



P A S A D E N A  
Water & Power

**TECHNICAL MEMORANDUM ON  
THE PERCHLORATE  
CONTAMINATION OF THE SUNSET  
RESERVOIR WELLS**

**MAY 2012**

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### Abbreviations and Definitions

Alluvium	Deposits of coarse-grained sands and gravels
AMPAC	American Pacific Corporation
amsl	Above mean sea level
Aquifer	A geologic formation or group of formations which store, transmit, and yield significant quantities of water to wells and springs
AMU	Atomic Mass Units – the metric for measuring mass of atoms and molecules
BMI	Basic Management Incorporated / Basic Magnesium Incorporated
Cal-Am	California American Water Company – An investor owned utility serving San Marino and San Gabriel
CTC	Carbon Tetrachloride
DLR	Detection Limit for Reporting – the lowest reportable concentration of a chemical to DPH
DPH	Department of Public Health
DTSC	Department of Toxic Substance Control
ft	Feet, foot
Fault	A fracture in the earth's crust, with displacement of one side of the fracture with respect to the other
Formation	A geologic term that designates a body of rock or rock/sediment strata of similar lithologic type or combination of types.
GEOSCIENCE	GEOSCIENCE Support Services, Inc.
GMWL	Global Meteoric Water Line
gpm	Gallon per minute
Ground Water	Water contained in interconnected pores located below the water table in an unconfined aquifer or located in a confined aquifer
JPL	Jet Propulsion Laboratory (Pasadena)
LA RWQCB	Los Angeles Regional Water Quality Control Board
LAWC	Lincoln Avenue Water Company
LCID	La Cañada Irrigation District

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### Abbreviations and Definitions (cont.)

LFWC	Las Flores Water Company
LMWL	Local Meteoric Water Line
mg/L	Milligrams per liter (= ppm)
MWD/MWDSC	Metropolitan Water District of Southern California
NASA	National Aeronautics and Space Administration
LCF	La Cañada - Flintridge
ppm	Parts per million
PEPCON	Pacific Engineering and Production Company
PPMC	Pearson Product Moment Correlation
PQL	Practical Quantization Limit
PWP	Pasadena Water and Power
SGM	San Gabriel Mountains
SIA	Stable Isotope Analysis
Source	For purposes of this study a "source" is a location where perchlorate was used
SWP	State Water Project
Total Dissolved Solids (TDS)	The quantity of minerals (salts) in solution in water.
TM	Technical memorandum
TU	Tritium Units
UIC	University of Illinois, Chicago
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
VOCs	Volatile Organic Compounds
VWC	Valley Water Company
WECCO	Western Electro-Chemical Company
yr(s)	Year or years

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## 1.0 EXECUTIVE SUMMARY

Pasadena Water and Power (PWP) has five wells around its Sunset Reservoir, which are contaminated with sufficient quantities of perchlorate that they are above the Maximum Contaminant Level (MCL), and by law must be treated before they can be used as a drinking water source. It has been PWP's contention that the source of the perchlorate is the National Aeronautics and Space Administration's (NASA) Jet Propulsion Laboratory (JPL) facility. NASA has contended that there are four distinct sources of perchlorate in the Raymond Basin; 1) A source unique to JPL from the Los Angeles WECCO facility, 2) the Basic Management Incorporated (BMI) Complex in Henderson Nevada, 3) Road Flares, and 4) Chilean nitrate fertilizers. NASA has argued that the Sunset Reservoir Wells have perchlorate from the BMI Complex while Bangham Well has perchlorate from both Chilean nitrate fertilizer and the BMI Complex. NASA based their argument upon ground water modeling, tritium and <sup>3</sup>He analysis, SIA of perchlorate, water, strontium as well as water typing to support this argument. PWP argues that Chilean nitrate fertilizer cannot be a source of perchlorate in the Sunset Reservoir area as there is no evidence that it was ever used in the recharge area for the Sunset Reservoir Wells and since agriculture was discontinued between 70 - 90 years ago, and even if it had been used, given the fact that water in the Sunset Reservoir Wells is between 20 - 30 years old so it is far too young to have been influenced by any agricultural activities. Further, the BMI Complex was owned and operated by the same company that operated the Los Angeles Facility (WECCO) and the latter was only operated for a brief time and produced only a tiny fraction of the perchlorate produced by WECCO during the period when perchlorate was being disposed of at JPL. The historical data argues strongly that all perchlorate found in the Raymond Basin comes from WECCO.

Beyond the historical record, the chemical analysis of the water found in the Raymond Basin strongly supports the theory that WECCO is the sole source of perchlorate. The Sunset Reservoir Wells receive water from three courses, southward directly out of the San Gabriel Mountains (SGM) parallel to the Arroyo Seco, which has very low concentrations of nitrate and no measureable perchlorate, and southwestward from the La Cañada-Flintridge (LCF) area, which has very high concentrations of nitrate and small, but measureable amounts of perchlorate. Where the SGM water flows beneath JPL, it is contaminated with perchlorate and CTC but not nitrate. The blending of these three courses can be measured by the mixing of nitrate and perchlorate. Nitrate and perchlorate blending data, indicates that water influenced by the Colorado River, from the LCF area, provides only a very minor contribution of perchlorate as compared to JPL. Using sulfate as a marker for the Colorado River, when combined with strontium analysis, indicates minimal influence upon the Sunset Reservoir Wells as the strontium data indicates that water is substantially similar to water from the San Gabriel Mountains and very different from the Colorado River and rain water. This is confirmed by SIA as well as by water typing indicates that this water is overwhelmingly local run-off from the SGM. Even the analysis of carbon tetrachloride, which NASA posits as the definitive marker of JPL contamination, is found both upgradient

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and downgradient from the Sunset Reservoir Wells. The results clearly indicate that the vast majority of perchlorate found in the Sunset Reservoir Wells is from JPL.

## 2.0 BACKGROUND

Currently, PWP has several wells that are contaminated with Volatile Organic Compounds (VOCs) and perchlorate. There are four wells in the Monk Hill area (Arroyo, Ventura, Well 52, and Windsor) located immediately across the Arroyo Seco from NASA's JPL facility and are collectively known as the Monk Hill Wells. There are three more wells located five kilometers (three miles) further south, also, near the Arroyo Seco near the Sunset Reservoir (Copelin, Bangham, and Sunset). Finally there are two wells about two kilometers (just over one mile) further south (Garfield and Villa). Collectively these five wells are known as the Sunset Reservoir Wells. Additionally, there are other local community water systems that have wells that also contain perchlorate and VOCs (California American Water Co. (Cal-Am), Lincoln Avenue Water Company (LAWC), and Las Flores Water Co. (LFWC). Figure 1 shows the location of the Sunset Reservoir Wells and other production wells in the Raymond Basin.

This Technical Memorandum (PWP TM) will show that the source of perchlorate at the Sunset Reservoir Wells originates from the JPL facility. PWP has contended that the Monk Hill Wells were contaminated by perchlorate and VOCs from JPL. NASA has agreed with this assessment and agreed to pay for the treatment of water for two wells, which belong to LAWAC (#3 / 1910063-002 and #5 / 1910063-003) and the four Monk Hill Wells which belong to PWP.

However, on January 31, 2007 NASA submitted a Technical Memorandum (NASA TM) to the United States Environmental Protection Agency (USEPA), the California Department of Toxic Substance Control (DTSC), and the California Regional Water Quality Control Board – Los Angeles Region (LA RWQCB) entitled: "Additional Investigation Results". In NASA TM NASA argued that the perchlorate at the five Sunset wells does not originate from the JPL facility. NASA's TM contends that there are other sources of perchlorate in the area. It was asserted in NASA's TM that there are four different sources of perchlorate in all, impacting different wells:

- 1) Los Angeles WECCO Facility (JPL, LAWAC Wells, and the Monk Hill Wells )
- 2) Chilean nitrate fertilizers (Bangham Well)
- 3) Road Flares (LFWC Well #2)
- 4) BMI Complex in Henderson Nevada via the Colorado River water and the MWDSC (Sunset Wells including Bangham)

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PWP does not believe that NASA's arguments are correct. PWP has responded in both writing and in direct conversations with NASA, USEPA, DTSC, and the LA RWQCB on how and why PWP disagrees with NASA's assessment of the source of perchlorate. This document presents additional information (not provided earlier), which supports PWP's position that the vast majority of perchlorate found at the five Sunset Reservoir Wells originates from JPL and not from other sources.

PWP's position is summarized in the following four opinions:

- 1) The Source of Perchlorate Found in Ground Water in the Sunset Reservoir Wells is of Recent Origin and not from Use of Chilean Fertilizers for Agriculture
- 2) Perchlorate Found in the Raymond Basin is from a Single Industrial Source
- 3) Perchlorate Measured in the Sunset Reservoir Wells is from Ground Water Flowing North to South Beneath the JPL Facility
- 4) Stable Isotope Analyses as well as General Mineral and Physical Data Validate that the Source of Perchlorate in the Sunset Reservoir Wells Originates from the JPL Facility

The following Technical Memorandum discusses each of the four opinions and the supporting basis for those opinions.

### **3.0 SOURCES OF DATA**

#### **3.1 Chemical Data**

There are four sources of chemical data used in this document

##### **3.1.1 NASA**

The vast majority of the chemical data presented here comes from the samples collected by NASA.

###### **3.1.1.1 Routine Monitoring**

There was the routine monitoring of all wells from 1996 until 2011 for perchlorate, nitrate, and carbon tetrachloride (CTC).

###### **3.1.1.2 Special Monitoring in 2005**

There was special data collected in 2005 and used in the preparation of the NASA TM. This includes all of the data from the monitoring wells, all of the SIA data for water and perchlorate, all of the tritium ( $^3\text{H}$ ) and helium-three ( $^3\text{He}$ ) data, and all of the strontium (Sr) data.

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### 3.1.2 DPH (Department of Public Health)

Some of the data comes from the DPH database for Drinking Water Program. This is largely the nitrate and perchlorate data from neighboring community water systems.

### 3.1.3 PWP (Pasadena Water and Power)

Some of the older nitrate data from the Monk Hill and Sunset Reservoir wells came from PWP records.

### 3.1.4 Peer-Reviewed Literature

A small amount of data was derived from the peer-reviewed literature (see References in Section 6).

## 3.2 Ground Water Flow Data

Ground water flow analysis was from ground water elevation data measured from wells and from a calibrated ground water flow model of the Raymond Basin.

## 3.3 Other Data

Other data was acquired from historical photographs from the Los Angeles Public Library.

## 4.0 OPINIONS

### 4.1 OPINION 1. The Source of Perchlorate Found in Ground Water in the Sunset Reservoir Wells is of Recent Origin and Not from Use of Chilean Fertilizers for Agriculture

#### 4.1.1 No Defendable Data on Widespread use of Chilean Fertilizers

It is noted in the NASA TM:

- 1) *“(1) NASA has determined that the chemicals from the JPL facility are contained within the Monk Hill Subarea, and (2) the perchlorate detected at the Sunset area wells is of a different origin than that used at, and originating from, JPL”*
- 2) *“The Sunset Reservoir Wells appear to be influenced by at least two separate (non-JPL) sources, including a naturally-occurring/fertilizer source (e.g., imported nitrate fertilizer from Chile) and at least one synthetic (i.e., manmade) source.”*
- 3) *“The  $\Delta^{17}\text{O}$  values of perchlorate in wells MW-25, Garfield, and Bangham show evidence of mixing with up to about 25% natural perchlorate (which is enriched in  $^{17}\text{O}$  relative to synthetic perchlorate). This natural perchlorate component could have been introduced by infiltration of agricultural fertilizers.”*

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This hypothesis does not agree with the historical data surrounding the manufacture and use of perchlorate. There is no defensible evidence that Chilean nitrate fertilizers (or "Nitrate of Soda") were ever actually used in the Raymond Basin area, much less the area around the Sunset Reservoir or in the LCF area. While some Chilean fertilizers were imported into the United States prior to 1920, the vast majority was imported much later. More to the point, by the early 1920's, there was no agricultural activity in the western reaches of the Pasadena area. Furthermore, agriculture in the LCF area was discontinued between 1920 and 1940. Appendix A is a land use map prepared by the California Department of Public Works – Water Rights Division (now part of the State Water Resources Control Board) in 1926 of the San Gabriel Valley. It clearly indicates that just about all of the lands in the Pasadena and Altadena area were already urbanized with no agriculture and only as small amount of irrigated land (e.g. golf courses). Historical photographs of both the Pasadena / Altadena / La Cañada area (Figure 2) and the Montrose area (Figure 3) from the mid-1920's confirm what is shown on the map. These areas are largely urbanized with little to no irrigated agriculture, certainly no tobacco, cotton, or fruit trees. This means that there is no reason for any Chilean nitrate fertilizer to have been applied in this area after this period. So unless the water in the Sunset Reservoir Wells is over 70 years old, it would be impossible for Chilean nitrate fertilizers to have contributed any perchlorate to those waters.

#### 4.1.2 Tritium Data Show Recent Water in the Raymond Basin

The data presented in NASA's TM supports this contention. As part of the investigation, in 2005, NASA collected samples from a number of wells and analyzed them for the quantities of tritium ( $^3\text{H}$ ) and helium-3 ( $^3\text{He}$ ) present, including some from Monk Hill area. In NASA's TM it was noted that: "...investigators have attempted to generalize the age of water based on relative levels of tritium, where  $<0.8$  TU [tritium units] represents water recharged prior to 1952. Where tritium levels were found between 2 and 8 TU represented modern recharge." In Figure 12, of NASA's TM (Figure 4 in this document), the vast majority of water in the Monk Hill sub-area was between 2 and 8 TU and thus entered the basin after 1952. Since there had been no agriculture of any significance since 1940 in the LCF area, and none in the Monk Hill area even earlier, Chilean fertilizers could not possibly have been the source of either nitrate or perchlorate for waters that entered the aquifer after 1952.

Tritium is introduced into the hydrological cycle in the atmosphere, where it is produced naturally by the interaction of cosmic radiation with atmospheric components in a process called "spallation". The major reaction involved is that of thermal neutrons with nitrogen-14 producing tritium and carbon-12 (Nir et al., 1966). This process, on its own, would produce a natural background of 2 – 8 TU corresponding to a rate of  $0.20$   $^3\text{H}$  atoms/cm<sup>2</sup>/sec, which is what was observed in samples collected prior to 1953 (Figure 5, from Brown 1961 and Kaufman & Libby 1954). After the beginning of above ground testing of hydrogen

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bombs, tritium concentrations increased dramatically. In the spring of 1963 the  $^3\text{H}$  content of precipitation at the northern hemisphere peaked at about 5000 TU and has been declining since (Figure 6, IAEA 2010)). Uchrin et al. (1987) report that in the northern hemisphere samples collected in the coastal areas had a concentration of 2 – 20 TU (more inland continental areas ranged from 8 – 80 TU).

Using the most current estimate of tritium's half-life of 12.3 years, if pre-1953 water had 2 – 8 TU and were not exposed to the atmosphere since, then by 1995 it should have 0.3 - 0.8 TU and by 2005 be in the 0.12 - 0.5 TU (or 0.39 to 1.6 pCi/L) (Rupert and Plummer, 2005). Rupert and Plummer write: " $^3\text{H}$  concentrations in precipitation prior to thermonuclear weapons testing are not well known, but probably did not exceed 2 to 8 TU (Plummer and others, 1993, p. 260). Because  $^3\text{H}$  has a half-life of 12.32 years, water derived from precipitation before thermonuclear weapons testing would contain a maximum  $^3\text{H}$  concentration of 0.12 to 0.5 TU by the early 2000's."

Using this standard, there is only one sample collected in 2005 that would unambiguously qualify as "old" (pre-1953), specifically MW-20-5, although there are a few that might be considered "borderline". This sample contained no perchlorate in 2005 when the tritium samples were collected. Notably this is the deepest screen in one of the deepest monitoring wells. This screen is 262 feet above mean sea level (amsl), the next closest screen in the Monk Hill area is MW-17-5, which is 463 ft amsl, over 200 feet higher. None of the production wells either up-gradient or down-gradient have screens this deep either. The closest is MW-52, which has its deepest screen at 428 ft amsl. It also has the lowest concentrations of calcium, magnesium, sulfate, chloride, and strontium measured in 2005. The water collected at this sample location is entirely different from that found at any other sample location in terms of the depth, age, and chemical composition. Most of the tritium found in the other wells was in the 0.8 – 8 range, which, working backwards, would correspond to the 2 – 20 TU range three half-lives earlier, or about 1987 for a coastal northern hemispheric area like Pasadena. Water in the Sunset Reservoir Wells, based on the tritium data, is about 20 – 30 years old.

#### 4.1.3 Helium 3 Data Confirms the Tritium Data as to a Recent Water Source

Estimates of the age of the water determined by the tritium data are supported by the age estimates from the  $^3\text{He}$  data, which was collected at the same time as the tritium was collected.  $^3\text{H}$  decays to  $^3\text{He}$  by beta particle emission so by using the ratio of  $^3\text{He}$  to tritium the age of the groundwater can be determined (Groundwater Age (in years) =  $-17.8 \ln(1 + ^3\text{He}/^3\text{H})$ ). Only a few sample locations were tested for  $^3\text{He}$ , but those that were, showed comparatively young water. For example, MW-17-3 had a measured age of 11.7 years and MW-24-1 had a measured age of 5.4. Garfield, Sunset, and Bangham wells had ages determined by  $^3\text{He}$  of around 20 years, which matches approximately with the  $^3\text{H}$  results. This means that the estimation of "old" and "young" water in Figure 4 errs by over-calculating how much "old" water is actually in the Raymond Basin. There is actually next to no pre-1953 water in the

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Monk Hill area according to the  $^3\text{He}$  data collected by NASA in 2005. Water in the Sunset Reservoir Wells, based on the  $^3\text{He}$ , is about 20 – 30 years old.

#### 4.1.4 Nitrate Data Also Supports a Recent Water Age

An examination of the nitrate data from PWP wells also supports the tritium and  $^3\text{He}$  data regarding the relatively recent age of the water. PWP has been collecting nitrate results since 1920 at wells in the Monk Hill and Sunset Reservoir areas. For the five wells with results from that era, the nitrate concentrations are very low as compared to today until the 1940's when they all began to increase. The three Monk Hill wells (Arroyo, Sunset, Windsor) increased in concentration only slowly and did not show an obvious increase until about 1960, while the two Sunset Reservoir Wells (Copelin and Sunset) showed an increase earlier (Figure 7). However, the rate of increase was about the same for all wells over the entire period and the concentrations today are very similar. This increase in nitrate concentration is due to the urbanization of the LCF area and the widespread use of septic tanks. The LCF area has historically been unsewered (Figure 8) and thus a source for nitrate. The increase following 1940 is entirely consistent with the final end of agriculture. This is clearly indicative of the fact that waters in the Raymond Basin has entirely turned over since 1940 more than once.

#### 4.1.5 Location for Contamination

NASA's TM argues that Bangham Well has perchlorate that is a mixture of Chilean nitrate fertilizers and perchlorate from the Colorado River. NASA's hypothesis is that MWDSC water entered the Raymond Basin through return flow and injection for aquifer storage and recovery, and then blended with local waters influenced by Chilean nitrate fertilizers, but only at Bangham Well. NASA has not been able to identify any location where Chilean nitrate fertilizers were supposed to have been applied, and could have partially influenced Bangham Well and no other wells. Bangham Well is only 236m from Sunset Well, but according to the NASA TM it shows no influence from Chilean nitrate fertilizers at Sunset Well. It seems extremely unlikely that Chilean nitrate fertilizer could have been applied in one particular location, which would have influenced no wells exclusively, only influence exactly one well partially, and no other well at all, even those located in the immediate proximity.

#### 4.1.6 Summary for Chilean Nitrate Fertilizer

All of the evidence available strongly suggests that the vast majority of water in the Sunset Reservoir Wells, the tritium data, the  $^3\text{He}$  data, and the nitrate data show that water is of comparatively recent origin, 20 to 30 years old. This water is much too recent to have been influenced by any agricultural activities which ended in the 1920's to 1940's (70 to 90 yrs ago), much less some hypothesized activities for which there is no evidence, nor any identified locations.

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## 4.2 OPINION 2 - Perchlorate Found in the Raymond Basin is from WECCO

### 4.2.1 Perchlorate found at the JPL facility is from the BMI Complex in Henderson NV

The perchlorate contamination of the JPL site occurred during the 1940's and '50's and came from "military grade" perchlorate. For a short time during this period, perchlorate was only manufactured in any quantity at two locations, Los Angeles, California and Henderson, Nevada. The Los Angeles facility was a small factory, which only operated for just a little more than two years. It began operation in January of 1944 producing 100 tons/month. Later that same year it doubled its production to 200 tons/month and the plant shut down in early 1946. The Henderson facility began production in July of 1945 and was producing 1,200 tons/month. In 1950 it expanded production to about 1,500 tons/day. Expansion of the facilities at Henderson continued for many years until the late 1980's. In its first four months of production in 1945, the Henderson facility produced more perchlorate than the Los Angeles facility did in its entire life-time (Schumacher 1999, See Attachment B). Western Electro-Chemical Company (WECCO) Los Angeles Facility operated between January 1944 and March of 1946 producing only 4,000 tons while WECCO's Henderson Facility began operation in July of 1945, and by 1950 had produced 79,200 tons of perchlorate, which was over 95% of all perchlorate manufactured in the United States until 1950. In years following, the percentage of perchlorate that had once been manufactured at WECCO's Los Angeles facility declined even more. WECCO was the sole manufacturer of perchlorate in the United States during the period when perchlorate was being used and disposed of at JPL. It is highly unlikely that all or even a major portion of the perchlorate disposed of at the JPL facility originated only at the Los Angeles plant, and that none or even a minority of the perchlorate disposed of at the JPL facility came from the Henderson plant (Trumpolt et al. 2005).

WECCO later merged with American Potash and Chemical Company in 1955 and was then acquired by Kerr-McGee in 1967. In 1958 other manufacturers began producing perchlorate, most notably Pacific Engineering and Production Company (PEPCON) which was also located in Henderson NV, immediately adjacent to the WECCO facility. These facilities were both acquired by American Pacific Corporation (AMPAC) in 1982 and were operationally merged (also known as the BMI Complex). The part of the BMI Complex that had been owned by PEPCON was destroyed by an explosion in 1988. Approximately 90 percent of perchlorate production in the United States has been as ammonium perchlorate for solid rocket engines and the remainder for pyrotechnics and explosives. Before the BMI Complex was destroyed, it was producing about 90 percent of the ammonium perchlorate for entire non-communist world Department of Toxic Substance Control (DTSC 2005). This being the case, it seems unlikely that fireworks manufacturers and flare manufacturers had a different, unique source for their perchlorate. It is entirely possible that both of these sources were also from the BMI Complex in Henderson NV.

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NASA's TM argues that only perchlorate with a certain range of  $\Delta^{17}\text{O}$ ,  $\delta^{18}\text{O}$ , and  $\delta^{37}\text{Cl}$  depletion can have originated from WECCO's Los Angeles facility (in the Figures 9 and 10, this shown as yellow box) and a different range of  $\Delta^{17}\text{O}$ ,  $\delta^{18}\text{O}$ , and  $\delta^{37}\text{Cl}$  can have originated from WECCO's Henderson facility. NASA's TM never explains how the yellow colored box was established, which separated the isotopic ratios of the "JPL Source" from the other samples. Most of the differences are in the degree of depletion in the  $\delta^{18}\text{O}$ , there is little difference in depletion of either the  $\delta^{37}\text{Cl}$  or  $\Delta^{17}\text{O}$ . Both MW-16 and the Operable Unit 1, which are physically very close to one another, fall within the range of the yellow box, -18 to -23  $\delta^{18}\text{O}$ , or five units. If the same range were extended to the right, it would include the BMI and Las Vegas Wash data. Further, there is considerable amount of variability between the various archived samples from the BMI Complex. There does not appear to be any reason that all of the data collected could not have originated from the same source or that the SIA is capable of resolving one source or another or that there are even two sources at all.

The industrial history of the production of perchlorate strongly indicates that the perchlorate used at the JPL facility was in fact produced at the facility that became known as the BMI Complex, just as the perchlorate released into the Colorado River was.

#### 4.2.2 Road Flares

As noted above, NASA's TM argues that there were four different sources of perchlorate in the Raymond Basin, the JPL (Los Angeles WECCO) Source, BMI Complex (Henderson WECCO), Road Flares, and Chilean Nitrate Fertilizer. However, since Chilean Nitrate Fertilizer has been eliminated as a possible source of perchlorate, and it has been shown that the "JPL Source" is the same as the BMI Complex, there is only one other possible source, "Road Flares". NASA's TM suggests some influence of perchlorate from road flares on Las Flores Water Company (LCFW) Well #2, however, there is no evidence supplied to explain any possible link. There were no road flare manufacturing operations in the area, there is no evidence for any unusually large number of road flares being used in the area in the last 30 years, further, there is good evidence that road flare manufacturers used perchlorate from the BMI facility. As noted above, between 1946 and 1958 the WECCO's Henderson facility was the only manufacturer of perchlorate in the United States and even after that, the BMI Complex produced over 90% of it until 1997. How likely is it that all of the perchlorate in LFWC Well #2 came from only perchlorate produced after 1958, and only from one of the small number of manufacturers not operating in Henderson? Moreover, the conclusion that perchlorate in LFWC Well #2 is somehow influenced by road flares is based on only two data points, one sample from one road flare and one sample collected from one well. It is important to note that these two data points do not actually match in the degree of depletion of  $\delta^{18}\text{O}$ . As with the Chilean nitrate fertilizer, it seems highly unlikely that perchlorate from road flares, originating from an unidentified location, could have influenced only one well while influencing no others. This

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hypothesized link between some unspecified road flares and the perchlorate found in LFWC Well #2 is tenuous at best. The most reasonable explanation is that all of the perchlorate in all of the local sources came from the same industrial source, WECCO.

#### 4.2.3 SIA of Perchlorate Signatures

##### 4.2.3.1 Method for SIA for Perchlorate

Perchlorate consists of a single chlorine atom surrounded by four oxygen atoms. There are three stable isotopes of oxygen ( $^{16}\text{O}$ ,  $^{17}\text{O}$ ,  $^{18}\text{O}$ ) and two of chlorine ( $^{35}\text{Cl}$ ,  $^{37}\text{Cl}$ ) so there are a large number of possible combinations these isotopes producing isotopomers with masses ranging from 99 to 109 Atomic Mass Units (AMU). There are expected ratios of these isotopes based on the measured concentrations found in ocean water. The expected ratio of  $^{16}\text{O}$  to  $^{17}\text{O}$  is 263,000:1 while the expected ratio of  $^{16}\text{O}$  to  $^{18}\text{O}$  is 49,000:1 based on the Vienna Standard Mean Ocean Water (VSMOW). Deviations from this mean ratio can be calculated by two equations;

$$1) \delta^{18}\text{O} = (^{18}\text{O}/^{16}\text{O})_{\text{sample}} / (^{18}\text{O}/^{16}\text{O})_{\text{vsmow}} - 1 \text{ vsmow},$$

$$2) \Delta^{17}\text{O} = (1 + \delta^{17}\text{O}) / (1 + \delta^{18}\text{O}) 0.525 \text{ vsmow}$$

Similarly, there is a Standard Mean Ocean Chloride (SMOC) with an expected ratio of  $^{35}\text{Cl}$  to  $^{37}\text{Cl}$  of 76:24 and an equation for measuring deviations from this standard.

$$3) \delta^{37}\text{Cl} = (^{37}\text{Cl}/^{35}\text{Cl})_{\text{sample}} / (^{37}\text{Cl}/^{35}\text{Cl})_{\text{smoc}} - 1$$

By measuring the ratios of these isotopes in perchlorate, different patterns of enrichment and depletion can be assessed. NASA collected a number of samples in 2005 in the Raymond Basin and had them analyzed for SIA for perchlorate. The results are summarized in NASA's TM Figures 16 and 17 (Figures 9 & 10 in this document with additions).

##### 4.2.3.2 Single Industrial Source of Perchlorate in the Raymond Basin

If this hypothesis is correct, that there is but a single source of perchlorate for all of the samples studied, then how is the difference in SIA data from the perchlorate explained. If the results from NASA's TM Figures 16 and 17 are re-plotted into a new graph, without the Chilean nitrate fertilizer points, a different pattern can be seen (Figure 11) (There were no  $\delta^{37}\text{Cl}$  results for either Garfield Well or MW-17-3. In both cases, a line was used to represent the range of results found in other samples with a range of -3 to +2). Two distinct groups of results can be seen:

- 1) Results marked MW-16, MW-16R, MW-17-3, MW-19-2, Las Vegas Wash, BMI Archived Samples, Ground Water from the BMI Complex, OU-11N, Road Flare, and Fireworks and Sunset Well are

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all clustered together with very little variability in the  $\Delta^{17}\text{O}$  and  $\delta^{37}\text{Cl}$  results. Almost all of the variability in these samples is found in the  $\delta^{18}\text{O}$  results.

- 2) Results marked MW-25-1, MW-25-2, MW-25-3, and MW-25-4, Bangham, and Garfield show a great deal of variability in all three variables. MW-25-1 and MW-25-4 show enrichment of  $\delta^{37}\text{Cl}$  while MW-25-2 and MW-25-3 show none and Bangham shows a marked depletion. The range is approximately -3 to +2. MW-25-2, MW-25-3, and Garfield, show marked enrichment of  $\Delta^{17}\text{O}$  while MW-25-1, MW-25-4 and Bangham show only a small amount of enrichment with an overall range of about 0.8 to 2.0. So there is a great deal more variability in the  $\Delta^{17}\text{O}$  and  $\delta^{37}\text{Cl}$  results among the Sunset Reservoir locations than among all of the other samples combined while the amount of  $\delta^{18}\text{O}$  is about the same.

This pattern of isotopic depletion cannot be explained by blending of different sources of perchlorate. This is so for two reasons:

- 1) The only "other source" in the Sunset Reservoir Wells was supposed to be Chilean nitrate fertilizer which is now known not to be possible.
- 2) The Sunset Reservoir Well results are scattered along three different axes ( $\delta^{37}\text{Cl}$ ,  $\Delta^{17}\text{O}$ , and  $\delta^{18}\text{O}$ ) in such a way that it would require four different sources to account of it.
  - a. There would need to be separate sources for Bangham Well with its depleted  $\delta^{37}\text{Cl}$  and enriched  $\Delta^{17}\text{O}$ .
  - b. There would have to be a separate source for MW-25-1 and MW-25-4 with their enriched  $\delta^{37}\text{Cl}$  and enriched  $\Delta^{17}\text{O}$ .
  - c. A third source would be needed for Garfield, WM-25-2, and MW-25-3 with their enriched  $\Delta^{17}\text{O}$  but un-enriched  $\delta^{37}\text{Cl}$ .
  - d. The WECCO source would be the fourth.

Since blending of different sources cannot explain the patterns of isotopic depletion observed, there must be some other process at work. PWP has argued previous and does here again, that the observed patterns can best be explained by the inherent variability of perchlorate SIA and biodegradation.

#### 4.2.4 Inherent Variability

If the overall variability of the industrial sources shown in NASA's TM figures 16 and 17 along all three axes of interest ( $\Delta^{17}\text{O}$ ,  $\delta^{18}\text{O}$ , and  $\delta^{37}\text{Cl}$ ) is compared with those from the "Natural/Fertilizer" sources, is about equal. The "Natural/Fertilizer Perchlorate" all comes from a single source, Chilean caliche. If this

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range of variability, approximately 10  $\delta^{18}\text{O}$  units, is produced by a single natural source, it hardly seems reasonable to argue that a single industrial source would produce results with the same range. As noted above, there is ample evidence that all of the industrial sources presented in NASA's TM come from WECCO. This range of variability is entirely consistent with a single industrial source.

Consider the two samples collected from the same well, MW-16 and MW-16R (which are replicates). They show considerable difference in the degree of depletion in the  $\delta^{18}\text{O}$ , approximately three  $\delta^{18}\text{O}$  units. That is about the difference between results from the OU1-IN sample and the Sunset Well sample and the MW-25 samples. Consider further the four "BMI Complex Archive Samples", there is a considerable amount of variability along the  $\delta^{18}\text{O}$  axis. As will the MS-16 samples, there is also approximately 3  $\delta^{18}\text{O}$  units of variability. The same arguments could be applied to the  $\Delta^{17}\text{O}$  and  $\delta^{37}\text{Cl}$  results.

The variability in the SIA results appears to be due to, at least partially, if not completely, the inherent variability in the manufacturing process and the analytical procedure.

#### 4.2.5 Biodegradation

It is well established that there are facultative anaerobic bacteria that, under anaerobic conditions, will consume perchlorate as a source of oxygen. This is the basis for the now widely used anaerobic bioremediation technology for the removal of perchlorate from contaminated ground waters. These bacteria use two enzymes, perchlorate reductase and chlorite dismutase (CD) to first reduce perchlorate to chlorite ( $\text{ClO}_2^-$ ) and molecular oxygen ( $\text{O}_2$ ) and then disproportionation (dismutation) of chlorite into molecular oxygen and chloride. CD is encoded by the *cd* gene, which is unique and highly conserved in perchlorate reducing bacteria (Bansal et al. 2011). Organisms collected from the ground water sampled were found to have had the *cd* gene, including on the JPL site (MW-24-1), off site and down gradient (MW-17-3 and LFWC #2), and in some of the Sunset Reservoir Wells (MW-25-3 and Sunset). In some case the mRNA for CD was also found and in others it was not. So clearly the microbiological conditions exist in the Raymond Basin for anaerobic biodegradation of perchlorate to occur.

However, the presence of bacteria with the *cd* gene and even the mRNA for CD is not necessarily sufficient to demonstrate anaerobic biodegradation is occurring. As NASA's TM states:

*"Biodegradation is most likely not occurring since the dissolved oxygen (DO) levels are near saturation and nitrate is relatively high (generally greater than 1 mg/L as  $\text{NO}_3$ ), indicating that the anaerobic conditions necessary for reductive degradation of the perchlorate are not present. DO and nitrate are*

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*competing electron acceptors and would be biodegraded preferentially before perchlorate degradation occurs."*

This is definitely observed in fluidized bed anaerobic bio-reactors where all of the DO and NO<sub>3</sub> is consumed before the bacteria will consume perchlorate. However, there is evidence that anaerobic biodegradation is occurring in the Raymond Basin. Carbon tetrachloride (CTC) is well established to be on the JPL site and Trichloromethane (TCM or chloroform) is found in many wells downgradient of JPL. CTC is degraded by bacteria under anaerobic conditions to TCM. Bacteria such as *Pseudomonas stutzeri*, *Methanosarcina barkeri*, *Desulfobacterium autotrophicum*, *Moorella thermoacetica*, and *Methanobacterium thermoautotrophicum* can use carbon tetrachloride reductive dehalogenase to consume CTC and produce TCM (Lee et al 1999). Lewis Mitani, the Remedial Project Manager for the USEPA on the JPL situation, notes this same process in his October 2007 memorandum. DTSC also notes that they determined that there is evidence that the conditions in the Raymond Basin are indeed reducing in their May 2008 memorandum on page 5, Section 16: "...much of the chemistry suggests local anaerobic conditions." Since TCM was not known to have been used or disposed of at JPL, its presence in wells that are well established to be influenced by JPL water demonstrates anaerobic biodegradation is occurring, irrespective of the DO and NO<sub>3</sub> concentrations. Further, Judy Huang of the USEPA, the current Remedial Project Manager, wrote in her 2010 memorandum: "... perchlorate degradation is qualitatively plausible...".

When bacteria consume perchlorate, they preferentially consume those molecules that are more depleted in <sup>18</sup>O, i.e. they favor <sup>16</sup>O (Sturchio et al 2007). As a result, as bacteria consumer perchlorate, they preferentially consume molecules with <sup>16</sup>O so that the unconsumed perchlorate becomes less depleted, or richer in <sup>18</sup>O, moving SIA distribution towards a positive value. Biogradation can in fact also explain the wide variability in the <sup>18</sup>O results. Notably, Bangham Well and LFWC #2 Well both show the lowest values for <sup>18</sup>O among the samples analyzed in 2005.

#### 4.2.6 Summary of Perchlorate Industrial Sources

There are three conclusions from this data: 1) Chilean nitrate fertilizers cannot be the source of any perchlorate found in the Raymond Basin; 2) Perchlorate that has been found is from a single, industrial source, and 3) SIA results for perchlorate in the Raymond Basin is the result of the inherent variability of perchlorate from industrial sources and biodegradation.

#### 4.3 OPINION 3 - Perchlorate Measured in the Sunset Reservoir Wells is Predominately from Ground Water Flowing North to South Beneath the JPL Facility

Water flows into the Monk Hill Sub-Basin through three courses:

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- 1) South from the SGMs parallel to JPL
  - 2) South from the SGMs beneath and downgradient of JPL
  - 3) Southeast from LCF Area

#### 4.3.1 Course North to South Parallel to the JPL Facility

Some water flows south out of the SGMs parallel to the JPL facility, but does not flow beneath the JPL facility, generally to the east around the mouth of the Arroyo Seco. Sampling locations for the area east of JPL, which capture some of this parallel SGM flow includes the JPL monitoring wells MW-1, MW-9, and MW-15. This water originates from precipitation in the SGM, which then flows south beneath the surface. **The water in this course has no measureable amounts of perchlorate or tetrachloride (CTC) and very low nitrate concentrations.**

#### 4.3.2 Course North to South Beneath and Downgradient of the JPL Facility

Water chemically identical to the water described in 4.3.1 but flows south out of the SGMs and beneath JPL. Beneath the JPL facility, there is a known source of both perchlorate and CTC but no sources of nitrate. There are monitoring wells in and around the JPL facility, some with only one screen, others with five. While the water entering the JPL facility has no measureable amounts of perchlorate or CTC, the water beneath the site and downgradient of the site has much **high concentrations of both perchlorate and CTC and very low nitrate concentrations.**

#### 4.3.3 Course Northwest to Southeast out of the LCF Area Parallel to the JPL Facility

A portion of the ground water flow is from the northwest to the southeast in the Monk Hill Sub-Basin from LCF area(see Figure 1). **Ground water elevations used for control in this northwest area are wells in the La Cañada Irrigation District (LCID) and Valley Water Company (VWC) as well as JPL monitoring wells MW-14 and W-21 (which are south of the JPL facility). The water in this area has very high concentrations of nitrate and very low, intermittent, but detectable concentrations of perchlorate and no detectable CTC.**

#### 4.3.4 Mixing of Water from the Three Courses

It is the contention of NASA's TM that all of the water found in the Sunset Reservoir Wells comes from the LCF area water course and that no water from the SGMs, either flowing parallel to or beneath JPL, has any influence on those five wells. This is based on the hypothesis that the production wells in the Monk Hill area, those belonging to PWP, LAWC, LFWC, and RCLWA, extracted all SGM water flow and prevented any of that water from migrating south of those wells. Therefore, all of the perchlorate found in the Sunset Reservoir Wells must be from the LCF area. It is PWP's contention that there was no such

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containment and that the water in the Sunset Reservoir Wells is a mixture of all three water courses and that the vast majority of the perchlorate found in these wells comes from JPL. **PWP's position is strongly supported by the fact that the concentrations of perchlorate found in the Sunset Reservoir Wells is higher than that found in the LCF area wells and lower than that found in the JPL wells while the nitrate concentrations are lower than that found in the LCF area wells and higher than that found in the JPL wells. If there were containment by the Monk Hill Wells, this would not be possible.**

#### 4.3.5 The Patton Well

The Cal-Am Company has wells that are physically located within the Raymond Basin north of the Raymond Fault and within the boundaries of the City of Pasadena, which do not serve Pasadena, but its neighbor to the south, San Marino. The Patton Well has had perchlorate contamination for a number of years and is located approximately 8 km (5 miles) due south of the Sunset Reservoir Wells. In the summer of 2011, this well was found to have CTC as well as perchlorate and nitrate in concentrations comparable to the Sunset Reservoir Wells. If NASA's hypothesis that CTC is a conservative and a locally unique indicator of contamination from the JPL facility, then the water in this well must be influenced by water from JPL. As the Sunset Reservoir Wells lie between JPL and the Patton Well, it would be expected that ground water containing perchlorate from the JPL area would impact both the Sunset Reservoir Wells and the Patton Well. Figure 12 presents a generalized summary of the ground water movement and perchlorate pathways from JPL to the Sunset Reservoir Wells.

Further, the Patton Well also has Perchloroethylene (PCE) and Trichloroethylene (TCE) in addition to the CTC and perchlorate, which are also found at JPL. Between March and November of 2011 28 samples were collected from the Patton Well. The mean concentration of CTC was 0.2 µg/L, PCE was 0.5 µg/L, TCE was 1.3 µg/L, and perchlorate was 4.1 µg/L. A Pearson Product Moment Correlation analysis was performed on the 2011 Patton Well VOC and perchlorate data and statistically significant correlations were found between all analytes except PCE and perchlorate (Table 2). Given the fact that all four of these compounds are found on the JPL site, are also found in the Monk Hill Wells and the Sunset Reservoir Wells, and show a strong statistically significant correlation, this would strongly suggest that the perchlorate and the VOCs share a common source at JPL.

A review of laboratory reports from the 1980's and 1990's indicates that a number of wells between JPL and the Patton Well had low level CTC detections. The Villa Well, Craig Well, and Woodbury Well had detections of CTC as well as for perchlorate and nitrate. The earliest detection was 1980 and latest was 1992 (see Appendix C). This would seem to indicate that there was considerable lateral dispersion through a wide area of the Raymond Basin of water containing perchlorate, nitrate, and CTC. It would also argue that there was no containment of water in the Monk Hill Sub-Basin and that water from JPL moved south into the Pasadena Sub-Basin.

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#### 4.3.6 Summary for JPL as the Source of the Majority of Perchlorate

In summary, although a minor amount of perchlorate originates in the LCF area and flows southeast into the Raymond Basin, the vast majority of the perchlorate originates from the JPL site and moves south with a water course which originates north of the JPL site, flows beneath the perchlorate disposal area within JPL, and then southerly to the Sunset Reservoir area and Patton wells.

#### 4.4 OPINION 4 - SIA as Well as General Mineral and Physical Data Validate that the Major Source Of Perchlorate in the Sunset Reservoir Wells Originates from the JPL Facility

##### 4.4.1 Data Presentation of Censored Data

The nitrate, perchlorate, and CTC data from the LCID, VWC, LAWC, LFWC, and PWP were collected from the DPH Drinking Water Program database and summarized in Table 1. Additionally, the routine monitoring data from the JPL monitoring wells for the same three compounds is included in that same table. All results reported to DPH for compliance purposes that are less than the Detection Limit for Reporting (DLR) were assigned a value 1/10th of the DLR, 200 µg/L for nitrate and 0.4 µg/L for perchlorate. All results from the NASA/JPL wells that were less than the Practical Quantization Limit (PQL) were also assigned the same values as the DPH compliance data. If no PQL was provided, the reported value was used irrespective of its value. Therefore, no zero results are found in this study data and the lowest possible result for a mean or median in Tables 1a and 1b, is 200 µg/L for nitrate and 0.4 µg/L for perchlorate. Additional notes are provided in Tables 1a and 1b to distinguish how many results were above the DLR or PQL.

##### 4.4.2 Evidence for Mixing Based on Median Nitrate and Perchlorate Data

Using data from wells in the LCF area, on the JPL site, and in the surrounding areas, Table 1 and Figure 13 were prepared. Figure 13 shows median concentrations of perchlorate and nitrate at these different well locations. The SGM water flowing parallel to JPL measured at MW-1, MW-9, MW-15, and some of the screens in MW-3 and MW-18 are marked with turquoise colored circles. The results from each of the LCF area water purveyors are marked with grey colored squares or diamonds (including LCID and VWC wells plus the JPL monitoring well MW-14 and MW-21). The green diamonds indicate all of the PWP Monk Hill and Sunset Reservoir Wells that do not have any samples with measurable CTC concentrations. The red circles, hexagons, and downward facing triangles represent all wells with CTC and perchlorate and thus must be influenced by JPL, if NASA's hypothesis about CTC as a conservative marker is correct. The yellow symbols are those JPL locations without any CTC. As can be seen in Figure 13, the three water courses, beneath JPL (high perchlorate, low nitrate, and high CTC), from the SGM parallel to JPL (no perchlorate, low nitrate, and no CTC), and LCF area wells are clearly visible (low perchlorate, high nitrate, and no CTC). That there is mixing between these three courses is apparent. A

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continuum of concentrations forming something of a triangle is quite visible with each course at an apex and directly at the center are PWP wells, including the Sunset Reservoir Wells. The mixing is occurring on the JPL site itself, and south of the JPL site. PWP wells are definitely at the center of this triangle with an intermediate mix of nitrate and perchlorate.

There are three wells that contain CTC, but no measurable perchlorate and very little nitrate, MW-3-3, LAWC #5, and MW-12-5. While these sample locations do have very low median concentrations, at the minimum value of 0.4 ppb, the mean value is significantly higher as there were individual results higher than the minimum. In contrast, the samples in turquoise had not a single positive perchlorate value.

PWP wells clearly have a mixture of water from the LCF area, JPL, and SGM courses. This data is incompatible with the hypothesis that there is containment of the water from JPL by the Monk Hill area wells.

#### 4.4.3 Evidence for Mixing Based on a Transect Across JPL

The mixing between the LCF, JPL, and SGM waters can be seen if the results shown on Table 1 are plotted across the northern edge of JPL, there is a line of monitoring wells as seen in Figure 14. From west to east they are MW-14, MW-6, MW-22, MW-13, MW-16, MW-24, MW-7, MW-8, MW-11, MW-15, MW-9, and MW-1. If median concentration of perchlorate and nitrate are plotted in the same fashion left to right representing west to east, the mixing of the three water sources is quite clear. The western most water (MW-14-1) has the highest concentration of nitrate and a fairly low, but detectable median concentration of perchlorate. Moving eastward (left to right), the concentrations of nitrate decline and the perchlorate increases as it reaches the locations with CTC (MW-13, MW-16, MW-24-1, and MW-8). Further to the right (east), the concentrations of both nitrate and perchlorate are very low, and there is no CTC. The east to west mixing is clearly present even on the JPL facility.

#### 4.4.4 Evidence for Mixing Based on a Transect Across the Monk Hill Area

When the same parameters are plotted for the Monk Hill Wells and the proximate monitoring wells from Windsor Well on the south to MW-3 northwest of Arroyo Well, there is strong evidence that there is mixing between SGM waters (no CTC, perchlorate, and low nitrate), the JPL water (low in nitrate, high in perchlorate and CTC), and the LCF area waters (high in nitrate, low in perchlorate, and free of CTC) (Figure 15). Once again, even though these wells are physically proximate to each other, the concentration of nitrate, perchlorate, and CTC vary dramatically both over distance and time. This can only be explained by mixing between the three water courses and is inconsistent with the hypothesis that the water from JPL was contained by the Monk Hill area wells.

#### 4.4.5 Evidence for Mixing Based on a Transect Across the Sunset Reservoir Area

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When the data from the five Sunset Reservoir Wells and the nearest monitoring well (MW-25) are plotted, it can be seen that there is little difference between these six wells in terms of perchlorate and nitrate (Figure 16). The water at this point, appears to be well mixed. The concentrations of perchlorate are higher than that found in the LCF area waters and SGM waters, but lower than that found on the JPL site. Conversely, the nitrate concentrations are significantly lower in the Sunset Reservoir Wells than in the LCF area waters, but higher than in the JPL waters and the SGM waters.

In conclusion, examining the perchlorate, nitrate, and CTC data from the LCF area wells, the JPL monitoring wells, and PWP's production wells, the evidence point very strongly to the water in the five Sunset Reservoir area wells as being a mixture of water moving southeast out of the LCF area, which has high nitrate concentrations, low perchlorate concentrations, and no CTC and other water moving southward out of the JPL facility that has low concentration of nitrate, high concentrations of perchlorate, and in some cases, CTC.

#### 4.4.6 Colorado River Water Is Only a Minor Source of Perchlorate

In NASA's TM, it was suggested that the perchlorate found in the wells in the Sunset Reservoir area has its origins in water delivered to the area by the MWDSC, a portion of which included water from the Colorado River. Since the Colorado River may have contained Perchlorate as far back as the 1950's, and since this water was used as irrigation water, it could have permeated into the groundwater. Return flow through septic tank leakage could also have introduced perchlorate into the groundwater of the LCF area. In addition, VWC injected MWDSC water into the upgradient wells, possibly injecting perchlorate as well.

However, since the water found in the Sunset Reservoir area is only 20 to 30 years old, the effects of return flow from Colorado River water prior to the mid 1980's is of no significance to this study. Moreover, the largest release of perchlorate was the explosion at the BMI Complex of May 4, 1988 when huge quantities of ammonium perchlorate exploded and large amounts were released into the environment. Given the fact that the maximum concentration of perchlorate found in the Colorado River at Whitsett Intake was only 8 µg/L in the 1999-2000 period, this ten years after the explosion, and the water delivered to the Raymond Basin area was a blend of Colorado River water with water from the California State Water Project (SWP), the concentrations that could have been delivered were only 3 or 4 µg/L.

If NASA's hypothesis that return and injection water from the Colorado River is a significant source of perchlorate in the Sunset Reservoir wells, it must come from the LCF area. The SGM cannot physically have been influenced by MWDSC water. Furthermore, the northern areas are entirely free of perchlorate while the wells in the LCF area do indeed have perchlorate. However, in examining the results from LCID and VWC, it can be seen that the long term median values are in the 3 - 5 mg/L range,

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with intermittent periods of non-detectable concentrations, exactly as would be expected if it were periodic influxes of Colorado River water. This would suggest that if Colorado River water were the source of perchlorate in wells in the Sunset Reservoir area, it would only be for a small portion. The concentrations of perchlorate are much higher than this in the Sunset Reservoir Wells.

#### 4.4.7 Groundwater Types in the Raymond Basin

NASA's TM divides the groundwater samples collected in 2005 into three types:

**Type 1:** Calcium-bicarbonate groundwater – Groundwater with calcium as the dominant cation and bicarbonate as the dominant anion. This is thought to represent younger water near the surface originating in the SGM (e.g., MW-1).

**Type 2:** Sodium-bicarbonate groundwater – Groundwater with sodium as the dominant cation and bicarbonate as the dominant anion (e.g. MW-24-4).

**Type 3:** Calcium-bicarbonate/chloride/sulfate groundwater – Groundwater with calcium as the dominant cation and bicarbonate the dominant anion, but this water type consistently has higher levels of TDS than the other two types. (e.g. MW-21-1).

PWP has questioned the meaningfulness of these classifications in previous correspondence in part because of the vagueness of how they were made. DTSC has likewise questioned the appropriateness of these classifications. Nonetheless, solely for the purposes of this investigation, PWP accepts this classification just as it did for the conservative nature of CTC as a tracer.

##### 4.4.7.1 Quantification of Groundwater Types

NASA's TM is not very explicit about how these types are defined nor is there any table explaining exactly which sample locations fall into which type. However, if it is assumed that "*dominant*" means "*greater concentration*" then the samples can be ranked based on the ratio of calcium to sodium and those with a ratio of less than 1 would be Type 2 and those with a ratio greater than 1 would be either Type 1 or Type 3, depending on the TDS. The term "*consistently has higher levels of TDS*" is not explained in NASA's TM. This can be taken to mean that all of the samples from Type 3 waters have greater concentrations of TDS than all of the other samples collected from Type 1 and 2 waters. For the purposes of PWP's TM, it will be assumed that the threshold for distinguishing Type 3 water is the 80<sup>th</sup> percentile of TDS concentration from the 2005 NASA Special Study, which was 535 mg/L. This means that all samples with a Ca:Na ratio greater than 1 based upon mass concentration (mg/L) and a TDS concentration greater 535 should be Type 3. Table 3 lists the samples by water type including the concentration of calcium, sodium, and TDS in mg/L.

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However, it is not clear that the definitions used in this document are the same as those used in NASA's TM. There is no table listing the sample locations with the corresponding concentrations of calcium, sodium, and TDS so that it can be known which samples correspond to which sample types. The closest to this would be found in NASA's TM Figure 11 (Figure 17 in this document), which shows the strontium isotope analysis, MW-24-3 is listed as Type 1. However, the calcium concentration for this sample is 18.9 mg/L and the sodium concentration is 44.8 mg/L so it would seem that this is actually a Type 2 sample. NASA's Figure 11 (Figure 17 in this document) lists the water types of a number of samples but does not explain how those were determined. The difference may have been that the water types were determined on a molar basis (mmole/L) or equivalent basis (meq/L). The data in Table 3 was re-analyzed on the basis of molarity and equivalents and presented in Tables 4 and 5. There is very little difference between the classifications based on mass (mg/L) versus equivalents (meq/L), only MW-20-3 differs, being Type 1 in the former and Type 2 in the latter. The big difference is when the classification is done on the basis of molarity, a significant number of samples that would otherwise be classified as Type 1 become Type 2, including both Garfield and Bangham Wells.

It is unclear how NASA distinguished Type 1 and Type 3 waters.. For example in Figure 17 (Figure 11 in NASA's TM), Bangham Well and Garfield Well are listed as Type 3. TDS of Bangham is only 380 mg/L, which is close to the median value of the 2005 study population for TDS of 324 mg/L and Garfield has a TDS of 274 mg/L, well below the median. MW-19-3 and MW-19-4 are also listed as Type 3 in Figure 22 (Figure 10 in NASA's TM) and they have concentrations of TDS of 426 and 494 mg/L respectively. However, Sunset Well and MW-20-1 also have high concentrations of TDS, 420 and 440 mg/L respectively, but are classified as Type 1.

For PWP's TM, the classification is based on mass concentration.

#### 4.4.7.2 Type 2 Waters

In regards to the Type 2 water, it is worth noting that all of them were collected from just five wells, MW-17, MW-18, MW-20, MW-24, and MW-25 which were confined to a small number of wells. Further, they were found in the deeper screens with the exception of the MW-24 where all but the shallowest screen had Type 2 waters (MW-17-4, MW-18-5, MW-20-3, MW-20-4, MW-20-5, MW-25-2, and MW-25-5) which NASA's TM concurs. However, NASA's TM also states that the Type 2 water was "Deep (Older) Native Groundwater". This is not correct as both the tritium and <sup>3</sup>He show that the water from MW-17-4, the only Type 2 water tested, was only 11.7 years old. Many of these samples also contain perchlorate and CTC. Interestingly, Type 2 waters are found at both the JPL site and the Sunset Reservoir area although none of PWP's production wells had water that was Type 2. This data might suggest that the chemical changes that cause Type 1 water to become Type 2 is occurring on the JPL site and the fact that Type 2 water was found in MW-25, immediately adjacent to the Sunset Reservoir Wells would contradict the hypothesis that the water on the JPL site is contained.

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#### 4.4.7.3 Type 3 Waters

According to NASA's TM, "Type 3 water is a mixture of native water and imported water" because of the high TDS and sulfate thought to originate from MWDSC imported surface water, which is a mixture of Colorado River water and State Water Project water. If this is so, it is important to note that all of the Type 3 samples were only found in four wells, MW-17, MW-19, MW-21, and MW-25. If MW-21 is ignored since all five screens produced water samples that were Type 3, there are only three wells with Type 3 water, all in the shallower screens (MW-17-2, MW-17-3, MW-19-2, and MW-25-1). This would suggest the shallower waters from the LCF area are the principal sources of Type 3 water. If none of PWP's Sunset Reservoir Wells have Type 3 waters then the water must not be a blend with MWDSC waters and the perchlorate cannot have originated from the Colorado River.

#### 4.4.7.4 Type 1 Waters

All of the SGM samples, and the majority of samples collected from the JPL facility, Monk Hill area, and Sunset Reservoir are Type 1. All of wells belonging to PWP, LAWC, LFWC, VWC, and RCLWA are Type 1, none are Type 2 or 3. NASA's TM argues that "...Type 1 [groundwater has historically been] associated with run-off from the San Gabriel Mountains". If this is so, then PWP's Sunset Reservoir Wells are all Type 1 waters, would argue that there is in fact little influence from imported Colorado River water. The only source of SGM water that can reach the Sunset Reservoir Wells, at least according to the ground water model results in Figure 1, is behind the production wells that are argued to have created the containment of waters on JPL. Further, these facts support the theory that there is a very strong influence of water from the SGMs in the Sunset Reservoir Wells, which can only mean that the water came from the JPL area and that the water cannot have been contained in that area.

#### 4.4.8 Strontium Geochemistry

NASA's TM discusses the mixing of local waters from the SGM with imported Colorado River water as measured by strontium: "Figure 11 [Figure 17 in this document] is a graph of the strontium stable isotope ratio ( $^{87}\text{Sr}/^{86}\text{Sr}$ ) versus the inverse strontium concentration ( $1/[\text{Sr}]$ ). The graph depicts a mixing between the native Type 1 water and imported Colorado River water. Native water in the area is generally heavier in its strontium isotope ratio than the Colorado River water. Groundwater collected from MW-24, located in the northern portion of the facility, has historically been categorized as Type 1, associated with run-off from the San Gabriel Mountains. This explains why MW-24 is heavier in its strontium isotope ratio. MWD water on the other hand, is lighter in its strontium isotope composition. Most of the other wells contain groundwater with an isotopic signature between these two end-points indicating mixing of the two waters. With ion-exchange and precipitation reactions occurring as the water passes through the subsurface, the strontium concentration is depleted and deeper screens, with Type-2 water, contain water with lower strontium concentrations, but almost identical strontium isotope

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ratios. Thus, Figure 11 reinforces the water typing as the different water types arrange in distinct clusters in the plot”.

#### 4.4.8.1 Method for Diagnostic Use of Strontium Geochemistry

Strontium exists in four stable isotopes, only one of which is radiogenic, one of which occurs very rarely, and one of which dominates the others:

- 1)  $^{84}\text{Sr} = 0.56$
- 2)  $^{86}\text{Sr} = 9.86$
- 3)  $^{87}\text{Sr} = 7.00$  (Radiogenic)
- 4)  $^{88}\text{Sr} = 82.58$

Based on the above observed percentages of these stable isotopes, the expected ratio of  $^{87}\text{Sr}/^{86}\text{Sr}=0.7099$ . Strontium is found in precipitation and is largely of marine origin and with  $^{87}\text{Sr}/^{86}\text{Sr}=0.7092$  with a concentration of approximately 5  $\mu\text{g}/\text{L}$ . As the precipitation permeates to the local ground water, the total strontium concentration can increase or decrease as it either precipitates on or is dissolved from local soils and minerals. Similarly, the proportion of radiogenic strontium, measured as  $^{87}\text{Sr}/^{86}\text{Sr}$ , can increase, remain the same, or decrease, depending in part on the compositions, ages and reactivates of minerals and other hydro geologic factors. The longer rainwater is in contact with soils and aquifers, the more of these reactions can occur. The same process can occur with imported surface water when it enters local aquifers. Colorado River water is nearly identical in strontium chemical characteristics to rain water.

#### 4.4.8.2 Strontium Geochemistry in the Raymond Basin

The strontium geochemical variables are plotted on Figure 11 from the TM (Figure 17 in this document). Along the x-axis is plotted the inverse of the total strontium concentration while along the y-axis the ratio of  $^{87}\text{Sr}/^{86}\text{Sr}$ . As presented, it does not identify which sample points are associated with sample locations except in a few cases so it is difficult to assess how this data illuminates the relationship between waters found on the JPL, SGM, and the LCF area waters, and the Sunset Reservoir Wells. Plotting all of the data produces a rather busy diagram. Most of the variability in the strontium analysis of water appears to be associated with three wells MW-18, MW-19, and MW-20. If these three wells are eliminated, a very clear pattern is visible (Figure 18). Wells MW-1, MW-24-1&2, MW-25-2,3,4, LAWC #3, LFWC #2, and Sunset and Garfield Wells are clustered together at the center of the diagram away from the rain water and Colorado River data. This represents water that has had a significant

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amount of strontium precipitated out as it has moved through the aquifer while at the same time acquiring a higher proportion of radiogenic strontium.

Notably, there is considerable variability among the different screens of the monitoring wells. MW-24 shows perhaps the greatest variability but MW-25 and MW-17 considerable as well. Screens 2 and 3 of MW-17, which contain CTC, are quite different from the other three screens of MW-17 but are very similar to screen 1 and 2 of MW-24 which also have CTC. LAWC #3 and LFWC #2 also have similar strontium values to these other wells and have CTC. MW-25 screens 2, 3, and 4 as well as the PWP Sunset Reservoir Wells do not have CTC but have very similar strontium concentrations and isotopic ratios. On the other hand, the water in screens of MW-21 clearly show influence from the Colorado River water. This would suggest that this water in MW-21 has had less local influence and is much more influenced by recent precipitation and Colorado River water than the MW-1 water, which is entirely of local origin and from local precipitation that has been in the aquifer long enough to have substantial chemical changes. Most of the other samples, particularly those in PWP's Sunset Reservoir Wells are chemically more similar to the MW-1 water than to Colorado River water or rain water. This conclusion is re-enforced by the fact that all of the sample locations that have CTC all have similar positions on the strontium diagram, around the MW-1 center. Rather than showing that the Sunset Reservoir Wells are primarily influenced by Colorado River water, the strontium data shows the exact opposite, that these wells more resemble quite closely the water found in MW-1, MW-24, and MW-25.

Figure 19 shows the same data as Figure 17 and 18 except it is grouped by Water Type (on a mass basis). While there is little overlap between Types 2 and 3, both of these types overlap extensively with Type 1 waters. The transition from water types as the waters move through the aquifers is clearer in this figure. Water influenced by imported Colorado River water, the Type 3 water, is isotopically between the Colorado River on the left and the local groundwater at the center forming a pretty clear link. The classification of waters based on the ratio of the mass of calcium and sodium plus TDS does indeed appear to be useful in demonstrating which waters are under the influence of the imported Colorado River water and which are not. Since PWP's Sunset Reservoir Wells are not Type 3 waters they have only minimal influence from the Colorado River water.

#### 4.4.8.3 Sulfate and Perchlorate Data

To test this hypothesis, another of the data sets from NASA's TM was used. NASA's TM argues that waters from the Colorado River are much higher in sulfate than the local ground waters. If this is so, then there ought to be some correlation between the strontium isotope data and the sulfate data. The sulfate data from the 2005 NASA samples was plotted against the  $^{87}\text{Sr}/^{86}\text{Sr}$  and  $1/[\text{Sr}]$  (Figure 20). As can be seen, the existing pattern is actually emphasized as the MW-21 and MW-17 -2 & 3 sample locations not only have strontium data that more closely resemble Colorado River water but also sulfate concentrations. A trend is quite visible from the Colorado River down the MW-21 series and into the

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MW-17 series, but the remaining sample locations have approximately the same amount of sulfate, indicating little blending.

This new plot does draw out the fact that Bangham Well is somewhat different from the other two PWP wells, Sunset and Garfield Wells. It does contain more sulfate and does somewhat resemble the MW-17-2&3 wells. Furthermore, this data would suggest that the main source of Colorado River influence is through south-western flow of water from the LCF area. If the main source of Colorado River influence is indeed the south-western flow of water from the LCF area, there ought to be some correlations between the strontium data and the perchlorate data.

As with the sulfate data, the same strontium data as used above was plotted against the perchlorate data. The data is very similar to the sulfate/strontium data except for the fact that the Colorado River water has very low concentrations of perchlorate (Figure 21). The results of this plot are quite dramatic. The three sources of water can be clearly delineated. There is nearly a straight line between MW-1 and MW-24-1 representing the subsurface flow from the SGM and JPL respectively. To the left is a train of results connecting the Colorado River through the LCF area (as expressed in MW-21) to the Raymond Basin. The MW-25 and PWP well data show more similarity with the MW-1 and MW-24 data with perchlorate and strontium than with strontium alone or with strontium with sulfate, then Colorado River Water. PWP's Sunset Reservoir Wells appear, based on the sulfate data, to have minimal influence from the Colorado River.

#### 4.4.8.4 Method for Diagnostic Use of SIA of Water

Water consists of a single oxygen atom with two hydrogen atoms. There are three stable isotopes of oxygen ( $^{16}\text{O}$ ,  $^{18}\text{O}$ ) and two of hydrogen ( $^1\text{H}$ ,  $^2\text{H}$ ) resulting in isotopomers with masses ranging from 18 to 22 AMU. There are expected ratios of these isotopes based on the measured concentrations found in the equatorial oceans. The key concept understanding SIA of water is Rayleigh Distillation. There is an effectively infinite supply of each of the five isotopomers in the ocean; however, the lighter isotopomers are vaporized preferentially as compared to the heavier species. As the moisture condenses into precipitation, there is further preferential enrichment and depletion of different isotopomers around the world. When the depletion of heavier hydrogen ( $\delta^2\text{H}$ ) and oxygen isotope ( $\delta^{18}\text{O}$ ), relative to the ratios found in the equatorial oceans, around the world is plotted, a Global Meteoric Water Line (GMWL) can be created. If the precipitation permeates the ground, it will retain the characteristic ratio of isotopomers of the GMWL. However, if the precipitation is accumulated in lakes and rivers, further Rayleigh Distillation will occur. However, unlike the equatorial oceans, there is not an infinite supply of each of the isotopomers and as Rayleigh Distillation occurs, while the resulting vapor is enriched in lighter species and depleted in heavier, the reverse is true for the liquid phase. If the  $\delta^2\text{H}$  and  $\delta^{18}\text{O}$  are plotted for local surface waters, a Local Meteoric Water Line (LMWL) is created, which has a shallower

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slope than the GMWL. If Global Meteoric Water is blended with Local Meteoric Water, a hybrid curve can be created.

#### 4.4.8.5 NASA TM Analysis of Global and Local Meteoric Waters

In the summer of 2005 NASA collected samples in the Raymond Basin and SIA for water performed. The results support the theory that the water in the Sunset Reservoir Wells is overwhelmingly local water with little to no influence from the Colorado River. Figure 10 from NASA's TM (Figure 22 in this document) shows the  $\delta^2\text{H}$  and oxygen isotope ratios  $\delta^{18}\text{O}$  for several sample locations. The dashed line indicates the GMWL and the solid line is an estimation of a blend with the LMWL with SWP and Colorado River Aqueduct (CRA) waters (similar to Williams & Rodoni 1997). Individual sample locations are shown and colored to match the water type. No clear pattern emerges with all three types of water being found on both sides of the GMWL and hybrid LMWL and there is much contradictory data.

The most confusing results are the five Type 3 samples, all exactly upon the GMWL (MW-17-3, MW-19-2, MW-19-3, MW-19-5, and MW-21-2) while there are only five Type 3 samples that fall on the hybrid LMWL (MW-17-2, MW-19-4, MW-21-1, MW-21-3, and MW-21-5) with one Type 3 sample ambiguously between the two (MW-21-4). If indeed Type 3 waters were indicative of blended local groundwater with imported surface water, they all ought to be upon the hybrid LMWL.

Conversely, there are several Type 1 samples that are on or below the hybrid LMWL. This includes MW-18-2, MW-18-3, MW-25-3, and MW-24-1, which are all Type 1 waters but is far above the GMWL, MW-25-3 is between the GMWL and the LMWL, and MW-24-1 is below the LMWL. Additionally, water with CTC was found in waters of both Type 1 and Type 3 and on both sides of both the GMWL and LMWL. Taken at face value, the results of this study indicates that water from the JPL facility, using CTC as the marker, can be found in waters both ostensibly unmixed with imported MWDSC water (above both the GMWL and LMWL such as MW-18-4) and water well mixed with imported MWDSC water (below both the GMWL and LMWL such as MW-24-1). This data is very difficult to interpret and is full of contradictions.

#### 4.4.8.6 PWP TM Analysis of Global and Local Meteoric Waters

Part of the problem is that there is a great deal of noise in this graph. Most of the variability in the SIA of water appears to be associated with three wells MW-18, MW-19, and MW-20. If the data from these three wells is eliminated, a rather different hybrid LMWL emerges (Figure 23). It can be seen that they line up quite neatly with each other with a very significant first order linear regression correlation coefficient of 0.98 ( $p < 0.001$ ). Furthermore, there is more overlap between the GMWL and the LMWL. This region of overlap (where the GMWL is within the 99% confidence interval of the LMWL) includes MW-1, MW-24, MW-25, and two of the Sunset Wells. This is the region where the local water most

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closely resembles the water uninfluenced by the enriching effects of evaporation and thus has the least influence from water sources as the Colorado River or the SWP. These are the waters lower in nitrate, sulfate, and chloride but higher in perchlorate. MW-24 does have CTC in some samples taken at some screens.

If the Water SIA data is replotted using the water types from Table 3 new information can be seen (Figure 24). All of the Type 1 and Type 2 water samples fall directly upon the GMWL with as many results on each side of the GMWL as the other. However, the Type 3 samples show signs of blending and are all on the one side of the GMWL as would be expected with blended water. These patterns are not fundamentally different even if the water types were determined based on mass, molarity, or equivalents. All three of the Sunset Reservoir Wells tested were Type 1, indicating very little, if any, blending with surface water.

#### 4.4.8.7 SIA of Water combined with Perchlorate Data

The SIA of water results are suggestive, but by themselves do not show any direct connection between the waters of JPL and the Sunset Reservoir Wells, they merely show that there is little influence from the Colorado River water. However, if the same water SIA is plotted against the corresponding perchlorate data, the connection becomes clear. The three distinct water courses can be seen in Figure 25. At the top is the JPL course with its very high concentrations of perchlorate while at the left is the LCF area course with its much lower concentrations of perchlorate and at the bottom is the SGM course, which is free of measurable perchlorate. The blending together of these three course produces the concentrations of perchlorate found at the Sunset Reservoir Wells in the center of the diagram. This diagram makes quite clear that the major source of perchlorate at the Sunset Reservoir Wells is from the JPL course.

#### 4.4.8.8 SIA of Water combined with Perchlorate Data and CTC Data

As has been noted previously, it is the contention of NASA's TM that CTC is a conservative and definitive marker for waters originating from the JPL facility. In work presented above, there appears to be some truth to this assertion. If this is so, then there ought to be some correlation between the CTC concentrations and the perchlorate concentrations as shown in Figure 25. To test this hypothesis, a new figure (Figure 26) was prepared using the data in Figure 25, but with the CTC values collected in 2005 presented alongside them. The sample with the highest perchlorate concentration collected in 2005, MW-24-1, which is very close to the original disposal pits, also has the highest CTC concentration. Other samples with CTC have lower perchlorate concentrations and lower CTC concentrations. Notably, there are no samples with CTC, which have concentrations of perchlorate near those found in the LCF area

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water. The CTC results confirm the results of the SIA of water and perchlorate data that there is a very large influence from the JPL facility on the Sunset Reservoir Wells in terms of perchlorate, much more than from the LCF area.

#### 4.4.9 Summary for SIA, General Mineral, and Physical Data Validate that the Major Source of Perchlorate in the Sunset Reservoir Wells Originates from the JPL Facility

All of the various markers, CTC, nitrate, perchlorate, sulfate, chloride, strontium, and SIA of water agree in indicating the water found in the Sunset Reservoir Wells is a mixture of water from JPL and water from the northwestern upgradient area, which includes water from the Colorado River. Given the concentrations of perchlorate found in the Colorado River, MWDSC water, the upgradient wells, and the wells at JPL, it seems clear that JPL is overwhelmingly the source of perchlorate at the Bangham and Copelin Wells and the dominant source at Sunset Well. Moreover, both the SGM sources of water and the JPL sources have about the same concentrations of nitrate 1.3 mg/L (as N) but the LCF area water has 10 – 14 mg/L NO<sub>3</sub>-N while the Sunset Reservoir has a concentration range of 5 – 7 mg/L NO<sub>3</sub>-N, very close to half (based on the 2005 TM data). This suggests that the SGM subsurface flow is diluting the LCF area subsurface flow by more than half by volume (remembering that the SGM water has a small concentration of nitrate). If JPL were not contributing perchlorate to the mixture, it would seem reasonable to assume that the Sunset Reservoir Wells would have less than half of the perchlorate that is coming into the area from the LCF area, 2-3 µg/L, which would be then 1 µg/L or less, which would not require treatment. This is of course a highly simplistic model but it is also a highly conservative one and probably over estimates the actual contribution for the LCF area. Since the concentrations of perchlorate found at the Sunset Reservoir Wells are much higher than that found in the LCF area water, it can only be concluded that the additional quantities of perchlorate are coming from JPL. If it were not for the perchlorate from the JPL facility, the concentrations of perchlorate in the Sunset Reservoir Wells would be diluted with perchlorate free water from the SGM and have a concentration less than the MCL (Figure 27).

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## 5.0 FINDINGS

- 5.1 In summary, although a minor amount of ground water flow originates in the northwest and flows southeast into the Raymond Basin; the majority of the ground water containing perchlorate originates north of the JPL site, and flows beneath the perchlorate disposal area and southerly to the Sunset Reservoir area and Patton wells.
- 5.2 The source of ground water recharge to the five Sunset Reservoir area wells is a mixture of water moving southeast out of the LCF area and water moving southward from the JPL facility.
- 5.3 Low nitrate/high perchlorate water from the JPL site mixes with high nitrate / lower perchlorate water from the northwestern upgradient area forming a combined recharge to the Sunset Reservoir area wells.
- 5.4 Water migrating southeast out of the LCF area has high nitrate concentrations (from septic tank seepage), and low perchlorate concentrations (from permeation of MWDSC water which includes Colorado River water), and no CTC.
- 5.5 Water migrating southerly from the JPL facility has low concentration of nitrate, high concentrations of perchlorate, and in some cases, CTC.
- 5.6 Chilean nitrate fertilizers cannot be the source of any perchlorate found in the Raymond Basin and that perchlorate that has been found is from a single, industrial source.
- 5.7 ~~The vast majority of water in the Monk Hill sub-area was between 2 and 8 TU and thus entered the basin after 1952. Since there had been no agriculture of any significance since 1940 in the northwestern upgradient area, and none in the Monk Hill area even earlier, Chilean fertilizers could not possibly have been the source of either nitrate or perchlorate for waters that entered the aquifer after 1952.~~
- 5.8 The industrial history of the production of perchlorate strongly indicates that the perchlorate used at the JPL facility was in fact produced at the facility that became known as the BMI Complex, just as the perchlorate released into the Colorado River was.
- 5.9 Given the concentrations of perchlorate found in the Colorado River, MWDSC water, the upgradient wells, and the wells at JPL, it seems clear that JPL is overwhelmingly the source of perchlorate at the Sunset and Garfield Wells and the dominant source at the Bangham Well.

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- 5.10** All of the various markers, CTC, nitrate, perchlorate, sulfate, chloride, strontium, and SIA of water agree in indicating the water found in the Sunset Reservoir Wells is a mixture of water from JPL and water from the northwestern upgradient area, which includes water from the Colorado River. Given the concentrations of perchlorate found in the Colorado River, MWDSC water, the upgradient wells, and the wells at JPL, it seems clear that JPL is overwhelmingly the source of perchlorate at the Sunset and Garfield wells and the dominant source at the Bangham Well.
- 5.11** The maximum concentration of perchlorate found in the Colorado River at Whitsett intake was only 8 µg/L in the 1999-2000 period. Water delivered to the Raymond Basin area was a blend of Colorado River water with water from the California State Water Project, the concentrations that could have been delivered were only 3 or 4 µg/L. These are much less than measured in the Sunset Reservoir wells.
- 5.12** The concentration of perchlorate found in the LCF area would be diluted with perchlorate free water from the SGMs to a level that would be below the MCL and, which would not require treatment except for the influence of perchlorate for the JPL facility, which has increased the concentrations above the MCL, requiring treatment.

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## 6.0 CONCLUSIONS

Ground water in the Monk Hill and Sunset Reservoir areas is of comparatively recent origin and contains high concentrations of nitrate originating from septic tanks in the northwestern upgradient area. Since agricultural activities ceased 60 - 90 years ago in all areas that might have potentially influenced these wells, Chilean nitrate could not be a source of perchlorate found in these wells. There appears to be two main sources of water influencing PWP's wells:

- 1 There is a source originating in the area northwest of the JPL facility in the LCF area, which has very high nitrate concentrations and has intermittent detections of perchlorate in low concentrations. This water appears to have been influenced by the infiltration and injection of MWDSC water with substantial amounts of Colorado River water.
- 2 There is a second source originating behind the JPL facility to the north, which has very low concentrations of nitrate and no measureable concentrations of perchlorate, but as it passes under the JPL facility it accumulates both perchlorate and CTC.

Both sources come from the same industrial source, military grade perchlorate from Henderson Nevada. PWP's wells, including the three wells near the Sunset Reservoir, appear to be a blend to these two sources with the majority of the perchlorate originating from the JPL facility. All available measures, CTC, nitrate, perchlorate SIA, cation/anion balances, strontium SIA, TDS, and water SIA all agree on this finding. Without the JPL source, the small amount of perchlorate in the LCF area water would be diluted down below the MCL with perchlorate free water from the SGM.

## 7.0 RECOMMENDATION

PWP's analysis clearly shows that current data demonstrate that the majority, of the perchlorate found in the Sunset Reservoir Wells originates from the JPL facility and that no further investigations are needed. The five Sunset Reservoir Wells should be included in the JPL Superfund Site.

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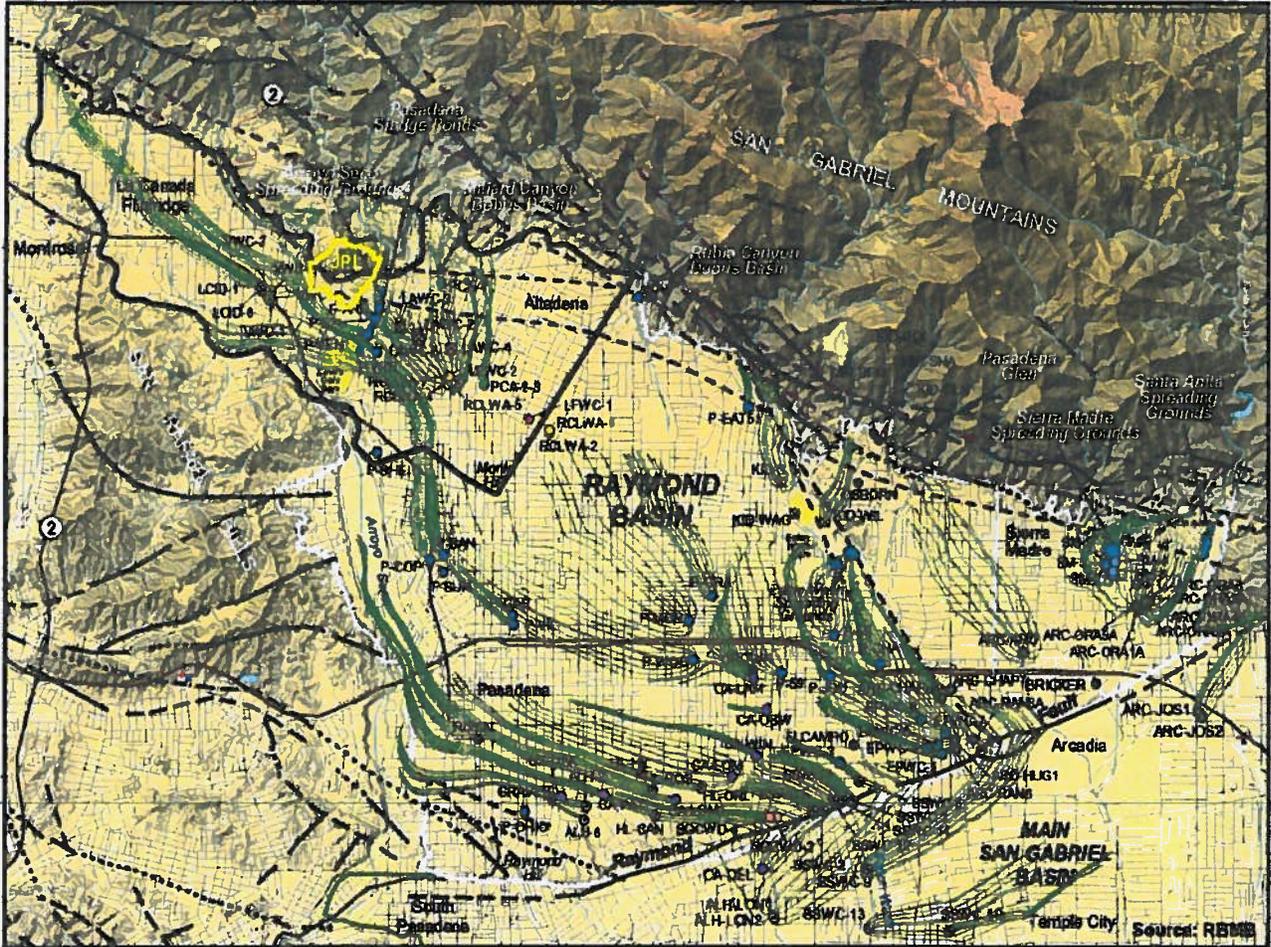
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**Figure 1**

**TM Figure 2: Location of Production Wells and Groundwater**



**Figure 2. Particle tracking simulations using the independently-developed RBMB Model indicate that capture zones of the Sunset Reservoir Wells are south of the JPL Facility.**

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**Figure 2**

**Aerial Photograph of Pasadena Looking North-East: 1926**



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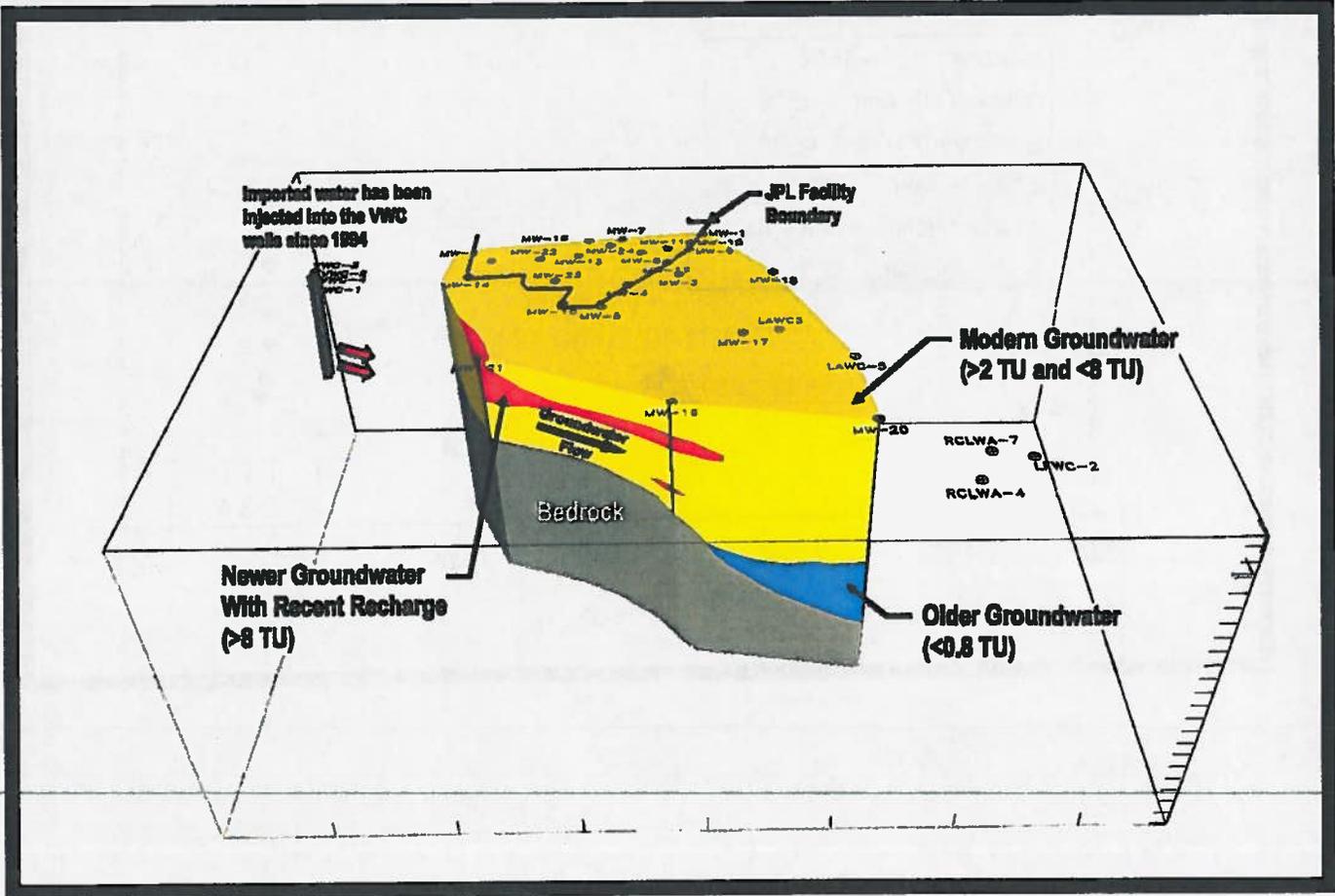
**Figure 3**

**Aerial Photograph of Montrose & Flintridge Looking North: 1927**



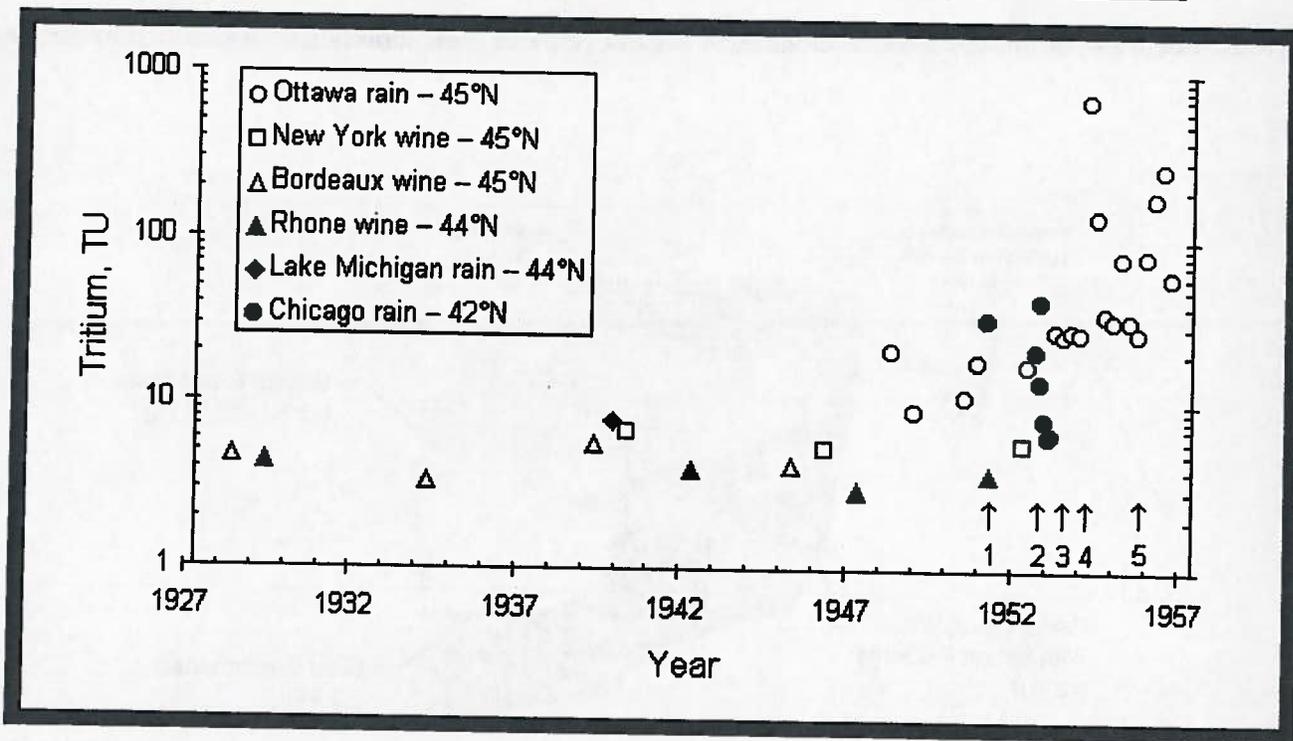
**Figure 4**

**TM Figure 12 – Tritium Concentrations in the Raymond Basin**



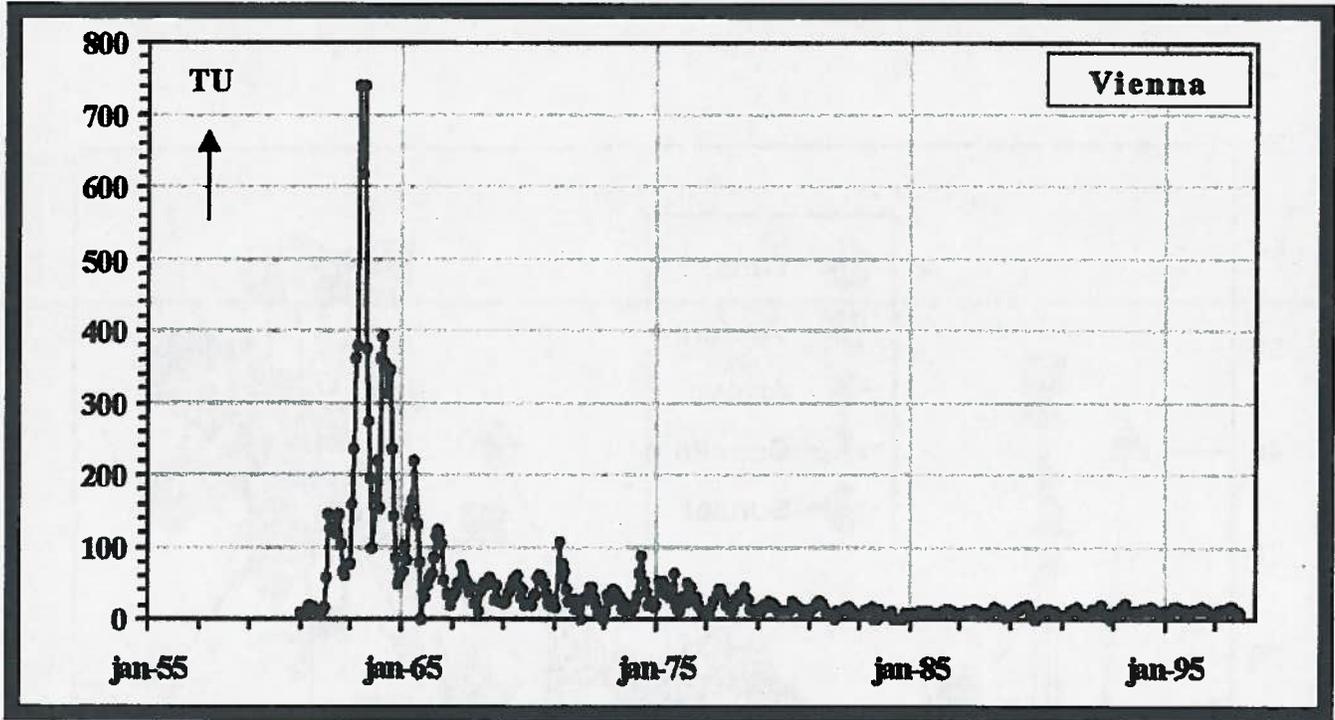
**Figure 5**

Pre-1957 Tritium Concentrations in Rainwater & Wine (IAEA – 2010)



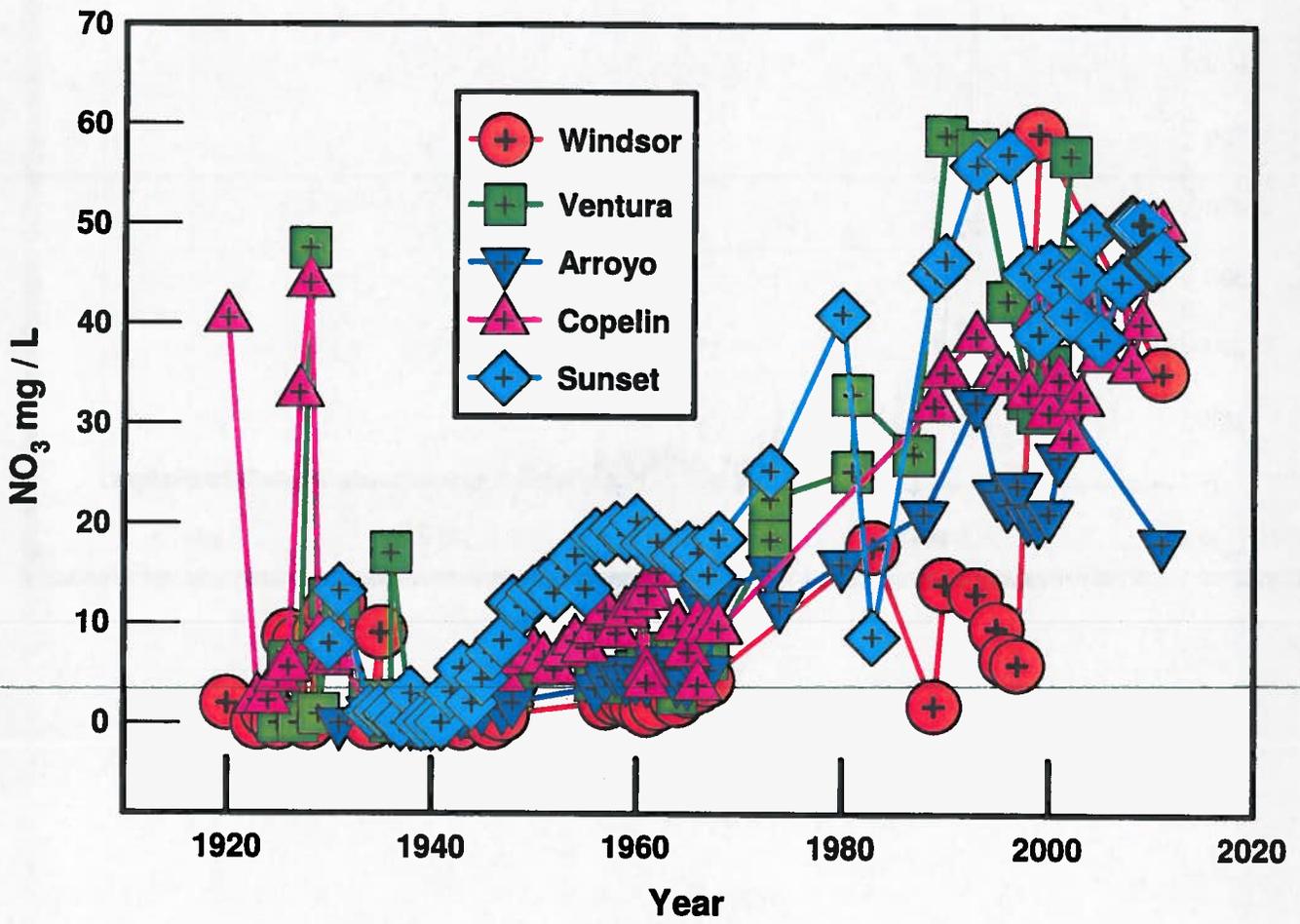
**Figure 6**

Post-1957 Tritium Concentrations in Rainwater & Wine (IAEA – 2010)



**Figure 7**

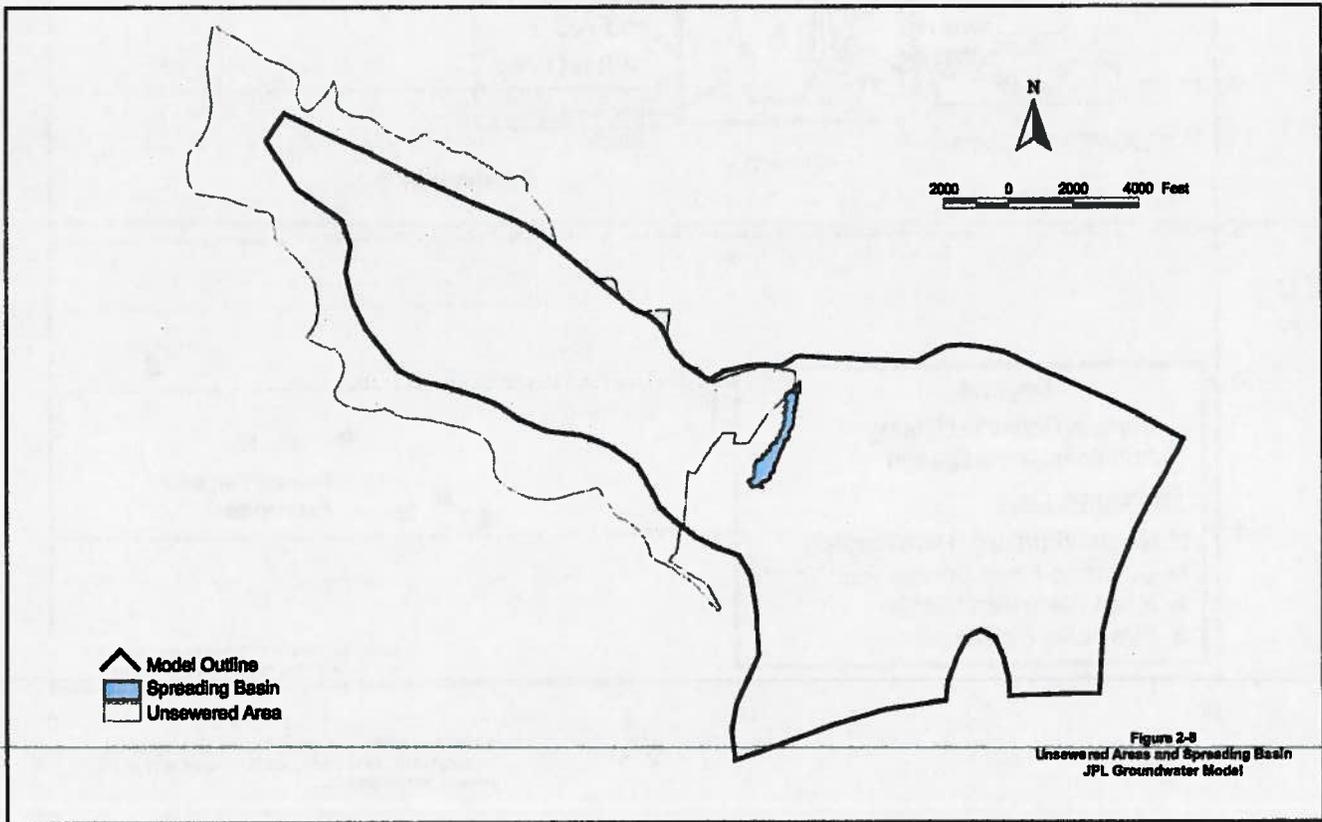
Nitrate Concentrations from 5 PWP Wells (1920 – 2011)



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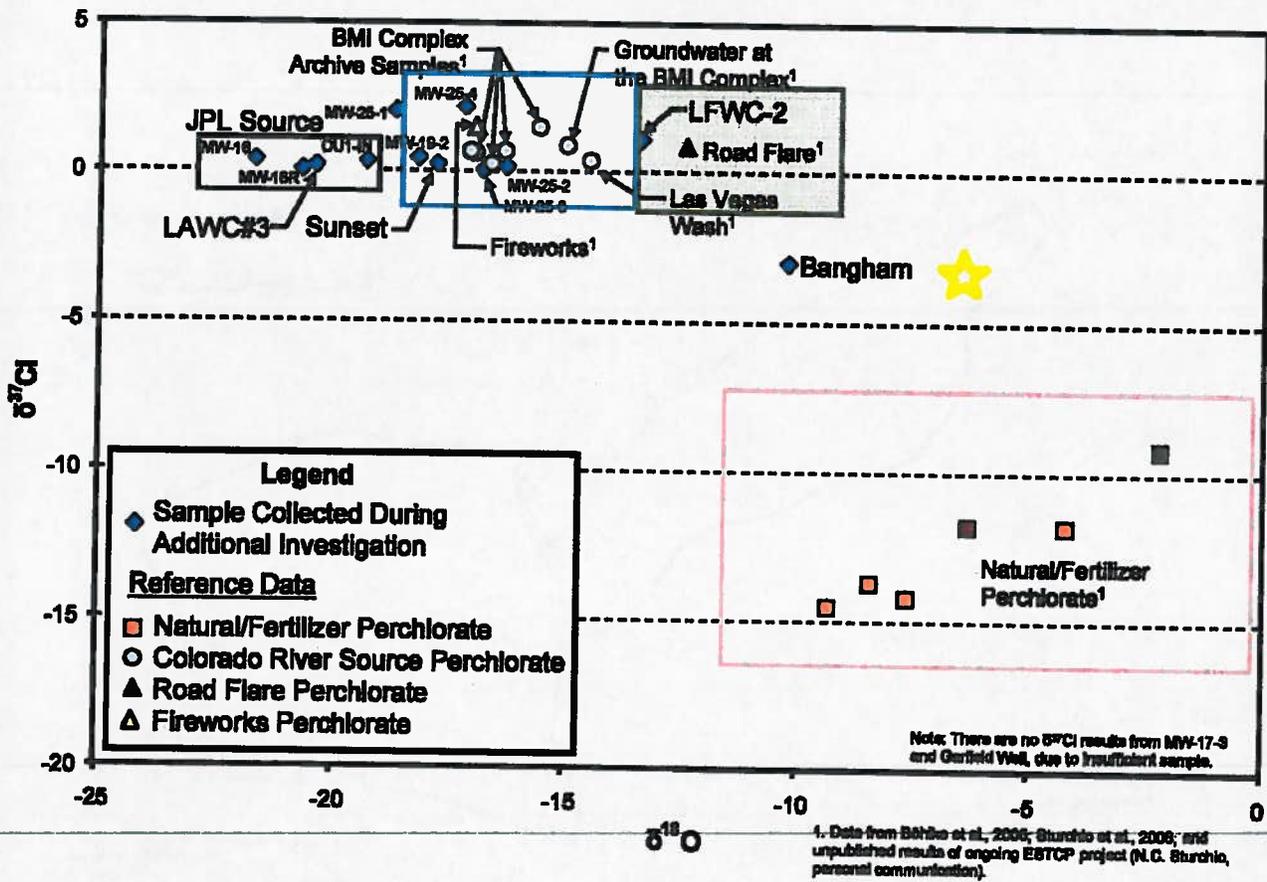
**Figure 8**

**Unsewered Areas North-West of Pasadena**



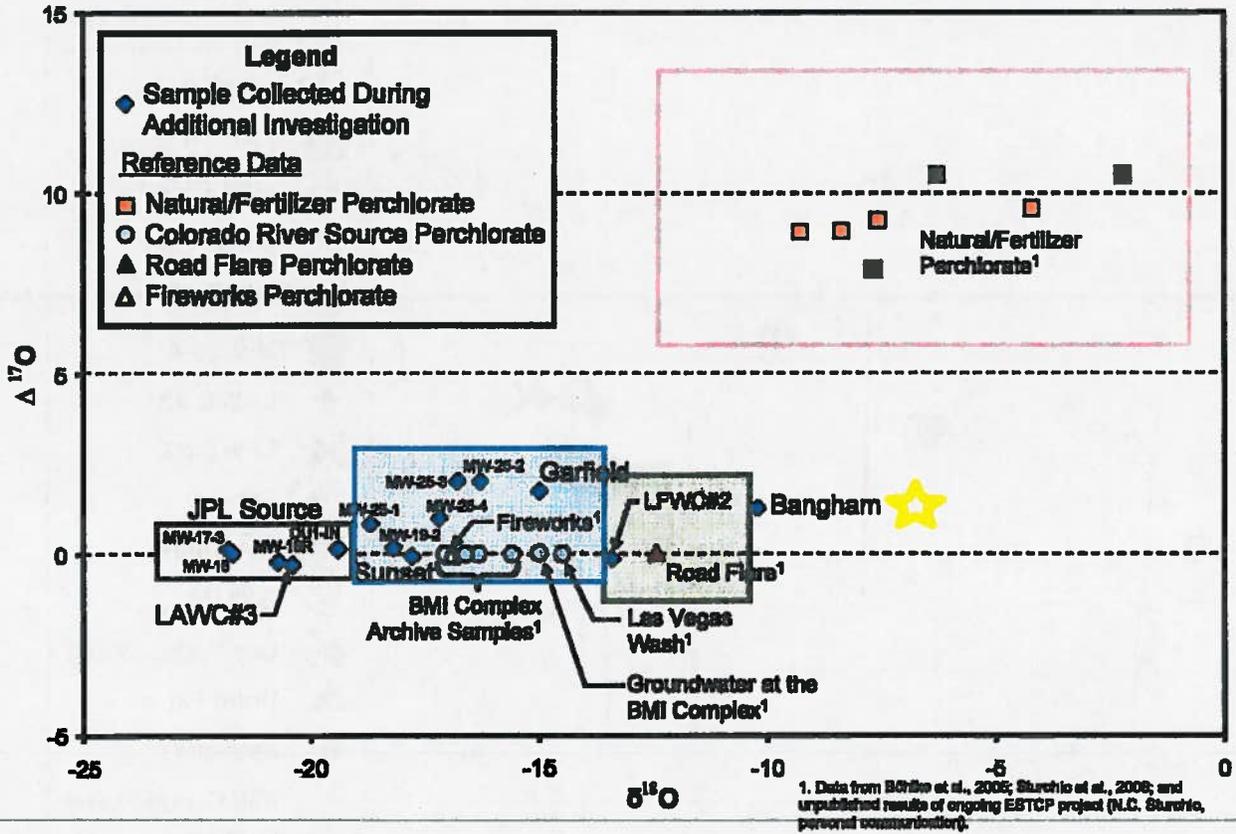
**Figure 9**

TM Figure 16 – SIA of  $\text{ClO}_4$   $\delta^{37}\text{Cl}$  vs.  $\delta^{18}\text{O}$  in the Raymond Basin



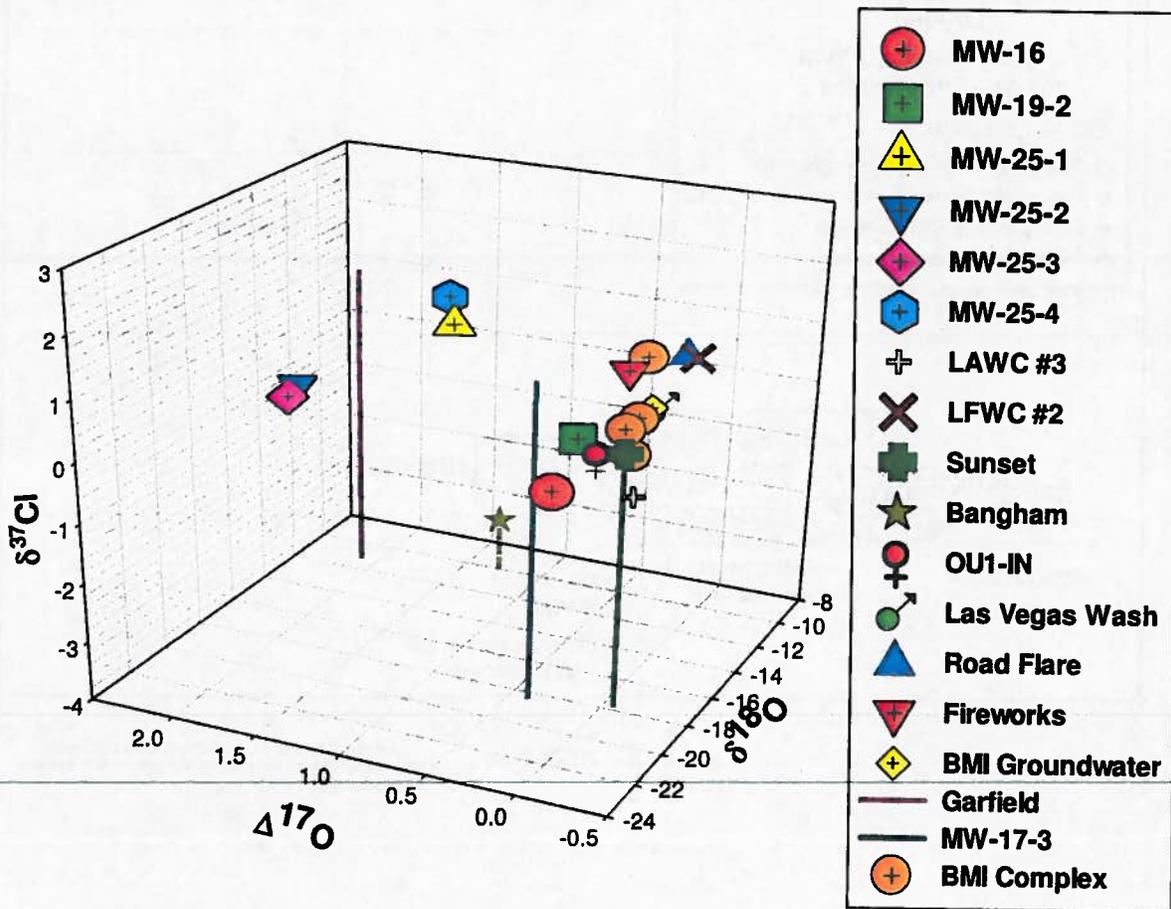
**Figure 10**

TM Figure 17 – SIA of  $\text{ClO}_4$   $\Delta^{17}\text{O}$  vs.  $\delta^{18}\text{O}$  in the Raymond Basin



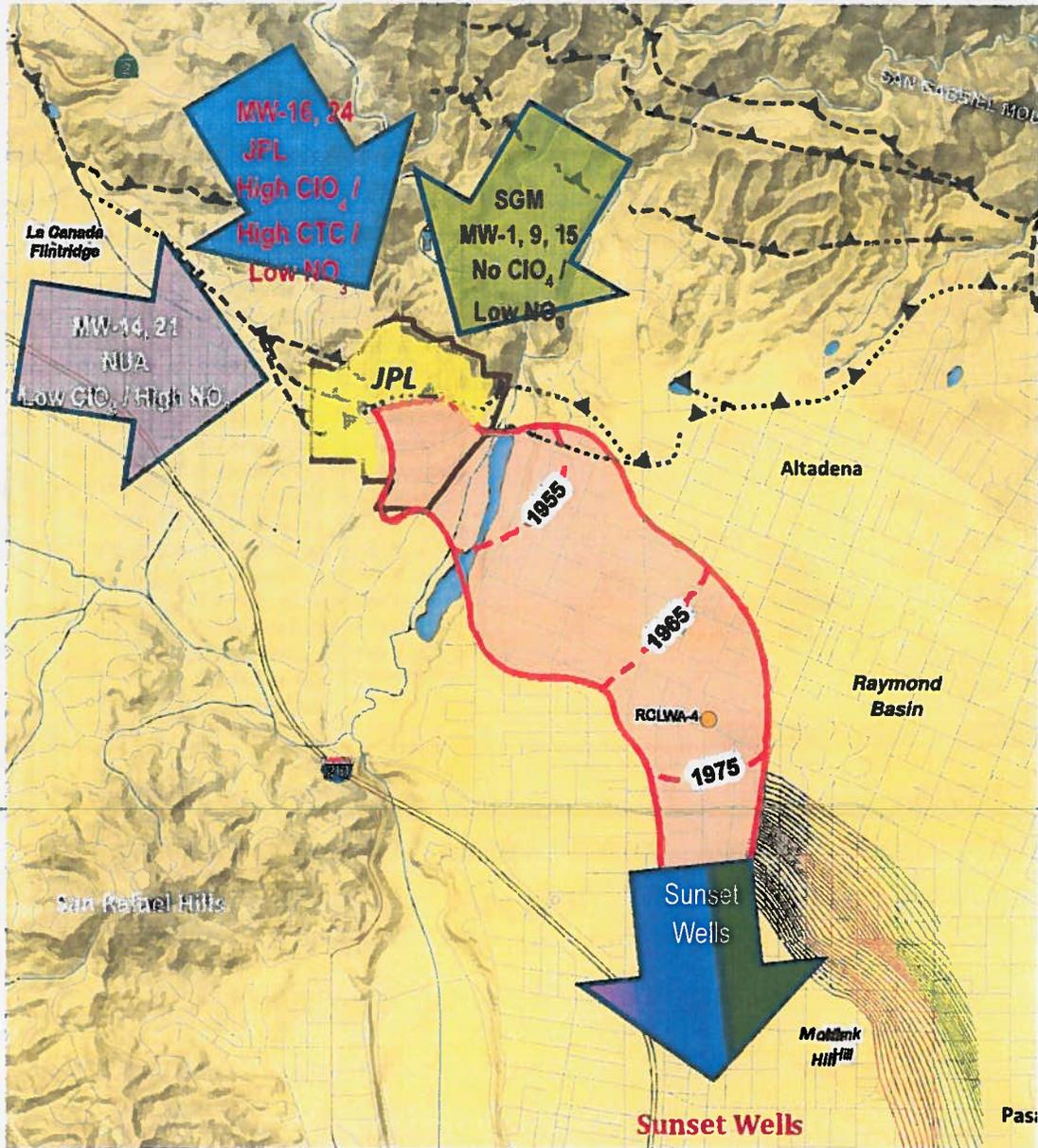
**Figure 11**

SIA of  $\text{ClO}_4$   $\delta^{37}\text{Cl}$  vs.  $\delta^{18}\text{O}$  vs.  $\Delta^{17}\text{O}$  in the Raymond Basin



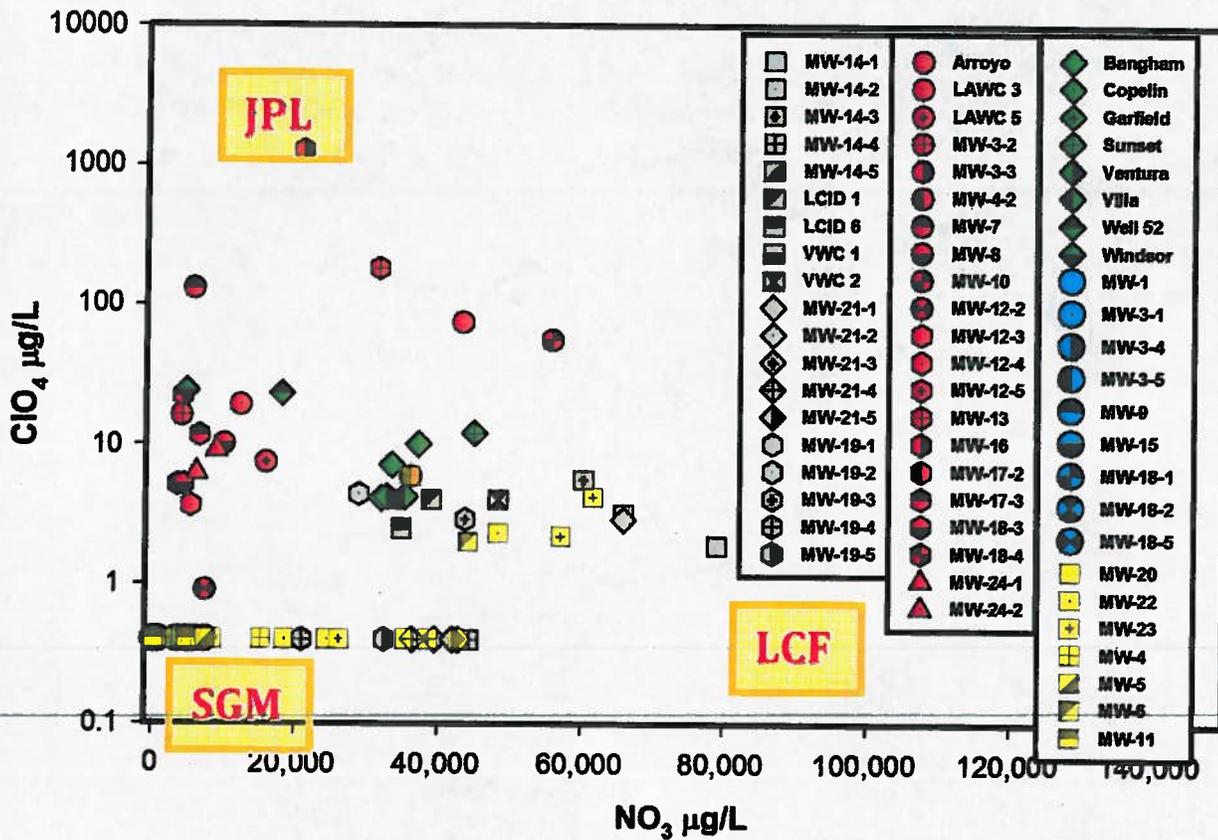
**Figure 12**

**Three Courses of Groundwater and General Flow in the Raymond Basin**



**Figure 13**

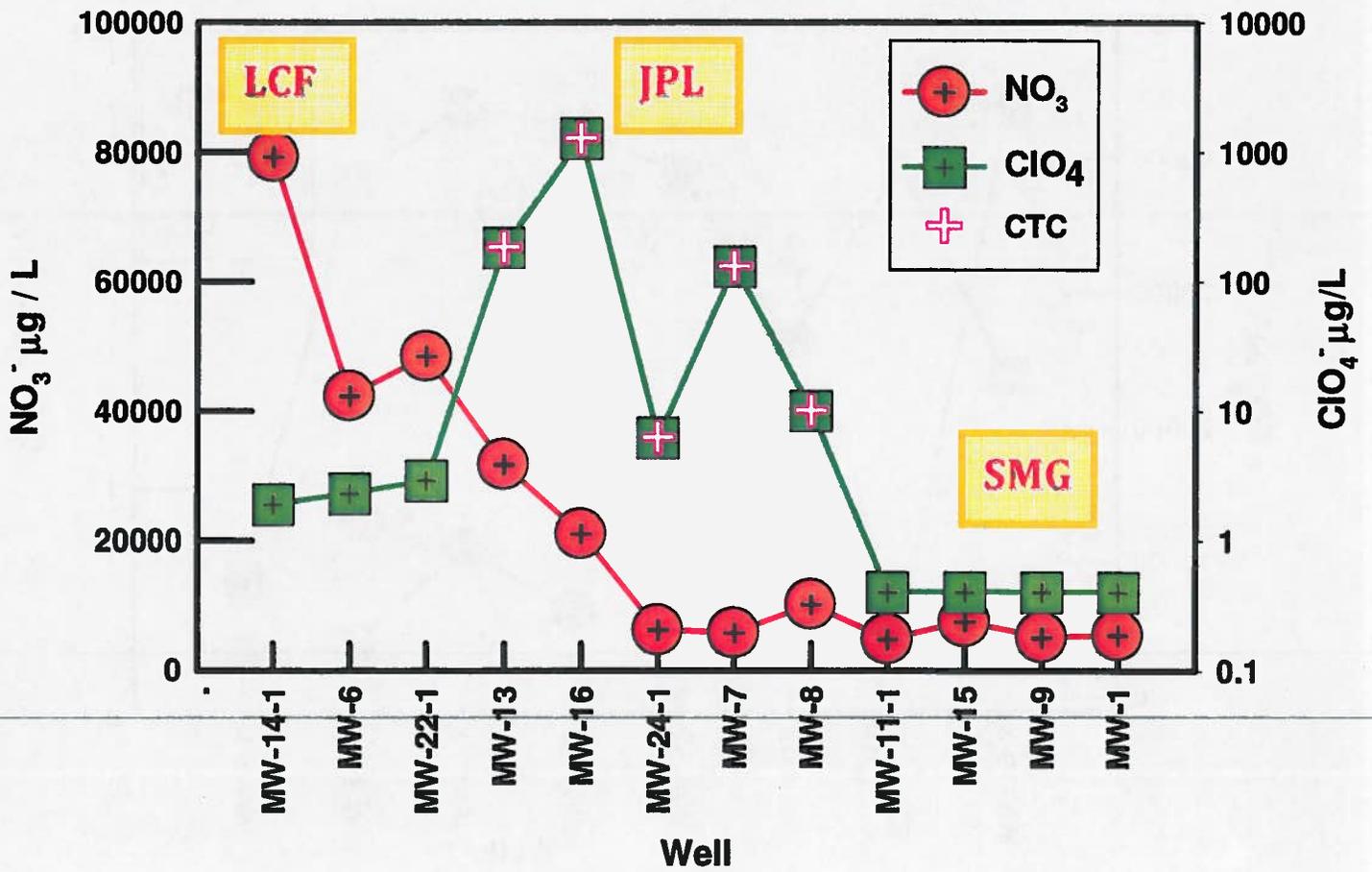
Median Concentration of  $\text{ClO}_4$  and  $\text{NO}_3$   
in Raymond Basin Wells, 1985 - 2011



**Figure 14**

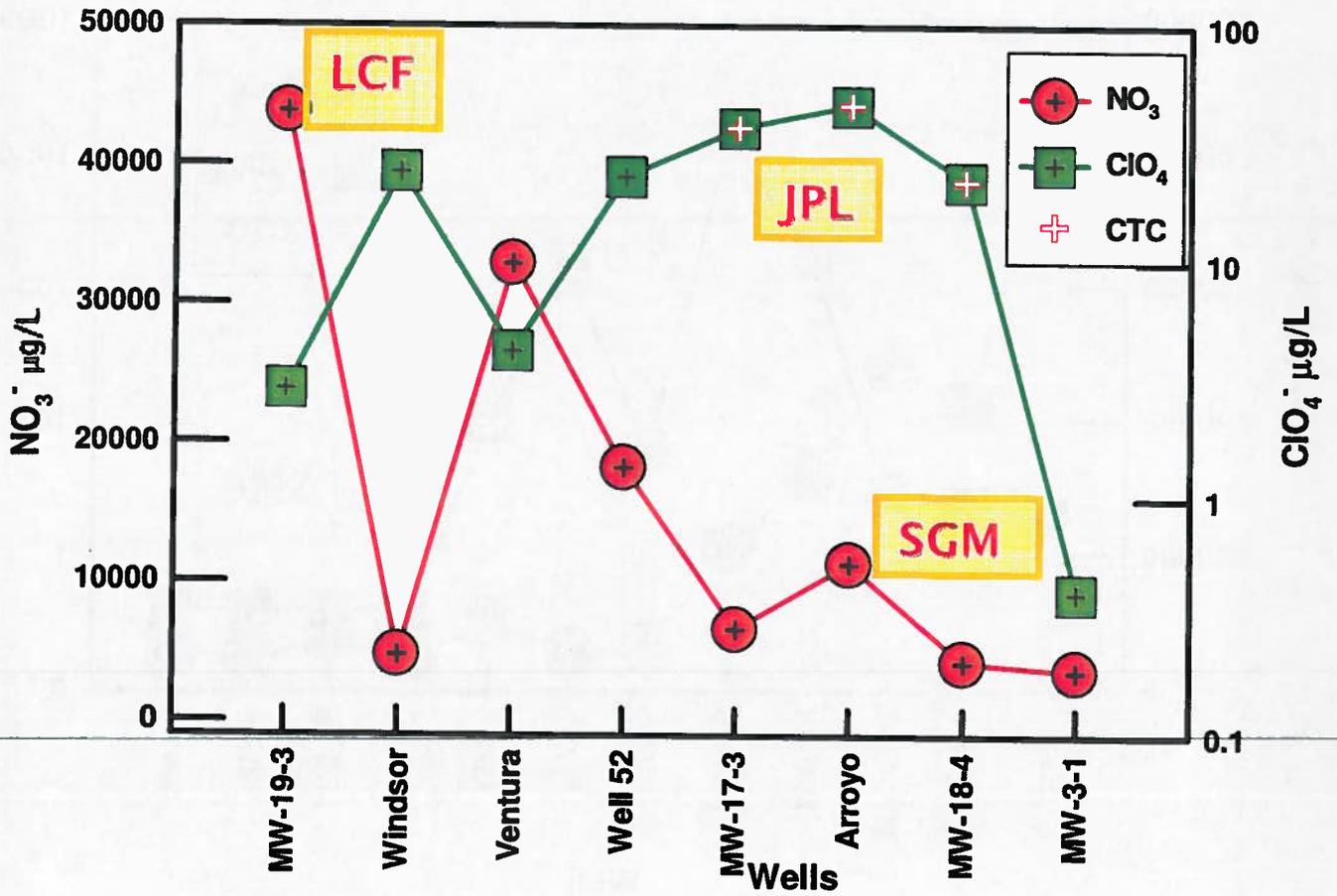
Median Concentration of  $\text{ClO}_4^-$  and  $\text{NO}_3^-$  from West to East Across JPL

1996 - 2011



**Figure 15**

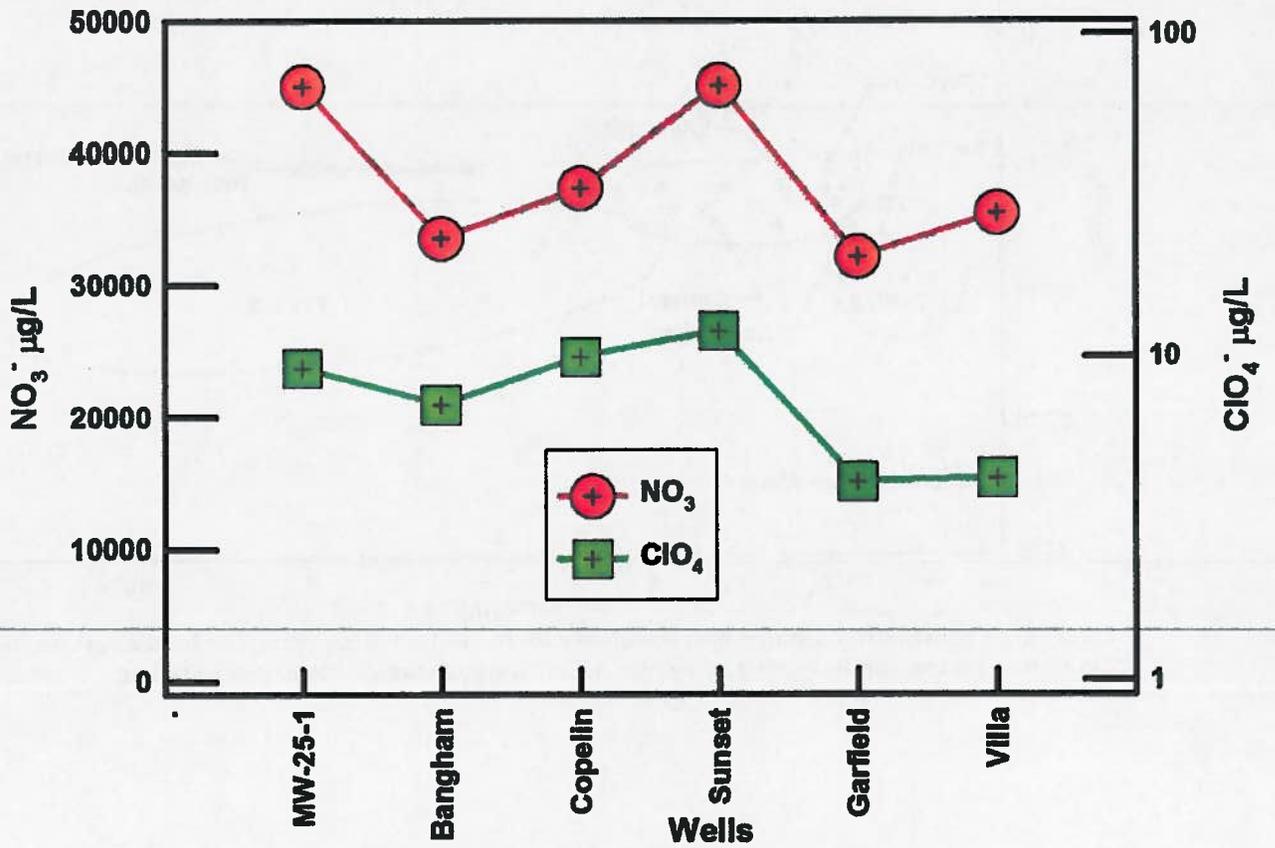
Median Concentration of  $\text{ClO}_4^-$  and  $\text{NO}_3^-$  from South to North Across Monk Hill  
1996 - 2011



**Figure 16**

Median Concentration of  $\text{ClO}_4^-$  and  $\text{NO}_3^-$  from Across Sunset Reservoir Well Area

1996 - 2011



**Figure 17**

TM Figure 11 - Relation Between  $1/[Sr]$  and  $^{87}Sr/^{86}Sr$  in Raymond Basin Wells

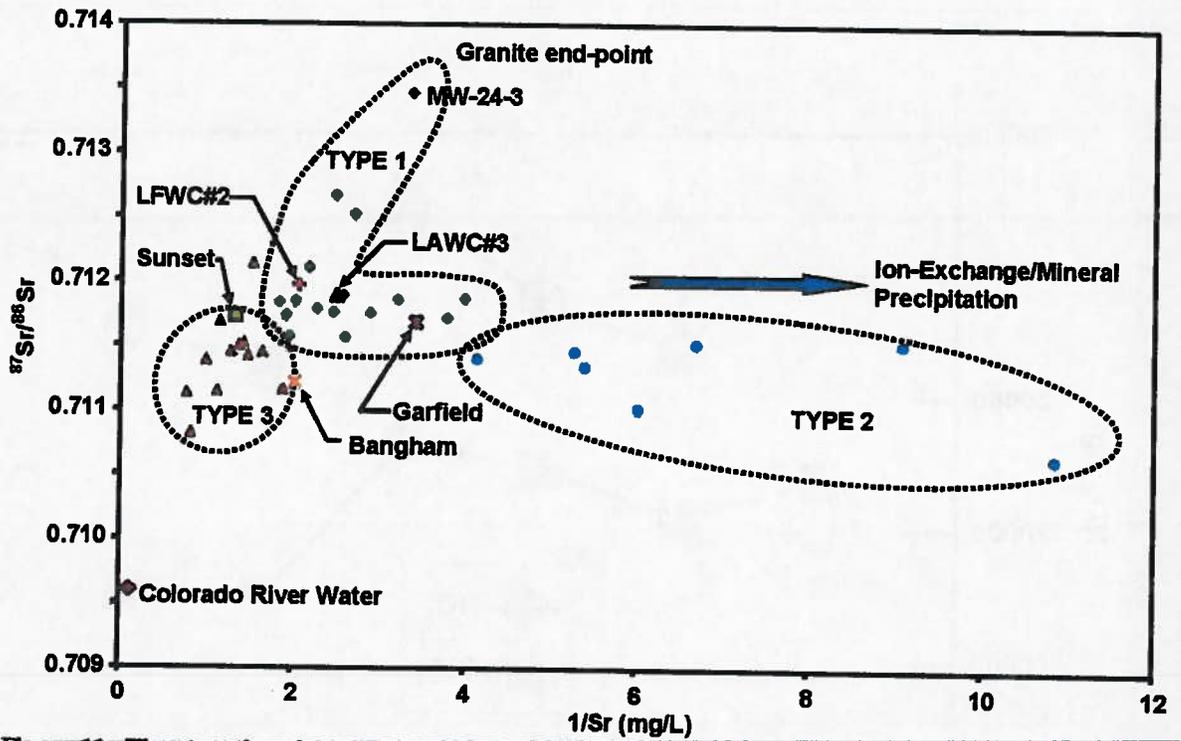
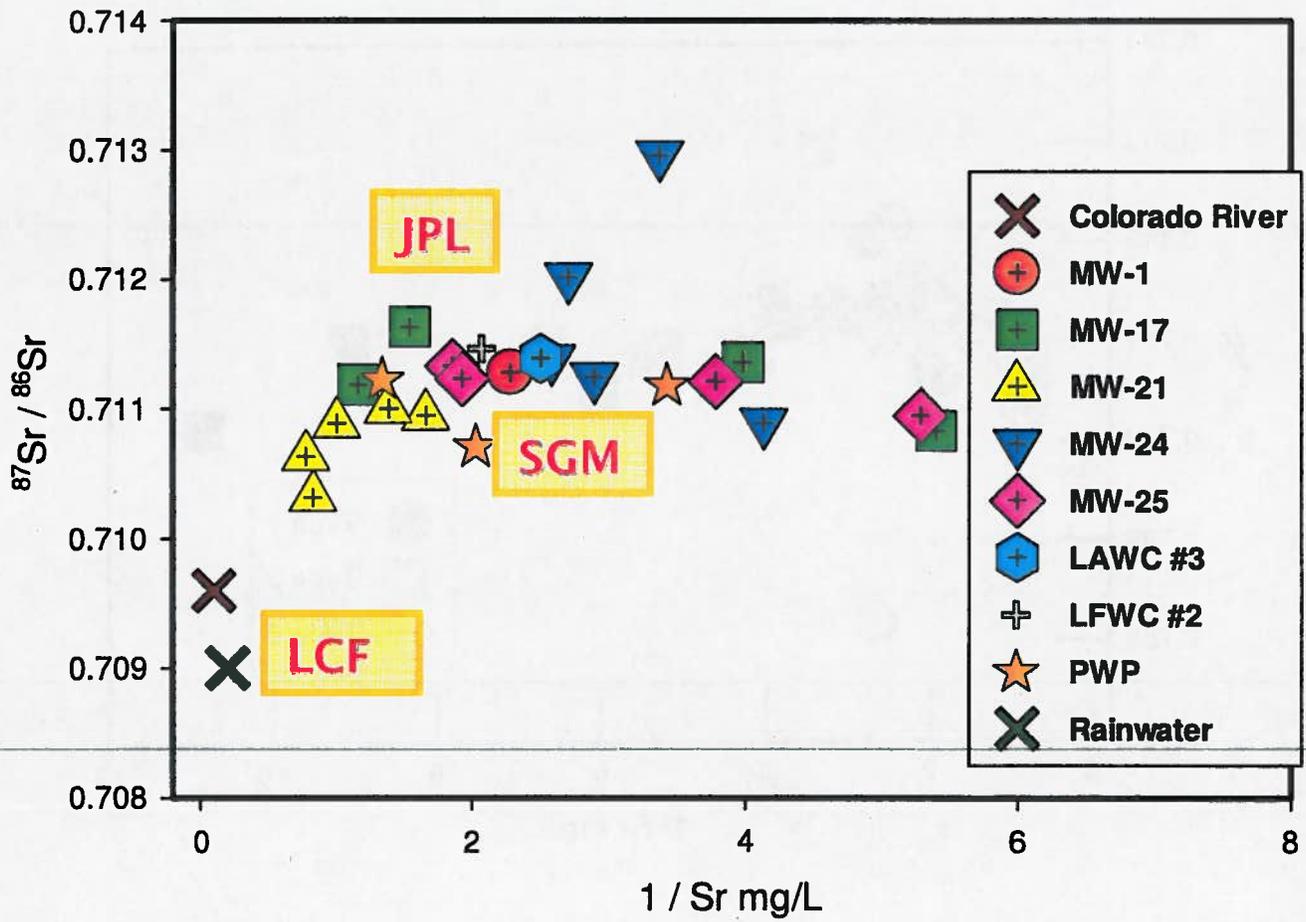


Figure 11. The strontium isotope data correlate with the water typing, grouping in distinct clusters on the above plot that can be explained by mixing and ion-exchange/mineral precipitation.

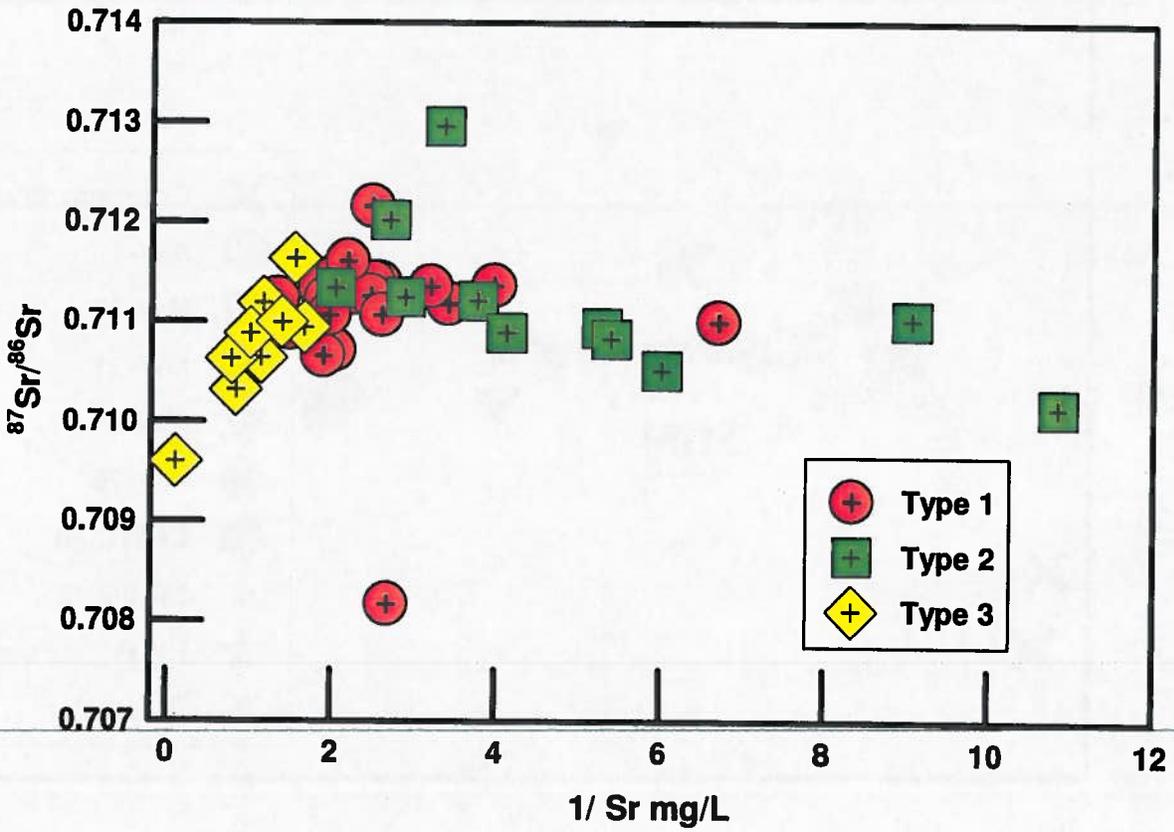
**Figure 18**

Relation Between  $1/[Sr]$  and  $^{87}Sr/^{86}Sr$  in Raymond Basin Wells - Replotted



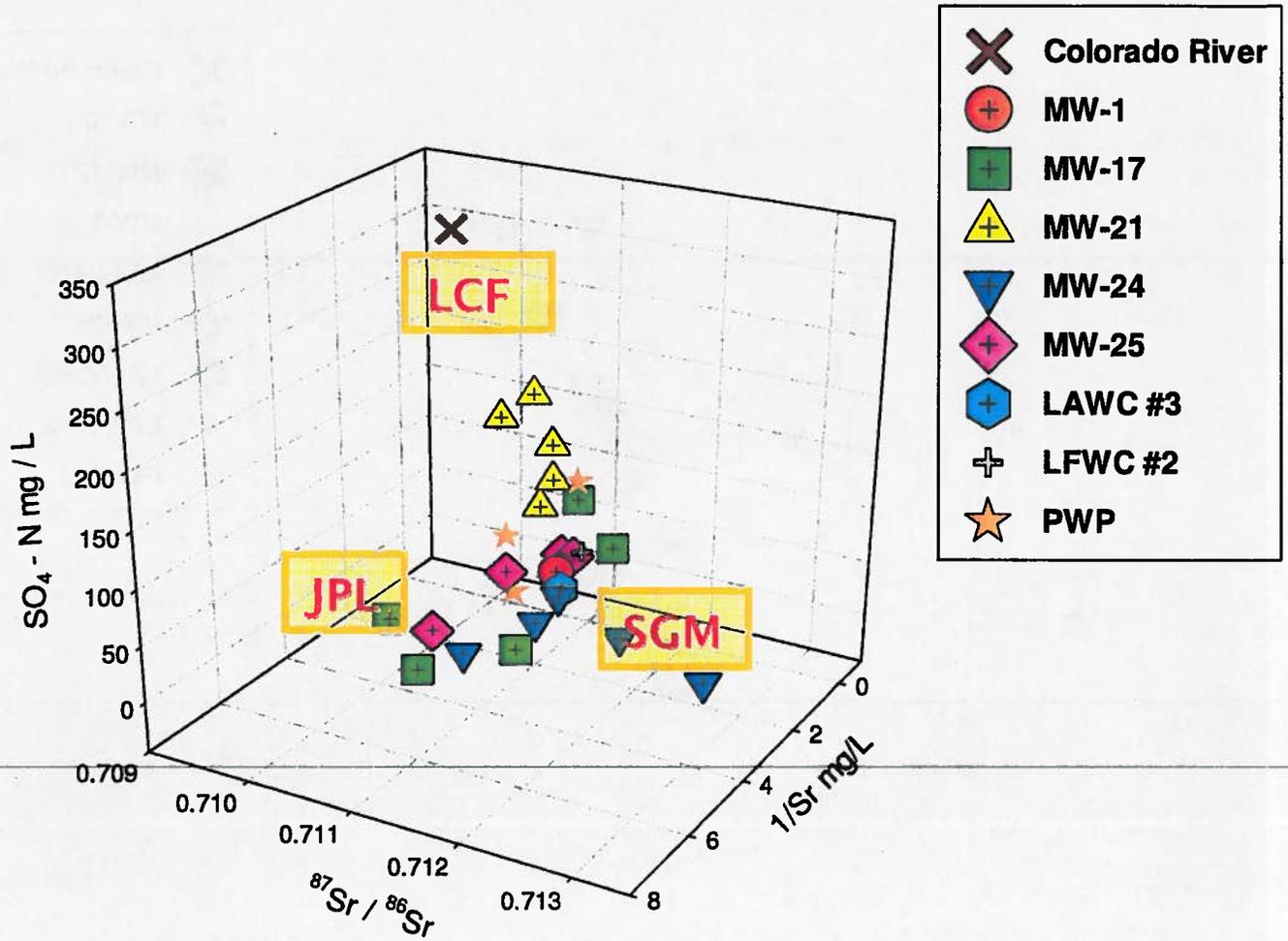
**Figure 19**

Relation Between  $1/[Sr]$  and  $^{87}Sr/^{86}Sr$  in Raymond Basin Wells by Water Type (from Table 2)



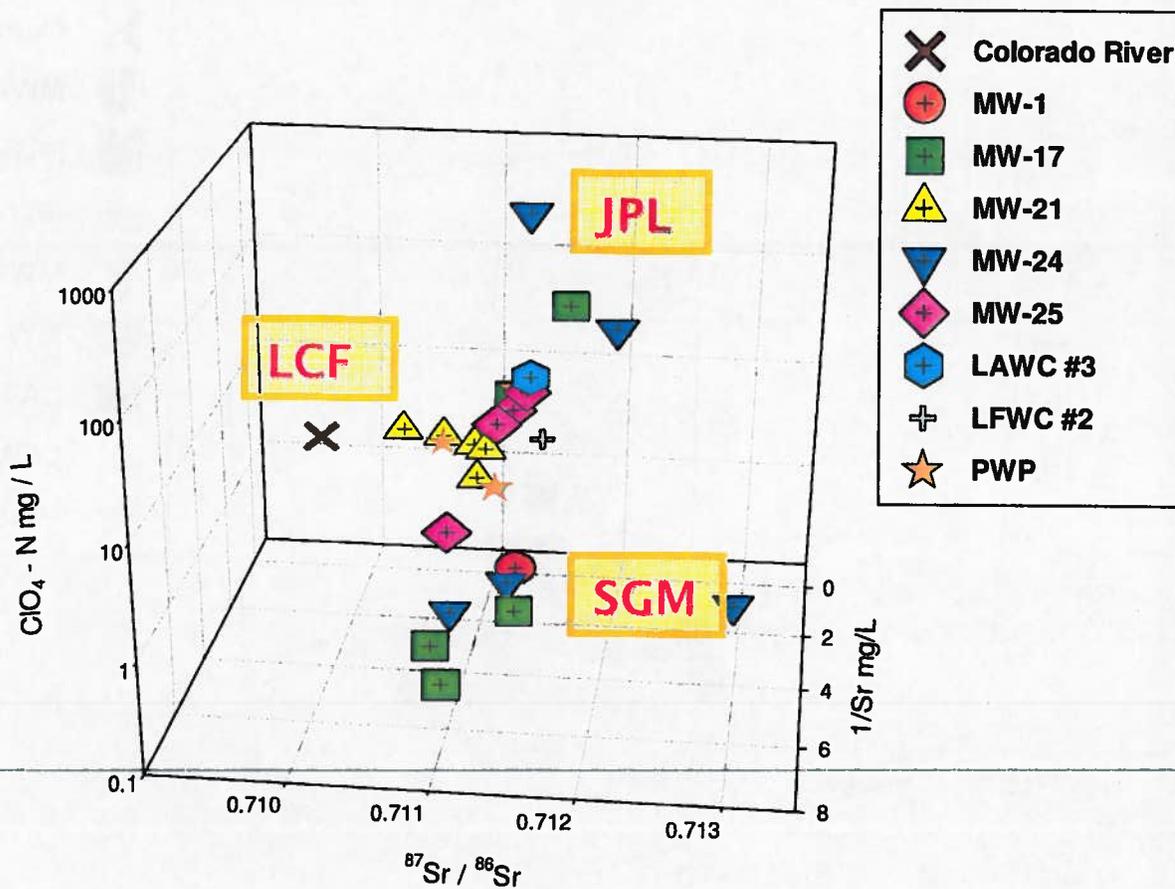
**Figure 20**

Relation Between  $1/[Sr]$  and  $^{87}Sr/^{86}Sr$  and  $SO_4$  in Raymond Basin Wells



**Figure 21**

Relation Between  $1/[Sr]$  and  $^{87}Sr/^{86}Sr$  and  $ClO_4^-$  in Raymond Basin Wells



**Figure 22**

TM Figure 10 - SIA Analysis of Water in Raymond Basin  
Wells with CTC Results

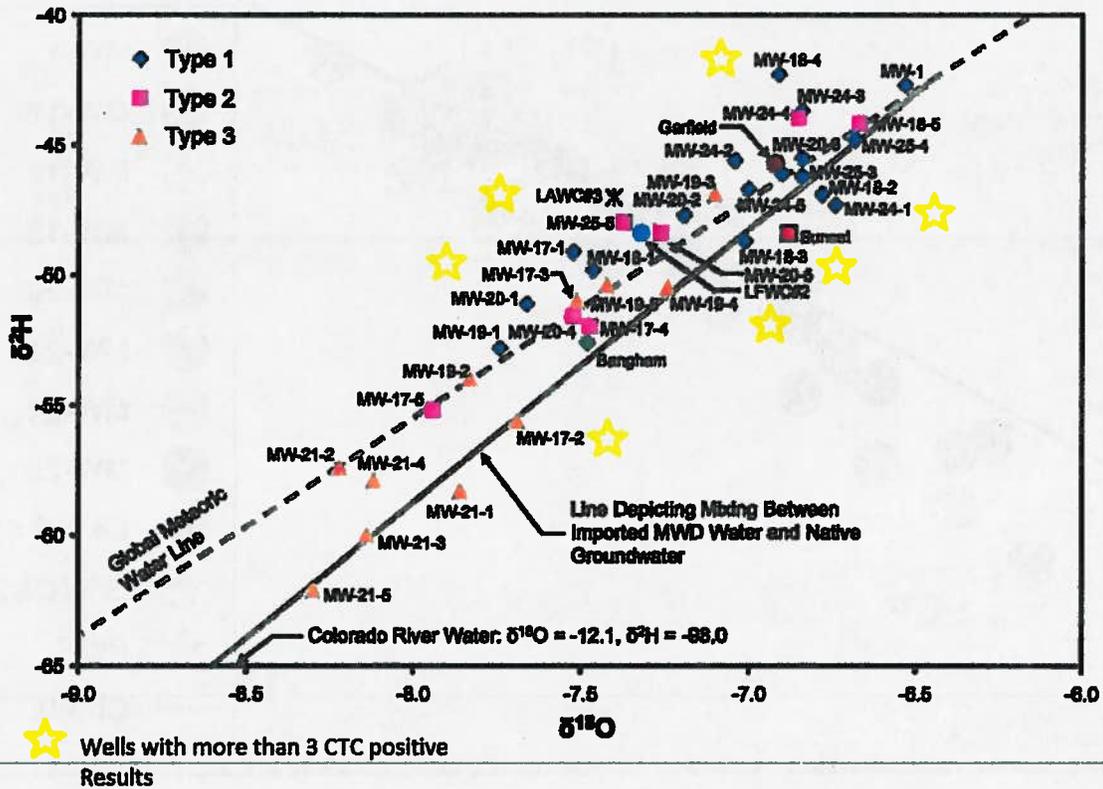
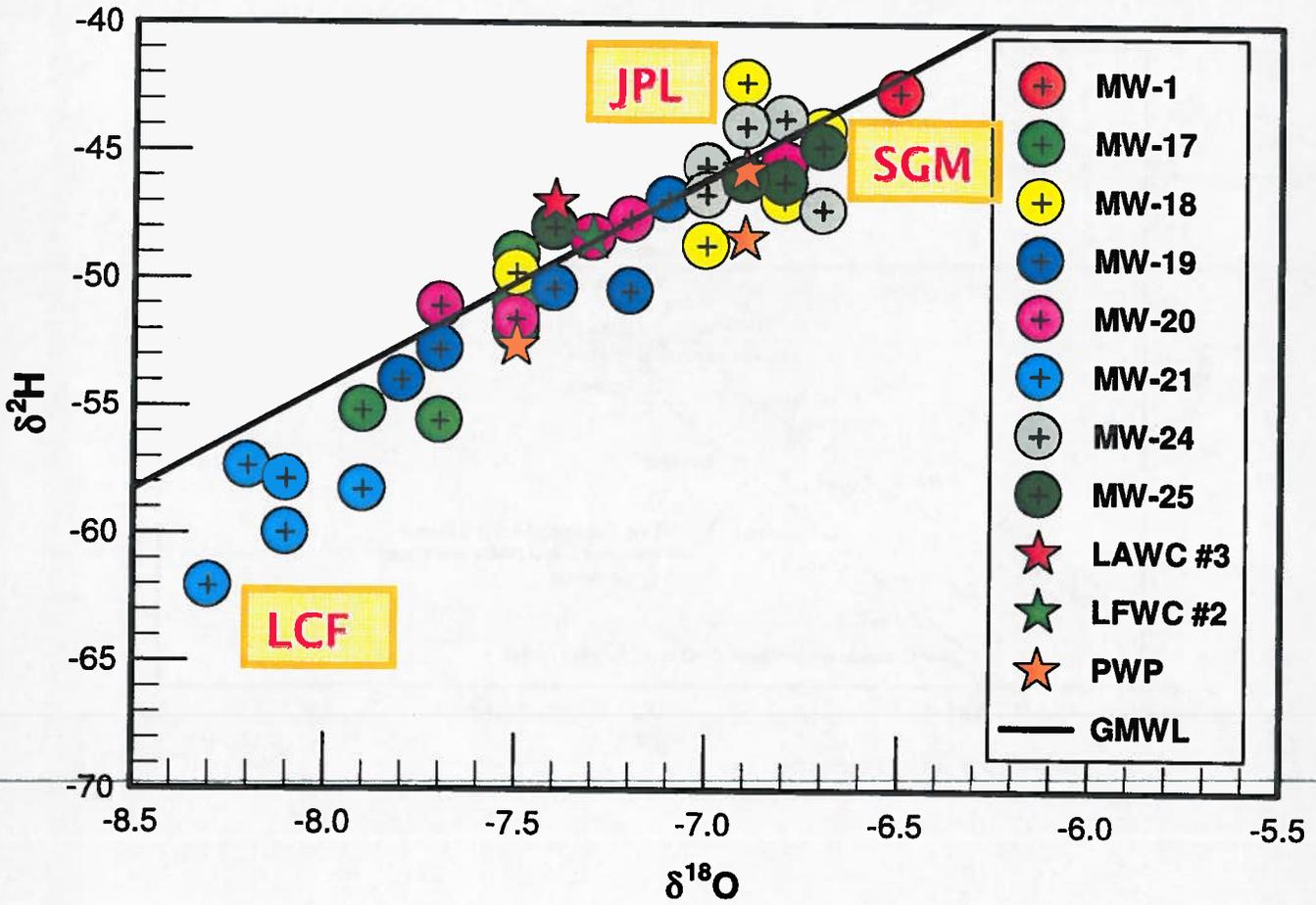


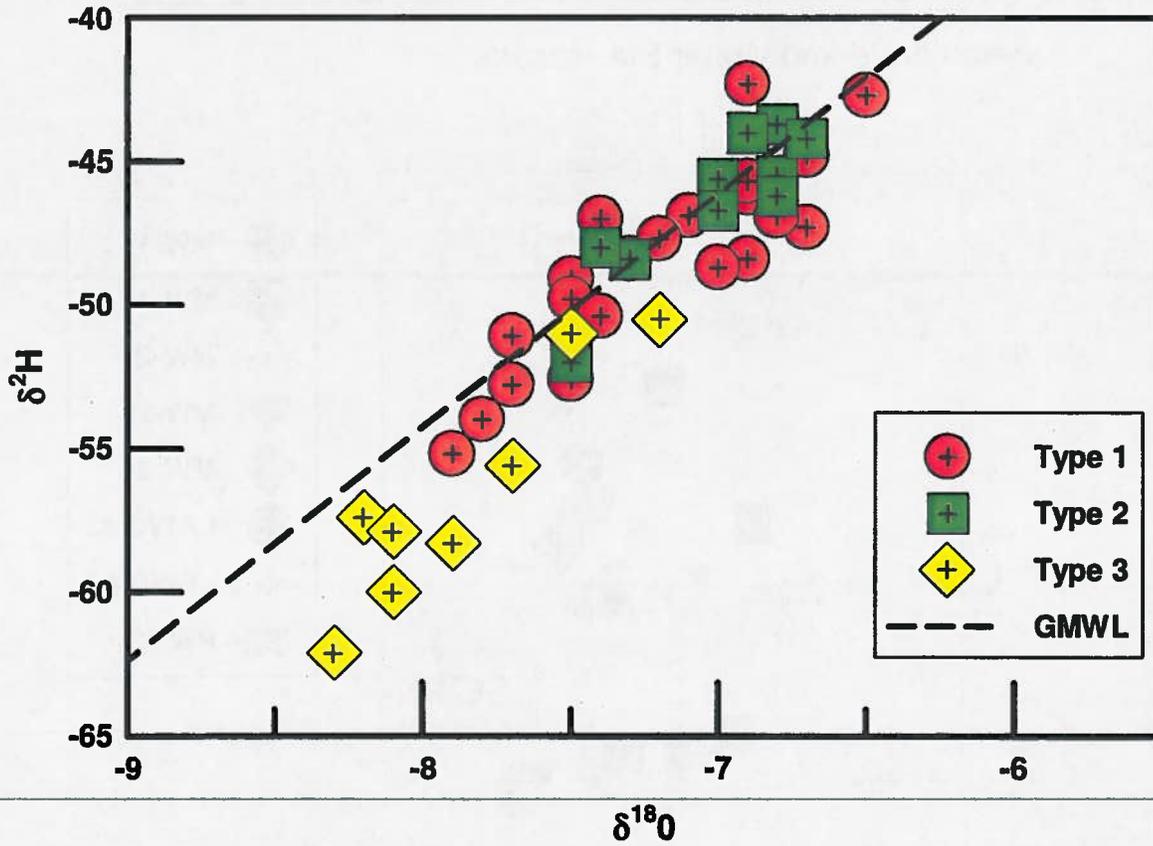
Figure 23

SIA Analysis of Water in Raymond Basin Wells



**Figure 24**

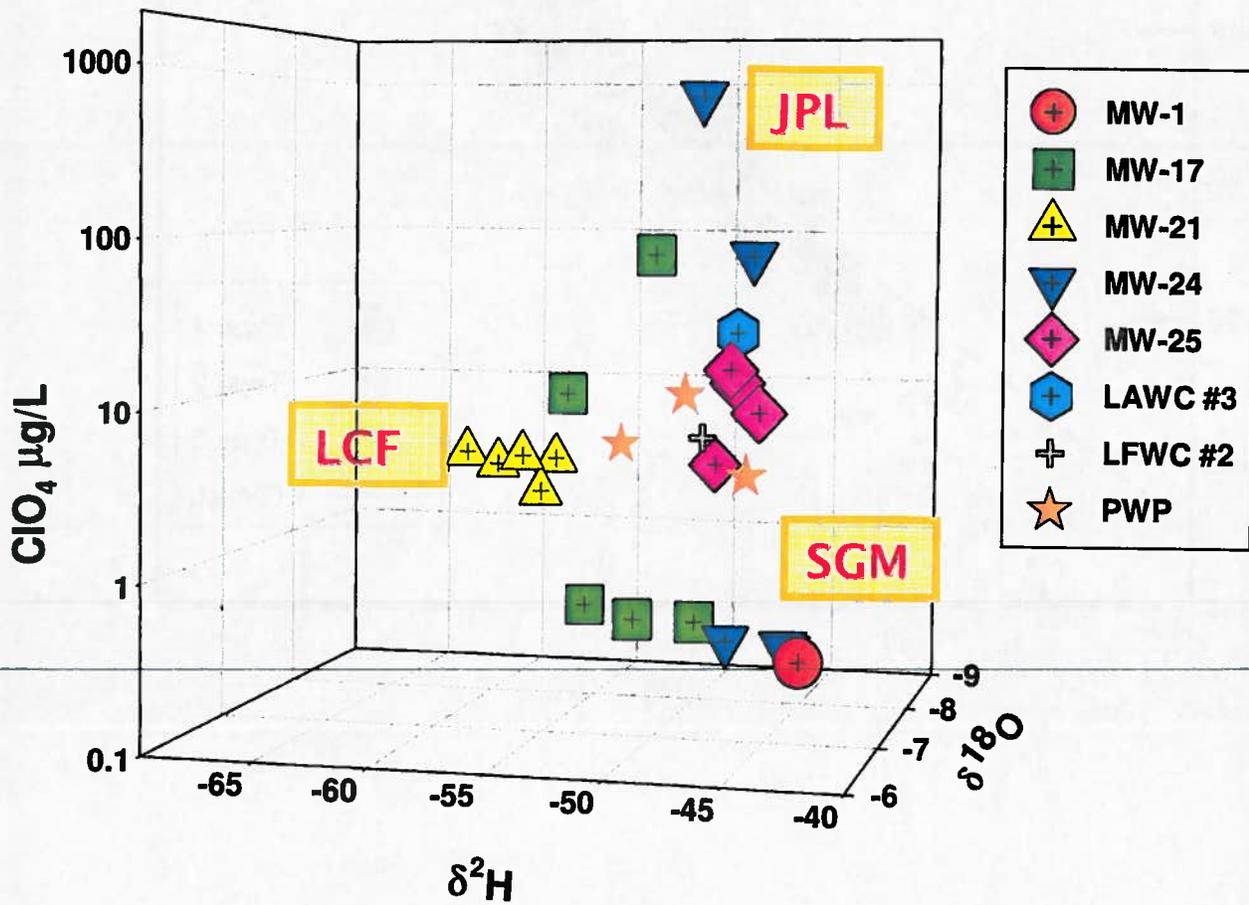
SIA Analysis of Water in Raymond Basin Wells Displayed by Water Type



**Figure 25**

SIA Analysis of Water in Raymond Basin Wells with Fewer Wells and Specific locations Identified and  $\text{ClO}_4$

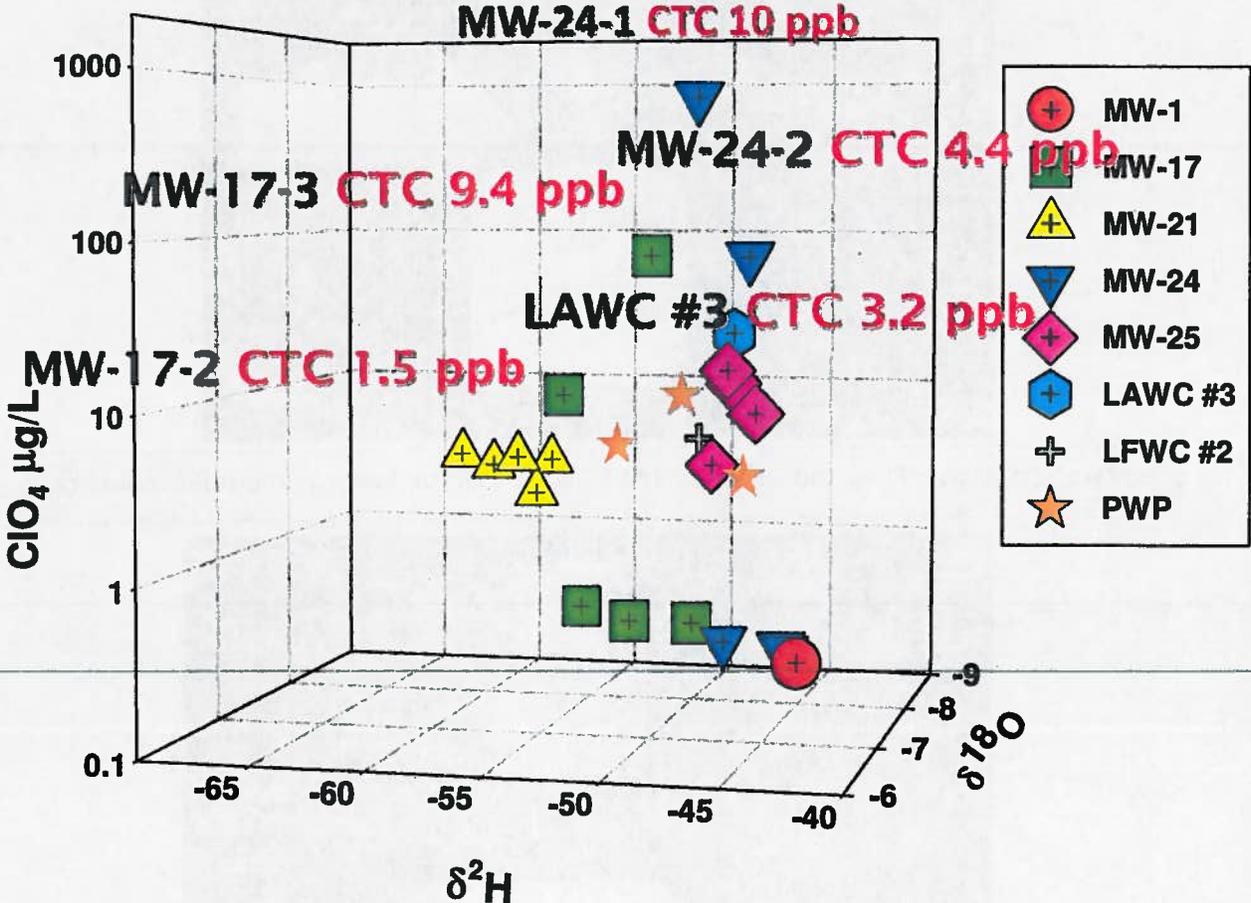
Perchlorate and Water SIA Results



**Figure 26**

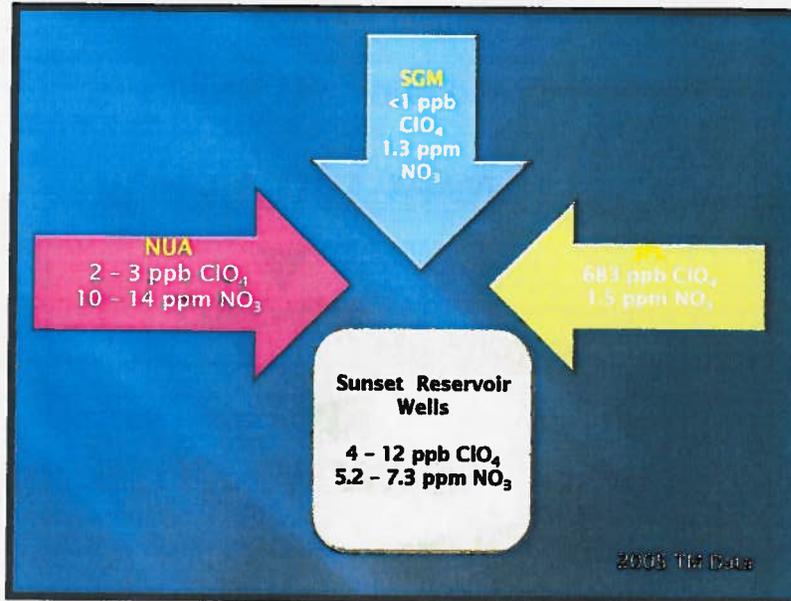
SIA Analysis of Water in Raymond Basin Wells with Fewer Wells and Specific locations Identified and ClO<sub>4</sub> and CTC

Perchlorate and Water SIA Results



**Figure 27**

**Schematic of Water Flow and Quality in the Sunset Reservoir Wells with JPL Influence**



**Schematic of Water Flow and Quality in the Sunset Reservoir Wells Without JPL Influence**

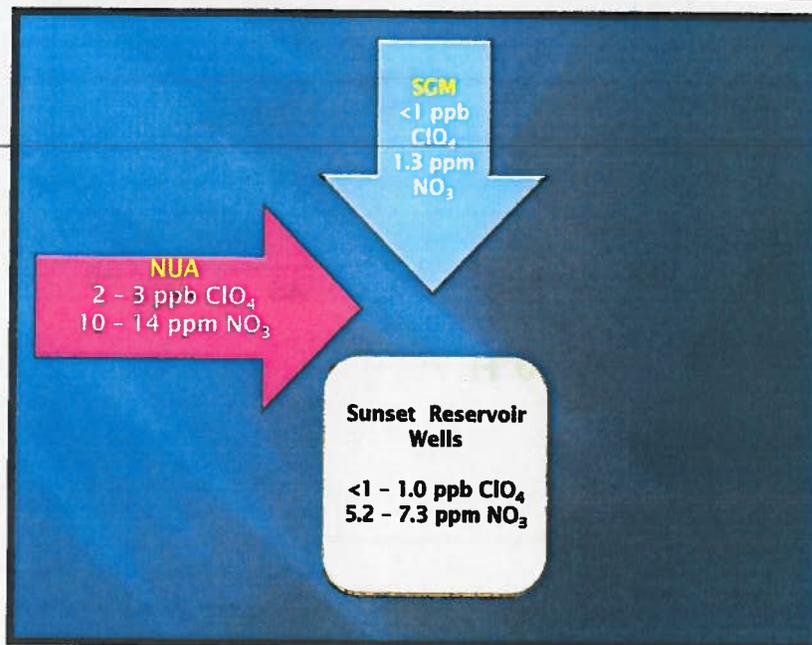


Table 1a  
Nitrate, Perchlorate, and Carbon Tetrachloride in Raymond Basin Wells  
1985 - 2011

Location	Station Code	NO3 as NO3		n	ClO4		n	Carbon Tetrachloride Number of Positives	Notes
		Mean	µg/L Median		Mean	µg/L Median			
LCID #1	1910054-002	39,300	39,000	68	2.7	4.0	17	0	
LCID #6	1910054-003	34,600	35,000	44	2.5	2.5	7	0	
VWC 1	1910166-002	35,600	34,100	104	3.4	4.0	38	0	
VWC 3	1910166-005	38,800	44,000	106	3.5	4.1	30	0	
MW-1		5,190	5,400	22	0.4	0.4	28	0	No ClO4
MW-3-1		4,100	3,600	22	0.4	0.4	28	0	
MW-3-2		5,440	4,070	18	57	16.0	52	19	
MW-3-3		470	340	53	3.5	0.4	53	20	2 ClO4+, No NO3 after 2005
MW-3-4		1,540	902	22	0.4	0.4	22	0	No ClO4+, No NO3 after 2005
MW-3-5		200	200	23	7.5	0.4	35	0	only 5 NO3+
MW-4-1		7,390	5,060	24	44	0.4	52	1	0.56 ppb in 2007
MW-4-2		36,300	36,200	63	17	5.9	63	34	No CTC after 2002
MW-4-3		12,800	1,580	23	0.4	0.4	52	0	No ClO4, No NO3 after 2005
MW-4-4		14,300	15,400	23	0.4	0.4	28	0	1 ClO4
MW-4-5		4,060	4,160	24	0.4	0.4	29	0	1 ClO4
MW-5		10,000	7,480	23	7.5	0.4	54	3	
MW-6		42,300	44,200	22	2.3	2.0	51	0	
MW-7		15,600	5,720	40	1,470	130	49	32	No CTC after 2005
MW-8		11,300	10,100	42	64	10	55	15	No CTC after 2005
MW-9		9,150	5,060	22	0.4	0.4	28	0	No ClO4
MW-10		53,400	55,900	23	60	56	67	5	No CTC after 2000
MW-11-1		4,590	4,800	41	0.5	0.4	51	3	4 ClO4+, 3 CTC
MW-11-2		1,070	700	23	0.4	0.4	51	12	1 ClO4
MW-11-3		452	200	23	0.4	0.4	51	12	1 ClO4
MW-11-4		565	200	23	0.4	0.4	50	0	3 ClO4, 3 NO3
MW-11-5		565	200	23	0.4	0.4	50	0	
MW-12-1		4,270	3,960	21	0.4	0.4	51	0	5 ClO4
MW-12-2		7,280	7,500	23	2.3	0.9	60	26	
MW-12-3		3,550	2,950	24	2.5	0.4	51	47	
MW-12-4		5,550	5,400	23	4.4	3.6	51	57	
MW-12-5		5,720	5,400	24	1.2	0.4	51	35	
MW-13		34,900	31,700	39	357.0	182	65	55	Only 4 CTC after 2007
MW-14-1		79,000	79,200	22	1.9	1.9	51	0	
MW-14-2		66,100	66,000	23	2.5	3.2	53	0	
MW-14-3		59,400	60,300	22	4.8	5.6	53	0	
MW-14-4		45,400	44,400	23	1.9	0.4	53	0	
MW-14-5		576	550	22	0.4	0.4	52	0	No ClO4
MW-15		10,000	7,480	23	0.4	0.4	54	0	1 ClO4
MW-16		29,900	21,000	37	1,960	1,270	52	41	Only 1 CTC after 2007
MW-17-1		4,180	3,040	22	42	0.4	29	1	1 ClO4
MW-17-2		12,300	3,500	23	6.3	5	52	6	
MW-17-3		13,600	6,600	23	37	12	55	42	
MW-17-4		5,920	7,150	24	4.6	0.4	53	1	
MW-17-5		5,880	7,480	23	6	4	37	0	
MW-18-1		7,340	5,940	16	0.4	0.4	23	0	No ClO4
MW-18-2		5,190	4,840	22	2	0.4	52	0	5 ClO4
MW-18-3		4,700	4,400	22	17	5.1	52	35	
MW-18-4		4,480	4,220	22	24	22	52	60	
MW-18-5		597	418	22	0.4	0.4	52	0	2 ClO4

**Table 1b**  
**Nitrate, Perchlorate, and Carbon Tetrachloride in Raymond Basin Wells**  
**1985 - 2011**

Location	Station Code	NO3 as NO3			ClO4			Carbon Tetrachloride Number of Positives	Notes
		Mean	µg/L Median	n	Mean	µg/L Median	n		
MW-19-1		7,270	3,960	23	1.4	0.4	52	0	
MW-19-2		37,000	29,000	22	3.0	4.4	52	0	
MW-19-3		44,200	43,800	24	2.7	2.9	52	0	
MW-19-4		21,200	21,100	23	0.9	0.4	52	0	
MW-19-5		27,700	32,500	24	1.0	0.4	52	0	
MW-20-1		41,700	42,900	24	2.0	0.4	52	0	
MW-20-2		8,710	8,430	24	0.6	0.4	52	0	
MW-20-3		8,120	7,480	24	0.4	0.4	52	0	
MW-20-4		200	200	24	10	0.4	52	0	
MW-20-5		200	200	24	2.7	0.4	52	0	
MW-21-1		62,000	66,000	20	3.6	2.9	52	0	
MW-21-2		38,300	39,600	22	1.2	0.4	52	0	
MW-21-3		42,400	42,900	24	1.4	0.4	52	0	
MW-21-4		35,400	36,500	23	1.3	0.4	52	0	
MW-21-5		38,000	42,100	24	1.8	0.4	52	0	
MW-22-1		48,200	48,400	18	2.4	2.3	51	0	
MW-22-2		35,000	24,600	18	0.9	0.4	51	0	
MW-22-3		35,600	35,500	18	1.4	0.4	51	0	
MW-22-4		18,000	18,700	18	0.4	0.4	34	1	No ClO4
MW-22-5		200	200	18	0.4	0.4	27	0	2 ClO4, 2 NO3
MW-23-1		55,000	57,200	17	9.7	2.2	51	3	
MW-23-2		59,300	61,600	17	4.0	4.2	51	0	
MW-23-3		33,800	38,700	17	0.4	0.4	51	0	6 ClO4
MW-23-4		25,200	26,300	17	0.4	0.4	51	0	2 ClO4
MW-23-5		200	200	17	0.5	0.4	51	0	2 ClO4, No NO3
MW-24-1		9,620	6,200	36	696	6.2	53	36	
MW-24-2		9,990	9,020	20	177	9.0	53	41	
MW-24-3		4,800	4,400	19	1.0	0.4	51	0	
MW-24-4		6,460	2,600	19	0.4	0.4	29	0	2 ClO4
MW-24-5		5,220	5,300	19	0.4	0.4	28	0	No ClO4
MW-25-1		46,500	45,300	9	8.5	9.2	25	0	
MW-25-2		35,400	39,200	9	14	14	25	0	
MW-25-3		41,200	37,800	9	10	9.8	25	0	
MW-25-4		22,900	22,000	9	7.7	7.6	25	0	
MW-25-5		333	200	9	4.3	0.4	25	0	3 NO3, 4 ClO4
MW-26-1		27,000	24,600	7	1.3	1.7	24	0	
MW-26-2		2,870	2,400	7	0.4	0.4	24	0	No ClO4
Arroyo	1910124-001	39,600	43,400	8	75	75.0	98	2	
Well 52	1910124-021	24,800	18,200	53	23	23.0	119	0	
Ventura	1910124-019	31,500	32,900	294	3.6	4.2	351	0	
Windsor	1910124-022	4,120	4,730	92	27	24.0	40	0	
LAWC 3	1910063-002	12,600	12,400	31	17	19.0	419	117	
LAWC 5	1910063-003	15,800	16,000	26	8.1	7.4	293	66	
Bangham	1910124-028	30,600	33,600	251	6.5	7.1	260	0	
Sunset	1910124-018	44,700	45,100	144	12	12.0	149	0	
Copelin	1910124-006	36,800	37,300	183	10	10.0	202	0	
Garfield	1910124-010	29,700	32,100	245	3.2	4.1	239	0	
Villa	1910124-020	33,400	35,400	154	3.0	4.2	157	0	

Table 2

Laboratory Results from the Patton Well

March – November 2011 All Results µg/L

Date	CTC	PCE	TCE	CIO4
3/16/2011	<DLR	<DLR	0.9	<DLR
5/11/2011	<DLR	<DLR	0.8	NA
5/16/2011	<DLR	<DLR	1.1	4.7
5/23/2011	<DLR	0.6	1.1	5.0
6/1/2011	<DLR	0.5	1.3	4.2
6/8/2011	<DLR	0.6	1.2	<DLR
6/13/2011	<DLR	0.6	1.1	4.8
6/20/2011	<DLR	0.6	1.0	<DLR
6/27/2011	<DLR	0.6	1.0	<DLR
7/5/2011	<DLR	0.6	1.1	<DLR
7/11/2011	<DLR	0.7	1.2	5.2
7/18/2011	<DLR	<DLR	1.1	5.3
7/25/2011	<DLR	0.6	1.1	4.8
8/1/2011	0.6	0.7	1.4	5.3
8/8/2011	0.5	0.6	1.5	5.3
8/16/2011	0.5	0.5	1.3	6.2
8/22/2011	0.5	0.7	1.3	5.3
8/29/2011	0.6	0.6	1.5	4.4
9/6/2011	0.6	0.8	1.6	5.1
9/14/2011	0.6	0.7	1.4	5.6
9/19/2011	0.5	0.7	1.5	4.8
9/26/2011	<DLR	<DLR	1.3	5.1
10/3/2011	<DLR	0.6	1.5	4.8
10/10/2011	<DLR	0.7	1.4	5.0
10/17/2011	<DLR	0.6	1.3	4.8
10/24/2011	<DLR	0.6	1.3	4.9
11/2/2011	0.6	0.8	1.6	4.8
11/7/2011	0.5	0.6	1.4	4.7
Mean	0.23	0.53	1.3	4.1
SD	0.25	0.24	0.21	2
N	28	28	28	27

Pearson Product Moment Correlation

		PCE	TCE	CIO4
CTC	R <sup>2</sup>	0.46	0.70	0.41
	p	0.015	<0.001	0.034
PCE	R <sup>2</sup>		0.59	0.13
	p		<0.001	0.53
TCE	R <sup>2</sup>			0.58
	p			0.001

NA = Not Analyzed

Table 3

Water Types based on the 2005 Study of Raymond Basin Wells by Mass

Well	Calcium mg/L	Sodium mg/L	Ca/Na	TDS mg/L	Type
MW-17-2	106	24.5	4.33	695	3
MW-20-1	82	20	4.10	440	1
MW-20-2	51.2	13.8	3.71	275	1
MW-21-1	126	34.2	3.68	760	3
MW-21-3	150	44.4	3.38	900	3
MW-19-2	115	34.4	3.34	736	3
LAWC No. 3	61.2	19	3.22	324	1
MW-21-4	96.8	30.5	3.17	545	3
MW-25-1	98.7	32	3.08	610	3
LFWC No. 2	73.5	24	3.06	460	1
Sunset	108	37	2.92	420	1
MW-17-3	73.6	25.6	2.88	535	3
MW-24-1	55.6	19.4	2.87	300	1
MW-21-5	99.6	35.3	2.82	590	3
MW-18-2	56.8	20.3	2.80	276	1
MW-18-3	66.2	23.8	2.78	316	1
MW-18-1	41.9	15.8	2.65	236	1
MW-17-1	35.5	14.4	2.47	190	1
MW-1	68.3	30	2.28	360	1
MW-19-3	64.8	28.9	2.24	426	1
MW-21-2	152	70.5	2.16	925	3
MW-19-1	42.5	19.8	2.15	240	1
MW-19-4	69.7	33.3	2.09	494	1
MW-19-5	67.8	35.9	1.89	504	1
MW-25-3	68.4	39.5	1.73	414	1
MW-18-4	39	29.3	1.33	224	1
Garfield	41.6	35	1.19	274	1
Bangham	55.5	50	1.11	380	1
MW-25-4	64.5	58.4	1.10	420	1
MW-17-5	65.7	59.8	1.10	185	1
MW-20-3	50.6	58.1	0.87	340	2
MW-24-5	34.3	39.9	0.86	235	2
MW-24-2	32.9	43.6	0.75	270	2
MW-24-3	18.9	44.8	0.42	235	2
MW-17-4	18.1	46.9	0.39	235	2
MW-25-5	21.9	68.4	0.32	264	2
MW-24-4	9.8	43.3	0.23	175	2
MW-20-4	12.8	59.1	0.22	205	2
MW-25-2	14.9	81.2	0.18	324	2
MW-18-5	9.3	53.1	0.18	160	2
MW-20-5	5.3	64.0	0.08	180	2

Table 4

Water Types based on the 2005 Study of Raymond Basin Wells by Molarity

Well	Calcium mm/L	Sodium mm/L	Ca/Na	TDS mg/L	Type
MW-17-2	2.65	1.07	2.49	695	3
MW-20-1	2.05	0.87	2.36	440	1
MW-20-2	1.28	0.60	2.13	275	1
MW-21-1	3.15	1.49	2.12	760	3
MW-21-3	3.75	1.93	1.94	900	3
MW-19-2	2.88	1.50	1.92	736	3
LAWC No. 3	1.53	0.83	1.85	324	1
MW-21-4	2.42	1.33	1.82	545	3
MW-25-1	2.47	1.39	1.77	610	3
LFWC No. 2	1.84	1.04	1.76	460	1
Sunset	2.70	1.61	1.68	420	1
MW-17-3	1.84	1.11	1.65	535	3
MW-24-1	1.39	0.84	1.65	300	1
MW-21-5	2.49	1.53	1.62	590	3
MW-18-2	1.42	0.88	1.61	276	1
MW-18-3	1.66	1.03	1.60	316	1
MW-18-1	1.05	0.69	1.52	236	1
MW-17-1	0.89	0.63	1.42	190	1
MW-1	1.71	1.30	1.31	360	1
MW-19-3	1.62	1.26	1.29	426	1
MW-21-2	3.80	3.07	1.24	925	3
MW-19-1	1.06	0.86	1.23	240	1
MW-19-4	1.74	1.45	1.20	494	1
MW-19-5	1.70	1.56	1.09	504	1
MW-25-3	1.71	1.72	1.00	414	2
MW-18-4	0.98	1.27	0.77	224	2
Garfield	1.04	1.52	0.68	274	2
Bargham	1.39	2.17	0.64	380	2
MW-25-4	1.61	2.54	0.64	420	2
MW-17-5	1.64	2.60	0.63	185	2
MW-20-3	1.27	2.53	0.50	340	2
MW-24-5	0.86	1.73	0.49	235	2
MW-24-2	0.82	1.90	0.43	270	2
MW-24-3	0.47	1.95	0.24	235	2
MW-17-4	0.45	2.04	0.22	235	2
MW-25-5	0.55	2.97	0.18	264	2
MW-24-4	0.25	1.88	0.13	175	2
MW-20-4	0.32	2.57	0.12	205	2
MW-25-2	0.37	3.53	0.11	324	2
MW-18-5	0.23	2.31	0.10	160	2
MW-20-5	0.13	2.78	0.05	180	2

Table 5

Water Types based on the 2005 Study of Raymond Basin Wells by Equivalents

Well	Calcium meq/L	Sodium meq/L	Ca/Na	TDS mg/L	Type
<b>MW-17-2</b>	<b>5.30</b>	<b>1.07</b>	<b>4.98</b>	<b>695</b>	<b>3</b>
MW-20-1	4.10	0.87	4.72	440	1
MW-20-2	2.56	0.60	4.27	275	1
<b>MW-21-1</b>	<b>6.30</b>	<b>1.49</b>	<b>4.24</b>	<b>760</b>	<b>3</b>
<b>MW-21-3</b>	<b>7.50</b>	<b>1.93</b>	<b>3.89</b>	<b>900</b>	<b>3</b>
<b>MW-19-2</b>	<b>5.75</b>	<b>1.50</b>	<b>3.84</b>	<b>736</b>	<b>3</b>
LAWC No. 3	3.06	0.83	3.70	324	1
<b>MW-21-4</b>	<b>4.84</b>	<b>1.33</b>	<b>3.65</b>	<b>545</b>	<b>3</b>
<b>MW-25-1</b>	<b>4.94</b>	<b>1.39</b>	<b>3.55</b>	<b>610</b>	<b>3</b>
LFWC No. 2	3.68	1.04	3.52	460	1
Sunset	5.40	1.61	3.36	420	1
<b>MW-17-3</b>	<b>3.68</b>	<b>1.11</b>	<b>3.31</b>	<b>535</b>	<b>3</b>
MW-24-1	2.78	0.84	3.30	300	1
<b>MW-21-5</b>	<b>4.98</b>	<b>1.53</b>	<b>3.24</b>	<b>590</b>	<b>3</b>
MW-18-2	2.84	0.88	3.22	276	1
MW-18-3	3.31	1.03	3.20	316	1
MW-18-1	2.10	0.69	3.05	236	1
MW-17-1	1.78	0.63	2.84	190	1
MW-1	3.42	1.30	2.62	360	1
MW-19-3	3.24	1.26	2.58	426	1
<b>MW-21-2</b>	<b>7.60</b>	<b>3.07</b>	<b>2.48</b>	<b>925</b>	<b>3</b>
MW-19-1	2.13	0.86	2.47	240	1
MW-19-4	3.49	1.45	2.41	494	1
MW-19-5	3.39	1.56	2.17	504	1
MW-25-3	3.42	1.72	1.99	414	1
MW-18-4	1.95	1.27	1.53	224	1
Garfield	2.08	1.52	1.37	274	1
Bangham	2.78	2.17	1.28	380	1
MW-25-4	3.23	2.54	1.27	420	1
MW-17-5	2.86	2.60	1.10	185	1
MW-20-3	2.53	2.53	1.00	340	1
MW-24-5	1.72	1.73	0.99	235	2
MW-24-2	1.65	1.90	0.87	270	2
MW-24-3	0.95	1.95	0.49	235	2
MW-17-4	0.91	2.04	0.44	235	2
MW-25-5	1.10	2.97	0.37	264	2
MW-24-4	0.49	1.88	0.26	175	2
MW-20-4	0.64	2.57	0.25	205	2
MW-25-2	0.75	3.53	0.21	324	2
MW-18-5	0.47	2.31	0.20	160	2
MW-20-5	0.27	2.78	0.10	180	2



P A S A D E N A  
Water & Power

**APPENDIX A  
TO THE  
TECHNICAL MEMORANDUM ON  
THE PERCHLORATE  
CONTAMINATION OF THE SUNSET  
RESERVOIR WELLS**

**MAY 2012**

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P A S A D E N A  
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**APPENDIX B  
TO THE  
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**AIAA Paper 99-2926**

**HISTORY OF ESTABLISHING A SOURCE OF  
POTASSIUM AND AMMONIUM PERCHLORATES  
FOR USE IN SOLID PROPELLANT ROCKETS**

**Joseph C Schumacher**

**35th AIAA/ASME/SAE/ASEE Joint Propulsion  
Conference and Exhibit  
20-24 June 1999  
Los Angeles, California**

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# HISTORY OF ESTABLISHING A SOURCE OF POTASSIUM AND AMMONIUM PERCHLORATES FOR USE IN SOLID PROPELLANT ROCKETS

Joseph C Schumacher\*

## Abstract

An Air Corps Jet Propulsion Project (ACJP) at the California Institute of Technology and Western Electrochemical Company Inc. (WECCO) agreed in December 1942 to establish a domestic source of supply of perchlorates in Los Angeles, California for use in solid rocket propellants. This project was designated GALCIT Project No.1. WECCO, with financial aid from ACJP, designed and constructed a perchlorate pilot plant in Los Angeles. Experimental quantities of potassium and ammonium perchlorates were produced as required by ACJP. The GALCIT project was successfully completed in November 1943. In 1943 WECCO designed and constructed a large-scale plant in Los Angeles to produce potassium perchlorate at the rate of 100 tons/month. Start-up began in January 1944. Expansion of the Los Angeles plant to 200 tons/month was started late in 1944. WECCO designed another potassium perchlorate plant to be constructed in Henderson, Nevada in 1945. This new plant was designed to produce potassium perchlorate at a rate of 1200 tons/month. Start-up of the Henderson plant began in the first week in July 1945. WECCO began production of ammonium perchlorate (AP) in a small plant in Henderson, Nevada in 1947. WECCO designed a new AP plant with production capacity of 50 tons/day. This new AP plant was constructed in Henderson, Nevada and began production in 1953

## Introduction

Robert L. Geisler, a member of the American Institute of Aeronautics and Astronautics (AIAA) Solid Rocket Technical Committee's History Subcommittee wrote to me in July 1998 stating that the history subcommittee arranges a history session at each annual propulsion meeting. He also stated that the committee has been trying to trace the origins of the introduction of each major ingredient in solid propellant as a function of time. Mr. Geisler stated that they have a pretty good handle on the various rubber binders used

and on the beginning of the use of aluminum powder fuel. They found that their knowledge of how potassium and then ammonium perchlorate evolved as propellant oxidizers is minimal. This is the place they needed my help. Even the oldest member on the history subcommittee has only a vague idea that use of KP and AP, made by American Potash in Henderson, Nevada under government support, came into use sometime in the early to mid 1950s. The committee would like the additional details that only I can provide, such as, who first conceived of using it in solid propellants, when the first mixes were made and by whom, and what was the first sizable rocket to fly with the new material. They also wanted to know how the materials became available in this country and when and at what level as well as who made this happen.

As I was the apparent principal architect of that aspect of the history, Professor Winfred A. Foster, chairman of the history subcommittee of AIAA's Solid Rocket Technical Committee, formally invited me to present a paper on the history of establishing a source of perchlorates for use in solid rocket propellants. I accepted Professor Foster's invitation and this paper represents my endeavor to fulfill that commitment.

## Early History of Perchlorates

The history of Perchlorates<sup>1</sup> can be traced back to 1816 when Count Frederick Von Stadion synthesized potassium perchlorate in his laboratory in Germany. He identified the sparingly water soluble salt as potassium "oxychlorate" ( $KClO_4$ ). In the course of identifying the composition and structure of the new salt, Von Stadion synthesized perchloric acid ( $HClO_4$ ). He also prepared  $KClO_4$  by electrolyzing a saturated aqueous solution of potassium chlorate ( $KClO_3$ ) between platinum electrodes. Von Stadion recognized the potential importance of electrochemistry as an effective method of chemical synthesis.

\* Co-founder Western Electrochemical Company, Inc., 1941; Vice President and Technical Director, Western Electrochemical Company, Inc. 1941-1954;

Member AIAA, Member Emeritus, The Electrochemical Society, Inc., Member Emeritus, American Chemical Society

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G.S. Serullas reported his discovery of ammonium perchlorate ( $\text{NH}_4\text{ClO}_4$ ) and other salts of  $\text{HClO}_4$  in 1831. G.S. Serullas can be credited with popularizing the name "perchlorate" to replace the name "oxychlorate" used earlier by Count Von Stadion and others.

During the next 60 years continuing basic research by many investigators provided a great treasure of knowledge of the physical and chemical characteristics of  $\text{HClO}_4$  and its salts. This research effort was driven to a great extent by scientific curiosity, but there was also a desire to find practical new uses for perchlorates in certain applications including analytical chemistry, pyrotechnics, and explosives.

The natural occurrence of  $\text{KClO}_4$  in Chilean nitrate fertilizer as reported by H. Beckhurts in 1886 and by B. Sjollem in 1896 is evidence that  $\text{KClO}_4$  was synthesized by a natural process probably in ancient times long before F. Von Stadion did so in 1816.

Other than H. Kolbe's verification<sup>2</sup> of F. Von Stadion's early work on electrolysis of chlorate to perchlorate very little work was done on electrolytic methods of production and use until about 1890. In 1890 O.F. Carlson, founder and president of Stockholms Superfosfat Fabriks AB (Fosfatbolaget), applied for a patent covering electrolytic cells without diaphragms for production of sodium chlorate ( $\text{NaClO}_3$ ). The formation of perchlorate in these cells was observed. Research to find conditions favorable to formation of perchlorate in these cells was intensified in the laboratory and in the pilot plant that Fosfatbolaget built in 1892. A commercial plant was constructed in 1893 in Mansbo, Sweden. Small quantities of sodium perchlorate were produced in 1898 with varying results. Sometimes a bath of  $\text{NaClO}_3$  could be oxidized to  $\text{NaClO}_4$  in 5 to 6 days. Other times the process lasted many weeks. Production was running smoothly in 1904. Sodium perchlorate is chemically converted into either ammonium perchlorate (AP) or potassium perchlorate (KP).

Ammonium perchlorate was produced in small quantities in Mansbo, Sweden in 1895. This product was intended for use as an ingredient in a new type of explosive for which O. F. Carlson was granted a patent in 1897. The well-known explosive "Carlsonit" was developed later and was covered by patents in many European countries and the United States.

France, Germany, Switzerland and the United States began producing perchlorates following Sweden's pioneering work. Sodium, potassium and ammonium perchlorates were produced in Chedde, France in 1901. Electrochemie Turgi began production

of perchlorates in Switzerland in 1907. Oldbury Electro-Chemical of Niagara Falls, New York started production of sodium perchlorate in 1908 and KP in 1910. Total world production of perchlorates was estimated to be in the range of 2000-3000 metric tons/year at the beginning of WW I in 1914. During WWI Chemical Works Griesheim, located in Bitterfeld, Germany, produced about 20,000 metric tons/year of perchlorates for various military uses. Fosfatbolaget constructed a new plant in Trollhatten, Sweden in 1915 with annual production capacity of 750 metric tons of AP and 475 metric tons of KP. Although demand for perchlorates declined after WWI, that trend reversed as WWII approached and new uses for perchlorates were developed. Cardox Corporation designed and constructed a potassium perchlorate production plant in Claremore, Oklahoma in 1941. Cardox designed and constructed a larger potassium perchlorate plant in Claremore in 1943 for the Defense Plant Corporation (DPC). Cardox operated these plants to supply potassium perchlorate for own requirements for use in a new type of coal mining device.

Western Electrochemical Company, Inc. (WECCO) constructed and operated a pilot plant in 1940 to produce experimental quantities of potassium chlorate ( $\text{KClO}_3$ ) (Fig. 1). WECCO constructed and operated a commercial  $\text{KClO}_3$  plant<sup>3</sup> in 1941 (Fig. 2). I designed both plants that were constructed in Los Angeles, California. Product from these two plants was sold to the match industry and to the U.S. Army for use in small arms ammunition. WECCO constructed a pilot plant I designed in 1943 in Los Angeles, California to produce KP and AP.

Vick Chemical Company constructed and operated a small AP plant in 1943 in Greensboro, North Carolina. The Cardox plants and the Vick plant were operated for a short time and were then shut down, and dismantled.

### Perchlorates for Solid Rocket Motors

I was working in my office at WECCO in Los Angeles, California on a quiet Saturday afternoon in December 1942 when I received a telephone call from a man who identified himself as Jack Parsons of the Guggenheim Aeronautics Laboratory at the California Institute of Technology in Pasadena, California (GALCIT). Mr. Parsons told me that GALCIT was working on a new classified military project that if successful would require very large quantities of perchlorates. He said he knew that WECCO was in commercial production of potassium chlorate and wanted to know if we would possibly be interested and capable of producing KP and other perchlorates for

GALCIT's research project. He went on to say that GALCIT was interested in developing a reliable domestic source of perchlorates. I told him that since producing perchlorates was part of our original business plan, we would be very interested in exploring the possibilities with GALCIT. Jack Parsons then invited me to attend a meeting in their office on Colorado Blvd. in Pasadena for further discussion on the following Monday morning.

I met Jack Parsons and others including Prof. Theodore Von Karman and Dr. Frank Molina in that meeting. After much discussion and many questions, it was decided that I should submit a proposal to design, construct and operate a small pilot plant to produce experimental quantities (100 to 200 lbs) of KP or AP as required by the GALCIT project.

Approximately one week later, as I recall, I submitted WECCO's proposal to the GALCIT group. WECCO proposed to perform the defined task during the next 6 to 12 months for the sum of \$20,000. After much discussion and many questions our proposal was verbally accepted. Professor Von Karman's presence, his questions and comments in these meetings, were very helpful to me and revealed his keen interest in this project.

#### The Agreement

Late in December 1942 the Air Corps Jet Propulsion Research Project (ACJP) and WECCO signed an agreement<sup>4</sup> to establish a source of supply of perchlorates in Los Angeles, California. WECCO designed and constructed a small pilot plant to produce experimental quantities of KP and/or AP as required by ACJP. The project was designated GALCIT Project No. 1.

The GALCIT project pilot plant was constructed during the next few months in space provided by WECCO within the building adjacent to their existing potassium chlorate plant. The pilot plant consisted of electrolytic cells and accessory equipment to produce sodium chlorate crystals, electrolytic cells and accessory equipment to produce a purified solution of sodium perchlorate, and process equipment to chemically convert sodium perchlorate into potassium or ammonium perchlorate (Figs. 3-6).

The pilot plant operated successfully for about four months. During this time several hundred pounds of KP and AP were produced and delivered to ACJP. The pilot plant was shut down after all objectives were accomplished. Soon afterward GALCIT decided to concentrate on KP as the preferred oxidizer for composite solid rocket propellants. However, interest in AP was maintained for future development.

GALCIT Project No.1 gave ACJP special perchlorates for their research with solid rocket propellants and gave WECCO valuable experience required to design a large-scale plant for KP production.

#### Los Angeles Potassium Perchlorate Plant

GALCIT Project No.1 was a prelude to the formation of Aerojet Engineering Corporation and large-scale commercial development of composite solid propellant rocket motors. The first application of these solid rocket motors was for military aircraft Jet-Assisted-Take-Off devices called "JATOs". The selection of KP as the oxidizer in JATO solid propellant created a new demand for KP that grew very rapidly. In mid 1943 DPC contracted with WECCO to construct and operate a manufacturing plant to produce KP at a rate of approximately 100 tons/month. As the oxidizer in solid rocket propellants, our product had to meet designated quality specifications.

The new plant<sup>5</sup> was constructed in a group of existing old industrial buildings in the city of Los Angeles, California (Figs. 6-10). Start-up of the plant began in January 1944. Product from the new plant was well received by manufacturers of solid rocket motors and demand continued to grow. Construction was begun later in 1944 to double the capacity of the plant to 200 tons/month.

#### New Opportunities in Henderson, Nevada

On a purely exploratory visit to the Basic Magnesium Inc. (BMI) magnesium metal manufacturing plant in Henderson, Nevada in June 1944 I had the good fortune to meet Dr. Harley Lee, Technical Director of BMI operations. Dr. Lee welcomed me and said my visit was very timely. He then related a brief history of their very large-scale electrochemical and electrothermal facilities and told me that since their goals for production of magnesium metal had been met, the plant was scheduled to be shut down. Dr. Lee went on to say that they were seeking possible alternative uses for their facilities. He arranged an impromptu meeting with his staff to provide an opportunity for exchanging ideas. After that meeting I was given a comprehensive conducted tour of certain sections of the plant. I was truly amazed especially to see 10 magnesium metal plant units in a row each designed to produce 15 tons of magnesium metal per day. All 10 units appeared to be of identical design and construction except for the electrical rectifier sections. Some were equipped with mercury

arc rectifiers and others with motor generator sets. I was deeply impressed with the high quality of the design, engineering and construction of these fine facilities and can recall visualizing at least one of those metal units converted into a chlorate and perchlorate manufacturing plant.

I returned to Los Angeles and immediately began to formulate a preliminary plan to convert one of the 10 magnesium metal production units into a chlorate-perchlorate manufacturing plant as I had envisioned it. Preliminary calculations indicated that one of the 10 units probably could be modified and converted to annual production of 15,000 tons of KP. I presented my preliminary plan to my business associate Kenneth Walsh and to the board of directors of WECCO. We received the board's approval to proceed with preparation of a definitive plan and a proposal to be presented to DPC and the Military Services for consideration.

Our proposal was presented to DPC in the latter part of 1944. We received notice of approval to proceed with detailed engineering and construction of a KP manufacturing facility for production at a rate of 1,200 tons/month. WECCO selected Bechtel-McCone of Los Angeles to engineer and construct the new plant.<sup>6</sup> Not long afterwards in my first meeting with him, Frank Case, General Manager of BMI, gave me the choice. I selected Metal Unit No. 4 as the location for the new perchlorate plant. I chose Unit No. 4 because it was equipped with Westinghouse mercury arc rectifiers and was centrally located in the complex. Modification of Unit 4 and construction of the new perchlorate plant<sup>6,7</sup> began in March 1945 and start-up began early in July 1945 (Figs. 11-13).

### Personnel

It was very fortunate that there was a large pool of experienced engineering, production and management personnel available to draw on when staffing the new Henderson perchlorate plant. These people had been employed by BMI and lived nearby in the town of Henderson, Nevada. Most of their families enjoyed living in that desert area which was an important factor contributing to the success of this project. J. Ray Coulter, an engineer with long experience in mining and metallurgy and the No. 3 man in BMI's management organization, was selected to be General Manager for WECCO's Henderson management organization. Mr. Coulter selected all of the 75 employees required to staff the operation. Fred D. Gibson, Sr., one of the original BMI group and WECCO's assistant General Manager, later replaced J Ray Coulter as General Manager of Nevada

Operations. All of the original staff contributed significantly to the success of our Henderson, Nevada operations.

### End of WWII - Plant Shutdown

WECCO received a telegram from the U. S. Government on August 13, 1945, the day after VJ Day, ordering us to shutdown the Henderson perchlorate plant. The plant had been in operation for about one month with barely enough time to demonstrate good performance. We were faced with an enormous problem (i.e., survival). It became necessary to immediately develop a plan to deal with the critical situation we faced.<sup>8</sup>

WECCO made a working arrangement with Reconstruction Finance (RFC) to recover all of the in-process chlorate and perchlorate products generated during the short period of start-up operations and to place the Henderson plant in a stand-by condition. WECCO made another working arrangement with RFC to continue operating the Los Angeles plant, with some modifications, to make it possible to produce sodium chlorate, potassium chlorate, and to test the post war market for these products. From August 15 to December 31, 1945, much to our surprise and relief, the market for our products increased substantially. In fact demand for our products exceeded production capacity of the Los Angeles plant.

### Post War Realignment and Consolidation

Previous experience following WWI showed that small domestic chlorate plants could not survive in a world market because of competition from large-scale, low-cost producers located in Europe. Therefore we knew that we had to obtain control of the plant we had constructed in Henderson, Nevada or establish a new one of at least the same size or we would eventually be forced out of business. Accordingly we worked out a plan to lease the Henderson plant facilities with an option to buy and submitted this plan as a proposal to the Reconstruction Finance Corporation (RFC) for consideration. When RFC accepted our proposal early in 1946, we took immediate action to implement our plan to modify the plant to produce and market sodium chlorate, potassium chlorate, sodium perchlorate, and potassium perchlorate. In the reorganization that followed all of WECCO's manufacturing operations were transferred to Henderson, Nevada. Research and Development operations were relocated in a new laboratory in Culver City, California; executive and Marketing offices were relocated in downtown Los Angeles and arrangements were made with DPC to

Production and sales of our products reached high levels in the late 1940s and our business began to show definite signs of survival and financial success.

#### AP Becomes The Preferred Oxidizer for Composite Solid Rocket Propellants

A new chapter in the history of WECCO began in 1950 when Aerojet, Thiokol and the US Navy informed us that military demand for AP could possibly grow to 50 tons/day or more in the near future. This renewed interest in AP caused us to begin an R&D project in our Culver City laboratory to design and develop a continuous process to produce AP at a rate of 50 tons/day. Details of the new process are described in a U.S. Patent No. 2,739,873 issued March 27, 1956.<sup>9</sup> One problem we were very concerned about in designing and engineering this new plant was safety. We were unable to find sufficient reliable information about safe handling and storage of large quantities of 50 tons or more of AP. We found it necessary to conduct experiments to determine sensitivity of AP to shock, heat and moisture as well as certain other basic characteristics. Results obtained from our research project<sup>10</sup> provided a sound basis for the design of the new large-scale plant.

#### Process Design and Engineering for a New AP Plant

WECCO signed a contract (NOAS51-1008) with the Bureau of Aeronautics of the U.S. Navy in 1950 to provide design criteria and process design for a new AP manufacturing plant to be constructed adjacent to our plant site in Henderson, Nevada. The new plant was designed for daily production capacity of 50 tons of AP crystals.

WECCO furnished basic design criteria and basic process design for the new AP plant. The Bechtel Corporation of Los Angeles and San Francisco furnished detailed process design and engineering. Haddock Engineers, Ltd. started construction of the new plant in 1952 on a plant site near WECCO's electrolytic sodium perchlorate plant and other electrolytic plants. Start-up of the new AP plant began in 1953. Production of AP at design capacity of 50 tons/day was successfully demonstrated within several months of operation. Thereafter the level of operation fluctuated depending on sales and market demand.

#### Major New Use for Sodium Chlorate Develops

Early in the 1950s Solvay Process Division of Allied Chemical Corp. introduced a new process for large-scale on-site generation of chlorine dioxide (ClO<sub>2</sub>) for use in bleaching wood pulp. This new bleaching

process became very successful. Its widespread use in the United States and Canada created a major new and expanding market for sodium chlorate (the starting material in the process of producing ClO<sub>2</sub>). This new market development gradually brought 100% utilization of WECCO's sodium chlorate plant capacity and discussions with Art Chadwick and Harold Merrit of Solvay Process Division of Allied Chemical about a merger of Solvay Division, American Potash and Chemical (AP&CC) and WECCO. Although the merger did not materialize, our discussions paved the way for other merger discussions with Peter Colefax, President of AP&CC. These discussions resulted in AP&CC's acquisition of about 48% of WECCO's stock in 1954 and 100% in 1955. After the merger, I became Vice President, Research of AP&CC, the surviving corporation.

#### More Expansion of AP Production Capacity and Competition

A new round of expansion AP production capacity was initiated in 1957 to meet projected requirements for new military solid rocket programs, including the ICBM and POLARIS missiles. As a result, the number of solid rocket propellant motor manufacturers increased from two to seven and the number of producers of AP increased from one to four. At this time AP&CC purchased the Henderson, Nevada AP plant constructed in 1952. Unfortunately, demand for AP did not increase as projected. In fact demand increased barely enough to exceed the capacity of AP&CC's Henderson plant. The net result was a large over-capacity for production of AP and the shutdown of Hooker and Foot's (HEF) joint venture plant located in Columbus, Mississippi and Penn Salt's plant in Portland, Oregon. There were now only two major domestic producers of AP: Kerr-McGee Chemical Corporation, the surviving company of the merger of Kerr-McGee Corporation and AP&CC in 1967, and Pacific Engineering and Production Company of Nevada which was founded by Fred D. Gibson, Sr. and other former employees of WECCO.

#### More Solid Rocket Motors

Late in the 1960s it appeared that demand for AP had peaked and would probably hold steady except in time of national emergencies. Then the Space Shuttle came along and changed the outlook again. The real stars of the space shuttle propulsion system are two solid rocket boosters which stand 115 feet tall and measure 12 feet in diameter. These boosters provide more than three fourths of the thrust necessary to lift the space shuttle during the 120 seconds they are fired. The three main engines burning liquid hydrogen and liquid

oxygen produce more than 1.1 million pounds of thrust at lift off. I am told that at full power this is the equivalent of 23 Hoover Dams. The two solid rocket boosters together provide an additional 5.8 million pounds of thrust needed to lift the 4.5-million pound space shuttle off the ground. Each booster is loaded with more than 1 million pounds of solid rocket propellant containing about 70% of AP. Therefore each flight of the space shuttle consumes about 1.5 million pounds of AP. I expect that AP will continue to be an important part of civilian and military programs involved with exploration and colonization of space for many years into the future. I know of no reason why AP production cannot keep pace with future demand whatever that may be.

### References

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3. Schumacher, Joseph C., "Ventures in Electrochemical Industry," *Journal of the Electrochemical Society*, Vol. 129, No.10, 1982, pp. 397C-403C.
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7. Schumacher, Joseph C., "Chlorates and Perchlorates," *Chemical Engineering Progress*, Vol. 43 No. 4, April 1947, pp.177-179.
8. Super Colossus, *Business Week*, Aug. 25, 1945. p. 32.
9. U.S. Patent No.2739873, (March 27, 1956), Process for Making Ammonium Perchlorate, Schumacher, Joseph C.
10. Schumacher, Joseph C., and Stern David R., "Large-Scale Continuous Production of Ammonium Perchlorate," *Chemical Engineering Progress*, Vol. 53 No. 9, 1957, pp. 428-432.

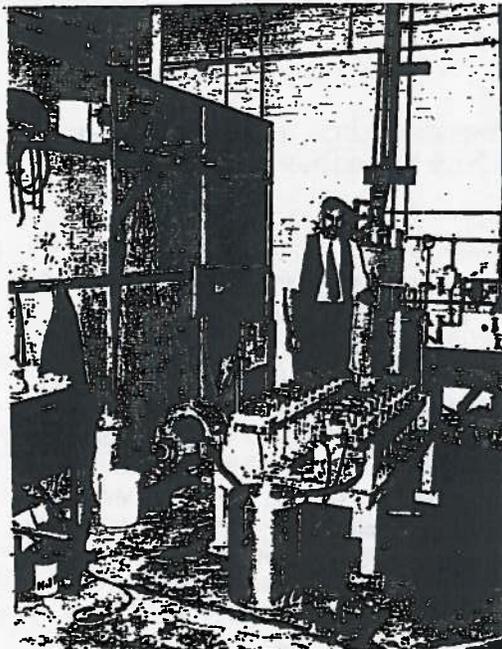


Figure 1. KClO<sub>3</sub> Pilot Plant

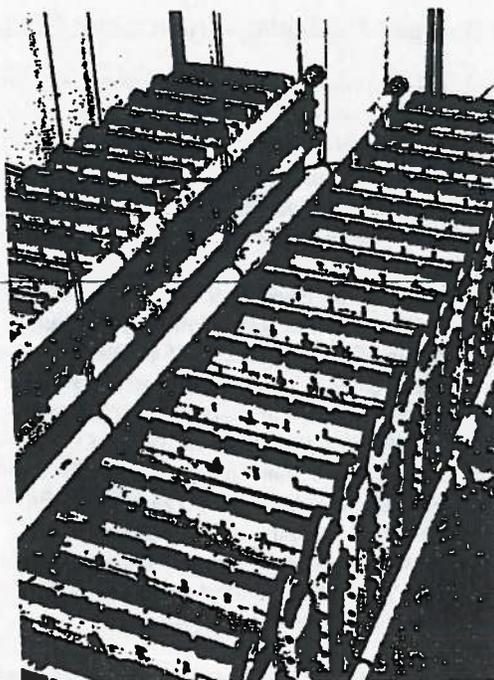
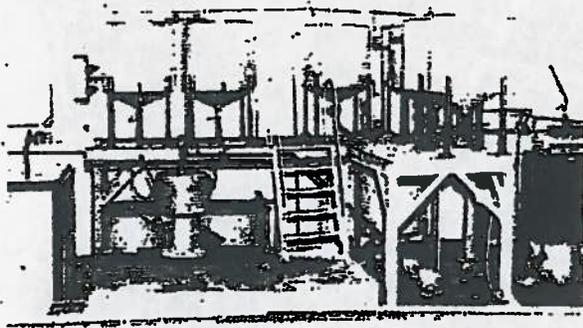
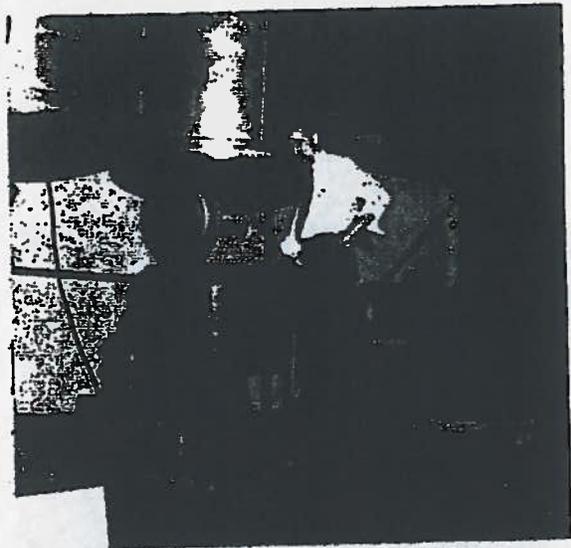


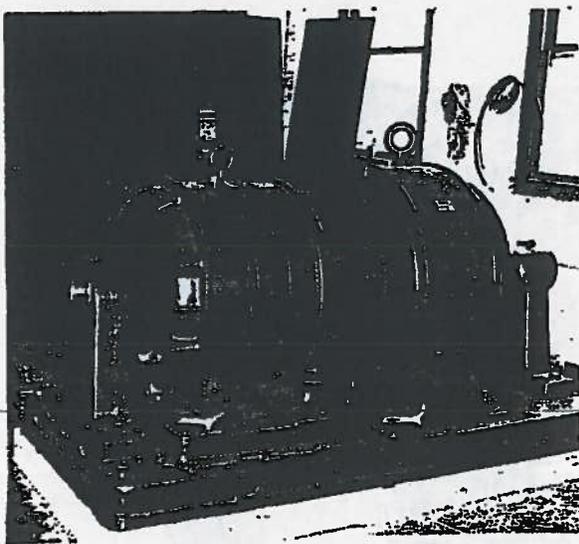
Figure 2. Los Angeles KClO<sub>3</sub> Production Plant  
800 Amp Electrolytic Cells



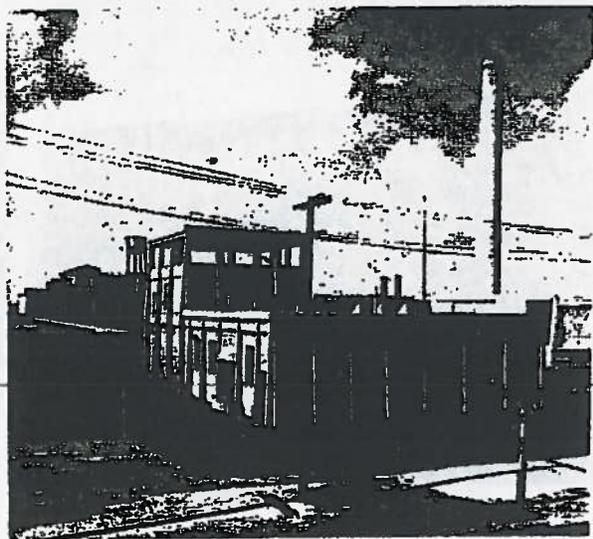
**Figure 3. Los Angeles Potassium and Ammonium Perchlorate Pilot Plant**



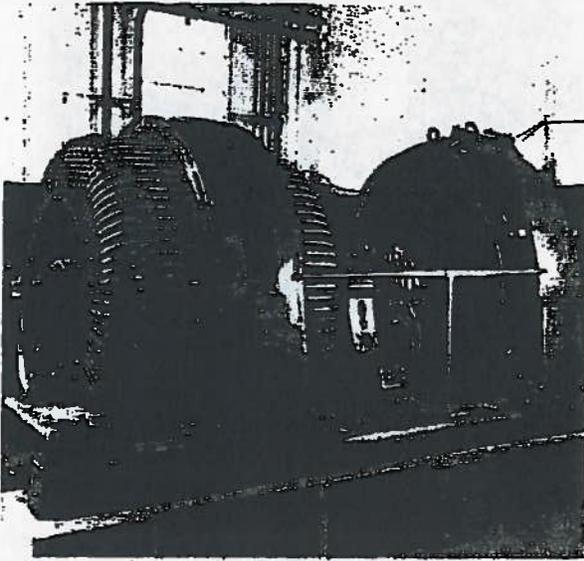
**Figure 5. Los Angeles  $KClO_3$  Plant Crystallizers and Centrifuge**



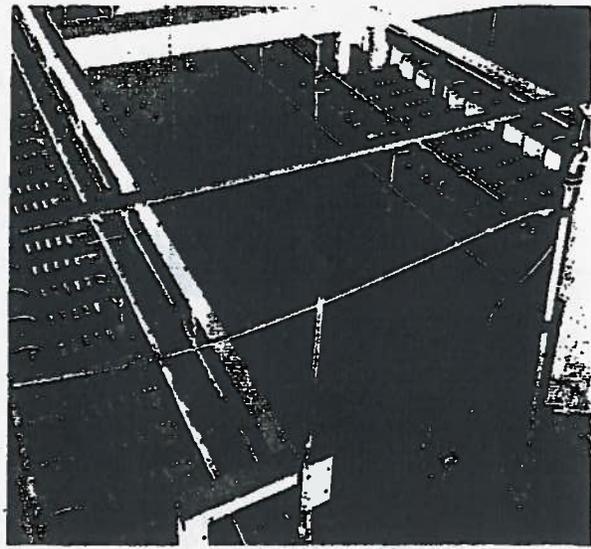
**Figure 4. Los Angeles  $KClO_3$  Plant Motor-Generator Set**



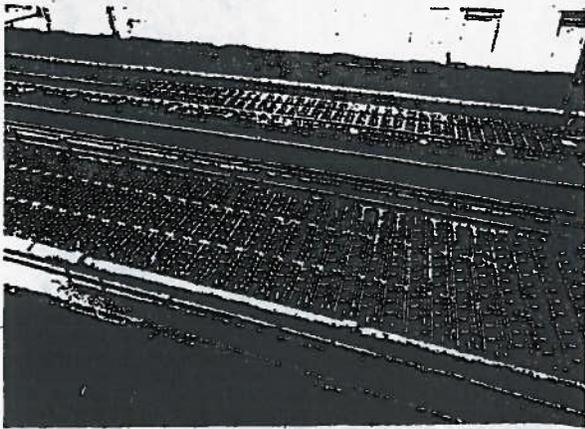
**Figure 6. Los Angeles Potassium Perchlorate Plant**



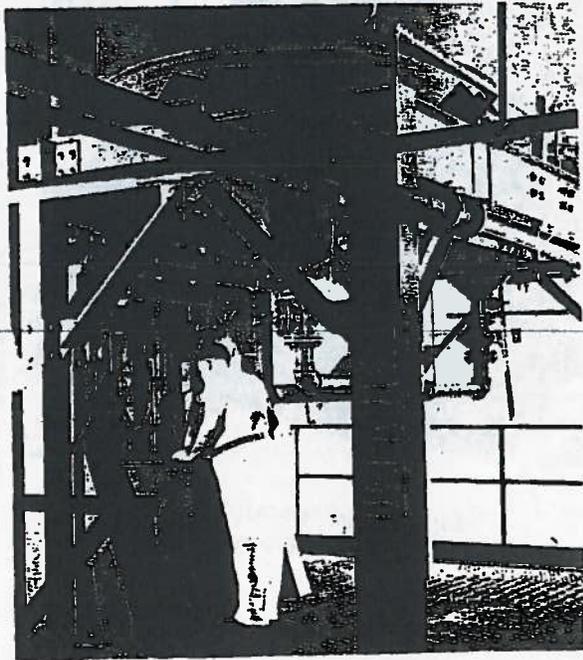
**Figure 7. Los Angeles  $KClO_4$  Plant  
Motor-Generator Set**



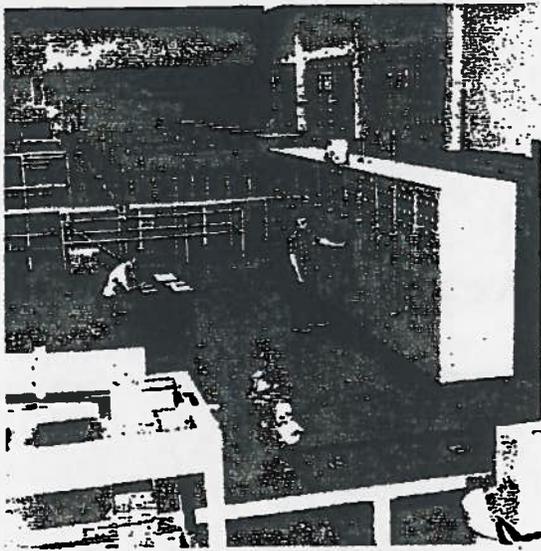
**Figure 9. Los Angeles  $KClO_4$  Plant  
Sodium Perchlorate Cells 2500 Amps**



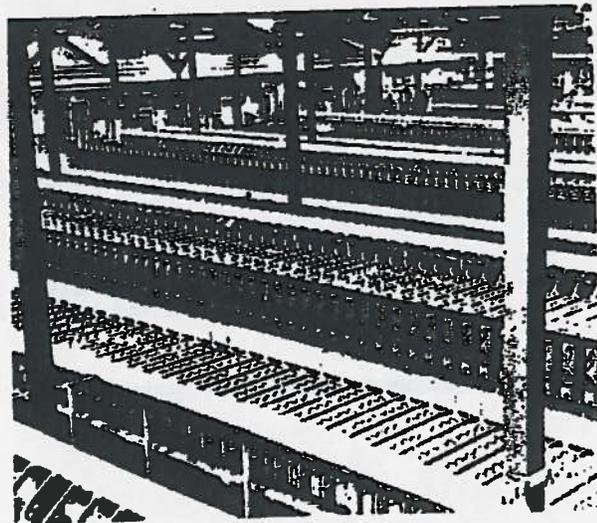
**Figure 8. Los Angeles  $KClO_4$  Plant  
 $NaClO_3$  Cells - 2500 Amps**



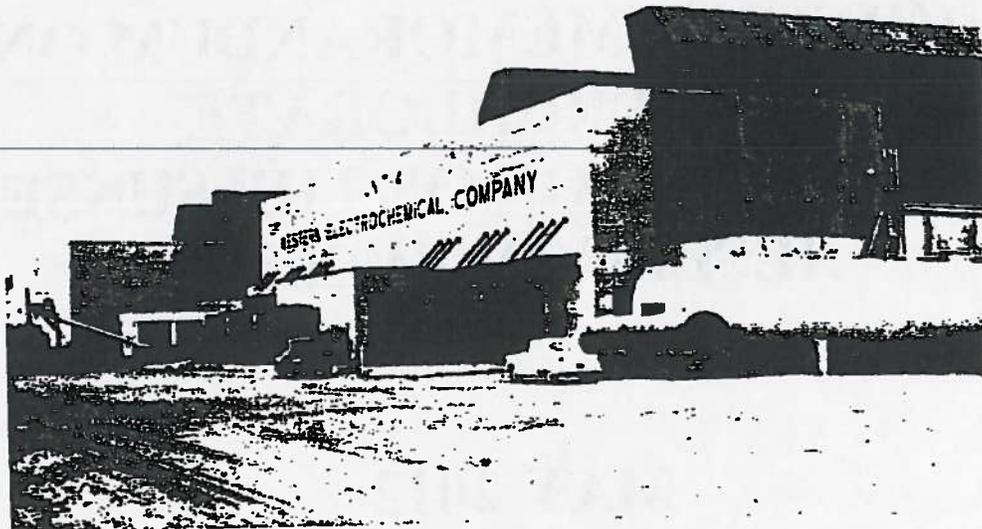
**Figure 10. Los Angeles  $KClO_4$  Plant  
Processing Equipment**



**Figure 11. Mercury Arc Rectifiers and Controls  
Henderson, Nevada Plant**



**Figure 12. WECCO Henderson, Nevada KClO<sub>4</sub> Plant  
5000 Amp Electrolytic Chlorate and Perchlorate  
Cell Room**



**Figure 13. WECCO Henderson, Nevada Perchlorate  
Plant Transformer Substation**



P A S A D E N A  
Water & Power

**APPENDIX C  
TO THE  
TECHNICAL MEMORANDUM ON  
THE PERCHLORATE  
CONTAMINATION OF THE SUNSET  
RESERVOIR WELLS**

**MAY 2012**

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**PJB LABORATORIES**  
ANALYTICAL CHEMICAL SERVICES

*LHB*

October 27, 1980

City of Pasadena  
311 W. Mountain Street  
Pasadena, California 91103

Lab No. P80-10-135

P. O. No. 83999

Attention: Joe Mulvihill

Report of Trichloroethylene Analysis

The following analytical results are for eight (8) samples of well water received by this laboratory on October 14, 1980. The sample was analyzed for trichloroethylene (TCE) and carbon tetrachloride by gas chromatograph using a liquid/liquid extraction procedure.

<u>Sample Identification</u>	<u>Carbon Tetrachloride</u>	<u>Trichloroethylene (TCE) ug/l (ppb)</u>
1. Copelin Well	< 0.2	< 0.2
2. Windsor Reservoir	4.4	4.9 ✓
3. Arroyo Well	5.4	13 ✓
4. Windsor Well	< 0.2	< 0.2
5. Woodbury Well	0.8	< 0.2
6. Garfield Well	< 0.2	< 0.2
<i>FILE</i> - 7. <u>Eaton Well</u>	< 0.2	< 0.2
8. Chapman Well	< 0.2	< 0.2

Respectfully submitted,

*Michael A. Geoffroy*

Michael A. Geoffroy  
Laboratory Director

fmc

Invoice 16472 separate cover

MONTGOMERY LABORATORIES  
 a division of James M. Montgomery, Consulting Engineers, Inc.  
 555 East Walnut Street, Pasadena, California 91101  
 (818) 796-9141 / (213) 681-4255 Telex 67-5420

Report of Liquid/Liquid Extraction Analysis for  
 CHLORINATED ORGANIC SOLVENTS

Pasadena, City of  
 Water Department  
 150 S. Los Robles, Suite 202  
 Pasadena, CA 91101  
 Attn: Brad Boman

Job#: 437.0810  
 PO#:   
 Workorder#: W18929  
 Report#: R79816  
 Phone #: 818-405-4630

Date Sampled: 9/14/88  
 Date Extracted: 9/16/88

Date Received: 9/14/88  
 Date Analyzed: 9/20/88

Lab#	Sample I.D.	CCl4 ug/l	TCE ug/l	PCE ug/l	TCA ug/l
I98173	WINDSOR WELL	1.3	2.8	1.3	<0.5
I98174	EATON WELL	<0.5	<0.5	<0.1	<0.5
I98175	GARFIELD WELL	<0.5	<0.5	<0.1	<0.5
I98176	WOODBURY WELL	<0.5	<0.5	<0.1	<0.5
I98177	COPELIN WELL	<0.5	<0.5	0.3	<0.5
I98178	CRAIG WELL	0.9	<0.5	<0.1	<0.5
I98179	SUNSET WELL	<0.5	0.7	0.6	<0.5
I98180	VILLA WELL	<0.5	<0.5	<0.1	<0.5

CCl4: Carbon Tetrachloride  
 TCE : Trichloroethene (Trichloroethylene)  
 PCE : Tetrachloroethene  
 TCA : 1,1,1-Trichloroethane

Minimum detection limit: PCE = 0.1 ug/l; TCE, CCl4, TCA = 0.5 ug/l  
 NA: Not analyzed

Approved by

*Charles J. Long*

APPROVED

SEP 23 1988

QC OFFICER

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 555 East Walnut Street, Pasadena, California 91101  
 (818) 796-9141 / (213) 681-4255 Telex 67-5420

Report of GC/MS Analysis for  
 VOLATILE ORGANIC COMPOUNDS  
 in Water

Pasadena, City of  
 Water Department  
 150 S. Los Robles, Suite 202  
 Pasadena, CA 91101  
 Attn: Brad Boman

Job#: 437.0810  
 PO#:   
 Workorder#: W21011  
 Report#: R88012  
 Phone #: 818-405-4630

Date Sampled: 2/8/89  
 Date Analyzed: 2/13/89

Date Received: 2/8/89

Lab Number:  
 Sample I.D.:

J21298  
 VILLA WELL

Compound	Concentration (micrograms/liter)	Detection Limit (micrograms/liter)
----------	-------------------------------------	---------------------------------------

VOLATILE PRIORITY POLLUTANTS:

Carbon Tetrachloride	0.1	0.10
1,2-Dichloroethane	ND	0.10
1,1,2-Trichloroethane	ND	0.10
Vinyl Chloride	ND	1.0
1,4-Dichlorobenzene	ND	0.50

ND: Not Detected  
 NA: Not Analyzed

Approved by Carole G. Hong

APPROVED  
 FEB 15 1989  
 QC OFFICER

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a division of James M. Montgomery, Consulting Engineers, Inc.  
555 East Walnut Street, Pasadena, California 91101  
(818) 796-9141 / (213) 681-4255 Telex 67-5420

Report of GC/MS Analysis for  
VOLATILE ORGANIC COMPOUNDS  
in Water

Pasadena, City of  
Water Department  
150 S. Los Robles, Suite 202  
Pasadena, CA 91101  
Attn: Brad Boman

Job#: 437.0810  
PO#:   
Workorder#: W21011  
Report#: R88014  
Phone #: 818-405-4630

Date Sampled: 2/8/89  
Date Analyzed: 2/13/89

Date Received: 2/8/89

Lab Number:  
Sample I.D.:

J21300  
CRAIG WELL

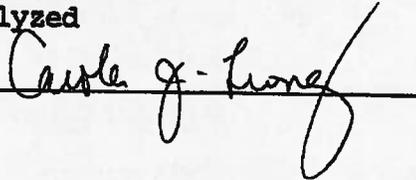
Compound	Concentration (micrograms/liter)	Detection Limit (micrograms/liter)
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VOLATILE PRIORITY POLLUTANTS:

Carbon Tetrachloride	0.3	0.10
1,2-Dichloroethane	ND	0.10
1,1,2-Trichloroethane	ND	0.10
Vinyl Chloride	ND	1.0
1,4-Dichlorobenzene	ND	0.50

ND: Not Detected  
NA: Not Analyzed

Approved by



APPROVED

FEB 15 1989

QC OFFICER