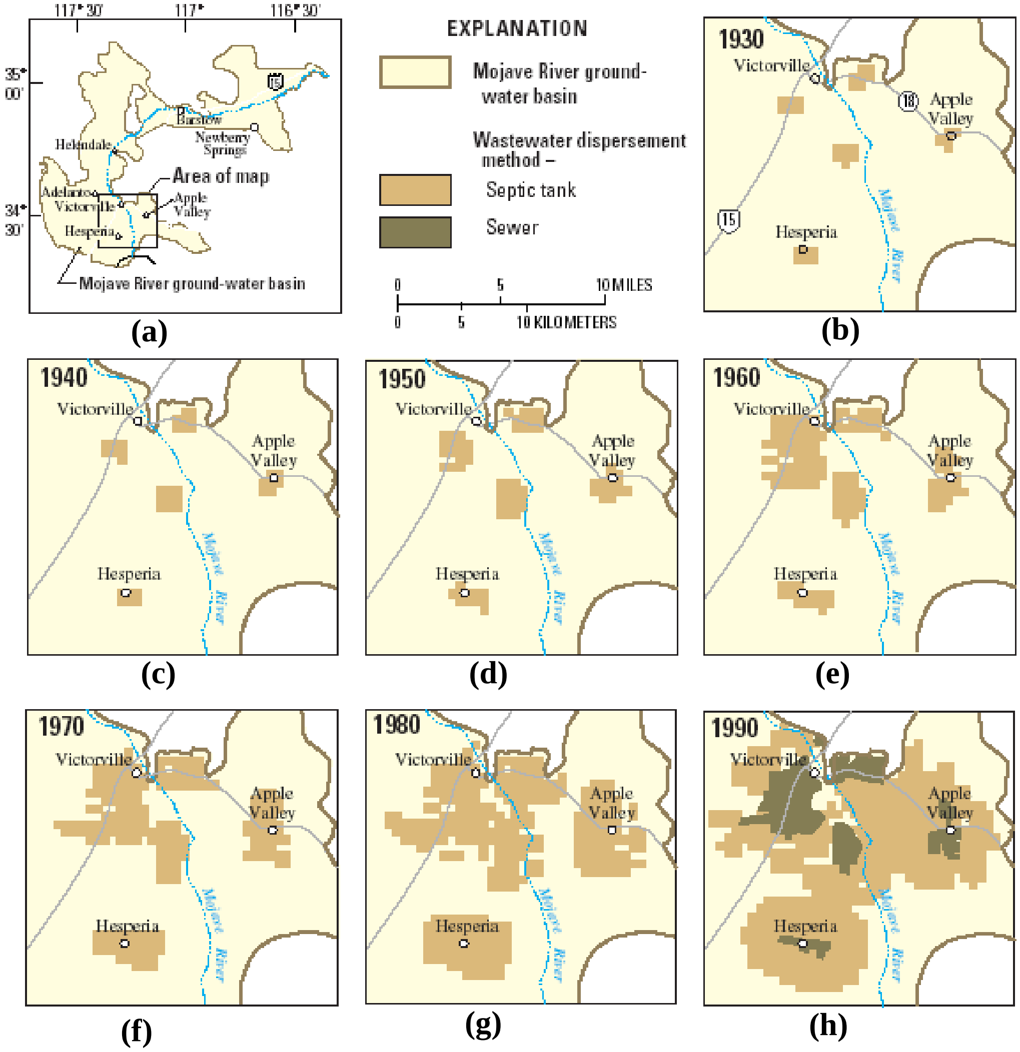


Figure 4.8 - Distribution of septic systems in the Alto sub-area from 1930 to 1990 (from Stamos 2001).

Assessment – Umari's findings indicate that septic systems are a potential mechanism for introduction and redistribution of TDS within the Mojave Service area. It is recommended that TDS from septic systems be included in the water quality planning model. Estimates of septic effluent discharge rate estimated by Bookman-Edmonston and effluent quality estimated by Umari will be used to develop an appropriate TDS flux mechanism. For areas other than Alto, septic return flows will be estimated from census data using Bookman-Edmonston and Umari data.

Fish Hatcheries

Two fish hatcheries are located adjacent to the Mojave River in the Alto subarea. The oldest hatchery is the Mojave River Fish Hatchery, which is operated by the California Department of Fish and Game. This hatchery began operation in 1949 and uses pumped groundwater. On average between 1994 and 1999, 6,400 acre-feet per year of the pumped water was returned for recharge. All but about 3,000 acre-feet per year of the water pumped from the floodplain aquifer to operate the hatchery is returned to the Mojave River bed for percolation recharge. The remaining 3,000 acre-feet per year have been diverted for irrigation.

The Jess Ranch Trout Farm is located approximately one mile upstream of the Fish and Game hatchery. Since operations began in 1951, groundwater has been pumped from the floodplain aquifer for circulation in fish-rearing ponds. Some of the effluent from the fish hatchery has been used for irrigation. Excess water has been discharged to the Mojave River. Between 1990 and 1993, an average of approximately 4,500 acre-feet per year of pumped water was returned for recharge (Stamos 2001). From 1994 to 1999 no water was returned for recharge (Stamos 2001).

The fisheries discharge their water into a reach of the Mojave River that is underlain by a shallow clay layer which inhibits the deep infiltration of the return flow to the underlying aquifer prior to reaching the Lower Narrows (Stamos, 2001).

Assessment – Fish hatcheries have been identified by Stamos (2001) as one of the major sources of recharge to the Mojave Basin. TDS influx associated with fish hatchery activity will be included in the water quality planning model.

Landfills and Mines

Background – Several landfills and mines exist in the Mojave and Morongo basins. Known mine and landfill locations are shown in Figure 4.5. Elevated TDS levels are reported to be possible (Andraski, 1995) in the vicinity of landfills. In general, anomalies in the water quality database do not correlate with the locations of mines and landfills. One exception to this is a TDS anomaly observed in Figure 4.3 in the vicinity of Newberry Springs. This anomaly correlates with the location of a landfill in Figure 4.5. Available well construction data for two of the wells in which this anomaly was observed suggest that this anomaly is being preferentially sampled from the near surface and may not be connected to the groundwater system. However, the magnitude of this anomaly suggests a potential impact to the groundwater system through even limited infiltration.

Assessment – Due to the very large number of mines and landfills it is not deemed practical to disaggregate the water quality planning model for each of these potential point sources. Further, with the exception of the anomaly noted at Newberry springs, the water quality database suggests that these are not significant sources of TDS into the groundwater system. Therefore, the water quality planning model will not be disaggregated to reflect mine and landfill locations. The anomaly at Newberry springs will be included as a discrete point source of TDS in the respective sub-aquifer unit.

4.5 Natural Sources of TDS

Mojave River and Tributary Flow

Background – The Mojave River is an intermittent river that averaged approximately 52,400 AF of base flow at the Lower Narrows for the period from 1931 to the present time (SWS, 2004). These flows recharge the floodplain aquifer as the streamflow percolates through the porous riverbed material. Historical data for the Mojave River have been tabulated for the RWMP. Table 4.1 shows a summary of gaged flow for the Mojave River from the 2004 RWMP (SWS, 2004).

Gage Name and Station Number	Period of Record (1)	Average Flow (2)	Median Flow (2)	Peak Flow (2) (Year)	Minimum Flow (2) (Year)
West Fork Near Hesperia (10261000) (3)	1930	23,500	6,200	134,400 (1978)	0 (1951)
Deep Creek Near Hesperia (10260500)	1905	47,800	21,000	304,400 (1993)	2,200 (1951)
Lower Narrows Near Victorville (10261500) (4)	1900	52,400	23,200	298,500 (1969)	5,300 (2001)
Barstow (10262500)	1931	16,700	0	151,800 (1969)	0 (Many)
Afton (10263000)	1930-32, 1952-78, 1981-02 (5)	8,100	900	75,600 (1969)	200 (1975)

Notes:

(1) All gages listed are currently operational.

(2) For period of record 1931-2001. Flow refers to acre-feet per year.

(3) The USGS has operated two gages at West Fork since 1930, 10261000 and 10260950.

(4) The Lower Narrows Gage was located about 3 miles upstream from its current location and operated there from 1900-1906 and 1931-36.

(5) USGS has estimated the record for the missing periods.

Table 4.1 – Gaged Mojave River flow data from 2004 RWMP (from Schlumberger Water Services, 2004)

Webb (2000) estimates that 7,200 acre-feet of ungaged water flows annually into the Este, Oeste, Alto, and Baja subareas of the Mojave Basin Area (Webb 2000). Gaged and ungaged river and tributary flows were compiled for the 2004 RWMP and are shown in Table 4.2.

	Este	**Oeste**	**Alto**	**Centro**	**Baja**	**Entire Basin**
WATER SUPPLY						
Surface Water Inflow						
Gaged	0	0	71,300[a]	0	0	71,300
Ungaged	1,700	1,500	3,600	34,700[1]	14,400[2]	7,200[3]
Subsurface Inflow	0	0	1,200	2,000	1,200	0[4]
Deep Percolation of Precipitation	0	0	3,500	0	100	3,600[5]
Import Wastewater						
Lake Arrowhead CSD	0	0	1,900	0	0	1,900[6]
Big Bear ARWWA	2,600	0	0	0	0	2,600[6]
Crestline Sanitation District	0	0	900	0	0	900[6]
Total:	**4,300**	**1,500**	**82,400**	**36,700**	**15,700**	**87,500**
OUTFLOW AND LOSSES						
Surface Water Outflow						
Gaged	0	0	0	0	8,100[b]	8,100
Ungaged	0	0	34,700[1]	14,000[7]	0	0[4]
Subsurface Outflow	800	400	2,000	1,200	0	0[4]
Phreatophyte Consumption	0	0	11,000[8]	3,000[8]	2,000[8]	16,000
Total:	**800**	**400**	**47,700**	**18,200**	**10,100**	**24,100**
NET AVERAGE ANNUAL WATER SUPPLY:						**63,400**

Notes:

(1) Estimates taken from Webb 2000

(2) Includes 14,000 ac.ft. of Mojave River flow from Centro and 400 ac.ft. of inflow from Kane Wash and Boom Creek; estimates taken from Webb 2000

(3) Sum of ungaged surface water inflows less ungaged surface water outflows; estimates taken from Webb 2000

(4) All subsurface flow is assumed to exchange within subareas (no external inflows or outflows). No external ungaged surface water outflow

(5) Estimates taken from Webb 2000

(6) Mojave Basin Area Watermaster 2001

(7) From reported flows at USGS gaging station, Mojave River at Barstow

(8) Phreatophyte consumption taken from Lines and Bilhorn (1996)

(a) Period of record from 1931-2001

(b) Period of record from 1931-2001; 1931-1952 are estimated values

Table 4.2 - Water balance showing groundwater between subareas and flows and gaged and ungaged surface flow (from Schlumberger Water Services, 2004)

Concentrations of TDS vary seasonally in the Mojave River, with lower concentrations occurring in the winter during peak flows and higher concentrations occurring in the summer.

Water quality also changes along the course of the river, with TDS concentrations increasing in the downstream direction. This downstream increase in TDS is likely attributed to percolation, evapotranspiration, wastewater discharge, irrigation return flow and other activities. Since 1908, the USGS has been collecting water quality data along the Mojave river. Most of the water quality data for the watershed was collected between 1944 and 1972, and these data was used to determine annual averages and 90th percentile vales from which to create regional water quality objectives (WQOs) to ensure maintenance of the existing quality of surface waters for the Mojave River and its headwaters tributaries. Table 4.3 lists TDS WQOs for the Mojave River obtained from Maxwell (1996) which are being used as representative of the historical water quality of Mojave River water.

Assessment - Water quality in the Mojave River will reflect the quality of contributing sources. The Mojave River itself will act as a significant pathway for inter-basin transport of water and associated dissolved solids from these sources. Aside from natural storm flow and tributary recharge, discharges from various municipal wastewater management systems will contribute significantly to the TDS levels of river water. The Mojave River is deemed to be a significant element in the water quality planning model for its role in inter-basin redistribution of TDS.

Location	TDS (mg/L)
Lake Arrowhead	78/107
Lake Gregory	87/95
Deep Creek below Lake Arrowhead	83/127
Deep Creek above the Mojave Forks Dam	184/265
East Fork of the West Fork of the Mojave River	140/200
West Fork of the Mojave River above Silverwood Lake	219/336
Silverwood Lake	220/440
West Fork of the Mojave River below Silverwood Lake @ Highway 173 Crossing	245
Mojave River at the Lower Narrows below Victorville	312
Mojave River at Barstow (base flow)	445
Mojave River at the Waterman Fault (underflow flow)	560
Mojave River at the Calico-Newberry Fault	340
Mojave River at Camp Cady Ranch (under flow)	300

Single numbers represent instantaneous maximum
Double numbers represent annual average/90th percentile value

Table 4.3 - Mojave River water quality WQOs (from Maxwell, 1996)

4.6 Groundwater Inflows

Discussion

It is known that there is significant movement of groundwater between some of the subareas in the Mojave Basin (Webb, 2000). Groundwater derived from mountain front runoff flows from both Este and Oeste Subareas into the Alto Subarea. From the Alto Subarea, groundwater flows downgradient to the Centro Subarea. Groundwater from the Centro Subarea flows down gradient to the Baja Subarea. There is believed to be no significant outflow from the Baja Subarea estimated at 400 acre-feet per year. The individual sub-basins of the Morongo Basin are believed to be hydraulically isolated from one another. Webb (2000) estimates that approximately 1,200 acre-feet of groundwater combined annually flows from Este and Oeste to Alto; 2,000 acre-feet flows from Alto to Centro; and 1,200 acre-feet per year flows from Centro to Baja. These subsurface flows are shown in Table 4.2 from the 2004 RWMP.

Assessment

Groundwater inflows and outflows between sub-aquifer units will be an important TDS redistribution mechanism and will be included in the water quality planning model. Groundwater flow will be implemented using the proxy relationships discussed in Section 3, derived from the USGS (Stamos, 2001) regional groundwater flow model for the Mojave Basin. Water quality of groundwater will be initialized from the water quality database developed in Task 1.

Precipitation

Background – The Mojave area receives a relatively small volume of precipitation and much of what is received is lost to evaporation or transpiration. The amount of precipitation that occurs in the region ranges from 4 inches on the desert valley floor to 40 inches in the San Bernardino Mountains (CA DWR, 1967). With the exception of surface runoff, direct precipitation does not recharge groundwater under normal conditions. Despite the large losses of precipitation to evaporation, precipitation falling on open, unlined water bodies is assumed to add to the water budget through direct percolation or runoff (URS, 2003). In addition to Floodplain Aquifer recharge from the Mojave River, several ephemeral ungaged streams and washes near the flanks of the San Bernardino and San Gabriel Mountains contribute surface water flow to the MWA area from winter storms and snowmelt runoff. Most mountain-front recharge occurs during wet years as storm runoff infiltrates the alluvial fan deposits of the regional aquifer located in the upper reaches of ephemeral streams and washes that lie between the headwaters of the Mojave River and Sheep Creek. In the Baja Subarea, minor recharge of the Regional Aquifer occurs near Coyote Lake and from Kane Wash (Stamos, 2001).

Assessment - Rain and snow, which are the sources of water for river and tributary flow, are nearly pure, typically having less than 10 mg/L TDS concentration. These flows represent influx of good quality water into the Mojave Basin. They are already represented in the 2004 RWMP model (shown in Table 4.2) as significant water influx mechanisms and should be included in the water quality planning model as TDS sources.

Evapotranspiration

Background – Return flows represent a significant part of the water balance for the MWA service area. Evapotranspiration is a large component of consumptive use. As such, accurately quantifying evapotranspiration is of key importance in the water balance computation. As an example, SWS estimates that in 2020 the Alto subarea will have municipal production of 118,000 acre-feet of water. If the overall consumptive use rate is off by 5% this represents a change of $^{+}$/-6000 acre-feet in return flow each year. If the overall consumptive use rate is off by 15% this represents a change of $^{+}$/-18,000 acre-feet in return flow each year. The report entitled *A Five-Year Investigation Into the Potential Water and Monetary Savings of Residential Xeriscape in the Mojave Desert, (Sovocool et al.),* notes that typically 60 to 90% of potable water drawn by single family residences in municipalities is used for outdoor irrigation. Whereas the US EPA estimates that 44% of residential water is the average outdoor irrigation for all of California. The Mojave Desert is atypical relative to California and the consumptive use factors currently applied, most notably municipal consumption, may vary significantly from actual values**.** The effect of evapotranspiration on return water quality was noted by previous authors investigating the hydrology of the Transition Zone. They suggest that the increases in TDS concentrations in the Floodplain Aquifer shallow zone are likely due to evapotranspiration effects (URS, 2003). use The mechanism driving this effect would be the evaporative removal of significant volume of water from the system while leaving the dissolved solids in place. The net effect would be a net increase in dissolved solids per volume unit of water, or an increase in TDS concentration. Outside the floodplain aquifer irrigation for domestic, agricultural, and recreational uses also result in significant amounts of evapotranspiration.

Assessment – Based upon the available literature it is felt that uncertainties in evapotranspiration estimates as discussed above will translate directly into uncertainties in TDS flux from surface water to groundwater. Evapotranspiration estimates for all sub-aquifer units have been computed using the Surface Energy Balance Land Algorithm (SEBAL) method of remote sensing image processing. These new results will be used to refine the evapotranspiration estimates for the water balance in the water quality planning model. The result will be improved estimate of TDS flux resulting from the evapotranspiration component of return flow.

Geology

Background - The Floodplain Aquifer comprises two stratigraphic units deposited by the Mojave River: recent alluvium of Holocene age and younger alluvium of Holocene to Pleistocene age. The Regional Aquifer is composed of younger alluvial fan deposits of Holocene to Pleistocene age, older alluvium of the ancestral Mojave River of Pleistocene age, and older fan and stream deposits of Pleistocene to Pliocene age. The upper 300 to 800 feet of the older, undifferentiated fan and stream deposits are more permeable than the underlying deposits of the same group. There is poor hydraulic connection between the upper and lower deposits, therefore the lower deposits transmit very little, if any, water to the overlying deposits. The low permeability and fine-grained nature of the lower sediments has resulted in groundwater with high TDS (Stamos, 2001). This is probably the result of limited mixing of the ancestral marine brine of the deeper sediments with the fresher recharge water available in shallower sediments.

Much of the deeper water in the Regional Aquifer is chemically degraded, particularly water associated with buried evaporates and the semi-stagnant water in the deeper, closed sub-basins (Subsurface Surveys, Inc., 1990). Underlying the Regional Aquifer are consolidated, volcanic and sedimentary rocks of Tertiary age (Densmore, 1997). High TDS concentrations, in excess of 2,000 mg/L have been detected in the groundwater within these rocks.

Stamos (2001) reports that faults and other geologic structures partially control groundwater flow in both the regional aquifer and, in many places, the floodplain aquifer. The 2001 USGS Mojave Basin regional groundwater flow model includes the effect of many known and previously unnamed faults. Although several of these faults were deemed by the authors to have sufficient impact on regional groundwater flow, it will not be practical to include this level of geologic detail in the water quality planning model. Geologic detail will be included as required and justified by the available water quality data.

Groundwater moves from the Transition Zone to the Centro Subarea across the northern extension of the Helendale Fault. Water-level data collected from USGS multiple-well monitoring sites and compiled from historical sources indicate that this fault restricts subsurface flow in the regional aquifer but not in the overlying floodplain aquifer (Hardt, 1971). Stamos (2001) reports that the restriction of groundwater flow has resulted in upward flow of groundwater in the past. It is believed that this upwelling has brought poor quality deeper water to the surface, resulting in the TDS anomaly seen near Helendale in Figure 4.3. Figure 4.9 shows TDS values plotted as a function of perpendicular distance from the Helendale fault on both the upgradient and downgradient sides of the fault. Overall average TDS values for the Transition Zone and Centro sub-areas are also shown. This figure suggests a build-up of TDS significantly above the sub-area average on the upgradient side of the fault, with somewhat more uniform lower levels on the downgradient side.

Assessment – Based upon observed anomalies in the water quality database and supporting literature we recommend an effort be made to discretize the TDS anomaly observed in the region of Helendale in the water quality planning model using the Helendale Fault as one boundary. This matter will be discussed further in Section 5 of this document.

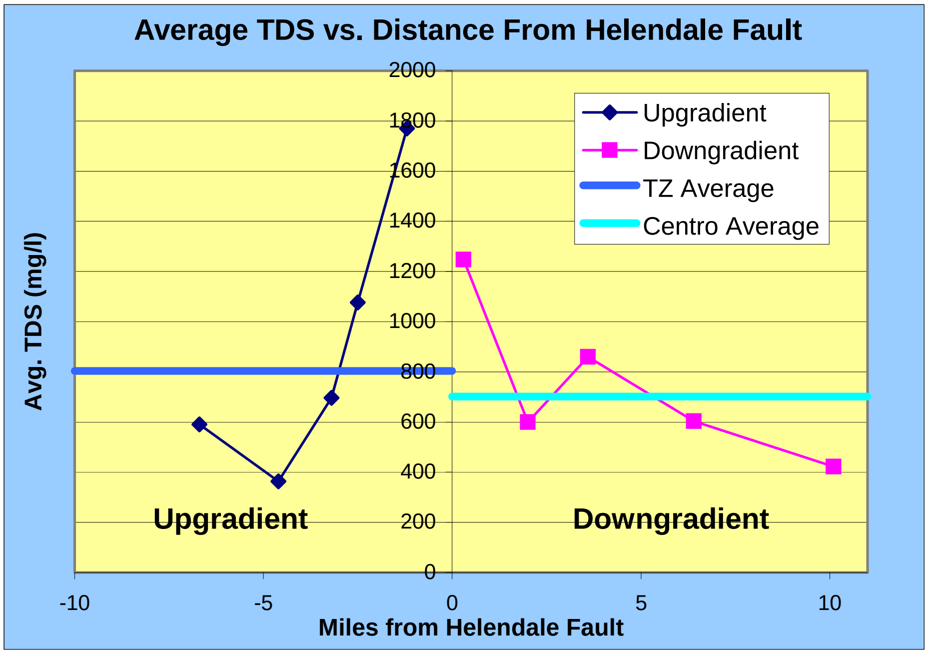


Figure 4.9 - TDS in wells in the vicinity of the Helendale Fault showing average TDS levels for Transition Zone and Centro Subareas.

Dry Lakes (Playas)

Background – Problems resulting from the overall inflow of salts to the area can be seen in the vicinity of dry lakes (CA DWR, 1967). Groundwater near many of the dry lakes in the Mojave River basin is typically highly saline (Izbiki, 2003). High TDS concentrations are observed in the water quality database in the vicinities of most of the dry lakes in the MWA service area as seen in Figure 4.3. It should be noted, though, that thick sequences of evaporite deposits in dry lakes often preclude water from percolating into subsurface. In the vicinity of some dry lake areas, since direct infiltration of precipitation does not typically occur, large accumulations of chloride and other soluble salts are present near the top of the unsaturated zone overlying the Regional Aquifer (Izbiki, 2003). Stamos (2001) reports that dry lakes tend to act as sinks from the groundwater system through free surface evaporation after flooding. These sinks have in the past been actively hydraulically connected to the hydrogeologic system. However, recent pumpage has altered the groundwater gradient away from these dry lakes, reducing but not eliminating the discharge effect.

Assessment – Although TDS anomalies are seen in the vicinities of dry lakes, these anomalies do not exhibit any downgradient movement with time in the water quality database. This is consistent with Stamos' observations that dry lakes are points of discharge rather than recharge. Although sufficient well construction data is not yet available to make an absolute determination, the available data suggest that high TDS values in the vicinity of dry lakes may be the result of preferential shallow sampling. In light of this, and Izbiki's observation that infiltration of precipitation does not typically occur in the vicinity of dry lakes, we do not feel that dry lakes represent a *strong* input mechanism. Yet, we feel that the extremely high TDS levels should be represented in the water quality planning model. Therefore, we recommend that, while not defining unique new management zones for dry lakes, the dry lakes should be included in the model as distinct TDS sources for their respective management zones. We feel that the high TDS levels in the database associated with dry lakes should be identified by statistical analysis and excluded from the ambient conditions for their respective management zones.

5

Task 2d: Physical Information

5.1 Scope and Deliverables

This task entails the refining spatial boundaries for aquifer units, salt flux mechanisms, and evapotranspiration estimates, and developing estimates of groundwater storage and ambient TDS concentrations.

5.2 General

This task will result in necessary modeling parameters and inputs. Digitally referenced data for each task will be developed as follows:

- Spatial boundaries for groundwater management zones.
- Parameters necessary to model groundwater management zone interactions.
- Estimates of current groundwater storage by groundwater management zone.
- Estimates of current TDS concentrations for each groundwater management zone.
- Quantify potential salt flux mechanisms for each management zone.
- Refined ET and return flow values for various land uses.

The following sections outline the scope and results of each of the six subtasks.

5.3 Task 2d.1: Refine Aquifer Units Into Smaller Management Zones as Needed

Scope

The objective of this task is to develop spatial boundaries for groundwater management zones. In previous work for MWA, the regional and floodplain aquifers were disaggregated to segments termed aquifer units in the Stella screening model. It is assumed that some sub-aquifer units might need further disaggregation to predict groundwater quality fluctuations. The spatial level of refinement will be a function of available data from which a hydrologically distinct zone can be delineated.

Discussion

Disaggregation of the RWMP sub-aquifer units was based on hydrogeological data and/or water quality considerations. While striving to develop an optimal water quality planning model, it is also important to recognize the limitations of the available data and to promote consistency with the RWMP screening model.

Hydrodynamic Considerations – MWA is executing a long-term systematic campaign to improve their conceptual model of the Mojave Basin through site specific studies. However, these studies do not yet have sufficient information density to justify changes to the regional conceptual model. Currently, the most well-developed regional model of the Mojave Basin is the ModFlow hydrodynamic model developed by Stamos (2001). This model was used as the basis for various physical parameter estimates and key groundwater interactions used in the RWMP screening model and will also serve as the basis for refinement of these properties to reflect new management zone(s) and flux processes.

A key parameter in the transport modeling process is effective porosity, or aquifer storage volume. Variation in specific yield is a good indicator of distinct hydrogeologic regions as well as a key parameter in determination of aquifer storage volume for each management zone in sub-task 2d.3. The USGS regional ModFlow model was used to develop estimates of porosity (storage volume) for the RWMP screening model based on specific yield of the upper model layer. Figure 5.1 shows the distribution of specific yield and the current RWMP sub-aquifer unit boundaries within the MWA service area excluding the Morongo Basin. We feel that these boundaries adequately capture the major variations in the distribution of this parameter within this area.

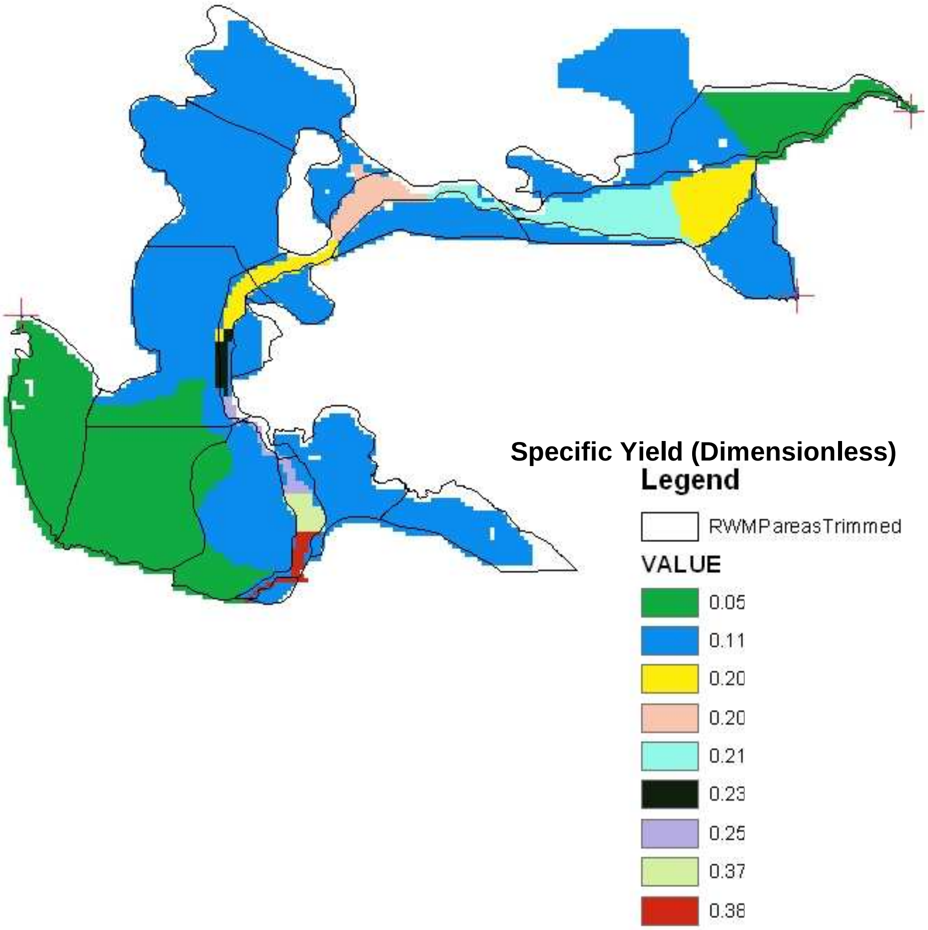
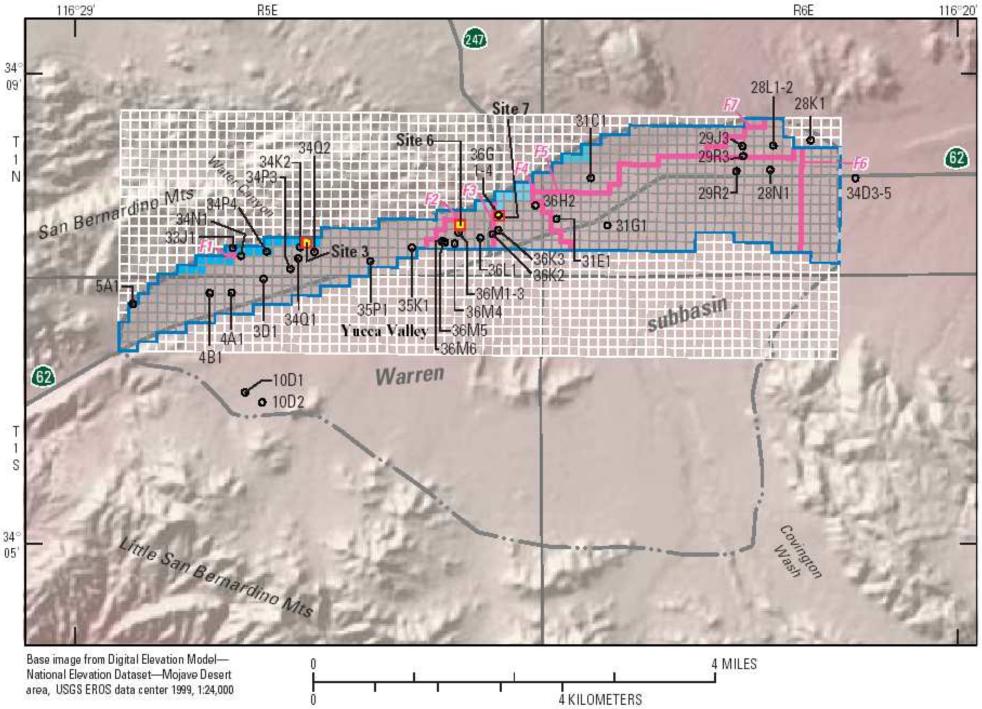


Figure 5.1 - Specific yield from Stamos (2001) used to estimate storage volume for the RWMP screening model and RWMP sub-aquifer unit boundaries excluding the Morongo Basin.

The USGS performed a study of groundwater and solute transport in the Warren Basin (Nishikawa, 2003) in cooperation with the High Desert Water District and the Mojave Water Agency. This study found that the groundwater basin covers only a portion of the greater Warren Basin, and that groundwater flow within this limited area is affected by several vertical faults. Figure 5.2 from Nishikawa (2003) shows the location of the groundwater basin (blue line) and the faults forming barriers to groundwater flow (magenta lines). These faults form five sub-units within the groundwater basin. Although we feel that this detailed understanding of the local hydrologic environment is important for the water quality planning model, the sparseness of water quality observations in the Warren Valley area limits the amount of spatial refinement that may be realized. It is our recommendation that the volume of water in storage be refined to reflect the reduced size of the Warren Basin groundwater system as reported by Nishikawa. However, we do not feel that the available water quality data supports further disaggregating the sub-aquifer unit into five sub-units to reflect the flow barriers.



Base image from Digital Elevation Model—National Elevation Dataset—Mojave Desert area, USGS EROS data center 1999, 1:24,000

Figure 5.2 - The Warren Valley sub-basin from Nishikawa (2003) showing the finite difference simulation grid, the boundary of the actual groundwater basin (blue) and the vertical faults (magenta).

Based on the available information and the value of consistency with the RWMP screening model we do not feel that further disaggregation of aquifer units should be performed on the basis of hydrodynamic properties.

Water Quality Considerations – Figure 5.3 shows the average TDS levels from the water quality database and the RWMP aquifer units. Analysis of the available water quality data yields several anomalies, which were high-lighted in Section 4. Key factors such as mobility and location of these anomalies were discussed. An important distinction was made between the need or ability to incorporate apparent water quality anomalies into the model, and the need to further disaggregate the model on the basis of such anomaly. The primary consideration in making this distinction for any observed anomaly is its estimated or assumed mobility. Other important factors are its size, location, and trend. For example, although each of the dry lakes has an associated water quality anomaly, the literature supports the conclusion that these anomalies are poorly connected to the groundwater table. Using this reasoning it is not recommended that further model disaggregation be performed based upon these anomalies. However, the high TDS values need to be identified through statistical analysis of the data and removed from the computation of ambient TDS levels of the respective management zones. Dry lakes will be treated in the water quality planning model as discrete TDS sources. The methodology for including dry lakes in the model is discussed later in this section under sub-task 2d.5.

As discussed in Section 4, a TDS anomaly exists in the vicinity of Helendale. This anomaly is in a critical location near the Transition Zone/Centro adjudication boundary. It is also in the center of the regional and floodplain aquifers. In Section 4 it was hypothesized that this anomaly may be the result of upwelling of deeper, poor quality water caused by disruption of subsurface flow by the Helendale fault. Figure 5.4 shows the behavior of average TDS for stations at varying distances from the Helendale fault on either side of the fault. Figure 5.5 shows the locations of wells used in this analysis. On the upgradient side of the fault TDS is observed to build up to a level significantly higher than the overall sample average for the Transition Zone Subarea. On the downgradient side of the fault TDS levels decease to a lesser extent with distance from the fault, and more closely approximate the overall sample average for the Centro Subarea. These observations suggest a conceptual model in which the amount of poor quality water upwelling from deeper aquifer units increases with proximity to the upgradient side of the fault.

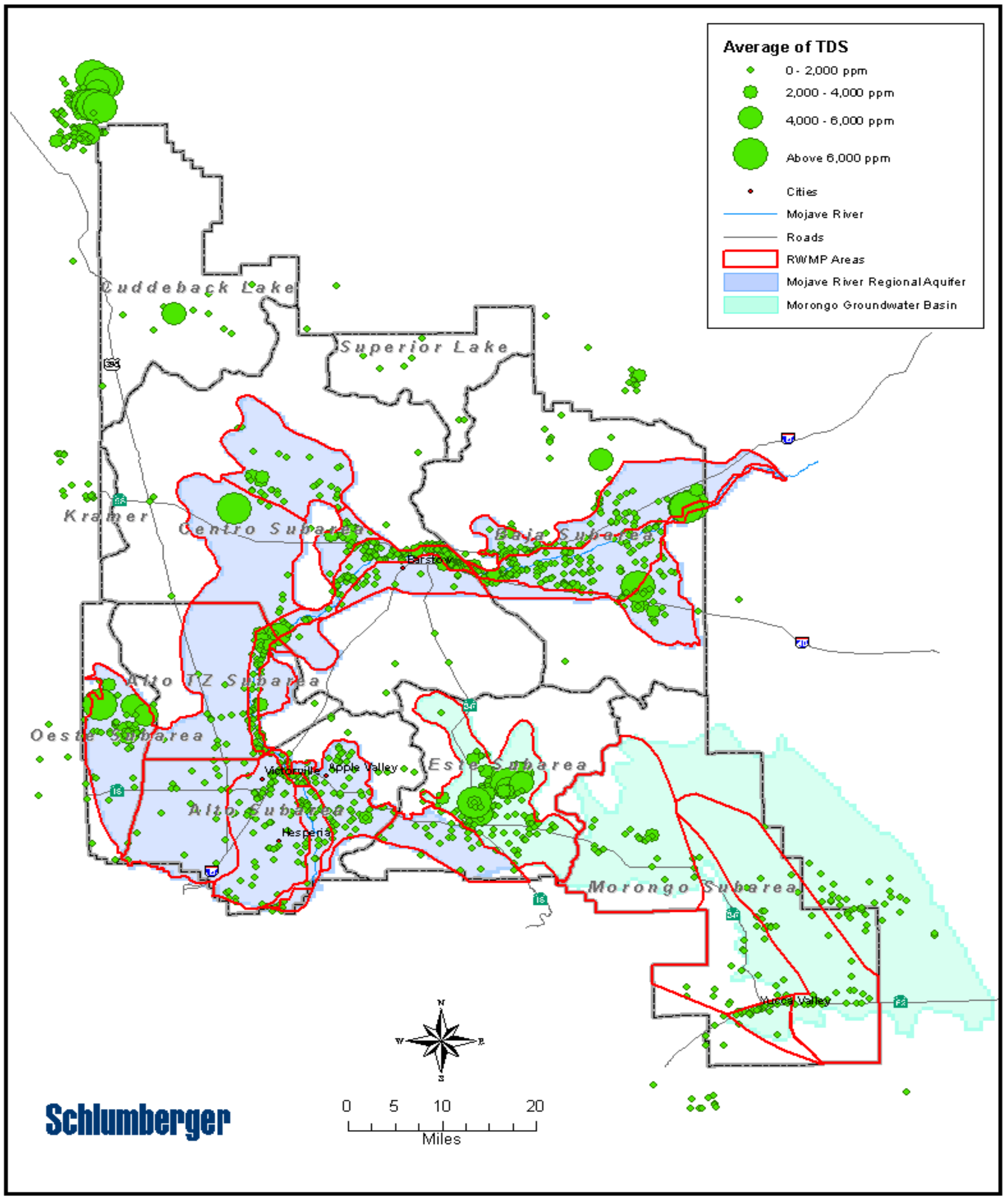


Figure 5.3 - Average TDS with 2004 RWMP sub-aquifer units.

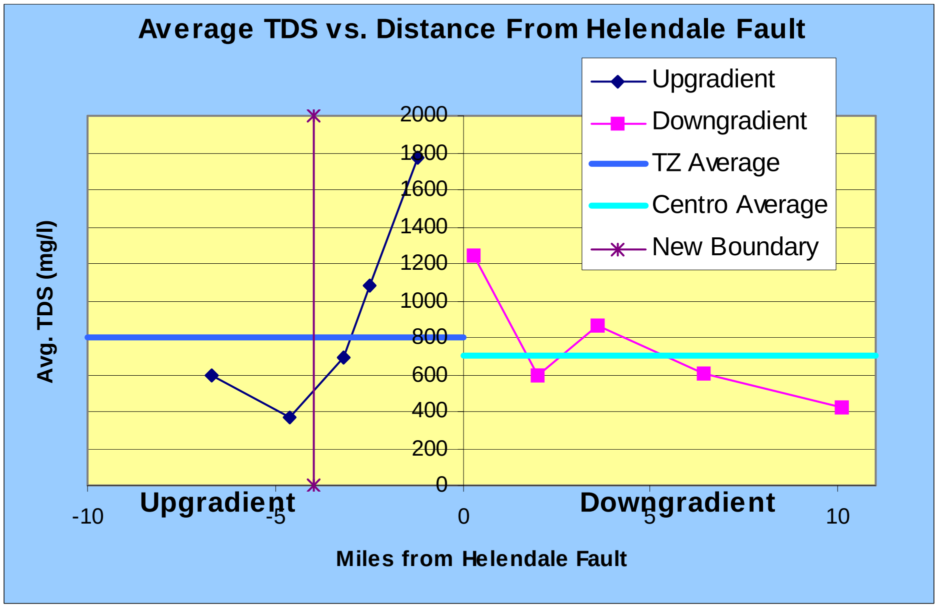


Figure 5.4 - TDS in wells in the vicinity of the Helendale Fault showing average TDS levels in Transition Zone and Centro Subareas and proposed boundary for Transition Zone Subarea refinement.

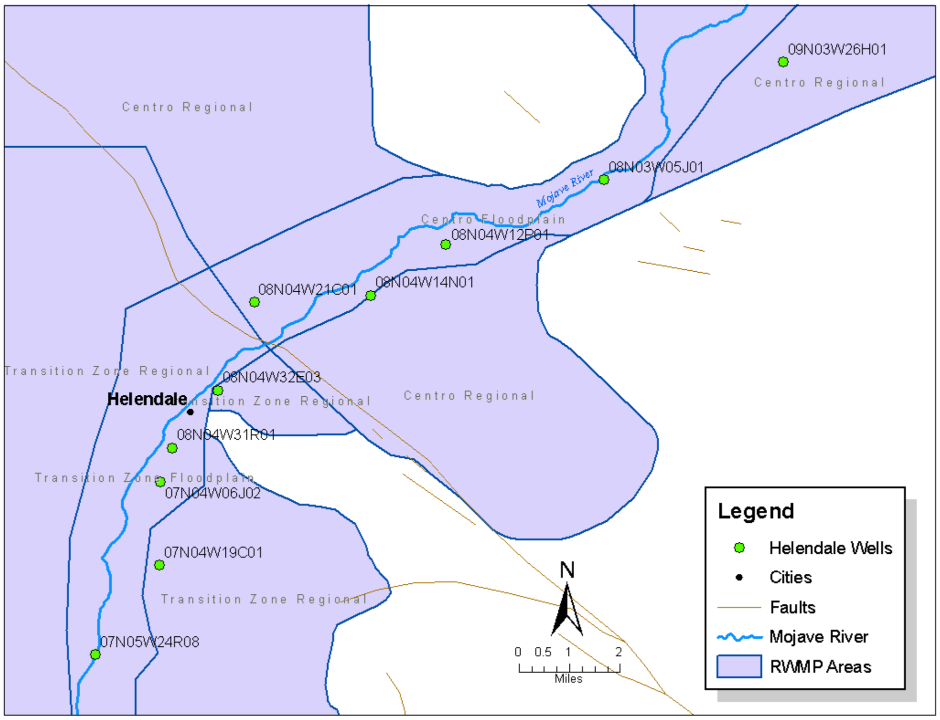


Figure 5.5 - Location of wells straddling the Helendale Fault used to analyze the observed TDS anomaly.

Based on these observations it is recommended that an additional management zone be created which encloses this anomaly, making it possible to include this seemingly active and critically located mechanism in the water quality planning model. The proposed sub-area boundary is located approximately four miles upgradient from the Helendale fault (as indicated in Figure 5.4), disaggregating the Transition Zone Floodplain sub-aquifer unit to create the new Transition Zone Floodplain and Helendale sub-aquifer units (Figure 5.6).

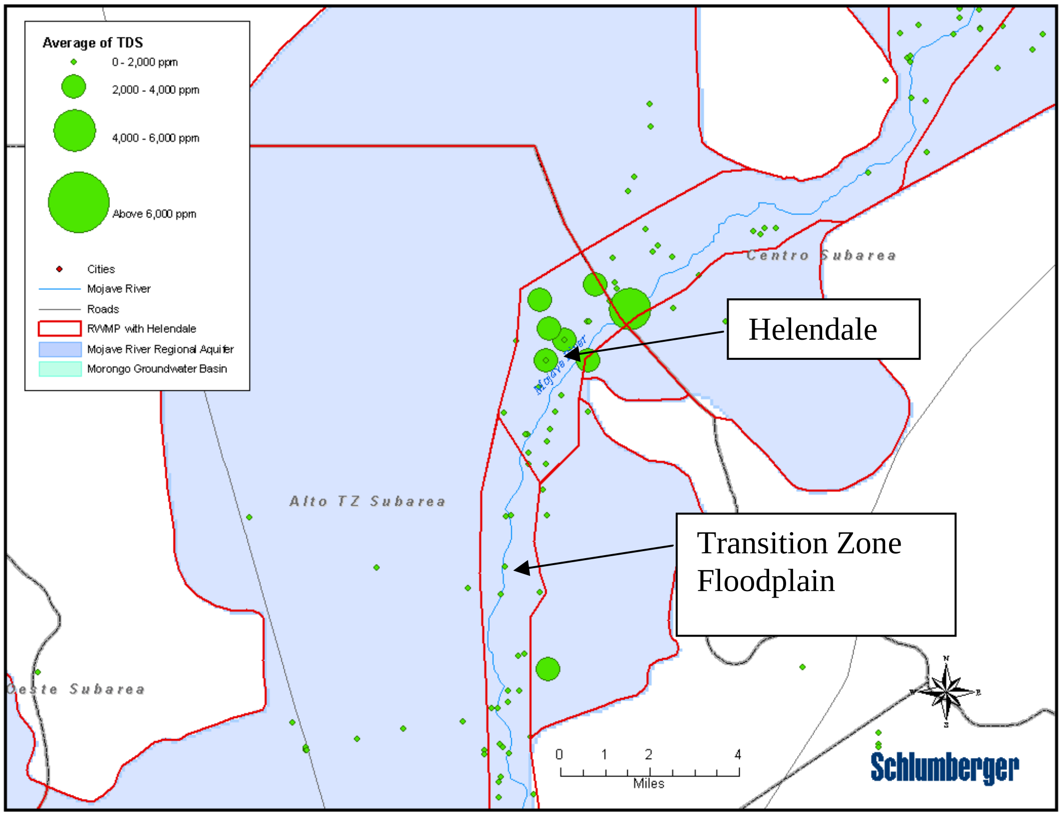


Figure 5.6 - Average TDS with all aquifer sub-units including the newly defined Transition Zone Floodplain and Helendale sub-aquifer units. Symbol radius is proportional to average TDS value.

5.4 Task 2d.2: Refine Management Zone Interactions as Needed

Scope

In this task, the management zones developed in Task 2d.1 will be evaluated to assess hydrologic interactions between zones and the necessary steps to model interactions.

Discussion

Groundwater Interaction – Groundwater flux between zones takes place as the result of naturally occurring and man-made gradients in the hydraulic head of the aquifer in each zone. For example, mountain front recharge results in regional scale head differential between basin margins and the Mojave River channel. Pumping and injection also cause groundwater head gradients at a more local scale. The flux of water due to a head differential is described by Darcy's law (Eq. 5.1). Figure 5.7 shows the aerial view of a simplified conceptual model for groundwater flow between two adjacent aquifer sub-units.

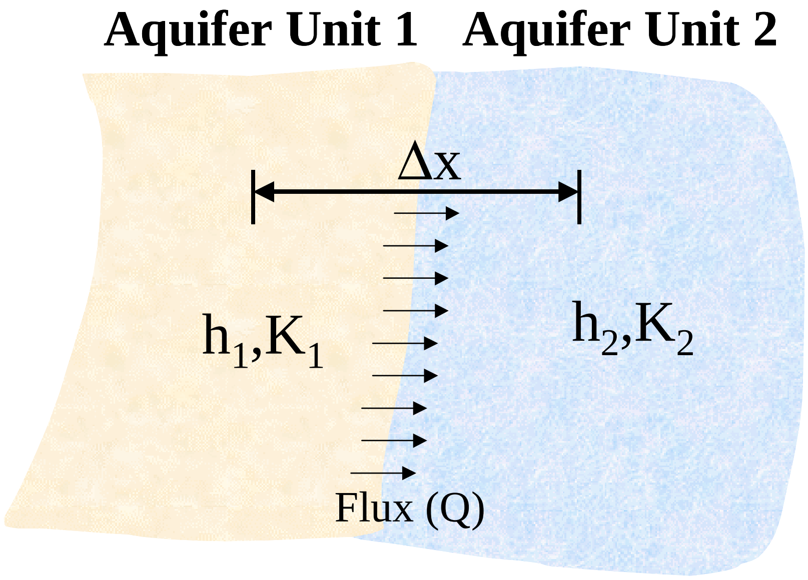


Figure 5.7 - Simplified conceptual groundwater flux model.

Darcy's law describes the flux between aquifer sub-units as:

$$Q = K_{avg} \cdot A \cdot \frac{\Delta h}{\Delta x} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5.1)$$

where;

K_{avg} = Average hydraulic conductivity
A = Cross-sectional area of inter-aquifer interface
Δh = Water table elevation difference
Δx = Distance

Figure 5.7 and Eq. 5.1 describe a very simplistic 1-dimensional case. Realistic systems are much more complex, involving two and three dimensional flow solutions. Although Eq. 5.1 may be applied directly in a water balance calculation if necessary, a more sophisticated, and therefore more representative, solution is preferred when available. A numerical model can be used to predict variations in head and resulting groundwater flux for complex hydrodynamic models. Numerical models also allow the delineation of model sub-units and calculation of fluxes between these model sub-units. Figure 5.8 shows a schematic representation of the average direction of inter-zone flux predicted by the USGS regional Mojave Basin ModFlow model as part of the 2004 RWMP study. The USGS study did not include the Morongo Basin. In that study, the output from ModFlow was used to develop “proxy” models for hydrodynamic flux between sub-aquifer units within the area covered by that model. The concept of a proxy model was introduced in Section 3. These proxy models were functional relationships that describe the head difference versus flux relationship for pairs of adjacent aquifer units such that:

$$Q(t)=\xi(\Delta h,t)\Delta h(t) \tag{5.2}$$

where;

$Q(t)$ = Groundwater flux at model time ‘t’
$\xi(\Delta h,t)$ = Proxy model function
Δh = Head difference between aquifer sub-units

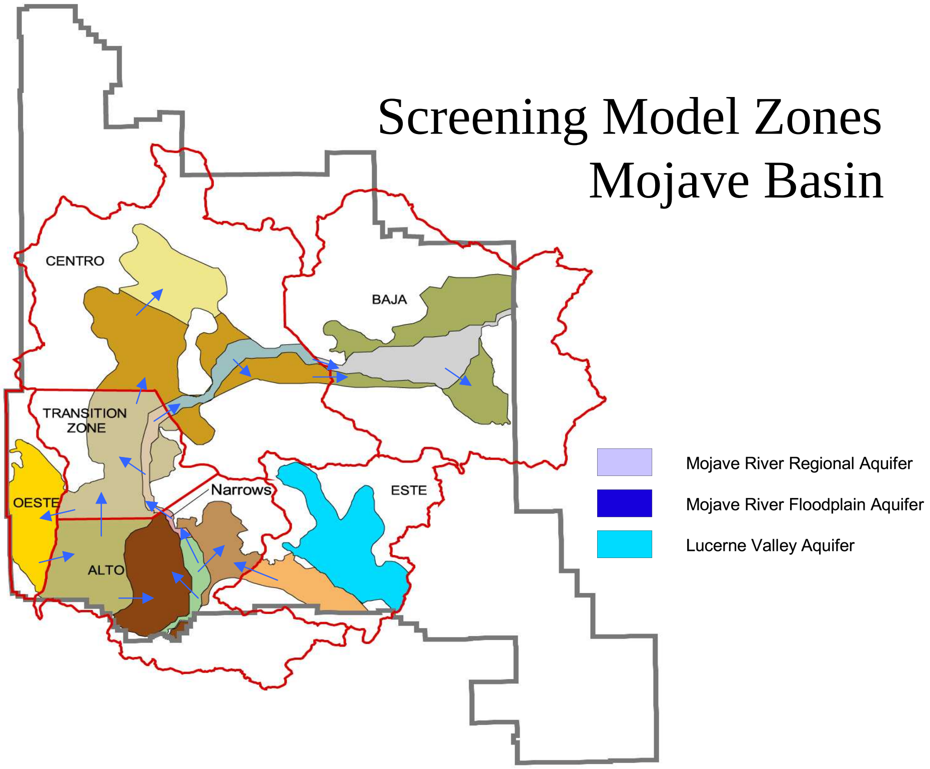


Figure 5.8 - Groundwater flux directions determined from Stamos (2001).

This method of using proxy functions for groundwater flow was used in the 2004 RWMP Stella model. Figure 5.9 shows a schematic diagram of the implementation process. The volumes and the elevation heads in each model aquifer sub-unit was initialized from historical information. At each model time step the head difference was computed for each adjacent aquifer sub-unit pair. This head difference was used to look up a corresponding inter aquifer sub-unit flux from the respective proxy model function. The flux for each adjacent sub-unit pair is computed as:

$$\Delta V_{ts} = Q_{\Delta h} \cdot \Delta t_{ts} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5.3)$$

where:

ΔV_{ts} = Volume of water transferred during the model time step
$Q(t)$ = Groundwater flux at timestep ts
Δt_{ts} = Timestep length

In reality there are many simultaneous transfers. This technique was used in the RWMP Stella screening model and will be coupled with the transport process as described in the discussion of sub-task 2d.5 later in this memorandum for use in the water quality planning model.

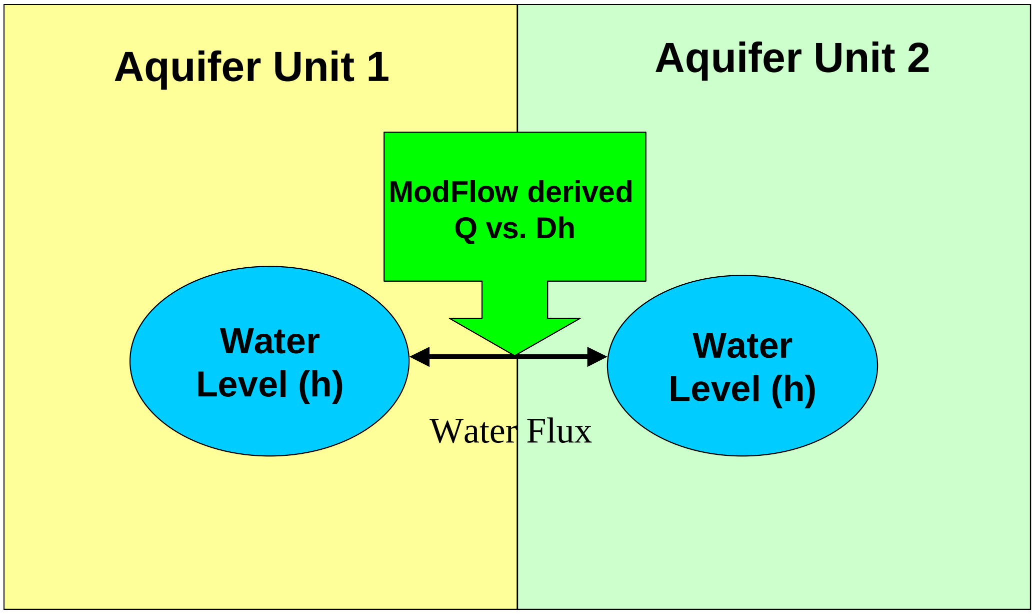


Figure 5.9 - Implementation of hydrodynamic material balance using 2004 RWMP ModFlow Q vs. Dh relationships.

Recent modeling studies performed by the USGS (Nishikawa, 2004) in the Joshua Tree area of the Morongo Basin indicate approximately 84 acre-feet per year of groundwater flux from the Warren Sub-basin into the Joshua Tree Sub-basin. These studies further indicate approximately 123 acre-feet per year of groundwater flux from the Copper Mountain Sub-basin to the Surprise Spring Sub-basin. In the RWMP water balance model the Warren Basin is distinguished as a separate sub-aquifer unit called Warren Valley sub-aquifer unit, while the various minor sub-basins in the Copper Mountain Valley are lumped into the Copper Mountain Valley sub-aquifer unit. The later includes Copper Mountain, Joshua Tree, Reche, Giant Rock, and Surprise Spring Sub-basins. Groundwater flux from the Warren Sub-basin to the Joshua Tree Sub-basin will be represented in water balance of the planning model as a constant flux between the Warren Valley and Copper Mountain Valley sub-aquifer units. Groundwater fluxes between the sub-basins of the Copper Mountain Valley sub-aquifer unit will be aggregated within that sub-aquifer unit and not distinguished in the water balance of the planning model.

Mojave River-Groundwater Interaction – Interaction between the Mojave River and the groundwater system is significant in several of the management sub-areas. Figure 5.10 shows an idealized schematic of surface water-groundwater interaction. The Mojave River flows at the surface (blue) only at limited reaches and in response to storm surges. However, river underflow (light blue) occurs over most of the length of the river for much of the year. This underflow is a source of recharge and discharge (blue arrows) to and from the groundwater system along various reaches of the river. The river bed (dark brown) forms a partial barrier to flux from the river to the groundwater system. The controlling hydrodynamic property of the streambed is the *conductance*, which dictates the head dependent flux across that interface.

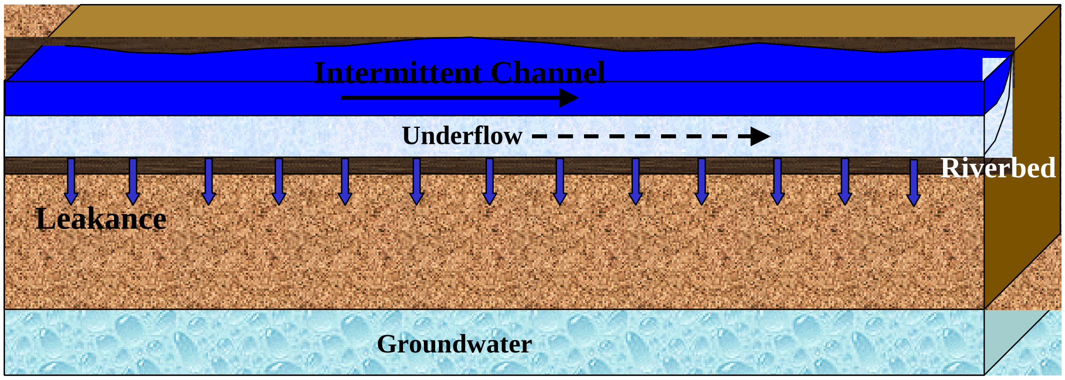


Figure 5.10 - Cross section of stream channel showing underflow and leakance through riverbed.

Stamos (2001) used river stage observations at several reaches along the river in order to calibrate river bed conductance in the 2001 USGS regional model of the Mojave Basin. This model, used to develop proxy relationships for inter-zone groundwater flux, was also used to compute similar relationships describing the flux from the river to the groundwater system as a function of the head difference between the groundwater system. These relationships will be utilized as the flux mechanism for advective TDS transport between from the Mojave River to the groundwater system using the mass transport relationships described later in this section.

5.5 Task 2d.3: Develop Estimates for Groundwater In Storage

Scope

In this task, the current amount of groundwater storage (volume) by management zone that can be expected to mix actively in a salinity flux is estimated**.** Changes in groundwater storage can be estimated based on average groundwater level changes by management zone.

Discussion

The true amount of water stored in the Mojave Basin may not be accurately determined by currently available survey methods. Furthermore, even if this volume were known, estimation of the depth to which water is actually being affected by current natural and anthropogenic activities would be uncertain. Estimates of the groundwater in storage *and* active in the dynamic hydrogeologic system may only be made using the best currently available survey techniques along with sound reasoning.

A geophysical gravity survey performed in 1990 (Subsurface Surveys Inc., 1990) over the Mojave Basin for the purpose of estimating groundwater storage yielded an estimate of approximately 428 million acre ft of total storage. This measurement is an estimate of the *total* pore volume. Of this total, approximately 174 million acre ft are estimated to be in the upper 1000 ft. of the aquifer. However, not all of the total 428 million acre ft. of water is available or suitable for usage. The authors of this study suggests that factors such as degradation of aquifer and water quality with depth along with increased well development costs impose practical limits on the usability of deeper water. They estimate that, due to such practical limits, approximately 150 million acre-ft. may be economically produced. This is an estimate of the *active* pore volume. Stamos (2001) estimated the thickness of the upper and lower aquifers as 200 ft. and 700 ft respectively for their numerical model, for a total of 900 ft, which is roughly commensurate with 870 ft. estimate from the geophysical survey. However, it is reasonable to assume that there will be a trend toward deeper drilling motivated by water supply or quality needs and facilitated by improved drilling technology and water treatment technologies. In a personal communication (Stamos, 2005) Christina Stamos suggested that future models of the Mojave basin might incorporate deeper portions of the regional aquifer. Furthermore, initial salt balance estimates performed by SWS used an estimate of 1000 ft depth for computation of the active aquifer water volume. In consideration of all of the above a depth of 1000 ft will be used to estimate the initial volume of water for use in the water quality planning model.

Although estimates for water in storage have been provided for the major and some of the minor sub-basins in the literature, in order to disaggregate these estimates for use in the water quality planning model an estimate of effective pore volume is needed. The best available estimate of effective pore volume is specific yield. Specific yield is the volume of water drained from a rock or soil per square unit of area per unit of head reduction. Estimates of specific yield for the Mojave Basin were taken from Stamos (2001). Specific yield for the Morongo Basin and its sub-basins were taken from Lewis (1972). These estimates are shown in Figure 5.11. Table 5.1 lists estimates the planametric surface areas of each management zone determined using GIS computational methods, estimates of specific yield, and computed water volume for the upper 1000 ft. of aquifer material. It should be noted that the total aquifer volume or 114 million acre ft for sub-basins of the Mojave Basin in Table 5.1 does not agree with estimate of 150 million acre feet of producible water reported from the geophysical survey. No immediate explanation is available for this discrepancy other than possible differences in the areas over which the volumes were computed and the Subsurface Survey report authors own definition of what may be producible given uncertain geological factors and future available drilling technologies.

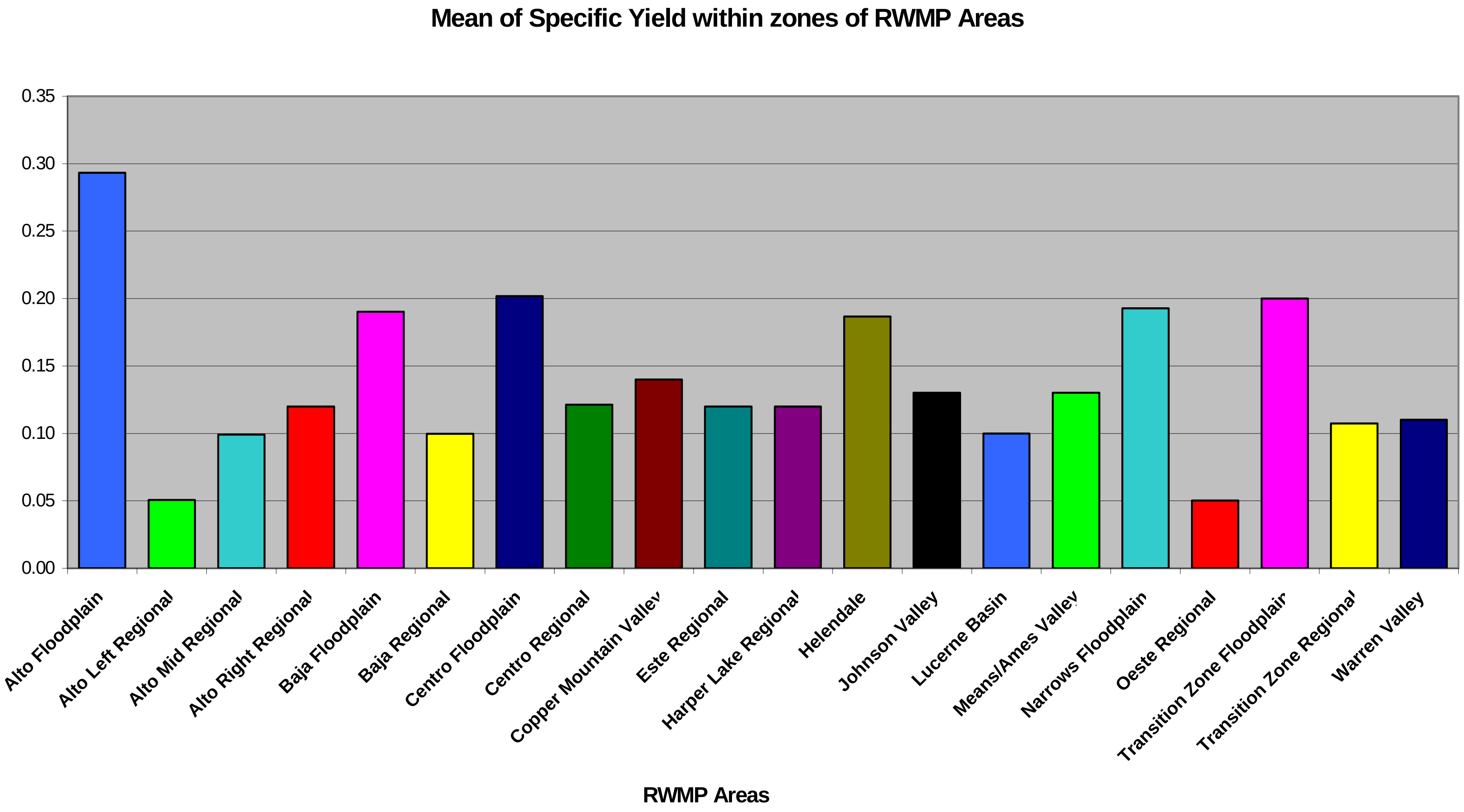


Figure 5.11 - Estimates of Specific Yield. Left and right refer to position with respect to the floodplain aquifer looking in the direction of the river gradient

Table 5.1 - Estimated Specific Yield from Stamos (2001)* and Lewis (1972)**, and groundwater storage computed for the upper 1000' of aquifer. Left and right refer to position with respect to the floodplain aquifer facing the gradient direction.

RWMP Area	Area (Sq. Mi.)	S_y Minimum	S_y Maximum	S_y Range	S_y Mean	S_y Std. Dev.	VOLUME (Acre-ft)
Alto Floodplain	28	0.05	0.39	0.34	0.29	0.12	5,252,950
Alto Left Regional*	141	0.05	0.12	0.07	0.05	0.01	4,557,085
Alto Mid Regional*	124	0.05	0.26	0.21	0.10	0.03	7,901,249
Alto Right Regional*	69	0.12	0.12	0.00	0.12	0.00	5,263,247
Baja Floodplain*	104	0.05	0.22	0.17	0.19	0.05	12,679,798
Baja Regional*	194	0.05	0.22	0.17	0.10	0.04	12,395,595
Centro Floodplain*	46	0.12	0.22	0.10	0.20	0.03	5,883,074
Centro Regional*	237	0.12	0.22	0.10	0.12	0.01	18,383,461
Copper Mountain Valley**	241	0.08	0.23	0.15	0.14		21,613,794
Este Regional*	65	0.12	0.12	0.00	0.12	0.00	4,994,171
Harper Lake Regional*	112	0.12	0.12	0.00	0.12	0.00	8,596,687
Helendale*	8	0.12	0.20	0.08	0.19	0.03	929,231
Johnson Valley Sub-basin**	213	0.08	0.18	0.10	0.13	N/A	17,759,738
Lucerne Basin**	162	N/A	N/A	N/A	0.10	N/A	10,349,144
Means/Ames Valley Sub-basin**	136	N/A	N/A	N/A	0.13	N/A	11,355,546
Narrows Floodplain*	5	0.12	0.26	0.14	0.19	0.07	635,625
Oeste Regional*	103	0.05	0.12	0.07	0.05	0.00	3,305,090
Transition Zone Floodplain*	12	0.12	0.26	0.14	0.20	0.05	1,593,884
Transition Zone Regional*	165	0.05	0.23	0.18	0.11	0.03	11,334,641
Warren Valley Sub-basin**	29	0.07	0.15	0.08	0.11	N/A	2,060,074

5.4 Task 2d.4: Develop Estimates of TDS by Management Zone

Scope

In this task, the current TDS concentrations of a management zone will be determined through statistical and geochemical analyses to account for such factors as measurement error and natural variability. The methods of statistical analysis will be similar to those utilized in the TIN/TDS Study – Phase 2A of the Santa Ana Watershed (Wildermuth Environmental, Inc., 2000). This data will represent initial water quality conditions in the water quality planning model.

Multiple quality control measures were employed in the Santa Ana Watershed study for screening of water quality data. These included both univariate statistical methods and geochemical analysis. In the following sections the results of individual statistical and geochemical quality assurance checks are reviewed, followed by merging of both statistical and geochemical quality assurance results for final determination of average TDS concentrations by aquifer sub-unit.

Univariate Statistical Analysis

The univariate statistical methods recommended by the Santa Ana Watershed TIN/TDS Task Force are the Shapiro-Wilk test for normality followed by normal standard error based outlier identification. The method applied in the Santa Ana Watershed Study is reviewed below. Data were first tested for normality in order to assure the applicability of outlier identification methods that assume normality. If data are not normally distributed then standard normal testing methods for outlier identification are invalid. Non-normal distributions should then be transformed to normal prior to outlier identification.

The Shapiro-Wilk method is used to test normality of a set of samples. A statistic *W* is computed for the sample set as follows:

$$W = {\left(\sum_{1}^{n} a_{i,n} \cdot X_i\right)^2} \bigg/ {\sum_{1}^{n} \left(X_i - X_{avg}\right)^2} \qquad \text{...} (5.4)$$

where:

$a_{i,n}$ = Coefficients based on the order of the observation and the number of observations

X_i = i^{th} observation

X_{avg} = mean of *n* observations

The resulting *W* computed using Eq. 5.4 is compared to a table of critical values and an assessment of the normality of the sample set is made. The Shapiro-Wilk method has two major limitations. First, a negative result can be used to determine that a sample set is unlikely to be a normal distribution. However, a positive result cannot be taken as proof that a sample set *is* normally distributed. Second, the test is limited to sample sets of less than 5000 samples.

If a dataset tested as non-normal according to the Shapiro-Wilk test then it may be transformed to normal. The choice of transformation is critical because the assumption of normality in the transformed dataset is critical in the subsequent standard error based outlier identification. A common distribution for naturally occurring phenomena is the *lognormal* distribution. All data will first be tested for lognormality by applying a lognormal transform and then testing using Shapiro-Wilk. Any dataset which is not normal or cannot be transformed to normal using a lognormal transform, may be transformed to a normal distribution using a *Normal Score* transform. The normal scores method exactly transforms any distribution to a normal distribution. The normal score transform is a powerful tool but must be used with caution. For example, the normal scores transform should not be applied to data that is random or strongly bi-modal.

After Shapiro-Wilks testing, assuming that the datasets do not test as non-normal, or that non-normal datasets have been correctly transformed, outlier identification was performed on the basis of a *mean +/- t** standard error criteria. The results of these tests are reported later in this section.

5.6 Geochemical Analysis

The Santa Ana Watershed Task Force recommended the following four geochemical analysis-based sample quality control analyses:

Quality Measure 1 - Anion-Cation Balance (Electro-Neutrality)

$$EN = 100 \cdot \frac{\sum cations - \sum anions}{\sum cations + \sum anions} \quad \text{......}(5.5)$$

Suggested acceptance criteria for quality assurance measure 1 used in the Santa Ana Watershed Study are listed in Table 5.2. These criteria were modified for the current study as discussed later in this section.

Table 5.2 - Recommended Electro-Neutrality criterion from the Santa Ana Watershed study (after Wildermuth Environmental, Inc., 2000).

Anion Sum (meq/L)	Acceptable Limit
0-3	+/- 0.2 meq/L
3-10	+/- 2% EN
10-800	+/- 2-5% EN

Quality Measure 2 - Measured TDS vs. Calculated TDS

$$1.0 < \frac{measured\ TDS}{calculated\ TDS} < 1.2 \quad \ldots\ldots\ldots\ldots (5.6)$$

where:

$$calculated\ TDS = 0.6 \cdot (alkalinity) + Na + K + Ca + Mg + Cl + SO_4 + SiO_3 + NO_3 + F \quad \ldots\ldots (5.7)$$

Quality Measure 3 - Measured EC and Ion Sums

$$0.9 \cdot EC < 100 \cdot anion\ sum, meq/L < 1.1 \cdot EC \quad \ldots\ldots\ldots\ldots (5.8)$$

Quality Measure 4 - TDS to EC Ratios

$$0.55 < \frac{measured\ TDS}{EC} < 0.7 \ldots\ldots (a)$$

$$and \quad \ldots\ldots\ldots\ldots (5.9)$$

$$0.55 < \frac{calculated\ TDS}{EC} < 0.7 \ldots\ldots (b)$$

Each of these quality control measures was applied to the TDS data in the water quality database, both individually and in selected combinations. For quality measure 4 the upper limit ratio limit was increased to 0.75.

5.7 Results

Statistical Quality Assurance Methods

There are a total of 8356 TDS samples in the water quality database, 7632 of which fall within the proposed sub-aquifer units of the water quality planning model. Figure 5.12 shows a histogram of TDS data from samples with TDS less than 1000 mg/L. The best fit normal distribution curve is also plotted for reference. Clearly these data are not normally distributed.

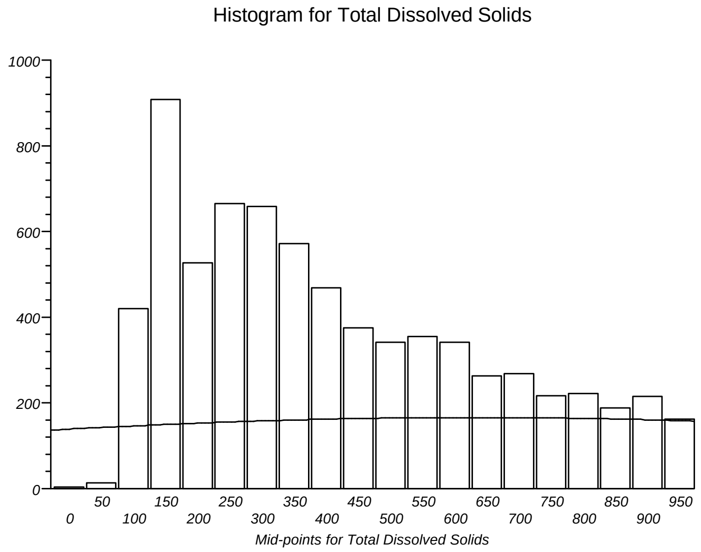


Figure 5.12 – Truncated TDS < 1000 mg/L histogram data for all sub-aquifer units with best fit normal distribution curve.

The Shapiro-Wilk test was applied independently to untransformed data from each management subarea. Histograms for each subarea, along with the best-fit normal distribution for each, are contained in Figures A1.1 through A1.20 in Attachment 1. All subareas tested as unlikely to be normal distributions by the Shapiro-Wilk test. The results of these tests are tabulated in Attachment 1. It is therefore necessary to apply an appropriate transform to these data prior to outlier testing.

Figure 5.12 shows a histogram of TDS data from all sub-aquifer unit after lognormal transformation. A best-fit normal distribution curve is also plotted for reference. Although the lognormal transformation has resulted in an improved fit with the normal distribution curve, results of Shapiro-Wilk testing indicate that the sample distribution is not likely to be normal.

Based on the above results it was decided that a normal scores transform should be used prior to outlier identification. Figure 5.14 shows the distribution of the same data shown in Figures 5.12 and 5.13 after normal score transformation. A perfect fit with the normal distribution curve is observed as expected.

This normal scores transformed data was used to evaluate the number of samples in each sub-aquifer unit passing +/- 1 standard deviation and +/- 2 standard deviation outlier tests. The results of these analyses are listed in Table 5.3. Although it is tempting to use these overall data population statistics for outlier identification, it may be seen in Figures A1.1 to A1.20 that the distributions from different sub-aquifer units show marked differences, indicating that it should not be assumed that they are sampled from the same population. Table 3 shows five sub-aquifer units for which less than 50% of the samples fall within +/- 1 standard deviation. This suggests that these data are not all from the same population and should therefore be transformed individually. Next, data from each sub-aquifer unit was individually transformed using normal scores transform. A summary of the numbers of samples passing the +/- 1 and +/- 2 standard deviation tests using individual transforms is listed in Table 5.4. An improvement in the pass rate can be seen with at least 68% of samples passing the +/- 1 standard deviation criteria for all sub-aquifer units. The overall number of samples passing the +/- 2 standard deviation criteria was also slightly improved.

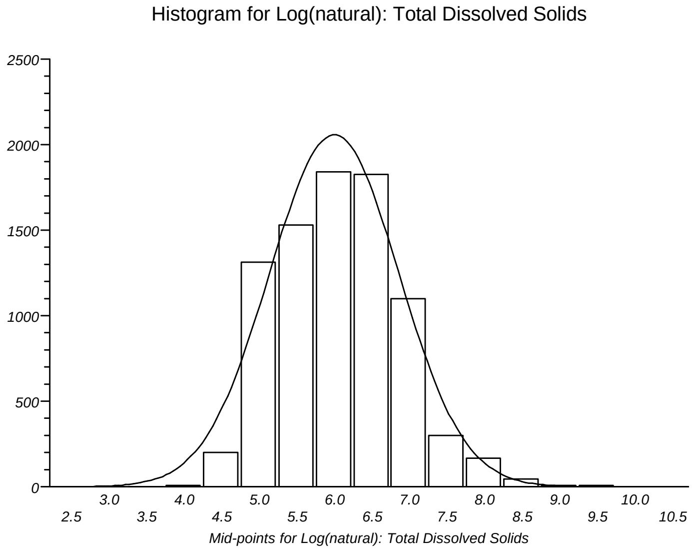


Figure 5.13 – Log transformed TDS data for all sub-areas with best fit normal distribution curve.

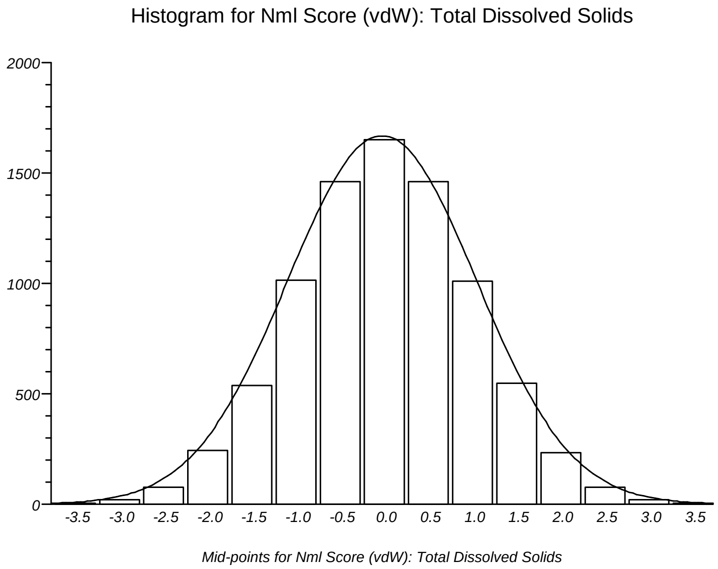


Figure 5.14 – Normal score transformed TDS data for all sub-areas with best fit normal distribution curve.

Table 5.3 - Summary statistics for normal scores transformed TDS data. Numbers and percentages of sample points falling within +/- 1 and +/- 2 standard deviations of the total population. Left and right refer to position with respect to the floodplain aquifer facing the gradient direction.

Management Zones	+/- 1 STD		+/- 2 STD		Overall
	N Passing	% Passing	N Passing	% Passing	N
Alto Floodplain	107	38%	252	91%	278
Alto Left Regional	90	97%	93	100%	93
Alto Mid Regional	89	11%	700	88%	795
Alto Right Regional	245	60%	379	93%	409
Baja Floodplain	774	91%	842	99%	847
Baja Regional	295	86%	340	99%	345
Centro Floodplain	1355	78%	1730	100%	1737
Centro Regional	256	90%	278	97%	286
Copper Mountain Valley	165	63%	261	99%	264
Este Regional	158	84%	187	100%	187
Harper Lake Regional	48	49%	91	93%	98
Helendale	76	48%	136	85%	160
Johnson Valley	150	72%	206	99%	208
Lucerne Basin	545	67%	722	88%	816
Means/Ames Valley	70	91%	76	99%	77
Narrows Floodplain	74	38%	171	88%	194
Oeste Regional	122	88%	131	95%	138
Transition Zone Floodplain	179	88%	204	100%	204
Transition Zone Regional	179	87%	194	95%	205
Warren Valley	196	67%	289	99%	291
All sub-aquifer units	5179	68%	7282	95%	7632
Outside sub-aquifer units	522	72%	700	97%	724
All of MWA Service Area	5701	68%	7982	96%	8356

Table 5.4 – Summary statistics for individual subarea normal scores transformed TDS data. Numbers and percentages of sample points falling within +/- 1 and +/- 2 standard deviations computed by individual sub-aquifer unit. Left and right refer to position with respect to the floodplain aquifer facing the gradient direction.

	+/- 1 STD		+/- 2 STD		Overall
Sub-Aquifer Unit	**N Passing**	**% Passing**	**N Passing**	**% Passing**	**N**
Alto Floodplain	187	67%	272	98%	278
Alto Left Regional	65	70%	89	96%	93
Alto Mid Regional	537	68%	760	96%	795
Alto Right Regional	279	68%	391	96%	409
Baja Floodplain	579	68%	810	96%	847
Baja Regional	237	69%	331	96%	345
Centro Floodplain	1185	68%	1697	98%	1737
Centro Regional	262	92%	272	95%	286
Copper Mountain Valley	185	70%	185	70%	264
Este Regional	129	69%	183	98%	187
Harper Lake Regional	68	69%	94	96%	98
Helendale	110	69%	154	96%	160
Johnson Valley	142	68%	204	98%	208
Lucerne Basin	558	68%	798	98%	816
Means/Ames Valley	53	69%	76	99%	77
Narrows Floodplain	133	69%	190	98%	194
Oeste Regional	94	68%	132	96%	138
Transition Zone Floodplain	172	84%	200	98%	204
Transition Zone Regional	140	68%	201	98%	205
Warren Valley Subbasin	244	84%	285	98%	291
All sub-aquifer units	5359	70 %	7324	96 %	7632
Outside sub-aquifer units	494	68%	708	98%	724

Geochemical Quality Assurance Methods

Of the more than 8300 samples, none have all major cations and anions needed to compute reliable estimates of TDS or electro-neutrality. Most have measured electrical conductivity which allows assessment of quality measure 5.9(a), which is based solely on the measured values of TDS and electrical conductivity.

Each of the recommended quality assurance measures was applied to the data individually, and in selected combinations. The quality assurance measures applied and the numbers of samples fulfilling each are listed in Table 5.4. It has been suggested by a SWS geochemist that a relaxation of the acceptance in Table 5.2 should be considered. Our recommendation is that +/- 5% EN deviation should be considered *excellent* while +/- 10% EN may be considered *acceptable* for all ion sum ranges. Acceptance criteria of +/- 5%, 10% and 15% were each applied and the results listed in Table 5.5. Table 5.5 also shows the results of applying ALL quality assurance measures. Only approximately 10% of all available samples meet all quality assurance measures. This high failure rate is expected in light of the afore mentioned deficiencies in the database with respect to ions required for computation of quality assurance measures 1, 2, and 3.

After consultation with MWA technical staff a combination of geochemical quality assurance measures was applied to the data. The combined acceptance criteria are:

Measure 4.a OR Measure 1.b (using +/- 10% tolerance)

The results of this combined geochemical quality assurance acceptance measure are listed in Table 5.5. Figure 5.15 shows a histogram for all samples passing this combined measure. Statistics computed by sub-aquifer unit computed for samples meeting the combined measure are listed in Table 5.6. Figure 5.1 shows an exceedance plot of TDS by individual sub-aquifer unit.

Table 5.5 - Numbers of samples passing geochemical acceptance measures out of a total of 8356 samples.

Quality Measure	MWA Service Area	RWMP Subareas
1.a (+/- 5 %)	852	743
1.b (+/- 10 %)	1346	1167
1.c (+/- 15 %)	1851	1644
2	606	462
3	854	781
4 .a	5398	4931
4 .b	387	272
1.b AND 2 AND 3 AND 4	81	61
1.b OR 4.a	5807	5290

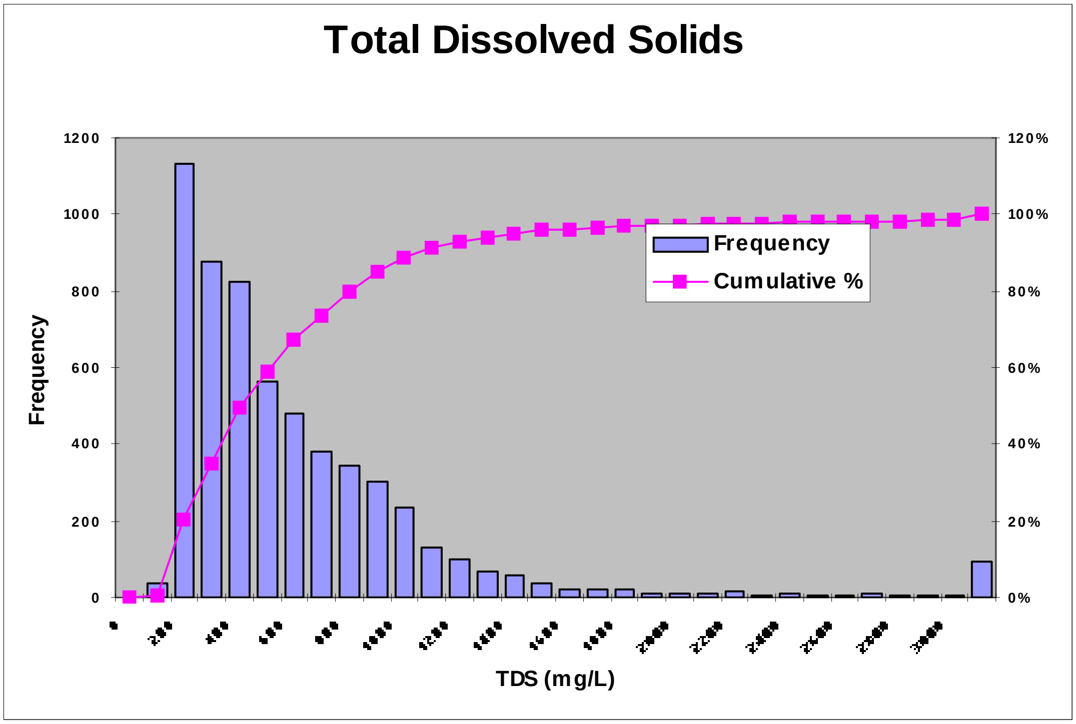


Figure 5.15 - Frequency and cumulative TDS distribution from samples meeting combined measure.

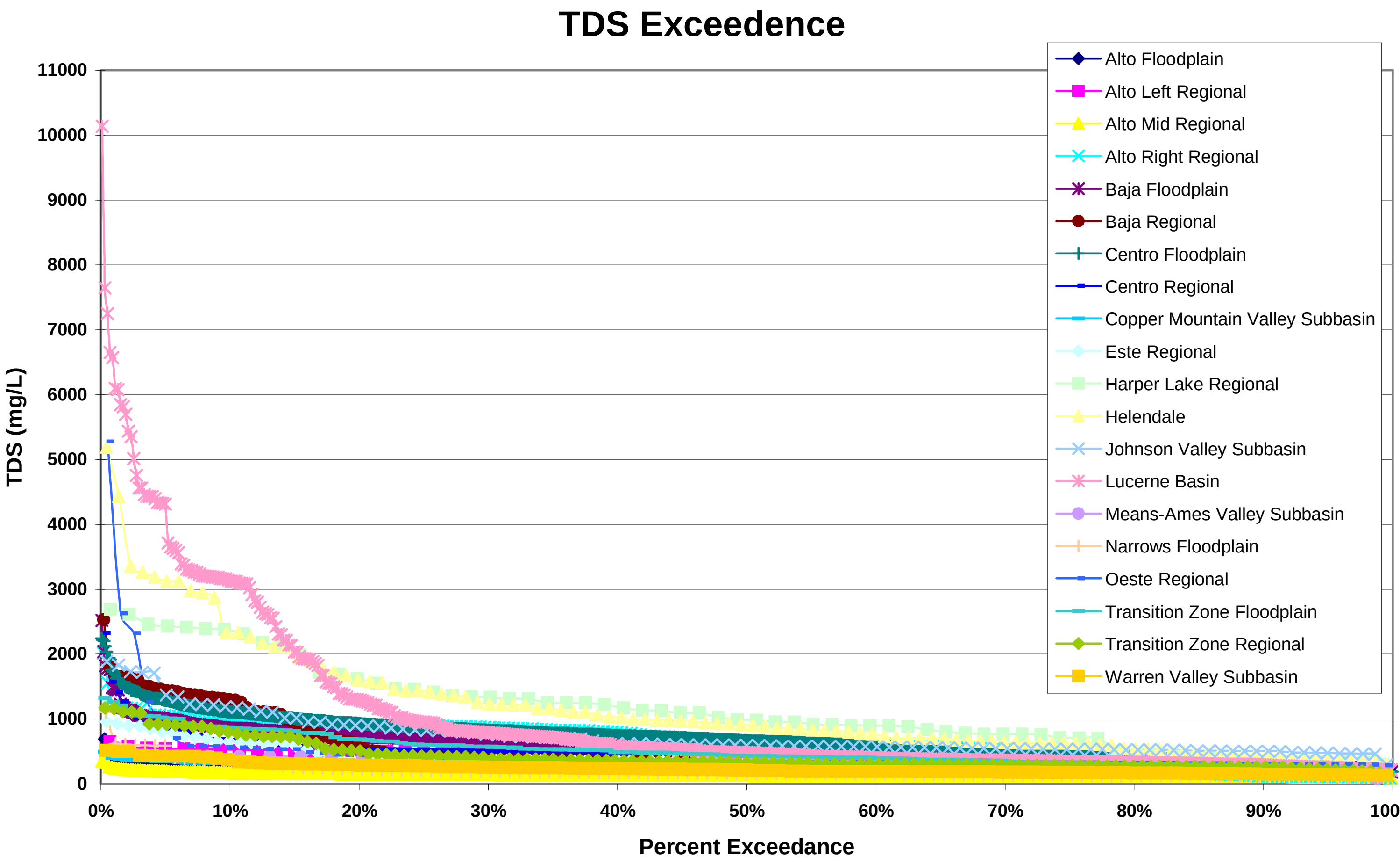


Figure 5.16 - Exceedance for samples meeting suggested standard. Left and right refer to position with respect to the floodplain aquifer facing the gradient direction.

Table 5.6 - Statistical summary by management sub-area for samples meeting combined geochemical quality assurance measure. Left and right refer to position with respect to the floodplain aquifer facing the gradient direction.

Sub-Aquifer Unit	Start Date	End Date	Number Wells	Number Samples	Average	Std Dev	% Exceeding 1000 mg/L
Alto Floodplain	12/13/49	1/15/04	40	176	170.4	62.6	0
Alto Left Regional	9/19/56	6/27/02	21	70	354.7	119.6	0
Alto Mid Regional	3/7/44	7/19/04	79	540	139.2	29.9	0
Alto Right Regional	3/7/44	6/30/04	48	274	646.4	313.6	9
Baja Floodplain	7/21/32	10/13/04	143	632	535.6	274.6	5
Baja Regional	4/22/52	8/13/03	79	226	507.5	401.8	14
Centro Floodplain	8/8/51	10/14/04	214	1047	696.4	327.0	15
Centro Regional	8/19/56	5/12/04	38	209	486.7	225.2	3
Copper Mountain Valley	12/27/56	5/10/04	38	174	224.8	68.2	0
Este Regional	7/24/57	1/23/02	21	116	375.8	171.0	0
Harper Lake Regional	2/6/52	5/17/04	27	68	1142.8	659.6	49
Helendale	6/24/45	1/23/04	28	108	1188.6	895.7	41
Johnson Valley Subbasin	3/19/51	9/11/96	25	109	730.5	317.3	15
Lucerne Basin	10/23/52	5/10/04	110	491	1051.4	1341.4	24
Means/Ames Valley Subbasin	12/28/56	6/3/04	19	42	292.8	97.8	0
Narrows Floodplain	9/21/42	10/18/04	26	131	202.3	135.7	0
Oeste Regional	6/5/56	5/17/04	36	97	482.4	591.4	5
Transition Zone Floodplain	1/14/57	2/12/04	54	157	506.8	240.7	5
Transition Zone Regional	3/7/42	10/14/04	33	147	415.4	224.7	4
Warren Valley Subbasin	11/23/53	5/10/04	33	117	234.9	86.8	0
All	7/21/32	10/18/04	1112	4931	553.5	586.6	

Merged Statistical/Geochemical Quality Assurance Results

Geochemical quality assurance measures are aimed at eliminating samples with inconsistent geochemical attributes on the basis that such inconsistencies may indicate unreliable analysis results. Univariate statistical quality assurance methods are aimed at eliminating extreme values from the dataset on the basis that such extremes have a low probability of being valid drawn from the normal population. As seen in the above discussions of geochemical and univariate quality assurance measures, rigorous application of either set of measures will severely limit the number of data points. In order to mitigate this effect a relaxation of geochemical quality assurance measures was proposed and statistical confidence intervals of +/- 2 standard deviations were investigated. However, it is necessary to select the largest number of data points possible while maintaining a reasonable level of confidence. In an effort to optimize the number of data points extracted from the database a final quality assurance step was performed in which both geochemical and statistical measures were combined by forming the intersection of the two. Table 5.7 shows the result of this intersection for samples meeting both the combined geochemical quality assurance measure 1(b) or 4(a), and the +/- 2 standard deviation statistical measure. This intersection provides a total of 5189 samples for all 20 sub-aquifer units.

Table 5.7 - Intersection of combined geochemical quality measures 1(b) or 4(a) and +/- 2 standard deviation statistical test.

Sub-Aquifer Unit	Number of Samples	Average TDS mg/L	Std. Dev. TDS mg/L
Alto Floodplain	178	173.1	60.4
Alto Left Regional	72	349.0	122.8
Alto Mid Regional	578	142.9	28.9
Alto Right Regional	284	653.6	304.3
Baja Floodplain	667	540.9	293.4
Baja Regional	255	527.3	449.5
Centro Floodplain	1083	706.2	340.3
Centro Regional	214	498.7	250.9
Copper Mountain Valley Sub-basin	180	232.2	94.3
Este Regional	131	369.1	179.7
Harper Lake Regional	66	1097.2	613.5
Helendale	106	960.4	495.9
Johnson Valley Sub-basin	116	738.8	335.6
Lucerne Basin	439	597.4	438.6
Means/Ames Valley Sub-basin	43	301.4	97.3
Narrows Floodplain	138	204.6	131.0
Oeste Regional	100	438.5	306.2
Transition Zone Floodplain	159	505.9	239.5
Transition Zone Regional	147	415.4	224.7
Warren Valley Sub-basin	127	230.0	85.3
Total	5189		

5.8 Task 2d.5: Define Surface and Groundwater Interactions Associated With Salt Flux Mechanisms.

Scope

In this task flux mechanisms specific to the MWA service area identified in Task 2c are quantified.

Discussion

As discussed in Section 3, TDS may be transported between adjacent sub-aquifer units by advection, dispersion, and diffusion. Although dispersion may potentially be significant at a local scale, modeling of dispersion requires reliably calibrated parameter input not available on a regional basis. Diffusion has been identified in Section 3 as being potentially significant at a local scale, but not significant on a regional sale. In light of both realistic scientific considerations and practical limitations, advection will be the only groundwater TDS transport mechanism implemented in the water quality planning model.

Figure 5.17 shows an aerial view of a simplified conceptual model of two adjacent sub-aquifer units.

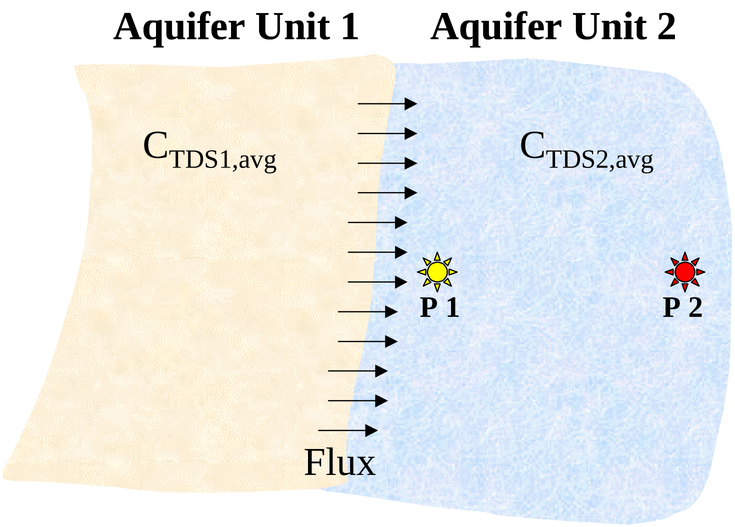


Figure 5.17 - Simplified conceptual model of inter-aquifer unit mass flux.

The rigorous solution for 1-dimensional time variant solute distribution in a homogeneous porous medium is given in Eq. 5.8.

$$\frac{C(x,t)}{C_0} = \frac{1}{2}\left(\operatorname{erfc}\left[\frac{L - v_x t}{2\sqrt{D_x t}}\right] + \exp\left(\frac{v_x L}{D_x}\right)\operatorname{erfc}\left[\frac{L + v_x t}{2\sqrt{D_x t}}\right]\right) \qquad (5.8)$$

where:

$C(x,t)$ = Concentration at point x at time t
erfc = Complementary error function
L = Length
v_x = Water velocity
D_x = Coefficient of hydrodynamic dispersion
C_0 = Initial concentration

Figure 5.18 shows concentration distributions along a 1-dimensional profile from a source located at the left hand boundary for different times assuming various transport scenarios. The result of advective transport *with* dispersion is shown by the green curves. The result of advective transport *without dispersion* is shown by the blue curves. Note that without dispersion the concentration front is distinct and "piston-like". The addition of dispersion causes a spreading of the concentration front.

Instantaneous Mixing Assumption – The assumption of instantaneous mixing is inherent in all transport modeling methods. Instantaneous mixing means that all of the mass transferred into a model volume element is instantaneously mixed throughout that volume. If the length of the volume element in the direction of travel is shorter than the distance that mass would travel (i.e. by advective transport) during the model time step then the mass will move down-gradient to the next model element too soon, introducing cumulative errors over time. Such errors may only be minimized through finer spatial discretization or longer model time steps. In the water quality planning model this instantaneous mixing will occur at the sub aquifer unit scale. TDS mass transfer will be computed as:

$$\Delta m_{ts} = \Delta V_{ts} \cdot c_{TDS} \tag{5.9}$$

where;

Δm_{ts} = the mass of TDS transferred during the timestep

ΔV_{ts} = the volume of water transferred during the time step

c_{TDS} = the TDS concentration of the source aquifer

This TDS mass transfer will be added to the water mass transport mechanism to simulate an advective transport system as illustrated in Figure 5.19. The resulting TDS concentration profile is illustrated by the orange dashed line in Figure 5.18. This concentration will be a good approximation for some parts of the sub-aquifer unit close to the flux boundary and significantly in error in other parts of the sub-aquifer unit farther removed from the flux boundary. One method of spreading out the errors caused by this instantaneous mixing assumption is to use shorter time steps. The red dashed lines in Figure 5.18 illustrate the concentration profiles that would result from 4 short time steps.

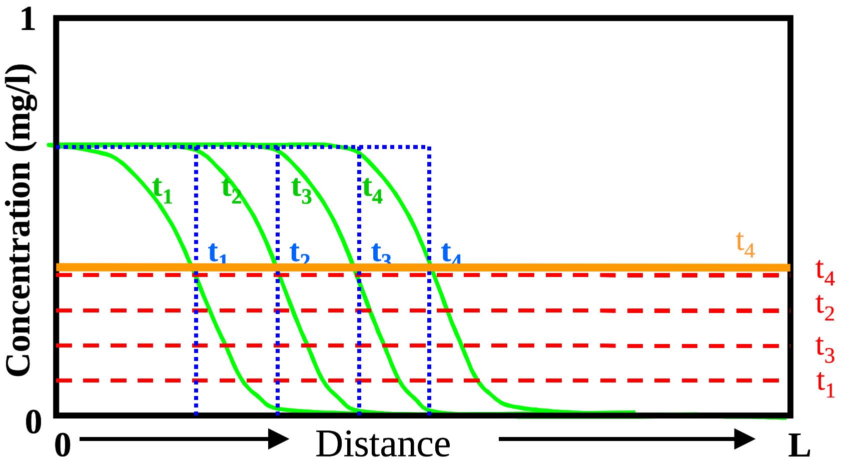


Figure 5.18 - Concentration vs. distance profiles for various transport mechanisms and for successive time steps. Green lines are advection with dispersion, blue lines are advection only, red lines are instantaneous mixing. Orange line represents instantaneous mixing with large time step.

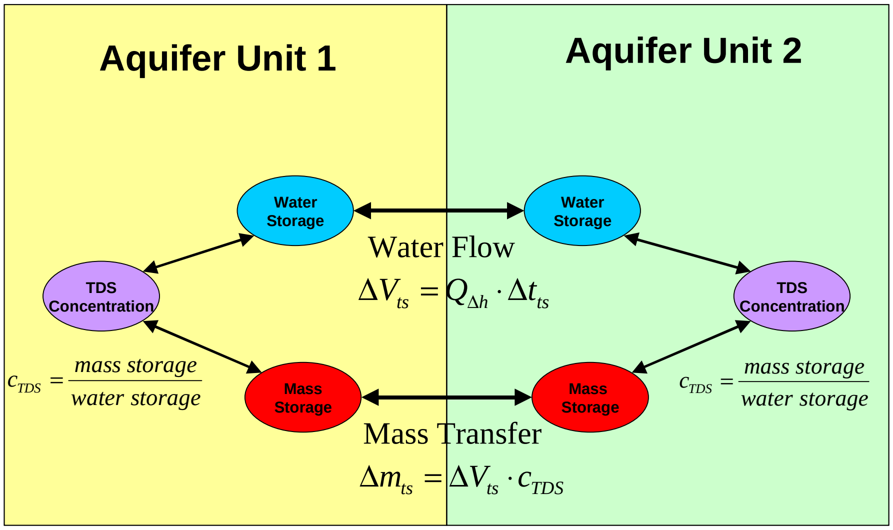


Figure 5.19 - Implementation of mass transport using existing hydrodynamic material balance model formulation.

Advective transport on the regional scale occurs over long time periods. The velocity that a particle travels through a porous medium through advective transport alone is;

$$v_i = \frac{v}{\phi} = Ki \qquad (5.10)$$

where;

v_i = interstitial velocity

v = darcy velocity

ϕ = porosity

K = hydraulic conductivity

i = hydraulic gradient = $\frac{dh}{dx}$

dh = head difference

dx = distance

and;

$$t = \frac{dx}{v_i} \tag{5.11}$$

where;

t = traveltime for distance dx

Modeling Dry Lakes – Dry lakes present a unique challenge to transport modeling using even sophisticated modeling environments. The available literature indicates that dry lakes have little or no hydraulic connection to the groundwater system. If true, TDS associated with these dry lakes would be stranded. In this scenario these high TDS concentrations would pose a risk to any activities or developments in the immediate vicinity, but not to the regional system. Although hydraulic connectivity between dry lakes and the aquifer may be small enough to be insignificant on a regional scale, considering the extremely high TDS concentrations involved the potential mass transport with even marginal hydraulic connectivity may be significant. Figure 5.20 illustrates a simplified conceptual model of a dry lake and aquifer. The dry lake itself is disconnected from the water table. The figure shows a hypothetical TDS fringe around and beneath the dry lake and the unsaturated vadose zone above the water table resulting from capillary effects. In this scenario the high TDS fringe is partially or intermittently saturated depending on the thickness of this zone. Occasional rises in the water table may cause the unsaturated zone to invade further into the fringe below the dry lake, mobilizing TDS. This is a plausible model for transport of TDS from dry lakes into the groundwater system. This mechanism may be formulated as an empirical relationship between the groundwater level and the elevation of the lake. Figure 5.21 shows a schematic of how this mechanism might be implemented in a Stella mass balance calculation.

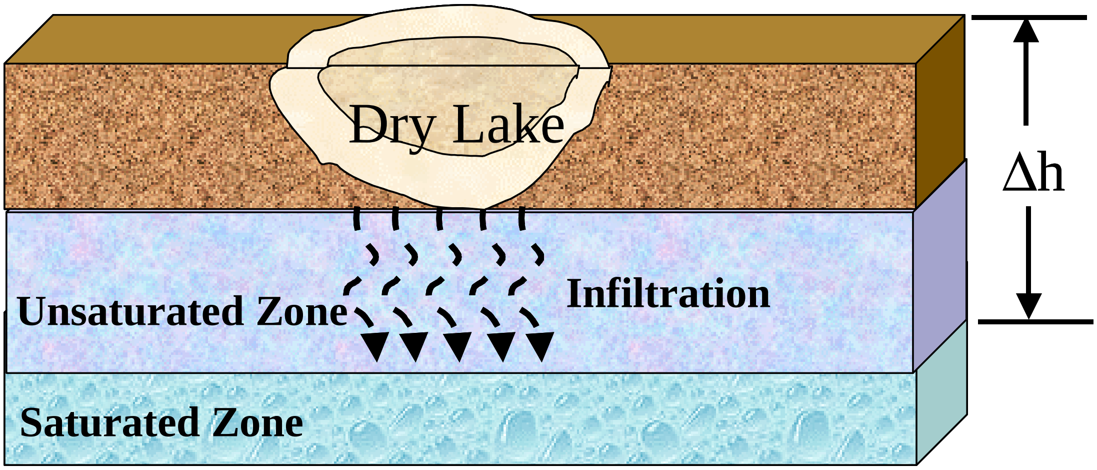


Figure 5.20 - Conceptual mass transport model for dry lakes.

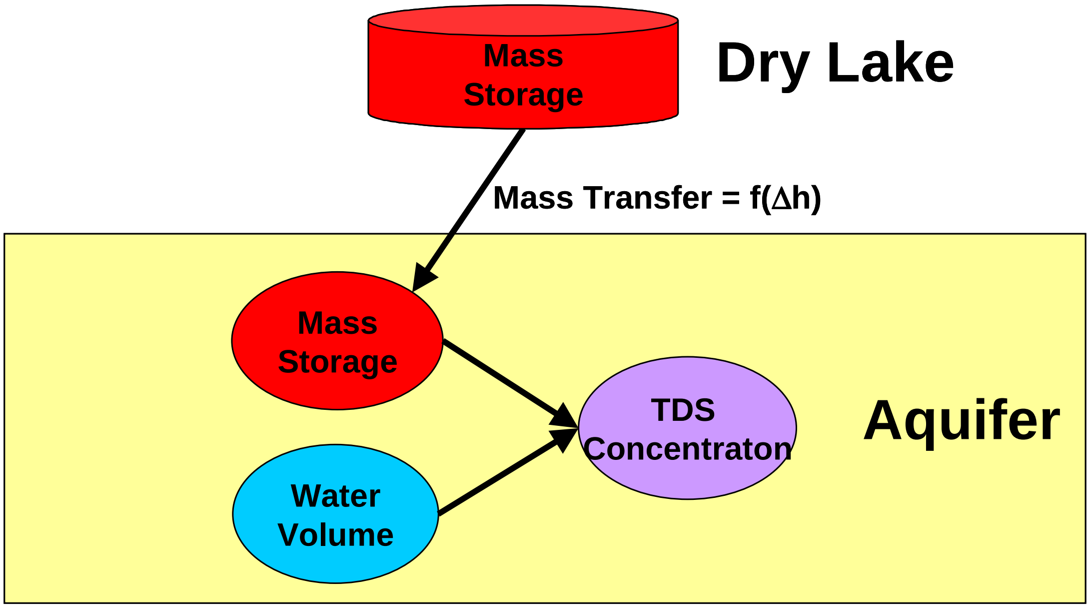


Figure 5.21 - Implementation of dry lake mass transport process using material balance formulation.

5.9 Task 2d.6: Refine Evapotranspiration and Return Flow Quantities

Scope

Evapotranspiration (ET) estimates in the MWA service area have been refined using the Surface Energy Balance Algorithm for Land (SEBAL) technique. SEBAL involves processing digital satellite imagery with specially developed algorithms, based on the concept of energy balance. SEBAL provides potential and actual ET for each pixel in a satellite image, independent from weather and crop/land use information. SEBAL has been tested in several countries around the world, and has provided excellent results in the U.S. for cropped and naturally vegetated portions of Idaho's Snake River Plain region.

This task required SWS to subcontract with SEBAL North America (Davids Engineering) for satellite imagery processing. To refine estimates of average annual ET eight satellite images were processed.

Discussion

These data will be used to refine return flows by determining water balances for each sector of demand. Return flows used in the 2004 RWMP were calculated by multiplying annual production in each sector of demand by a consumptive use factor. In most cases the consumptive use factor is based on values deemed representative by the Watermaster. The municipal consumption for the entire Mojave Service Area is assumed to be 50%. In the 2004 Stella screening model consumptive use for each sub-aquifer unit was calculated discretely from several demand sectors. For example, consumptive use in the Alto Floodplain management zone is calculated as:

Alto Consumptive Use = Ag Consumptive Use + Golf Course Consumptive Use + Recreational Consumptive Use + Municipal Consumptive Use + Phreatophyte Consumptive Use

Newly processed SEBAL data has been used to refine the estimate of evapotranspiration consumptive use, such as phreatophyte and golf course consumptive use, which may be a significant factor in several of the sub-aquifer units located along the Mojave River.

Results

Due to considerations of image quality and data availability satellite coverage for year 2002 was selected for this project. A total of 33 SEBAL images have been created. These are:

- 16 daily images
- 16 period average images (monthly or bi-weekly)
- 1 annual average image

The 16 period images were selected to provide two images per month for the most active evapotranspiration period of June through September, with the remaining eight images at monthly intervals throughout the remainder of the year. The ET values estimated from the SEBAL process have been spatially correlated to the different sectors of demand in the MWA service area. Figure 5.22 shows the annual average ET image. The daily and period average images are located in Attachment 2 to this memorandum. All units are mm/image period. ET estimates from the 16 period images are listed in Table 5.8 in units of mm/day. These data will be used to improve consumptive use calculations in the water balance of the water quality planning model.

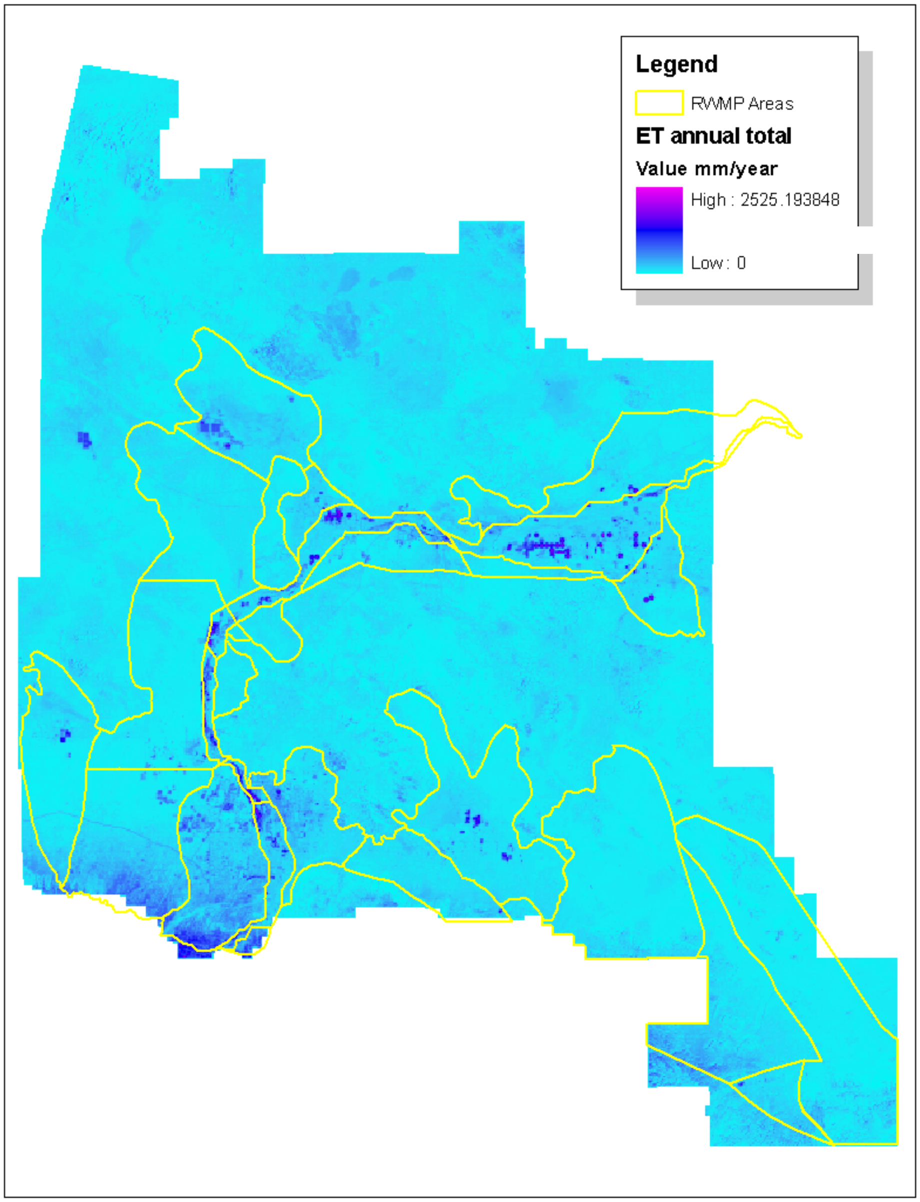


Figure 5.22 – Average annual evapotranspiration in mm/year computed from satellite imagery using SEBAL.

Table 5.8 – SEBAL ET estimates in units of mm/day for 16 monthly and bi-weekly image periods.

	Image Period															
Management Zone	**Jan 1 - Jan 31**	**Feb 1 – Feb 28**	**Mar 1 – Mar 31**	**Apr 1 – Apr 30**	**May 1 – May 31**	**Jun 1 – Jun 15**	**Jun 16 – Jun 30**	**Jul 1 – Jul 15**	**Jul 16 - Jul 31**	**Aug 1 – Aug 15**	**Aug 16 – Aug 31**	**Sep 1 – Sep 15**	**Sep 15 – Sep 30**	**Oct 1 – Oct 31**	**Nov 1 – Nov 30**	**Dec 1 – Dec 31**
Alto Floodplain	0.73	0.32	0.43	2.20	1.10	2.22	0.61	0.93	2.22	0.92	0.80	0.67	0.67	0.63	0.65	0.61
Alto Left Regional	0.28	0.36	0.16	1.13	0.47	1.61	0.25	0.96	1.70	0.43	1.14	0.22	0.35	0.42	0.51	0.24
Alto Mid Regional	0.59	0.38	0.43	2.15	1.31	2.00	0.47	1.01	2.44	0.82	0.95	0.64	0.70	0.64	0.88	0.48
Alto Right Regional	0.70	0.09	0.20	1.09	0.39	0.96	0.19	0.47	1.79	0.30	0.22	0.34	0.34	0.48	0.58	0.60
Baja Floodplain	0.21	0.67	0.33	0.71	0.80	0.61	0.43	2.08	2.33	1.10	1.24	0.84	0.52	0.38	0.55	0.14
Baja Regional	0.10	0.54	0.11	0.15	0.22	0.19	0.10	0.74	1.54	0.78	0.65	0.19	0.12	0.15	0.13	0.07
Centro Floodplain	0.47	0.62	0.53	0.98	0.76	0.78	0.45	1.80	2.30	1.12	1.05	0.67	0.74	0.85	0.59	0.35
Centro Regional	0.36	0.44	0.17	0.22	0.09	0.21	0.06	0.63	1.06	0.23	0.14	0.09	0.14	0.39	0.17	0.28
Copper Mountain Valley	0.05	0.16	0.14	0.04	0.04	0.07	0.06	0.06	1.87	0.12	0.19	0.18	0.24	0.16	0.11	0.04
Este Regional	0.49	0.05	0.26	0.12	0.17	0.11	0.07	0.19	2.51	0.09	0.07	0.27	0.25	0.37	0.64	0.40
Harper Lake Regional	0.34	0.64	0.51	0.52	0.14	0.41	0.09	0.79	0.71	0.28	0.40	0.15	0.22	0.39	0.20	0.25
Helendale	0.65	0.76	0.61	1.55	1.26	1.35	1.03	1.88	2.41	1.16	1.24	1.03	0.94	0.90	0.82	0.54
Johnson Valley Sub-basin	0.05	0.05	0.07	0.04	0.03	0.05	0.05	0.06	2.56	0.07	0.09	0.17	0.18	0.08	0.23	0.05
Lucerne Basin	0.34	0.03	0.09	0.30	0.12	0.19	0.11	0.21	2.12	0.16	0.10	0.14	0.15	0.28	0.29	0.27
Means/Ames Valley	0.13	0.60	0.32	0.08	0.07	0.07	0.05	0.06	3.11	0.40	0.59	0.45	0.72	0.28	0.22	0.12
Narrows Floodplain	1.09	0.58	0.82	2.68	2.48	2.50	1.66	2.25	3.50	1.40	1.40	1.63	1.37	1.11	1.26	1.01
Oeste Regional	0.23	0.30	0.03	0.57	0.12	0.23	0.11	0.54	0.90	0.12	0.15	0.08	0.12	0.28	0.23	0.21
Transition Zone Floodplain	0.73	0.50	0.49	1.87	1.57	1.39	0.86	1.57	2.58	0.79	0.96	1.02	0.92	0.93	0.99	0.64
Transition Zone Regional	0.36	0.18	0.05	0.22	0.09	0.11	0.09	0.31	0.71	0.08	0.17	0.08	0.08	0.36	0.20	0.31
Warren Valley	0.06	0.86	0.32	0.07	0.08	0.14	0.07	0.08	2.90	0.61	0.93	0.37	0.86	0.27	0.20	0.06

6

Task 2e: Modeling Platform

6.1 Scope

In this section the recommendation of the modeling environment to be used for the water quality planning model is summarized. Possible modeling environments under consideration for the water quality planning model include customized spreadsheets, an extension of the Stella model developed by SWS to include a salinity balance, or a more complex model such as Qual2E.

6.2 Review of Key Issues

Previous sections of this technical memorandum summarized the result of extensive investigation into the requirements for water quality modeling in the Mojave Basin as required for selection of the optimal modeling environment. The topics investigated included:

- The role of the water quality planning model is described in Section 2. In this section we outlined the role of the water quality planning model. This section included direct input from the Water Quality Workgroup as well as consideration of relevant stakeholder input to the 2004 RWMP development process. Section 2 also included a discussion the goals, objectives, and expectations for a model during execution of the RWMP.
- Key modeling requirements were discussed in Section 3. In this section we reviewed the fundamentals of hydrodynamic and mass transport modeling. The key parameters and data requirements for three potential modeling approaches were presented. These approaches represented increasing stages of model complexity with corresponding

benefits. These increased demands on the quantity and quality of data required to parameterize these models was also discussed.

- Potential inputs and outputs required to compute a salt budget for the MWA service area were presented in Section 4. This system contained a systematic review of natural and anthropogenic TDS sources and sinks. Available literature and the water quality database developed in Task 1 of this study were used to evaluate the potential impact of each salt flux mechanism. Various TDS anomalies were high-lighted and discussed. The physical information required for construction of a water quality planning model were discussed and further refined where needed and justified by available data. Based on an observed TDS anomaly in the vicinity of Helendale, the RWMP sub-areas were further refined to include one additional management zone. It is felt that the extensive body of information available in the literature and from prior models is sufficient to support the current level of spatial refinement in the 2004 RWMP screening model. However, further spatial disaggregation is not justified by the information currently available. Quality assurance steps similar to those used in the Santa Ana Watershed Study were applied. These included univariate statistical and geochemical quality assurance techniques. Newly acquired evapotranspiration data acquired using the sophisticated Surface Energy Balance Algorithm for Land (SEBAL) image processing technique were introduced.

The key considerations guiding selecting of the optimal modeling platform presented and discussed in previous sections of this memorandum may be summarized as follows:

Model Objectives – The primary use of the water quality planning model will be for long term salt loading analysis. Much of the potential value of this model will be in support of the RWMP.

Management Strategy - As evidenced by the 2004 RWMP, MWA has adopted a systematic, long-term approach to management of water resources of the Mojave and Morongo basins. The water quality planning model developed under this program is the initial step in this long term effort with respect to water quality issues. The emphasis at this stage is on developing the model that is most appropriate for the near-term objectives.

Data Requirements – The amount and quality of available hydrogeological and water quality input data imposes limits on the reliability of the solution of any model. Although a sophisticated computational engine may be applied to any given dataset, it is felt that a sophisticated model such as a finite difference numerical model, is not realistic given the available dataset. MWA is actively working to improve the characterization of the area through both new data acquisition and compilation of existing data. These efforts will, in time, facilitate comprehensive basin-wide hydrogeological conceptual modeling and more sophisticated TDS transport modeling. The initial water quality planning model developed in this effort will help to identify data gaps and to help evaluate water quality data acquisition options.

Model Compatibility - Although compatibility with the 2004 RWMP Stella screening model has not been imposed as a design constraint in this study, such compatibility would greatly facilitate use of the water quality planning model in support of the RWMP. Adoption of the Stella modeling environment for the water quality planning model will take advantage of the extensive work invested in the Stella RWMP screening model, thus providing a highly advanced starting point for the water quality modeling efforts.

Recommended Modeling Platform

Based on the findings of Task 2 we recommend use of Stella as the modeling environment of the water quality planning model. The water quality planning model will be created through extension of the existing RWMP screening model. The base Stella screening model includes:

- Time series of surface water inflows
- Time series of groundwater inflows
- Water mass balance at each node in each time step
- Water mass balance at each groundwater storage node from one time step to the next

- Flow between groundwater aquifers as a function of storage in each aquifer
- Flow to/from the river to/from the floodplain aquifer as a function of flow in the river and storage in the aquifer
- Losses in the river flow due to riparian habitat use
- Return flow to the regional and floodplain aquifers as a function of use by each demand sector
- Water demand for each sector in each subarea

TDS transport will be added to the base screening model through the following modifications:

- TDS mass tanks will be added to each management zone
- The model will be initialized using ambient TDS concentrations computed as described in Section 5
- Water quality of each TDS source will be included
- Pseudo steady state advective transport of dissolved solids between management zones will be achieved through the groundwater flux mechanism
- TDS mass balance will be recomputed for all management zones at each model time step
- Instantaneous mixing within management zones will be assumed
- Updated estimates of consumptive use based on newly acquired SEBAL analysis will be included

Key Model Limitations

The major limitations of the water quality planning model will result from the effect of coarse discretization on modeling of the TDS mass transport process. This will manifest itself in the following ways;

1. Averaging of concentrations within sub-aquifer units – Although realistic particle velocities in the groundwater system are on the order of 0.3 feet per day, all TDS inputs and outputs within a sub aquifer unit will be instantaneously mixed to calculate an average concentration for the unit at each time step. Distribution of TDS concentrations from sources within a sub aquifer unit cannot be spatially resolved within the unit.
2. Averaging of concentrations resulting from groundwater transport – As a result of the instantaneous mixing assumption, TDS mass transported through groundwater flow from one sub aquifer unit to the adjacent down-gradient sub aquifer unit will have an instantaneous effect on the (average) concentrations of both sub aquifer units. The spatial distribution of TDS concentrations resulting from to flux across sub aquifer unit boundaries may not be resolved within the sub aquifer units. The concentrations computed will represent the average for the sub aquifer unit and will not necessarily be representative of a specific point within the unit.
3. Numerical dispersion of concentration – Sample calculations using representative values of gradient and hydrodynamic properties yield particle travel times between sub aquifer units longer than the anticipated planning predictive periods through the advection mechanism. However, as a result of the instantaneous mixing model assumption the TDS mass moved between adjacent sub aquifer units will be immediately available for transport to the adjacent down-gradient sub-aquifer unit. This artificial acceleration of mass transport will be mitigated through a buffering mechanism in the model formulation.

The above limitations are a direct result of the coarse discretization of the model. Given representative hydrodynamic properties and gradients, the time required for TDS mass to travel 5 miles by advective transport would be approximately 100 years. Development of a model to predict even such long term concentration changes at moderate spatial resolution would require numerical modeling methods with several hundred grid block, associated inputs, and interactions. Such a modeling effort is beyond both the resolution and quality of the current water quality data and the scope of the water quality planning model project.

6.3 Model Advantages

Use of the Stella modeling environment for the water quality planning model has several advantages over spreadsheet based salt loading calculations:

- Stella has an intuitive graphical user interface which facilitates development of complex systems with many inputs, processes, nodes and interactions.
- Stella solves systems of equations, making it possible to approximate complex head dependent interactions involving both natural and anthropogenic mechanisms.
- Stella has many pre-programmed process functions, significantly reducing the effort involved in programming and testing of many macros and subroutines.
- Stella may be run in an automated mode, which can be used to perform successive computations under various model states.
- Stella has versatile built in functionality for exploring model sensitivity
- Stella has graphical and tabular output functionality.

References

Andraski, B.J., Prudic, D.E., and Nichols, W.D., Waste Burial in Arid Environments – Application of Information From a Field Laboratory in the Mojave Desert, Southern Nevada, USGS Fact Sheet FS-179-95, August 1995.

Billhorn, T. (2003) pers. comm.

Bookman-Edmonston Engineering, Inc., 1991 Investigation for the Establishment of zones of benefit: draft consultant report prepared for the Mojave Water Association, Glendale, Ca, 34p.

California Department of Water Resources, Bulletin No. 84, Mojave River Ground Water Basins Investigation, August 1967

California Regional Water Quality Control Board, Lahontan Region, Mojave, Trona, and Amargosa Hydrologic Units Water Body Fact Sheets for Mojave River Between Upper and Lower Narrows, Total Dissolved Solids 2002 Section 303(d) List Update, November 2001

Densmore, J.N., Cox, B.F., and Crawford, S.M., Geohydrology and Water Quality of Marine Corps Logistics Base, Nebo and Yermo Annexes, near Barstow, California, USGS Water-Resources Investigations Report 96-4301, 1997

Fife, D.L., and Brown, A.R., Geology and Mineral Wealth of the California Desert, Dibblee Volume, South Coast Geological Society, 1980.

Hardt, W.F., 1971, Hydrogeologic analysis of the Mojave River basin, California, using electrical analog model: U.S. Geological Survey Open-File Report [71-157], 84p.

Izbicki, John A., Source and Movement of Ground Water in the Western Part of the Mojave Desert, Southern California, USA, USGS Water-Resources Investigations Report 03-4313, 2004

Harter, T., Associate Cooperative Extension Specialist, University of California, Davis. Personal communication August 24, 2005.

Jones-Lee, Anne and Lee, G. Fred, Groundwater Pollution by Municipal Landfills: Leachate Composition, Detection and Water Quality Significance, Sardinia ‘93IV International Landfill Symposiums. Margherita di Pula, Italy, October 1993, taken from www.gfredlee.com 2/28/2005.

Lewis, R.E., Groundwater Resources of the Yucca Valley-Joshua Tree Area, San Bernadino County, California, USGS Open File Report 72-234, March 24, 1972.

Lines, Gregory C., Groundwater and Surface Water Relations along the Mojave River, Southern California USGS Water-resources investigations report; 95-4189, 1996

Maxwell, C.R., A Watershed Management Approach to Assessment of Water Quality and Development of Revised Water Quality Standards for the Ground Waters of the Mojave River Floodplain, USGS Water-resources investigations report; 95-4189, 1996

Mojave River Watershed Solid Waste Management Plan, July 1, 2003.

Nishikawa, T, Densmore, J., Martin, P. Matti, Jonathan, Evaluation of the Source and Transport of High Nitrate Concentrations in Ground Water, Warren Subbasin, California, 2003, U.S. Geological Survey Water-Resources Investigations Report 03-4009, prepared in cooperation with the HI-DESERT W ATER DISTRICT and the Mojave Water Agency

Nishikawa, T, Izbiki, J., Hevesi, J. Stamos, C., Martin, P., Evaluation of Geohydrologic Framework, Recharge Estimates, and Groundwater Flow of the Joshua Tree Area, San Bernadino County, California, 2004, U.S. Geological Survey Scientific Investigations Report 2004-5267.

Patterson, Mark, Crestline Sanitation District. Phone conversation on 3/11/05.

Schlumberger Water Services, Mojave Water Agency 2004 Regional Water Management Plan, 2004

Stamos, C.L., Martin, P., Nishikawa, T., and Cox, B.F., Simulation of Ground-Water Flow in the Mojave River Basin, California, USGS Water-Resources Investigations Report 01-4002, Version 1.1, 2001

Stamos, C.L., Cox, B.F., Izbicki, J.A., and Mendez, G.O., Geologic Setting, Geohydrology and Ground-Water Quality near the Helendale Fault in the Mojave River Basin, San Bernardino County, California, USGS Water-Resources Investigation's Report, 4-Mar 069, 2003.

Stamos, C., Personal telephone communication, Feb. 2005.

Subsurface Surveys Inc, Inventory of Groundwater Stored in the Mojave River Basins, Prepared for the Mojave Water Agency, May 1990

Umari, M.J., Martin, P., Schroeder, R., Duell, L. Fay, R.G., Potential for Groundwater Contamination From Movement of Wastewater Through The Unsaturated Zone, Upper Mojave River Basin, Ca. S.S.G.S. Water Resources Investigations Report 93-4137, 80p.

URS Corporation, Mojave River Transition Zone Recharge Project Phase II Report Groundwater Supply and Demand in the Transition Zone, June 13, 2003. Pgs 38, 40, 49, 90-91

URS, Mojave River Transition Zone Recharge Project Phase I Report Transition Zone Hydrogeology, March 13, 2003

Webb (2000) Consumptive Water Use Study and Update of Production Safe Yield Calculations for the Mojave Basin Area. Albert A. Webb Associates, Riverside, CA.

Wildermuth Environmental, Inc., TIN/TDS Study – Phase 2A of the Santa Ana Watershed, Final Technical Memorandum., July 2000.

Attachments

Attachment 1

Univariate Statistical
Water Quality Data Summary

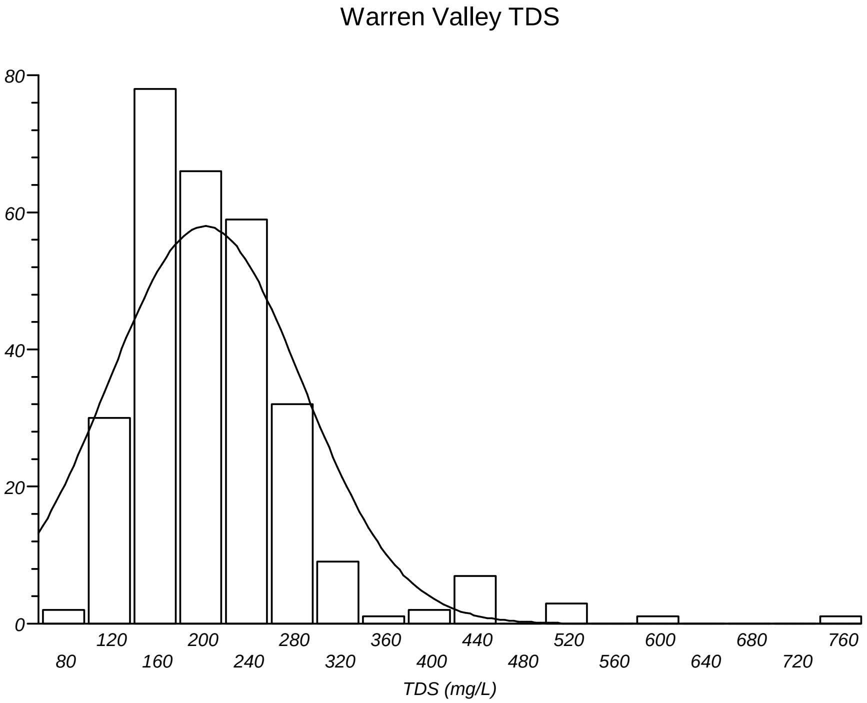


Figure A1.1 – TDS Histogram for Warren Valley sub-basin.

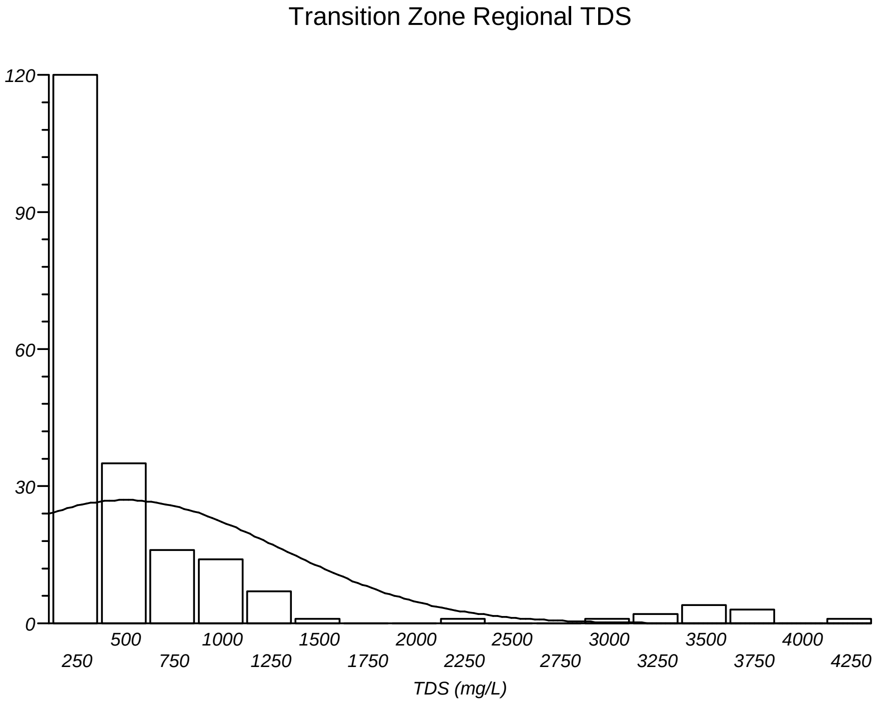


Figure A1.2 – TDS Histogram for Transition Zone Regional subarea.

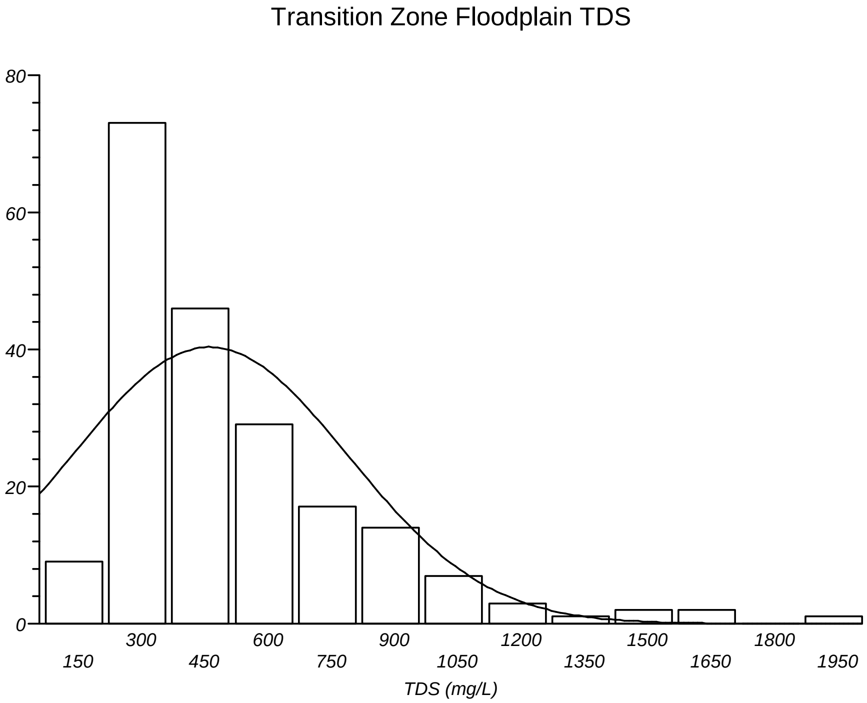

Transition Zone Floodplain TDS

Figure A1.3 – TDS Histogram for Transition Zone Floodplain subarea.

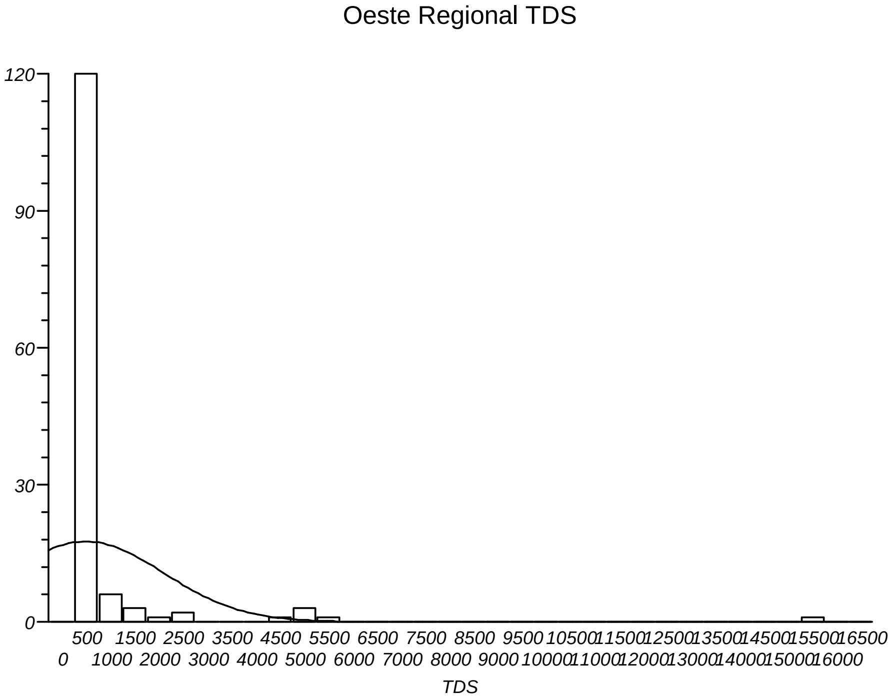

Oeste Regional TDS

Figure A1.4 – TDS Histogram for Oeste Regional subarea.

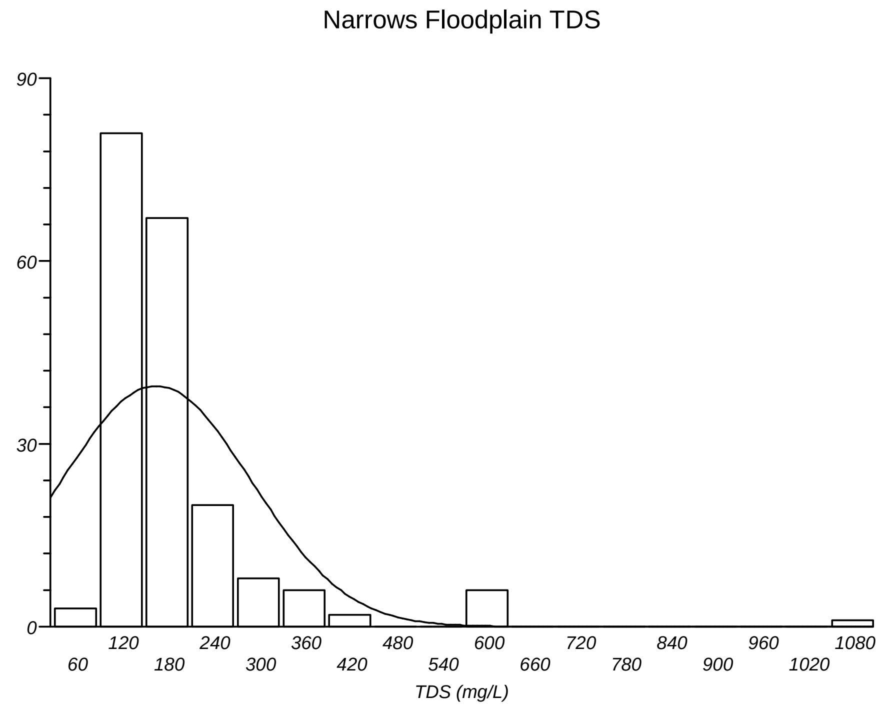

Narrows Floodplain TDS

Figure A1.5 – TDS Histogram for Narrows Floodplain subarea.

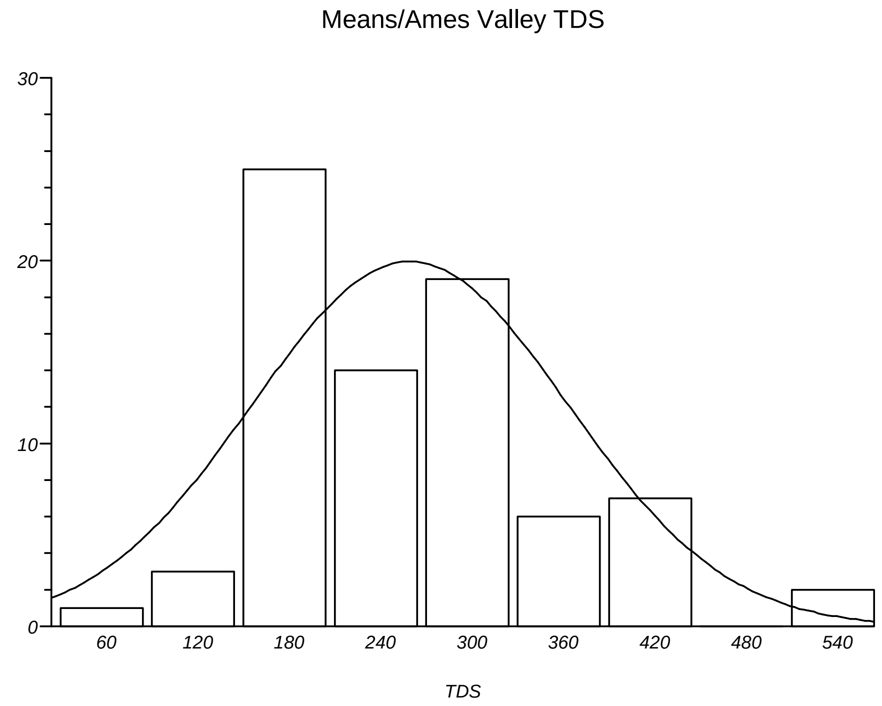

Means/Ames Valley TDS

Figure A1.6 – TDS Histogram for Means/Ames Valley subarea.

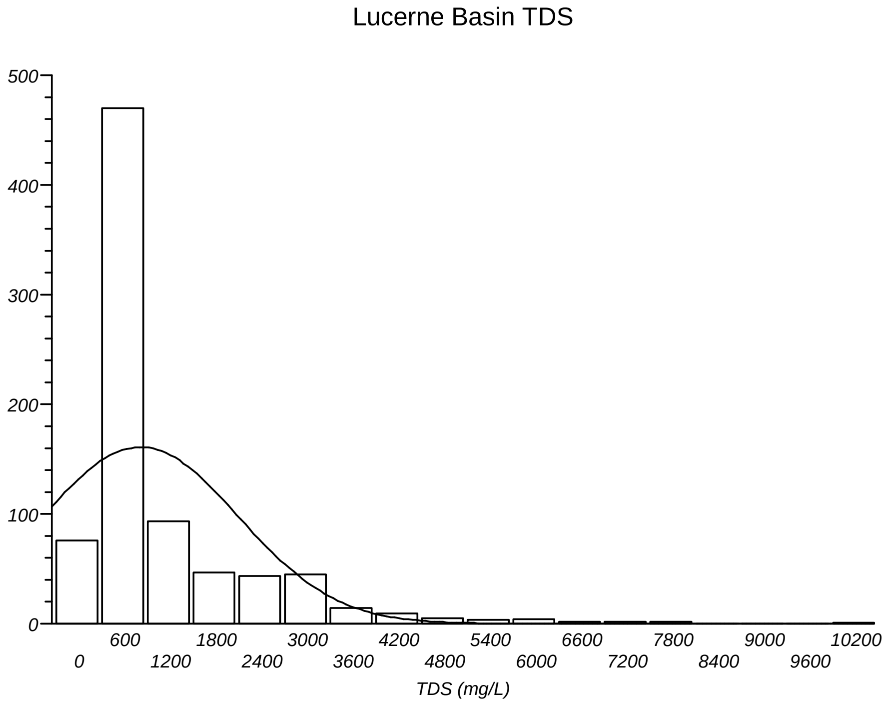


Figure A1.7 – TDS Histogram for Lucerne Basin subarea.

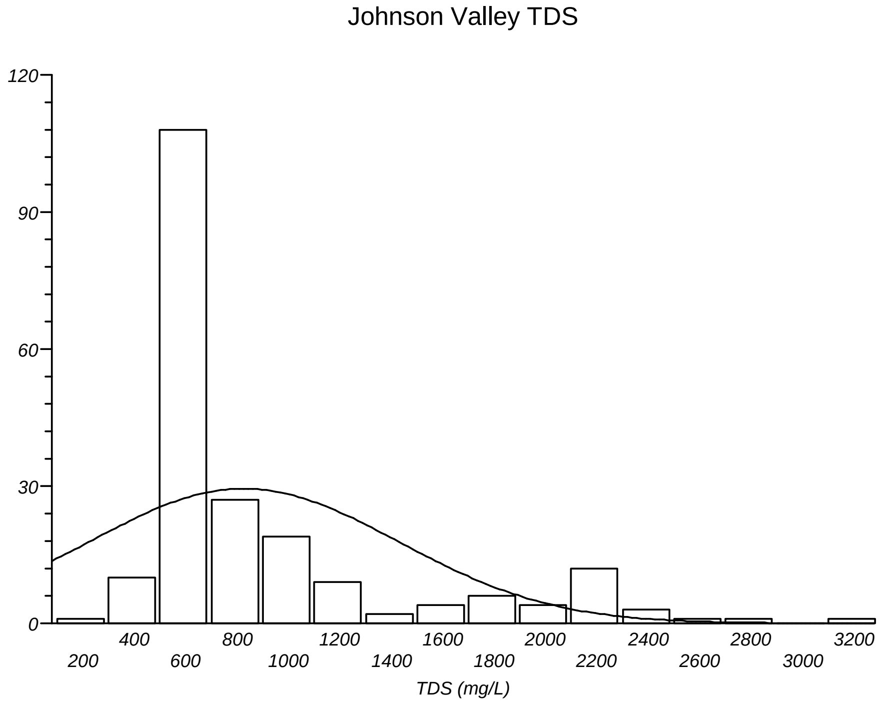


Figure A1.8 – TDS Histogram for Johnson Valley subarea.

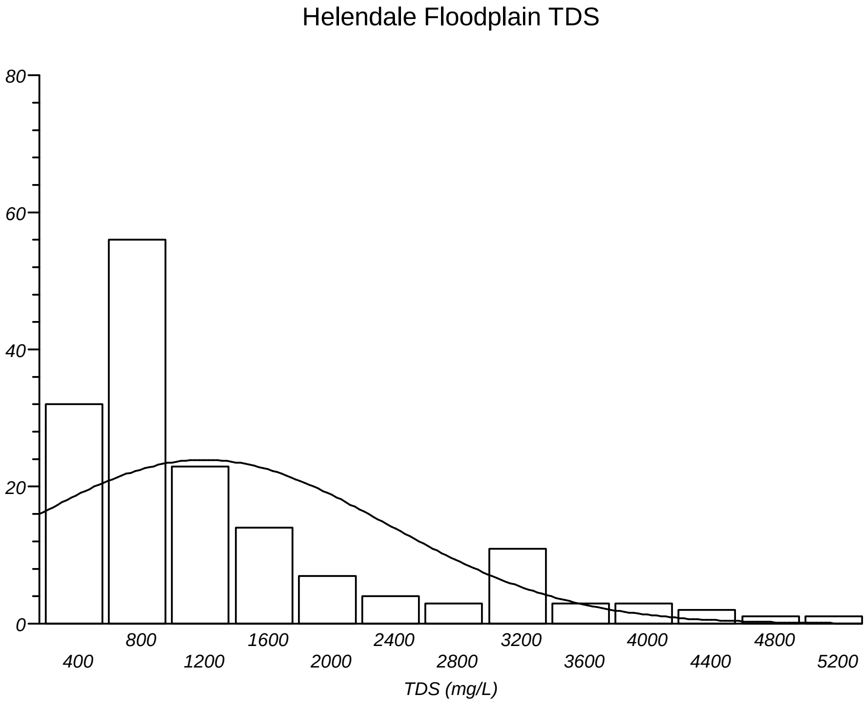


Figure A1.9 – TDS Histogram for Helendale Floodplain subarea.

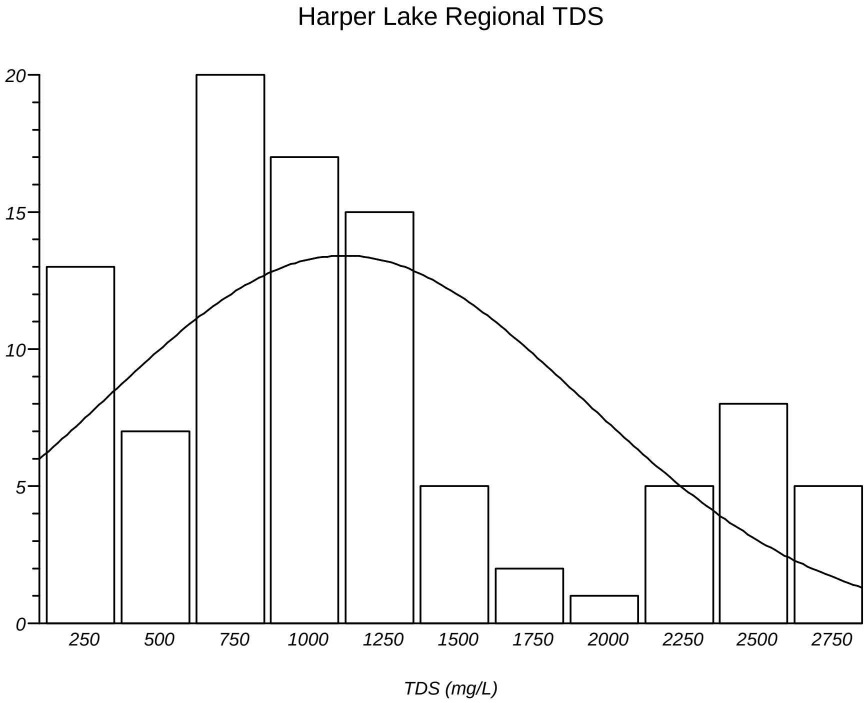


Figure A1.10 – TDS Histogram for Harper Lake Regional subarea.

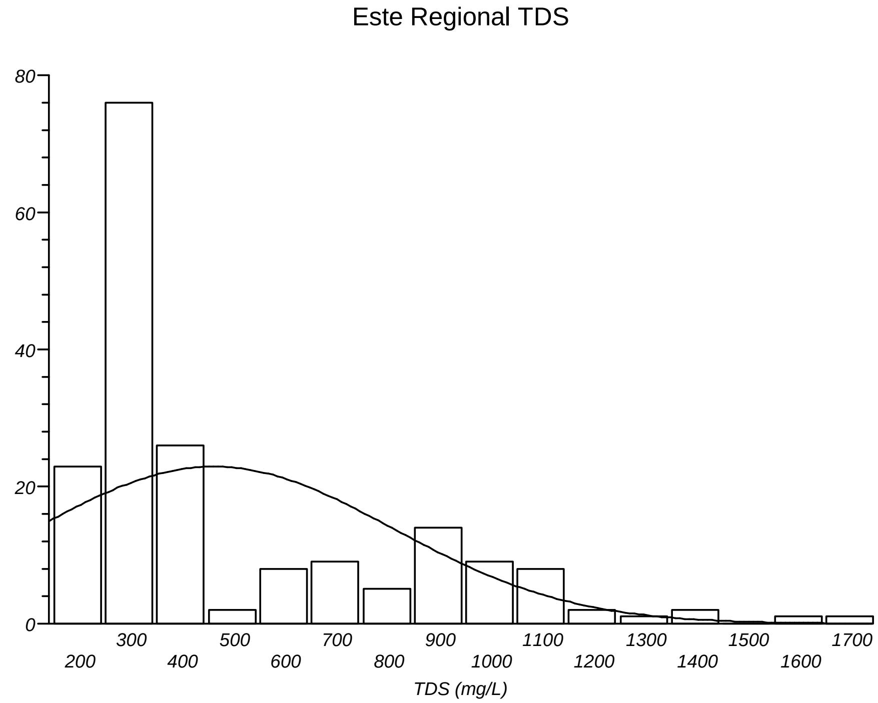


Figure A1.11 – TDS Histogram for Este Regional subarea.

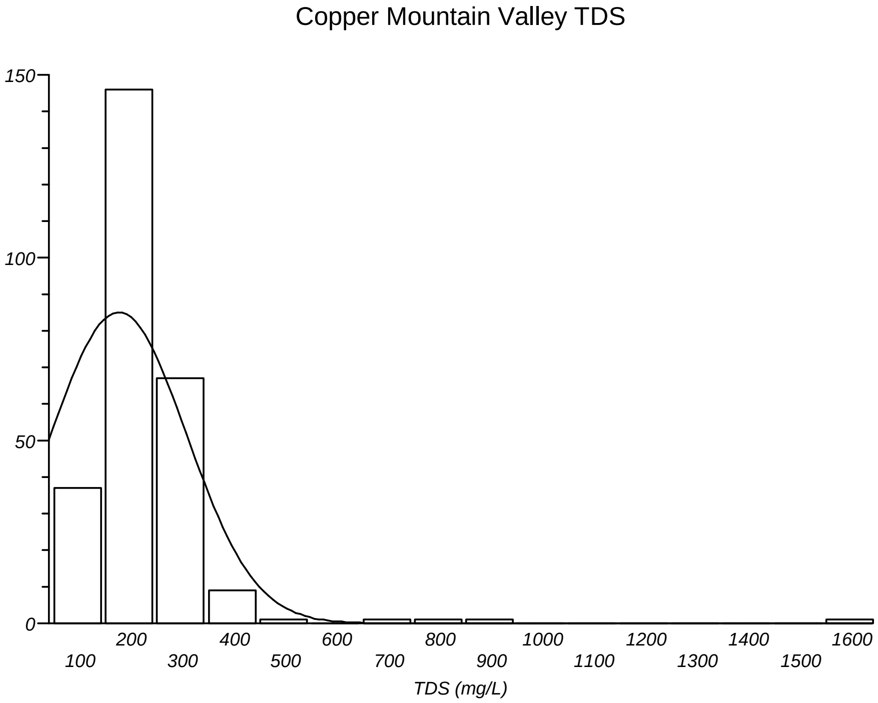


Figure A1.12 – TDS Histogram for Copper Mountain Valley subarea.

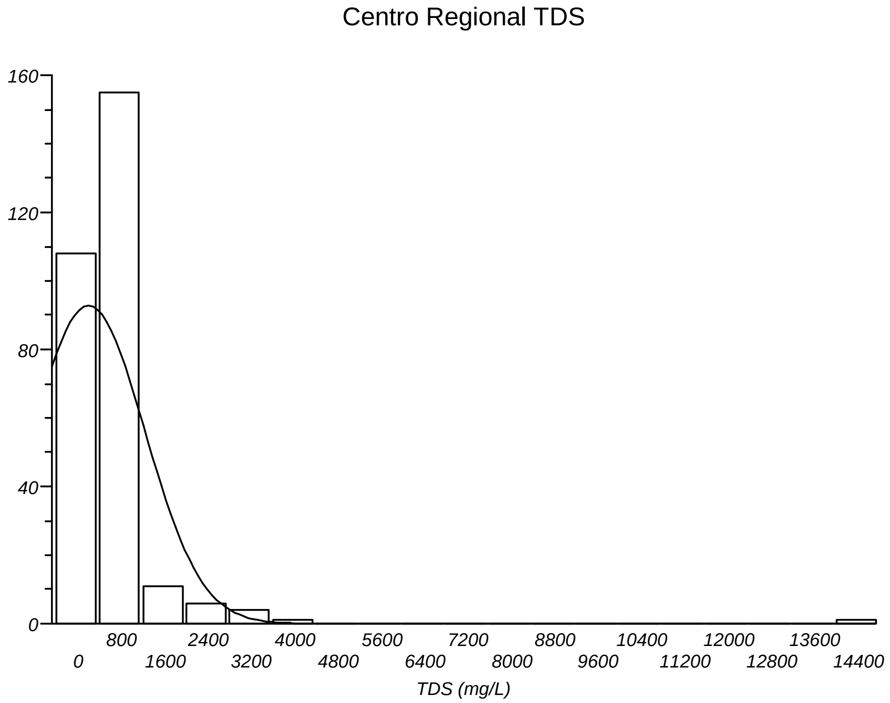


Figure A1.13 – TDS Histogram for Centro Regional subarea.

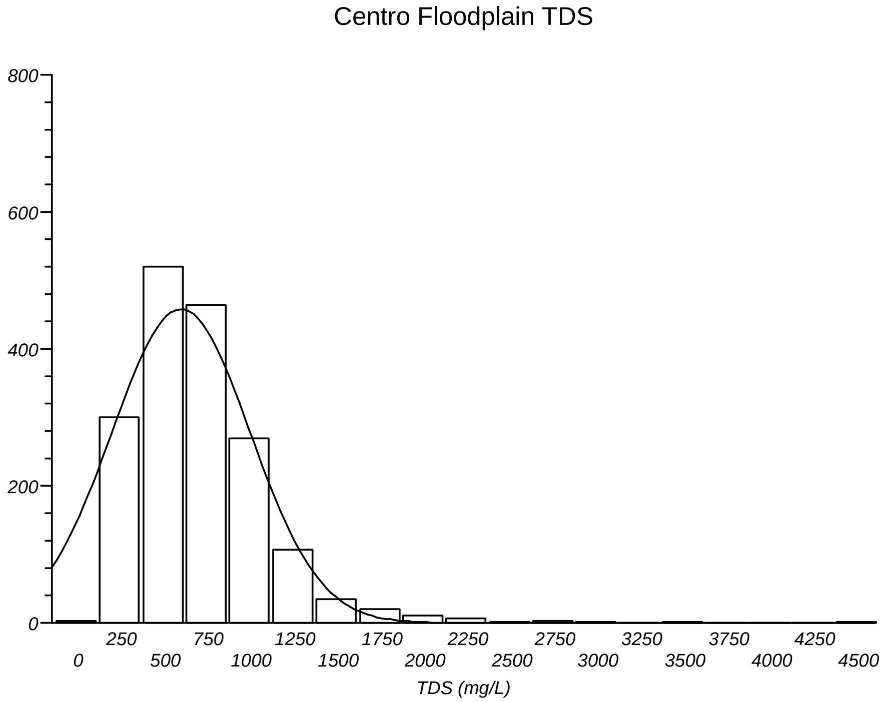


Figure A1.14 – TDS Histogram for Centro Floodplain subarea.

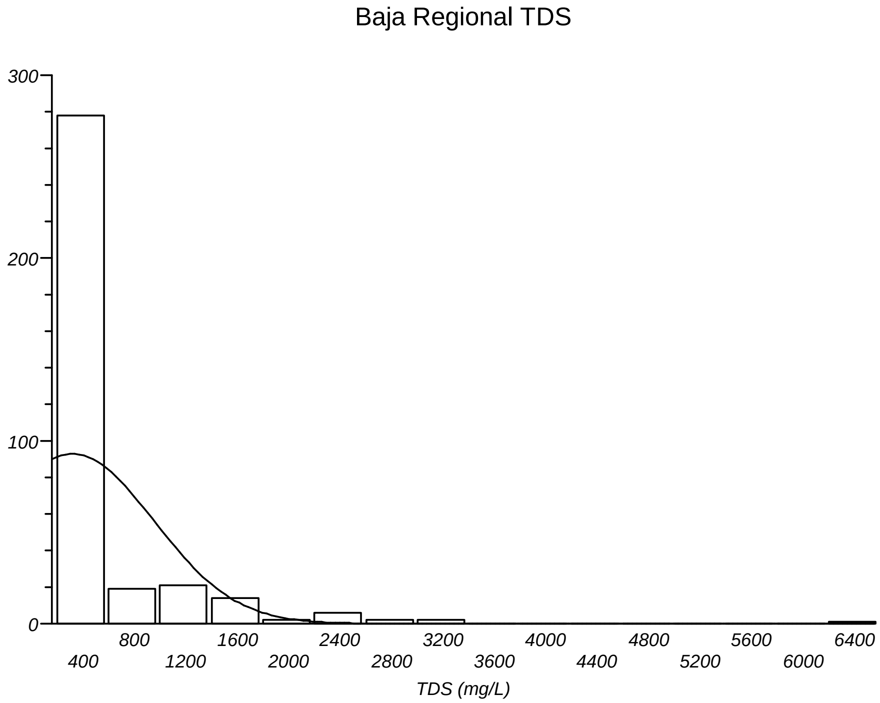


Figure A1.15 – TDS Histogram for Baja Regional subarea.

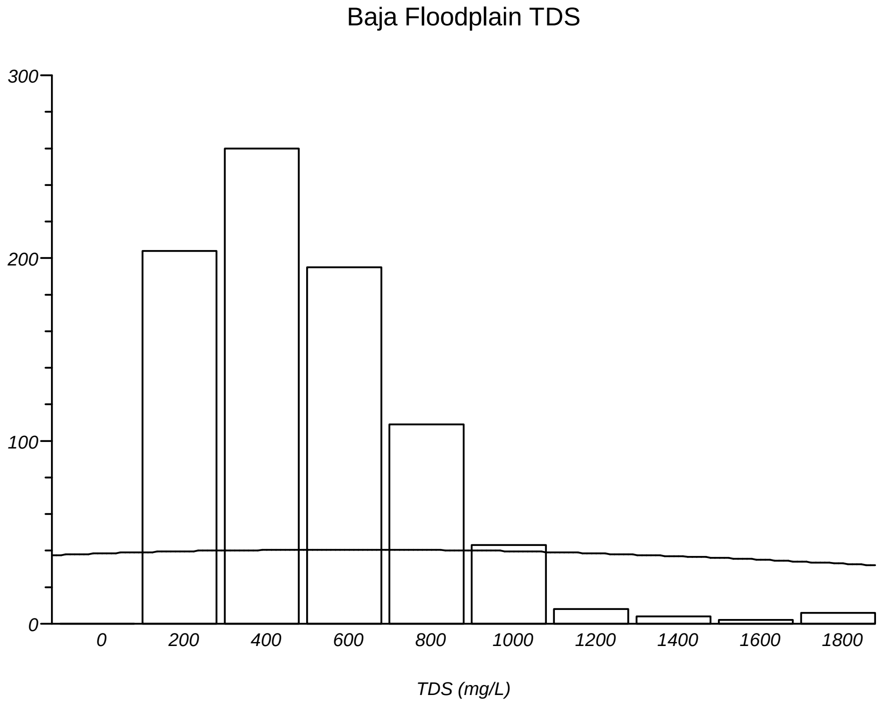


Figure A1.16 – TDS Histogram for Baja Floodplain subarea.

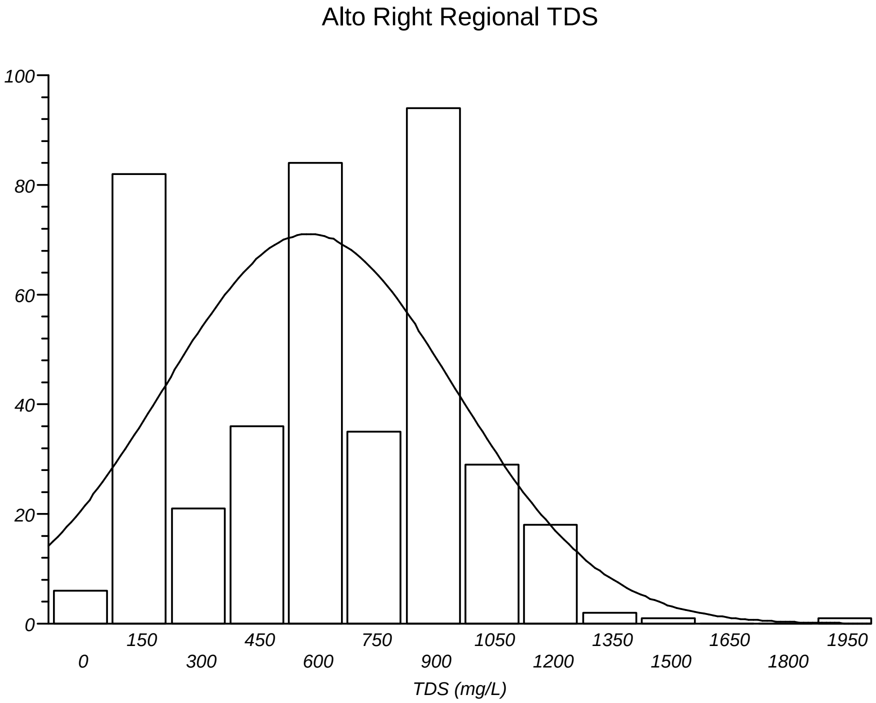


Figure A1.17 – TDS Histogram for Alto Right Regional subarea.

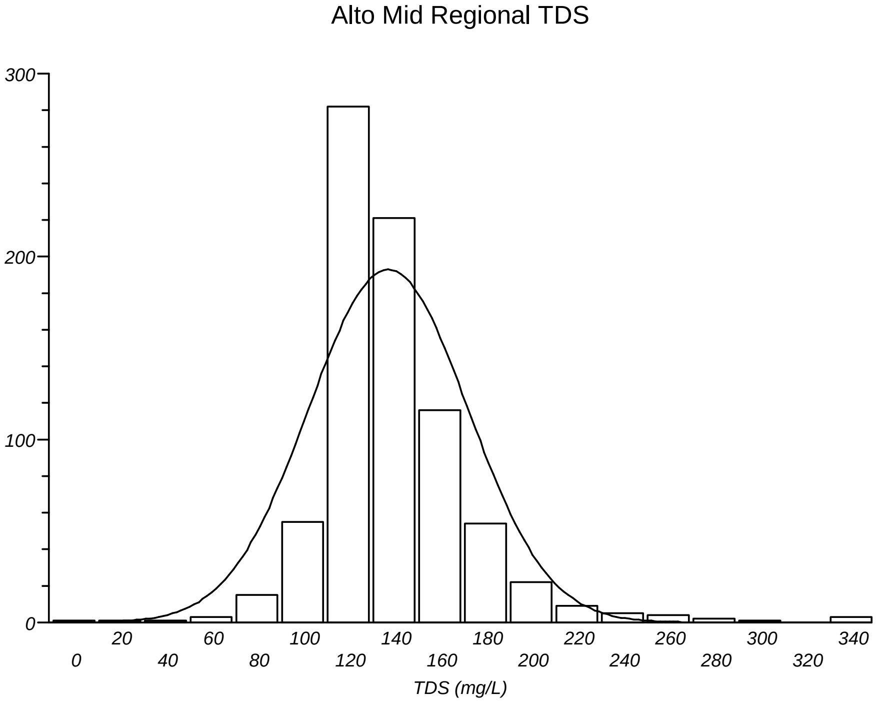


Figure A1.18 – TDS Histogram for Alto Mid Regional subarea.

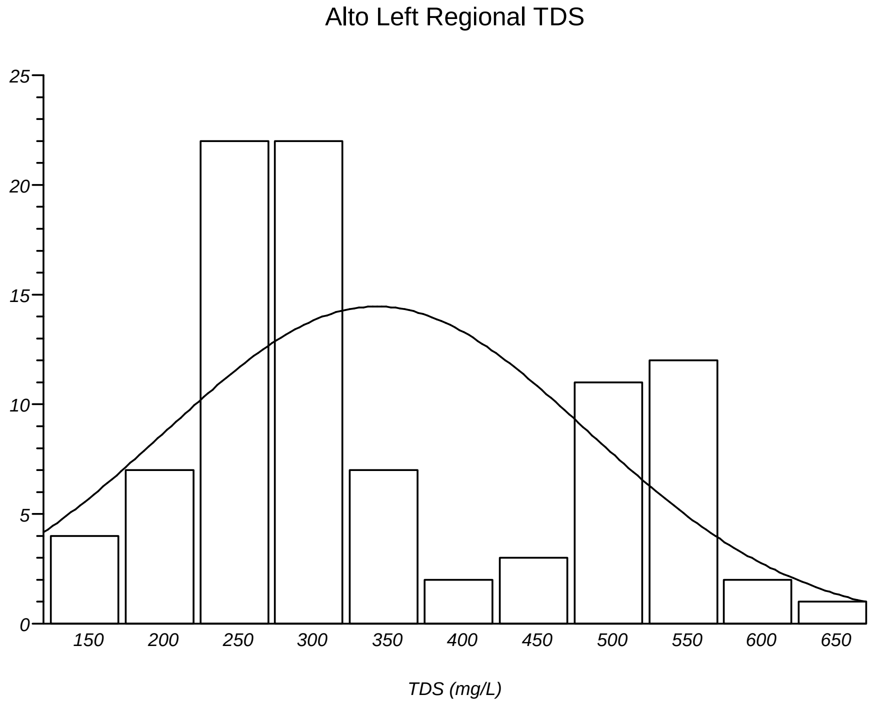


Figure A1.19 – TDS Histogram for Alto Left Regional subarea.

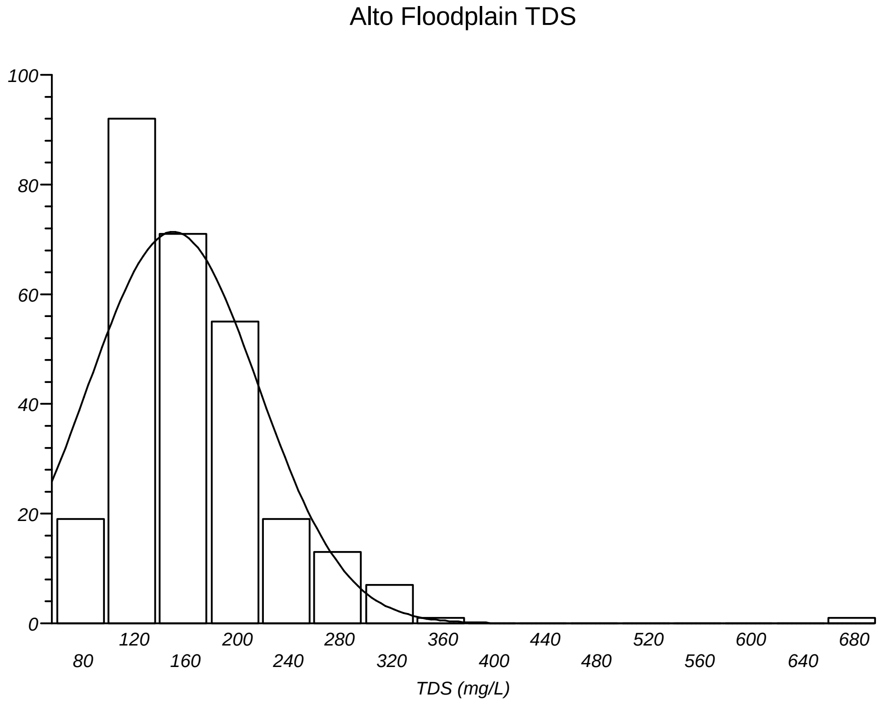


Figure A1.20 – TDS Histogram for Alto Floodplain subarea.

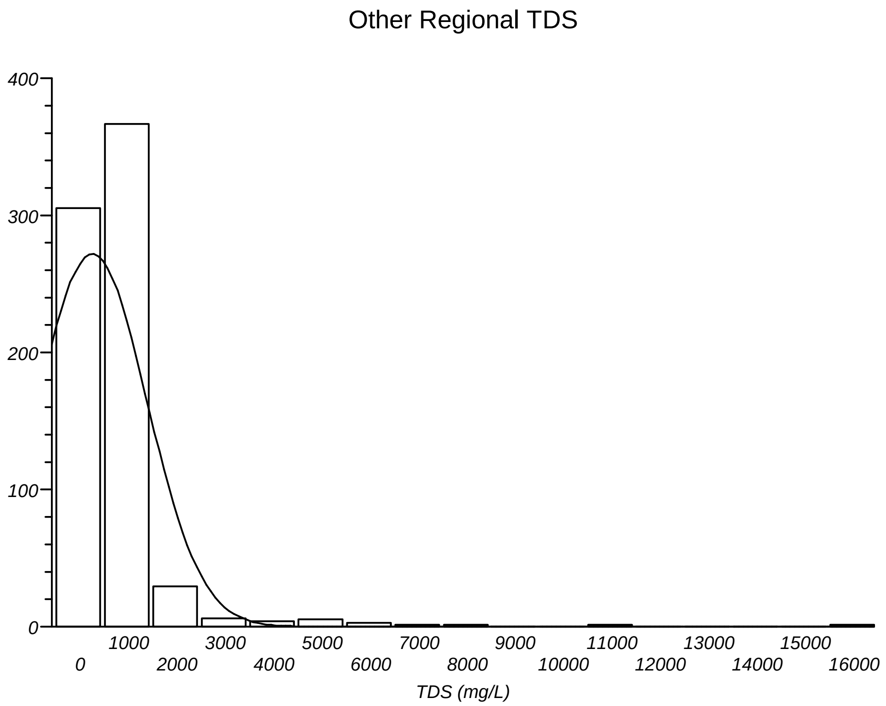


Figure A1.21 – TDS Histogram for data outside the defined management subareas.

Subarea	Data Points	Mean	Standard Deviation	Squares about Mean	W	Normal
Warren Valley	291	217.817182	80.106194	1860930.677802	0.824895	Unlikely
Transition Zone Regional	205	620.336585	758.50326	117366747.77561	0.514207	Unlikely
Transition Zone Floodplain	204	522.994118	302.639303	18592881.178816	0.836132	Unlikely
Oeste Regional	138	747.07971	1566.467788	336173522.123188	0.278715	Unlikely
Narrows Floodplain	194	191.286598	117.552725	2666998.144813	0.626625	Unlikely
Means/Ames Valley Sub-basin	77	269.2406	92.358937	648293.163345	0.945397	Unlikely
Lucerne Valley	816	1098.990196	1212.408086	1197995693.92157	0.684001	Unlikely
Johnson Valley Sub-basin	208	900.490385	563.820422	65803947.980769	0.7173	Unlikely
Helendale Floodplain	160	1361.745625	1068.984858	181693851.754624	0.803748	Unlikely
Harper Lake Regional	98	1175.479592	728.72063	51510274.459184	0.892226	Unlikely
Este Regional	187	500.628342	325.701835	19731193.469461	0.786755	Unlikely
Copper Mountain Valley	264	227.150758	123.806288	4031263.169465	0.554842	Unlikely
Centro Regional	286	641.856643	984.264879	276101545.122378	0.278297	Unlikely
Centro Floodplain	1737	705.928382	378.627637	248871028.557124	0.874583	Unlikely
Baja Regional	345	550.53913	592.575517	120794135.721739	0.515498	Unlikely
Baja Floodplain	847	650.357733	1667.01534	2350983360.60685	0.134527	Unlikely
Alto Mid Regional	795	140.277107	32.882039	858495.42477	0.87417	Unlikely
Alto Left Regional	93	352.517204	128.330362	1515118.730735	0.900655	Unlikely
Alto Floodplain	278	168.627338	62.158455	1070237.551373	0.821811	Unlikely
Other	723	788.781466	1060.382527	811824817.471646	0.438844	Unlikely

W=Shapiro-Wilks statistical measure.

Attachment 2

SEBAL Period Evapotranspiration Images

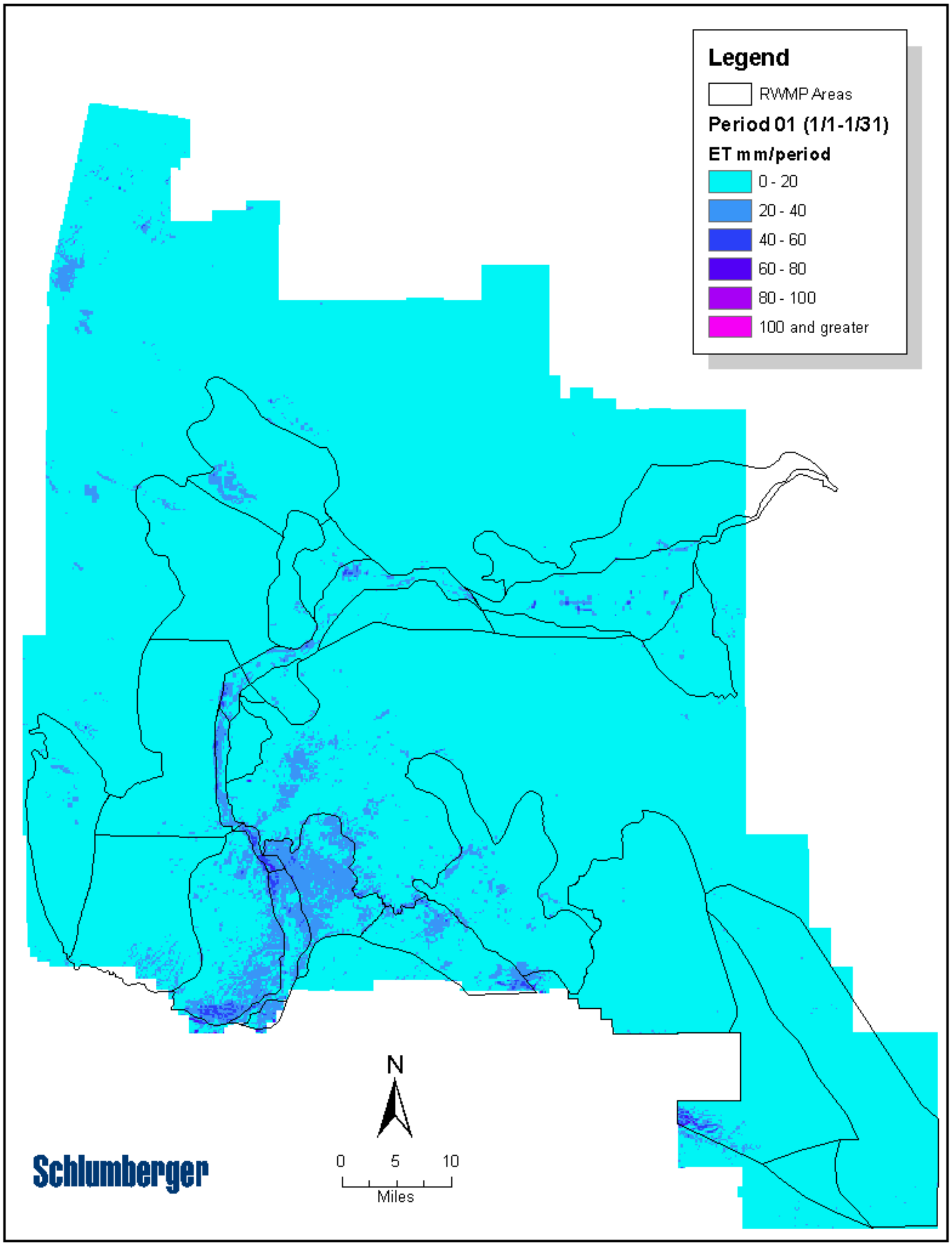


Figure A1.1 – SEBAL ET image for period 1/1-1/31.

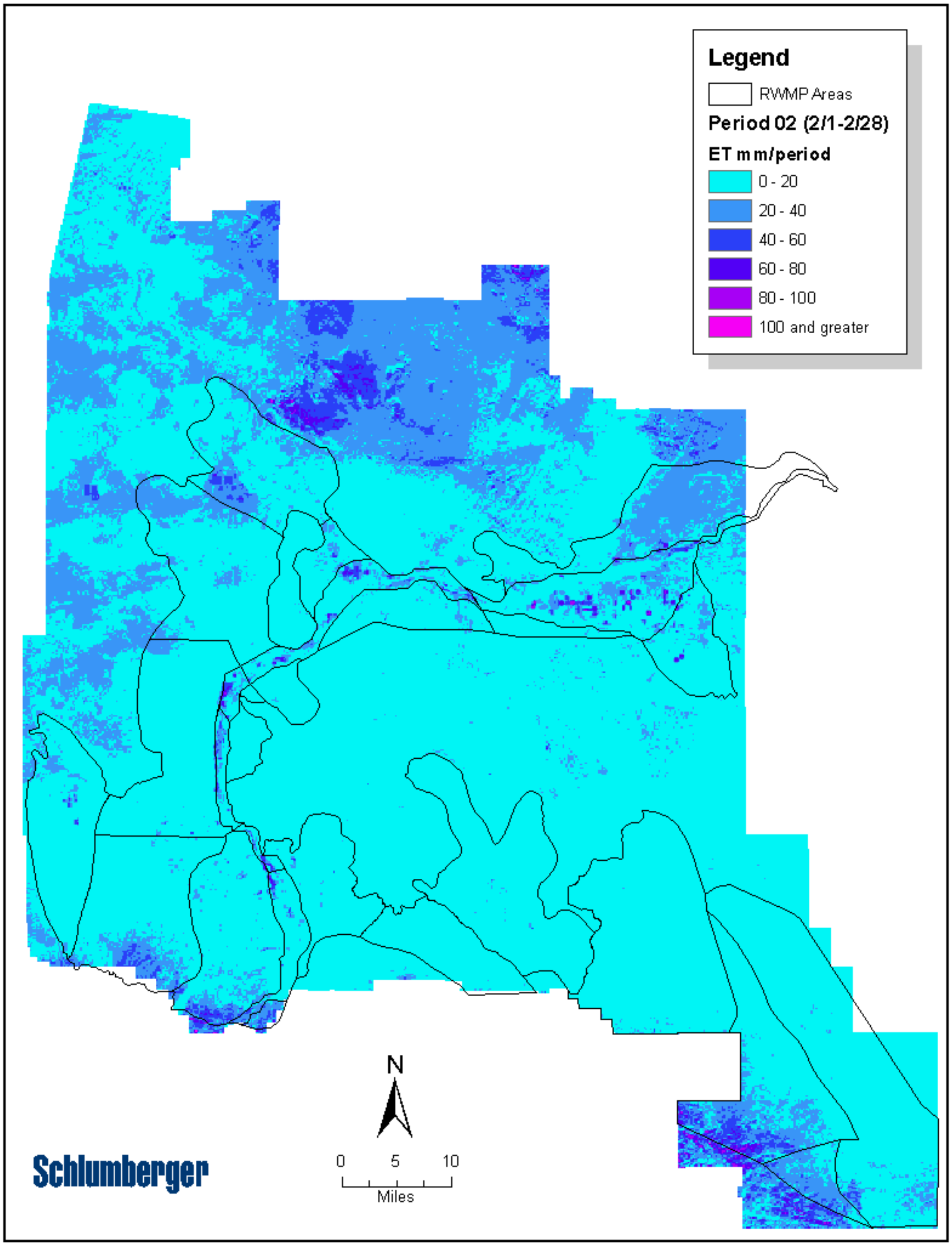


Figure A2.2 – SEBAL ET image for period 2/1-2/28.

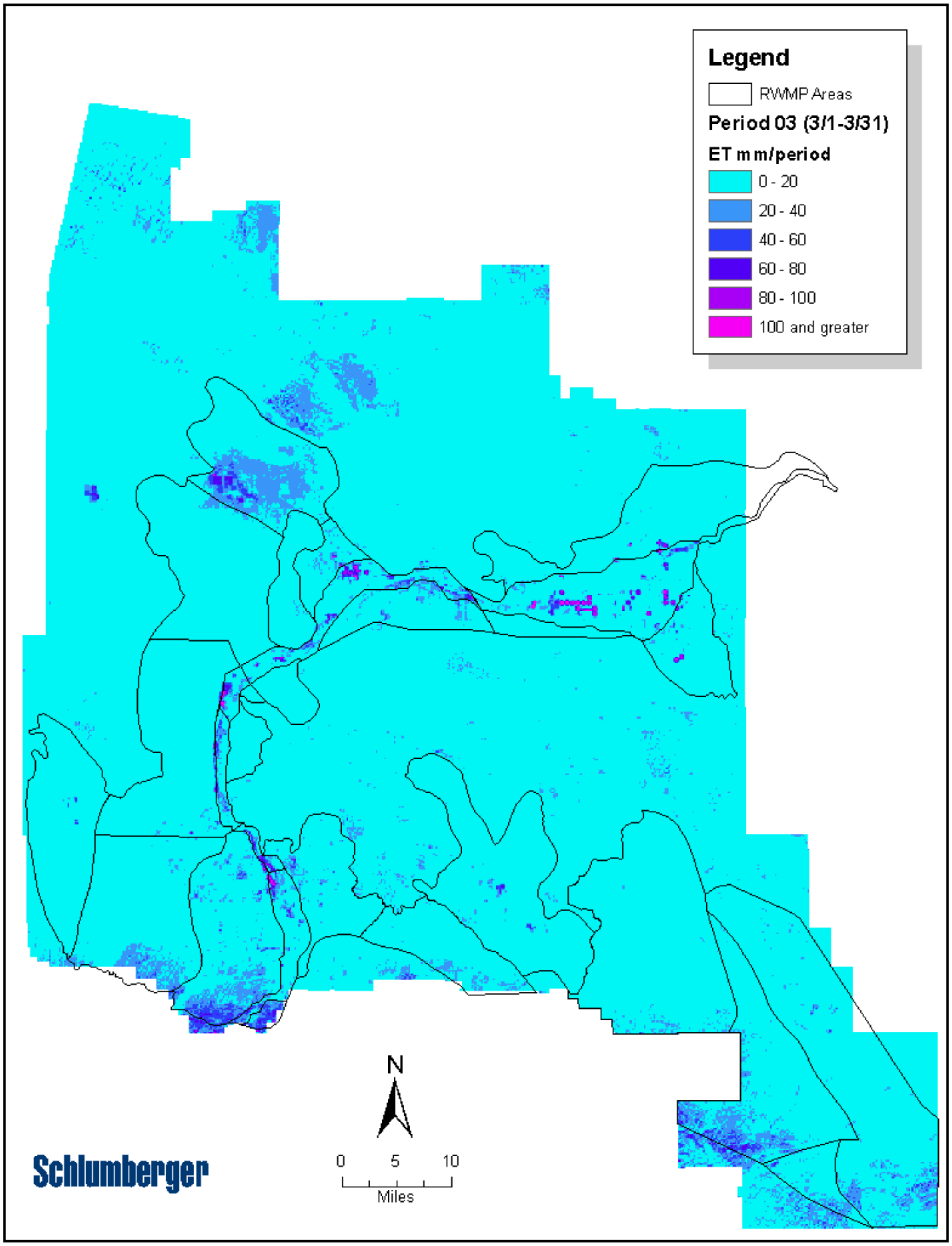


Figure A2.3 – SEBAL ET image for period 3/1-3/31.

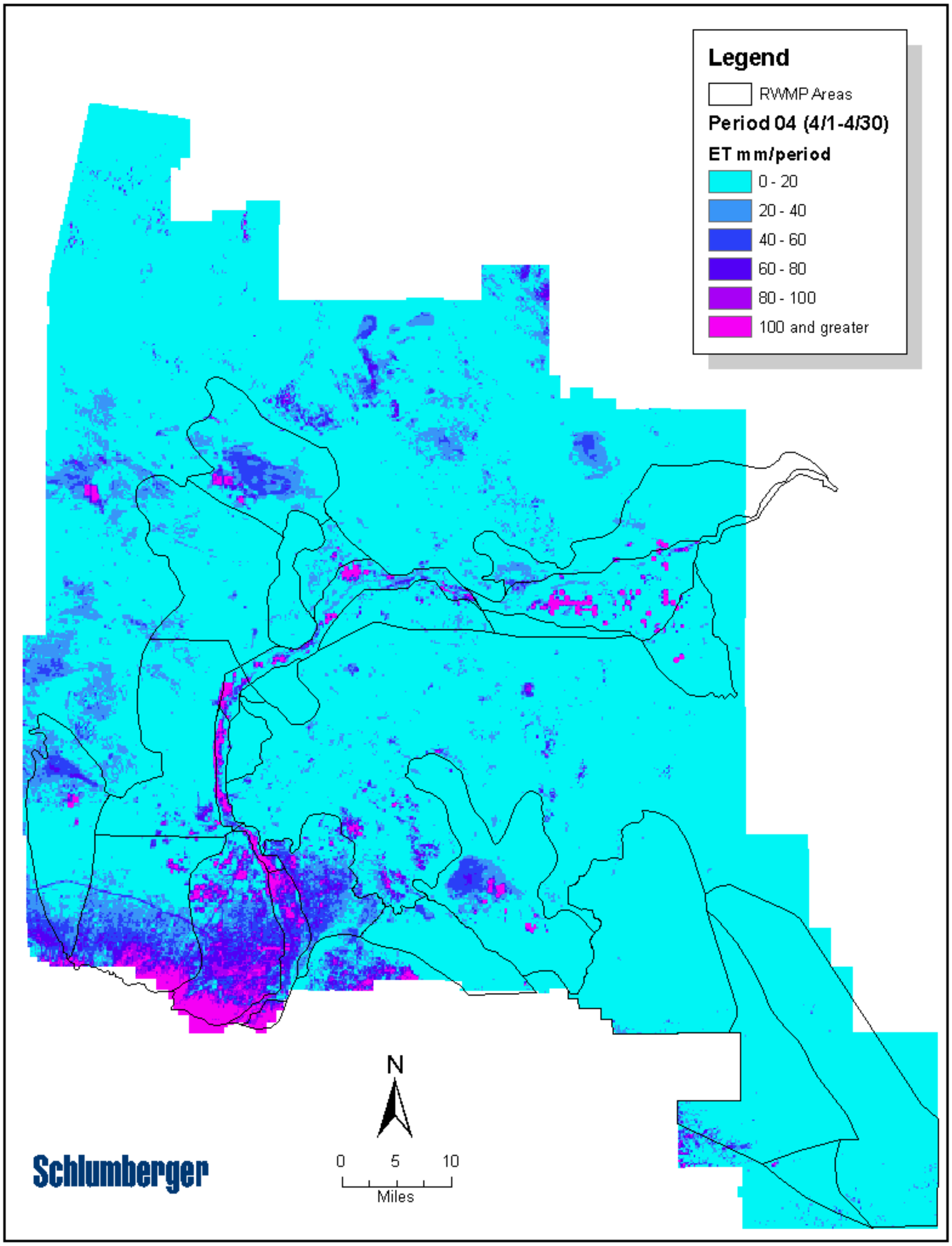


Figure A2.4 – SEBAL ET image for period 4/1-4/30.

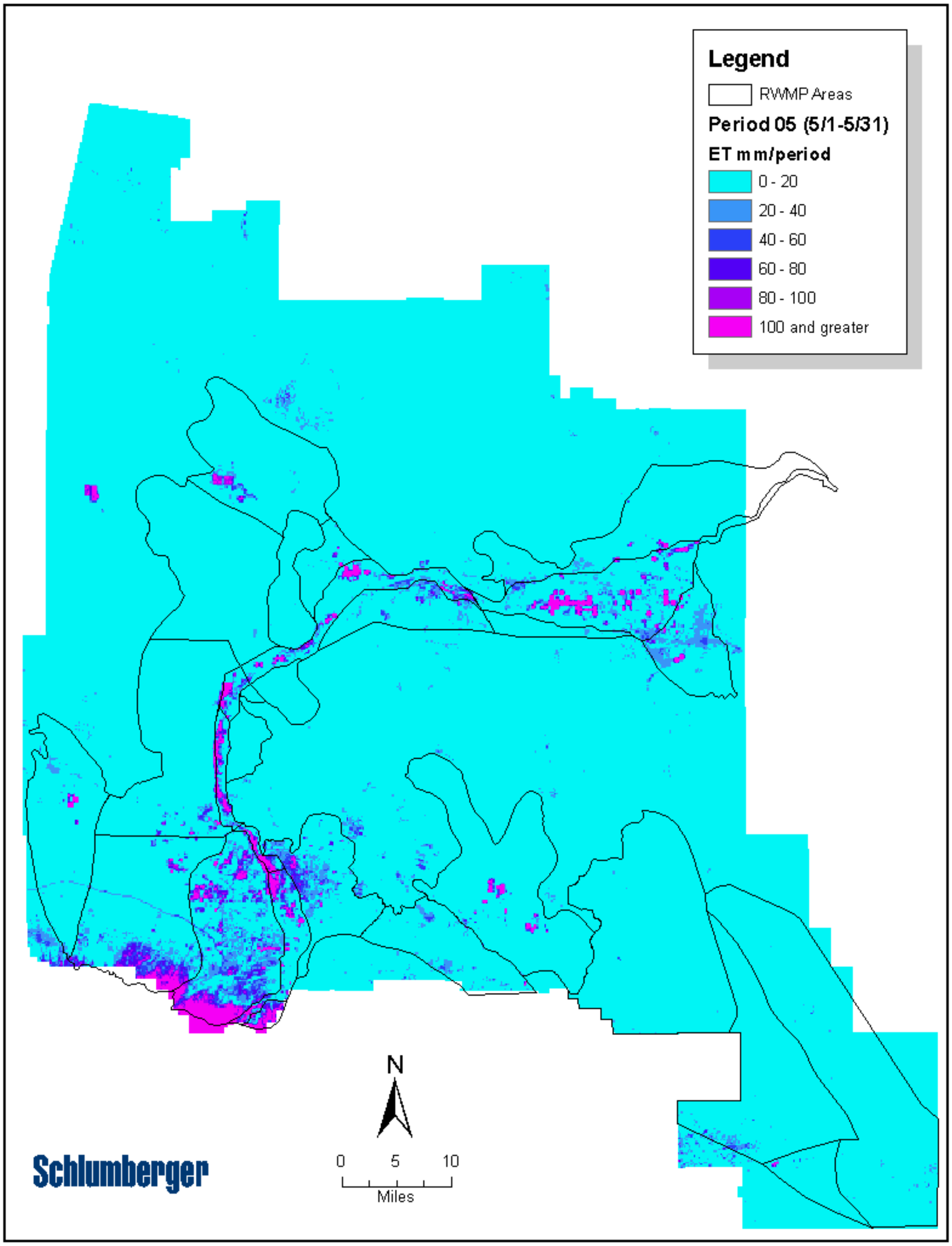


Figure A2.5 – SEBAL ET image for period 5/1-5/31.

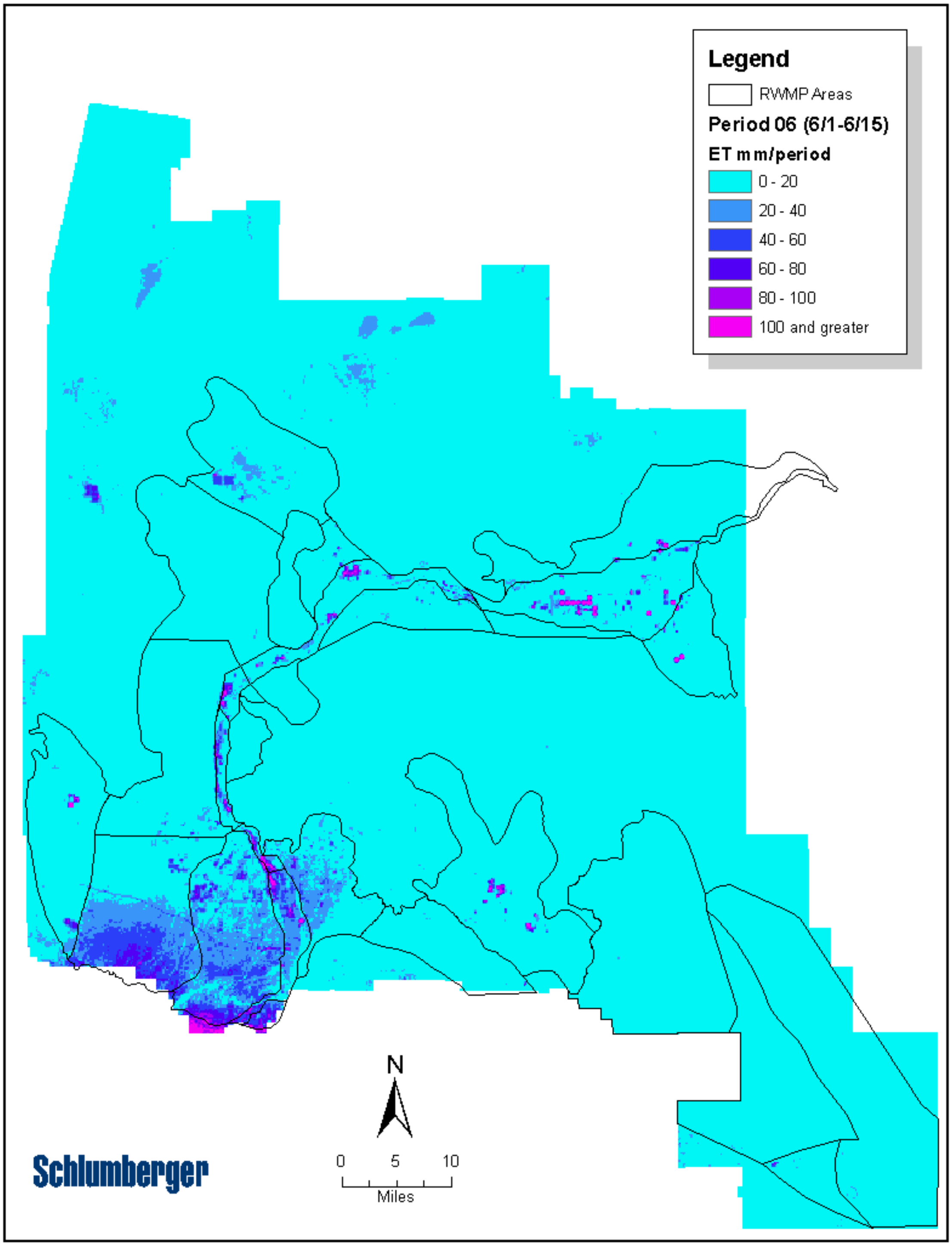


Figure A2.6 – SEBAL ET image for period 6/1-6/15.

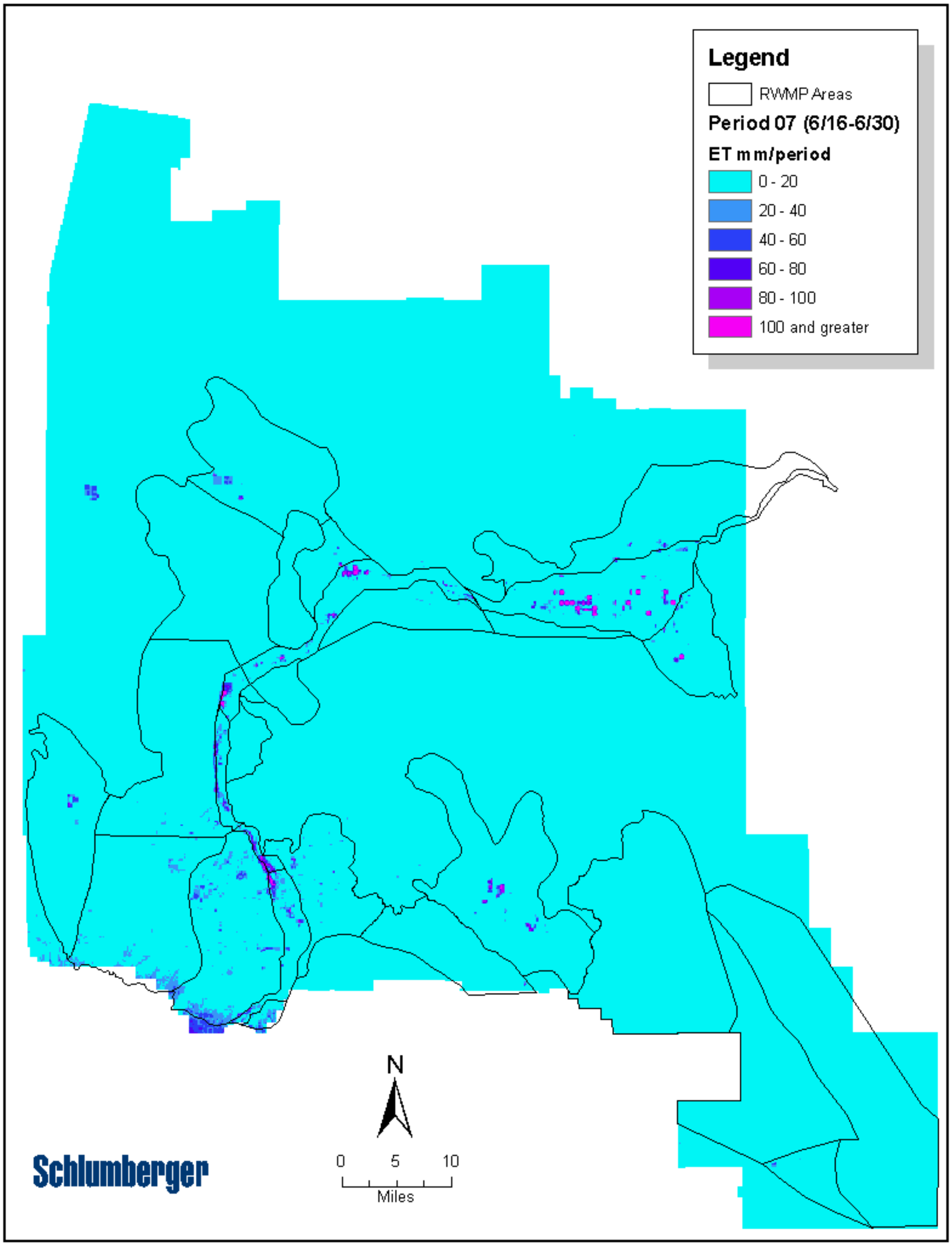


Figure A2.7 – SEBAL ET image for period 6/16-6/30.

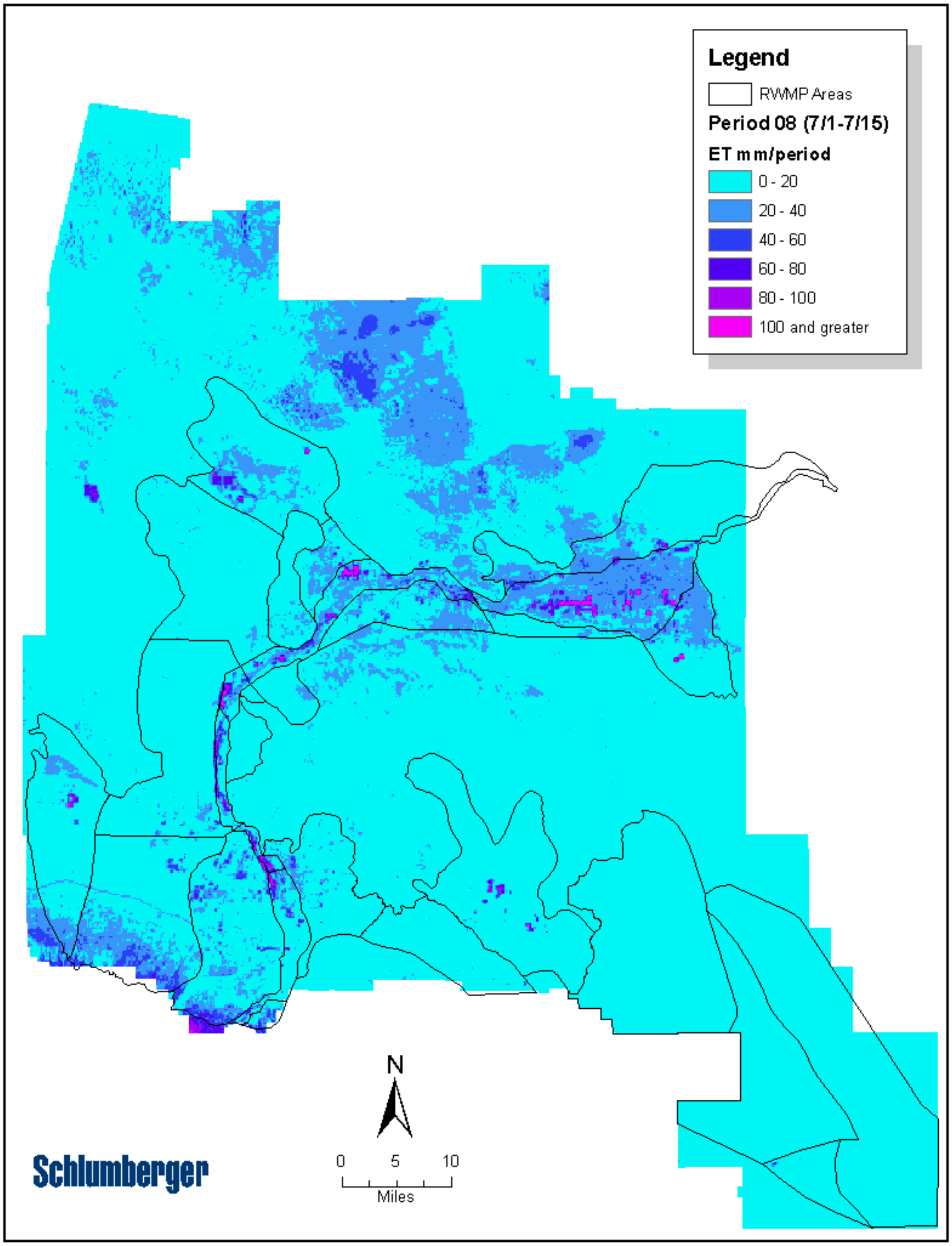


Figure A2.8 – SEBAL ET image for period 7/1-7/15.

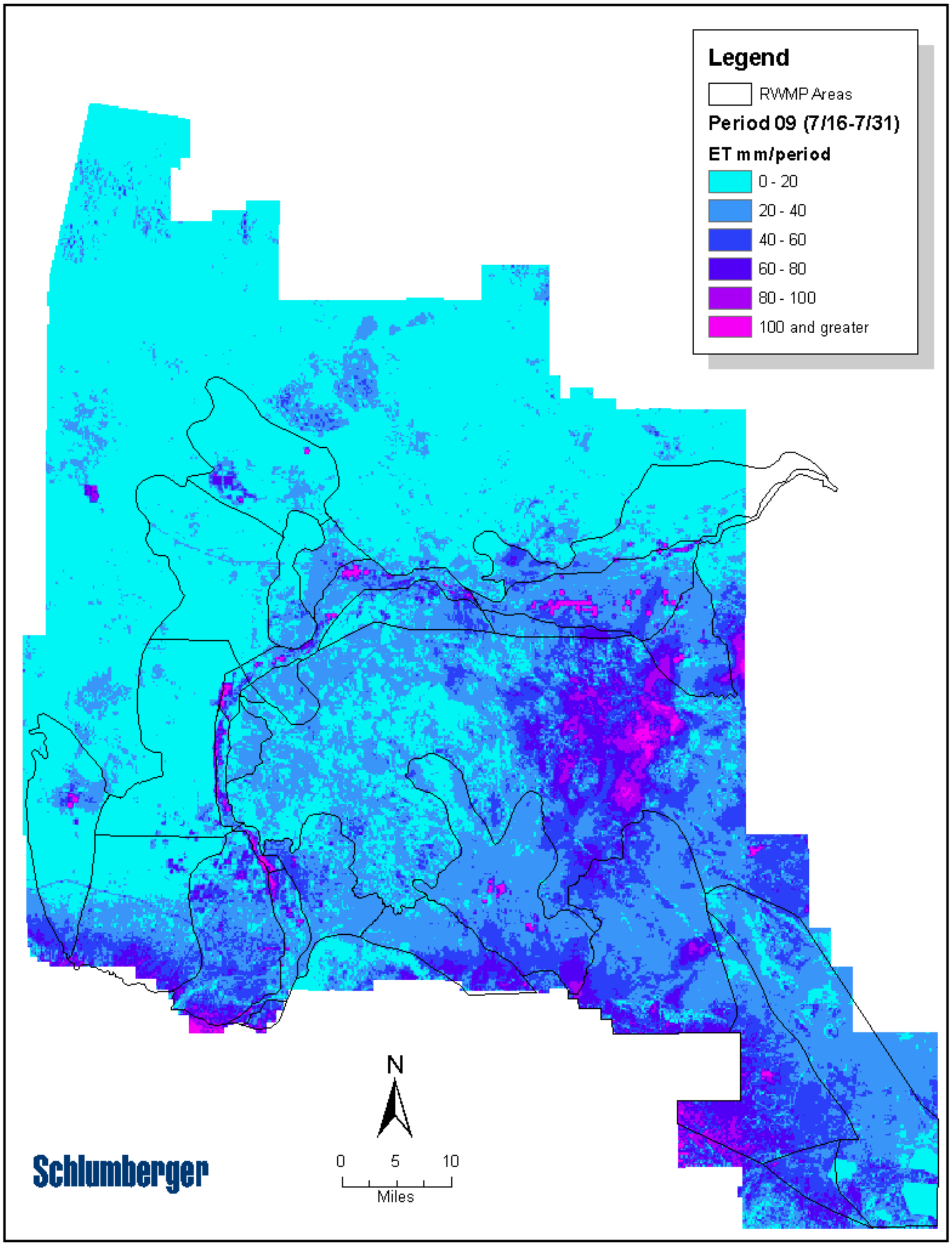


Figure A2.9 – SEBAL ET image for period 7/16-7/31.

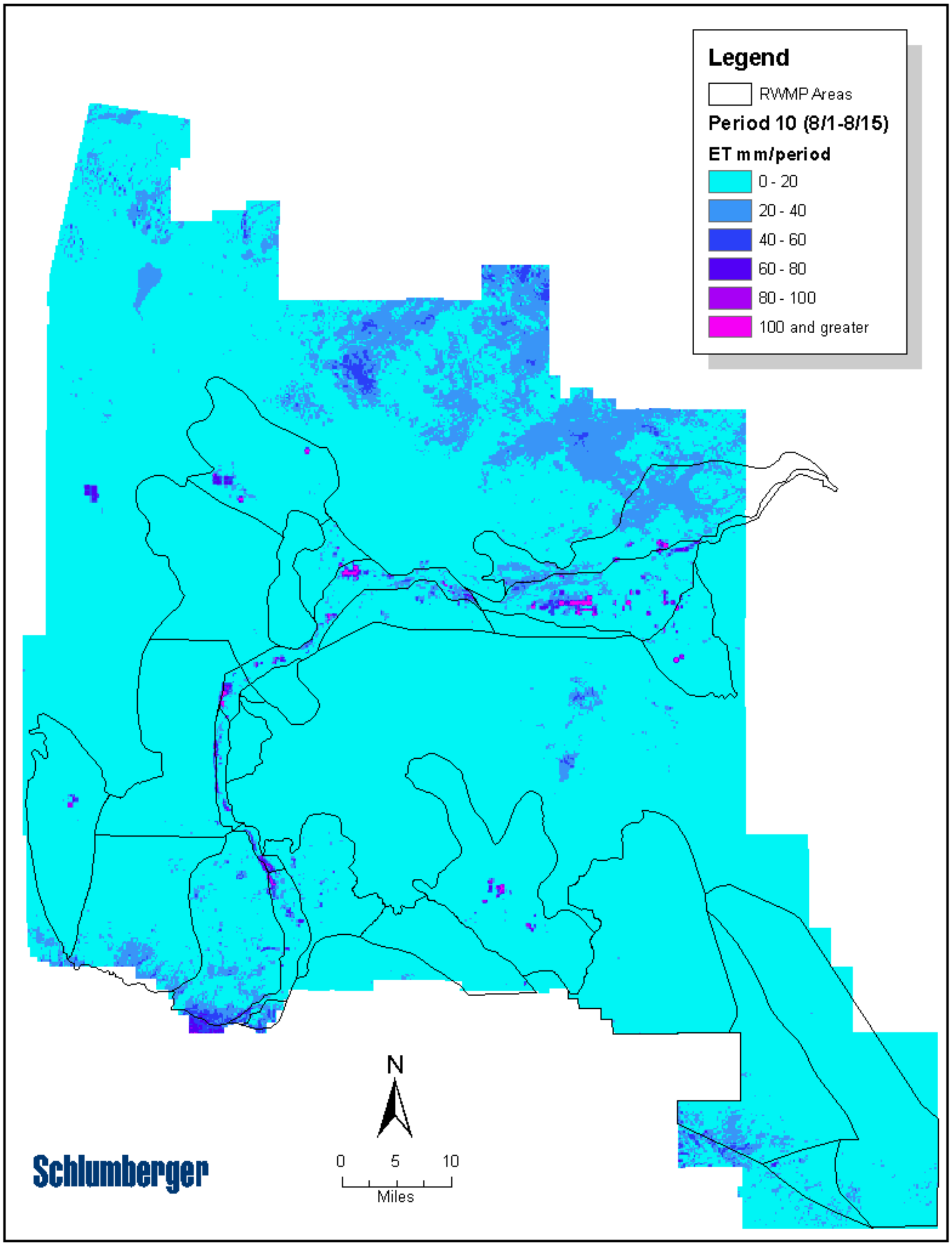


Figure A2.10 – SEBAL ET image for period 8/1-8/15.

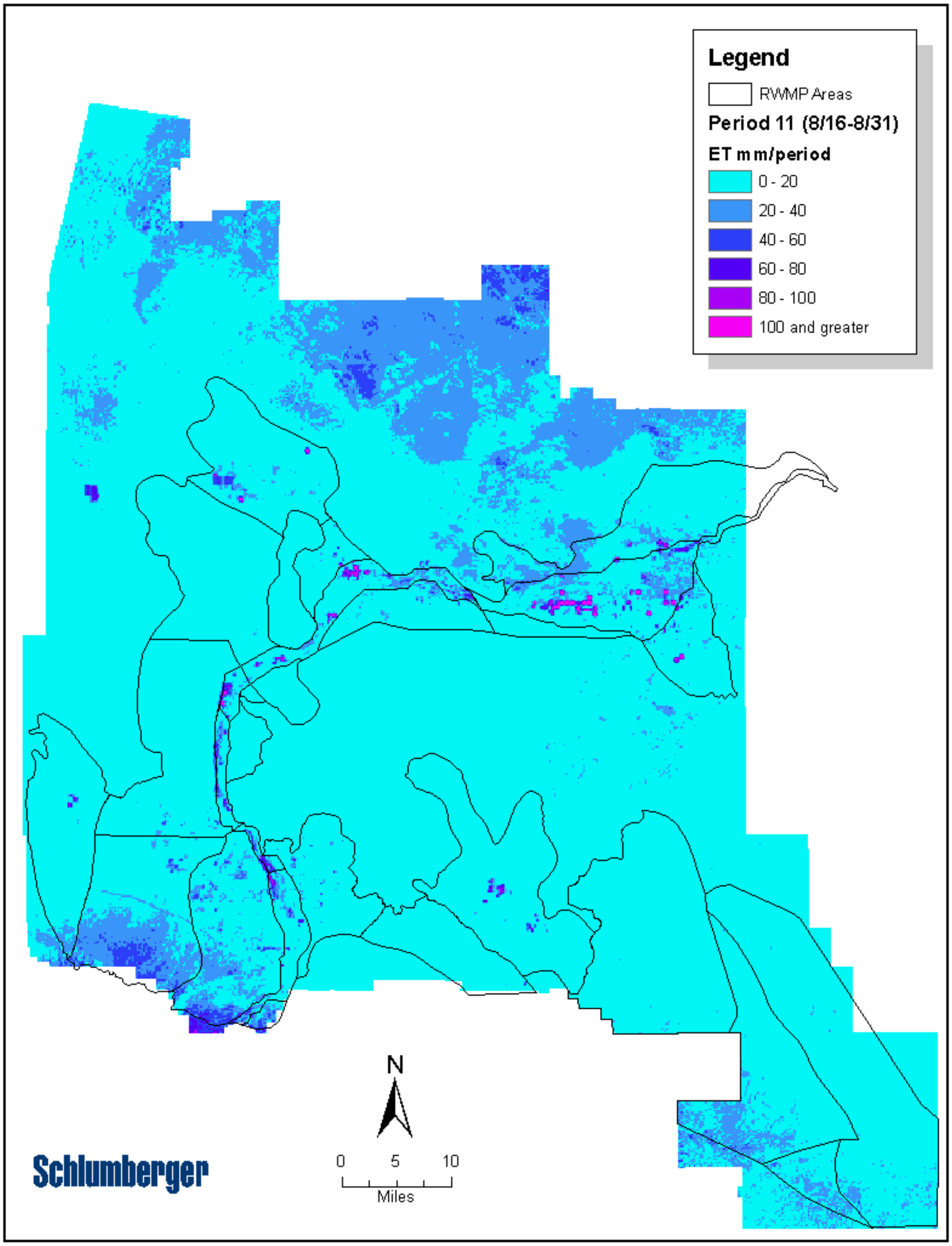


Figure A2.11 – SEBAL ET image for period 8/16-8/31.

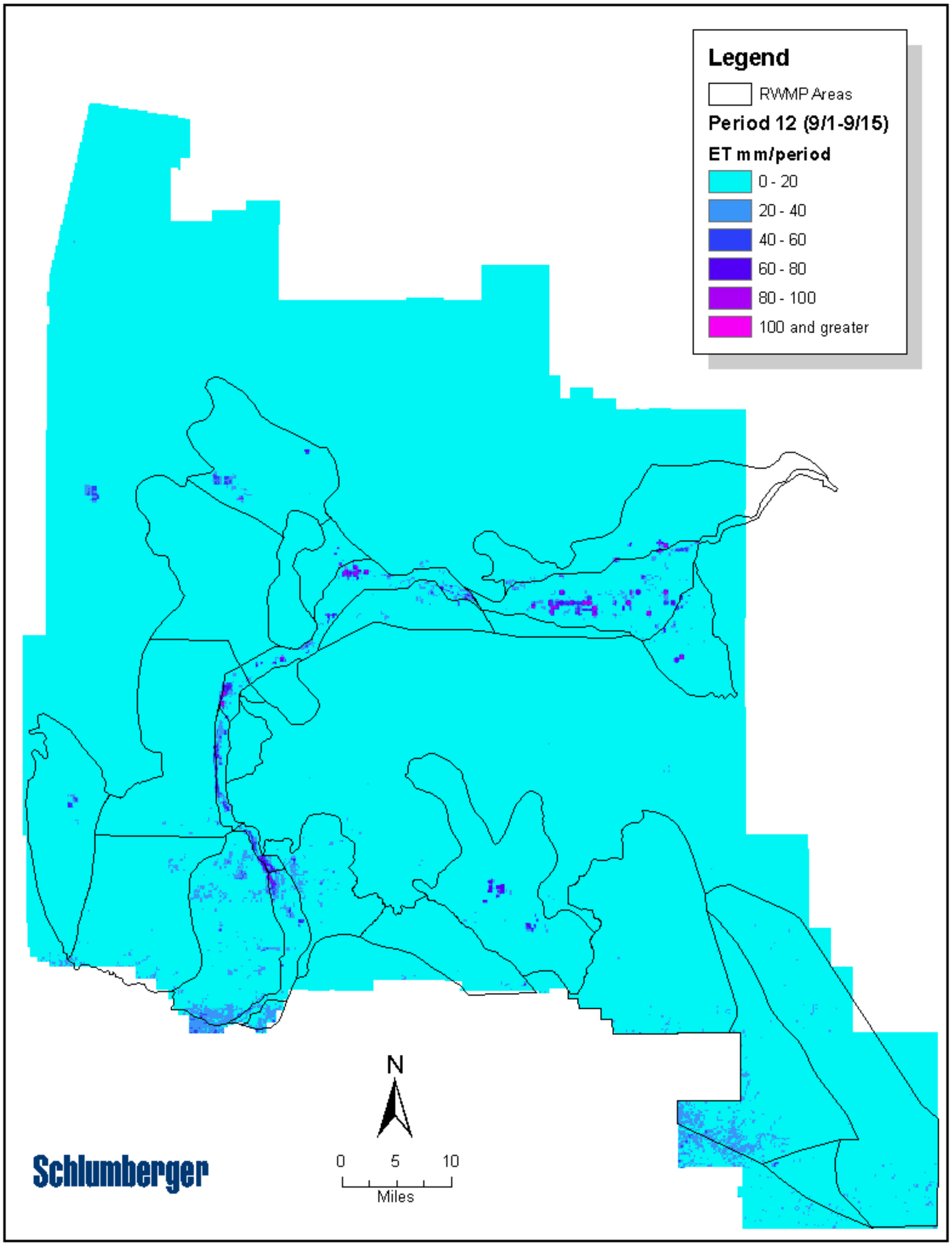


Figure A2.12 – SEBAL ET image for period 9/1-9/15.

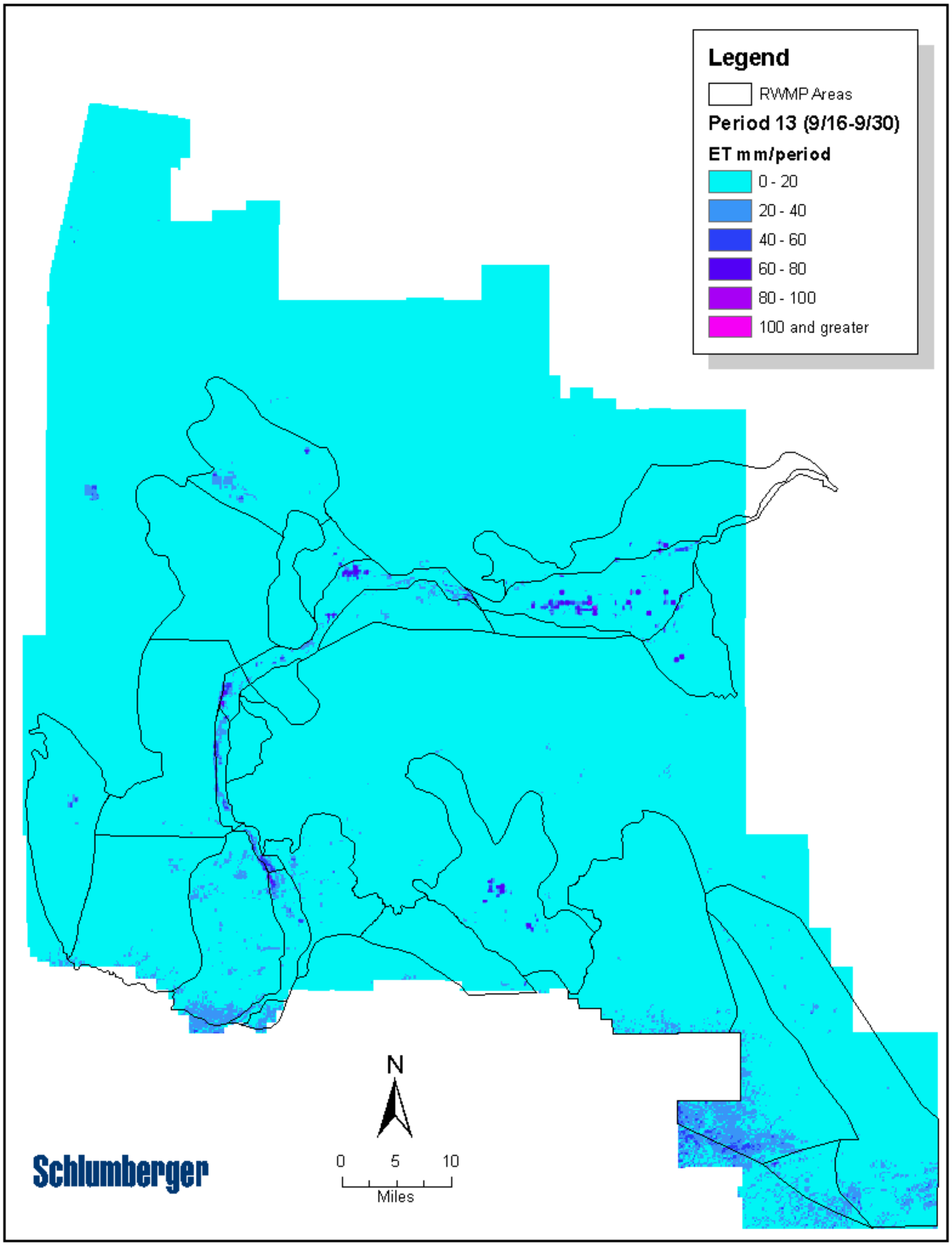


Figure A2.13 – SEBAL ET image for period 9/16-9/30.

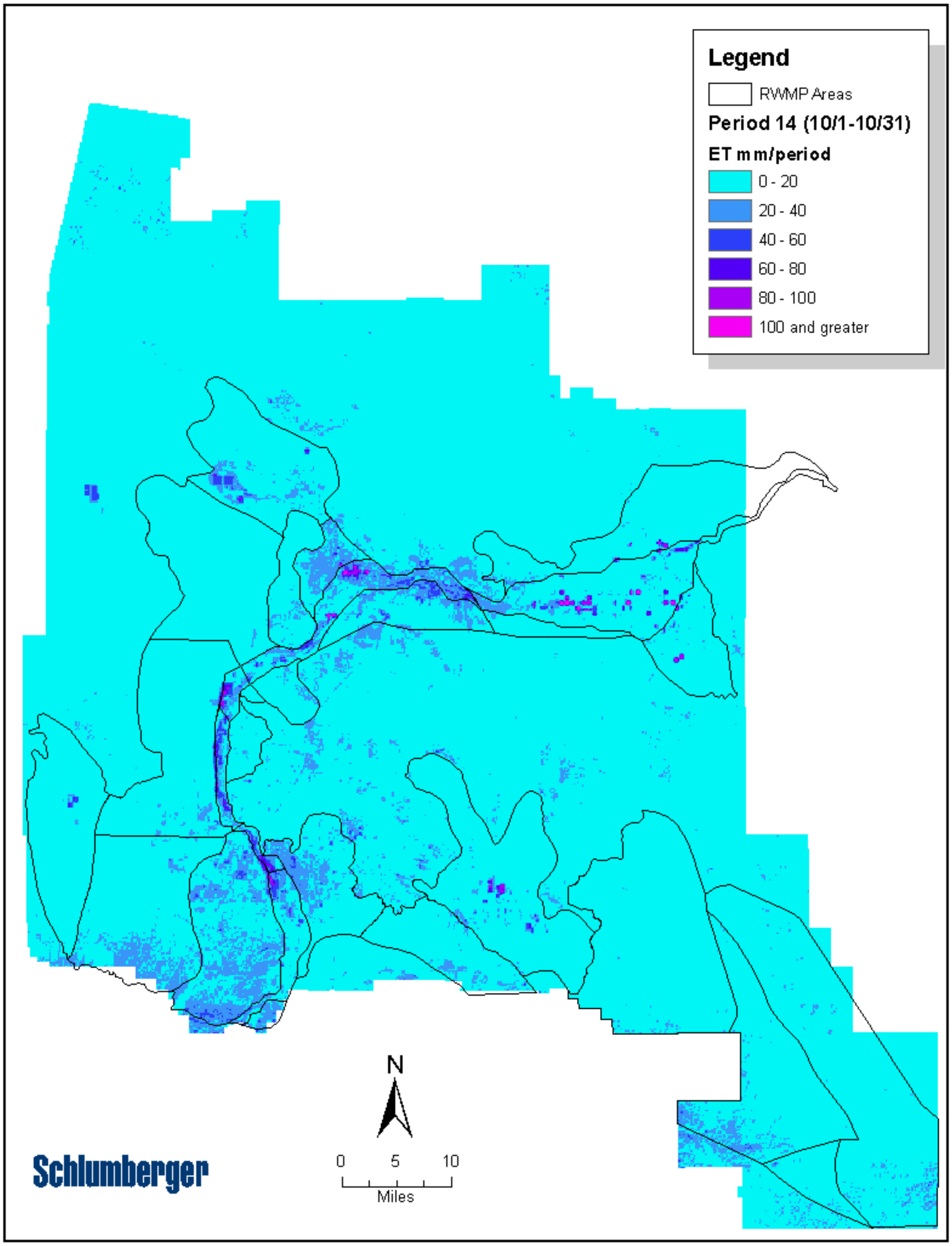


Figure A2.14 – SEBAL ET image for period 10/1-10/31.

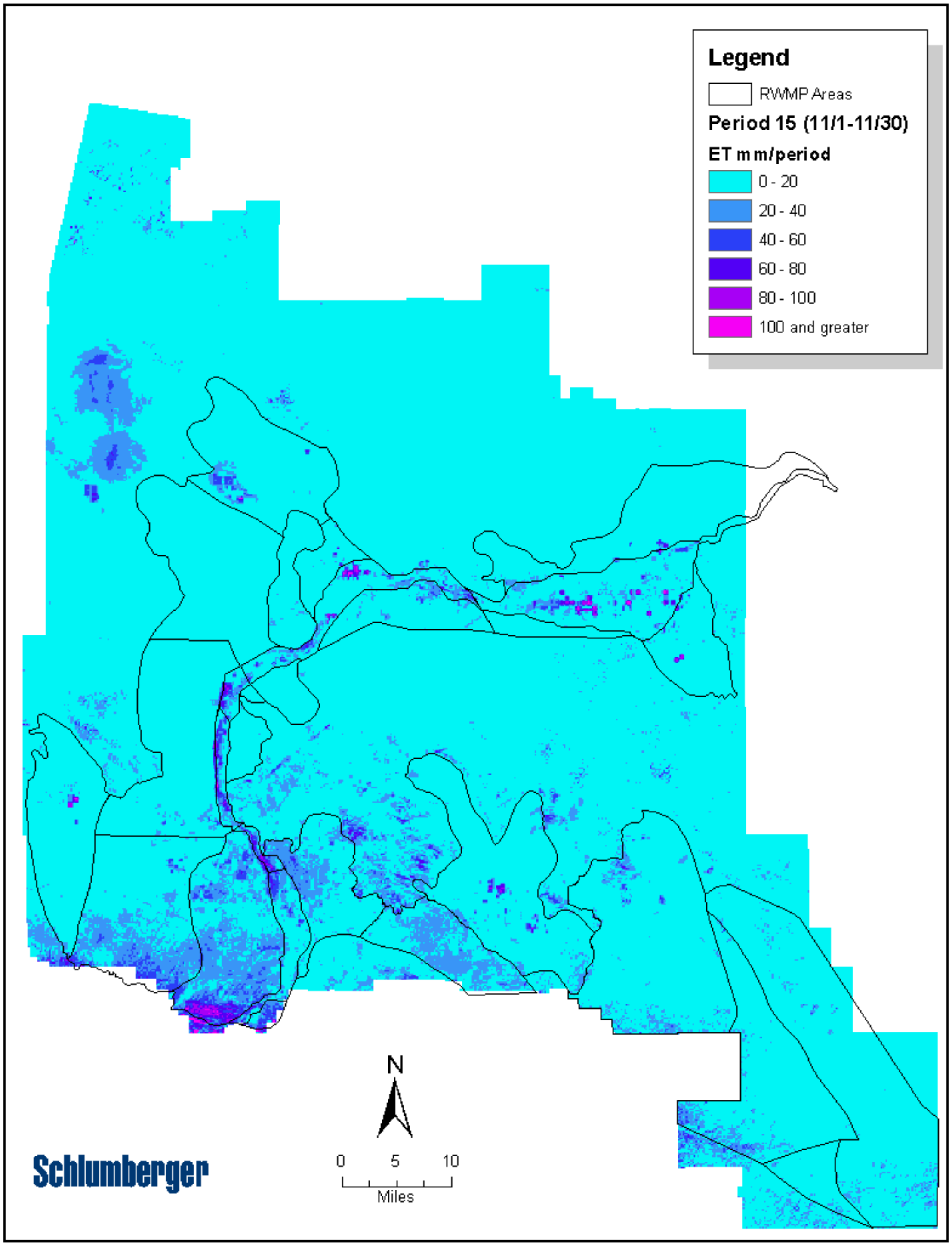


Figure A2.15 – SEBAL ET image for period 11/1-11/30.

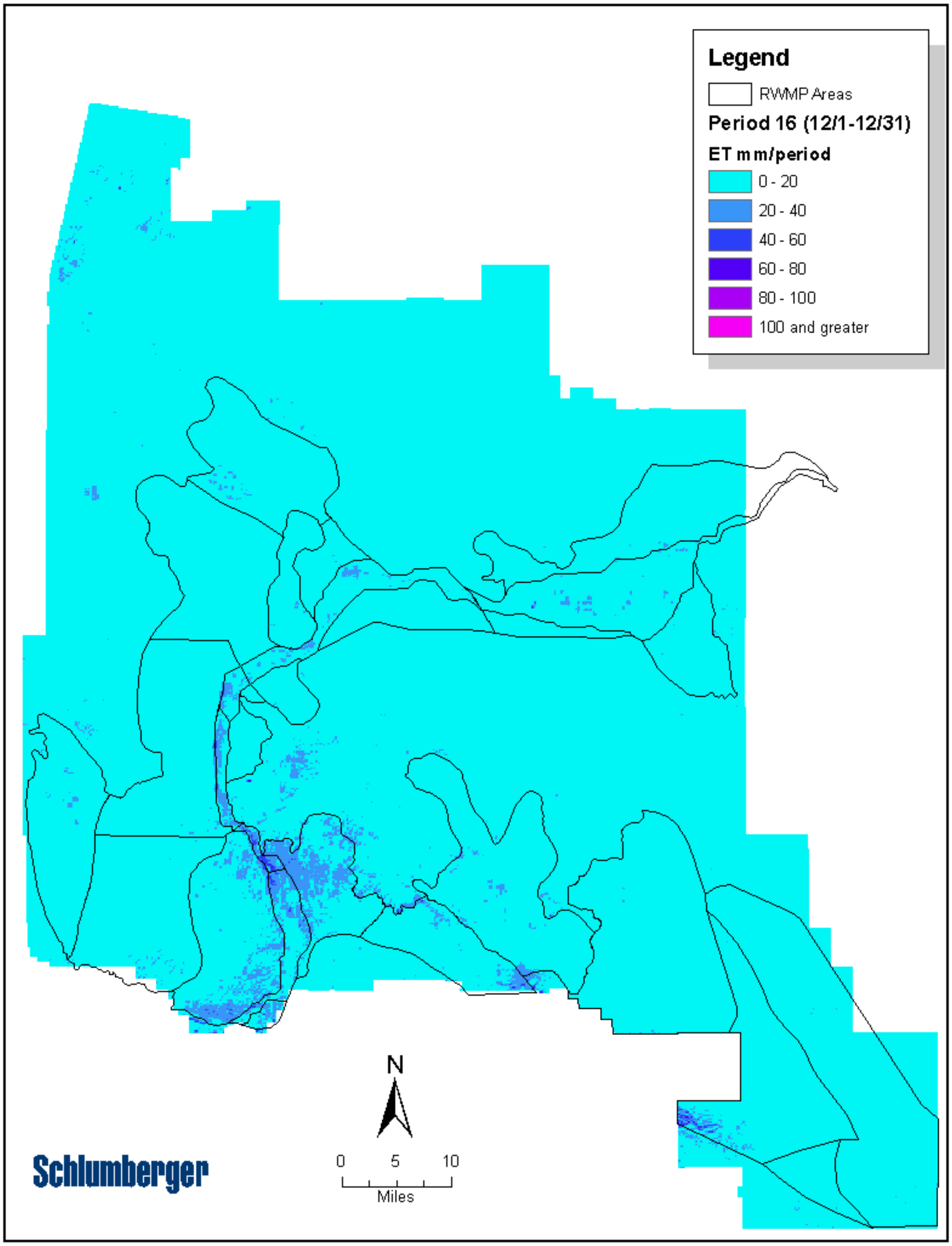


Figure A2.16 – SEBAL ET image for period 12/1-12/31.

Attachment 3

Septic Effluent Water Quality Data
(after Umari, 1995)

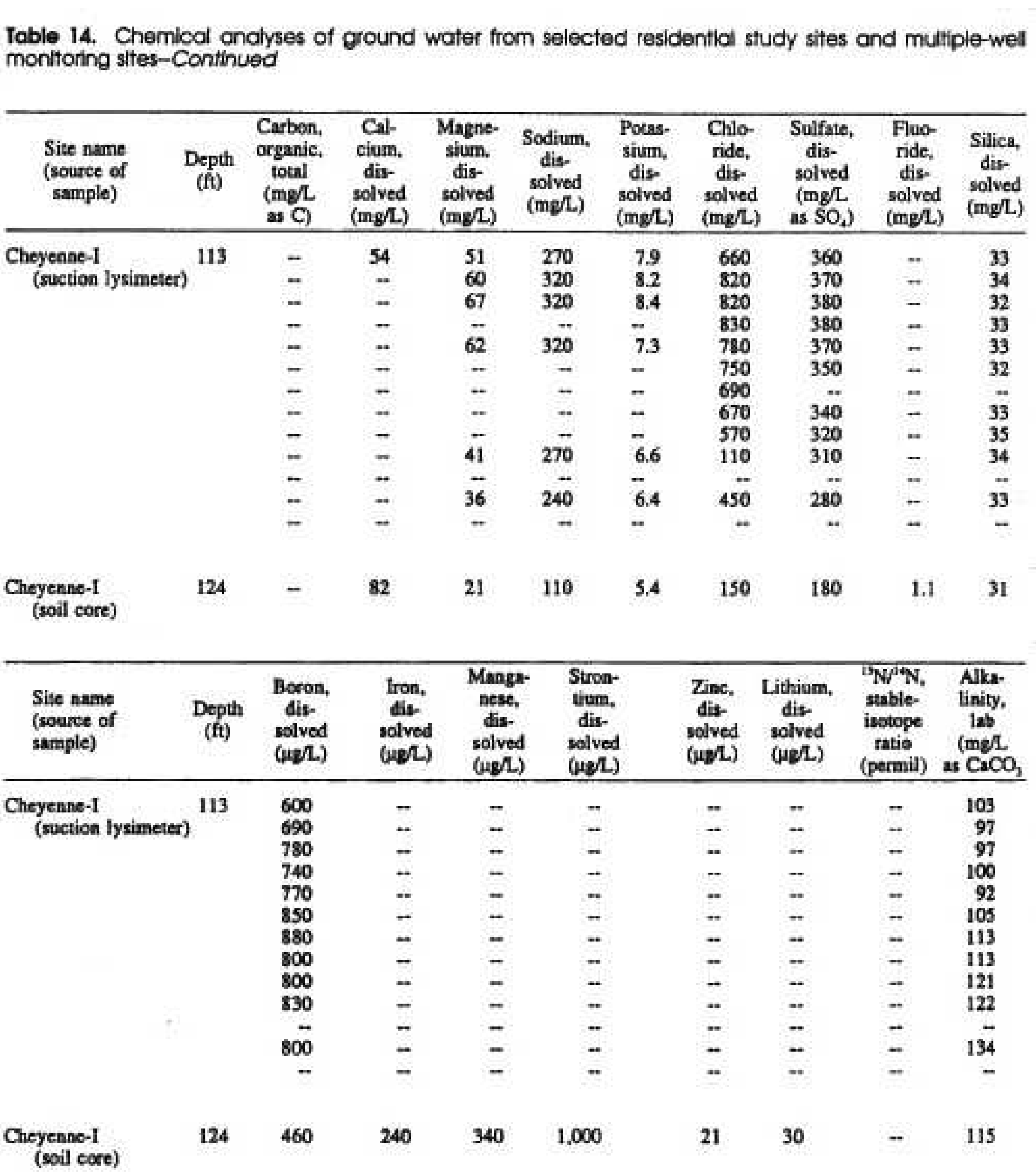


Table 14. Chemical analyses of ground water from selected residential study sites and multiple-well monitoring sites–*Continued*

Site name (source of sample)	Depth (ft)	Carbon, organic, total (mg/L as C)	Cal- cium, dis- solved (mg/L)	Magne- sium, dis- solved (mg/L)	Sodium, dis- solved (mg/L)	Potas- sium, dis- solved (mg/L)	Chlo- ride, dis- solved (mg/L)	Sulfate, dis- solved (mg/L as SO_4)	Fluo- ride, dis- solved (mg/L)	Silica, dis- solved (mg/L)
Cheyenne-I (suction lysimeter)	113	--	54	51	270	7.9	660	360	--	33
		--	--	60	320	8.2	820	370	--	34
		--	--	67	320	8.4	820	380	--	32
		--	--	--	--	--	830	380	--	33
		--	--	62	320	7.3	780	370	--	33
		--	--	--	--	--	750	350	--	32
		--	--	--	--	--	690	--	--	--
		--	--	--	--	--	670	340	--	33
		--	--	--	--	--	570	320	--	35
		--	--	41	270	6.6	110	310	--	34
		--	--	--	--	--	--	--	--	--
		--	--	36	240	6.4	450	280	--	33
		--	--	--	--	--	--	--	--	--
Cheyenne-I (soil core)	124	--	82	21	110	5.4	150	180	1.1	31

Site name (source of sample)	Depth (ft)	Boron, dis- solved (µg/L)	Iron, dis- solved (µg/L)	Manga- nese, dis- solved (µg/L)	Stron- tium, dis- solved (µg/L)	Zinc, dis- solved (µg/L)	Lithium, dis- solved (µg/L)	$^{15}N/^{14}N$, stable- isotope ratio (permil)	Alka- linity, lab (mg/L as $CaCO_3$)
Cheyenne-I (suction lysimeter)	113	600	--	--	--	--	--	--	103
		690	--	--	--	--	--	--	97
		780	--	--	--	--	--	--	97
		740	--	--	--	--	--	--	100
		770	--	--	--	--	--	--	92
		850	--	--	--	--	--	--	105
		880	--	--	--	--	--	--	113
		800	--	--	--	--	--	--	113
		800	--	--	--	--	--	--	121
		830	--	--	--	--	--	--	122
		--	--	--	--	--	--	--	--
		800	--	--	--	--	--	--	134
		--	--	--	--	--	--	--	--
Cheyenne-I (soil core)	124	460	240	340	1,000	21	30	--	115

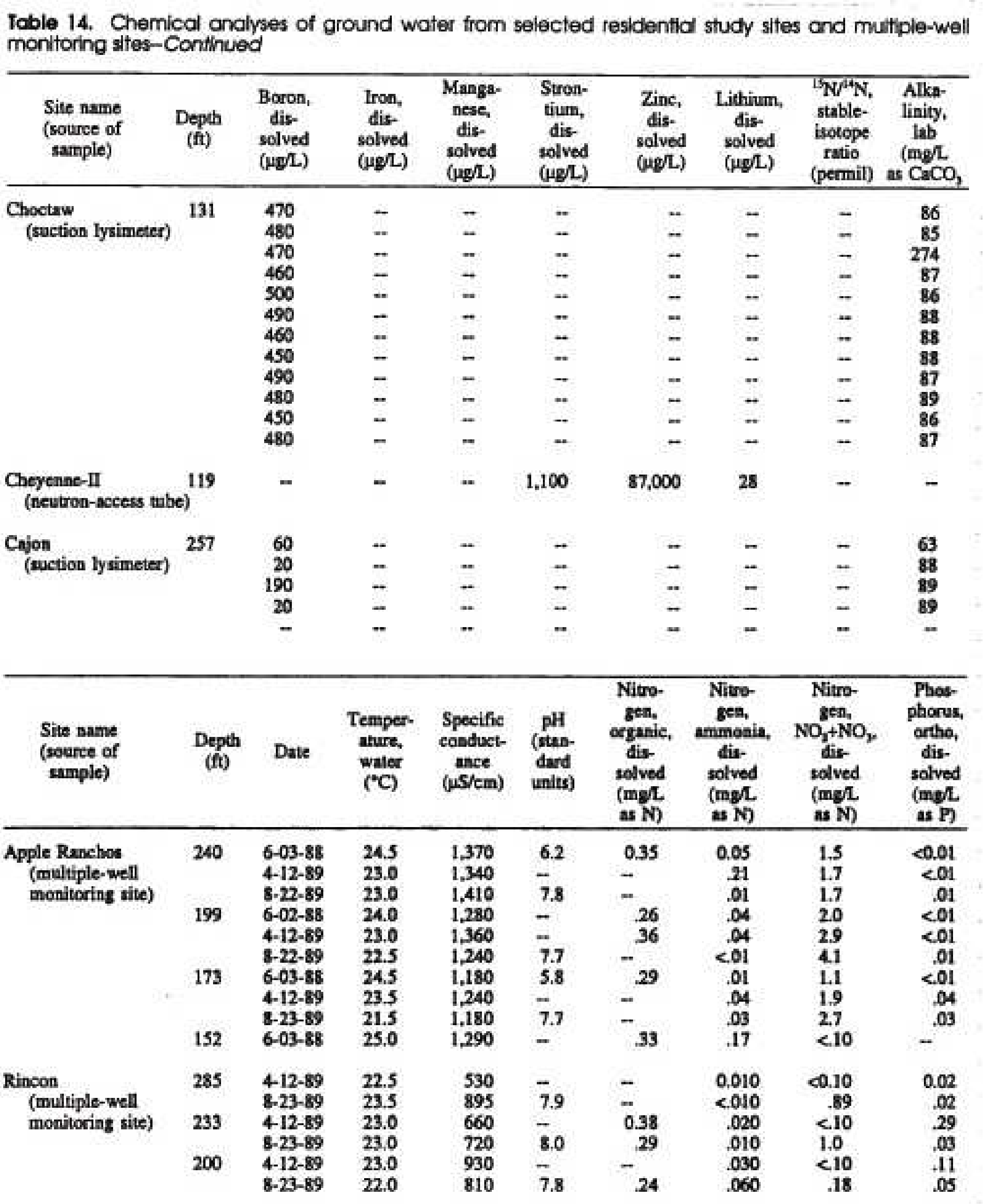


Table 14. Chemical analyses of ground water from selected residential study sites and multiple-well monitoring sites–*Continued*

Site name (source of sample)	Depth (ft)	Boron, dissolved (µg/L)	Iron, dissolved (µg/L)	Manganese, dissolved (µg/L)	Strontium, dissolved (µg/L)	Zinc, dissolved (µg/L)	Lithium, dissolved (µg/L)	$^{15}N/^{14}N$, stable-isotope ratio (permil)	Alkalinity, lab (mg/L as $CaCO_3$
Choctaw (suction lysimeter)	131	470	--	--	--	--	--	--	86
		480	--	--	--	--	--	--	85
		470	--	--	--	--	--	--	274
		460	--	--	--	--	--	--	87
		500	--	--	--	--	--	--	86
		490	--	--	--	--	--	--	88
		460	--	--	--	--	--	--	88
		450	--	--	--	--	--	--	88
		490	--	--	--	--	--	--	87
		480	--	--	--	--	--	--	89
		450	--	--	--	--	--	--	86
		480	--	--	--	--	--	--	87
Cheyenne-II (neutron-access tube)	119	--	--	--	1,100	87,000	28	--	--
Cajon (suction lysimeter)	257	60	--	--	--	--	--	--	63
		20	--	--	--	--	--	--	88
		190	--	--	--	--	--	--	89
		20	--	--	--	--	--	--	89
		--	--	--	--	--	--	--	--

Site name (source of sample)	Depth (ft)	Date	Temperature, water (°C)	Specific conductance (µS/cm)	pH (standard units)	Nitrogen, organic, dissolved (mg/L as N)	Nitrogen, ammonia, dissolved (mg/L as N)	Nitrogen, NO_2+NO_3, dissolved (mg/L as N)	Phosphorus, ortho, dissolved (mg/L as P)
Apple Ranchos (multiple-well monitoring site)	240	6-03-88	24.5	1,370	6.2	0.35	0.05	1.5	<0.01
		4-12-89	23.0	1,340	--	--	.21	1.7	<.01
		8-22-89	23.0	1,410	7.8	--	.01	1.7	.01
	199	6-02-88	24.0	1,280	--	.26	.04	2.0	<.01
		4-12-89	23.0	1,360	--	.36	.04	2.9	<.01
		8-22-89	22.5	1,240	7.7	--	<.01	4.1	.01
	173	6-03-88	24.5	1,180	5.8	.29	.01	1.1	<.01
		4-12-89	23.5	1,240	--	--	.04	1.9	.04
		8-23-89	21.5	1,180	7.7	--	.03	2.7	.03
	152	6-03-88	25.0	1,290	--	.33	.17	<.10	--
Rincon (multiple-well monitoring site)	285	4-12-89	22.5	530	--	--	0.010	<0.10	0.02
		8-23-89	23.5	895	7.9	--	<.010	.89	.02
	233	4-12-89	23.0	660	--	0.38	.020	<.10	.29
		8-23-89	23.0	720	8.0	.29	.010	1.0	.03
	200	4-12-89	23.0	930	--	--	.030	<.10	.11
		8-23-89	22.0	810	7.8	.24	.060	.18	.05

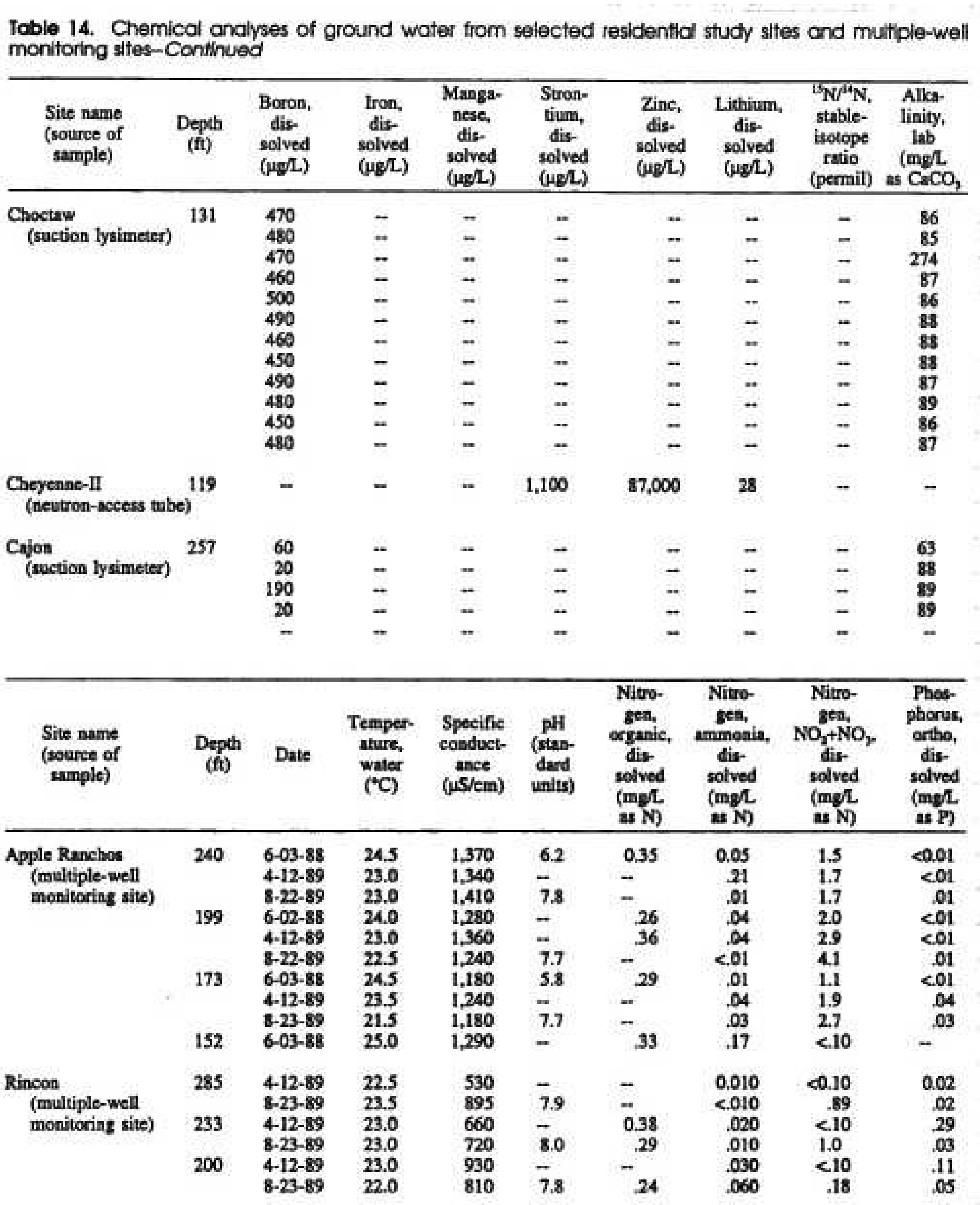


Table 14. Chemical analyses of ground water from selected residential study sites and multiple-well monitoring sites–*Continued*

Site name (source of sample)	Depth (ft)	Boron, dissolved (µg/L)	Iron, dissolved (µg/L)	Manganese, dissolved (µg/L)	Strontium, dissolved (µg/L)	Zinc, dissolved (µg/L)	Lithium, dissolved (µg/L)	$^{15}N/^{14}N$, stable-isotope ratio (permil)	Alkalinity, lab (mg/L as $CaCO_3$
Choctaw (suction lysimeter)	131	470	--	--	--	--	--	--	86
		480	--	--	--	--	--	--	85
		470	--	--	--	--	--	--	274
		460	--	--	--	--	--	--	87
		500	--	--	--	--	--	--	86
		490	--	--	--	--	--	--	88
		460	--	--	--	--	--	--	88
		450	--	--	--	--	--	--	88
		490	--	--	--	--	--	--	87
		480	--	--	--	--	--	--	89
		450	--	--	--	--	--	--	86
		480	--	--	--	--	--	--	87
Cheyenne-II (neutron-access tube)	119	--	--	--	1,100	87,000	28	--	--
Cajon (suction lysimeter)	257	60	--	--	--	--	--	--	63
		20	--	--	--	--	--	--	88
		190	--	--	--	--	--	--	89
		20	--	--	--	--	--	--	89
		--	--	--	--	--	--	--	--

Site name (source of sample)	Depth (ft)	Date	Temperature, water (°C)	Specific conductance (µS/cm)	pH (standard units)	Nitrogen, organic, dissolved (mg/L as N)	Nitrogen, ammonia, dissolved (mg/L as N)	Nitrogen, NO_2+NO_3, dissolved (mg/L as N)	Phosphorus, ortho, dissolved (mg/L as P)
Apple Ranchos (multiple-well monitoring site)	240	6-03-88	24.5	1,370	6.2	0.35	0.05	1.5	<0.01
		4-12-89	23.0	1,340	--	--	.21	1.7	<.01
		8-22-89	23.0	1,410	7.8	--	.01	1.7	.01
	199	6-02-88	24.0	1,280	--	.26	.04	2.0	<.01
		4-12-89	23.0	1,360	--	.36	.04	2.9	<.01
		8-22-89	22.5	1,240	7.7	--	<.01	4.1	.01
	173	6-03-88	24.5	1,180	5.8	.29	.01	1.1	<.01
		4-12-89	23.5	1,240	--	--	.04	1.9	.04
		8-23-89	21.5	1,180	7.7	--	.03	2.7	.03
	152	6-03-88	25.0	1,290	--	.33	.17	<.10	--
Rincon (multiple-well monitoring site)	285	4-12-89	22.5	530	--	--	0.010	<0.10	0.02
		8-23-89	23.5	895	7.9	--	<.010	.89	.02
	233	4-12-89	23.0	660	--	0.38	.020	<.10	.29
		8-23-89	23.0	720	8.0	.29	.010	1.0	.03
	200	4-12-89	23.0	930	--	--	.030	<.10	.11
		8-23-89	22.0	810	7.8	.24	.060	.18	.05

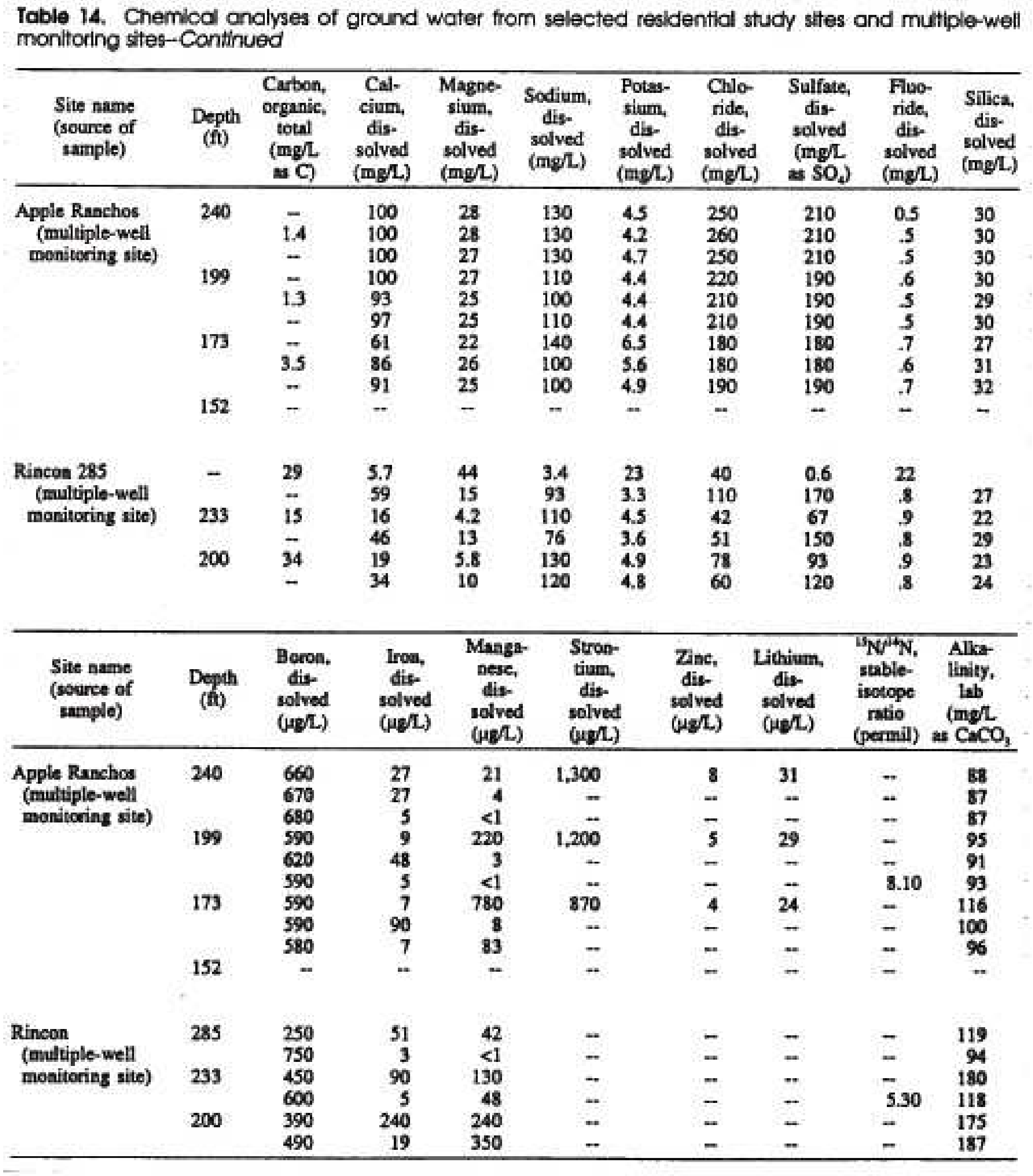


Table 14. Chemical analyses of ground water from selected residential study sites and multiple-well monitoring sites--*Continued*

Site name (source of sample)	Depth (ft)	Carbon, organic, total (mg/L as C)	Calcium, dissolved (mg/L)	Magnesium, dissolved (mg/L)	Sodium, dissolved (mg/L)	Potassium, dissolved (mg/L)	Chloride, dissolved (mg/L)	Sulfate, dissolved (mg/L as SO_4)	Fluoride, dissolved (mg/L)	Silica, dissolved (mg/L)
Apple Ranchos (multiple-well monitoring site)	240	--	100	28	130	4.5	250	210	0.5	30
		1.4	100	28	130	4.2	260	210	.5	30
		--	100	27	130	4.7	250	210	.5	30
	199	--	100	27	110	4.4	220	190	.6	30
		1.3	93	25	100	4.4	210	190	.5	29
		--	97	25	110	4.4	210	190	.5	30
	173	--	61	22	140	6.5	180	180	.7	27
		3.5	86	26	100	5.6	180	180	.6	31
		--	91	25	100	4.9	190	190	.7	32
	152	--	--	--	--	--	--	--	--	--
Rincon 285 (multiple-well monitoring site)	--	29	5.7	44	3.4	23	40	0.6	22	
		--	59	15	93	3.3	110	170	.8	27
	233	15	16	4.2	110	4.5	42	67	.9	22
		--	46	13	76	3.6	51	150	.8	29
	200	34	19	5.8	130	4.9	78	93	.9	23
		--	34	10	120	4.8	60	120	.8	24

Site name (source of sample)	Depth (ft)	Boron, dissolved (µg/L)	Iron, dissolved (µg/L)	Manganese, dissolved (µg/L)	Strontium, dissolved (µg/L)	Zinc, dissolved (µg/L)	Lithium, dissolved (µg/L)	$^{15}N/^{14}N$, stable-isotope ratio (permil)	Alkalinity, lab (mg/L as $CaCO_3$
Apple Ranchos (multiple-well monitoring site)	240	660	27	21	1,300	8	31	--	88
		670	27	4	--	--	--	--	87
		680	5	<1	--	--	--	--	87
	199	590	9	220	1,200	5	29	--	95
		620	48	3	--	--	--	--	91
		590	5	<1	--	--	--	8.10	93
	173	590	7	780	870	4	24	--	116
		590	90	8	--	--	--	--	100
		580	7	83	--	--	--	--	96
	152	--	--	--	--	--	--	--	--
Rincon (multiple-well monitoring site)	285	250	51	42	--	--	--	--	119
		750	3	<1	--	--	--	--	94
	233	450	90	130	--	--	--	--	180
		600	5	48	--	--	--	5.30	118
	200	390	240	240	--	--	--	--	175
		490	19	350	--	--	--	--	187

Mojave Water Agency

Groundwater Quality Analysis

Phase 1 / Task 3

Model User Reference Documentation

Technical Memorandum

December 6, 2005

Schlumberger
WATER SERVICES

Water Quality Planning Model
User Reference Manual

1

Introduction

The Mojave Water Agency (MWA) Water Quality Planning Model (WQPM) is has been designed to evaluate the long-term effect of water management alternatives on the total amount and distribution of dissolved solids (TDS) in the MWA operating area. The WQPM is built using Stella software. Stella facilitates development and analysis of models describing complex dynamic systems that may be characterized by system nodes and active process links. A technical description of Stella may be found in the Water Quality Planning Model technical description document.

Stella was used to model the water budget for screening of alternatives during development of the MWA 2004 Regional Water Management Plan (RWMP). The WQPM model uses the water budget calculation developed for the 2004 RWMP screening process as the underlying mechanism for transport of dissolved solids (TDS) between sub-aquifer units within the MWA operational area. Dissolved solids have been introduced into the Stella model through additional nodes describing initial state of groundwater quality as well as the quality of significant active TDS sources and sinks. Transport of TDS within the model domain is described by links containing approximations of processes such as river flow, groundwater flux, and anthropogenic redistribution mechanisms. The WQPM is used to generate predictions of TDS distribution among pre-defined sub-aquifer units. A set of model conditions is set which is representative of initial conditions and potential management actions. Stella performs automated repetitive solution of the complex system of equations describing the hydrodynamic system and TDS concentrations in each sub aquifer unit. The result is a quasi-steady state approximation of water and mass transport between sub-aquifer units over a period of 75 years. A more complete technical description of the WQPM may be found in the Water Quality Planning Model technical description document. A post processing macro is provided for evaluation of water quality management alternatives by automated comparison of model output files from multiple runs.

This user reference document is designed to provide step-by-step instructions for loading and execution of planning model files, modification of user inputs, and analysis of results. A section is also provided describing use of built-in Stella features to generate custom model output, and to perform model parameter sensitivity analysis.

2

File Overview

2.1 Introduction

Three types of files are involved in analysis of a management alternative using the WQPM. These are:

- Stella model files (.stm extension)
- Tabular ASCII format data export files (.txt extension)
- Provided Excel macro files (.xls extension)

The following sections describe the origination and use of each of these file types in evaluation of a management alternative.

2.2 Stella Model File

The Stella WQPM model file contains the complete model description. This file is in native Stella format and may only be executed or modified from within the Stella user interface. All model input and output data are contained within the Stella WQPM model file. No data are either input or output from or to other files by Stella during WQPM model execution. The Stella WQPM model file may reside anywhere on the user's computer.

2.3 Tabular ASCII Export

Execution of the WQPM results in creation of pre-determined data tables. Although data tables may be viewed within the Stella environment, detailed evaluation of management alternatives through comparison of multiple model runs requires post processing of model results outside of the Stella environment. Some of the data tables generated by a model run are specifically designed for such post-processing using spreadsheet macros provided with the model files. Tabular data must first be exported from Stella in ASCII text format to make it available for post-processing. Detailed instructions for exporting tabular data in ASCII format are provided in Chapter 5.

2.4 Excel Macro Post-Processing Worksheet

Evaluation of management alternatives is accomplished through comparison of standard set of model output from two model configurations. A set of standardized excel spreadsheet macros have been provided to post process the output of multiple model runs exported from the Stella environment after each model run as discussed in Section 2.3. Post processing macros generate tabular and graphical comparative information, and also output data in suitable format for creation of color-coded map view displays using standard GIS system functionality.

3

Running the Planning Model

3.1 Opening the Stella Model

The Stella model file may be opened in one of two ways;

Opening the Model File From Within Stella

To launch Stella, at the Windows desktop select:
<Start>
<Programs>
<Stella Research>
<Stella Research>
In Stella select:
<File>
<Open>
Navigate to folder containing the Stella model (.stm) file
Select the model file
Click "Open"

Opening the Model File From a Folder

Using either Windows Explorer or "My Computer", navigate to the folder containing the Stella model file and double click on the file.

3.2 Navigating the Model File

The WQPM has 2 main computational flows;

- Water balance – Consistent with the water balance developed for screening of alternatives for the 2004 RWMP.
- Mass Transport – Keeps tr5ack of mass inputs and outputs, and calculates movements of mass based on the water flux calculated in the water balance.

The interface to the WQPM is designed to allow user input of key parameters for water balance and mass transport computations, as well as to navigate through the model in order to view its structure. The ability to navigate through the model has been provided because of its value in understanding the model structure and operation. However, the user *should not* modify the model in any way other than through the specific user inputs described in this document. It is, unfortunately, not possible to lock the computational part of the model while allowing selected user input. The organization of the Stella model file is described in detail in the model technical description document. The following sections provide instructions for typical model usage.

Stella provides 3 levels of model access, the Interface level, the Map/Model level, and the Equation level. The user will interact with the model at the Interface level.

Navigating to the Interface View

If upon opening the model it is not at the Interface level, use the level navigation tool located in the upper left hand corner of the Stella interface window to navigate to the top (interface) level. Figure 3.1 shows an example of the model open at the Map/Model level. The yellow circle indicates the model level navigation tool. Figure 3.2 shows an example of the same model after navigation to the interface level. The model interface is divided into three sections organized logically to provide input and navigation control for the water balance computation, the TDS transport computation, and ancillary calculations. The user may move between the three interface sections using the horizontal scroll bar located at the bottom of the Stella window.

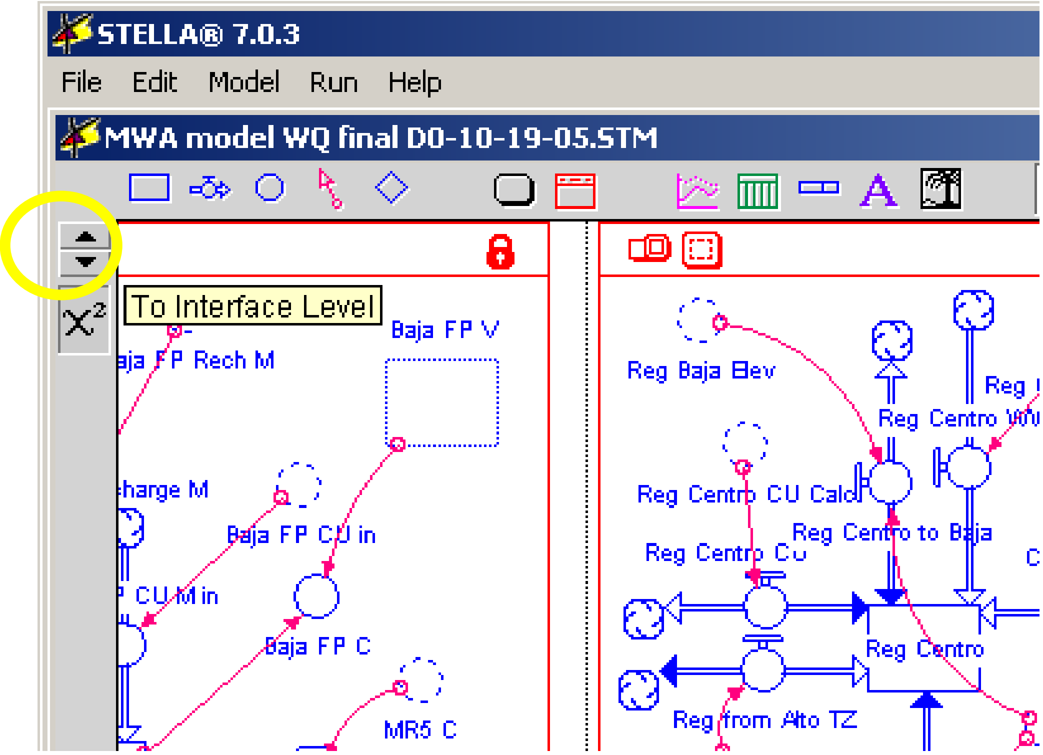


Figure 3.1 – Example (partial window view) of the WQPM at Map/Model level. The yellow circle shows the location of the level navigation tool.

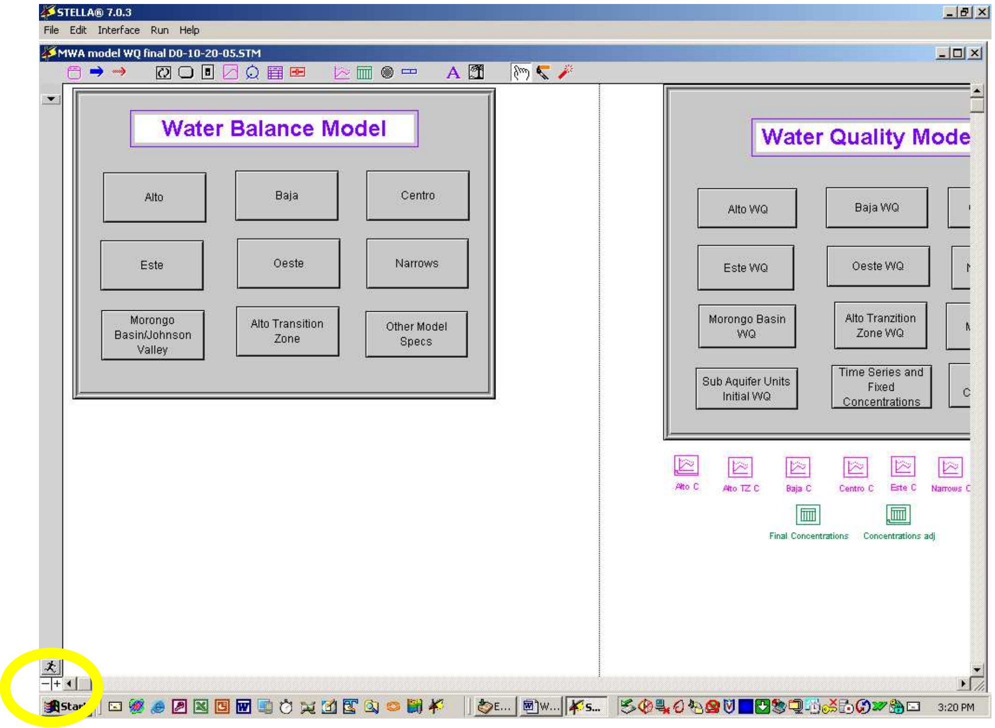


Figure 3.2 – Example of model Interface level. The yellow circle shows the location of the horizontal scroll control.

The Water Balance Calculation Interface

Figure 3.3 shows the Water Balance Model interface. This interface has links to the Map/Model view of the hydrology for each adjudicated subarea and the Morongo Basin. A link is provided to the interface for ancillary water balance computational elements. Figure 3.4 shows the Alto hydrology Map/Model view.

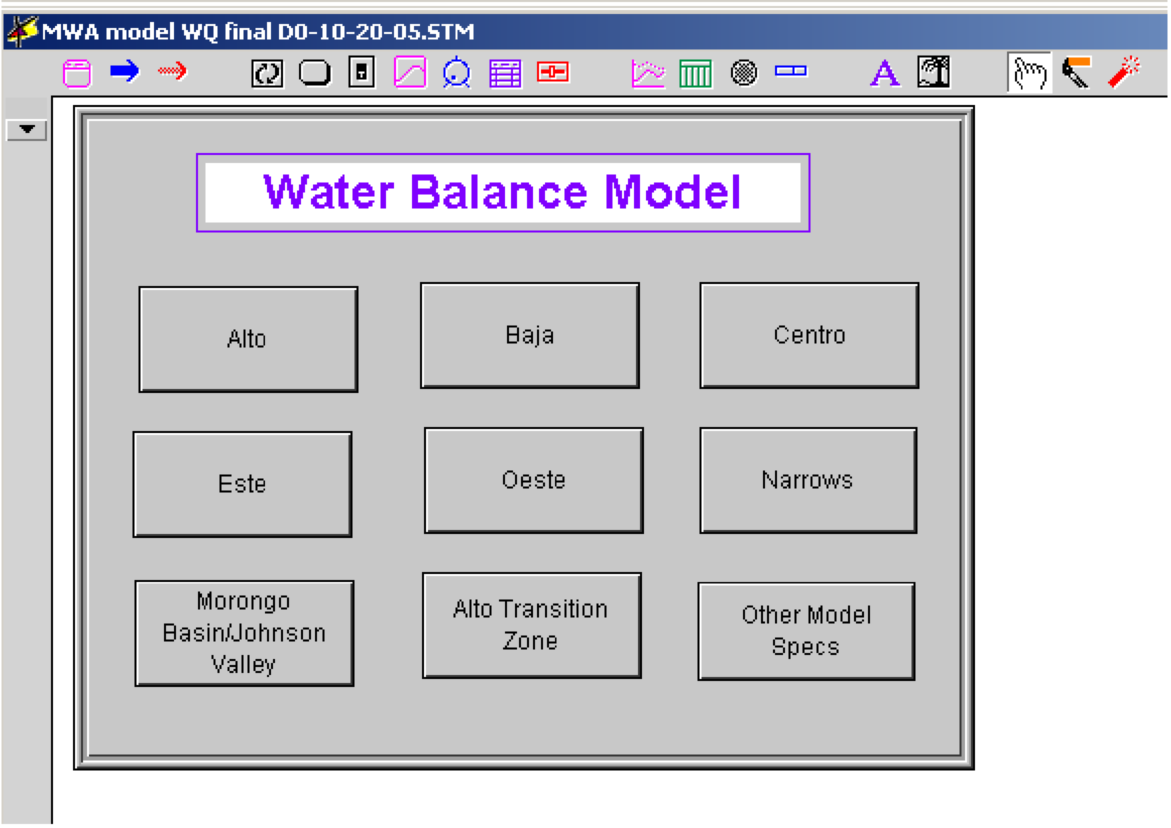


Figure 3.3 – Water balance computation interface view.

Each hydrology Map/Model view contains a link to the consumptive use Map/Model view for that subarea. Figure 3.5 shows the Map/Model view for the Alto consumptive use calculation.

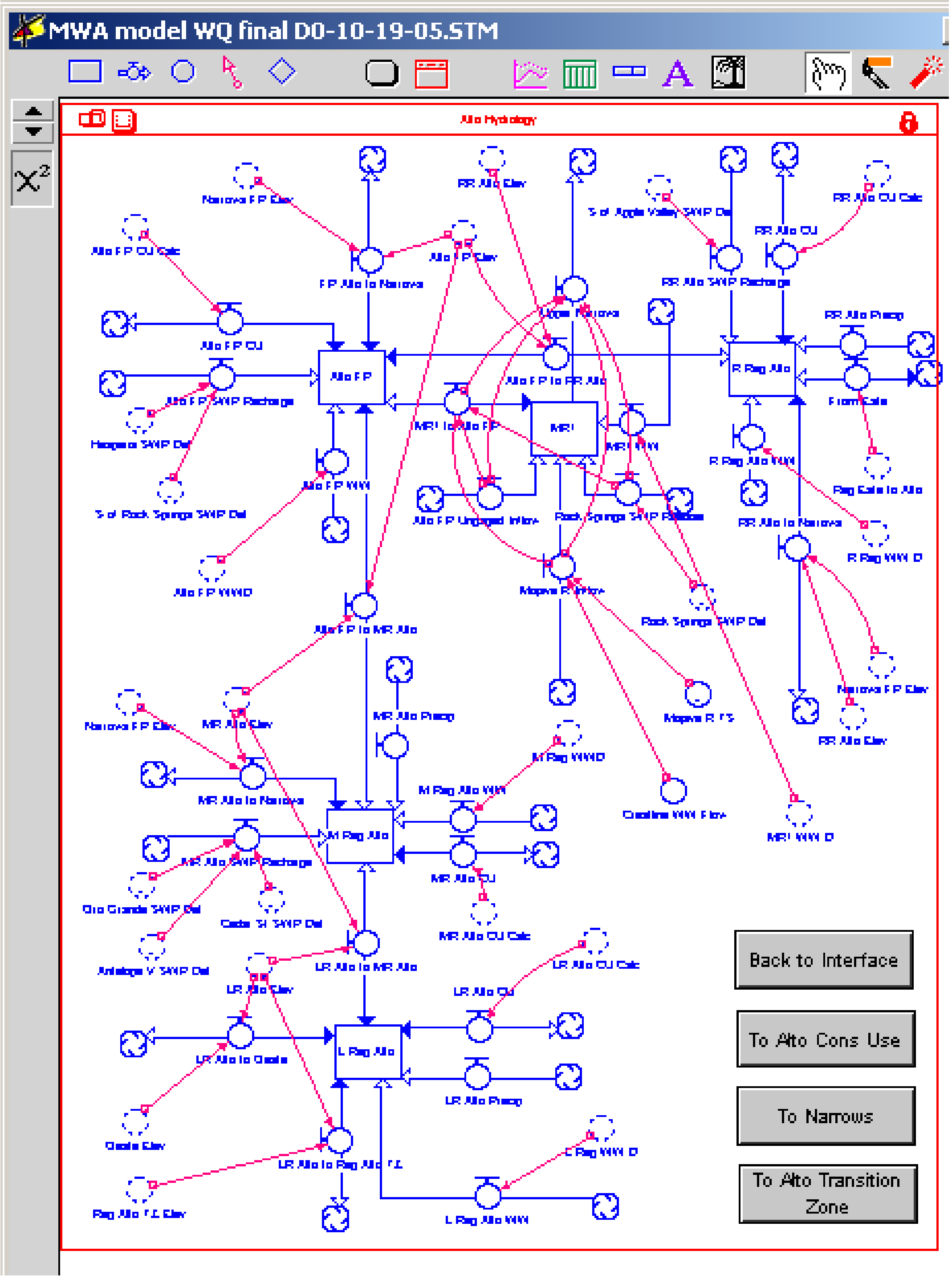


Figure 3.4 – Example subarea hydrology Map/Model view.

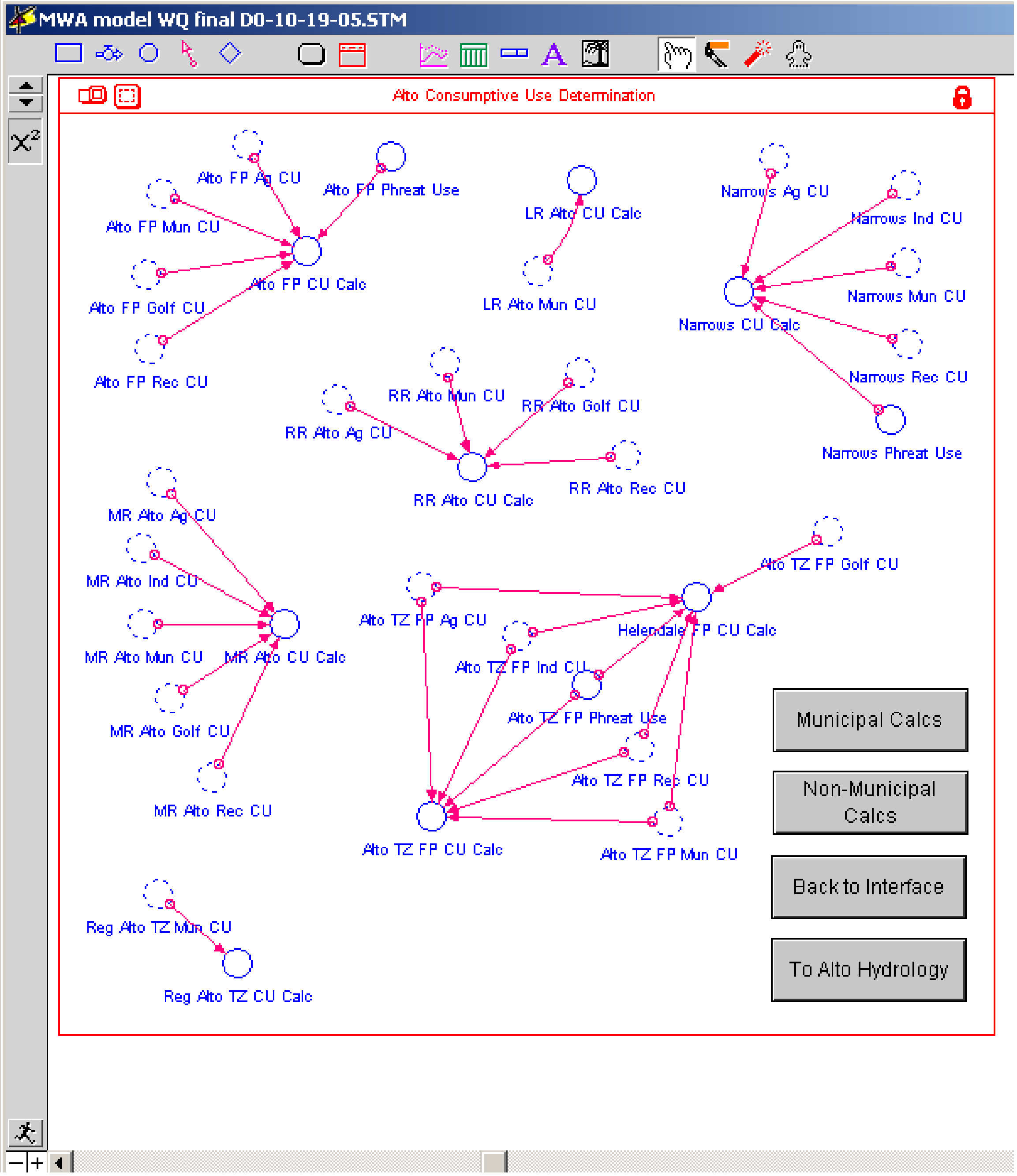


Figure 3.5 – Example subarea consumptive use calculation.

The Water Quality Calculation Interface

Figure 3.6 shows the Water Quality Model interface. This interface has links to the Map/Model view of the mass transport mechanisms for each adjudicated subarea and the Morongo Basin.

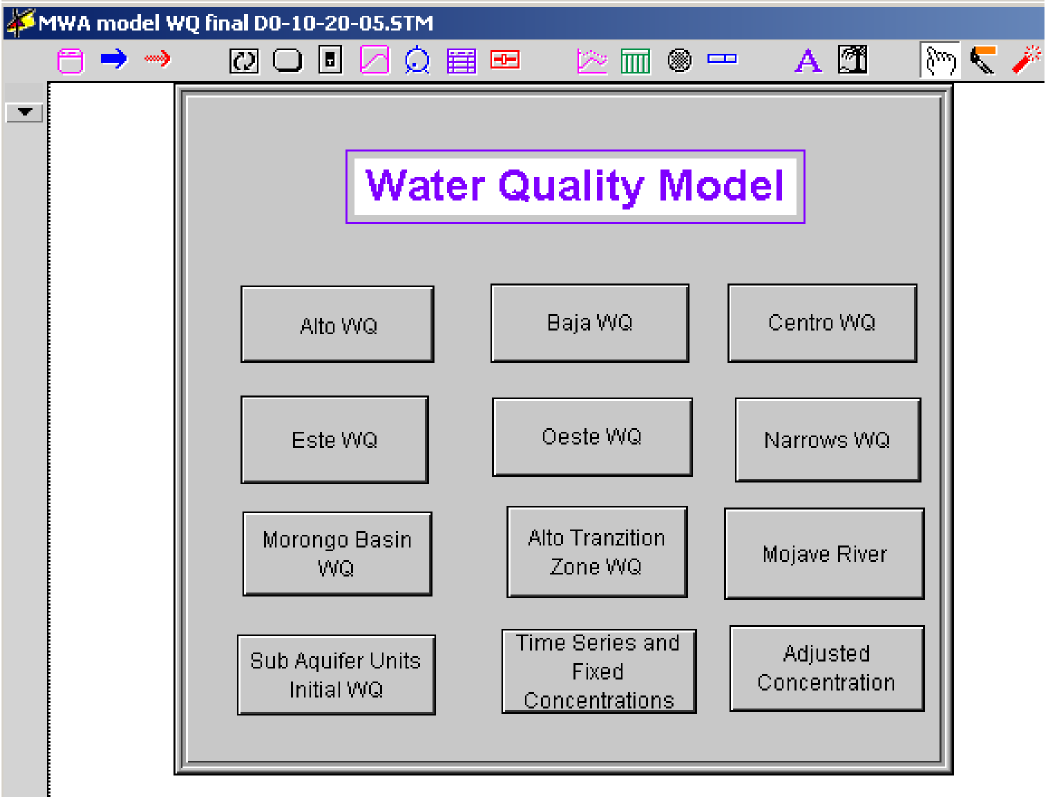


Figure 3.6 – Water quality interface view.

Figure 3.7 shows the Alto water quality Map/Model view. This view shows TDS mass nodes for each TDS source and sink represented in the water balance. Initial and fixed concentrations for each node are entered using the links to “Sub Aquifer Unit Initial WQ” and “Time Series and Fixed Concentrations” on the Water Quality Model interface. Figure 3.8 shows the “Time Series and Fixed Concentrations” input Map/Model view. The concentration of any node of the underlying RWMP water balance model may be adjusted by double clicking on that node and entering the desired value.

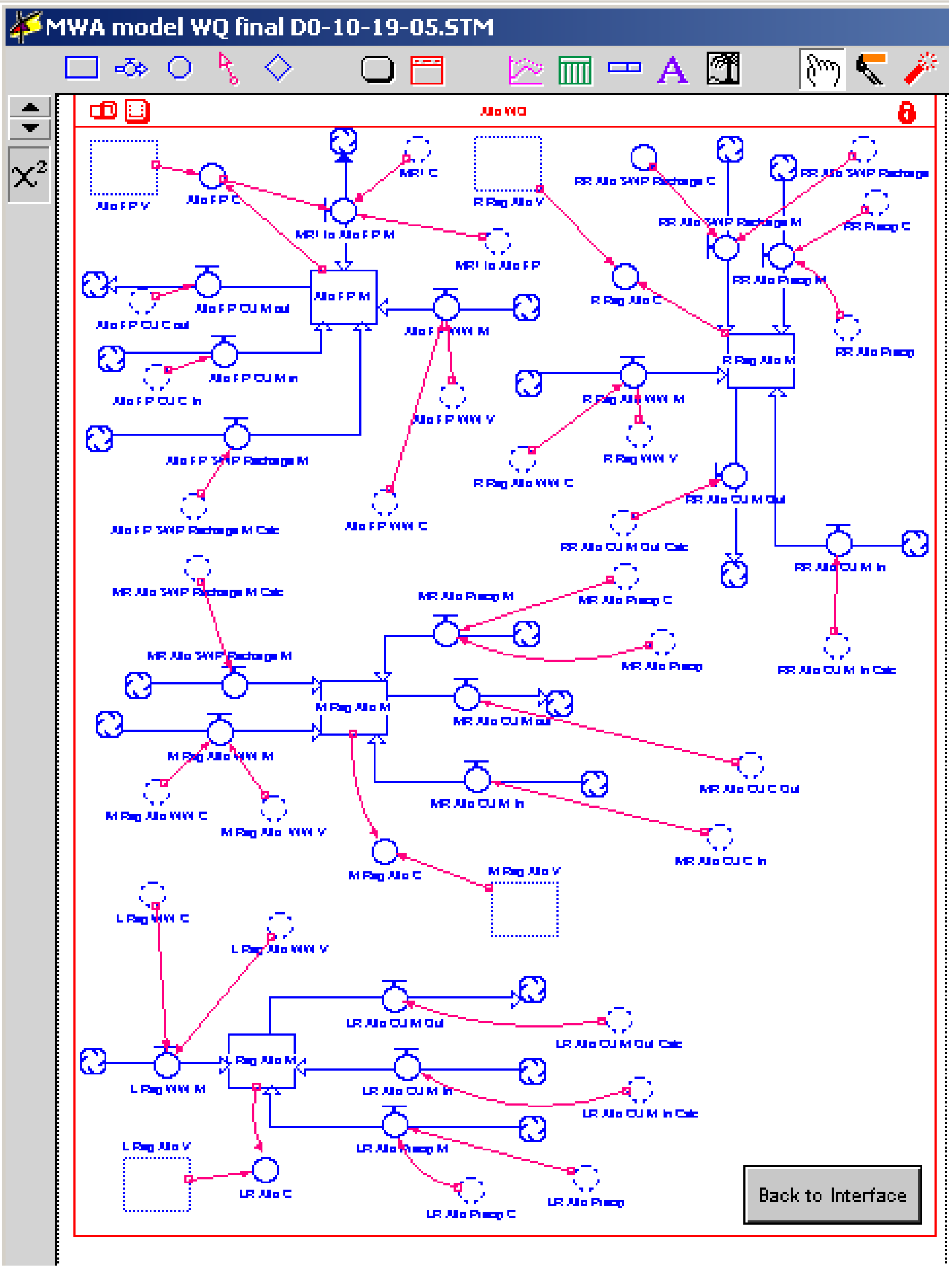


Figure 3.7 – Alto water quality Map/Model view.

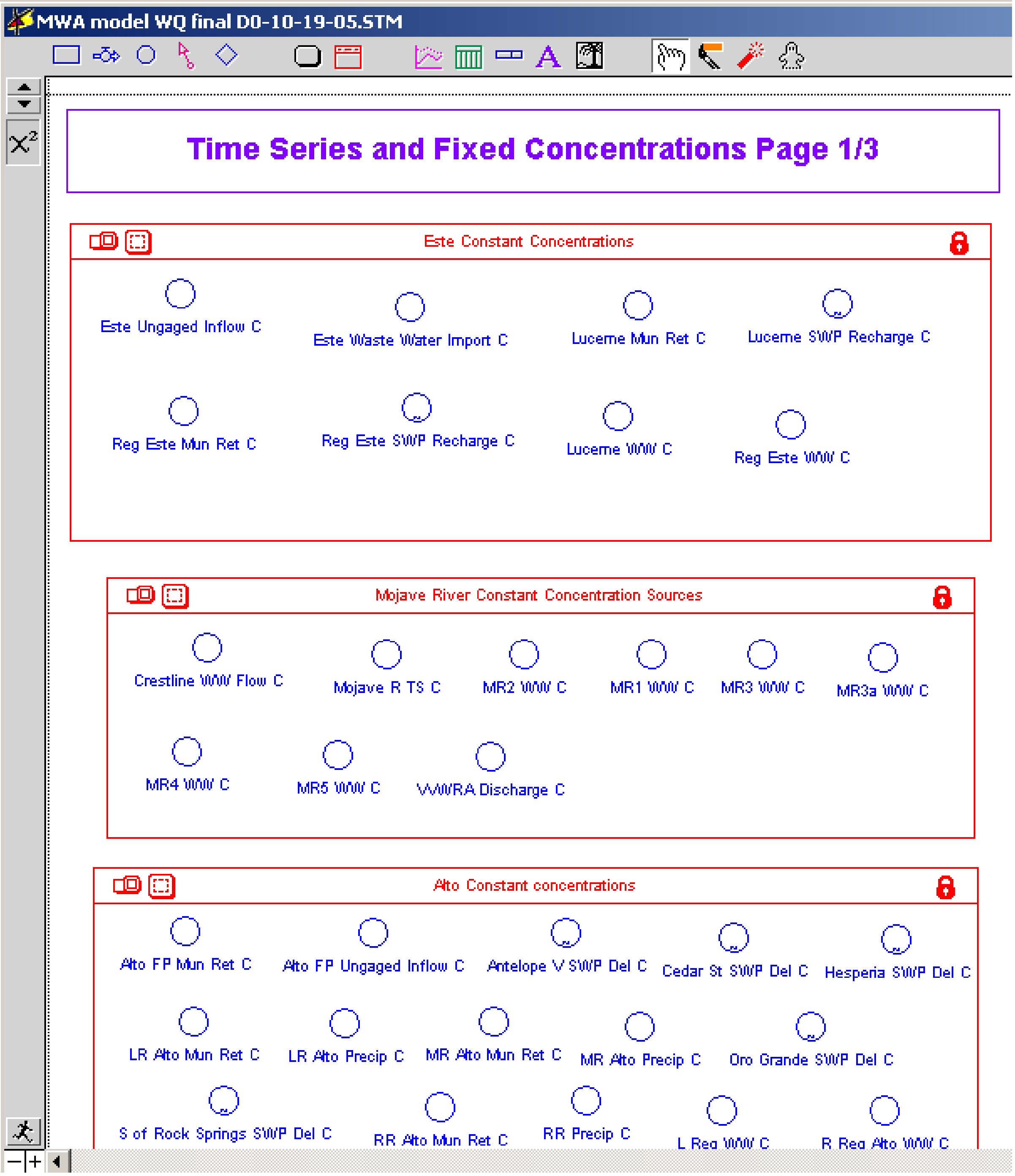


Figure 3.8 – Time Series and Fixed Concentrations Map/Model

Figure 3.9 shows the “Initial Sub Aquifer Unit Initial Volume” and “Initial Sub Aquifer Unit Initial Concentration” Map/Model view. The volumes concentration of any node of the underlying RWMP water balance model may be adjusted by double clicking on that node and entering the desired value.

Figure 3.9 shows the “Initial Sub Aquifer Unit Initial Volume” and “Initial Sub Aquifer Unit Initial Concentration” Map/Model view. The volumes concentration of any node of the underlying RWMP water balance model may be adjusted by double clicking on that node and entering the desired value.

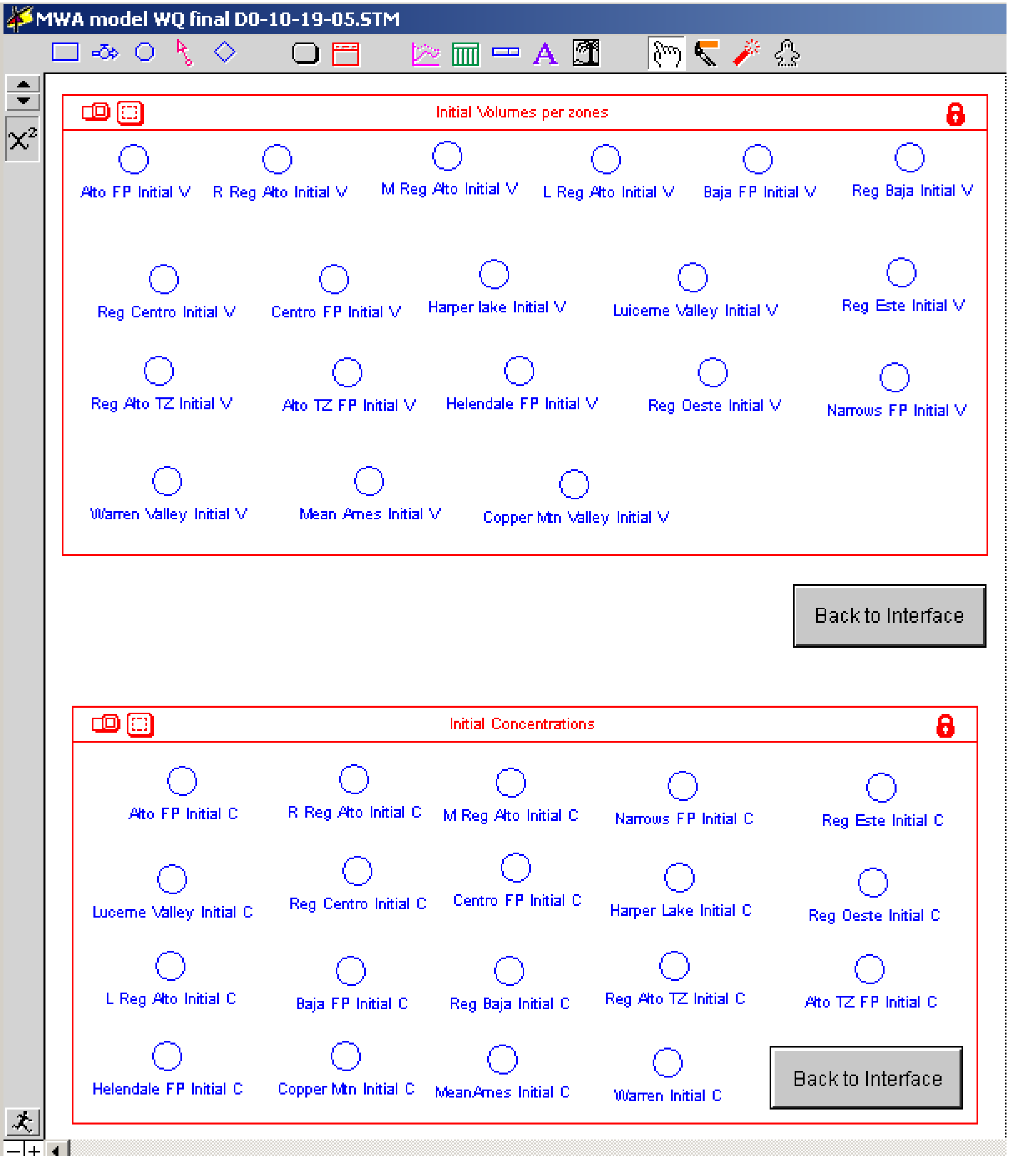


Figure 3.9 – Sub Aquifer Unit initial volumes and initial concentrations input Map/Model view.

The Ancillary Model Specs Interface

Figure 3.10 shows the Ancillary Model Specs interface view. This interface contains links to several sub-elements of the water balance model described in the technical description document. This interface also provides a link to the input page for defining generic water balance and TDS concentration nodes describing sub-regional wastewater treatment plants (Figure 3.11). One generic node is provided for each model sub-aquifer unit.

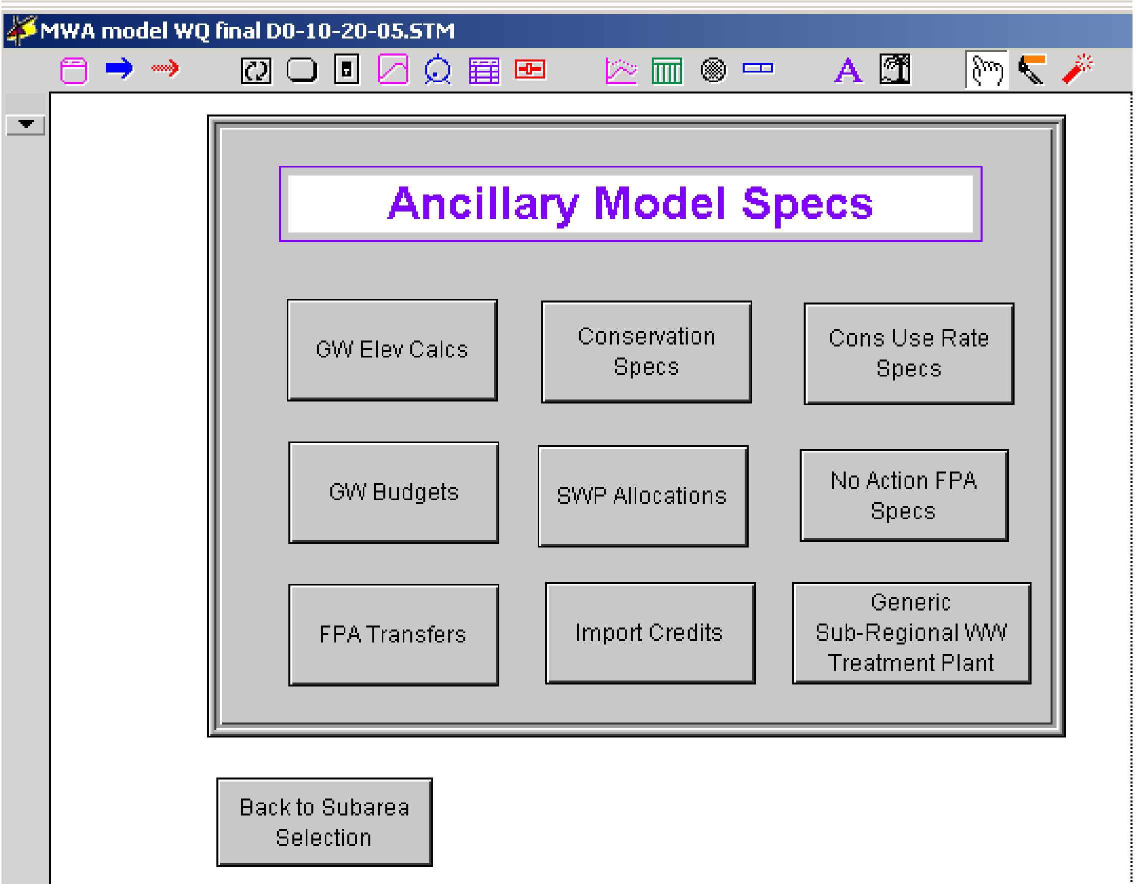


Figure 3.10 – Ancillary Model Specs interface view.

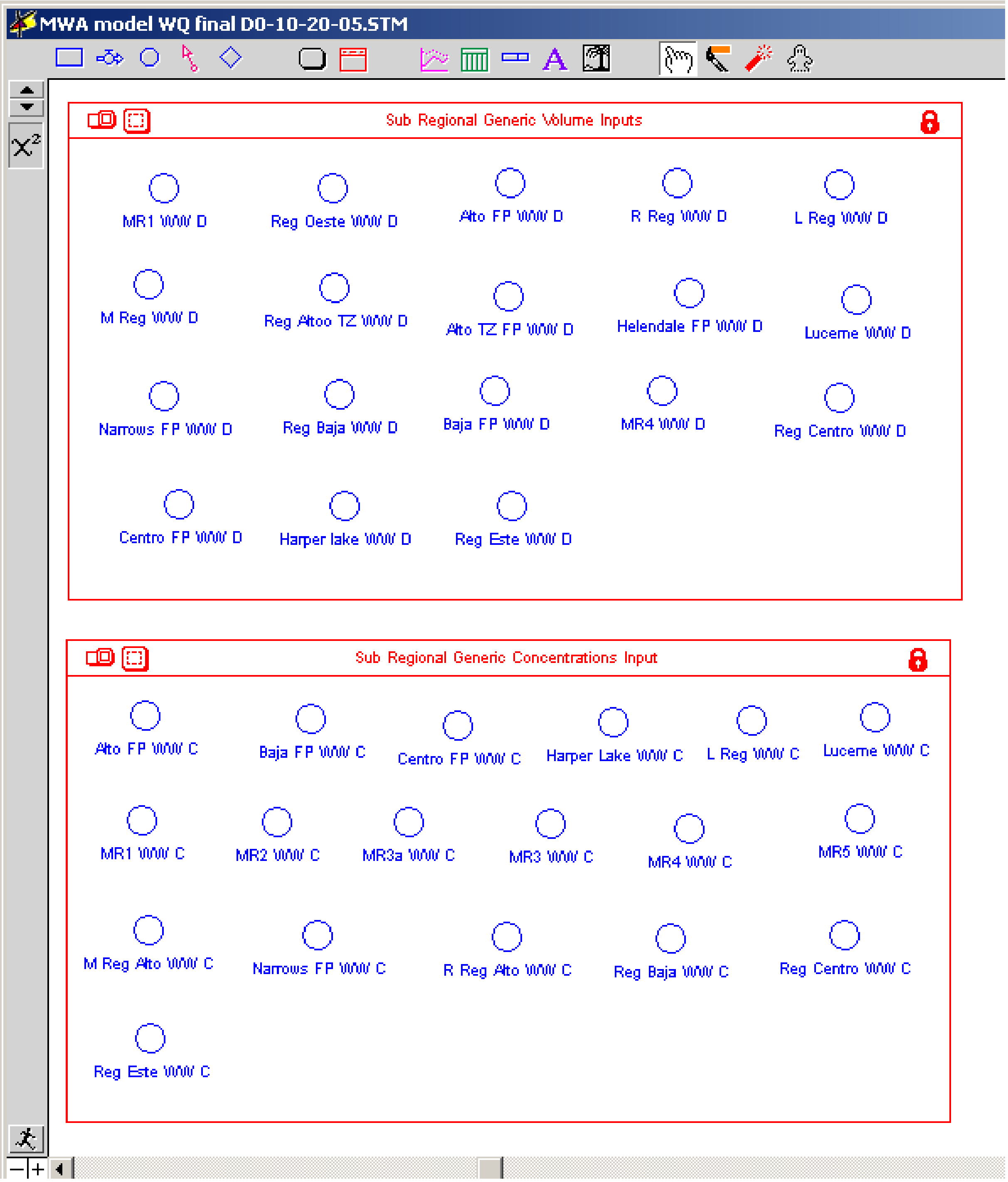


Figure 3.11 – Sub-regional wastewater treatment plant definition page.

3.3 Changing Model Parameter Inputs

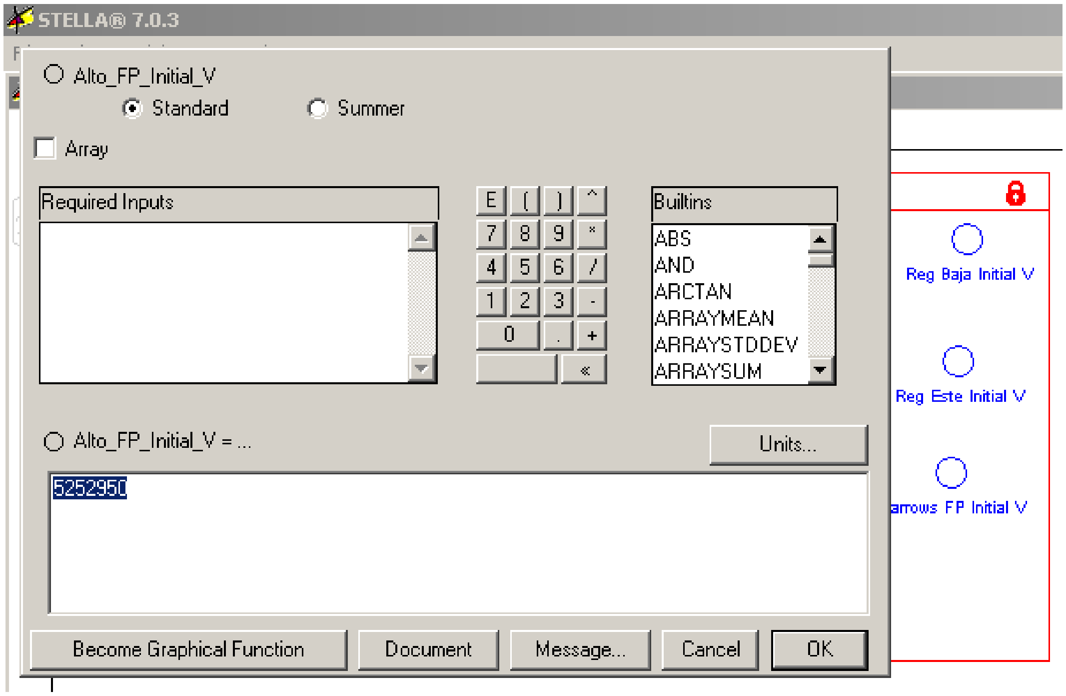
Various model parameter input values will be changed during routine use of the WQPM. Parameter changes will typically be made to of one of the following model elements:

- Initial sub aquifer unit volumes and/or concentrations
- Various water budget element fixed concentrations or concentration time series
- Addition of a new source or sink such as a sub-regional wastewater treatment plant.

The following sections illustrate input mechanisms for the above 3 types of parameter inputs.

Sub-Aquifer Unit Initial Volumes and Concentrations

The initial water volumes and TDS concentrations of sub-aquifer units are entered through the *Sub Aquifer Unit Initialization* link on the Water Quality Model interface. Input nodes for initial sub aquifer unit volumes are located in the top half of the input view (Figure 3.9). Double clicking on any of the nodes opens the input dialog as shown in Figure 3.12. Volumes are entered in units of acre-feet.



○ Alto_FP_Initial_V

● Standard ○ Summer

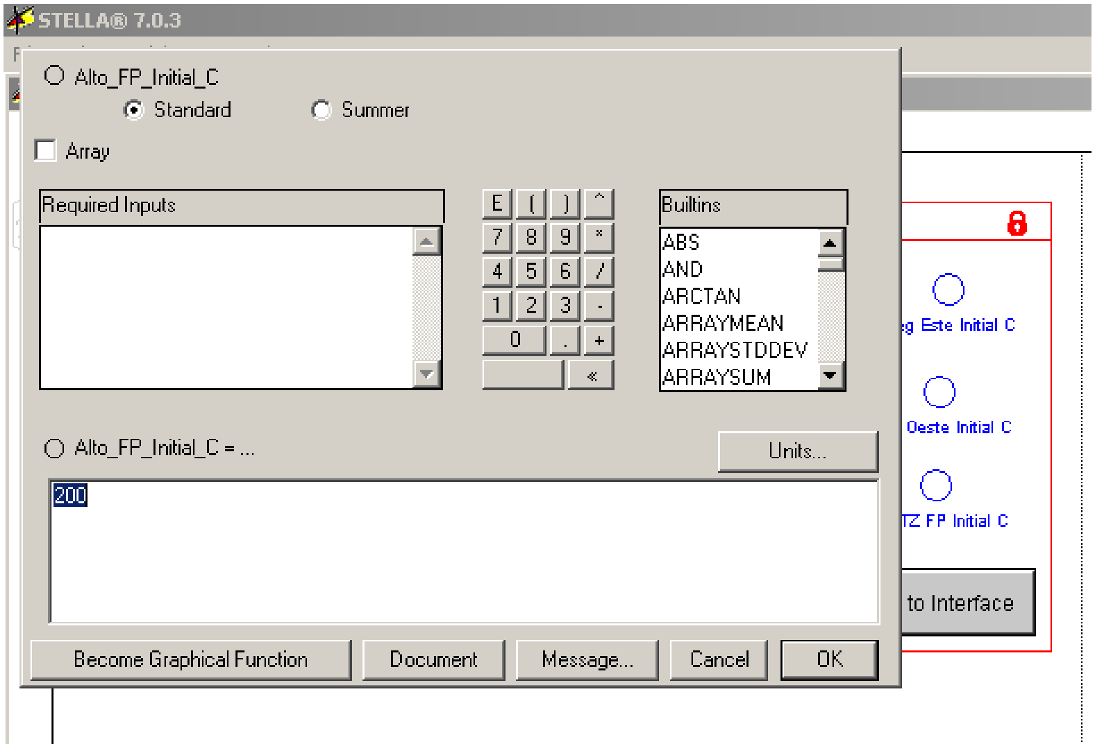
☐ Array

○ Alto_FP_Initial_V = ...

5252950

Figure 3.12 – Sub-aquifer unit initial volume input screen.

Input nodes for initial sub aquifer unit TDS concentrations are located in the bottom half of the input view (Figure 3.9). Double clicking on any of the nodes opens the input dialog as shown in Figure 3.13. Concentrations are entered in units of mg/L.



○ Alto_FP_Initial_C

● Standard ○ Summer

☐ Array

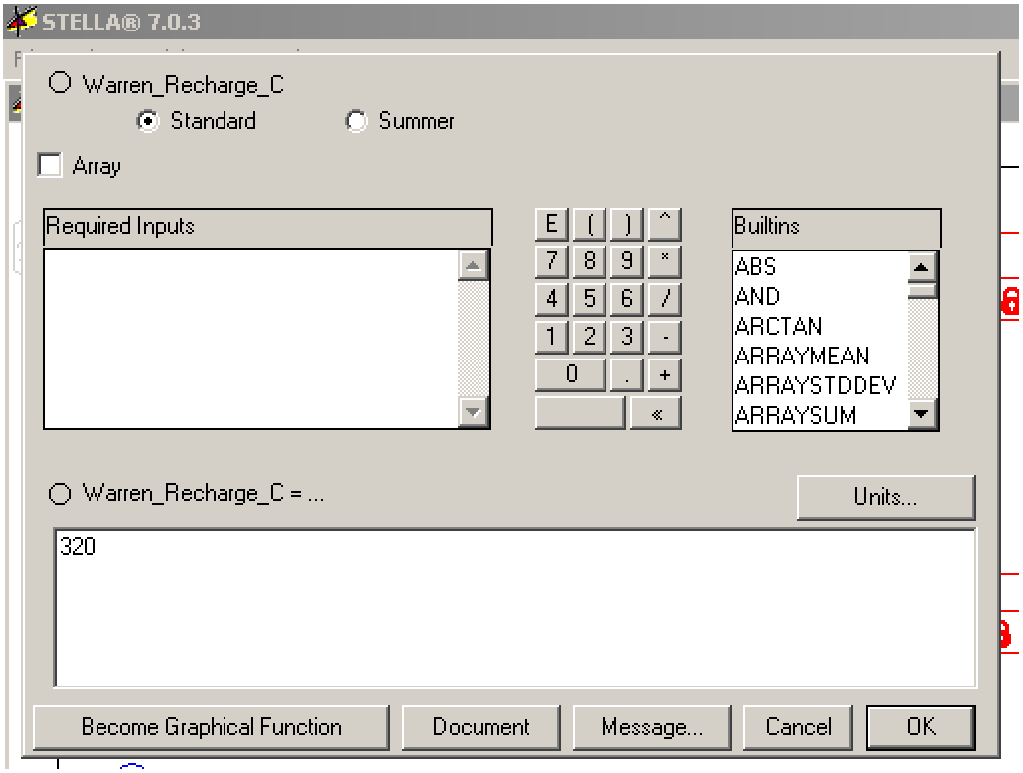
○ Alto_FP_Initial_C = ...

200

Figure 3.13 – Example sub-aquifer unit initial concentration input screen.

Various Water Budget Fixed Concentrations and Concentration Time Series

The initial concentrations of various fixed nodes of the water budget are entered through the *Time Series and Fixed Concentrations* link on the Water Quality Model interface. These inputs include SWP deliveries, return flows, Mojave River inflow, precipitation, etc. Input nodes for fixed water budget nodes are located on 3 pages (Figure 3.8). Double clicking on any of the nodes opens the input window as shown in Figure 3.13. Concentrations are entered in units of mg/L. Known time variant concentration time series may be entered by cut-and-paste into the input dialog box as shown in Figure 3.15.



○ Warren_Recharge_C

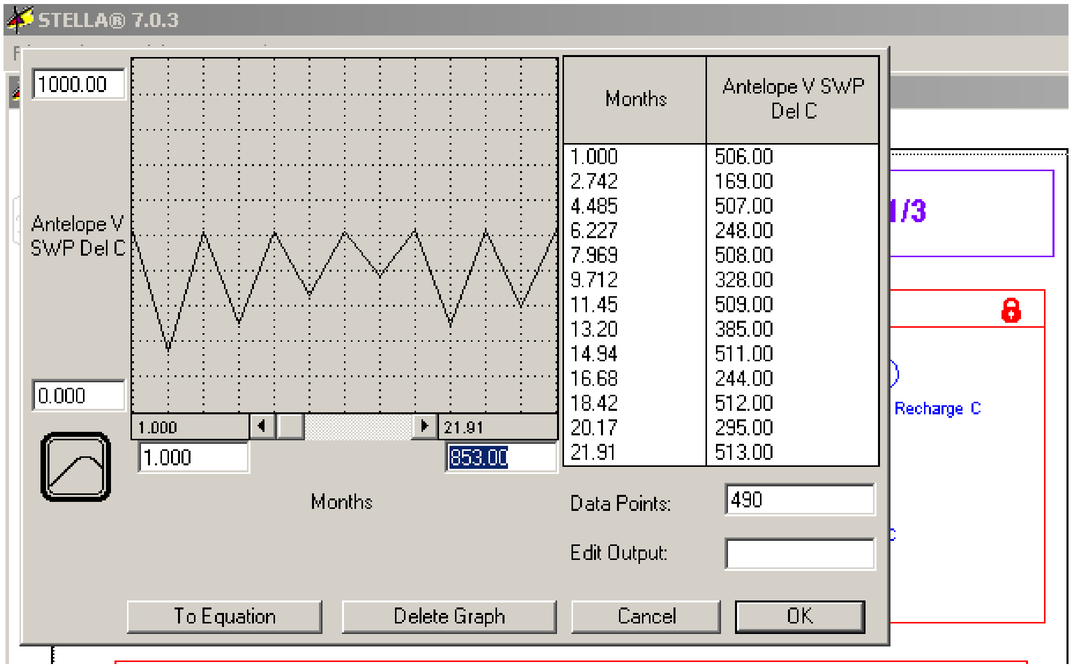
● Standard ○ Summer

☐ Array

○ Warren_Recharge_C = ...

320

Figure 3.14 – Example fixed concentration node concentration input screen.



1000.00

0.000

1.000 – 21.91

1.000 853.00

Months	Antelope V SWP Del C
1.000	506.00
2.742	169.00
4.485	507.00
6.227	248.00
7.969	508.00
9.712	328.00
11.45	509.00
13.20	385.00
14.94	511.00
16.68	244.00
18.42	512.00
20.17	295.00
21.91	513.00

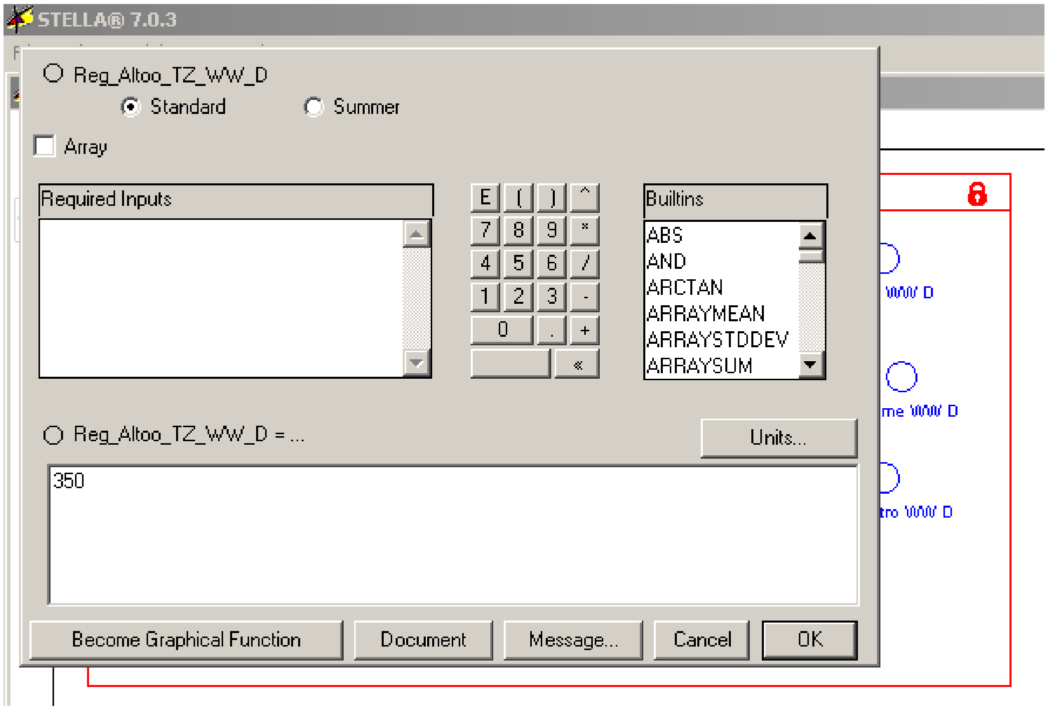
Data Points: 490

Edit Output:

Figure 3.15 – Example fixed node concentration entered with a time series.

New TDS Source/Sink

A new TDS source or sink may be added to the model *Generic Sub-Regional Waste Water Treatment Plant* link on the Ancillary Model Specs interface. Input nodes for discharge volumes are located in the top half of the input view (Figure 3.11). Double clicking on any of the nodes opens the input dialog as shown in Figure 3.16. Volumes are entered in units of acre-feet per month.



○ Reg_Altoo_TZ_WW_D

● Standard ○ Summer

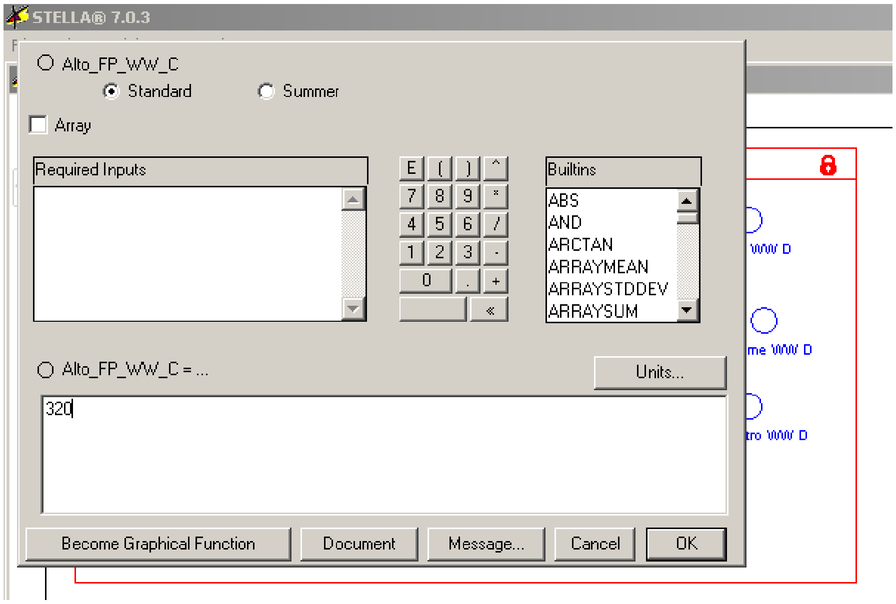
☐ Array

○ Reg_Altoo_TZ_WW_D = ...

350

Figure 3.16 – Example fixed concentration node concentration input screen.

Input nodes for wastewater treatment plant discharge TDS concentrations are located in the bottom half of the input view (Figure 3.11). Double clicking on any of the nodes opens the input dialog as shown in Figure 3.17. Concentrations are entered in units of mg/L.


STELLA® 7.0.3

○ Alto_FP_WW_C

● Standard ○ Summer

☐ Array

○ Alto_FP_WW_C = ...

320

Figure 3.17 – Example fixed concentration node concentration input screen.

3.4 Executing the Water Quality Planning Model

The WQPM is executed through the *Run* pulldown menu of the mail Stella interface shown in Figure 3.18. Execution is complete when the File button on the main interface becomes active. Model execution may be paused and restarted from the *run* pulldown menu. Typical model execution times are roughly 1 minute or less.

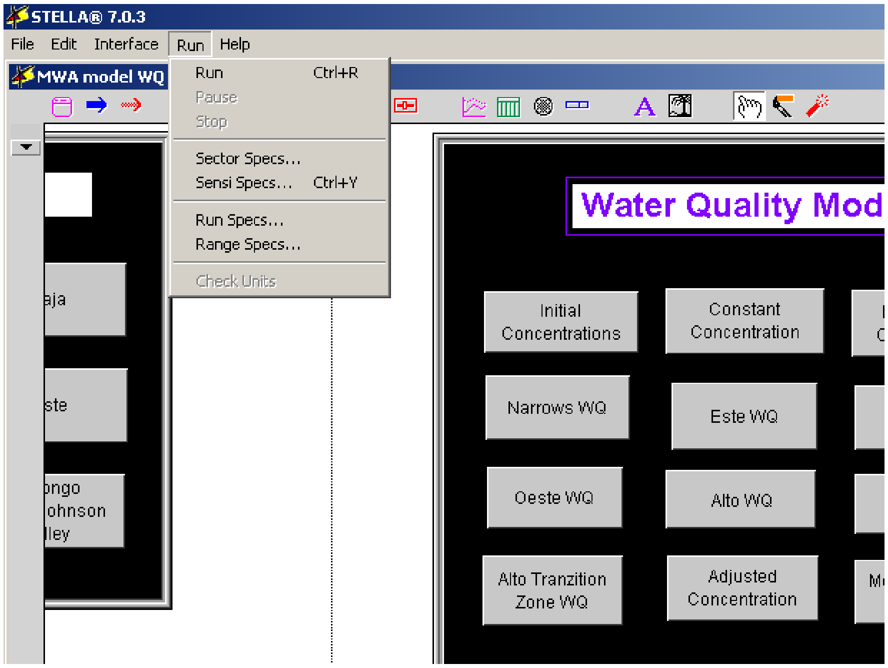


Figure 3.18 – *Run* pulldown **menu of the Stella main interface.**

4

Viewing Results

4.1 Pre-set Tables and Charts

Execution of the WQPM automatically generates several tables and charts for reviewing model run results. These are located immediately below the Water Quality Model interface as shown in Figure 4.1.

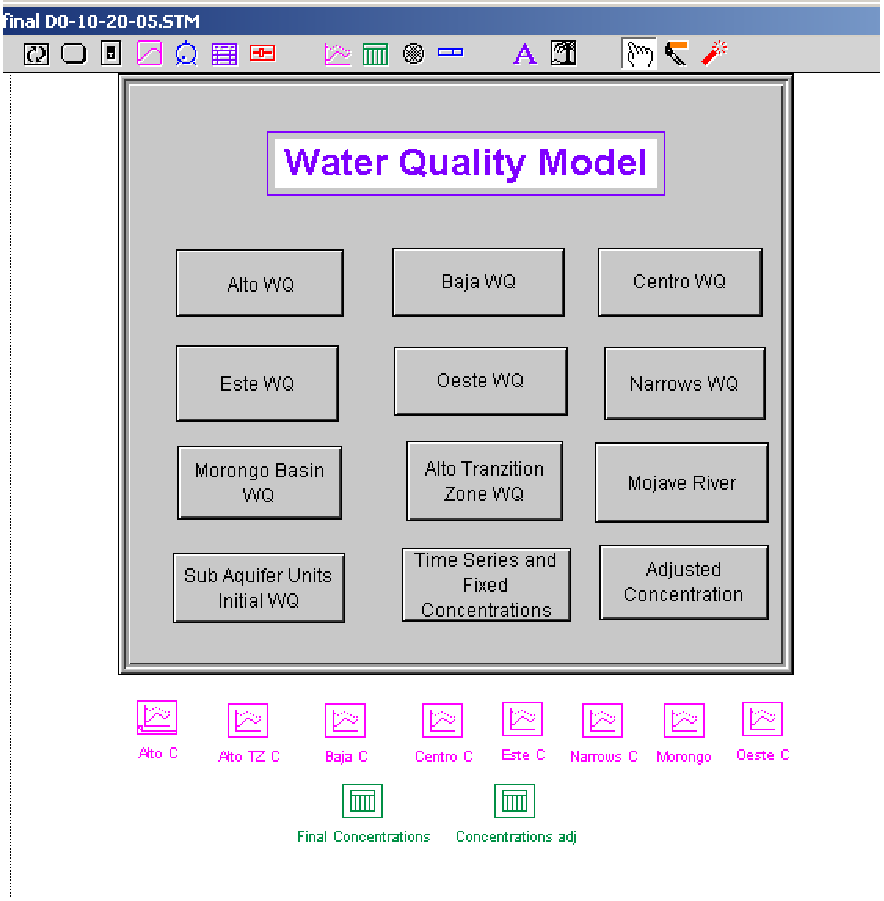


Figure 4.1 – Location of pre-set tables and graphs.

TDS Charts

One TDS variation chart is created for each hydrologic (adjudicated) model sub area and for the Morongo Basin hydrologic model sub area. A chart is viewed by double clicking on the chart icon. Each chart shows the concentrations for each sub aquifer unit in the hydrologic sub area. Charts may be open during model execution and will be automatically updated. An example TDS concentration chart is shown in Figure 4.2.

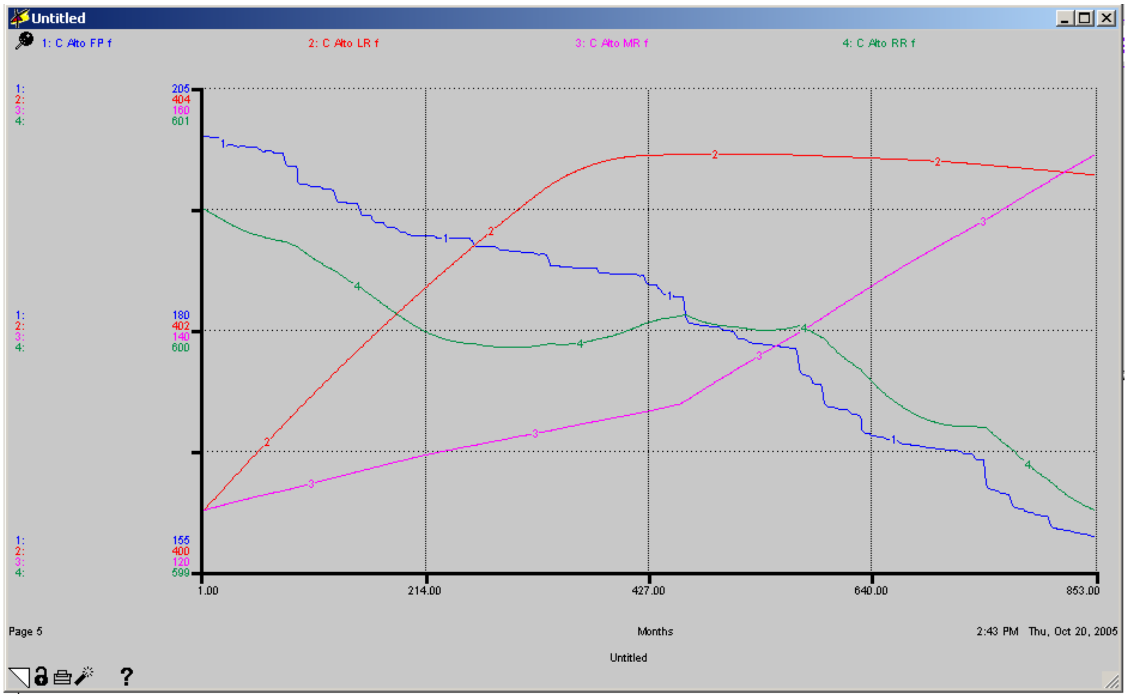
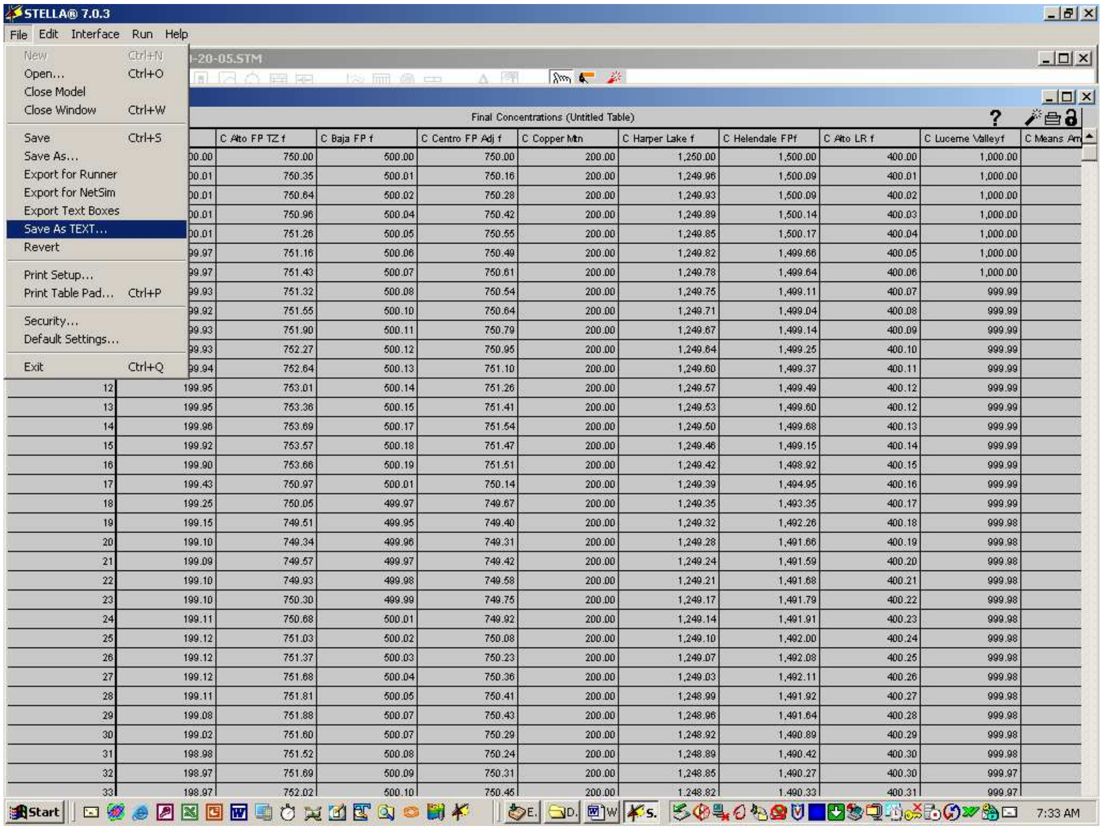


Figure 4.2 – Example pre-set graph of concentration changes for the Alto hydrologic sub area.

TDS Tables

Execution of the WQPM automatically creates a summary table of TDS concentration in each sub-aquifer unit for each model time step. This table may be browsed by double clicking on the chart icon labeled “Final Concentrations”. Tables may be open during execution and will be automatically updated. This table may be exported to an ASCII text file using the *File, Save as Text* pulldown menu commands as shown in Figure 4.3. The table must be open to activate this function.



Final Concentrations (Untitled Table)

		C Alto FP TZ f	C Baja FP f	C Centro FP Adj f	C Copper Mtn	C Harper Lake f	C Helendale FPf	C Alto LR f	C Lucerne Valleyf	C Means Am
	00.00	750.00	500.00	750.00	200.00	1,250.00	1,500.00	400.00	1,000.00	
	00.01	750.35	500.01	750.16	200.00	1,249.96	1,500.09	400.01	1,000.00	
	00.01	750.64	500.02	750.28	200.00	1,249.93	1,500.09	400.02	1,000.00	
	00.01	750.96	500.04	750.42	200.00	1,249.89	1,500.14	400.03	1,000.00	
	00.01	751.26	500.05	750.55	200.00	1,249.85	1,500.17	400.04	1,000.00	
	99.97	751.16	500.06	750.49	200.00	1,249.82	1,499.66	400.05	1,000.00	
	99.97	751.43	500.07	750.61	200.00	1,249.78	1,499.64	400.06	1,000.00	
	99.93	751.32	500.08	750.54	200.00	1,249.75	1,499.11	400.07	999.99	
	99.92	751.55	500.10	750.64	200.00	1,249.71	1,499.04	400.08	999.99	
	99.93	751.90	500.11	750.79	200.00	1,249.67	1,499.14	400.09	999.99	
	99.93	752.27	500.12	750.95	200.00	1,249.64	1,499.25	400.10	999.99	
	99.94	752.64	500.13	751.10	200.00	1,249.60	1,499.37	400.11	999.99	
12	199.95	753.01	500.14	751.26	200.00	1,249.57	1,499.49	400.12	999.99	
13	199.95	753.36	500.15	751.41	200.00	1,249.53	1,499.60	400.12	999.99	
14	199.96	753.69	500.17	751.54	200.00	1,249.50	1,499.68	400.13	999.99	
15	199.92	753.57	500.18	751.47	200.00	1,249.46	1,499.15	400.14	999.99	
16	199.90	753.66	500.19	751.51	200.00	1,249.42	1,498.92	400.15	999.99	
17	199.43	750.97	500.01	750.14	200.00	1,249.39	1,494.95	400.16	999.99	
18	199.25	750.05	499.97	749.67	200.00	1,249.35	1,493.35	400.17	999.99	
19	199.15	749.51	499.95	749.40	200.00	1,249.32	1,492.26	400.18	999.98	
20	199.10	749.34	499.96	749.31	200.00	1,249.28	1,491.66	400.19	999.98	
21	199.09	749.57	499.97	749.42	200.00	1,249.24	1,491.59	400.20	999.98	
22	199.10	749.93	499.98	749.58	200.00	1,249.21	1,491.68	400.21	999.98	
23	199.10	750.30	499.99	749.75	200.00	1,249.17	1,491.79	400.22	999.98	
24	199.11	750.68	500.01	749.92	200.00	1,249.14	1,491.91	400.23	999.98	
25	199.12	751.03	500.02	750.08	200.00	1,249.10	1,492.00	400.24	999.98	
26	199.12	751.37	500.03	750.23	200.00	1,249.07	1,492.08	400.25	999.98	
27	199.12	751.68	500.04	750.36	200.00	1,249.03	1,492.11	400.26	999.98	
28	199.11	751.81	500.05	750.41	200.00	1,248.99	1,491.92	400.27	999.98	
29	199.08	751.88	500.07	750.43	200.00	1,248.96	1,491.64	400.28	999.98	
30	199.02	751.60	500.07	750.29	200.00	1,248.92	1,490.89	400.29	999.98	
31	198.98	751.52	500.08	750.24	200.00	1,248.89	1,490.42	400.30	999.98	
32	198.97	751.69	500.09	750.31	200.00	1,248.85	1,490.27	400.30	999.97	
33	198.97	752.02	500.10	750.45	200.00	1,248.82	1,490.33	400.31	999.97	

Figure 4.3 – Example pre-set table of concentrations for all sub-aquifer units at all model time steps.

4.2 Creating User Defined Charts and Tables

The user may easily create custom charts or tables of model results through the Stella interface.

Creating a Custom Table

To create a custom table, first click the green *Table Pad* icon on the Stella toolbar as shown in Figure 4.1 and insert the table model by clicking in the desired location. This will automatically open a blank table as shown in Figure 4.5.

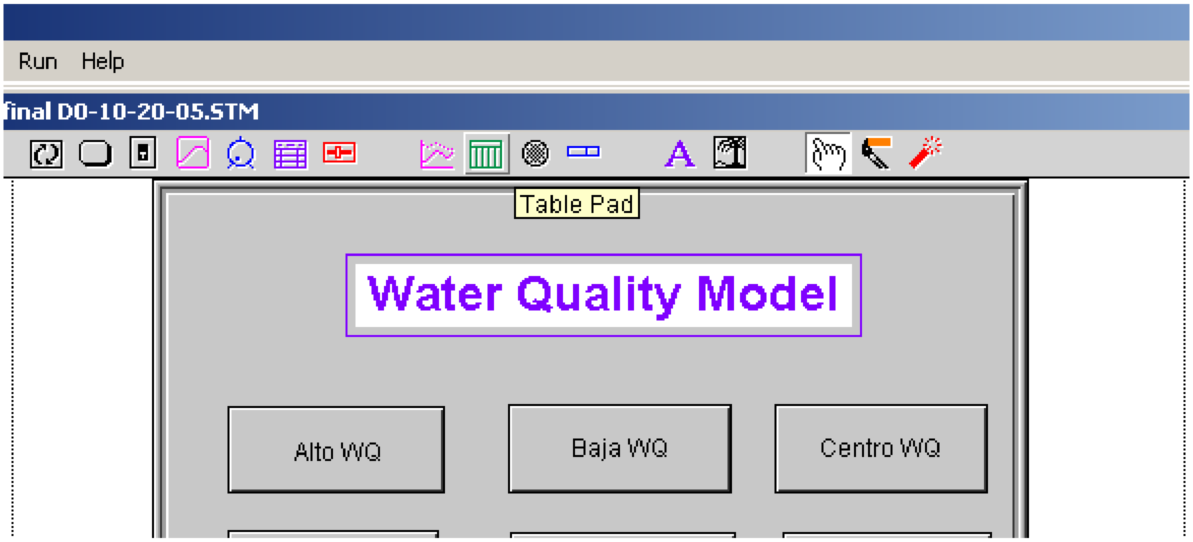


Figure 4.4 – Location of the green *Table Pad* icon on the user interface.

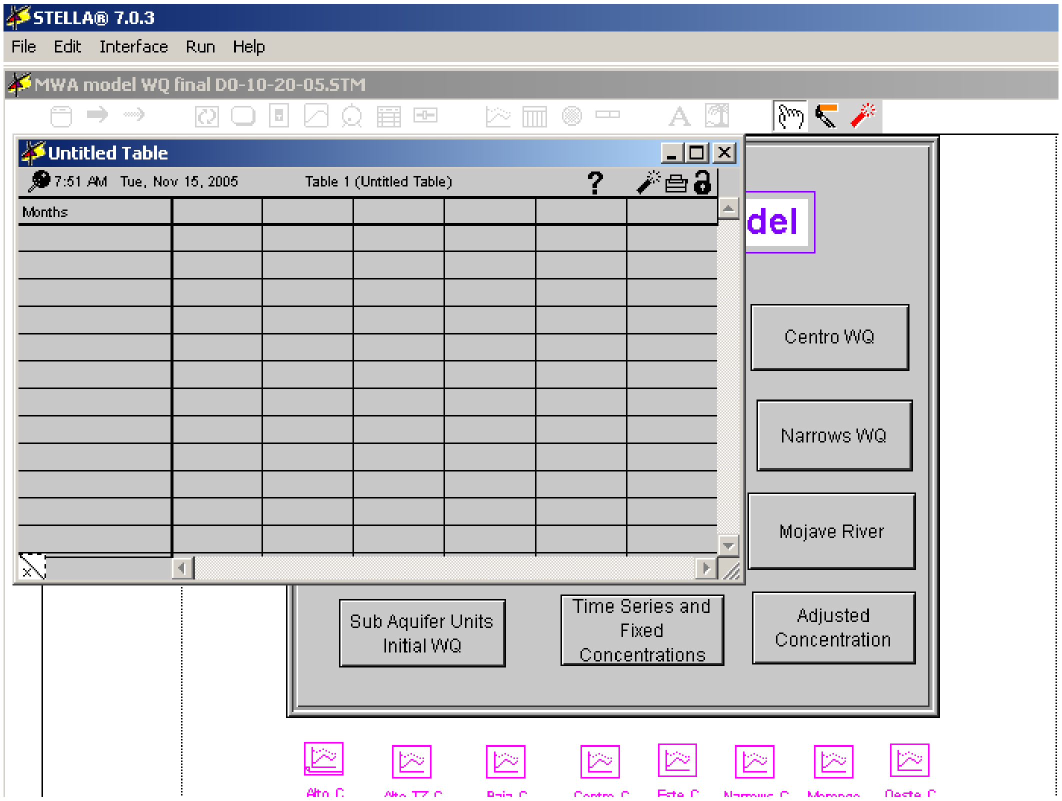
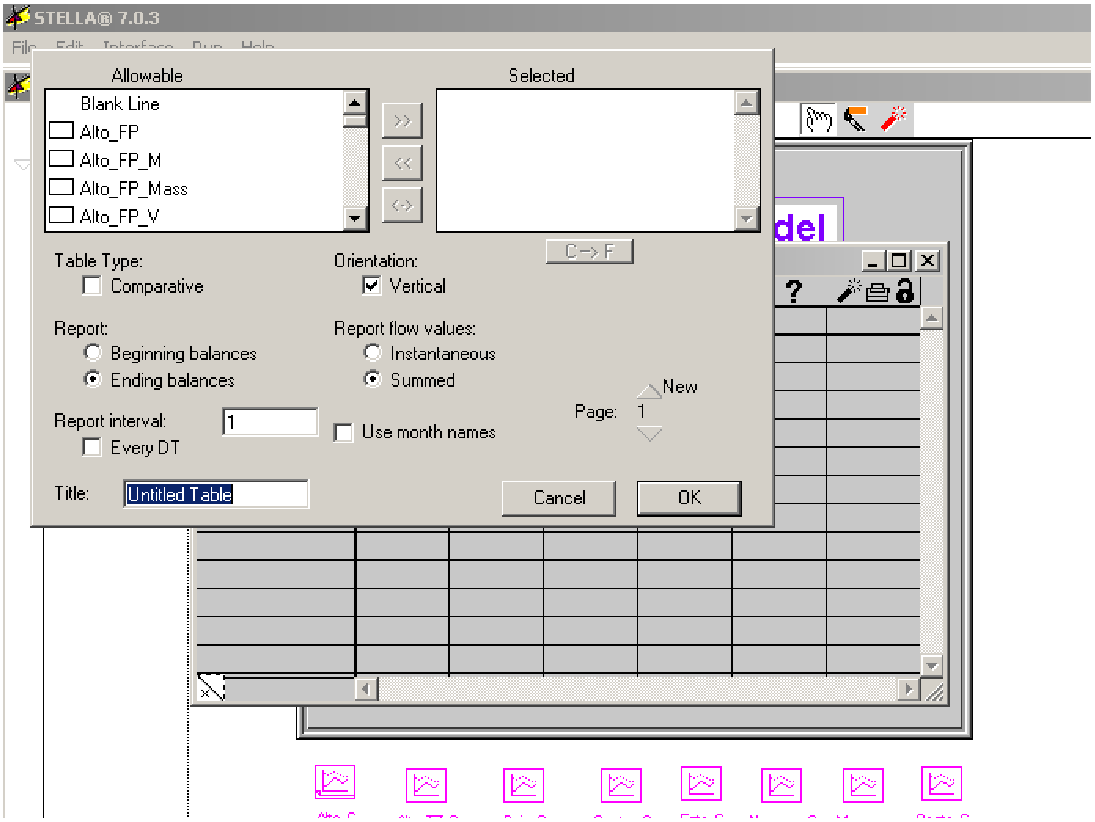


Figure 4.5 – Blank Table Pad.

To add new elements to the table, double click anywhere in the open Table Pad. This will open a data selection interface as shown in Figure 4.6. Select the desired model element in the left hand window of the data selection interface and then click the “>>” button (Figure 4.7). When finished, close the data selection interface window by clicking “OK”. The contents of the new table will be updated during the next model execution.



Allowable:
- Blank Line
- Alto_FP
- Alto_FP_M
- Alto_FP_Mass
- Alto_FP_V

Table Type: ☐ Comparative

Orientation: ☑ Vertical

Report: ○ Beginning balances ● Ending balances

Report flow values: ○ Instantaneous ● Summed

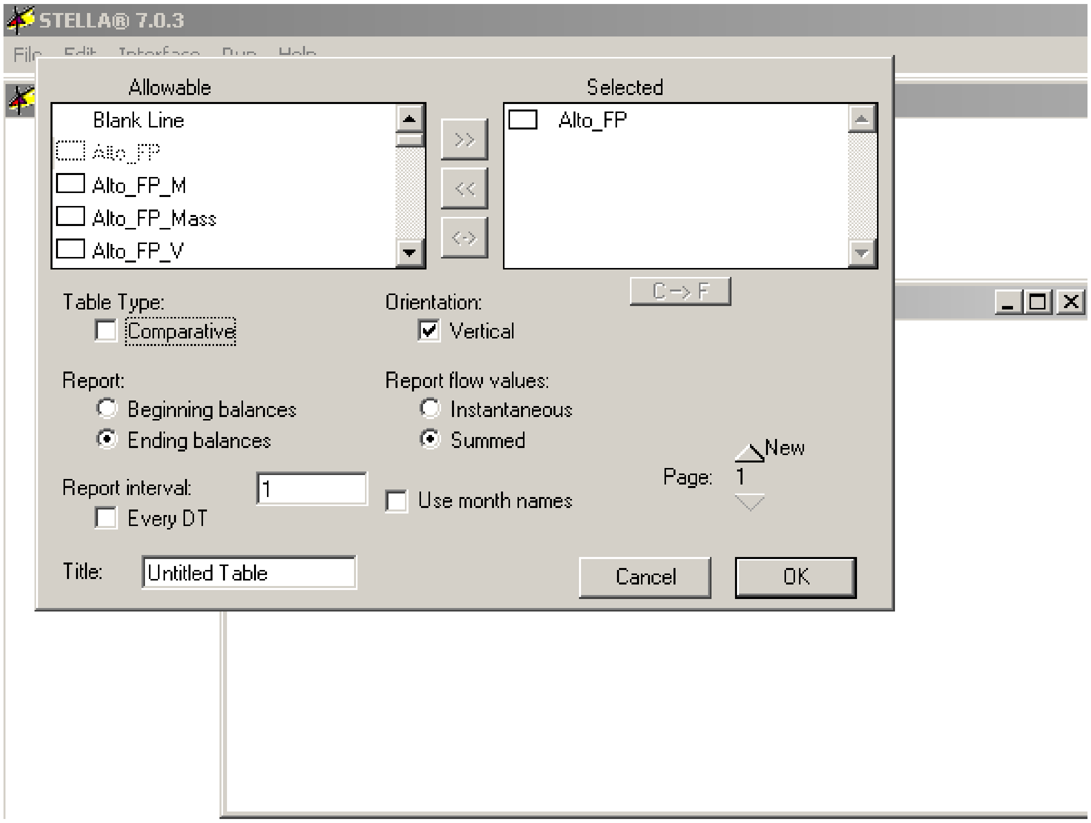
Report interval: 1 ☐ Every DT

☐ Use month names

Page: 1 New

Title: Untitled Table

Figure 4.6 – Table data selection interface.



Allowable:
- Blank Line
- ☐ Alto_FP
- ☐ Alto_FP_M
- ☐ Alto_FP_Mass
- ☐ Alto_FP_V

Selected:
- ☐ Alto_FP

Table Type: ☐ Comparative

Orientation: ☑ Vertical

Report: ○ Beginning balances ● Ending balances

Report flow values: ○ Instantaneous ● Summed

Report interval: 1

☐ Every DT

☐ Use month names

Page: 1

Title: Untitled Table

Figure 4.7 – Selecting new data for the table.

Creating a Custom Graph

To create a custom graph, first click the magenta *Graph Pad* icon on the Stella toolbar as shown in Figure 4.8 and insert the table model by clicking in the desired location. This will automatically open a blank graph as shown in Figure 4.9.

Figure 4.7 – Location of the magenta *Graph Pad* icon on the user interface.

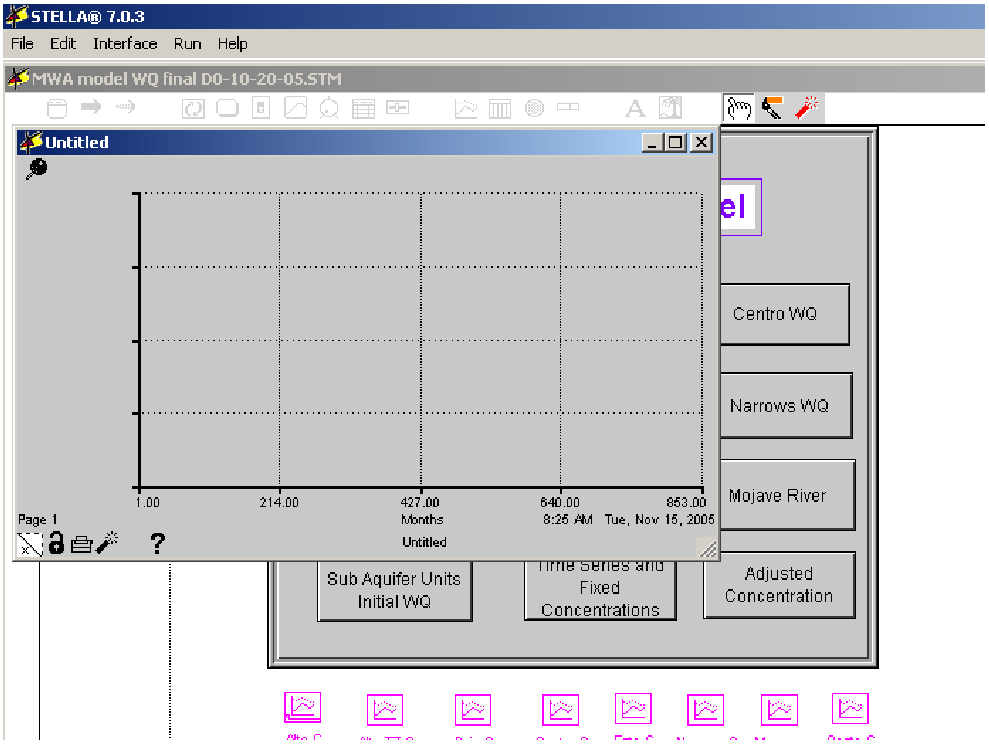
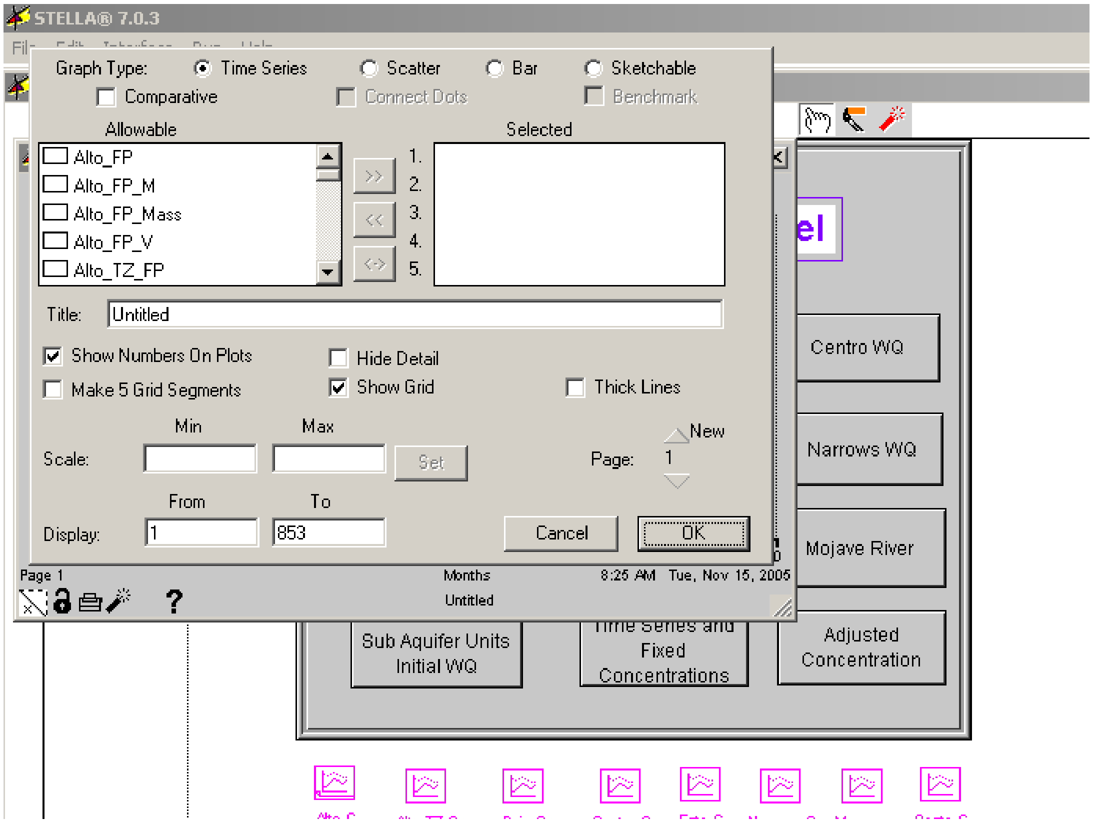


Figure 4.9 – Blank Graph Pad.

To add new elements to the graph, double click anywhere in the open Graph Pad. This will open a data selection interface as shown in Figure 4.10. Select the desired model element in the left hand window of the data selection interface and then click the “>>” button. When finished, close the data selection interface window by clicking “OK”. The contents of the new graph will be updated during the next model execution.

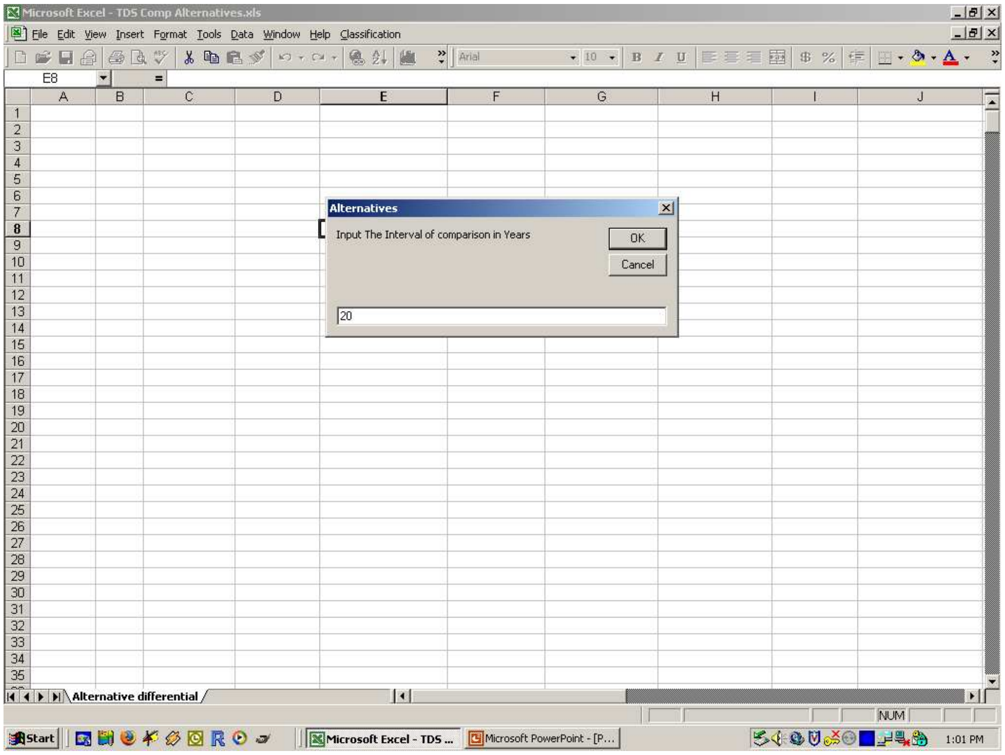


Graph Type: ● Time Series ○ Scatter ○ Bar ○ Sketchable
☐ Comparative ☐ Connect Dots ☐ Benchmark
Title: Untitled
☑ Show Numbers On Plots ☐ Hide Detail
☐ Make 5 Grid Segments ☑ Show Grid ☐ Thick Lines
Scale: Min Max
Page: 1
Display: From 1 To 853

Figure 4.10 – Graph data selection interface.

Alternative Comparison Post-Processing Macro

An Excel macro has been provided with the WQPM to facilitate comparison of management alternatives by means of post-processing the results exported from multiple management alternative model runs. The macro requires one base (reference) model case file and one or more management alternative model output files for comparison. The required files are exported from the concentrations table as described in the previous section describing the use of TDS Tables for each individual alternative model runs. TDS changes in each sub-aquifer unit relative to the Base Case are reported by the macro in tabular format for each planning alternative. Comparative results are reported at a user defined time interval. The macro is implemented in autoexec mode in the excel spreadsheet. Upon opening the excel file the user will be prompted to select the time interval in years for output summary comparison (Figure 4.11). A value of 20-25 years is recommended.



Input The Interval of comparison in Years

20

Figure 4.11 – Alternatives comparison macro prompt for output summary interval.

The user will next be prompted to select the Base Case model output file (Figure 4.12), exported from the concentrations table of a Base Case model run. Next, the user will be prompted to input the number of alternatives to be compared to the Base Case. Finally, the user will be prompted to the model output files for each of the alternatives (Figure 4.13).

Figure 4.14 shows an example of the comparison summary tables created by the post-processing macro. A worksheet is created for each management alternative evaluated. The change in TDS from the Base Case is reported for each output time for each sub-aquifer unit. Results are reported in two ways;

1. Raw Data Report – TDS concentration is reported for the Base Case and each management alternative.
2. Quality Degradation Report – The value of the change in TDS concentration relative to the Base Case is reported for each management alternative is reported.
3. MCL Referenced report – The difference between the model result and the MCL for TDS (1000 mg/L) is reported for the Base Case and each management alternative.

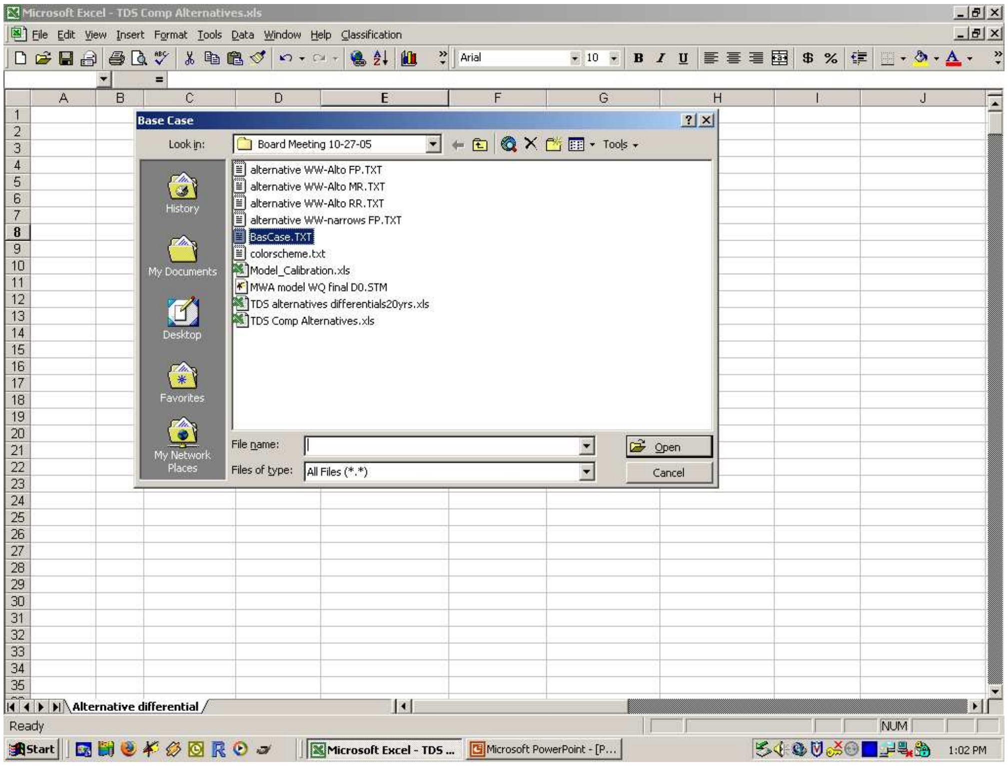


Figure 4.12 – Alternatives comparison macro prompt for selection of Base Case model output file.

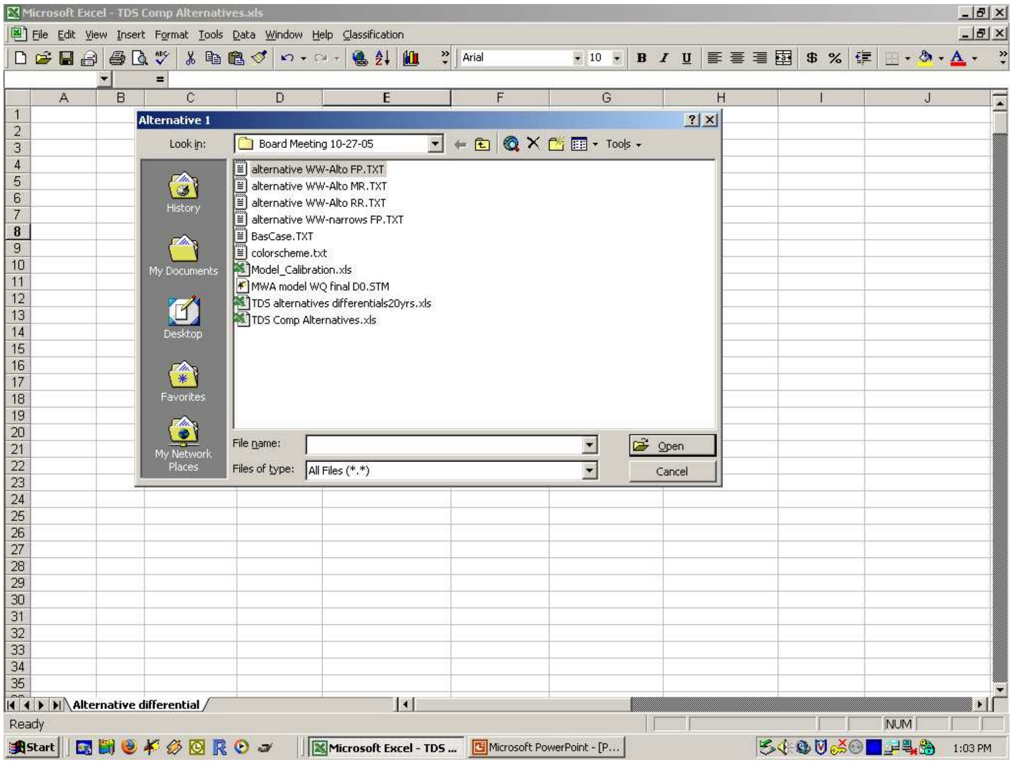
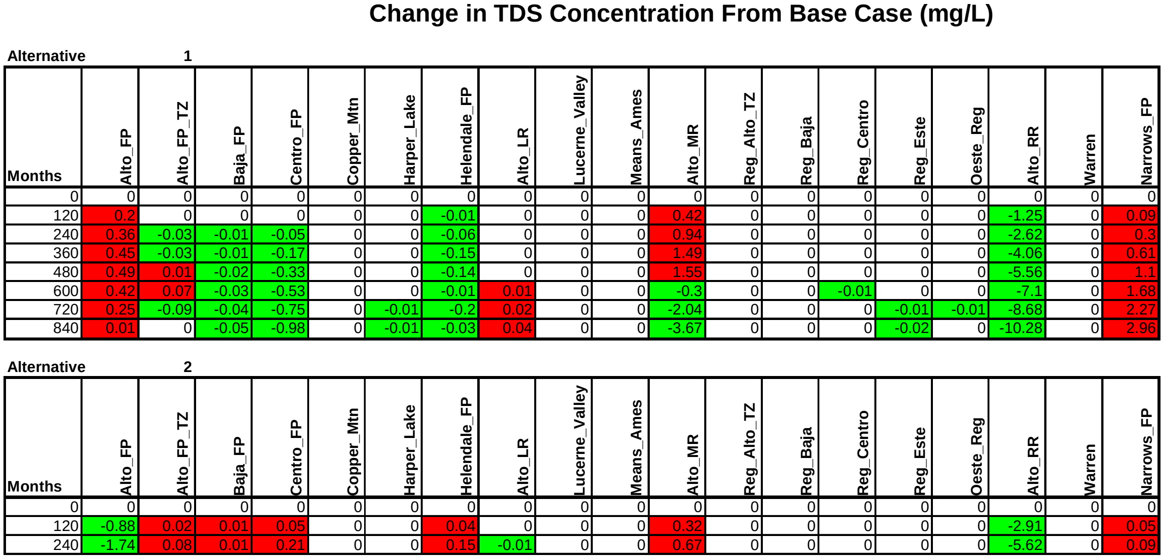


Figure 4.13 – Alternatives comparison macro prompt for selection of alternative case model output file.



Change in TDS Concentration From Base Case (mg/L)

Alternative **1**

Months	Alto_FP	Alto_FP_TZ	Baja_FP	Centro_FP	Copper_Mtn	Harper_Lake	Helendale_FP	Alto_LR	Lucerne_Valley	Means_Ames	Alto_MR	Reg_Alto_TZ	Reg_Baja	Reg_Centro	Reg_Este	Oeste_Reg	Alto_RR	Warren	Narrows_FP
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
120	0.2	0	0	0	0	0	-0.01	0	0	0	0.42	0	0	0	0	0	-1.25	0	0.09
240	0.36	-0.03	-0.01	-0.05	0	0	-0.06	0	0	0	0.94	0	0	0	0	0	-2.62	0	0.3
360	0.45	-0.03	-0.01	-0.17	0	0	-0.15	0	0	0	1.49	0	0	0	0	0	-4.06	0	0.61
480	0.49	0.01	-0.02	-0.33	0	0	-0.14	0	0	0	1.55	0	0	0	0	0	-5.56	0	1.1
600	0.42	0.07	-0.03	-0.53	0	0	-0.01	0.01	0	0	-0.3	0	0	-0.01	0	0	-7.1	0	1.68
720	0.25	-0.09	-0.04	-0.75	0	-0.01	-0.2	0.02	0	0	-2.04	0	0	0	-0.01	-0.01	-8.68	0	2.27
840	0.01	0	-0.05	-0.98	0	-0.01	-0.03	0.04	0	0	-3.67	0	0	0	-0.02	0	-10.28	0	2.96

Alternative **2**

Months	Alto_FP	Alto_FP_TZ	Baja_FP	Centro_FP	Copper_Mtn	Harper_Lake	Helendale_FP	Alto_LR	Lucerne_Valley	Means_Ames	Alto_MR	Reg_Alto_TZ	Reg_Baja	Reg_Centro	Reg_Este	Oeste_Reg	Alto_RR	Warren	Narrows_FP
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
120	-0.88	0.02	0.01	0.05	0	0	0.04	0	0	0	0.32	0	0	0	0	0	-2.91	0	0.05
240	-1.74	0.08	0.01	0.21	0	0	0.15	-0.01	0	0	0.67	0	0	0	0	0	-5.62	0	0.09

Figure 4.14 – Example of the Quality Degradation Report summary table.

GIS Map Display

Results from the alternatives comparison macro may be exported for map display using any GIS system. Recommended modes of display are;

1. Raw Data Plot – Map view of MWA area with sub-aquifer unit polygons gradationally shaded by the values from the raw data report, high values shaded in hot colors, low values shaded in cool colors. One map for the Base Case and for each management alternative. Color scale limits are identical for all maps.
2. Quality Degradation Data Plot – Map view of MWA area with sub-aquifer unit polygons gradationally shaded by the values from the degradation report, positive changes shaded in hot colors, negative changes shaded in cool colors, zero change white. One map per management alternative. Color scale limits are identical for all maps.
3. MCL Referenced Data Plot – Map view of MWA area with sub-aquifer unit polygons gradationally shaded by the values from the MCL reference report, positive deviation from MCL shaded in hot colors, negative deviation from MCL shaded in cool colors, zero deviation from MCL white. One map each for the Base Case and management alternatives. Color scale limits are identical for all maps.

5

Model Sensitivity Analysis

5.1 Overview

The user may investigate the sensitivity of model results to any of the input parameters such as flow rates, volumes, and input node TDS concentrations. Multiple model runs are executed automatically. Parameter values for each run may be selected based on specified range upper and lower limits, or on random selection from either normal or uniform distribution with user defined population statistics. The results of multiple model runs may be displayed automatically in line charts, scatter charts, and pie charts, or output to a table.

5.2 Running Sensitivity Analysis

Sensitivity analysis runs are set up using the *Sensi Specs* option on the *Run* pulldown of the Stella toolbar. Figure 5.1 shows an example of the *Sensi Specs* setup interface.

Selecting Sensitivity Parameters

The user first selects the parameter to vary in the sensitivity run from the parameter list on the left hand side of the window by hi-lighting the desired parameter and pressing “>>” to move it to the right hand side of the window (Figure 5.2). Multiple parameters may be varied in a single sensitivity analysis although this makes interpretation of results more difficult.

Parameter Variations

Parameter variations are set up by hi-lighting one of the selected parameters in the right hand list. This activates the parameter variation controls located in the lower part of the *Sensi Specs* interface as seen in Figure 5.2. After inputting parameter variation specification data click *Set* on the *Sensi Specs* interface.

Setting Up a Sensitivity Graph

Selecting the *Graph* button on the *Sensi Specs* interface activates the graph data selection interface (Figure 5.3). Select the desired graphical data objects from the left hand list by hi-lighting the data element and clicking “>>”. When finished click *OK* on the graph data selection interface. A blank graph will be displayed.

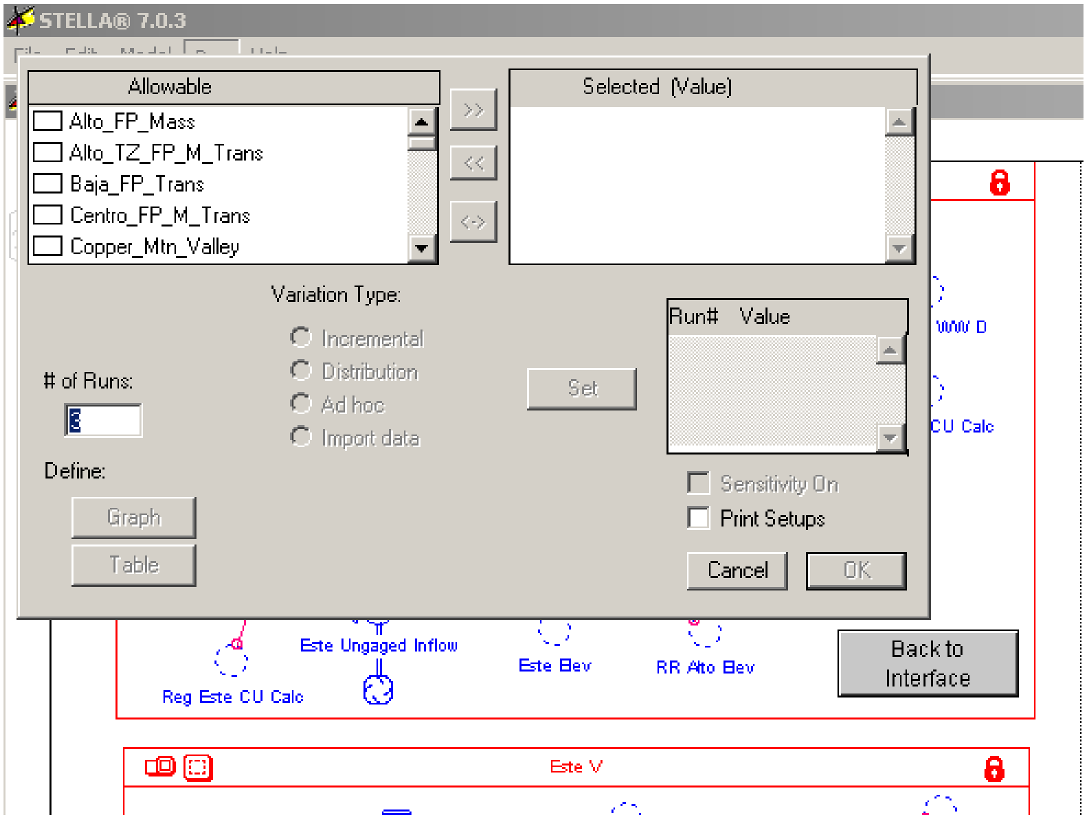
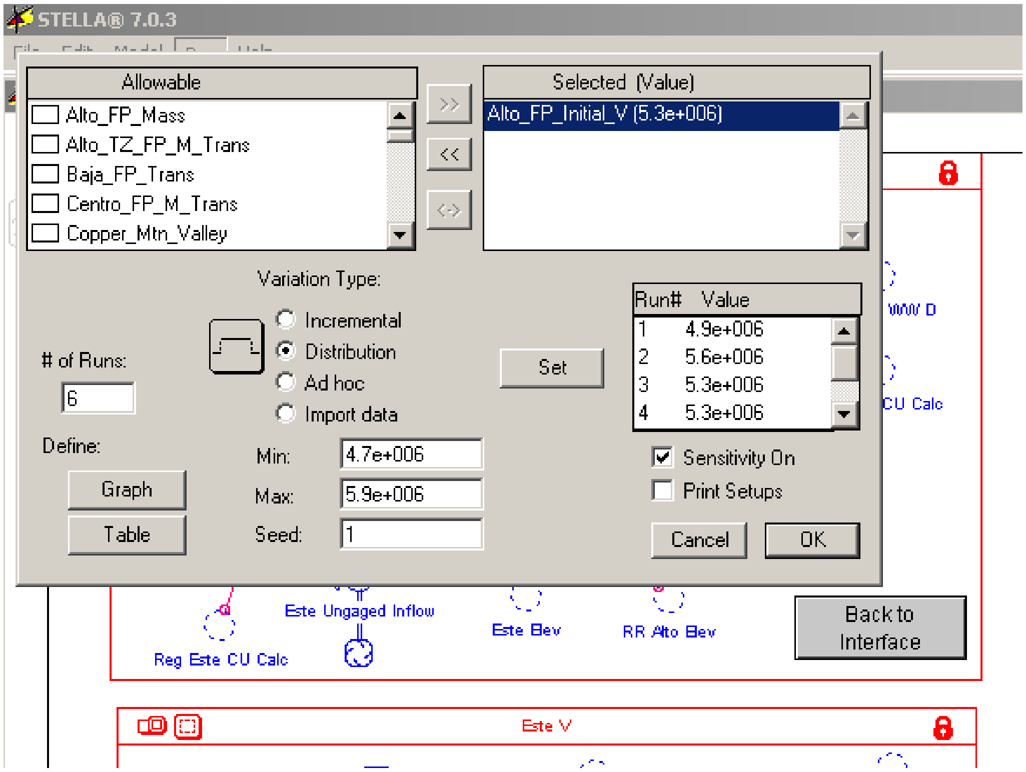


Figure 5.1 – Sensi Specs interface.



Allowable:
- ☐ Alto_FP_Mass
- ☐ Alto_TZ_FP_M_Trans
- ☐ Baja_FP_Trans
- ☐ Centro_FP_M_Trans
- ☐ Copper_Mtn_Valley

Selected (Value): Alto_FP_Initial_V (5.3e+006)

Variation Type:
- ○ Incremental
- ● Distribution
- ○ Ad hoc
- ○ Import data

# of Runs: 6

Min: 4.7e+006

Max: 5.9e+006

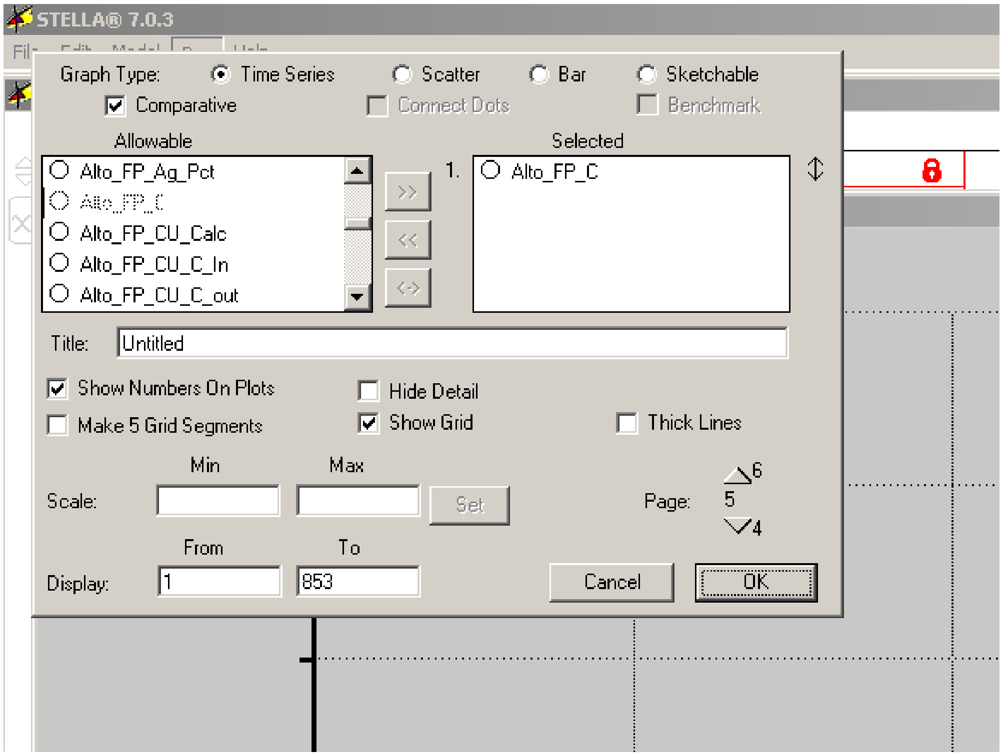
Seed: 1

Run#	Value
1	4.9e+006
2	5.6e+006
3	5.3e+006
4	5.3e+006

☑ Sensitivity On

☐ Print Setups

Figure 5.2 – *Sensi Specs* interface with activated parameter variation controls.



Graph Type: ● Time Series ○ Scatter ○ Bar ○ Sketchable

☑ Comparative ☐ Connect Dots ☐ Benchmark

Allowable:
- ○ Alto_FP_Ag_Pct
- ○ Alto_FP_C
- ○ Alto_FP_CU_Calc
- ○ Alto_FP_CU_C_In
- ○ Alto_FP_CU_C_out

Selected:
1. ○ Alto_FP_C

Title: Untitled

☑ Show Numbers On Plots ☐ Hide Detail

☐ Make 5 Grid Segments ☑ Show Grid ☐ Thick Lines

Scale: Min Max

Display: From 1 To 853

Figure 5.3 – Sensitivity graph setup interface.

Executing the Sensitivity Run

The sensitivity run is executed from the *S-Run* option on the *Run* pulldown of main Stella interface toolbar. Figure shows an example of the graphical result from a sensitivity run set up to investigate the effect of initial sub-aquifer unit volume on computed TDS concentration for the Alto Floodplain sub-aquifer unit. Data may also be output in tabular format.

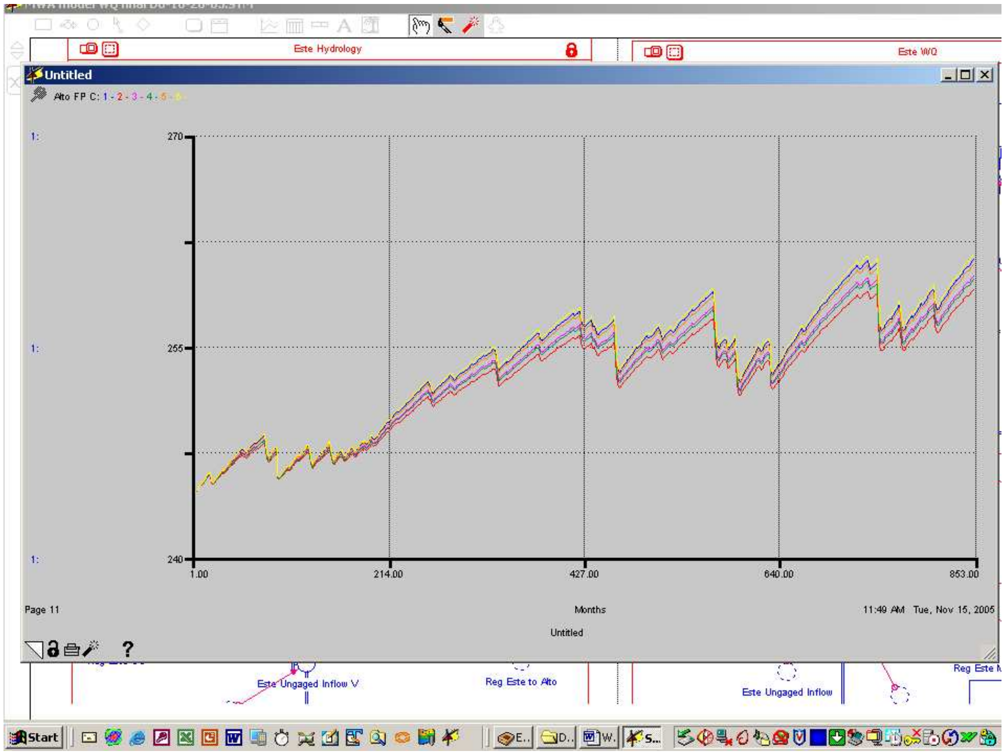


Figure 5.4 – Sensitivity run graphical result.

Attachment A

Tutorial

Tutorial Exercise

Sub-Regional Water Treatment Plants

A.1 Overview

In this tutorial various alternatives will be explored for placement of a sub-regional waste water treatment plant in the Alto subarea. The alternatives explore placement of the plant in 4 different sub-aquifer units within the Alto area. The water for the treatment plant will be taken from Alto septic returns. In each alternative the treated water is returned to the groundwater system in the sub aquifer unit containing the treatment plant (assuming infiltration ponds).

This exercise will involve 1 Base Case run and 4 alternative model runs. Hypothetical sub-regional wastewater treatment plants will be placed in the Alto Floodplain, Alto Right Regional, Alto Mid-Regional, and Narrows sub-aquifer units. Water to these treatment plants will be diverted from septic returns in Hesperia and Apple Valley. Quality of the discharge from the Victor Valley wastewater treatment plant will be used for quality of the discharge from sub-regional treatment plants. This tutorial will illustrate set-up and execution of the appropriate WQPM models, followed by post-processing spreadsheet analysis. The files used in this tutorial will be found in the “tutorial” folder.

A.2 Model Set-Up and Execution

Base Case

The Base Case for this example is provided in the tutorial folder and is named “base.stm”. Although the Base Case does not need to be altered for this example, it will be instructive to navigate the model to inspect the current parameters for the two sections of the model that will be altered during alternative runs. These are the septic returns and the regional wastewater treatment plants.

Septic Returns – To inspect the current settings for septic return flow in Alto;

1. Open the BASE.STM model and go to the Water Balance Model Interface (Figure A1-1).

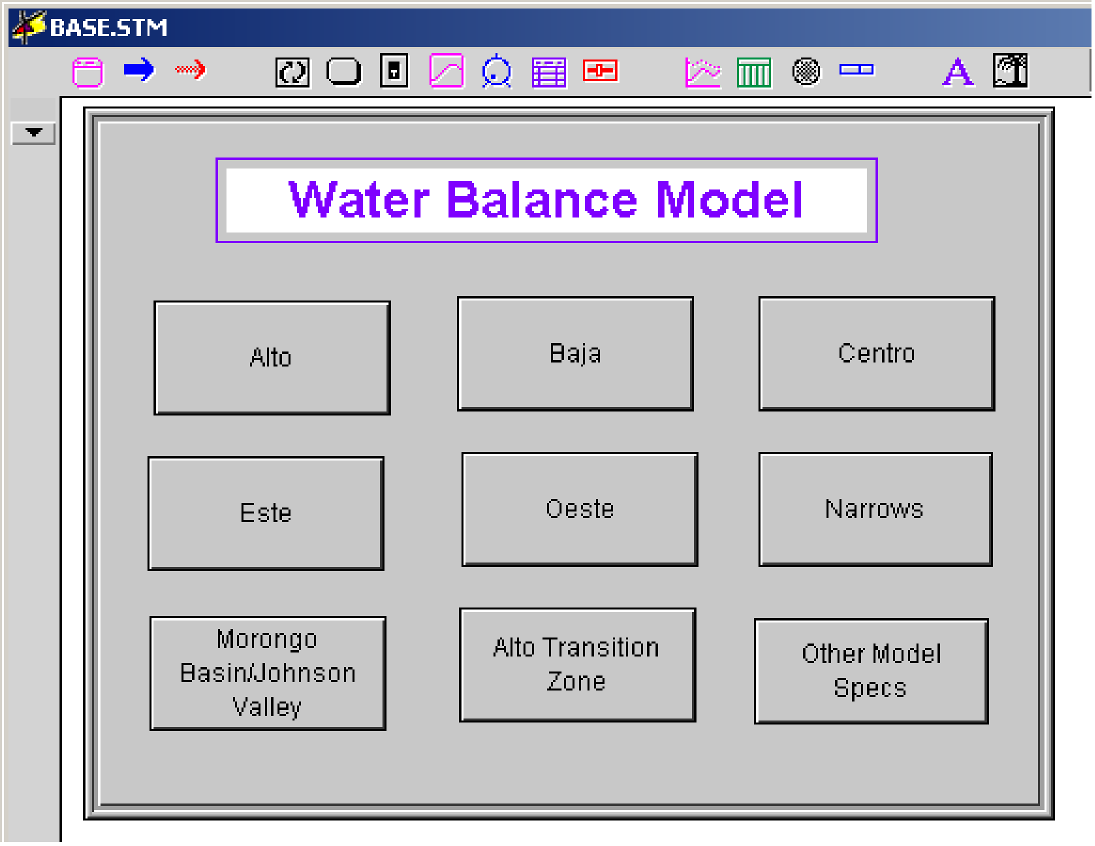


Figure A1-2 – Water Balance Model Interface

2. Select “Alto” to go to the Alto Hydrology Page (Figure A1-2)

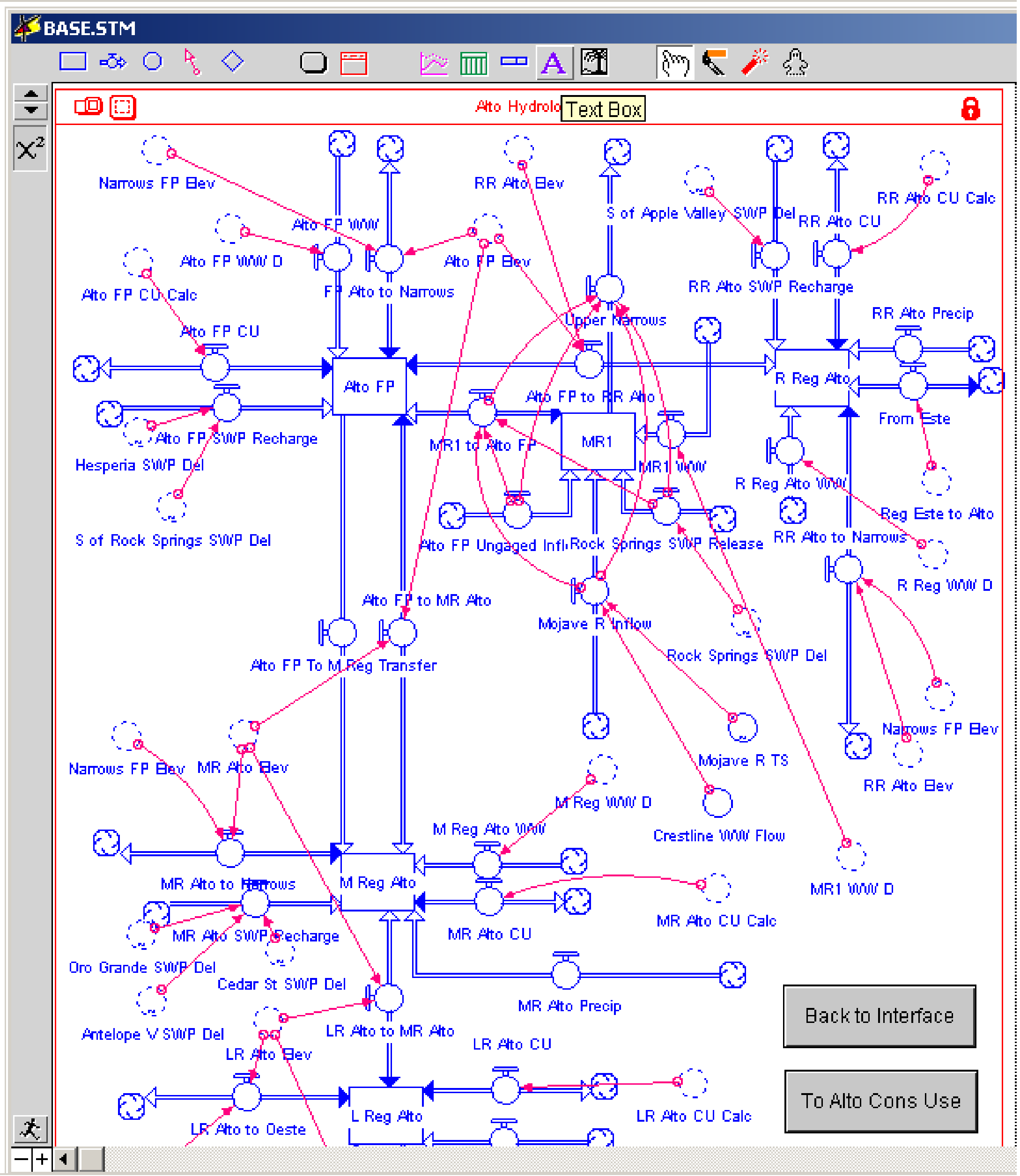


Figure A1-2 – Alto Hydrology Interface

3. Select “To Alto Cons Use” to go to the consumptive use calculation page (Figure A1-3).

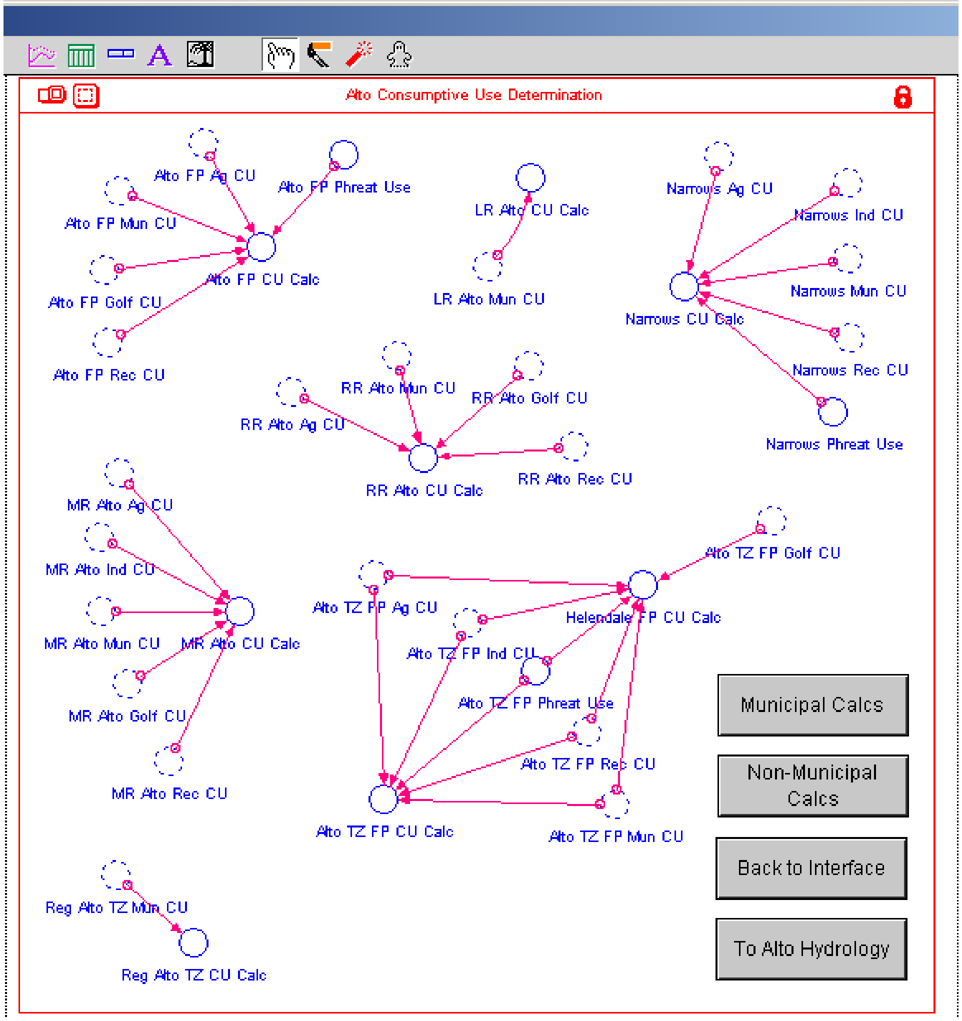


Figure A1-3 – Alto Consumptive Use calculations.

4. Select “Municipal Calcs” to go to the municipal consumptive use calculation page (Figure A1-4).

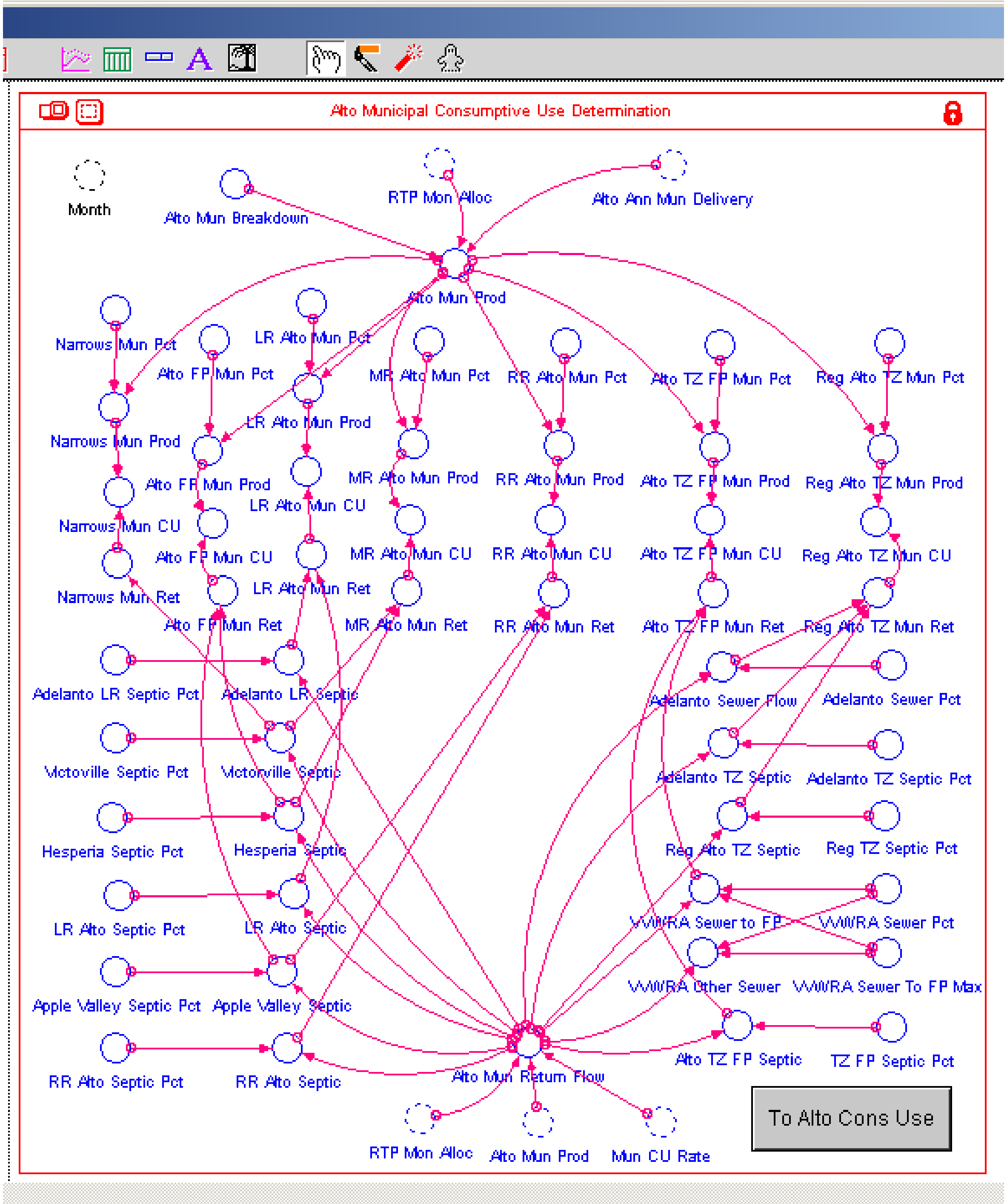
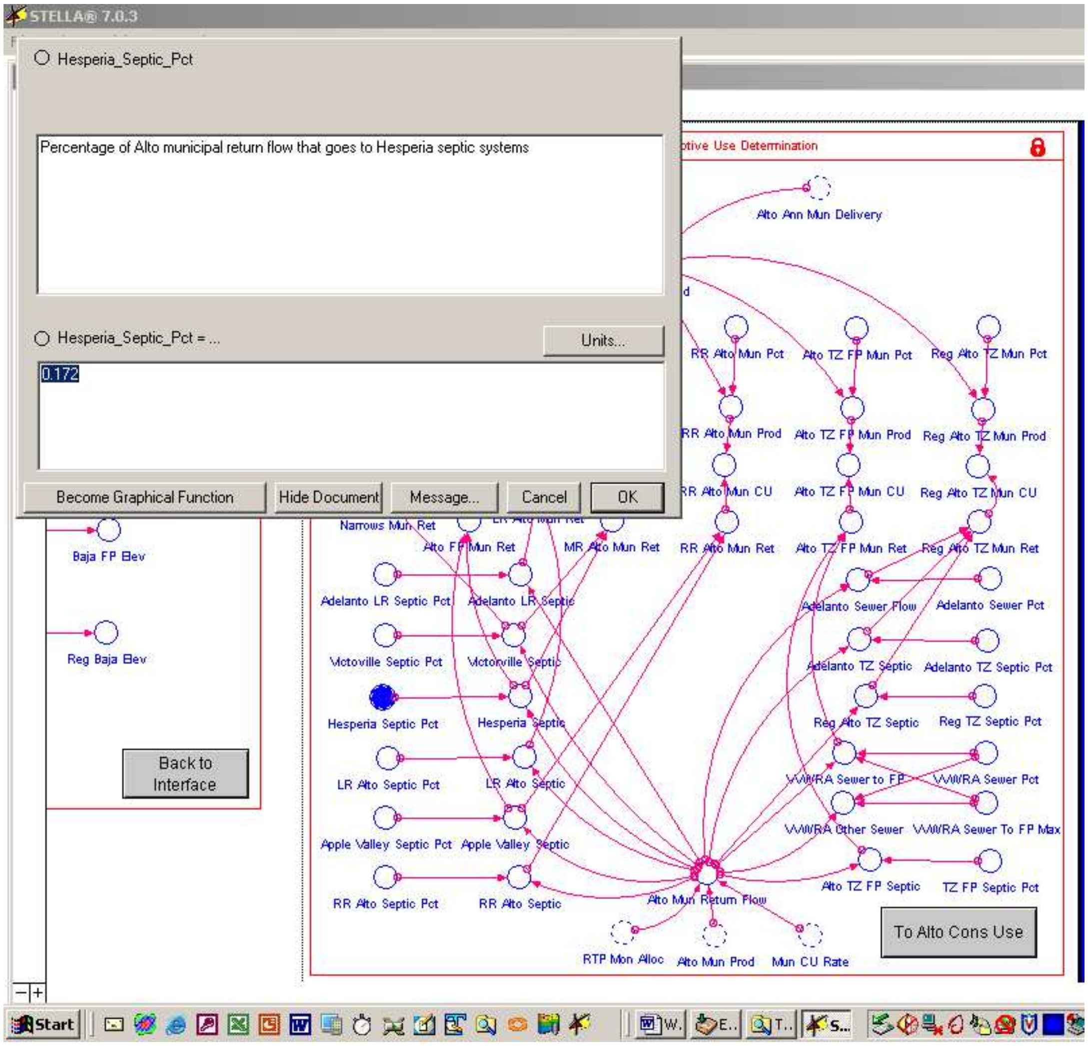


Figure A1-4 – Alto municipal consumptive use calculations.

5. Double click on “Hesperia Septic PCT” to inspect the percentage of Alto return flows going to septic systems in Hesperia (Figure A1-5). These are the default values for the Base Case. Close this window without change.

6. Click on “Alto Cons Use” and “Back To Interface” to return to the Water Balance Model Interface.



○ Hesperia_Septic_Pct

Percentage of Alto municipal return flow that goes to Hesperia septic systems

○ Hesperia_Septic_Pct = ...

0.172

Figure A1-5 – Hesperia septic return percentage.

Regional Wastewater Treatment Plants **–** To inspect the current settings for regional wastewater treatment plants:

1. Open the BASE .STM model and go to the Ancillary Model Specs Interface using the horizontal slider bar (Figure A1-6).

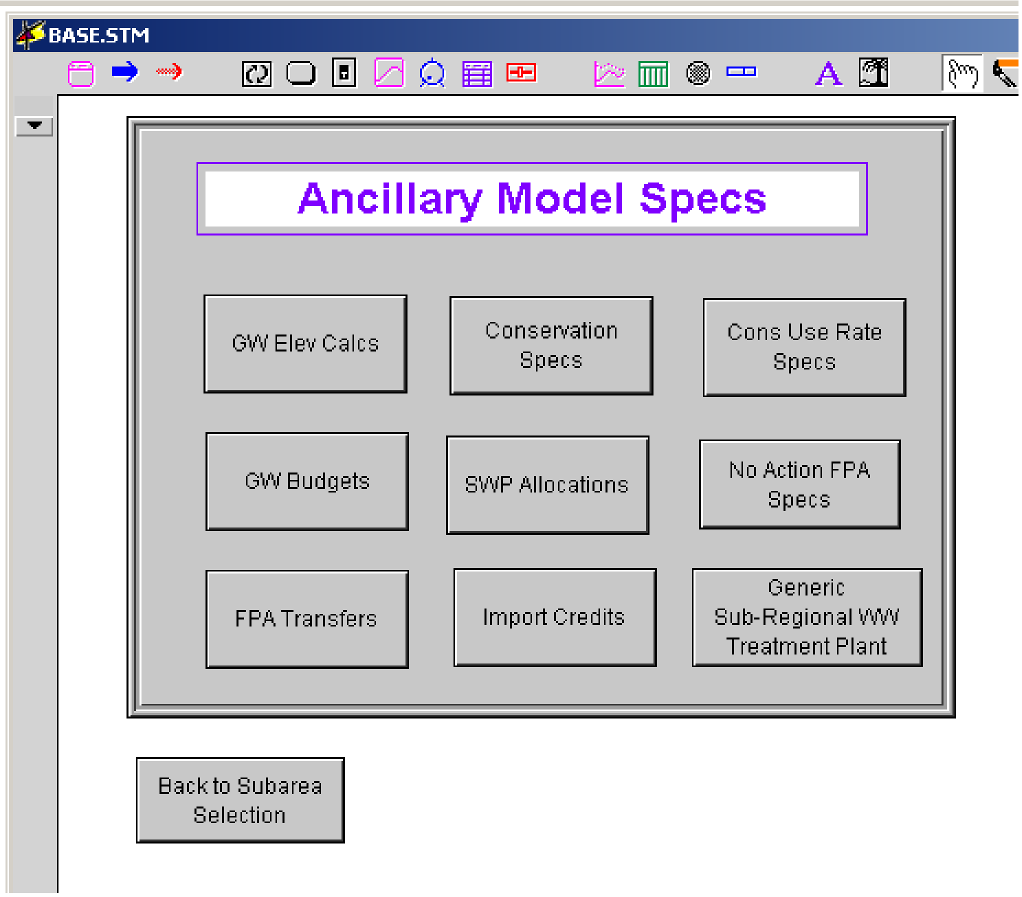


Figure A1-6 – Ancillary Model Specs Interface.

2. Select “Generic Sub-Regional WW Treatment Plant” to go to the input page for treatment plant parameters (Figure A1-7). You will see input nodes for volumes (top) and qualities (bottom) of discharges from wastewater treatment plants for each sub-aquifer unit. Double click the “Alto FP WW D” volume node. Double check that the value is set to zero. Double check that the discharge volume is set to zero for each sub-aquifer unit. This may also be done by holding the pointer over the node, resulting in display of the current parameter value without opening the node interface. Select “Back to Interface”.

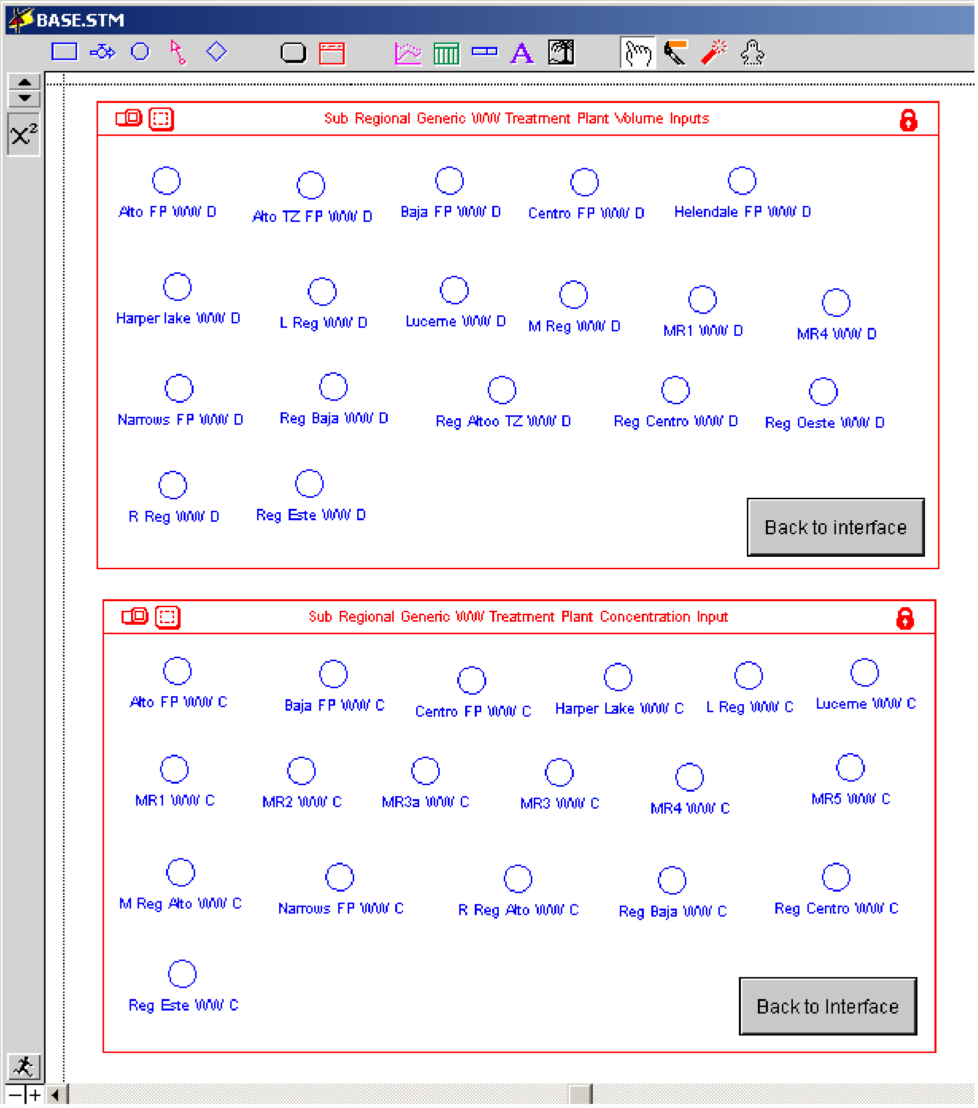


Figure A1-7 – Generic Sub-Regional Wastewater Treatment Plant interface.

3. The base model is now ready to run through the Run pulldown option from the main Stella toolbar. After the run is finished navigate to the “Water Balance Model” interface page and open the table pad named “Final Concentrations”. Save this file as a text file named “Base.txt” Use the File=> Save As pulldown.

Alternative Cases

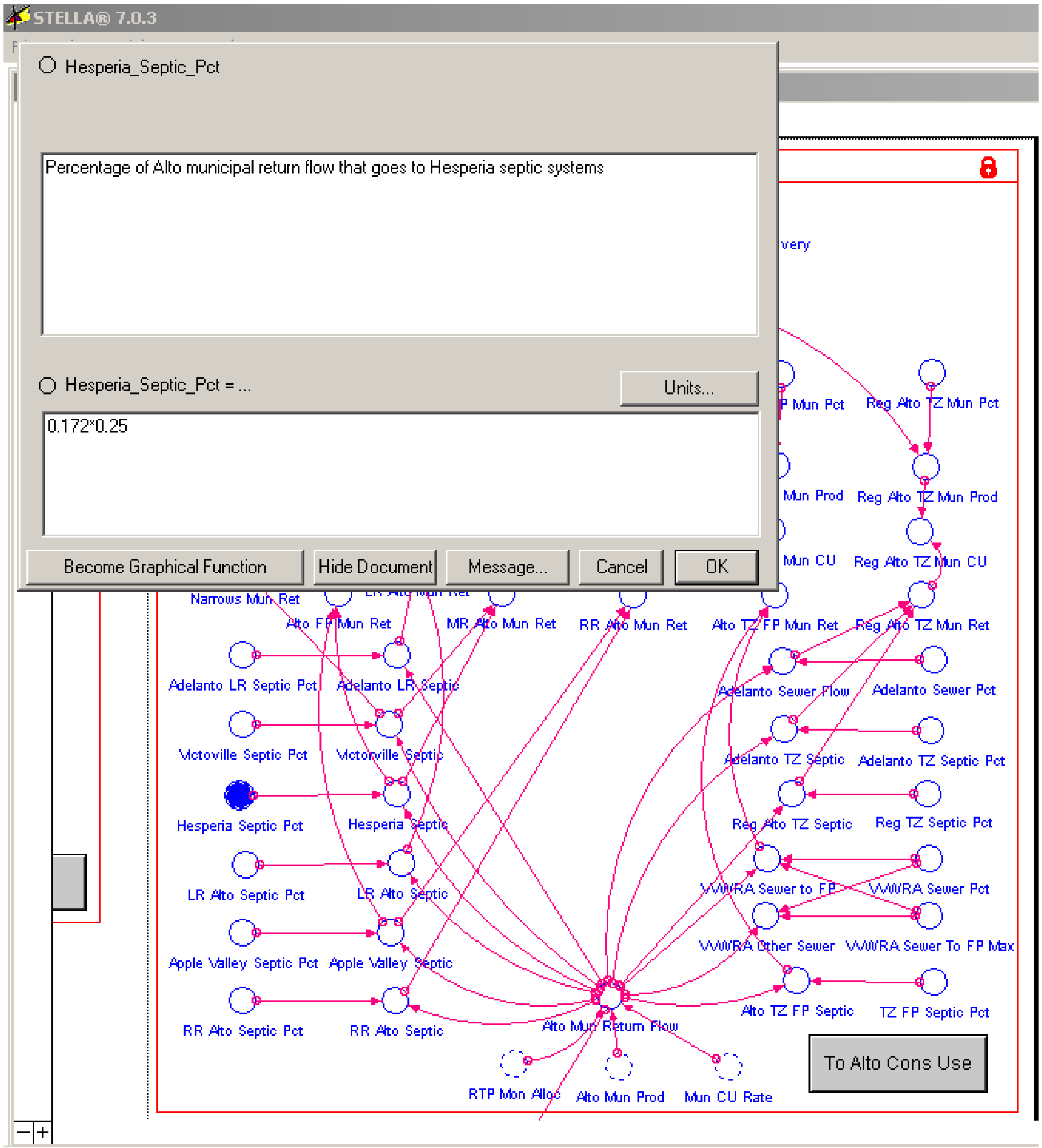
The alternative case for this example is provided in the tutorial folder and is named “ALTERNATIVE.stm”. Although the all 4 alternatives are easily created through successive simple modifications to this single file. The following procedure will describe verifying the reduction of Alto septic returns, followed by implementation of the 4 different regional treatment plant model nodes.

Septic Returns – To inspect the settings for septic return flow in Alto;

1. Open the ALTERNATIVE.STM model and go to the Water Balance Model Interface.
2. Navigate to the Municipal Consumptive Use interface page using the procedure described in steps 2-5 of Section A1.1 (Base Case).
3. Double click on the “Hesperia Septic PCT” node. Note the factor of 0.25 applied to the original percentage of 0.172 used in the base model (Figure A1-8). Confirm similar modification to the “Apple Valley Septic PCT” node. These modifications reduce septic returns.
4. At the bottom part of the page find the node labeled “Alto Sb Reg TP”. This is a calculation of the amount of water diverted from septic returns which will be sent to the sub regional wastewater treatment plants in our alternative cases. Placing the cursor over this node will display the result. Write this number down for later use.

Sub-Regional Wastewater Treatment Plants – To implement sub-regional wastewater treatment plants;

1. Navigate to the Generic Sub Regional Wastewater Treatment Plant interface page using the procedure described in step 2 of Section A1.1 (Alternative Cases).
2. To implement the Alto Floodplain sub-regional wastewater treatment plant double click on the node labeled “Alto_FP_WW_D”. Enter the discharge volume recorded in step 4 above and click OK (Figure A1-9).



○ Hesperia_Septic_Pct

Percentage of Alto municipal return flow that goes to Hesperia septic systems

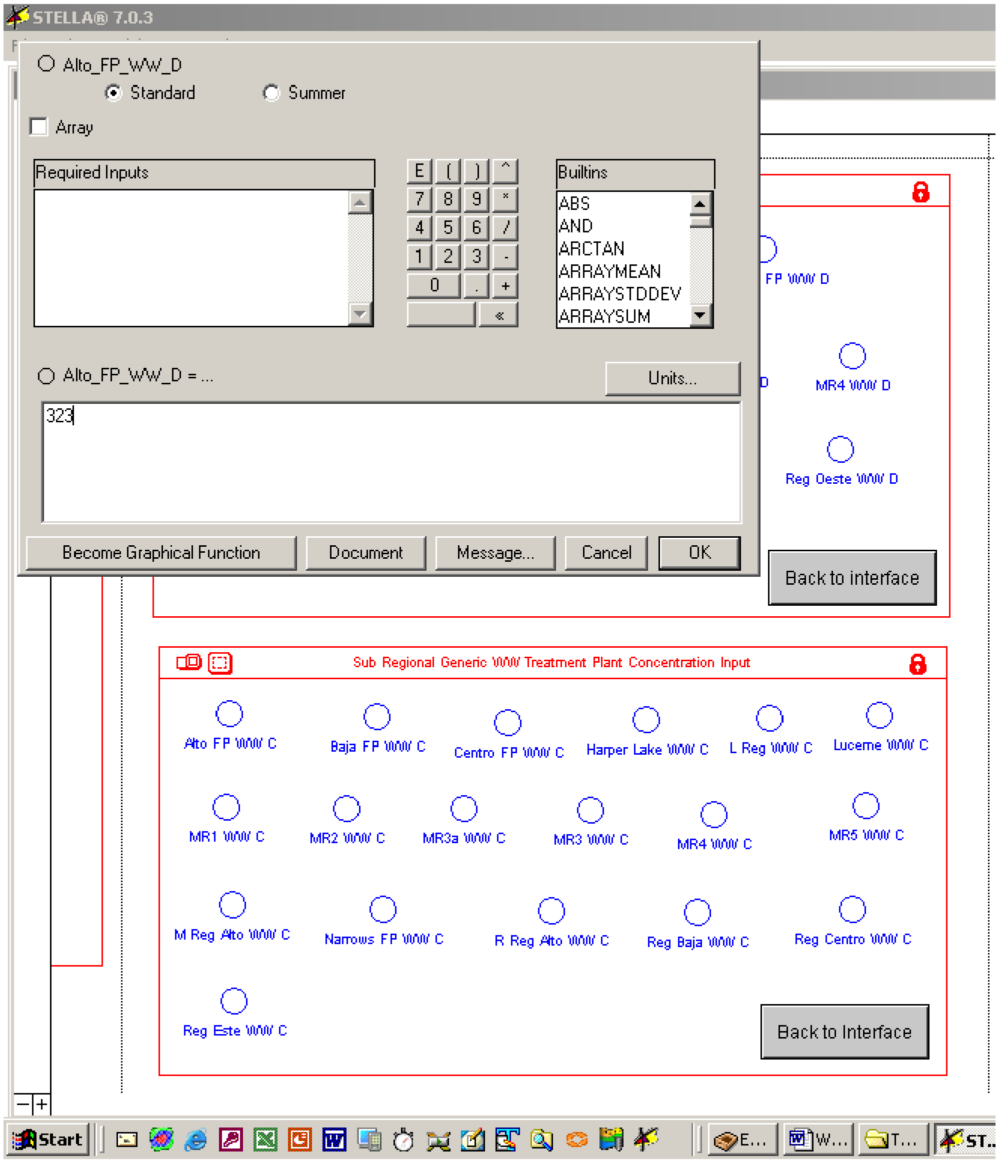
○ Hesperia_Septic_Pct = ...

0.172*0.25

Figure A1-8 – Hesperia septic returns reduced for diversion to sub-regional wastewater treatment plant.

3. To enter the water quality for the Alto Floodplain sub-regional wastewater treatment plant double click on the node labeled “Alto_FP_WW_C”, enter 348, and Click “OK” (Figure A1-10).
4. You are now ready to run the first alternative case model through the main Run pulldown on the main Stella interface toolbar.

5. After the run is finished navigate to the “Water Balance Model” interface page and open the table pad named “Final Concentrations”. Save this file as a text file named “Alto_FP_RTP.txt” Use the File=> Save As pulldown.
6. Repeat steps 1-5 above for Alto Right Regional, Alto Mid Regional, and Narrows sub-aquifer units. Be sure to reset the treatment plant discharge volume from the previous alternative to 0 for each new alternative run and give appropriate names for each export performed in step 5.



○ Alto_FP_WW_D

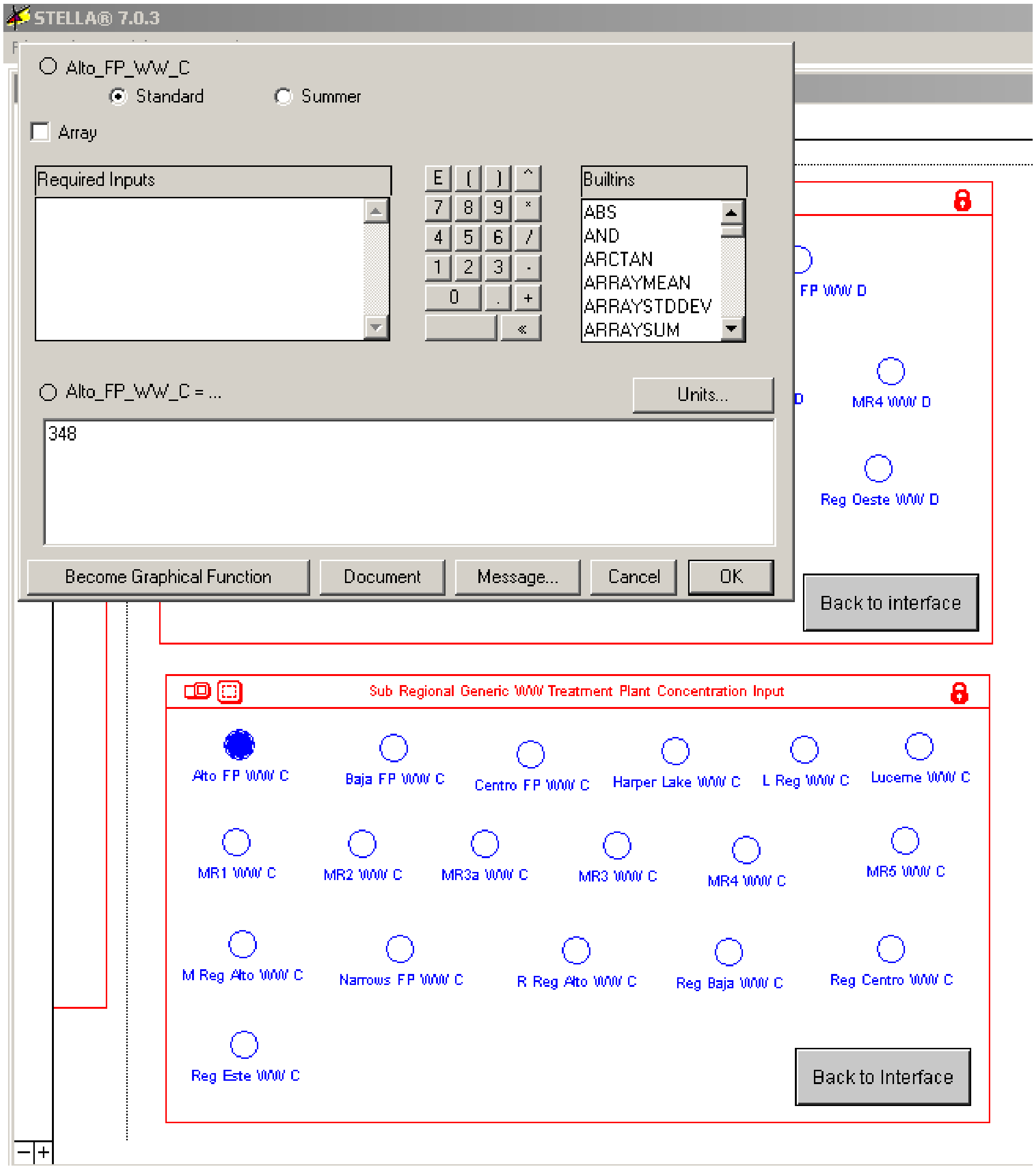
● Standard ○ Summer

☐ Array

○ Alto_FP_WW_D = ...

323

Figure A1-9 – Entering discharge volume for Alto Floodplain sub-regional wastewater treatment plant.



STELLA® 7.0.3

○ Alto_FP_WW_C

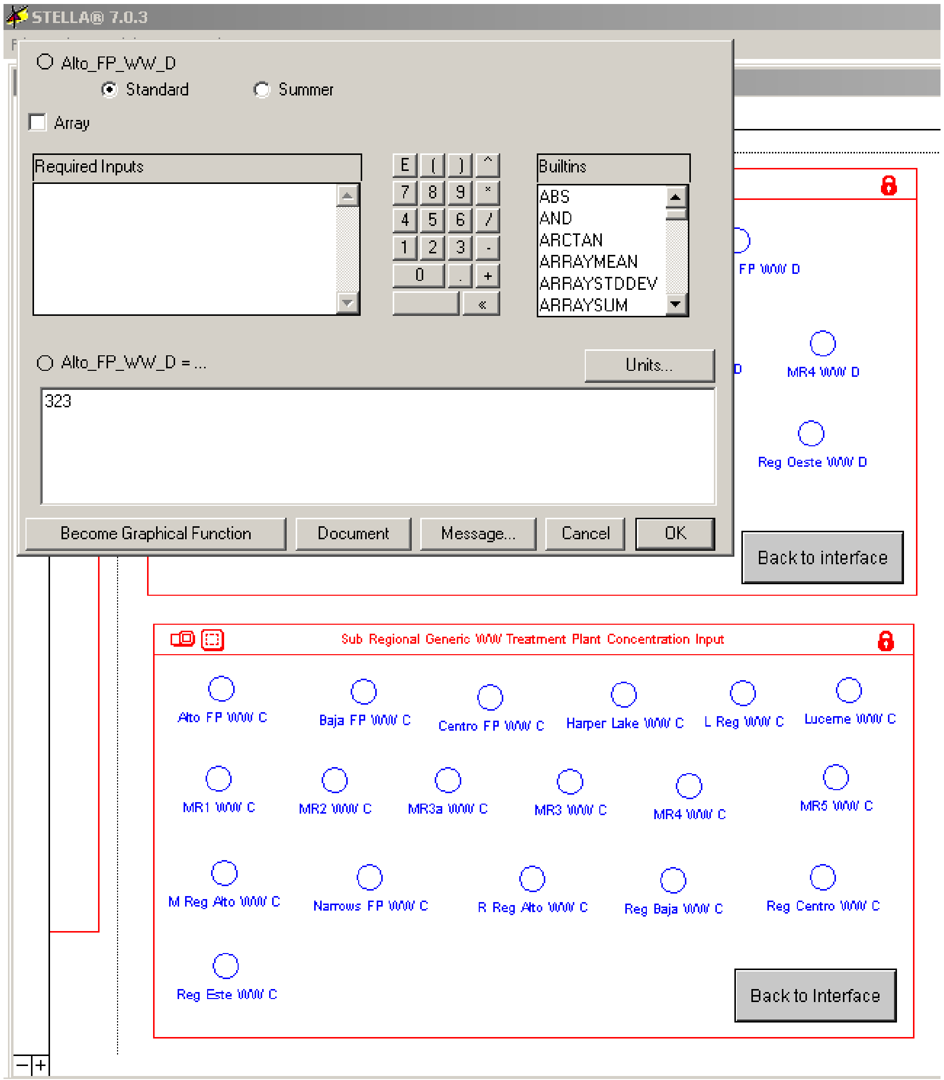
● Standard ○ Summer

☐ Array

○ Alto_FP_WW_C = ...

348

Figure A1-10 – Entering water quality for Alto Floodplain sub-regional wastewater treatment plant.



○ Alto_FP_WW_D
● Standard ○ Summer
☐ Array

○ Alto_FP_WW_D = ...
323

Figure A1-9 – Entering discharge volume for Alto Floodplain sub-regional wastewater treatment plant.

A.3 Post Processing

You are now ready to post process the results of the alternative runs using the provided excel utility spreadsheet.

1. Open the spreadsheet "Alternatives_PP.xls".
2. If you have previously run the post processing macro you must delete all worksheets in the workbook.
3. To run the macro, simultaneously press "Ctrl-Shift-q".

4. When prompted, enter the interval in years at which you would like to compare the alternatives. A typical value would be between 10 and 25 years.
5. When prompted, enter the number of alternative cases to evaluate. In this example the number is 4.
6. When prompted, use the window to browse to and select the Stella table export file created for the Base Case.
7. When prompted, use the window to browse to and select the Stella export files created for the 4 alternative cases. The macro will take approximately 10 seconds to compute comparison statistics.

Mojave Water Agency

Groundwater Quality Analysis

Phase 1 / Task 4

Water Quality Alternative Evaluation

Technical Memorandum

September, 2006

Schlumberger
WATER SERVICES

List of Figures

List of Tables

1

Introduction

This report presents the results and recommendations of Phase 1, Task 4 of the Groundwater Quality Analysis conducted by Schlumberger Water Services (SWS) for the Mojave Water Agency (MWA). This phase was initiated following the completion of the Regional Water Management Plan (RWMP).

The MWA Regional Water Management Plan (RWMP) was designed to address the key water management issues facing the MWA. A final report that outlined the key issues along with alternatives solutions was produced in 2002 (RWMP Update Phase 1 Report). The RWMP Update Phase 1 Report identified issues specific to each sub-area and provided management actions that could be used to solve these issues. Potential remedial actions were grouped into alternatives that were then evaluated to determine how well they mitigated the key management issues previously identified. This assessment was conducted using a simulation model developed within the Stella 7.0 software environment.

The Water Quality Analysis Project was initiated in August of 2004. Its primary objective was to understand the long-term effect of State Water Project (SWP) imports on the levels of total dissolved solids (TDS) in the Mojave Basin. The water quality planning model (WQPM) was developed as the final task of the Water Quality Analysis Project and will serve as a screening tool for management activities executed as part of MWA's implementation of the RWMP. Wide ranges of modeling tools were considered in selection of a platform for the WQPM. Ultimately the scope of the project, the distribution and quality of data in the database and the availability of a water balance model developed during the implementation of the RWMP led to the choice Stella 7.0 as the modeling platform for the WQPM.

The water quality planning model was used to investigate the relative impact of variations in management actions proposed in the RWMP, as well as to understand the impact of SWP water imports on salt loading in the Mojave Basin.

2

Background

2.1 Location

The MWA was founded by the legislature of the State of California to manage water in the Mojave Basin Area, El Mirage Basin. MWA's operational area was later expanded to include Morongo Basin and Johnson Valley (Figure 1). Under the Mojave Basin Area Judgment, MWA split the Mojave River watershed and associated groundwater basins into five separate "sub-areas." The sub-areas (Oeste, Este, Alto, Centro, and Baja) are shown in Figure 1. The Transition Zone is a sub-management unit of Alto. Though implemented under the Judgment these boundaries are based on hydrologic divisions defined in previous studies (DWR 1967), evolving over time to include a combination of hydrologic, geologic, engineering and political considerations (RWMP Update Phase 1 Report, 2002).

2.2 Water Balance Model Overview

The Water Balance Model or MWA Screening Model has been developed to simulate groundwater hydrology, Mojave River flows, and pumping and return flow patterns that would result from the implementation of the projects and management actions identified in the Phase 1 Report. The model was developed using Stella 7.0 software. Which is a platform built around the Systems Thinking or Object-Oriented (OO) modeling concept. It is a way of thinking about problems using models organized around real world concepts (Rumbaugh et al., 1991). The software is organized as a collection of discrete objects that incorporate both data structure and system behavior (Simonovic et al., 1997). Data are organized into discrete, recognizable entities called objects. These objects could be concrete (such as a river reach) or conceptual (such as a policy decision). The Basin was divided into management zones and hydrodynamic relationships defined between individual zones (flow, water budget, water balances, evapotranspiration etc.).

The Mojave Basin is divided into 14 interconnected aquifer units. The Lucerne Valley, Copper Mountain Valley, Means/Ames Valley, and Warren Valley aquifers are modeled independently. Johnson Valley was not included in the RWMP Stella water balance model and is therefore not included in the WQPM. The model simulates groundwater flow, storage, leakance and flow from the Mojave River. Relationships between heads, storages and flow are derived from the USGS Modflow model (Stamos et al, 2001). The model also incorporates time series from hydrologic data (river discharge, rainfall) for the period of 1931-2001. For each alternative pumping, return flows, appropriate SWP import and consumptive use are implemented and the storage in each sub-aquifer unit is updated. Data in the model is organized into sector frames (Figure 2) each of which holds a different kind of data:

- Hydrology for a certain sub-area
- Consumptive use determination
- Head in groundwater aquifers as a function of storage

All these sectors are interconnected based on known hydrologic regimes and changes in each sector are reflected throughout the model.

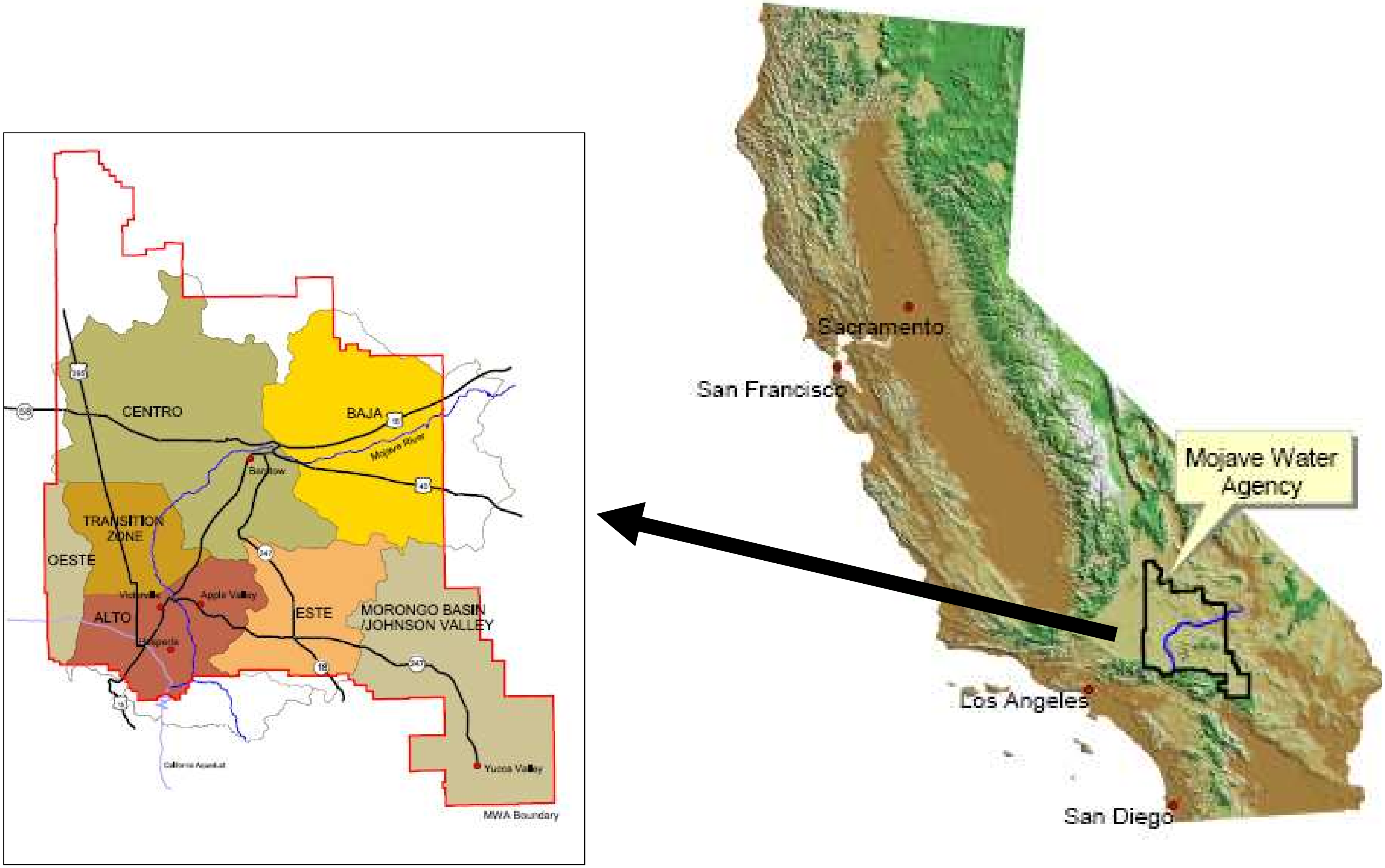


Figure 1 - MWA Operational zone location (from Schlumberger, 2004)

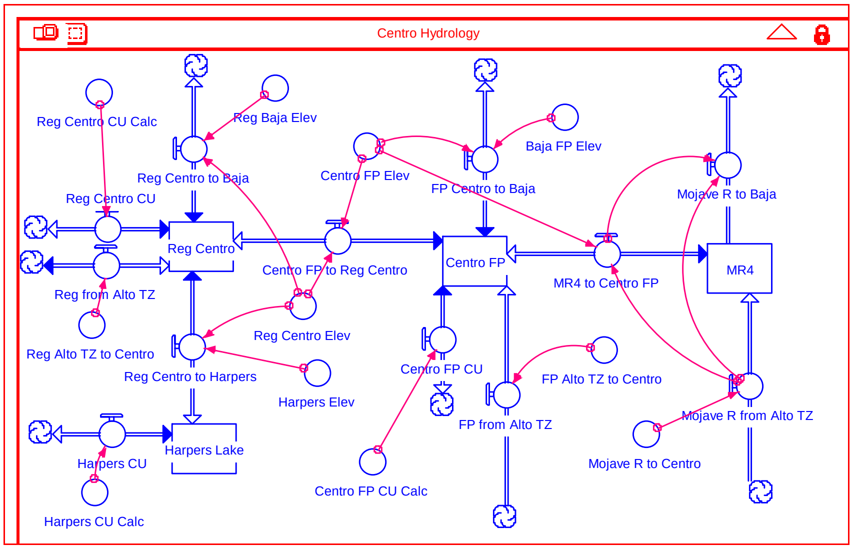


Figure 2 - Example of sector frame representing the hydrology of Centro

Water Balance Alternatives

During the development of the RWMP a number of management alternatives were investigated. Water management alternatives considered various combinations of assumptions regarding key factors effecting future water availability such as population growth, trends in agriculture, conservation measures, reclamation, treatment, imports, exports, and implementation of The Judgment. As the development of the RWMP progressed the many different combinations of assumptions defining alternatives were divided into groups A through D. A detailed description of all these alternatives can be found in the 2004 Regional Water Management Plan report (Schlumberger, 2004). Table 1 shows an example of the principal characteristics defining alternative groups C and D. Alternative D6 and D6r (D6 revised) were selected as the most appropriate management scenarios to use for planning estimates. Alternative D6r was selected for evaluation using the WQPM. Variations on D6r investigated include increase in SWP deliveries to meet projected population increase, implementation of sub-regional water treatment plants, diversion of water to power plants, and redistribution of water in a configuration similar to the proposed Regional Recharge and Recovery (R^3) program. Details of WQPM configurations used will be discussed in later sections.

Alternative:	C		D							
	C0	C3	D0	D2	D3	D5	D5r	D6	D6r	D7
Common	AVEK, Hodge, Lenwood, Warren Valley									
Judgement Implementation	Full	80% Ag	Full							
Ag demand scenario	Ag Scenario 1		Ag Scenario 2							
Municipal Conservation	0%		0%	5%		20%*	10%*	20%*	10%*	20%*
Regional WTP				46K		26K	12K			
Alto Reclamation		6.3K		9.9K	8.7K	6.8K	8.7K	6.8K	8.7K	6.8K
Rock Springs release		10K			10K	10K	10K	10K	10K	40K

*Municipal conservation in the Morongo Basin/Johnson Valley Area is 5% in these alternatives

Demands Met (KAF/yr)										
Total	102	216	101	198	200	182	199	185	198	185
Percent Total	40%	85%	47%	95%	96%	98%	99%	100%	98%	100%
Agricultural	30	56	20	20	20	20	20	20	20	20
Municipal	59	138	63	153	148	131	146	131	145	131

Table 1 - Revised and Final Alternative Assumptions and Results (from Schlumberger, 2004)

3

Water Quality Model

3.1 Ambient conditions

Tasks 1-3 of the Water Quality Analysis Project involved creation, analysis and quality control of a comprehensive water quality database for the Mojave Basin. The database contains contributions from the Mojave Water Agency, the Department of Health Services, the US Geological Survey, the Department of Water Resources, the US Environmental Protection Agency, and the State Water Quality Control Board resulting in 400,000 discrete samples of all available measured constituents from more than 7,000 wells. The data show high variability in TDS concentrations both in space (Figure 3) and time.

The number of wells sampled for TDS concentrations has increased significantly over time but has also fluctuated considerably. In the early 1900s up until 1950, a maximum of 64 wells were sampled in a given decade. This number climbed to 2258 between 1990–2000 and then dropped back to 770 for the following 5 years (Schlumberger, 2005). The sampling has also changed spatially over time but in general the bulk of the sampling is located in or around the Mojave River Floodplain. The unavailability of sampling depth in a lot of wells made interpretation difficult simply because deep waters are commonly of poorer quality.

Significant anomalies are observed in the vicinity of dry lakes and Helendale fault (Figure 4). In fact, according to Stamos (2001) the Helendale fault TDS anomaly is due to upwelling of poor quality deep water because of subsurface flow restriction by the Helendale fault. TDS anomalies in the vicinities of dry lakes, do not exhibit any downgradient movement with time. This is consistent with Stamos observations that dry lakes are points of discharge rather than recharge. Although sufficient well construction data is not yet available to make an absolute determination, the available data suggest that high TDS values in the vicinity of dry lakes may be the result of preferential shallow sampling. In light of this, and USGS observation that infiltration of precipitation does not typically occur in the vicinity of dry lakes, we do not feel that dry lakes represent a strong input mechanism. Further sampling and studies are needed to confirm this conclusion. Nevertheless nodes have been implemented in the model to account for dry lakes are currently inactive (zero TDS contribution). However, these nodes may be used if further studies or sampling suggest a significant TDS contribution. On the other hand the Helendale anomaly is located in a critical location near the Transition Zone/Centro adjudication boundary. Therefore the Phase 1 Task 2 Tech Memo (2005) recommended that an additional management zone be created which encloses this anomaly, making it possible to include this seemingly active and critically located mechanism in the water quality planning model. The proposed sub-area boundary is located approximately four miles upgradient from the Helendale fault (Figure 4).

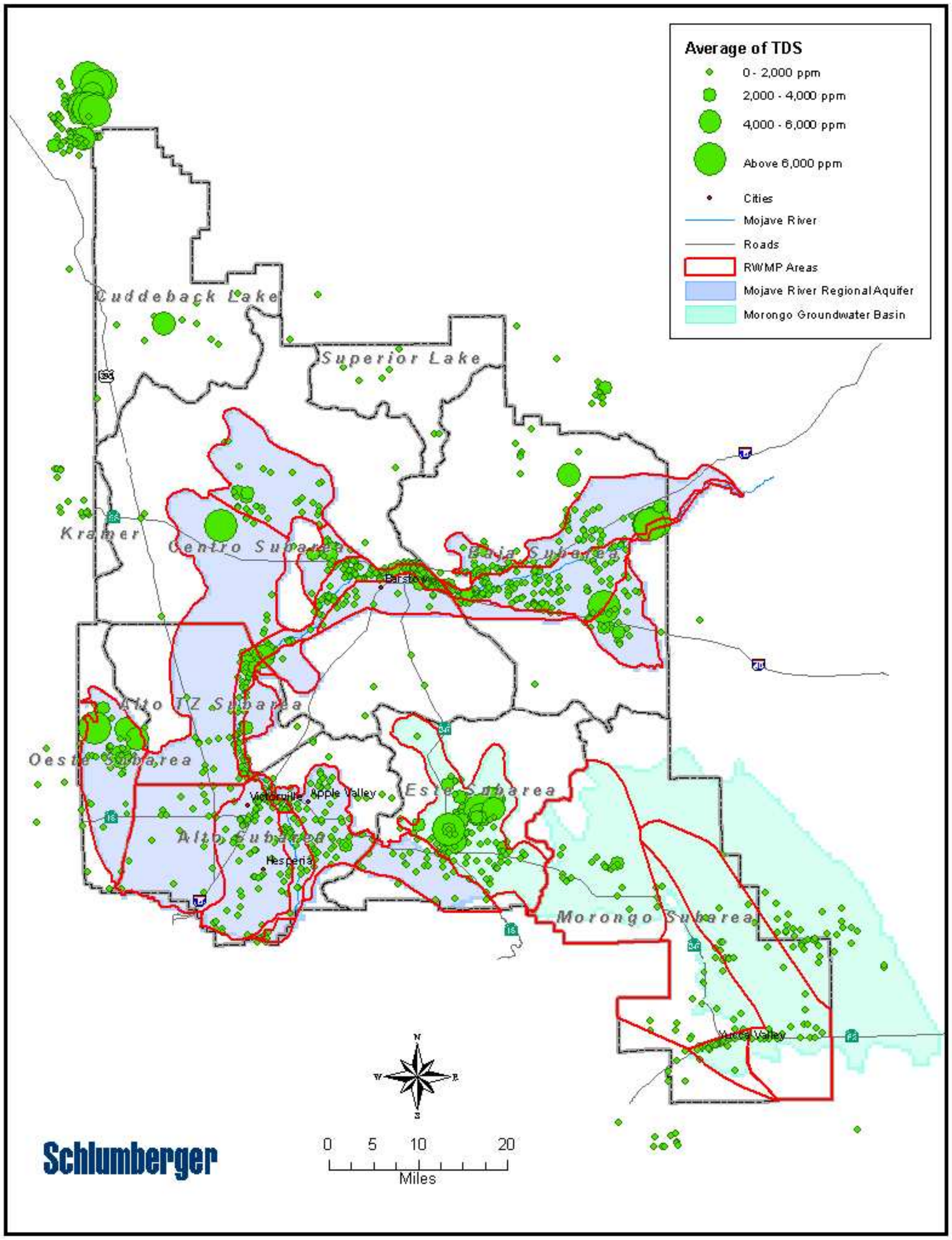


Figure 3 - Average TDS with 2004 RWMP sub-aquifer units (from Schlumberger, 2005).

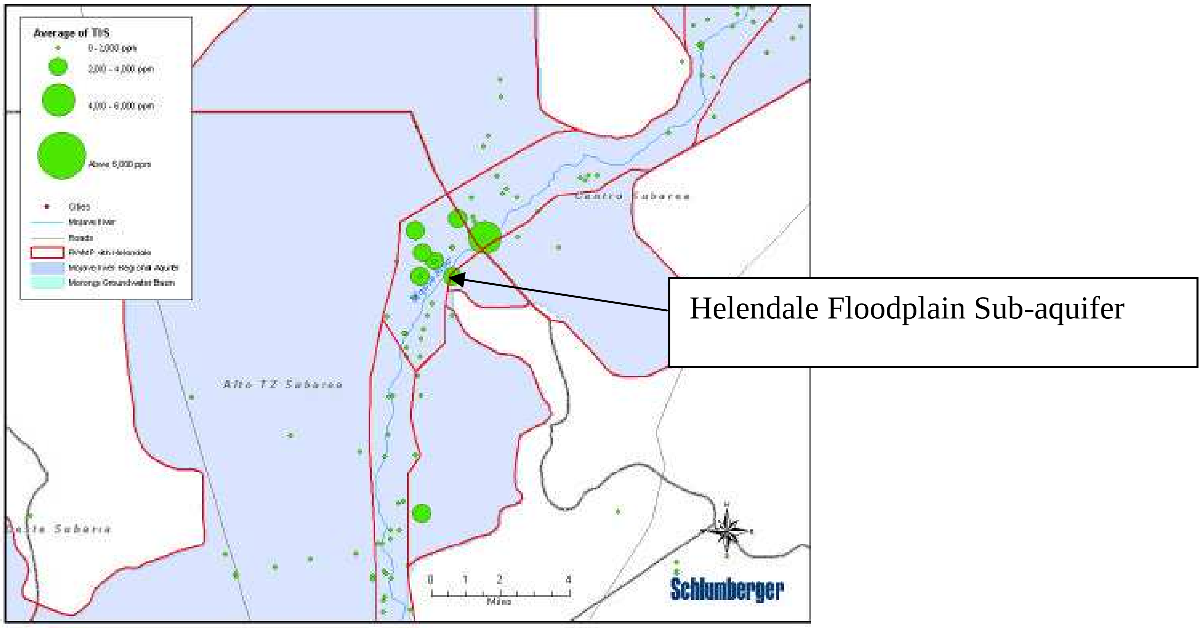


Figure 4 - Average TDS showing new Helendale Floodplain sub-aquifer Unit (from Schlumberger, 2005)

The final layout of sub-areas with their respective names is shown in Figure 5.

3.2 Model design

The water quality model is built on the previously designed Stella flow model. The flow pattern in the previous model is kept roughly the same. For each management zone represented by a reservoir in the flow model a corresponding reservoir is created to store the mass of TDS. Flow into a zone brings in mass equal to the volume multiplied by the concentration of the outflowing zone resulting in a mass gain for the receiving zone and a loss for the outflowing zone. Mass fluxes are computed in a similar fashion for sinks and sources in and out of sub-aquifer units. Concentrations are obtained by dividing the mass in a reservoir by the corresponding volume from the water balance model. Figure 6 shows a simplified version of Oeste sub-area.

This approach assumes that at each time step, for every infinitesimal amount of mass moved from one reservoir (or zone) to another the concentration in each individual reservoir is homogenized and computed hence assuming instantaneous mixing. Because TDS is moved from one sub-area to the next at every time step and mixed instantaneously, mass moves across the basin at a much faster rate than it would in actuality. According to the model for a time step of 1 month, it would take about 6 months for a tracer to cross the whole groundwater basin while actual computations and studies by USGS suggest hundreds of years. This situation is inherent to the Stella model, which allows little to no spatial discretization. A work around was implemented by limiting mass transfer only between adjacent zones. This is done by creating additional (parallel) groundwater and mass storage nodes for each sub-aquifer unit to account for the mass from adjacent zones.

1- Oeste Regional
2- Alto Left Regional
3- Este Regional
4- Transition Zone Regional
5- Centro Regional
6- Harper Lake Regional
7- Baja Regional
8- Afton Canyon
9- Baja North Regional
10- Alto Floodplain
11- Transition Zone Floodplain
12- Centro Floodplain
13- Baja Floodplain
14- Alto Right Regional
15- Narrows Floodplain
16- Alto Mid Regional
17- Helendale Floodplain
18- Lucerne Basin
19- Johnson valley
20- Copper Mtn Valley
21- Mean Ames
22- Warren Valley

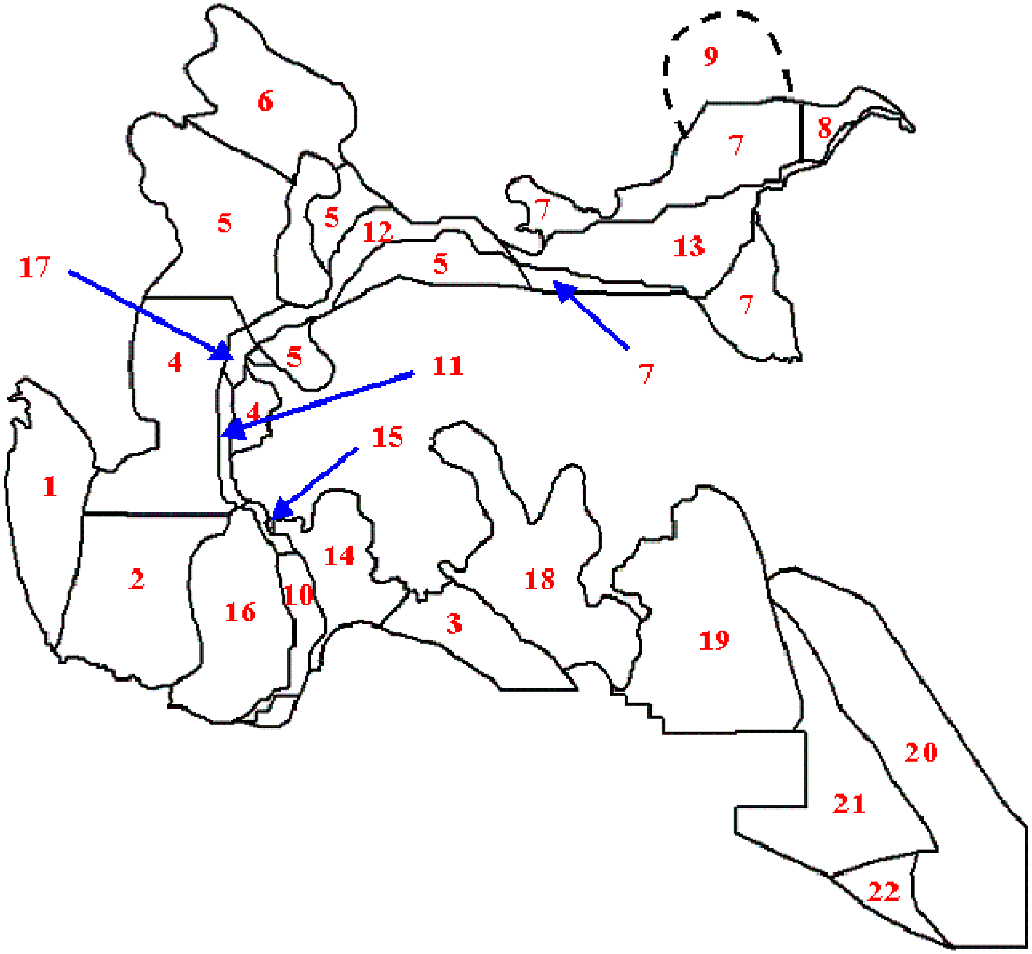


Figure 5 - Sub-aquifer units names and locations

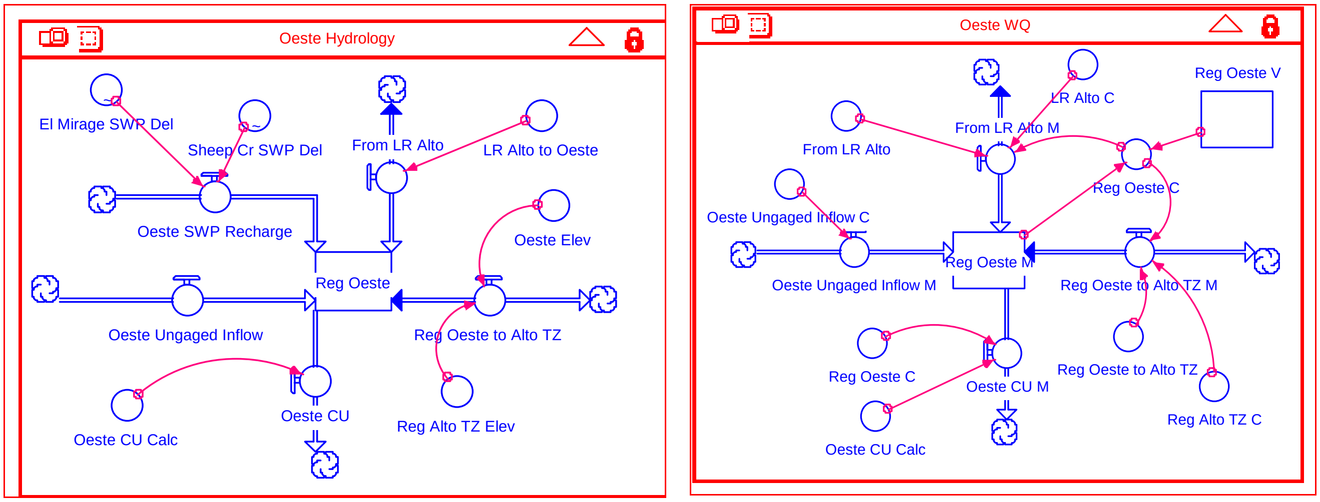


Figure 6 - Simplified water balance and corresponding mass transfer sector frame for Oeste

3.3 Initial Condition

Initial concentrations were obtained by averaging concentrations from the Task 2 water quality database in individual zones. Because data were so variable and sparse, regional, long and continuous data trends were favored over single and short-term measurements. Figure 7 shows a map of initial conditions in the model.

The following sub-aquifer units have initial TDS concentration above the secondary recommended Maximum Contamination Level (MCL) of 500 mg/L: Transition Zone Floodplain, Baja Floodplain, Centro Floodplain, Harper Lake, Helendale Floodplain, Lucerne Valley, Baja Regional, Alto Right Regional, and Johnson Valley (not modeled).

Sources and Sinks

Based on water quality Task 2 technical memo and a November 2005 meeting with MWA TAC, the following sources of TDS were identified and determined significant, they were therefore implemented in the model:

- Artificially recharged State Water Project Water
- Treated wastewater recharge
- Irrigation return flow
- Septic systems
- Groundwater inflow
- Mojave River
- Dairies

The sinks are:

- Public water systems
- Domestic wells
- Agriculture supply
- River outflow
- Evapotranspiration

Dairies return flow TDS loads were computed using a procedure applied in the Chino Basin model. This spreadsheet computation uses cows head count to evaluate effluent volumes and concentrations based on a contribution per head. Septic return flows concentrations are derived from the work of Umari et al. (1995).

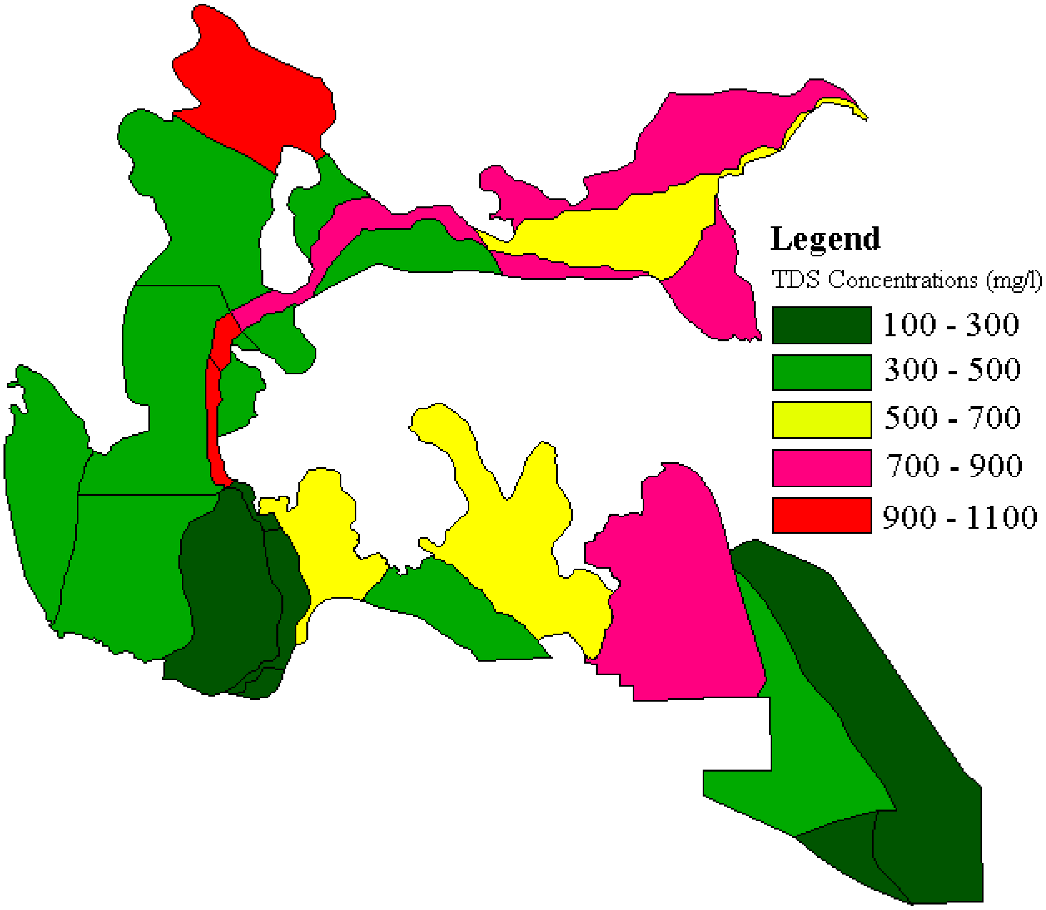


Figure 7 - Initial TDS concentration map

4

Model Applications

The Water Quality Planning Model (WQPM) was used to make comparisons between various management actions which may be implemented under the RWMP and to evaluate the long term effects of importation of SWP water into the basin. The management actions that were investigated focused on distributions of future SWP allocations, and considered various scenarios involving wastewater treatment, intra-basin water transfers, and consumptive use by power plants. The following sections describe the configuration of each modeled scenario and discuss results of simulations.

4.1 Review of RWMP Water Balance Scenarios

During the development of the 2004 RWMP, several management action scenarios were developed to evaluate the relative effects of several primary water management actions:

- Level of Judgment Implementation
- Agricultural demand
- Amount of municipal conservation
- Presence and size of a regional water treatment plant in Alto
- Amount of Victor Valley Water Reclamation Authority (VVWRA) discharge that is used for reclamation
- Amount of SWP discharge into the Mojave River at Rock Springs

The following assumptions were common to each of the RWMP scenarios:

- 2020 demand assumptions from the RWMP Update Phase 1 report
- Implementation of the Mojave Basin Area Judgment to some degree

- Delivery of SWP water to the Antelope Valley-East Kern Water Agency (AVEK), to the Warren Valley sub-basin for use by the Hi-Desert Water District (HDWD), and to the Hodge and Lenwood recharge ponds to meet Alto makeup obligations to Centro under the Judgment

Refer to Table 1 for key aspects of the RWMP scenarios.

4.2 WQPM Model Scenarios

The WQPM model was run in several configurations which represent variations management actions such as sub-regional waste treatment plants, consumptive use by power plants, and intra-basin transfers, and long term water imports. Modeling scenarios differ by the way the imported water is distributed and the amount of water that is reclaimed. The modeled scenarios are outlined below. Key variable assumptions are summarized in Table 3.

1. **RWMP Scenario D6r –** RWMP scenario D6r was identified as one of two scenarios to be carried forward for detailed post-RWMP evaluation. Project management actions for scenario D6r are listed in Table 2. In scenario D6r 99% of total MWA demand is met with no significant shortage in any subarea or demand sector. D6r includes an attainable level of 10% municipal conservation, provides water quality improvements over existing conditions, and provides benefits to all subareas without negatively impacting other areas. RWMP scenario D6r will hereafter be referred to as the “Base Case”.

2. **D6r Alternative 1 (Figure 8a):** All assumptions in the Base Case plus an increase SWP deliveries to meet additional demand at existing recharge points in Baja, Centro, Este, Morongo, Alto, and Oeste. SWP deliveries are pro-rated based on proportions from Table 2, SWP deliveries will be used at a 50% consumptive use rate with 30% of returns going to septic and 70% of returns going to Victor Valley Wastewater Reclamation Authority (VVWRA). Where VVWRA is not available, the return is 50% to septic.

3. **D6r Alternative 2 (Figure 8b):** This scenario is the same as Alternative 1 except that 6,000 acre- ft/yr is diverted from VVWRA to a 100% consumptive use (0% return) in a power plant.

4. **D6r Alternative 3 (Figure 8c):** This scenario starts with Alternative 2 as a basis, then 4,000 acre- ft/year is transferred from VVWRA to irrigation in Alto Regional TZ with 50% consumptive use (CU). Then 4,500 acre-ft/year is diverted to each of two Sub Regional Waste Water Treatment Plants in Alto Right Regional and Alto Mid Regional; 2/3 of these volumes will go to irrigation, with 50% CU and 1/3 to direct recharge. Remaining water in VVWRA should exceed 10,000 acre-ft/yr (per California Dept of Fish and Game MOU).

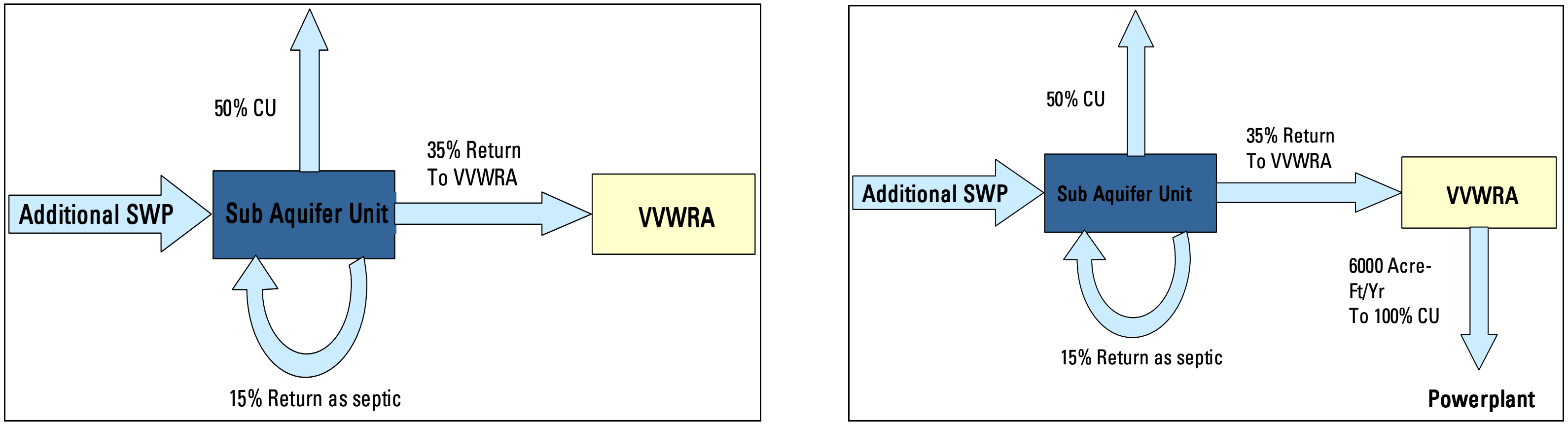
5. **D6r Alternative 4 (Figure 8d):** Also starts with Alternative 1, then continues with the routing of 40,000 a-ft/yr from Alto MR SWP deliveries to Alto FP (mixed with groundwater), pumping of 40,000 a-ft/yr from Alto FP to Alto MR where it is used at a 50% CU rate and 30% of the return flow goes directly to groundwater and the rest is routed to VVWRA. Alternative 4 is an approximation of the Regional Recharge and Recovery (R^3) program configuration.

6. **D6r Alternative 5 (No SWP Water Deliveries)** - To facilitate evaluation of the effects of long term effects on TDS levels in the Mojave Basin a scenario was developed having all of the attributes of Scenario D6r but with no SWP deliveries at all. This differs from scenario D6r which includes SWP deliveries fixed at levels defined in Table 2.

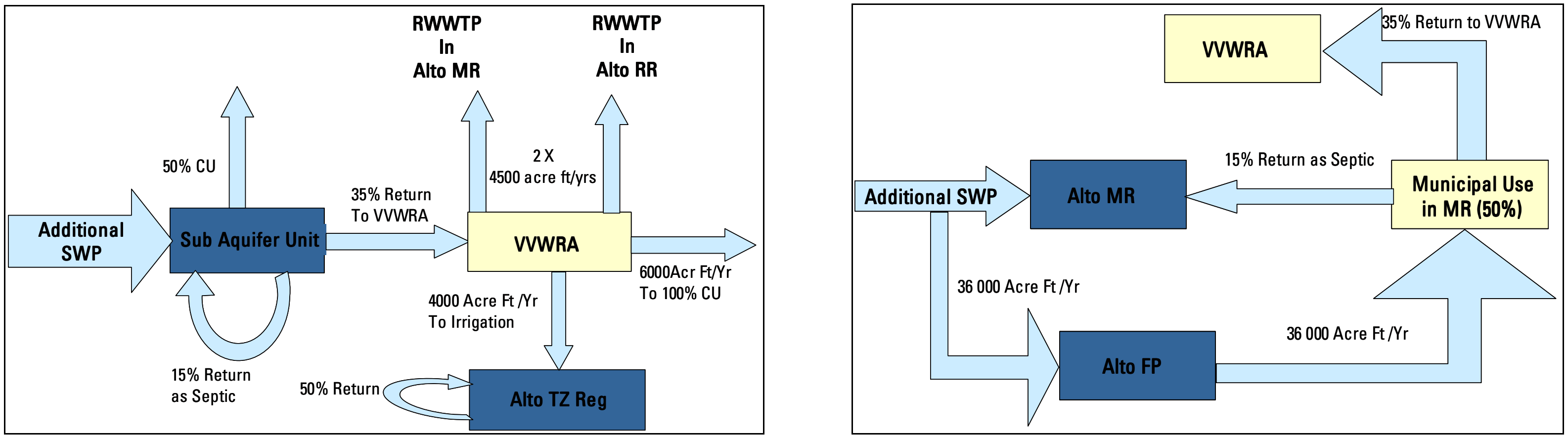
All of the scenarios modeled included the assumption of continuous population growth at a rate of 2.6% for 15 years followed 1.8% for 55 years. In all D6r Alternatives SWP imports were increased to meet the additional demand induced by the population growth. The water demand is evaluated with the projected population growth and per capita water use of .25-acre ft/year/person.

Project/Management Action	Subarea	D6r Base Case
Additional Recharge Facilities South of Rock Springs Outlet	Alto	
Alto wellhead treatment	Alto	0*
Antelope Valley Wash Recharge Ponds	Alto	7,157
Cedar Street Detention Basin Recharge	Alto	7,157
Hesperia Lakes Recharge	Alto	7,885
Mojave River Pipeline Extension - Transition Zone	Alto	
Oro Grande Wash Recharge Ponds	Alto	12,015
Recharge Ponds South of Apple Valley	Alto	3,755
Regional surface Water Treatment Plant	Alto	
Silver Lakes In-Lieu Recharge	Alto	2,253
Rock Springs Release	Alto	7,591
Baja Stormflow Retention	Baja	2,000
Daggett/Newberry Springs Recharge Ponds	Baja	
Kane Wash Recharge Ponds	Baja	2,800
Alto Makeup (to Hodge and Lenwood)	Centro	908
AVEK	Centro	1,372
Hinkley water supply	Centro	0*
Cushenbury Wash Stormflow retention	Este	400
Lucerne Valley Recharge Ponds	Este	
Recharge Ponds West of Helendale Fault	Este	369
Hi-Desert WD: Warren Valley	MBJV	1,450
Joshua Basin District Recharge and Pipeline	MBJV	393
Means/Ames Recharge Ponds	MBJV	1,000
Pioneertown water supply	MBJV	0*
Sheep Creek Recharge Ponds	Oeste	2,260
SUBTOTAL IMPORTS		60,765
Urban Conservation		15900
VVWRA Reclamation		8437
*This project does not represent a new water supply		

Table 2 – RWMP scenario D6r Projects and Management Actions (modified from Schlumberger, 2005)



(a) Alternative 1 (b) Alternative2



(c) Alternative 3 (d) Alternative 4

Figure 8 - Modeled Alternatives Scenarios diagrams

	Base D6r	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5
Population increase	Yes[1]	Yes[1]	Yes[1]	Yes[1]	Yes[1]	Yes[1]
SWP Deliveries	Yes[2]	Yes[2]	Yes[2]	Yes[2]	Yes[2]	No
Increased SWP deliveries to meet demand	No	Yes[3].	Yes[3].	Yes[3].	Yes[3].	No
VVWRA transfers	No	No	- 6,000 acre-ft to power plant[4]	- 6,000 acre-ft to power plant[4] - 4,000 to Alto Reg TZ irrigation[5] - 2 x 4,500 acre-ft sub-regional WTP's[6]	- 6,000 acre-ft to power plant[4]	No
SWP delivery diversions[10]	No	No	No	No	- 40,000 acre-ft from Alto Mid Reg to Alto Floodplain[7]	No
New production infrastructure	No[8]	No[8]	No[8]	No[8]	- 40,000 acre-ft produced at Alto FP and transferred to Alto Mid Reg[9].	No[8]

Note 1: Population increase 2.6% 15 years, 1.8% 55 years, 0.25 acre-ft /year/person.

Note 2: SWP deliveries per Table 2.

Note 3: Increased SWP deliveries pro-rated proportionally per quantities in Table 2. 50% CU, 30% returns to septic, 70% to VVWRA where available, else 50% septic.

Note 4: Power plant is 100% CU.

Note 5: Alto Reg TZ irrigation 50% CU.

Note 6: Sub-regional WTPs in Alto Right Reg and Alto Mid Reg. 50% CU. 2/3 returns to irrigation at 50% CU, 1/3 to diret recharge.

Note 7: R3 scenario. Mixed directly with groundwater.

Note 8: Additional production added proportional to population increase in each model zone.
Note 9: 40,000 acre-ft used in Alto Mid Reg at 50% CU. 30% returns to groundwater, 70% to VVWRA.
Note 10: Diversion of SWP imports from recharge facilities per RWMP alternative D6r to other modeled recharge locations.

Table 3 – Key assumptions for all modeled alternatives.

4.2 Simulation Results

Several modeling runs were conducted using the various scenarios described in the previous sections. Modeling results were analyzed in both absolute and relative terms in an effort to evaluate relative performance of different management alternatives and to understand the long term effects of SWP imports on TDS levels in the Mojave Basin. Histogram displays of absolute model output at 70 years in the future are shown in Figures 9–12 along with lines indicating the recommended and upper secondary drinking water standards for California.

Comments By Key Sub-Aquifer Unit

Figures 9–12 exhibit the following notable characteristics of several sub-aquifer units;

Alto Transition Zone Floodplain – The TDS concentration in the Alto Transition Zone Floodplain sub-aquifer unit is lowered as the result of all of the Alternatives 1-4, while remaining relatively unchanged from initial conditions in Alternative 5. Improved water quality from Alternatives 1–4 are likely the result of the SWP deliveries to this sub-aquifer unit. Stability of water quality in the absence of any SWP imports may be explained by the fact that this sub-aquifer unit, located in the up stream reaches of the river, enjoys relatively large amounts of fresh water from the river channel.

Centro Floodplain – The Central Floodplain sub-aquifer unit sees an increase in TDS concentration in all scenarios modeled. Because of its location in the mid-lower reaches of the river and the inclusion of Barstow, a large population center which is a concentrated source of waste water, initial water quality in the Centro Floodplain sub-aquifer unit is relative poor. Because of this, the elimination of better quality SWP imports, as represented by Alternative 5, results in an increase of TDS levels. Imports of better quality SWP water as represented in Alternatives 1–4 results in a constant or slight improvement in water quality in all cases.

Helendale Floodplain – This sub-aquifer unit displays counter-intuitive behavior which results from the interaction between the river and the groundwater system. The amount of water passing from a river to the groundwater system at any given time is dependent upon the difference between water levels in the river and the groundwater. Lower groundwater levels allow infiltration of river water into the ground water by leakance through river bottom sediments. When groundwater levels are high this infiltration is inhibited. It is believed that, although the Mojave River does not perennially run on the surface in the Transition Zone Floodplain and Helendale Floodplain model zones, there remains a component of subsurface flow still interacting with the Floodplain aquifer groundwater system in the manner described above. In the model, SWP deliveries and VVWRA discharges are connected to the groundwater system. Therefore, contribution of these water balance elements result in higher groundwater levels in the Helendale Floodplain downgradient. These higher groundwater levels inhibit leakance of high quality water from the river into the groundwater system. Absence of SWP deliveries results in lower groundwater levels in Helendale Floodplain, thus allowing leakance of the better quality river water into the groundwater system. Therefore, TDS levels in Alternatives 1–4 are slightly higher than Alternative 5 because the leakance from the river is reduced by SWP deliveries. Helendale floodplain is also influenced by all surrounding sub-aquifer units, all of which are larger and all of which have lower TDS levels.

Alto Left Regional – The Alto Left Regional sub-aquifer unit sees an increase in TDS concentration in all modeled scenarios. This is probably because this area receives no SWP water imports and is in overdraft, thus reducing water volume while solids remain. Alternatives 1–4 show a slight improvement over Alternative 5, probably as the result of influx of SWP water from adjacent sub-aquifer units.

Alto Mid Regional – The Alto Mid Regional sub-aquifer unit sees an increase in TDS concentration in all modeled scenarios. In Alternative 5 water quality deteriorates due to overdraft however to a much lesser extent than seen in the Alto Left Regional sub-aquifer unit. This is probably because of the higher level of mountainfront recharge and groundwater influx from the Alto Floodplain sub-aquifer unit enjoyed by Alto Mid Regional. Addition of SWP imports represented by Alternative 1–4 slightly increase TDS levels over Alternative 5 because the native water in that sub-aquifer unit is better than the SWP water.

Alto Right Regional – The Alto Right Regional sub-aquifer unit sees an increase in TDS concentration in all scenarios modeled. This sub-aquifer unit hosts approximately 20% of the population in the Mojave Basin and bears the impact of the related anthropogenic TDS sources. Elimination of SWP imports exacerbates the effect. The deterioration of water quality is somewhat mitigated by the SWP imports included in Alternatives 1–4.

Narrows Floodplain – The Narrows Floodplain experiences a decrease in TDS concentration in Alternative 5 and an increase in TDS concentration in Alternatives 1–4. These results are intuitive because of the relatively high quality of the native water as compared to SWP water. Elimination of SWP deliveries results in an improvement in water quality while an increase in SWP deliveries into the upper regions of the basin (Alternatives 1–4) has the opposite effect.

Alternatives Comparison – In order to more easily evaluate the differences between Alternatives 1 through 5 these alternatives were normalized against the Base Case (RWMP scenario D6r). Refer to Tables 2 and 3 for a summary of model assumptions. Figures 13-16 show histograms of differences in modeled TDS between the Base Case and each alternative (1–4) at 70 years in the future. TDS levels higher in the Alternative than in the Base Case (degradation) are red, TDS levels lower in the Alternative than in the Base Case (improvement) are green.

These histograms reflect the mechanisms described above, particularly with respect to Helendale Floodplain, Narrows Floodplain, and Alto Right Regional sub-aquifer units. In general there are minor differences between Alternatives 1, 2, and 3. Alternative 4 displays some unique behavior compared to Alternatives 1–3;

- Increased TDS levels in Alto Mid Regional – This is believed to be the result of the diversion of SWP imports from Alto Mid Regional to Alto Floodplain and the subsequent increase in return flows (relatively higher TDS) routed back to Alto Mid Regional.
- Moderation of highs and lows – This is felt to be the result of a greater degree of anthropogenically driven mixing.

However, it should be noted that this configuration deviates significantly from The D6r configuration being implemented as called for in the RWMP and was developed for investigation purposes only. In fact, it is expected that Alternative D6r will result in lower

TDS concentrations in Alto Mid Regional.

From the many modeling runs we are able to also draw the following general observations;

1. The river acts as a fast conduit and plays a dominant role in transport of TDS down-gradient throughout the Flood Plain.
2. Sub-area size is a factor. Small zones like Helendale Floodplain, Centro Floodplain, Alto Transition Zone Floodplain, and Narrows are more sensitive to TDS changes.

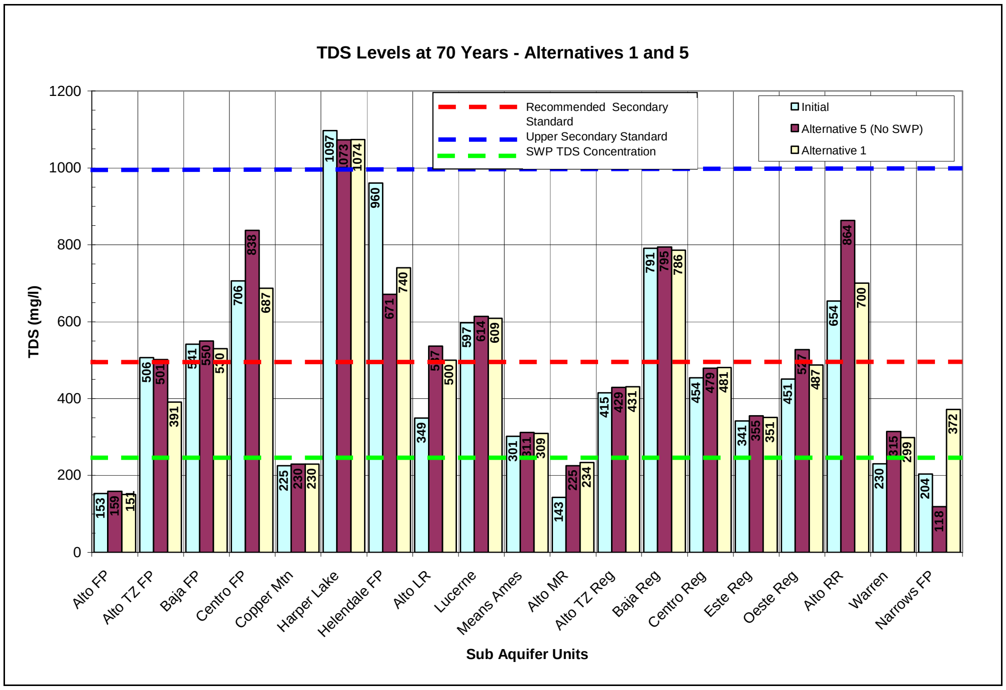


Figure 9 – Absolute TDS levels for initial conditions and modeled Alternative 1 and Alternative 5 at 70 years.

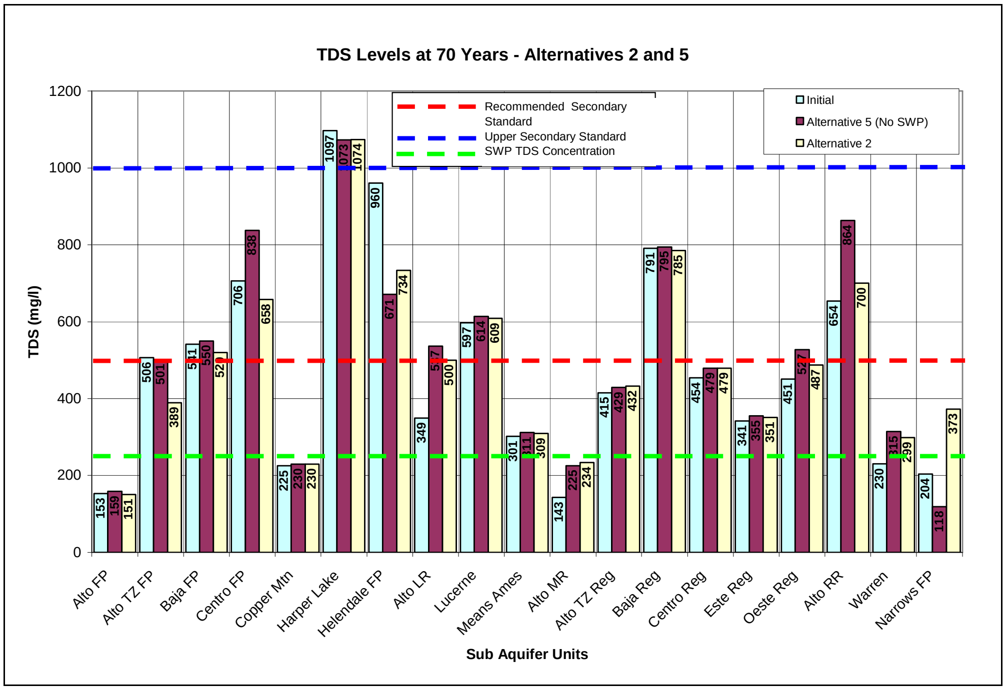


Figure 10 – Absolute TDS levels for initial conditions and modeled Alternative 2 and Alternative 5 at 70 years.

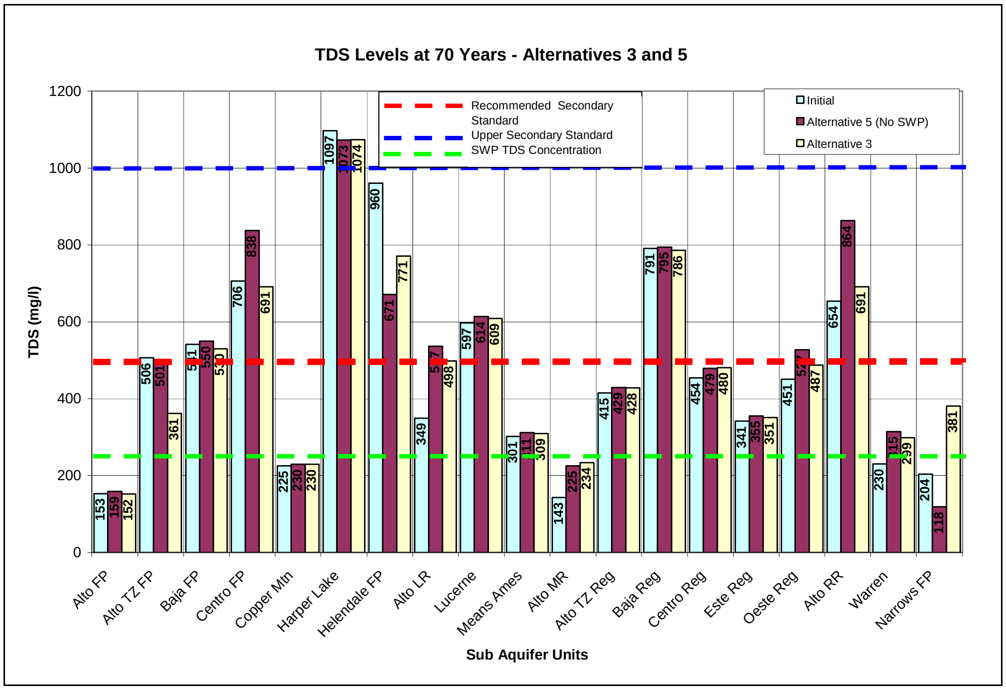


Figure 11 – Absolute TDS levels for initial conditions and modeled Alternative 3 and Alternative 5 at 70 years.

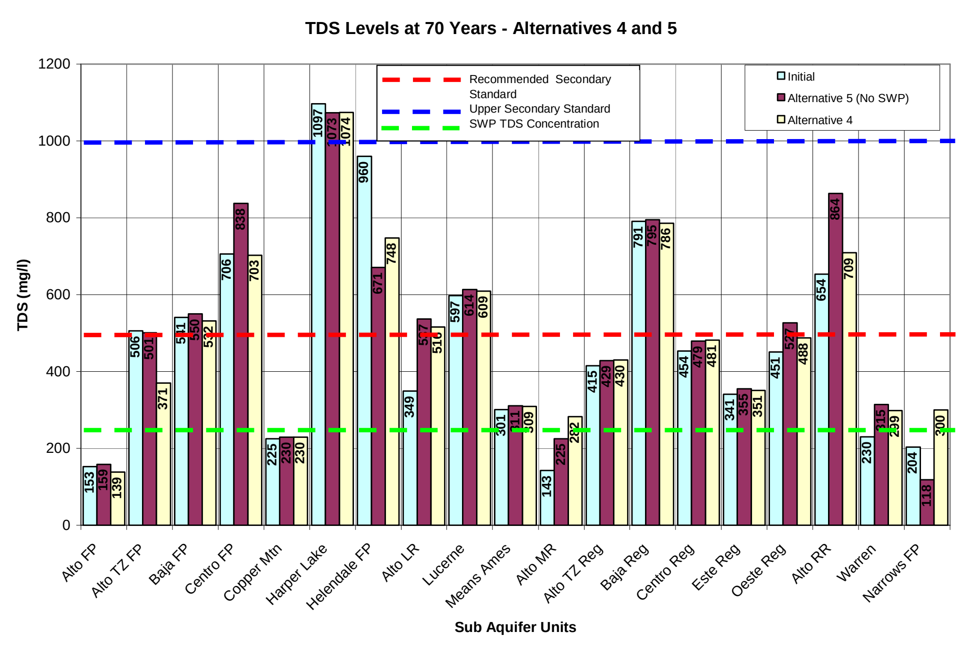


Figure 12 – Absolute TDS levels for initial conditions and modeled Alternative 4 and Alternative 5 at 70 years.

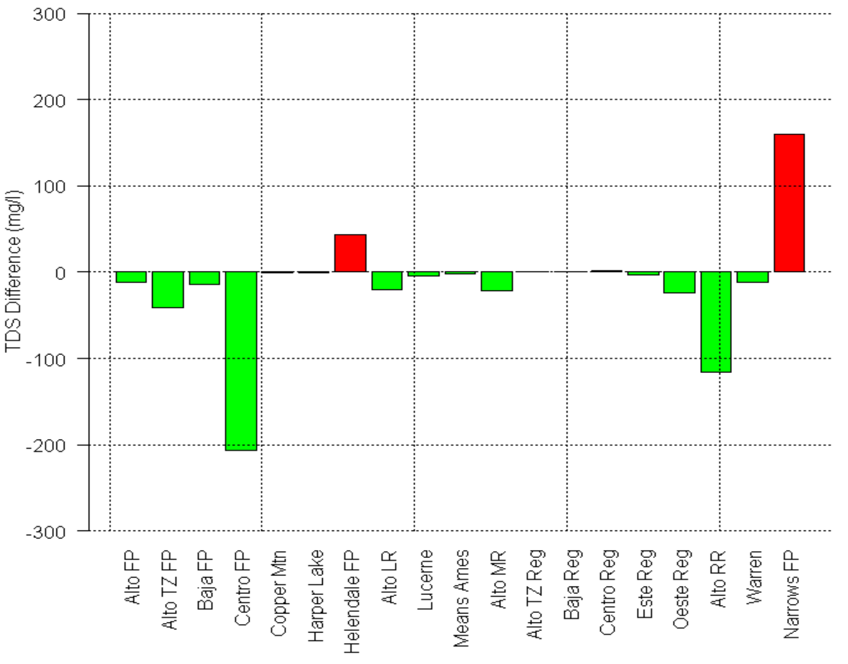


Figure 13 - Alternative 1 Departure from Base Case Map (after 70 yrs).

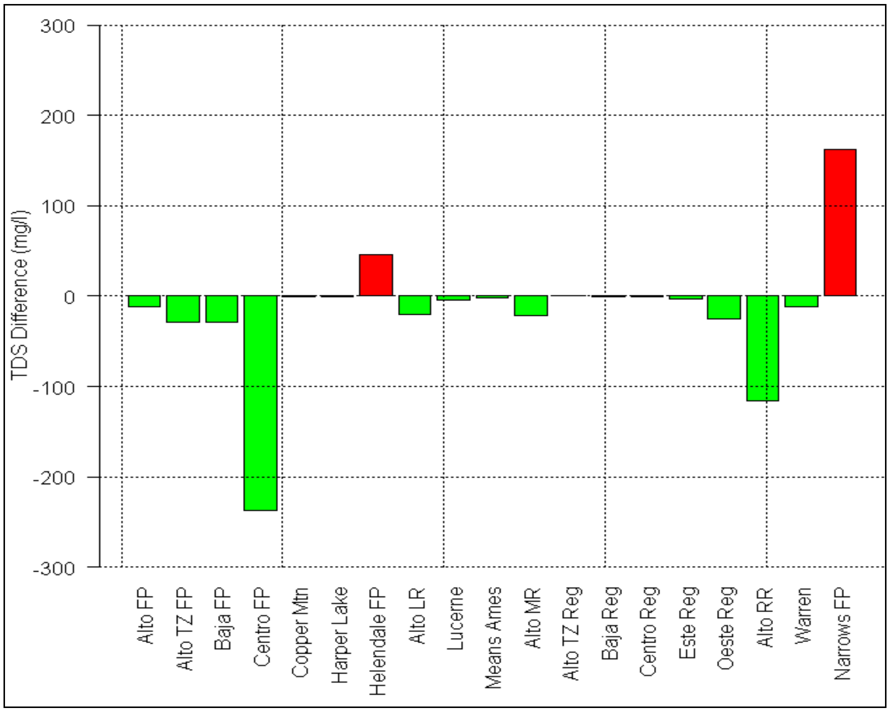


Figure 14 - Alternative 2 Departure from Base Case Map (after 70 yrs).

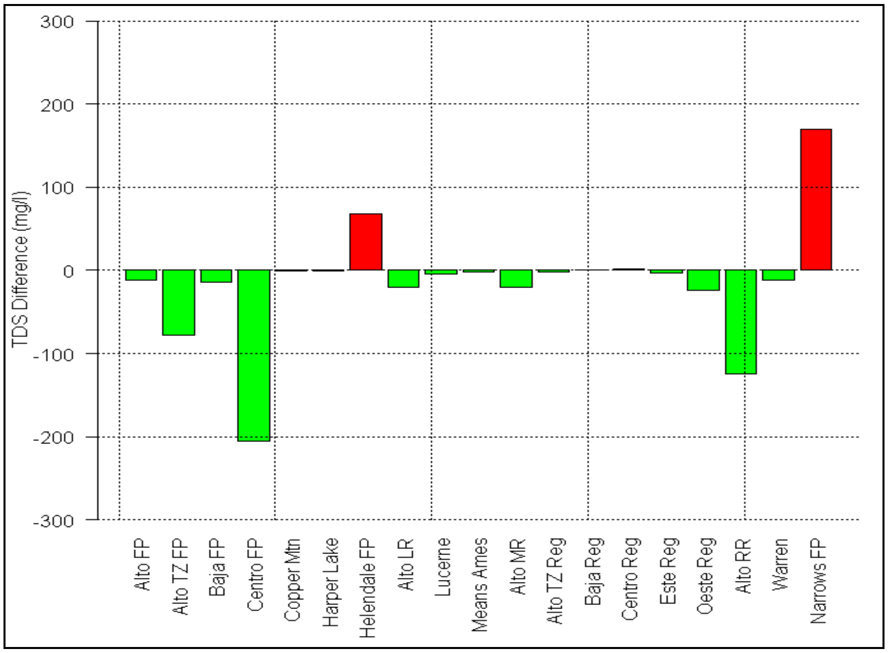


Figure 15 - Alternative 3 Departure from Base Case Map (after 70 yrs).

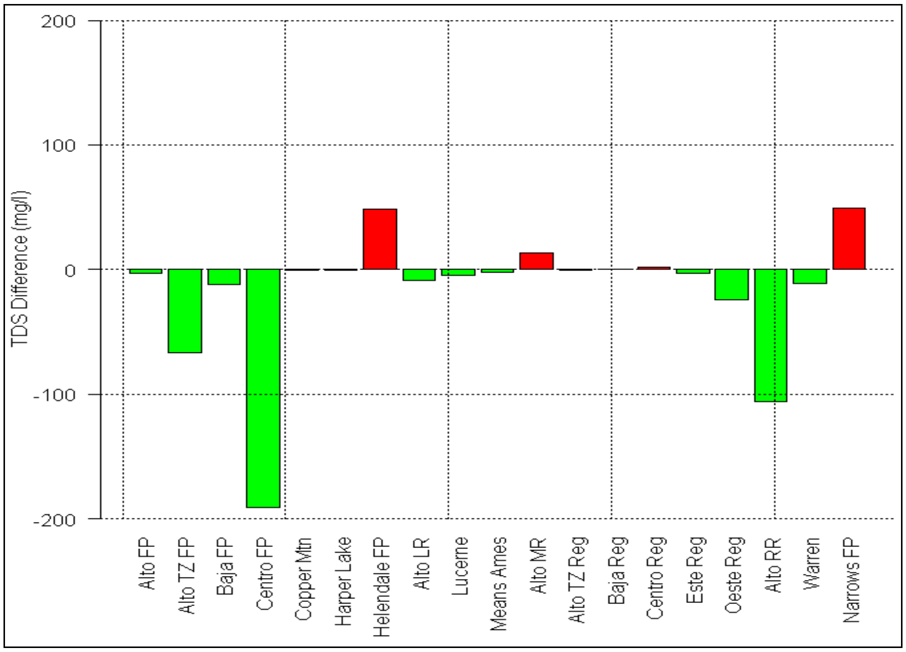


Figure 16 - Alternative 4 Departure from Base Case Map (after 70 yrs).

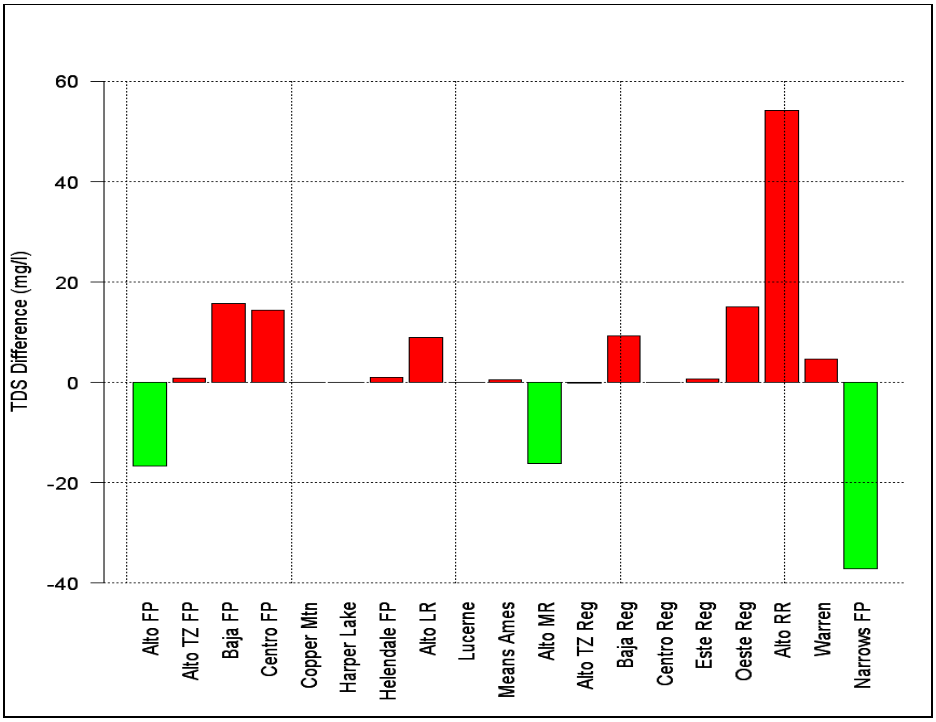


Figure 17 - Alternative 5 Departure from Base Case Map (after 70 yrs).

Assimilative Capacity

Uncertainty surrounding the overall long term effects of anthropogenic influences on the TDS levels in closed basins such as the Mojave Basin has drawn a great deal of attention in recent years. The concept of assimilative capacity has been developed to represent the *remaining* capability of a system at a point in time to assimilate input of a foreign or toxic substance before a given threshold is reached. The threshold is generally related to some health standard. Although no formal definition of assimilative capacity for TDS has been found, for the purpose of this study an ad-hoc definition has been adopted as "*the ability of the surface and groundwater system to sustain long term influx of TDS from internal and external anthropogenic sources*".

The TDS load in a basin at any point in time is a function of an initial water quality plus the cumulative sum of all TDS sources and sinks during the study period. The purpose of the model is to provide a strong foundation for future, more directed studies in each of the sub-basins. The collection and processing of water quality data included with this study represents the most comprehensive and complete set of water quality data for the region. Additional work to determine the assimilative capacity for a sub-basin or localized region should use the data from this study as a foundation. It should be noted that water quality in each of the sub basins has been averaged and localized changes in water quality within a sub-basin are expected.

As previously discussed in this report, average native water quality for each of the sub basins varies significantly. Many of the sub-basins have average TDS concentrations above the recommended California secondary standard (500 mg/l) and the upper California secondary standard (1000 mg/l) making policy decisions in the sub basins challenging with regards to assimilative capacity. Future planning and policy decisions should leverage the work conducted during this study as well as ongoing groundwater sampling and data collection programs conducted by the MWA, DHS, USGS and other entities.

5

Conclusions and Recommendations

5.1 Conclusions – Planning Model

The coarsely discretized bucket-type formulation used for the water quality planning model is the best representation possible given the available data. Consistency with the RWMP screening model was an important factor in selection of Stella as the modeling platform for the Water Quality Planning Model. The Stella platform facilitated development of a highly sophisticated water mass balance model within which the TDS mass balance could be implemented. Stella provided the functionality required to easily implement all key water balance and TDS sources/sinks required for the study. The level of detail contained in both the water balance and mass balance formulations adequately represents the known major hydrological and water quality elements, making it a useful screening tool for management alternatives.

The model successfully allows a quick evaluation of the future impact of different alternatives based on realistic regional management scenarios. However, the water quality planning model is not a true transient predictive model. The model assumes a steady-state or quasi-steady state condition and is therefore most suitable for evaluation of long-term trends over the large regional areas represented. It is not suitable for site-specific impact analysis. Development of a more sophisticated and specialized model for water quality transport studies is not warranted at this time due to limitations on the quantity and distribution of available water quality data. One key piece of information missing from most of the samples now existing in the database is the depth of sample. Expansion and continued focus on regional groundwater monitoring programs will help facilitate more sophisticated modeling efforts and science based decision making. Some areas of the region have adequate existing monitoring coverage while other areas of the region have virtually no available data. Efforts should be made to fill these data gap areas.

5.2 Conclusions

The following general conclusions and observations are drawn from the modeling study;

- Most sub-aquifer units maintain a steady trend over time: continuous increase or decrease in TDS (Appendix A). This indicates that the gradient trends tend to remain uniform given the natural and anthropogenic stress conditions imposed in the model.
- Most sub-aquifer units show an increase in TDS concentrations in time, but TDS increases at a lower rate when SWP water is imported to meet the growing future demands.
- All subareas except Helendale Floodplain have modeled 25/75 year concentrations less than 1,000 ppm (upper state secondary standard).
- The majority of sub-aquifer units have positive assimilative capacity with respect to the recommended secondary drinking water standard (less than 500 mg/L).
- Because water imported from the SWP is of better quality than the current ambient groundwater quality in many of the sub-areas, internal man made sources (domestic, septic, industrial, agricultural, etc.) are the main driving mechanism for water quality degradation.
- In almost all cases evaluated SWP water imports improve groundwater quality through a process of dilution.
- Alternative 4, which represents the R3 project, seems to have an overall balanced impact on water quality in the region as compared to other modeled alternatives. Fewer extreme values are observed. This is the result of a greater degree of mixing and man made redistribution involved in this alternative.

5.3 Recommendations

Water quality sampling has been performed continuously in the Mojave Basin since the early 1900’s. As a result, an extensive body of water quality data is available. The Water Quality

Analysis Phase 1 project highlighted the many strengths and weaknesses of these data.

The frequency and spatial distribution of historic groundwater sampling in the region by multiple entities has been highly variable in response to funding cycles, changes in responsibility, and short term or localized priorities. As a result, although adequate field and laboratory practices were generally maintained, the existing body of data lacks the consistency and some of the key elements of information required for more sophisticated modeling at a regional scale using currently available state-of-the-art tools and techniques. However, the available data is diverse, widely distributed, of reasonable quality, and therefore suitable for qualitative and limited quantitative regional modeling as performed in this study.

Notwithstanding the above, as a result of the Water Quality Analysis Phase 1 project, it is possible to make a number of recommendations for future actions;

- Responsibility – Many agencies currently have partial and overlapping jurisdiction over water quality sampling and database management. However, no one agency is charged with maintenance of a single consistent water quality database. This study has highlighted the drawbacks of this situation from a historical perspective. Unless some deliberate action is taken it is reasonable to expect this condition to persist into the future.
- Water Quality Data – The Water Quality Analysis highlighted deficiencies in the available data, particularly with respect to depth specific sampling. More comprehensive regional monitoring programs will allow better resource management in the future. More frequent and depth specific sampling, as well as wider distribution of monitoring wells is needed. Expanded monitoring programs may require more sophisticated field procedures and/or permanent monitoring installations, both of which tend to increase data acquisition cost. Therefore, we recommend that funding levels for future planned water quality sampling and monitoring be reviewed. It is also strongly recommended that this and further modeling efforts be utilized to optimize design and planning of future data acquisition campaigns.
- Project Specific Monitoring – The water quality planning model was used to estimate the future impact of various management actions. This analysis showed, for example, that the

R3 project has a favorable moderate overall impact on water quality. We recommend that an optimized water quality monitoring program be conducted in conjunction with R3 program implementation. The results may be used to improve future predictions.

- Helendale Anomaly – The Water Quality Analysis highlighted a TDS anomaly in the river Floodplain in the vicinity of Helendale. Various possible mechanisms have been suggested for this anomaly. Mechanisms include both natural (upwelling of deeper poor quality water caused by the Helendale Fault seal in the subsurface), and anthropomorphic (pumping poorer quality water from deep wells). Additional detailed studies including depth specific sampling, age dating, and localized modeling should be considered in order to resolve the mechanism responsible for this anomaly.
- Data Access/Security – During the course of this study it was possible to gain only limited access to geo-referencing data from the Department of Health Services on the grounds of national security. Further, although access was provided by the USGS to georeferencing information for their water quality data, it was suggested that access to such information may be also be limited on the same grounds at some time in the future. We believe that MWA will be able to overcome these access limitations through appropriate bureaucratic processes. However, permission for MWA to grant data access to sub-contractors if needed may require an additional level of authorization from the agencies providing the data.
- Future Modeling Requirements – As stated above, more sophisticated water quality modeling at the regional scale would require significant improvements in the overall uniformity of the water quality database. The data from MWA's monitoring program, used to initiate the database was complete and consistent with respect to geo-referencing, constituents, quality indicators, etc. However, some of the older data gathered and archived over several decades by various other agencies lacks the information required to verify sample integrity, location, or depth. This may be due to the original sampling and analysis procedures, or the data lost in the archival process. However, as a result of MWA's continuing monitoring program the overall consistency of the database will improve over time. With given detailed localized analysis of the available data, more sophisticated modeling should be possible at a local, project specific, scale.

- Assimilative Capacity – As noted in Section 4, the issue of assimilative capacity is made complex by the wide variation of ambient water quality across the Mojave Basin and many interacting processes. Some sub-aquifer units have conditions currently above current drinking water standards. Others have relative good quality water with respect to these standards. Further, as the model demonstrates, processes such as mixing between sub-aquifer units and interaction between groundwater, surface water, and man made TDS sources may result in either improvement or degradation of water quality on a localized basis. These findings suggest that assimilative capacity may be managed to some degree over the long term through a combination of monitoring, modeling, and optimized management actions.

Appendix A

Alternatives	Years	Alto FP	Alto TZ FP	Baja FP	Centro FP	Copper Mtn	Harper Lake	Helendale FP	Alto LR	Lucerne	Means Ames	Alto MR	Alto TZ Reg	Baja Reg	Centro Reg	Este Reg	Oeste Reg	Alto RR	Warren	Narrows FP
Initial	0	153	506	541	706	225	1097	960	349	597	301	143	415	791	454	341	451	654	230	204
Base Case	25	162	484	540	752	226	1090	878	381	600	303	167	419	789	456	344	466	690	246	211
	50	167	492	536	783	228	1082	786	438	606	306	204	423	788	465	348	487	743	273	180
	70	175	500	534	824	230	1073	670	528	614	311	242	429	786	479	354	512	809	310	155
Base with No SWP	25	157	484	543	755	226	1090	881	381	600	303	166	419	793	456	344	470	700	246	173
	50	157	492	546	792	228	1082	787	440	606	306	207	423	794	465	349	496	771	274	124
	70	159	501	550	838	230	1073	671	537	614	311	225	429	795	479	355	527	864	315	118
Alternative 1	25	154	467	541	745	226	1090	891	381	600	303	169	419	789	456	343	464	680	246	224
	50	153	423	536	732	228	1082	802	435	604	305	202	424	788	465	347	477	698	270	270
	70	151	391	530	687	230	1074	740	500	609	309	234	431	786	481	351	487	700	299	372
Alternative 2	25	154	468	540	738	226	1090	888	381	600	303	169	419	789	456	343	464	680	246	224
	50	153	438	531	716	228	1082	816	435	604	305	202	425	788	465	347	477	698	270	270
	70	151	389	520	658	230	1074	734	500	609	309	234	432	785	479	351	487	700	299	373
Alternative3	25	154	473	541	745	226	1090	909	381	600	303	169	419	789	456	343	464	679	246	224
	50	153	414	536	734	228	1082	829	434	604	305	203	423	788	465	347	477	692	270	272
	70	152	361	530	691	230	1074	771	498	609	309	234	428	786	480	351	487	691	299	381
Alternative 4	25	157	478	541	747	226	1090	904	381	600	303	184	419	789	456	343	464	681	246	229
	50	150	425	537	744	228	1082	815	436	604	305	237	424	788	465	347	477	703	270	255
	70	139	371	532	703	230	1074	748	516	609	309	282	430	786	481	351	488	709	299	300

Table of TDS concentrations in mg/l per sub-areas at initial condition and at each modeled time

References

DWR (1967) Mojave River Ground Water Basins Investigation Bulletin No. 84. CA Department of Water Resources, Sacramento, CA.

Rumbaugh, J., Blaha, M., Premerlani, W., Eddy, F., Lorensen, W., 1991. Object-oriented modeling and design. Prentice Hall, Englewood Cliffs, NJ.

Schlumberger Water Services, Mojave Water Agency 2002 Regional Water Management Plan Update Phase 1, 2002

Schlumberger Water Services, Mojave Water Agency 2004 Regional Water Management Plan, 2004

Schlumberger Water Services, Mojave Water Agency 2005 Groundwater Quality Analysis Phase 1, 2005

Simonovic, S.P., Fahmy, H., 1999. A new modeling approach for water resources policy analysis. Water Resources Research 35 (1), 295-304.

Stamos, C.L., Cox, B.F., Izbicki, J.A., and Mendez, G.O., Geologic Setting, Geohydrology and Ground-Water Quality near the Helendale Fault in the Mojave River Basin, San Bernardino County, California, USGS Water-Resources Investigation's Report, 4-Mar 069, 2003.

Stamos, C.L., Martin, P., Nishikawa, T., and Cox, B.F., Simulation of Ground-Water Flow in the Mojave River Basin, California, USGS Water-Resources Investigations Report 01-4002, Version 1.1, 2001

Umari, M.J., Martin, P., Schroeder, R., Duell, L. Fay, R.G., Potential for Groundwater Contamination From Movement of Wastewater Through The Unsaturated Zone, Upper Mojave River Basin, Ca. S.S.G.S. Water Resources Investigations Report 93-4137, 80p 1995.