PASADENA WATER AND POWER

June 5, 2007

Mr. Steven Slaten
NASA Remedial Project Manager
JPL CERCLA Program
4800 Oak Grove Drive
Pasadena, California 91109

SUBJECT: National Aeronautics and Space Administration (NASA), Jet Propulsion Laboratory (JPL) Technical Memorandum (TM): Additional Investigation Results, January 31, 2007

Dear Mr. Slaten:

Pasadena Water and Power (PWP) retained the services of Geoscience Support Services Inc. (Geoscience) to assist in the review of the subject document. Geoscience provides strong arguments that question the analysis performed and conclusions submitted by NASA. Therefore, PWP disputes NASA's conclusion that the perchlorate impacting the Sunset Wells is not migrating from JPL. Attached is a copy of Geoscience's report. This letter, along with the attached report, constitutes the comments of PWP on the TM.

Geoscience was instructed to evaluate the TM and to determine the soundness of the rationale for the scientific and engineering analysis performed, if the data were applied and interpreted correctly and used accurately, and if the stated conclusions were supported by the analysis and findings.

The findings of Geoscience do not support NASA's conclusion that the perchlorate captured by the Sunset wells is from a source different than that originating from JPL. In its report, Geoscience challenges NASA's approach, analysis, and conclusions on each of the four scientific tools applied: Groundwater Modeling, Groundwater Geochemistry, Groundwater Chemical Concentrations, and Perchlorate Isotope Analysis. For specific details, please refer to the report.

PWP respectfully requests that NASA respond accordingly to each of the points made by Geoscience. PWP welcomes the opportunity to have an open discussion with NASA on the findings of Geoscience.

If you have any questions or need additional information please contact Mr. Shan Kwan, Business Unit Director, Water Services Division at (626) 744-4416 or by e-mail at skwan@cityofpasadena.net.

Sincerely,

Phyllis E. Currie
General Manager
Pasadena Water and Power

RK/hs

Attachment

c: Mr. Lewis Mitani, U.S. Environmental Protection Agency, Region 9
Mr. Michael Iskarous, California Environmental Protection Agency
Mr. Mohammad Zaidi, Regional Water Quality Control Board, Los Angeles Region
Mr. Jeff O'Keefe, California Department of Health Services
Mr. Tony Zampiello, Raymond Basin Management Board
Mr. Jeffrey Kightlinger, Metropolitan Water District of Southern California
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Review and Comments of NASA's Jet Propulsion Laboratory 31-Jan-07 Technical Memorandum: Additional Investigation Results

Prepared for: Pasadena Water and Power

June 1, 2007

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REVIEW AND COMMENTS OF NASA'S 31-JAN-07 JET PROPULSION LABORATORY TECHNICAL MEMORANDUM: ADDITIONAL INVESTIGATION RESULTS

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REVIEW AND COMMENTS OF NASA'S 31-JAN-07 JET PROPULSION LABORATORY TECHNICAL MEMORANDUM: ADDITIONAL INVESTIGATION RESULTS

1.0 EXECUTIVE SUMMARY

This report presents comments relating to a review of the Technical Memorandum: *Additional Investigation Results*, prepared by National Aeronautics and Space Administration (NASA) for the Jet Propulsion Laboratory (JPL), dated January 31, 2007. Essentially, the Technical Memorandum concluded that perchlorate originating from the JPL facility was not responsible for impacting the City of Pasadena Sunset Reservoir wells.

GEOSCIENCE's scope included reviewing the NASA technical memorandum (TM), and the criteria and methodologies used in the various analyses supporting their conclusions. Specifically, the quality and accuracy of data were evaluated as related to the conclusions made on geochemistry, ground water chemistry and isotopes analyses. In addition, historical water quality data for various City of Pasadena wells were compiled from hard copy records and electronic sources provided by the City. The Raymond Basin Ground Water Flow Model was used to examine the movement of ground water in the vicinity of the JPL facility using "back tracking" of water particles.

A summary of GEOSCIENCE's comments relating to the NASA TM's four main points are included in the following subsections.

1.1 Ground Water Modeling

- The NASA TM used a future pumping scenario instead of historical pumping to make conclusions regarding movement of contaminated ground water in the Monk Hill subarea.
- Particle tracking using historical data show ground water pathways from the JPL facility to the Sunset Reservoir wells.
- Particle tracking models do not take into account hydrodynamic dispersion (i.e., spreading of plumes).
- The southern limit of JPL's perchlorate plume has not been adequately characterized.

1.2 Ground Water Geochemistry

- The NASA TM does not adequately characterize the anion and cation constituents of imported water used in the Raymond Basin, or take into account the blend of waters from the Weymouth and Jensen Plants.
- The NASA TM claims of imported water impacts on ambient water quality are not supported by data.
- The NASA TM does not take into account vertical variations of water quality in the aquifer system.
- Anions and cations for Valley Water Company wells contradict NASA's TM water types.
- There are no consistent trends in sulfate concentration in the Sunset Reservoir and Valley Water Company wells that show an increase related to importation of Colorado River water.
- The results from $\delta^{18}O/\delta^{2}H$ isotopes are inconsistent with regards to classification of water types.
- Use of tritium isotopes contradict classifications by other methods.
- The NASA TM data on strontium isotopes shows a wide range of values that are not conclusive.

1.3 Ground Water Chemical Concentrations

- The NASA TM conclusions regarding the association of carbon tetrachloride and perchlorate are not supported by data, and do not take into account the different fate and transport of the two chemicals.
- The NASA TM does not correctly estimate the amount of Colorado River water imported into the Raymond Basin, as it does not take into account the blend of water from both the Jensen and Weymouth Plants.
- The NASA TM findings inferring Colorado River water is responsible for Sunset Reservoir wells' perchlorate is flawed, as the concentrations found in ground water are at least an order of magnitude higher than in the Colorado River water.

1.4 Perchlorate Isotopes

- The NASA TM did not measure the isotopic signature of perchlorate in imported water from MWD; and did not measure the isotopic signature of the perchlorate source material responsible for ground water contamination in the JPL area.
- Water quality data and functional genomic testing do not support the statement that "perchlorate degradation is likely not occurring at the site". The water quality data presented in the TM provides evidence that perchlorate biodegradation is occurring (i.e., reducing conditions).
- The stable isotope method for perchlorate has only been applied for distinguishing between natural and anthropogenic perchlorate sources. The presence of localized regions of biodegradation introduces a component, which makes distinguishing isotopic signatures from different anthropogenic perchlorate sources substantially more complex than distinguishing between a natural source and an anthropogenic source.
- There are several method and quality control shortcomings in the water quality data (e.g., detection levels too high, anomalous dissolved organic carbon data, conductivity values not corresponding with total dissolved solid concentrations, anomalous organic nitrogen results).
- The study does not provide adequate support for the analytical error associated with the stable perchlorate isotope method, and the study did not conduct replicate sampling.

2.0 INTRODUCTION

2.1 Purpose and Scope

At the request of the City of Pasadena (City), GEOSCIENCE Support Services, Inc. has conducted a review and provided comments on the January 31, 2007 Technical Memorandum entitled *Additional Investigation Results*, prepared by National Aeronautics and Space Administration (NASA) for the Jet Propulsion Laboratory (JPL). The Additional Investigation was performed as part of NASA's Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) program for JPL.

The scope of work included reviewing the NASA technical memorandum (TM), and the criteria and methodologies used in the various analyses supporting their conclusions. Specifically, the quality and accuracy of data were evaluated as related to the conclusions made on geochemistry, ground water chemistry and isotopes analyses. In addition, historical water quality data for various City wells were compiled from hard copy records and electronic sources provided by the City. The Raymond Basin Ground Water Flow Model was used to examine the movement of ground water in the vicinity of the JPL facility using "back tracking" of water particles.

2.2 Background

The JPL facility was developed and operated by the United States Army between 1945 and 1957, with jurisdiction transferred to NASA in 1958 (see Figure 1 for facility location). The EPA's site narrative on JPL states that:

> *"among the sources of hazardous substances at the site are numerous seepage pits, where liquid and solid wastes were reportedly disposed of; a "settling" chamber in the JPL storm drain system; contaminated soil excavated from part of the system; and an area where waste solvents were dumped into three holes. The general types of hazardous substances at JPL, now and in the past, include waste solvents such as tetrachloroethene*

(PCE), solid rocket fuel propellants [including perchlorate], cooling tower chemicals, sulfuric acid, Freon, mercury, and chemical laboratory wastes".

In 1990, contractors for JPL detected significantly elevated levels of carbon tetrachloride, trichloroethene, PCE, and other volatile organic compounds (VOCs) in ground water both under and hydraulically downgradient of the facility. Four City of Pasadena wells in the Monk Hill subarea were shut down due to VOC contamination attributable to JPL: Arroyo Well and Well 52 stopped contributing to the distribution system in June 1985 and January 1986, consecutively; and Windsor Well and Ventura Well were shut down after February and April 1989, consecutively (see Figure 1 for well locations). A treatment plant consisting of air stripping was installed in 1990 by NASA to treat ground water from the four City wells, and production resumed again in September 1990. In addition, two Lincoln Avenue Water Company wells (Well No. 3 and Well No. 5) were shut down in 1987 due to VOCs attributable to JPL. A NASA funded granular activated carbon plant to treat ground water pumped from these wells was installed in 1992.

Prior to 1997, perchlorate had not been detected at low concentrations in ground water anywhere in the United States because an analytical method did not exist yet to detect perchlorate at low enough concentrations. In 1997, an improved perchlorate detection method was developed that was sensitive to 4 µg/L. The California Department of Health Services then directed the sampling and testing of drinking water wells, at this level, throughout California. Since that time, perchlorate has been detected in ground water in the Monk Hill subarea and portions of the Pasadena subarea (see Figure 1). In 2004, NASA installed an ion exchange plant to treat Lincoln Avenue Water Company's Well No. 3 and Well No. 5. NASA and the City of Pasadena are presently preparing a preliminary engineering evaluation and cost analysis for perchlorate treatment at the City of Pasadena Wells: Arroyo Well, Well 52, Ventura Well, and Windsor Well.

In the Pasadena subarea, there is a group of five wells near the Sunset Reservoir (Sunset, Bangham, Copelin, Villa and Garfield) that have also been impacted by perchlorate (see Figure 1). NASA's TM was prepared to (1) evaluate the downgradient (southern) extent of chemicals originating from the JPL facility, and (2) determine if the occurrence of perchlorate in the Sunset Reservoir area ground water was associated with migration from the JPL facility.

2.3 Structure of Review and Comments Provided in this Report

The review and comments in this report are organized into the same four main sections in NASA's TM, namely:

1. Ground water modeling,
2. Ground water geochemistry,
3. Ground water chemical concentrations, and
4. Perchlorate isotope analysis.

For each of the four main sections, a brief summary of the NASA TM findings and conclusions are presented followed by GEOSCIENCE's comments. Supporting figures are attached at the end of this report.

3.0 GROUND WATER MODELING

3.1 NASA Technical Memorandum Summary

Two models were cited by NASA in drawing their conclusion that:

"dissolved perchlorate originating from JPL would be contained by the production wells located in the Monk Hill subarea and not migrate to the Sunset Reservoir Wells".

The models cited are:

1. Raymond Basin Management Board's (RBMB) ground water flow model of the Raymond Basin was developed as a regional management tool for predictive analyses of potential changes in ground water levels and movement of contaminated ground water based on various conjunctive use scenarios (GEOSCIENCE, 2005b). The RBMB ground water model covers the entire Raymond Basin and is a finite difference, two-layered, transient ground water flow model with monthly stress periods. The model uses the USGS model code MODFLOW and has particle tracking (MODPATH) capabilities. See Figure 1 for the model boundary location. Steady-state calibration was carried out for 1980, and transient calibration from 1981 to 2002. The predictive model was developed for the period 2003 to 2024.

2. NASA's JPL ground water flow model was developed to evaluate the potential fate and transport issues related to the chemicals in the ground water, and to develop site remediation strategies for both on-facility and off-facility ground water (NASA, 2003). This localized FEFLOW four-layered model was developed as both a steady-state and transient model that uses average fluxes over the simulation period (see Figure 1 for model boundary). Transient calibration was based on the average recharge conditions and water levels for water years[1] 1996/97 through 1999/00. As the ground water flow field produced by the steady-state model was similar to that produced by the transient

[1] Water year starts on October 1, and ends on September 30.

model, the steady-state model was determined by NASA to be appropriate for use in predictive simulations (NASA, 2003).

Based on particle tracking results from the two above models, the TM asserts that:

"particles released in the vicinity of JPL would not migrate downgradient to the Sunset Reservoir wells. Rather they would be captured by extraction wells in the Monk Hill subarea".

3.2 GEOSCIENCE Comments on Ground Water Modeling

3.2.1 Comment 1: The NASA TM used a future pumping scenario instead of historical pumping to make conclusions regarding movement of contaminated ground water in the Monk Hill subarea.

The NASA TM includes one of the figures used in the Raymond Basin Ground Water Flow Model Predictive Simulations report (GEOSCIENCE, 2005b) that depicts particle tracking from production wells (see NASA TM Figures 2 and 3). However, the NASA TM failed to mention that these particles represent the capture zones of production wells tracked backwards for a future scenario (2024 to 2003). The particle tracks referenced by NASA's TM referred to a model scenario which assumed the amount of artificial recharge, natural recharge, injection and underflow would be the same as the historical period 1981 to 2002. The amount of production for the scenario was equal to the amount pumped in 2003, with the addition of 5,600 acre-ft/year to be pumped from two City of Pasadena wells near the Arroyo Seco (Well 52 and Windsor Well). This future pumping (2003-2024) is different from historical pumping (1981-2002) and as such, ground water elevations, direction and rates of ground water flow are also different. Therefore, the particle tracks shown in these figures are predictive and not representative of historical ground water movement and historical movement of contaminants in the Basin.

Backward particle tracking which defines well capture zones from 1980 to 2002 are shown on Figure 2. This figure clearly shows that particle tracks originating from the Sunset Reservoir

wells backtrack to the JPL source area, thus the well capture zones include water contaminated by the JPL facility. This was verified by examining the individual capture zones for the Sunset Reservoir wells. The differences in the Sunset reservoir wells' capture zones for the future scenario (2003-2024) and the historical period (1980-2002) are due to differences in production rates and timing.

3.2.2 Comment 2: Particle tracking models do not take into account hydrodynamic dispersion (i.e., spreading of plumes)

NASA's TM particle tracking (TM Figures 2, 3 and 4) are used to conclude that all perchlorate originating from the JPL facility would be contained by the production wells located in the Monk Hill subarea. This is misleading as particle tracking models do not account for hydrodynamic dispersion (i.e., longitudinal and transverse spreading of plumes). This was recognized in GEOSCIENCE's (2005b) report:

> *"A limitation associated with the use of particle tracking in water quality applications is that as particle tracking only simulated the advective transport of water particles, transport of contaminants with different properties than water cannot be accurately tracked. It must be understood that the transport of contaminants will usually be slower than the transport of water due to factors such as dispersivity, retardation and biodegradation. In order to more accurately determine concentration and fate of the contaminants over time, a solute transport model would need to be developed."*

If a solute transport model was used, it would show a larger footprint of the contaminant plumes (due to hydrodynamic dispersion and other transport parameters) than contaminated ground water movement defined by particle tracking of the wells' capture zones alone.

3.2.3 Comment 3: The southern limit of JPL's perchlorate plume is not adequately characterized.

It is likely that the perchlorate plume at some time after 1941 (when perchlorate was first used at JPL) may have extended off-site south of the JPL property boundary. The perchlorate plume depicted in 2006 by JPL is shown to extend off-site in a south to southwesterly direction towards MW-21 (see Figure 4; NASA, 2006). The southernmost on-site JPL monitoring wells (MW-5 and MW-10) are shallow, and both have had historical measurements of perchlorate greater than 25 μg/L and as high as 110 μg/L in the case of MW-10. The closest southern off-site monitoring well is the multi-level well MW-21, which was installed in 1995, and is located over 1,500 ft south of the JPL facility boundary. Due to the lack of perchlorate data between MW-10 and MW-21 (see Figure 4), there is uncertainty as to where the southern extent of the JPL perchlorate plume is currently or has been in the past. Based on these observations, the JPL perchlorate plume in this southern area has not been adequately characterized.

Given the uncertainty due to data gaps between monitoring wells, there is a possibility that a perchlorate plume extending south of the JPL facility could have intersected the capture zones of the Sunset Reservoir wells (see Figure 2). Movement of the perchlorate plume towards MW-21 is possible due to the fact that MW-21 lies within the alluvial channel of the Arroyo Seco, which may be a preferential flow path for ground water.

4.0 GROUND WATER GEOCHEMISTRY

4.1 NASA Technical Memorandum Summary on Anions and Cation Geochemistry

Plotting the anions and cations of groundwater from production wells and monitoring wells on trilinear (or piper) diagrams shows that there are three different types of water in the Monk Hill subarea.

1. Type 1 – Native Ground Water (calcium-bicarbonate type)
2. Type 2 – Deep (Older) Ground Water (Sodium-bicarbonate type)
3. Type 3 – Ground Water Influenced by Colorado River Water (Calcium-bicarbonate/chloride/sulfate type)

Type 3 is most prevalent in wells located cross-gradient, upgradient and south of the JPL facility, as well as near Sunset Reservoir. The NASA TM states that:

> *"Geochemical analysis indicates that Type 3 water is created by ion exchange of imported Colorado River water as it passes through the subsurface soil. This results in water becoming enriched in calcium (primarily) and magnesium (i.e., calcium and magnesium are released from the soil), and depleted in sodium (primarily) and potassium (i.e., sodium and potassium are preferentially sorbed onto soil). Because only cations are affected by this process, sulfate and chloride, which are elevated in the river water, migrate to the aquifer where they contribute to the overall increase in TDS. The bicarbonate concentration may actually decrease somewhat, due to precipitation of calcium carbonate (calcite)."*

Additionally, some of the wells demonstrate the influence of Colorado River water on the ground water. For example, a number of wells have migrated from a Type 1 to a Type 3 ground water, e.g., Sunset Well (NASA TM Figure 7).

4.2 GEOSCIENCE Comments on Anions and Cation Geochemistry

4.2.1 Comment 1: The NASA TM does not adequately characterize chemical constituents of imported water used in the Raymond Basin

NASA's TM defines Type 3 waters as water influenced by imported Colorado River Water; however, water imported into the Raymond Basin is a blend of water from the Colorado River and water from the Sacramento-San Joaquin Delta (California State Project Water). The TM does not:

a. List the water quality concentrations used to define cation/anion composition of water imported into the Raymond Basin
b. Plot a range of imported water quality, which varies seasonally and as a function of the blend percentage of Colorado and State Project water sources.

4.2.2 Comment 2: The NASA TM claims of imported water impacts on ambient water quality are not supported by data

Enrichment of Colorado River water blends with respect to calcium, which causes an increase in the overall TDS, is not supported by any analytical data in the TM. The TM indicates calcium is leaching from soils and aquifer material. Moreover, statements made in the TM with respect to the geochemical transformation of imported water are not supported by the data, as there is no observational justification that TDS concentrations will increase due to calcium leaching and associated sodium and potassium adsorption.

4.2.3 Comment 3: The NASA TM does not take into account vertical variations of water quality

JPL off-site monitoring wells MW-17 through MW-21 (see Figure 3) are screened at varying depths ranging from shallow (less than 100 ft below ground surface) to deep (greater than 700 ft below ground surface) and the production wells in the Sunset Reservoir area are also screened at multiple intervals of several hundreds of feet. NASA's TM does not distinguish between

different water compositions at varying depths within either the monitoring wells or production wells in the Sunset Reservoir area.

4.2.4 Comment 4: Valley Water Company wells contradict NASA's TM water types

The Valley Water Company wells which have certainly been impacted by imported water due to injection of MWD water in Wells 2 and 3 since 1994, do not show evolution of water types as seen in the Sunset Well (see NASA TM Attachment 2 showing piper diagrams for VWC-1 through VWC-4). These figures show that the water type prior to the start of injection is not markedly different from the water type after injection.

4.3 NASA Technical Memorandum Summary on Sulfate

The NASA TM states that sulfate concentrations have increased significantly in the Raymond Basin over the past 50 years. They consider sulfate to be a reliable chemical tracer associated with water imported into the Basin from the Colorado River.

4.4 GEOSCIENCE Comments on Sulfate: There are no consistent trends in sulfate concentration in the Sunset Reservoir and Valley Water Company wells

It is agreed that sulfate in the Basin has increased in some areas, possibly due to the importation of Colorado River Water and recharged as return flow including septic tank discharge in unsewered areas. Also, in the Sunset Reservoir and Valley Water Company wells, historical sulfate trends show a range of increases, no changes and decreases as shown in Figures 5 – 31, and summarized in Table 1.

Table 1. Summary of Trends of Selected Constituents in Sunset Reservoir and Valley Water Company Wells

Well	Location Relative to JPL Facility	Injection and Period of Injection	1980 - 2007			1997 - 2007	Report Figures
			Sulfate Trend	Chloride Trend	Total Dissolved Solids Trend	Perchlorate Trend	
P-SUN (Sunset)	downgradient	next to P-BAN	+	+	+	+	5, 14, 23, 32
P-BAN (Bangham)	downgradient	Sep-93	+	+	+	+	6, 15, 24, 33
P-COP (Copelin)	downgradient	next to P-BAN	O	O	O	+	7, 16, 25, 34
P-VIL (Villa)	downgradient	next to P-GAR	O	O	–	+	8, 17, 26, 35
P-GAR (Garfield)	downgradient	Oct-92 to Nov-93	+	O	O	+	9, 18, 27, 36
VWC-1	upgradient	next to VWC-2	+	+	–	O	10, 19, 28, 37
VWC-2	upgradient	Jul-94 to present	–	–	–	O	11, 20, 29, 38
VWC-3	upgradient	Jan-97 to Nov-99 infrequent	+	+	+	O	12, 21, 30, 39
VWC-4	upgradient	next to VWC-2	+	O	O	O	13, 22, 31, 40

Notes: "+" indicates a historical increase in concentrations
"O" indicates no appreciable change in concentrations
"-" indicates a historical decrease in concentrations

4.5 NASA Technical Memorandum Summary on $\delta^{18}O/\delta^{2}H$ Isotopes

Isotope analyses were performed on water samples from the following wells:

- Pasadena Wells: Garfield, Sunset, Bangham
- Las Flores Water Company Well 2
- Lincoln Avenue Water Company Well 3
- JPL monitoring wells: MW-1, MW-21, MW-20, MW-17, MW-25, MW-19, MW-18, and MW-24

The TM states a considerable variability and overlap in the isotopic compositions of the three water types (Type 1, 2 and 3) – see NASA TM Figure 10. NASA used $\delta^{18}O/\delta^{2}H$ isotope data to generally correlate Type 1 and 2 water from trilinear diagrams as being isotopically similar (on average) and lie on the Global Meteoric Water Line[2]. Type 3 water lies below the Global Meteoric Water Line, which the TM states reflects the presence of a significant amount of imported Metropolitan Water District of Southern California (MWD) water (as it is depleted in $\delta^{2}H$ and enriched in $\delta^{18}O$ relative to Types 1 and 2), resulting in the distinctive geochemistry of Type 3 water.

4.6 GEOSCIENCE Comments on use $\delta^{18}O/\delta^{2}H$ isotopes being inconsistent with regards to classification of water types

There do not appear to be consistencies between methods for characterizing the source water for certain wells. For example, $\delta^{18}O/\delta^{2}H$ isotope data for the Garfield Well show a value plotting above the Global Meteoric Water Line which classes it as a Type 1 or 2 water – whereas, using anions and cations plotted on a trilinear diagram classified it as a Type 3 water.

Furthermore, the NASA TM does not discuss the relevance of data plotting on the Global Meteoric Water Line.

4.7 NASA Technical Memorandum Summary on Tritium Isotopes

NASA's tritium analyses shows MW-19 and MW-21 having tritium unit (TU) values greater than 8 – correlating with Type 3 water (it must be noted that the Valley Water Company wells were not analyzed for tritium isotopes and therefore cannot be compared to MW-19 and MW-21). Samples from deeper screened intervals showed tritium values less than 0.8 TU indicating older, deeper Type 2 water. The remainder of wells tested had tritium levels between 2 and 8 TU, indicating modern ground water.

[2] The global meteoric water line defines the relationship between $\delta^{18}O$ and $\delta^{2}H$ in worldwide fresh surface waters and is global in application. It is actually an average of many local or regional meteoric water lines which differ from the global line due to varying climatic and geographic parameters. It usually indicates waters of meteoric origin.

4.8 GEOSCIENCE Comments on Tritium Isotopes: Use of tritium isotopes contradict classifications by other methods

The TM did not point out that the Sunset Reservoir wells had between 2 – 8 TU, which indicates that they are not Type 3 water as concluded using trilinear diagrams (anion and cation geochemistry). The use of tritium isotopes to characterize groundwater is therefore not consistent with results from other methods.

4.9 NASA Technical Memorandum Summary on Strontium Isotopes

The strontium isotope analysis shows mixing between Type 1 and MWD water – most data is spread between the MW-24 and Colorado River water ratio (see NASA TM Figure 11). Type 2 water (deeper aquifer) shows ion-exchange and precipitation reactions, which depletes the strontium concentration but still has almost identical strontium isotope ratios.

4.10 GEOSCIENCE Comments on Strontium Isotopes: The NASA TM data on strontium isotopes shows a wide range of values that are not conclusive

Due to the wide spread of data points plotted on NASA's TM Figure 11, it is not possible to draw conclusions on water types from these data. The groups representing water types shown on NASA TM Figure 11 appear to have been drawn based on results from previous methods and not based purely on the strontium isotope data.

Furthermore, strontium isotopes ($^{87}Sr/^{86}Sr$) are known to rapidly assimilate with local ground water due to contact with the aquifer and dilution, thereby reflecting the water quality of the specific site where the sample was collected, and does not provide a true representation of the water source.

Also, there are a number of data points shown on NASA TM Figure 11 that are not identified as to which wells they represent.

5.0 GROUND WATER CHEMICAL CONCENTRATIONS

5.1 NASA Technical Memorandum Summary on Carbon Tetrachloride

Carbon tetrachloride is regarded by NASA to be a reliable tracer for chemicals originating from JPL because "significant quantities were disposed of at JPL" and no other sources are known to exist in the Monk Hill subarea.

Monitoring well and production well concentrations show that carbon tetrachloride is completely contained within the Monk Hill subarea. The NASA TM states that "…co-location of carbon tetrachloride and perchlorate in samples adjacent to and hydraulically connected to JPL indicates a source of perchlorate originating from JPL."

The TM points out that carbon tetrachloride has not been detected in the Sunset Reservoir wells or in NASA's furthest downgradient monitoring wells (MW-19, MW-20, MW-21 and MW-26).

5.2 GEOSCIENCE Comments on Carbon Tetrachloride: The NASA TM conclusions regarding the association of carbon tetrachloride and perchlorate are not supported by data and do not take into account the different fate and transport of the two chemicals

Some monitoring wells on the JPL facility show detections of perchlorate but not of carbon tetrachloride (e.g., MW-6, MW-14, MW-15, MW-20, MW-21, MW-22). Also, off-site wells showing detections of perchlorate but not of carbon tetrachloride are: MW-17 (Screen 5), MW-19 (with the exception of Aug/Sep 1996 = 0.5 μg/L). There is one on-site well (MW-11) with more detection of carbon tetrachloride than perchlorate. Additionally, some JPL monitoring wells that are hydraulically upgradient of the greatest onsite perchlorate concentrations at MW-16 and MW-24, have had low detections of perchlorate but none of carbon tetrachloride (i.e., MW-1, MW-9 and MW-15). These data illustrate that perchlorate and carbon tetrachloride

have different fate and transport mechanisms, each affected somewhat differently by hydrodynamic dispersion, retardation and biodegradation.

Carbon tetrachloride is subject to retardation, reductive dechlorination and dispersivity that will slow its transport, change its form and where it is found spatially. In particular, carbon tetrachloride may undergo reductive dechlorination in the presence of free sulfide and ferrous ions, or naturally occurring minerals providing those ions (ATSDR, 2005).

Retardation is the result of sorption processes which cause solutes to move slower through the aquifer. The process is dependant on numerous factors such as aquifer material type, concentration of the chemical in the ground water, presence of organic material, bulk density of the aquifer materials, aquifer porosity and ground water velocity. Carbon tetrachloride has a retardation factor of 1.44 – 1.8 (water has a retardation factor of 1), (USEPA, 2007), and perchlorate is known to have a retardation factor less than carbon tetrachloride and similar to water (published retardation values for perchlorate are not readily available). As such, due to the different transport parameters for perchlorate and carbon tetrachloride, the association of the two chemicals is less reliable the further from the JPL facility.

5.3 NASA Technical Memorandum Summary on Perchlorate

The NASA TM states that Colorado River water contains perchlorate originating from the Basic Management and Industrial (BMI) Complex in Henderson, Nevada adjacent to the Las Vegas Wash (which drains into Lake Mead and ultimately into the Colorado River). The TM purports that:

> *"assuming perchlorate was present in the river water prior to its discovery in 1997, a large mass of perchlorate could have been introduced into the Raymond Basin aquifer via leaks in the distribution system, injection, unsewered areas, and irrigation."*

Table 2 of NASA's TM lists the amount of imported water from the Colorado River from 1945 to 2002.

NASA's explanation of how chemicals in the water recharged to the Basin from applied water would have higher concentrations of chemicals than the purveyed water is:

> *"Applied water (e.g., watering lawns) may account for more than 50% of the water used in the Basin on an annual basis. Due to evapotranspiration, much of the applied water would not infiltrate to the aquifer during the warmer and dryer summer months. However, the chemicals (e.g., sulfate and perchlorate) in the applied water would accumulate in the shallow soil until heavier periods of rain occurred, which would dissolve these chemicals as the water infiltrates to the aquifer. Therefore, it is likely that the water recharged to the Basin from applied water would have higher concentrations of chemicals than the purveyed water due to the chemicals being concentrated as a result of evapotranspiration."*

5.4 GEOSCIENCE Comments on the Amount of Colorado River Water Imported in the Raymond Basin: The NASA TM does not correctly estimate the amount of Colorado River Water imported into the Raymond Basin

Although a reference for the source of data in NASA TM Table 2 is provided, it was not possible to find the annual volumes of Colorado River water imported in the Basin from the references cited. Assumptions made by NASA in their calculation of the amount of perchlorate that could have been introduced into the Basin (i.e., 3,000 lbs) is incorrect as the sources of imported water MWD to the Raymond Basin is a blend from the Jensen and Weymouth Treatment Plants. The sources of water entering these plants are as follows:

Jensen Plant	Mostly State Project water but is sometimes blended with Los Angeles Department of Water and Power water (has no measurable perchlorate)

Weymouth Plant	Blend of State Project water and Colorado River water (detectable perchlorate concentrations in the plant effluent from 1997 to 2007 ranges from 3.4 μg/L to 7 μg/L, and averages 4.6 μg/L. Non-detects (i.e., less than 2 μg/L) have been reported since December 2003, see Figure 32)

Due to the blending of different water sources imported into the Raymond Basin, the amount of perchlorate introduced into the Basin from imported MWD water would be less than the 3,000 lbs estimated by NASA.

5.5 GEOSCIENCE Comment on Perchlorate Concentrations in Sunset Reservoir Wells: The NASA TM findings inferring Colorado River water is responsible for Sunset Reservoir wells' perchlorate is flawed

If the mechanism described by NASA for concentrating perchlorate in the ground water to levels above the source/recharge water was valid, it would be expected that other salts, such as sulfate, chloride and TDS would also increase in the ground water to concentrations exceeding the recharge water. Figures 5 through 13 show that sulfate in ground water (both Sunset Reservoir area and Valley Water Company wells) have mostly remained at or below imported Colorado River and State Project water concentrations, while Figures 32 through 36 show perchlorate in ground water significantly higher than concentrations in imported water for wells hydraulically downgradient of the JPL facility.

Furthermore, assuming all water imported into the basin was from the Colorado River (a worst case scenario), a mass balance analysis was performed using NASA's estimate of 3,000 lbs of perchlorate introduced into the Basin from the Colorado River. The mass balance results are summarized in Table 2. Results show an approximate concentration of 0.6 μg/L in ground water throughout the Basin. For an even worse case it was assumed the 3,000 lbs of perchlorate was introduced only into the area upgradient of the Sunset Reservoir wells. If this were the case, the

perchlorate concentration in ground water would only be approximately 2.2 μg/L. These simple mass balances serve to illustrate that the perchlorate concentration in ground water resulting from imported Colorado River water would be at least an order of magnitude lower than perchlorate measured in the Sunset Reservoir wells (see Figures 32 to 36 for historical perchlorate concentrations).

Table 2. Mass Balance of Perchlorate in Ground Water (Given 3,000 lbs Introduced into the Basin by Colorado River Water)

Area			Aquifer Thickness[a]	Aquifer Volume	Effective Porosity	Ground Water Volume	3,000 lbs of Perchlorate Converted to Micrograms	Concentration of Perchlorate in Ground Water
Location	[miles^2]	[ft^2]	[ft]	[ft^3]		[liters]	[μg]	[μg/L]
Entire Raymond Basin	38.2	1.07×10^9	500	5.33×10^{11}	0.15	2.26×10^{12}	1.36×10^{12}	0.6
Area Hydraulically Upgradient of Sunset Reservoir Wells	13.3	3.71×10^8	400	1.48×10^{11}	0.15	6.30×10^{11}	1.36×10^{12}	2.2

Notes: [a] estimated from geological cross-sections in the RBMB Baseline Assessment (GEOSCIENCE, 2004b)

Therefore, given the high perchlorate concentrations observed in ground water, another source other than Colorado River water must be responsible for the elevated perchlorate concentrations.

6.0 PERCHLORATE ISOTOPES

6.1 NASA Technical Memorandum Summary on Perchlorate Isotopes

The stable perchlorate isotope analyses sought to distinguish the isotopic signatures of perchlorate in wells within the JPL perchlorate plume and perchlorate in the Sunset Reservoir wells. Specifically, the study sought to address the following questions:

1. Is the isotopic fingerprint of perchlorate in the JPL wells different from that of the Sunset Reservoir wells?
2. Is the isotopic signature of perchlorate in the Sunset Reservoir wells consistent with that of natural perchlorate sources, such as Chilean fertilizer, or consistent with the isotopic signature of water imported to the basin from MWD?
3. Is perchlorate undergoing natural attenuation due to microbial processes (e.g., biodegradation) in the aquifer, which would alter the perchlorate isotopic signature?

The results of the perchlorate isotope analyses are expressed, relative to a sea water standard (i.e., the $\delta^{37}Cl$ ($Cl/^{35}Cl$) isotope ratio for chlorine and $\delta^{18}O$ ($^{18}O/^{16}O$) and $\Delta^{17}O$ ($^{17}O/^{16}O$) isotope ratios for oxygen). Table 3 summarizes the stable perchlorate isotope data presented in the TM, which were either measured as part of JPL's study or measured as part of another study referenced in the NASA TM.

Based on the stable perchlorate isotope data presented in Table 3, the TM makes the following conclusions:

1. The isotopic signature of JPL-source perchlorate is maintained during sub-surface transport as evidenced by the isotopic similarities between MW-16, located in the JPL perchlorate source area, and MW-17-3 and LAWC-3, which are located approximately 3,000 ft downgradient in the Monk Hill subarea;
2. The isotopic signature of JPL-source perchlorate is distinct from that of perchlorate in the Sunset Reservoir wells, as well as other wells in the Monk Hill subarea; mixing of JPL-

source perchlorate and another perchlorate source "does not appear to be a viable explanation for the differences in perchlorate signatures" between JPL wells and wells in the Sunset Reservoir area;

3. Perchlorate isotope signatures in the Sunset Reservoir wells and in MW-19 and MW-25 are consistent with reference samples and ground water samples from the BMI complex in Henderson Nevada and other Non-JPL anthropogenic sources such as perchlorate found in road flares and fireworks; and
4. Based on dissolved oxygen measurements, oxidation reduction potential (ORP) measurements, and functional genomics measurements, perchlorate has not been subject to biodegradation, which is the only (known) mechanism that could alter the isotopic signature. Consequently, the isotopic signatures of the JPL and non-JPL perchlorate sources have not been altered and reflect their respective source.

Table 3. Stable Perchlorate Isotope Data Presented in the NASA TM

Sample Site	Data Source cited in NASA TM	Attributed Perchlorate Source	Reported Values*			
			Perchlorate (μg/L)	$\delta^{37}Cl$ (‰)	$\delta^{18}O$ (‰)	$\Delta^{17}O$ (‰)
MW-16	JPL study	JPL	NR	0.1-0.4	- (21.8–20.7)	0.023–0.2
MW-17	JPL study	JPL	76.4	NR	-21.8	0.12
MW-19	JPL study	Non-JPL	6.7	0.48	-18.2	0.17
MW-24	JPL study	JPL	683	0.3	NR	MR
MW-25	JPL study	Non-JPL	10-17.4	0.06–2.19	- (18.7–16.3)	0.99 – 2.01
LAWC-3	JPL study	JPL	26	0.21	-20.4	-0.3
OU1-IN	JPL study	JPL	NR	0.3	-19.3	0.1
LFWC-2	JPL study	Non-JPL	6	1.1	-13.4	-0.13
Garfield	JPL study	Non-JPL	4	NR	-15.0	1.74
Sunset	JPL study	Non-JPL	12	0.27	-17.8	-0.06
Bangham	JPL study	Non-JPL	5	-3.01	-10.2	1.27
BMI Archive Sample†	Other studies	Non-JPL	NR	0-1	-(15–17)	0
BMI Ground Water†	Other studies	Non-JPL	NR	1	-15	0
Las Vegas Wash†	Other studies	Non-JPL	NR	0	-14	0
Road Flare†	Other studies	Non-JPL	NR	1	-13	0
Fireworks†	Other studies	Non-JPL	NR	1.5	-17	0
Natural Fertilizer†	Other studies	Non-JPL	NR	-(9–14)	-(2–9)	8-11

*Upper and lower values of ranges are shown for sampling sites where replicates were measured or where different well depths were sampled
NR = Not reported in the NASA TM
† Approximate values estimated from Figure 16 and Figure 17 in the NASA TM (2007)

6.2 GEOSCIENCE Comments on Perchlorate Isotopes

6.2.1 Comment 1: The NASA TM did not measure the isotopic signature of perchlorate in imported water from MWD; and did not measure the isotopic signature of the perchlorate source material responsible for ground water contamination in the JPL area

It is acknowledged that some of the water imported into the Raymond Basin from MWD contains perchlorate, however, the TM makes the inferred assumption that the isotopic signature of perchlorate source materials, as measured in the BMI complex samples and the Las Vegas wash sample, has not substantially changed; therefore, water imported to the Raymond Basin will contain a similar signature. While it is not possible to measure historical signatures of perchlorate imported by MWD, follow-up investigations should measure the isotopic signature of the water currently imported into the Raymond Basin, over several samplings at different times and at different locations within MWD's Colorado River conveyance system, to establish a baseline signature for the perchlorate in MWD water

The TM makes the statement that the isotopic signature of JPL-source perchlorate has not been altered due sub-surface transport. While this statement may be true based on the results measured in MW-16 and MW-17, the study is not able to determine:

1. What changes, if any, have occurred to the isotopic signature of the perchlorate source materials, which leached into the ground water beneath JPL; and
2. The variation in isotopic signature of the JPL perchlorate source materials.

Based on the lack of information on perchlorate source characteristics for imported water as well as JPL-source perchlorate, there is not enough data to support the statement that the isotopic signature is maintained during transport.

6.2.2 Comment 2: Water quality data and functional genomic testing do not support the statement that "perchlorate degradation is likely not occurring at the site"

Published data on perchlorate biodegradation show that when perchlorate is subjected to biodegradation, there is a substantial shift in the isotopic signature (Sturchio, 2007; Coleman, 2003). Consequently, biodegradation under reducing conditions is the only known mechanism where the isotopic signature may be substantially changed from that of the original source. Conditions required for reductive perchlorate degradation include: (1) Low Dissolved Oxygen (DO) and Oxidation Reduction Potential (ORP), and (2) an organic electron donor source. Additionally, if substantial amounts of biodegradation are occurring, species such sulfides, which are the products of biological reduction sulfate, may be present (Postgate, 1979).

Water quality data for the Monk Hill subarea and Sunset Reservoir wells are listed in Attachment 1 of the NASA TM. Generally, the data show that all wells have high DO as well as high ORP. However, indications of reducing conditions (i.e., conductive to perchlorate reduction) are present in a number of samples, suggesting some of the reported DO values may correctly reflect actual subsurface conditions. Indications of reducing conditions are summarized as follows:

1. In most of the multi-depth samples collected from JPL's monitoring wells, DO values exceed the (atmospheric) saturation level, which is approximately 9 mg/L. Although high DO levels in shallow ground water are common, supersaturated DO levels in deep zones (e.g., 10-12 mg/L in the lower zones of MW-17-MW-21) are suspect and suggest that the high DO may be a sampling artifact and not actually present in ground water. One mechanism for supersaturated DO in well water occurs when water cascades through well perforations and entrains air in the well casing. The entrained air is subsequently pressured in the pump and saturates the water with air.
2. The ORP values reported for MW-20 Zones 4 and 5 are too low for the reported DO levels.
3. High levels of reduced iron (8 mg/L) were reportedly detected in well MW-17 (Zones 3 and 5);

4. High levels of sulfide were detected in MW-20 (Zone 4); and
5. Ammonia was detected in MW-19, MW-20, MW-21, MW-24, and MW-25 and organic nitrogen was detected in all of the wells sampled.

A strong argument can be made that biological reduction is occurring in MW-20, which is located downgradient of the JPL plume in the Monk Hill sub-area. If the reported sulfide values are accurate, then biological reduction is likely occurring as sulfide was not detected in upper zones. This is further supported by nitrate and perchlorate levels that are measurable in the upper zones (nitrate = 2.1-6.1 mg/L in Zones 1-3 and perchlorate = 2.2 μg/L in Zone 1) and below detection limits in the lower zones. Sulfate concentration also decreases with depth (5.2 mg/L in Zone5 compared to 15-79 mg/L in Zones 1-3) with respect to the upper zones.

Data presented in the TM on functional genomics testing do not provide a strong argument for the absence of perchlorate degradation due to the following:

1. The negative control sample (MW-1) showed a positive result for both the *cld* enzyme and *cld* mRNA, which implies that the native microorganisms in MW-1 are actively degrading perchlorate where perchlorate is not present in detectable concentrations.
2. Perchlorate degradation will occur under the appropriate chemical conditions (e.g., reducing conditions and presence of an electron donor) and may be inferred through other water quality parameters such as the presence of reduced species of nitrogen and sulfur. Moreover, perchlorate reduction occurs after oxygen and nitrogen reduction, which means that nitrate will first be consumed[3]. Therefore, if water contains high nitrate then perchlorate reduction is likely not ***actively*** occurring.

Although biodegradation may not be occurring on a widespread basis throughout the study area, data presented in the TM suggest that it may be occurring locally and in deeper strata (e.g., MW-20, Zone 5). The TM acknowledges that biodegradation will alter the perchlorate

[3] Nitrate, sulfate, oxygen, and carbon dioxide all function in biochemical reactions where an organic electron donor is present; microorganisms will use oxygen first followed by nitrate, sulfate, and carbon dioxide. Therefore the absence of oxygen and nitrate suggests that sulfate reduction may occur; the presence of sulfides is a strong indication of active biological sulfate reduction, as measured in well MW-20.

signature; however, it does not properly consider the potential of localized biodegradation and the resulting effect on the isotopic signature.

Finally, based on published literature, the stable isotope method for perchlorate has only been applied for distinguishing between natural and anthropogenic-perchlorate sources, which have substantial separation between their respective oxygen and chlorine isotopes (Böhlke, 2005; Bao, 2004; Alder, 1991). The presence of localized regions of biodegradation introduces a component, which makes distinguishing isotopic signatures from different anthropogenic perchlorate sources substantially more complex than distinguishing between a natural source and an anthropogenic source. Given the likely presence of localized biodegradation, which may be ongoing or which has occurred historically, and the potential influence of perchlorate in imported water, stable perchlorate isotope signatures may not be able to differentiate the isotopic signatures of perchlorate in the Monk Hill wells and Sunset Reservoir wells, once the following are taken into consideration:

1. Isotopic fractionation in the source materials;
2. Isotopic changes from localized degradation; and
3. Mixing with other perchlorate sources (e.g., imported water)

6.3 GEOSCIENCE Comments on Analytical Methods and Quality Control

6.3.1 Comment 1: There are several method and quality control shortcomings in the water quality data

1. The analytical method used for measuring reduced (ferrous) iron had a 5 mg/L detection limit, which is several orders of magnitude too high. Future analysis should filter iron samples in the field to remove interfering sediment and use an analytical method with low detection limits (e.g., an ICPMS method such as EPA 200.7). Iron solubility relationships with pH can then be used to determine speciation.

2. Dissolved organic carbon (DOC) analysis:
    a. The anomalous DOC results, which were due to improper filtration methods, should have been caught somewhere early on in the QA/QC procedure at the laboratory and the data should not be presented in the TM as they are erroneous. This raises the question of whether a certified laboratory conducted the analyses; if not, a certified laboratory should be used in the future
    b. A useful parameter in future samples would be to measure the biologically-available portion of the organic carbon using a method such as the Biological Dissolved Organic Carbon method (Huck, 1990). This may provide more information on the ability of the organic carbon to be biologically assimilated potentially be used as an electron donor in biological reduction reactions.

3. Data listed under "Conductivity" in the analytical results table of Attachment 1 of the NASA TM, show some very high values (i.e., correlated TDS would be several tens of thousands mg/L) and do not agree with data shown in the "Specific Electrical Conductance" column.

4. The analytical method used for sulfide detection was very high (1 mg/L). Future sampling should use a method with a detection limit on the order of 50 μg/L or less.

5. The results showed that organic nitrogen (Total Kjeldahl Nitrogen) was found in nearly every sample, with the exception of several zones in MW-18. The widespread occurrence of organic nitrogen should be verified through re-sampling and the source should be identified.

6.3.2 Comment 2: The study does not provide adequate support for the analytical error associated with the stable perchlorate isotope method and the study did not conduct replicate sampling.

Comments on the analytical method and test plan (NASA, 2004) used for stable perchlorate isotope analysis are summarized as follows:

1. The sampling protocols did not include a negative control (e.g., MW-1, which is located upgradient of the JPL plume).

2. Based on a statistically acceptable number of method duplicates for several sampling sites, the total analytical error should be quantified as a function of measured precision and bias. The TM only reports data on the instrumental accuracy, which does satisfy standard procedures for reporting analytical method errors (ASTM, 2006; APHA, 2005). Data used for determining analytical precision should be based on replicate extractions of several different sources representing a range of water quality values.

3. The analytical method used for stable perchlorate isotope analysis requires a number of purification steps to remove potential interferences. These interferences include sulfate, nitrate, and natural organics (NASA, 2007). Although the method includes a number of QC checks on sample purity, the study should provide evidence that the aforementioned constituents do not interfere in the method precision or accuracy. Specifically, data should be provided that show the results of replicate sample analyses where interfering constituents (e.g., nitrate, sulfate, and organics) have been spiked over a range of reasonable values.

4. In addition to the error associated with the analytical method, additional variation in the isotopic signature will likely result from replicate samplings over time. The magnitude of isotopic variation in replicate samples will much likely be larger than the magnitude of the analytical error. Thus, time-replicate samples will reflect the analytical error as well as isotopic differences associated with natural variation, which may be caused by a number of different factors as previously discussed.

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FIGURES

Monthly Average Sulfate Concentrations in Imported Water and Sunset Well (P-SUN)

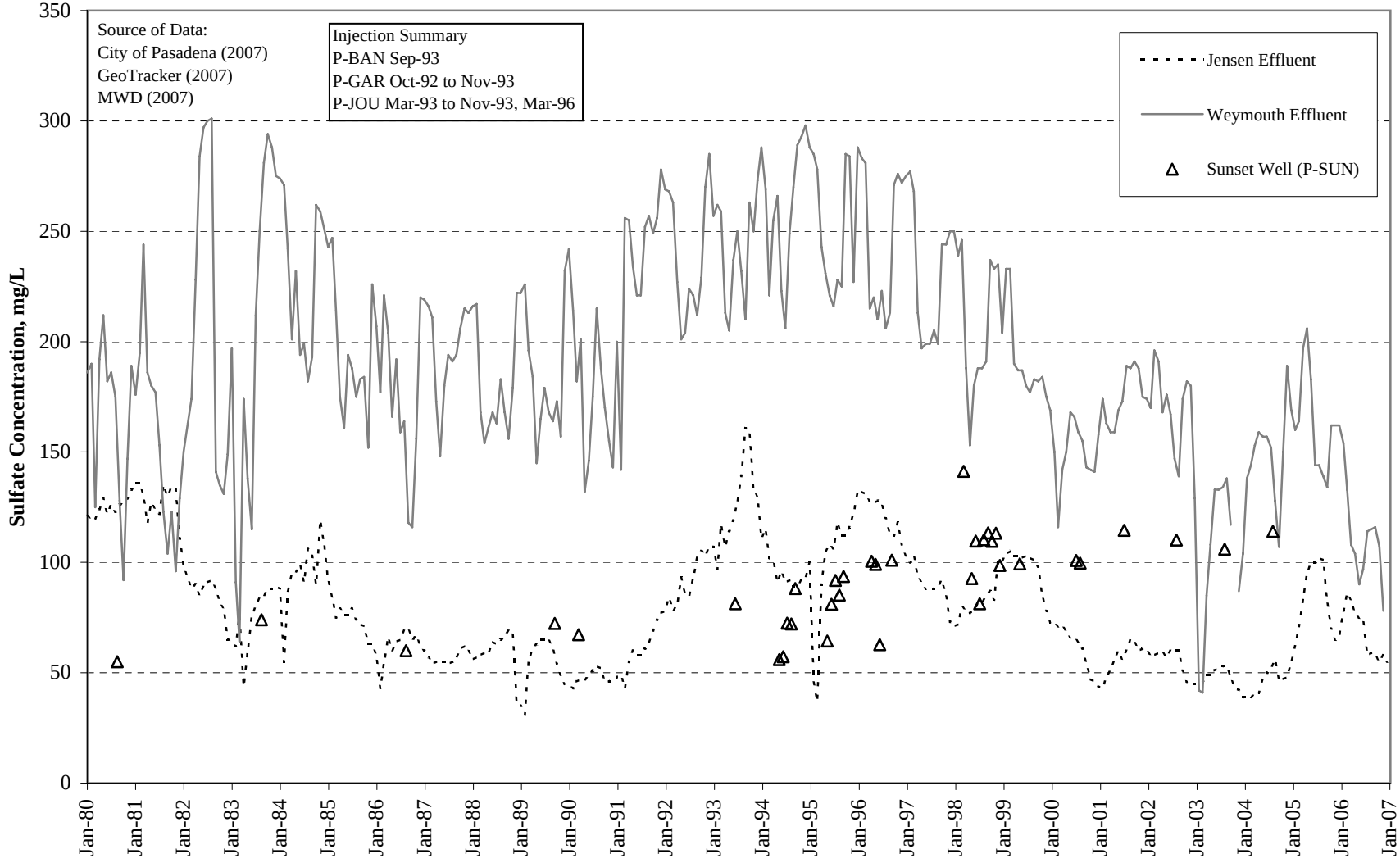

Figure 5

Monthly Average Sulfate Concentrations in Imported Water and Bangham Well (P-BAN)

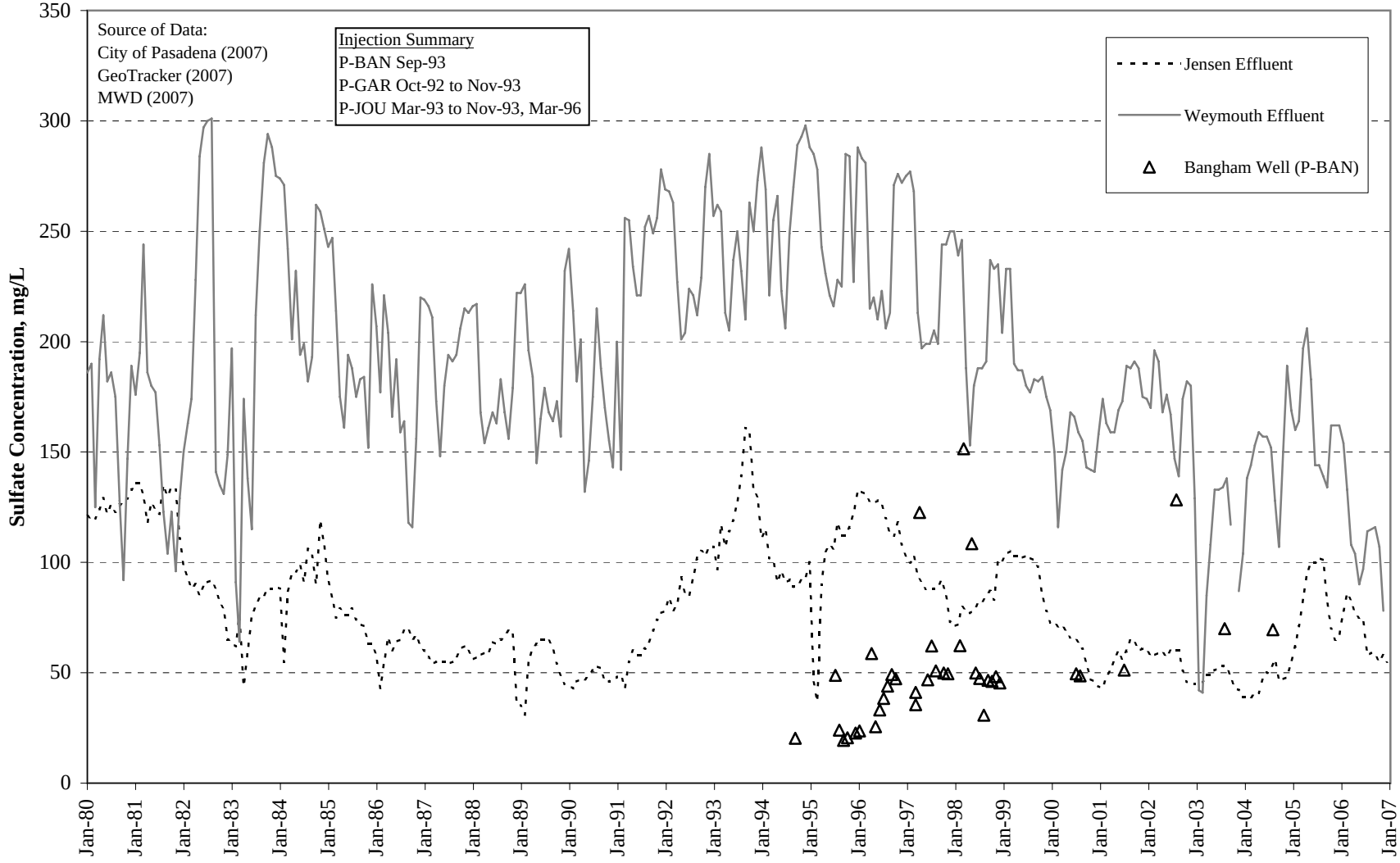

Figure 6

Monthly Average Sulfate Concentrations in Imported Water and Copelin Well (P-COP)

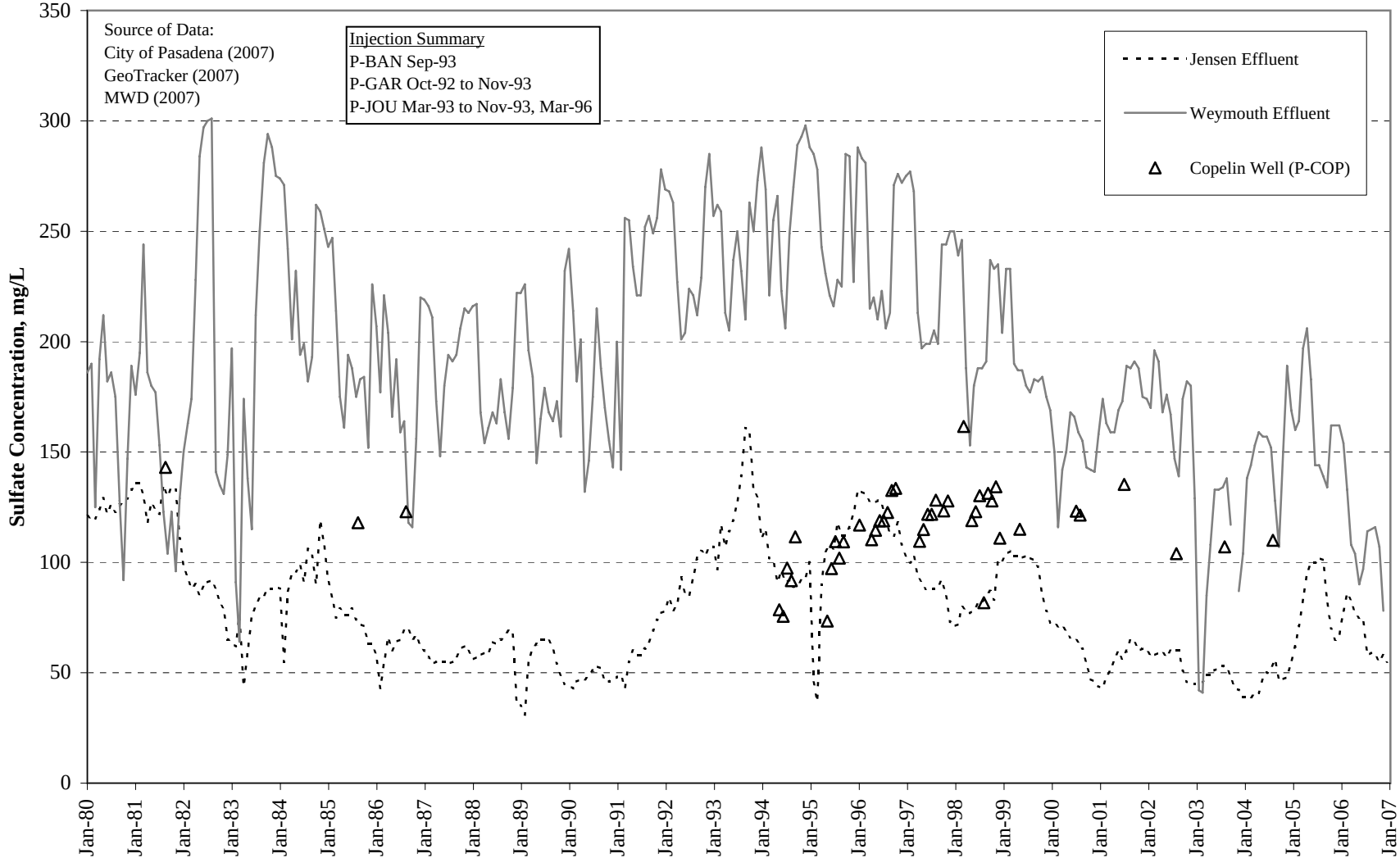

Figure 7

Monthly Average Sulfate Concentrations in Imported Water and Villa Well (P-VIL)

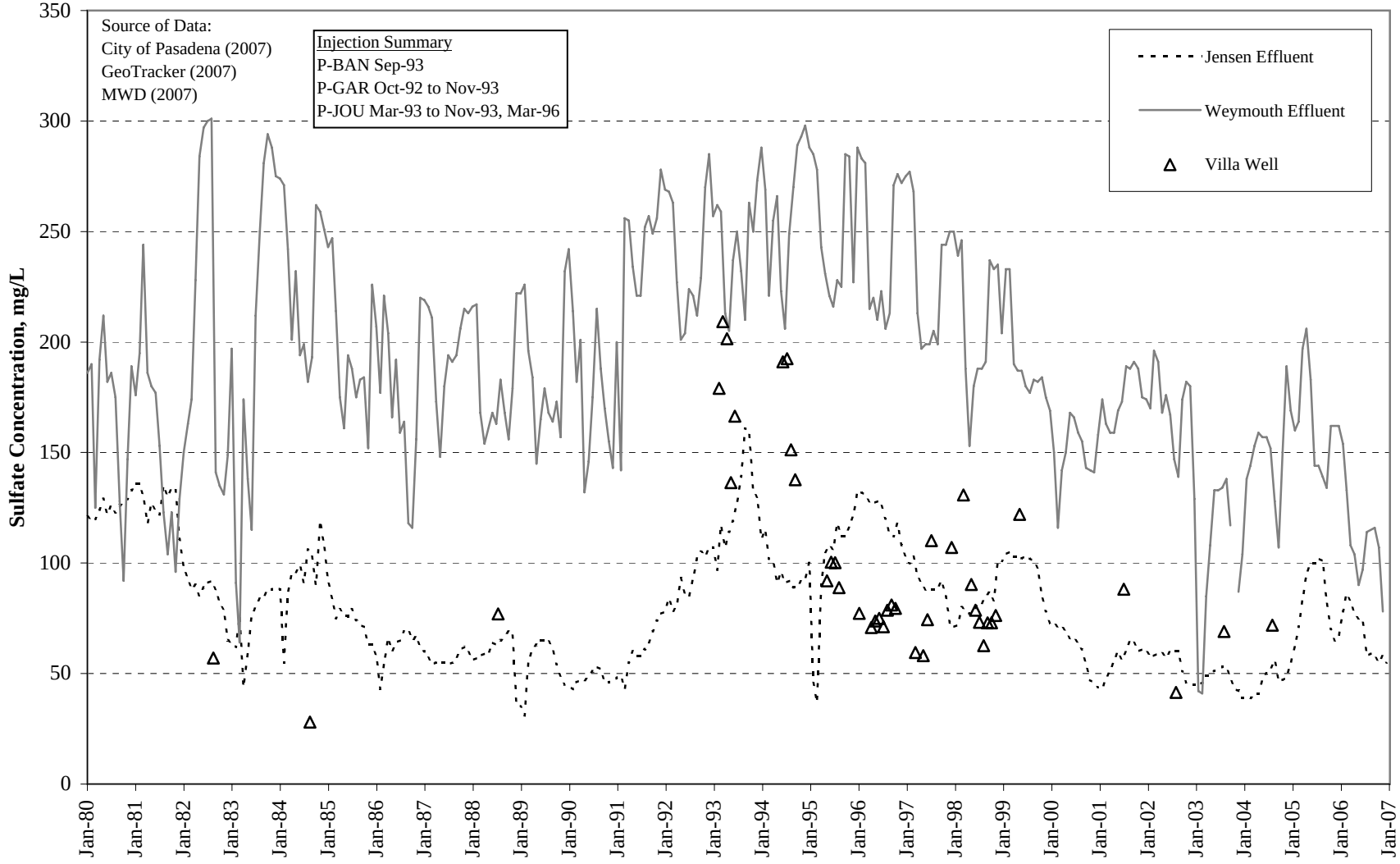

Figure 8

Monthly Average Sulfate Concentrations in Imported Water and Garfield Well (P-GAR)

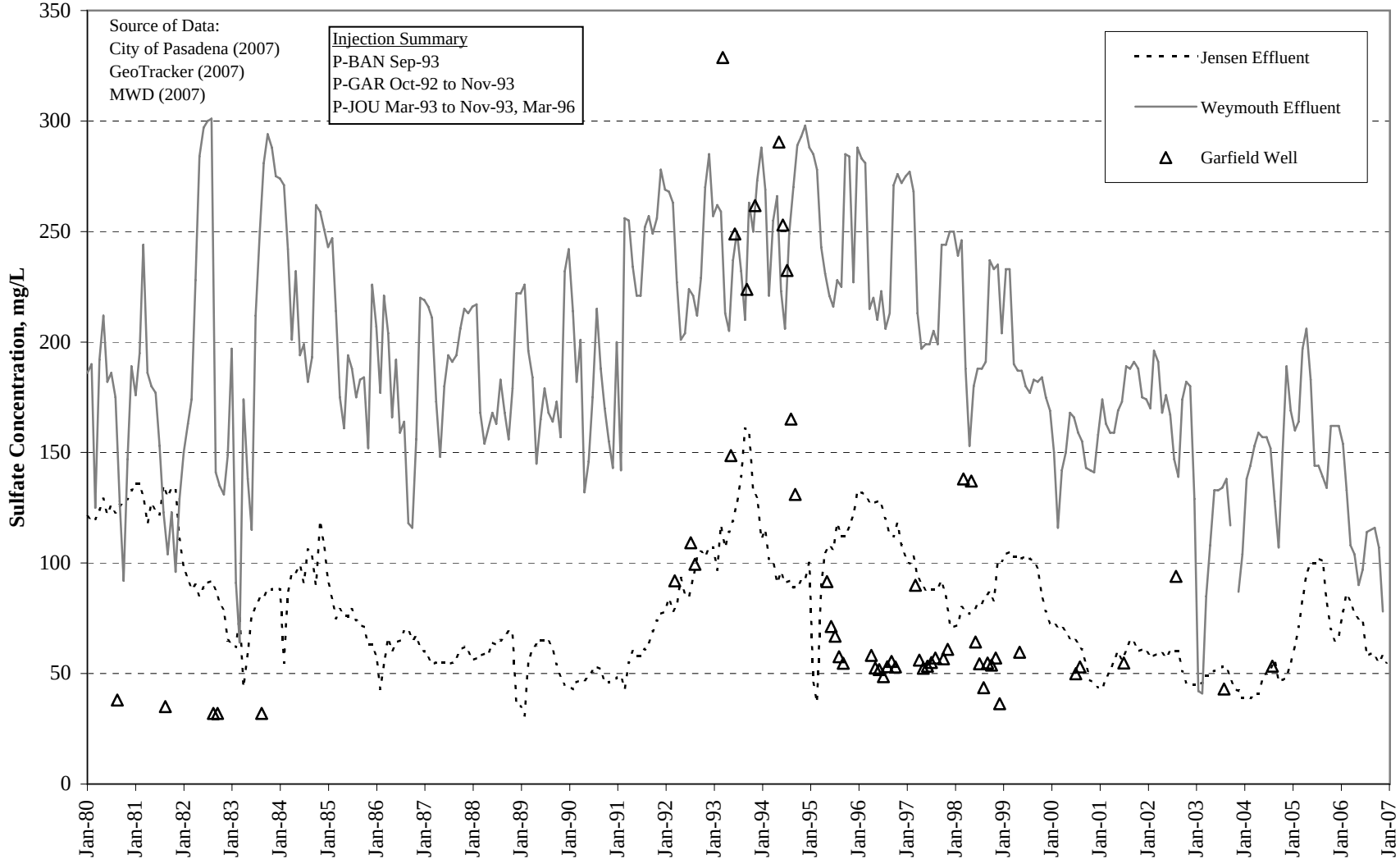

Figure 9

Monthly Average Sulfate Concentrations in Imported Water and Valley Water Company Well 1

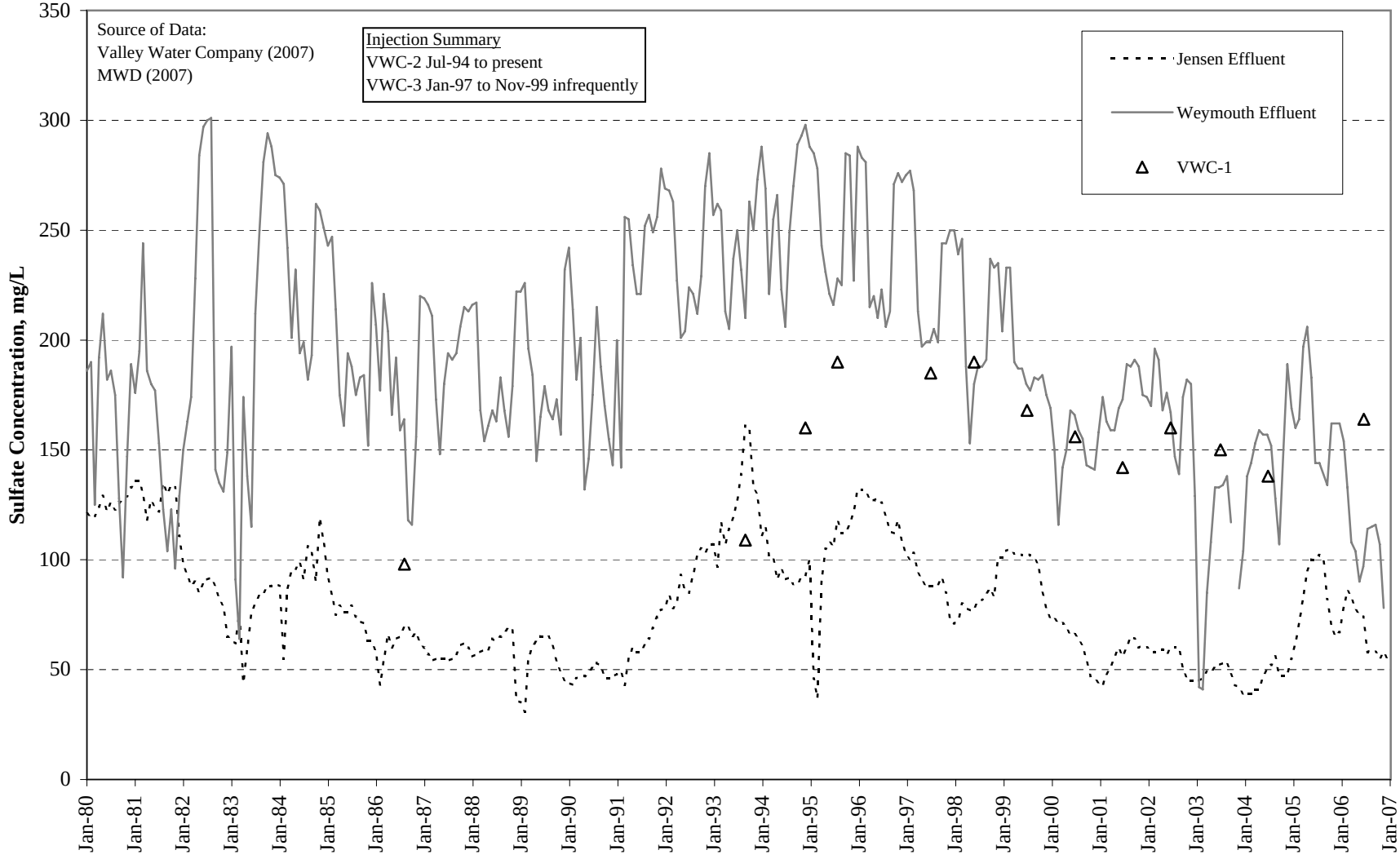

Figure 10

Monthly Average Sulfate Concentrations in Imported Water and Valley Water Company Well 2

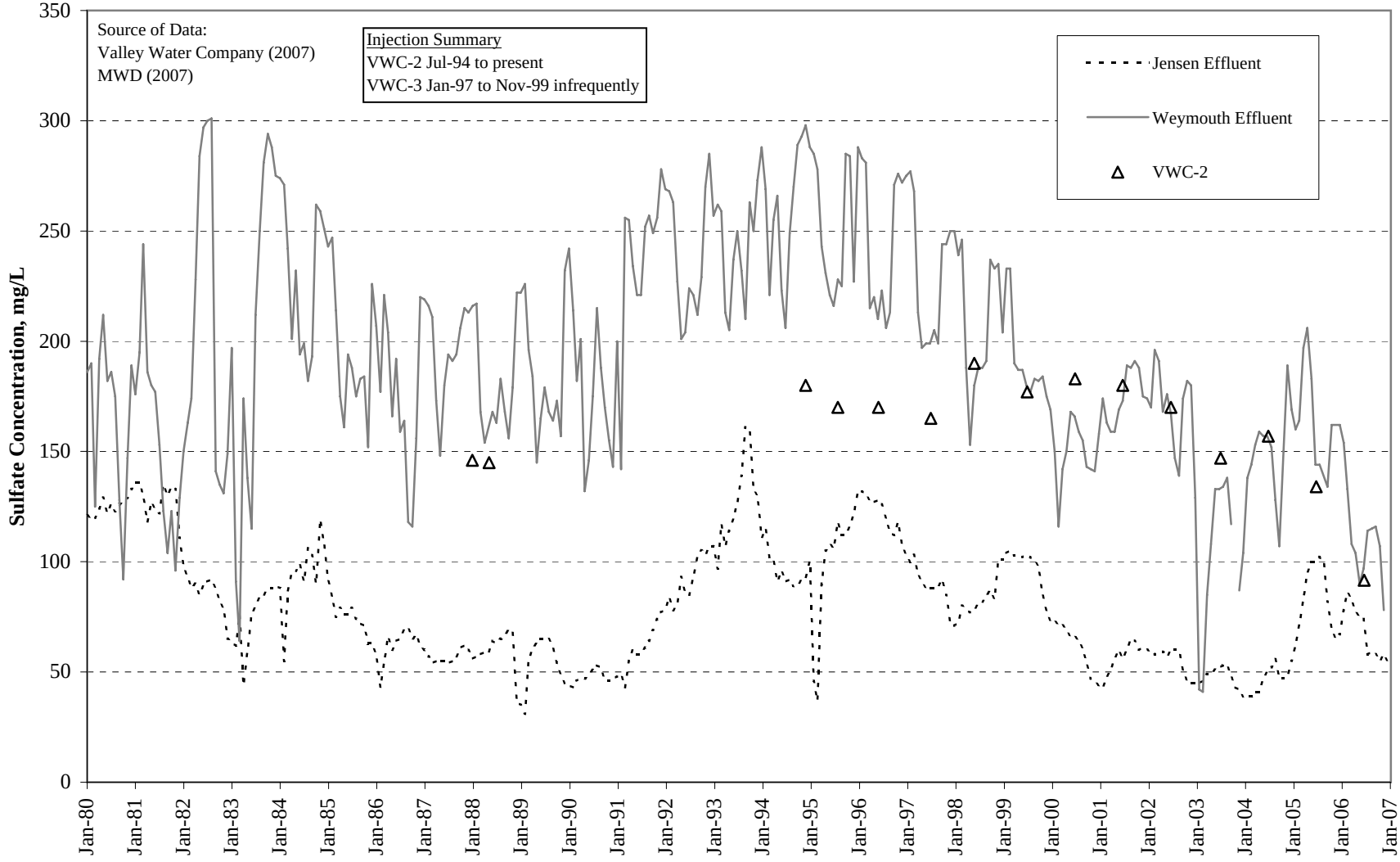

Figure 11

Monthly Average Sulfate Concentrations in Imported Water and Valley Water Company Well 3

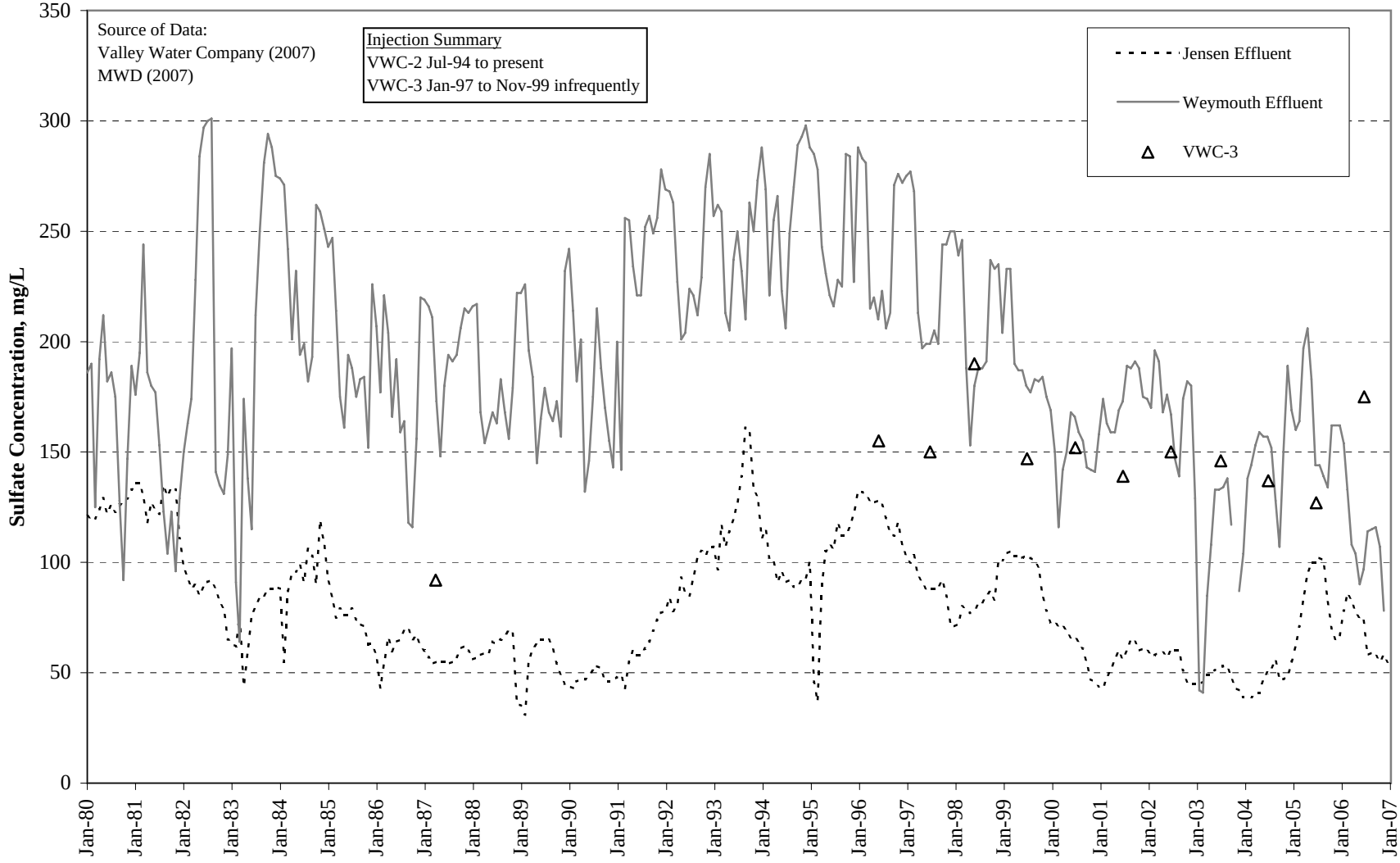

Figure 12

Monthly Average Sulfate Concentrations in Imported Water and Valley Water Company Well 4

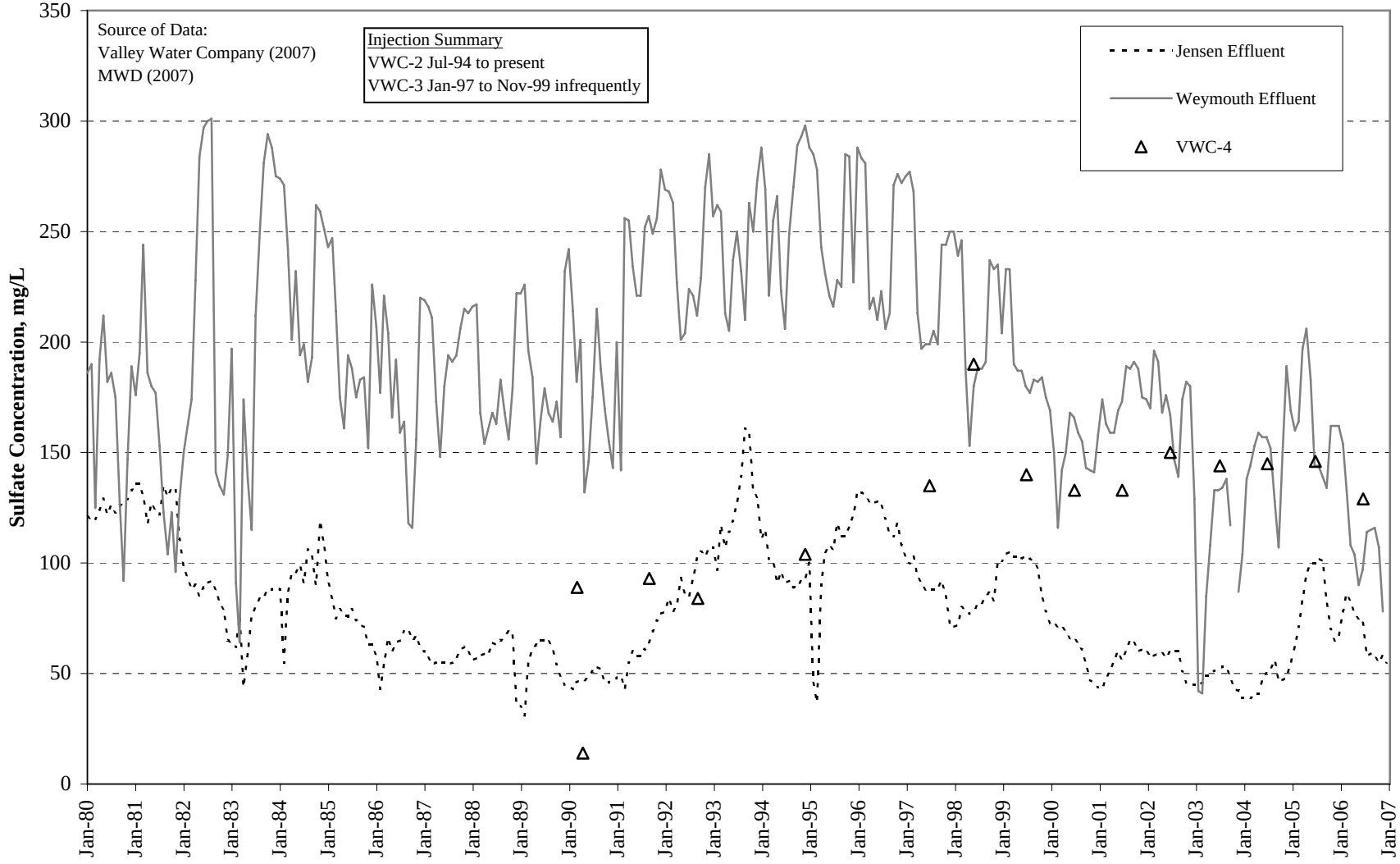

Figure 13

Monthly Average Chloride Concentrations in Imported Water and Sunset Well (P-SUN)

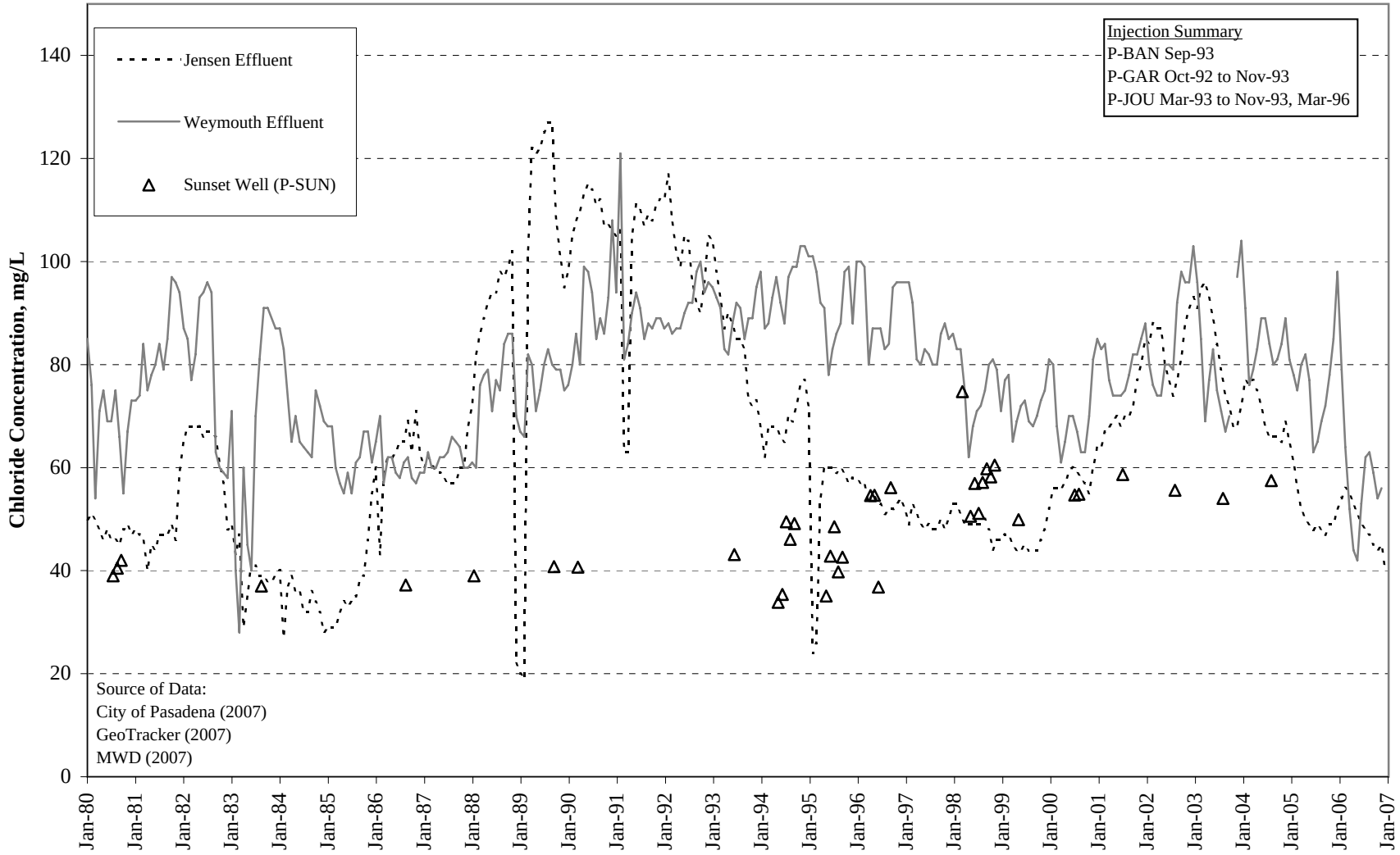

Figure 14

Monthly Average Chloride Concentrations in Imported Water and Bangham Well (P-BAN)

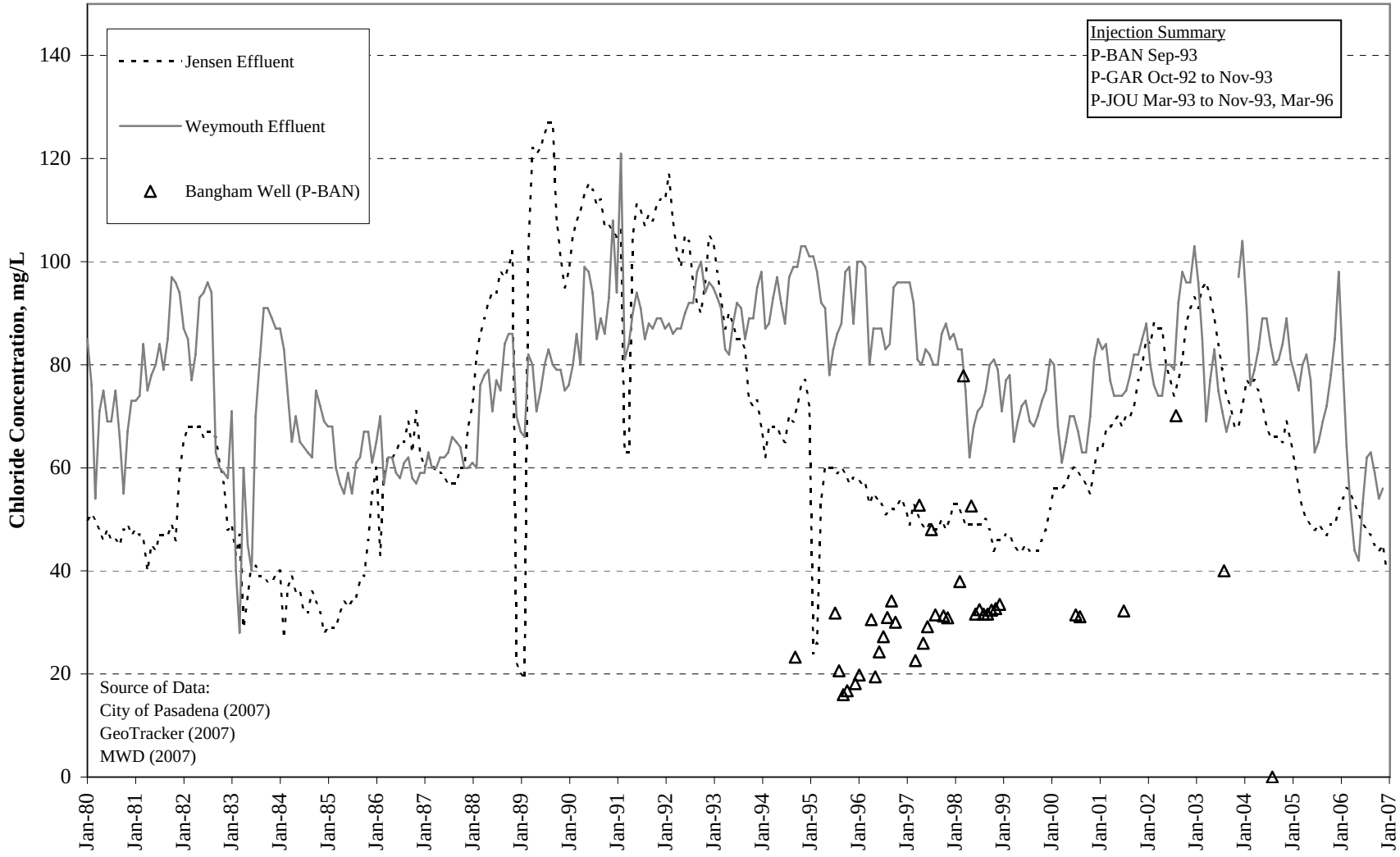

Figure 15

Monthly Average Chloride Concentrations in Imported Water and Copelin Well (P-COP)

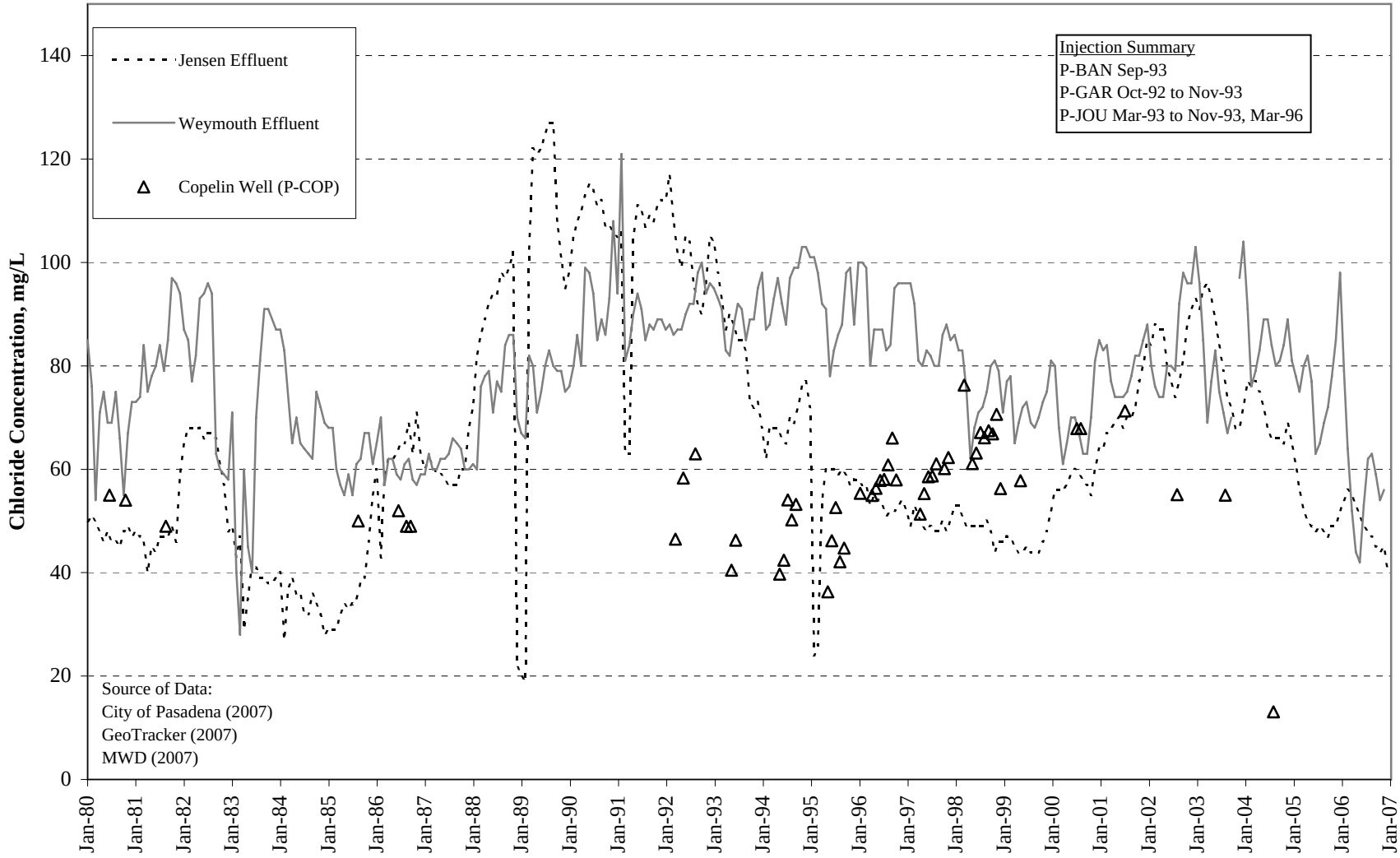

Figure 16

Monthly Average Chloride Concentrations in Imported Water and Villa Well (P-VIL)

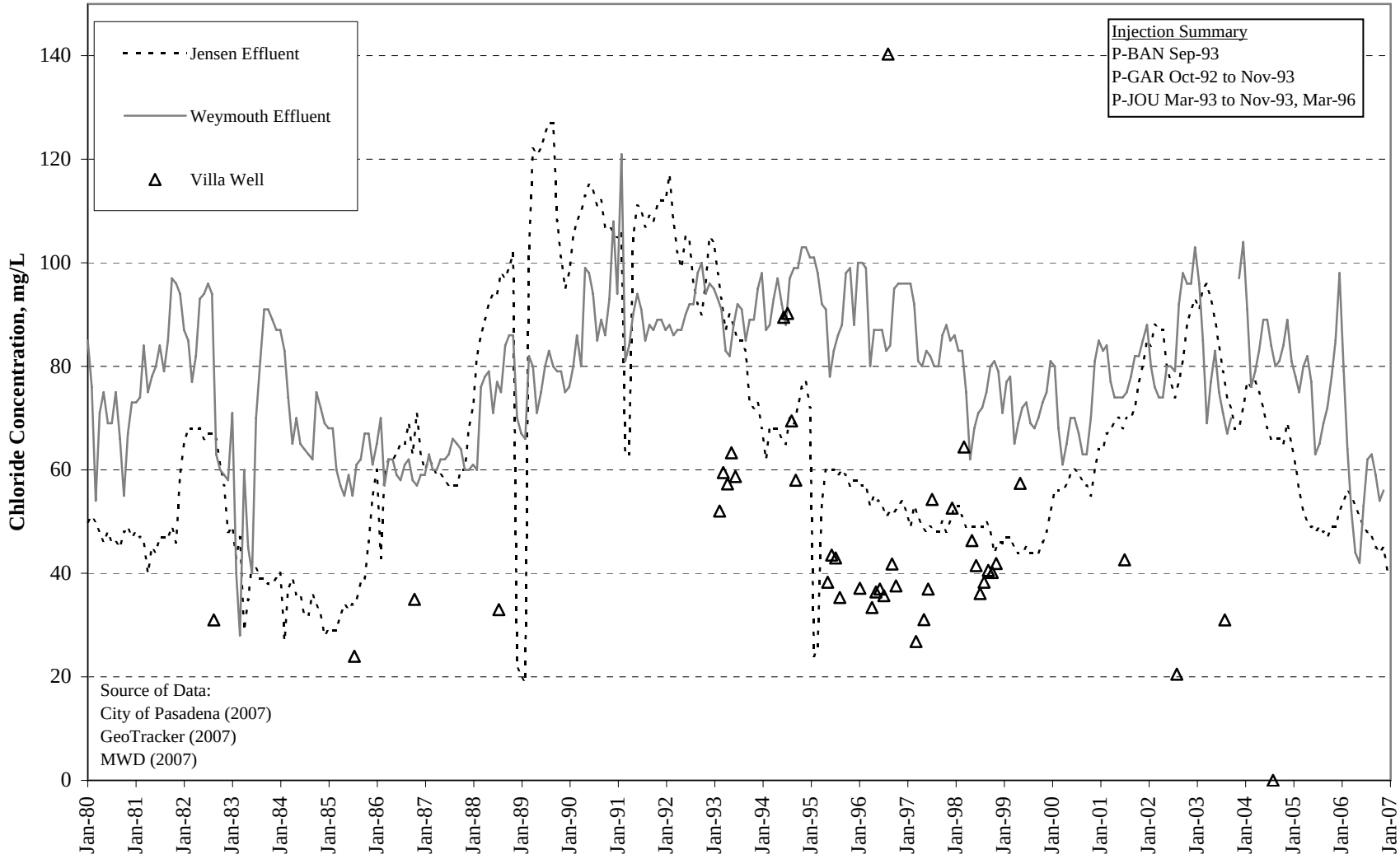

Figure 17

Monthly Average Chloride Concentrations in Imported Water and Garfield Well (P-GAR)

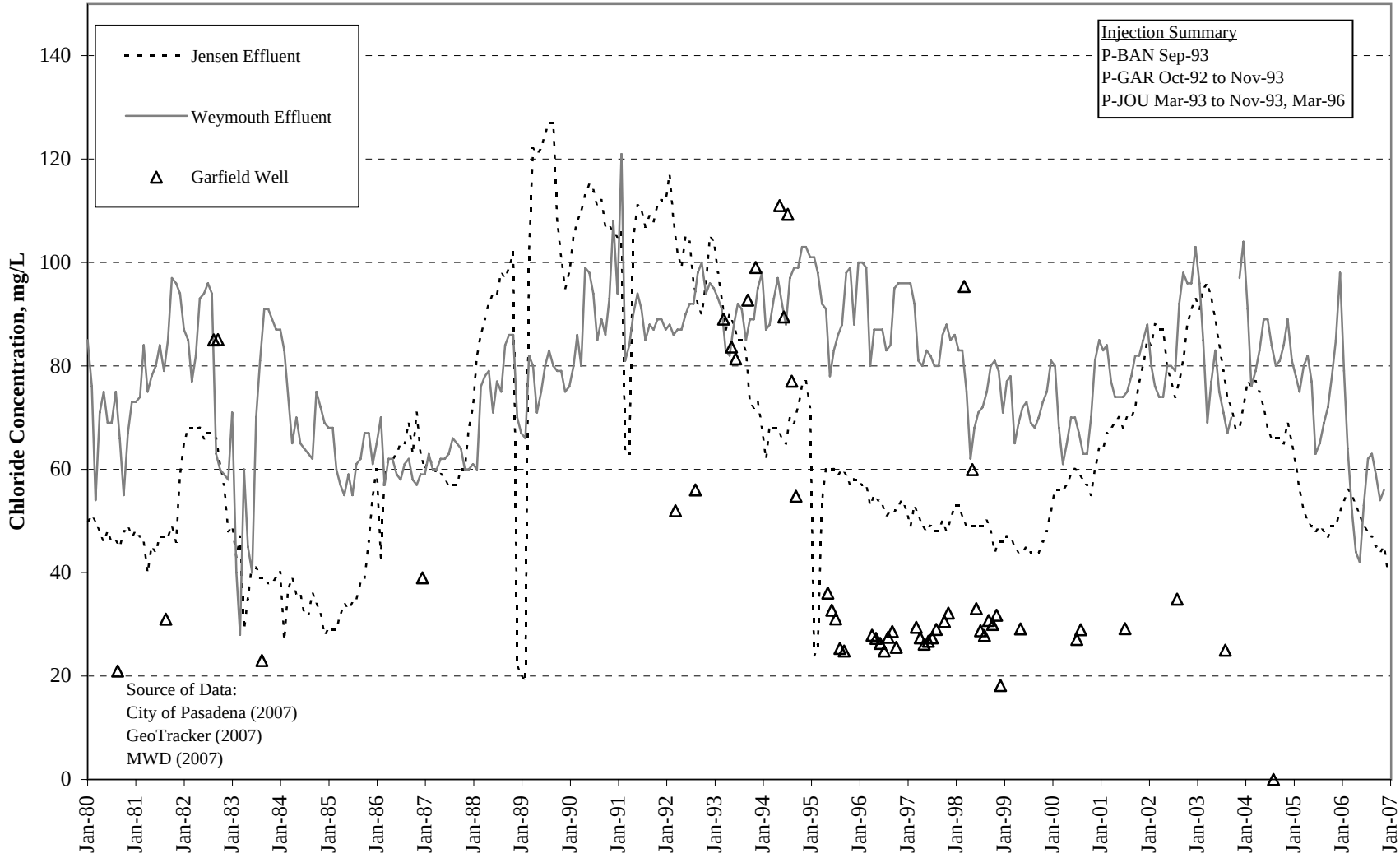

Figure 18

Monthly Average Chloride Concentrations in Imported Water and Valley Water Company Well 1

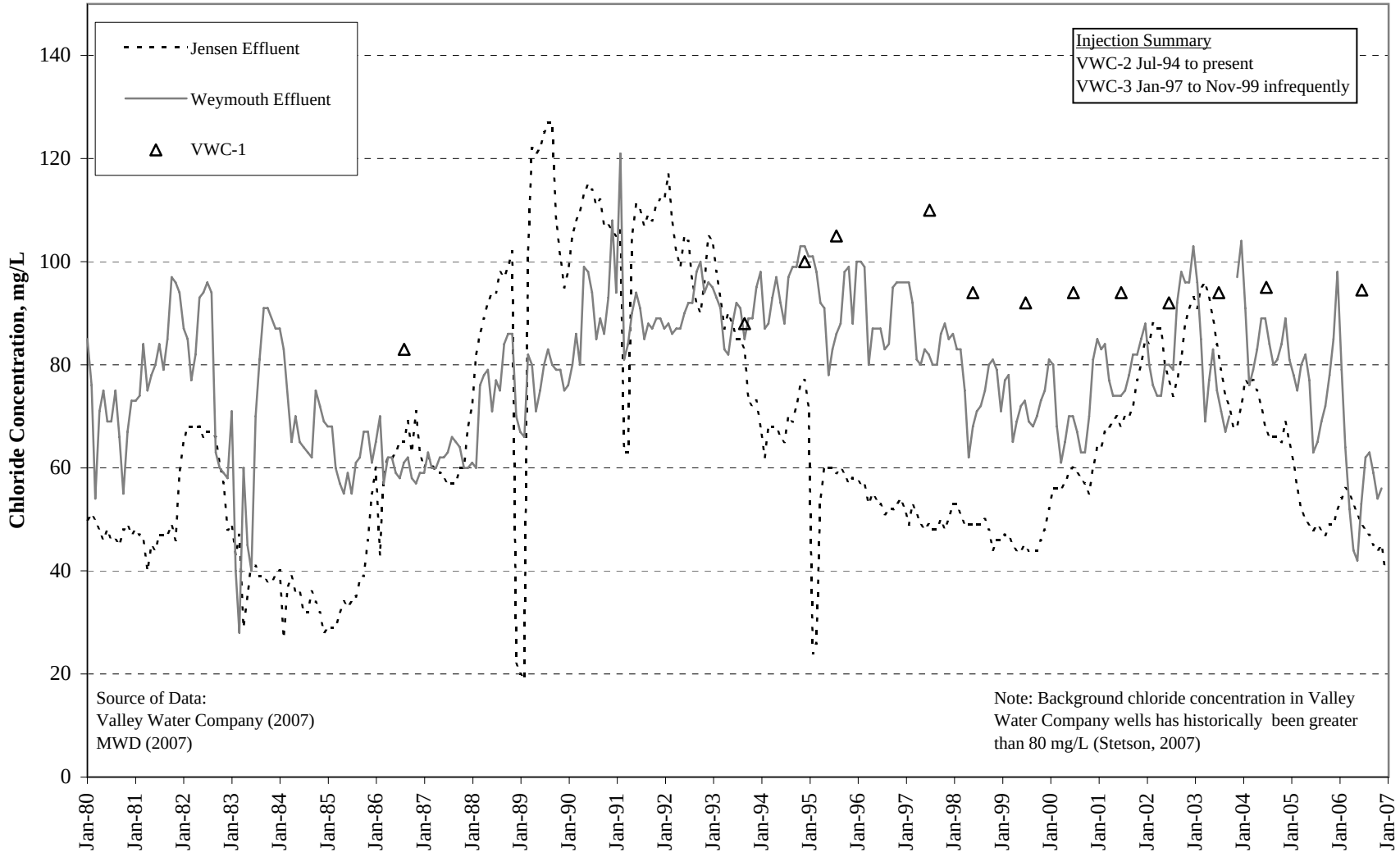

Figure 19

Monthly Average Chloride Concentrations in Imported Water and Valley Water Company Well 2

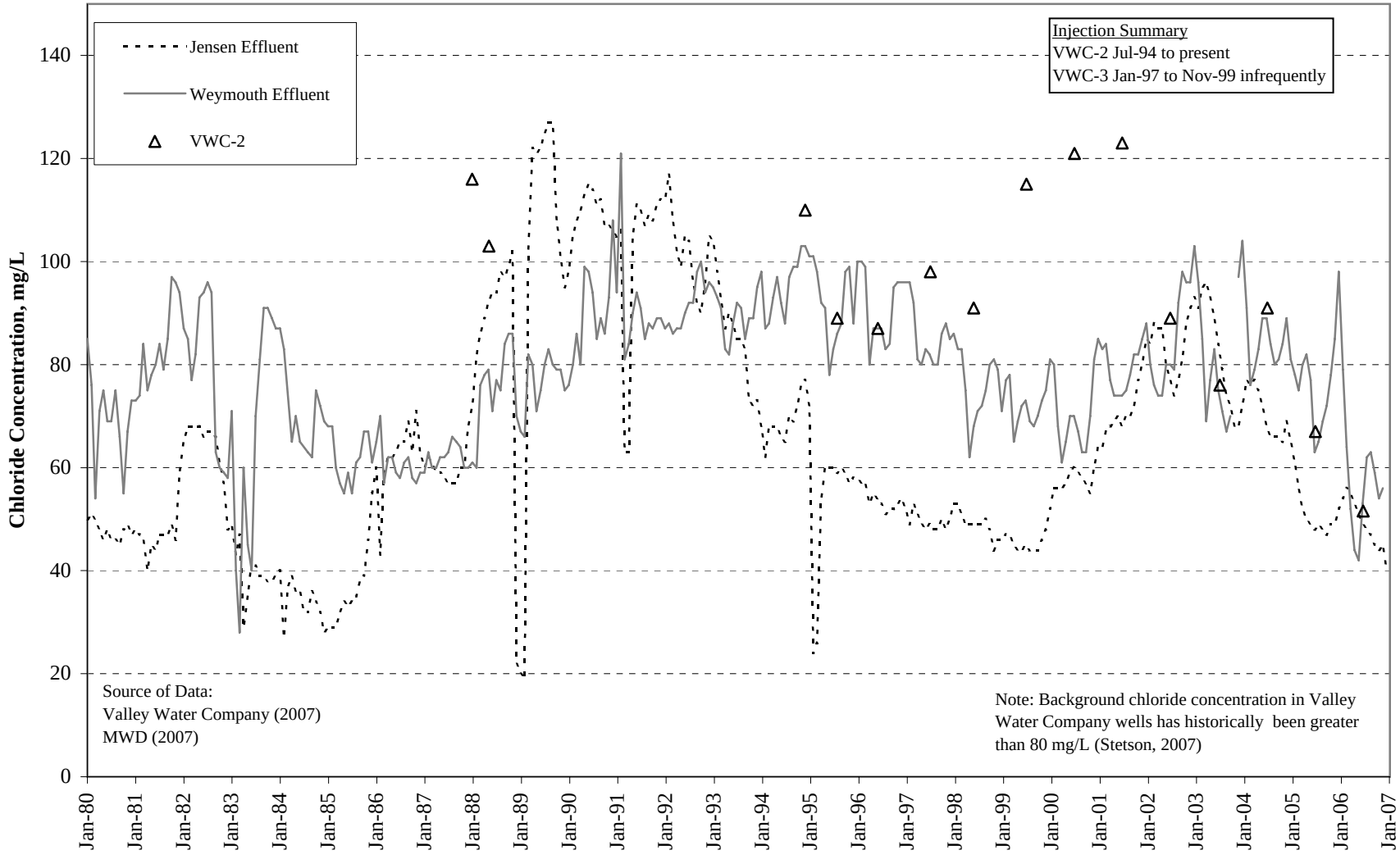

Figure 20

Monthly Average Chloride Concentrations in Imported Water and Valley Water Company Well 3

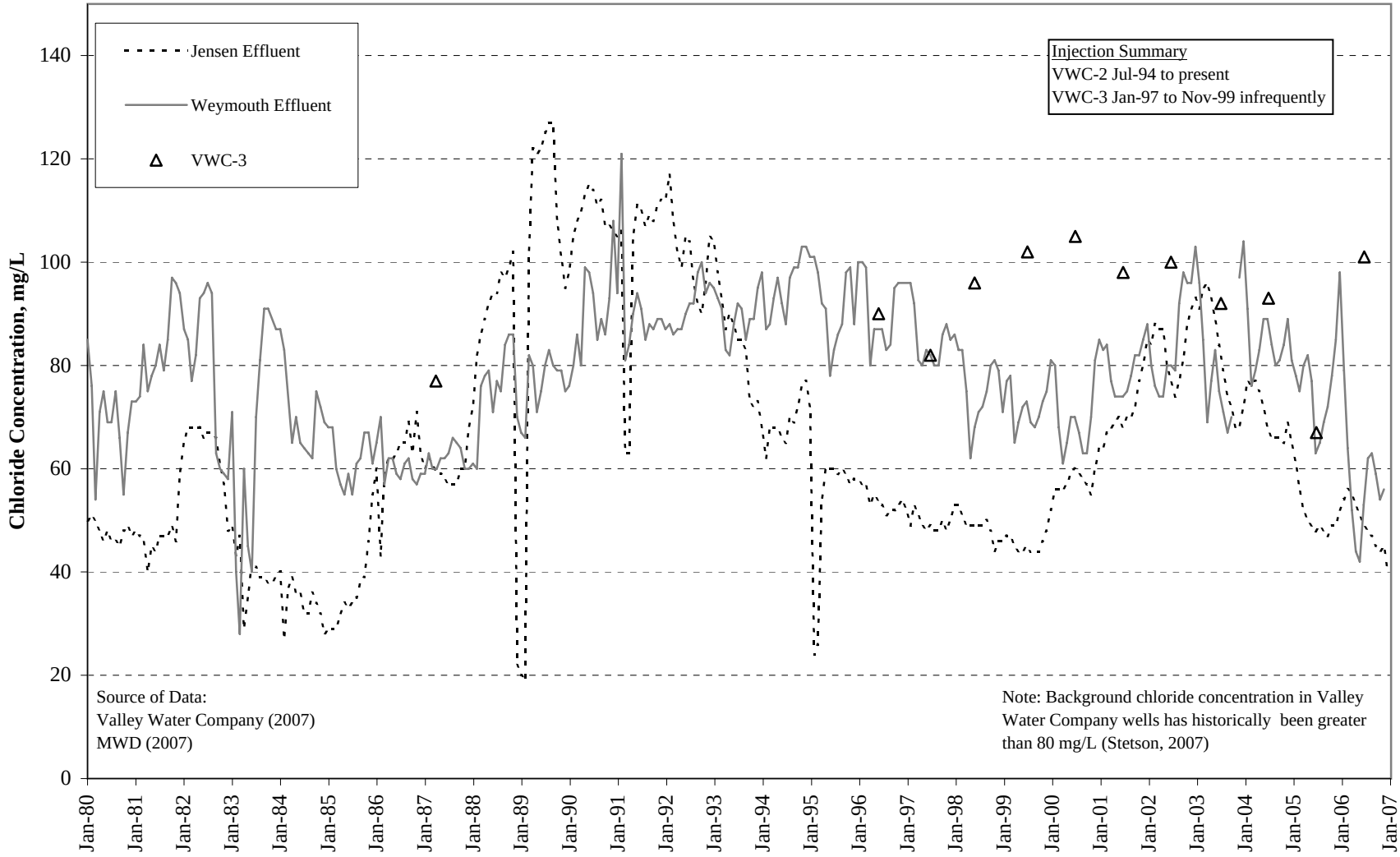

Figure 21

Monthly Average Chloride Concentrations in Imported Water and Valley Water Company Well 4

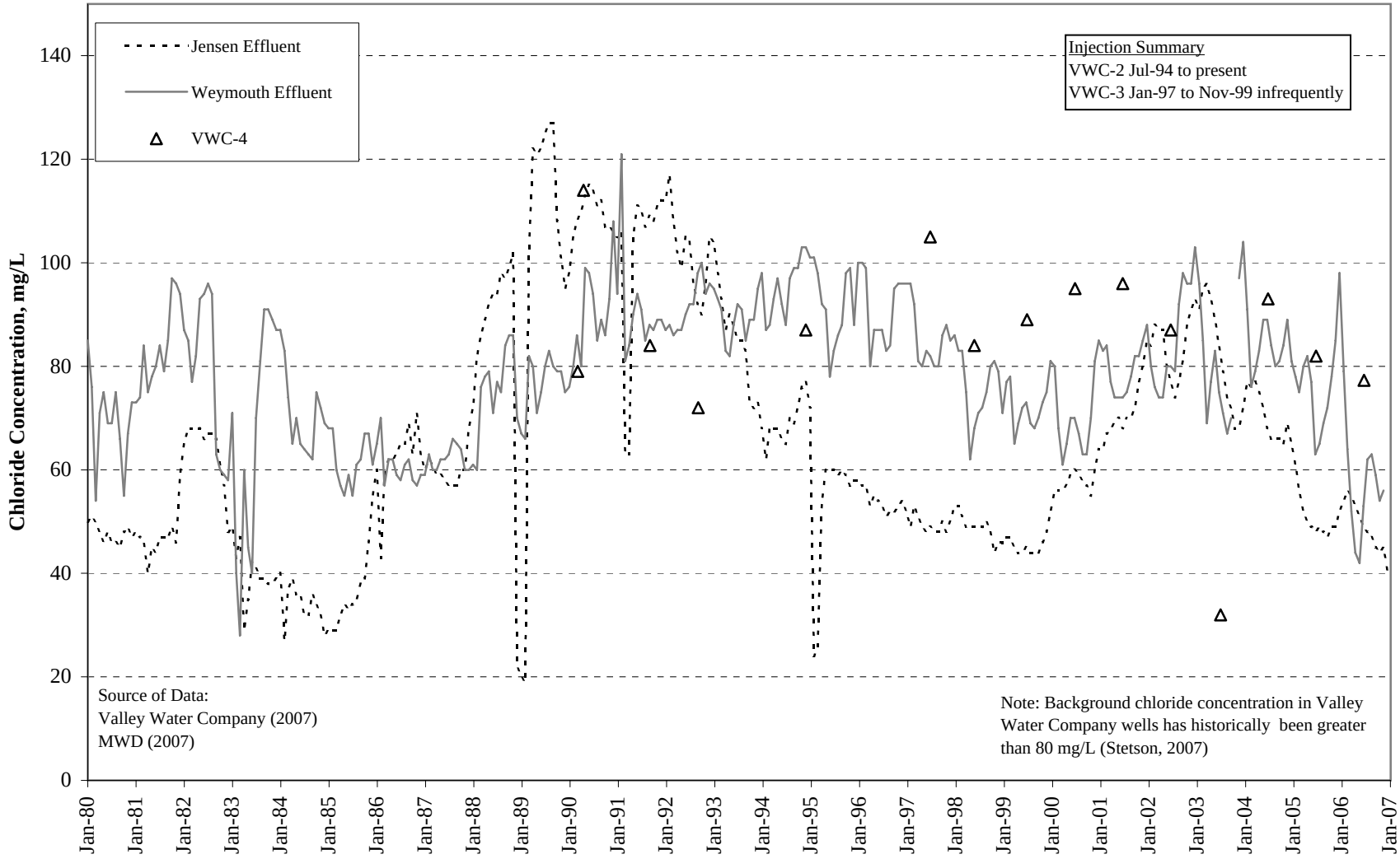

Figure 22

Monthly Average Total Dissolved Solids Concentrations in Imported Water and Sunset Well (P-SUN)

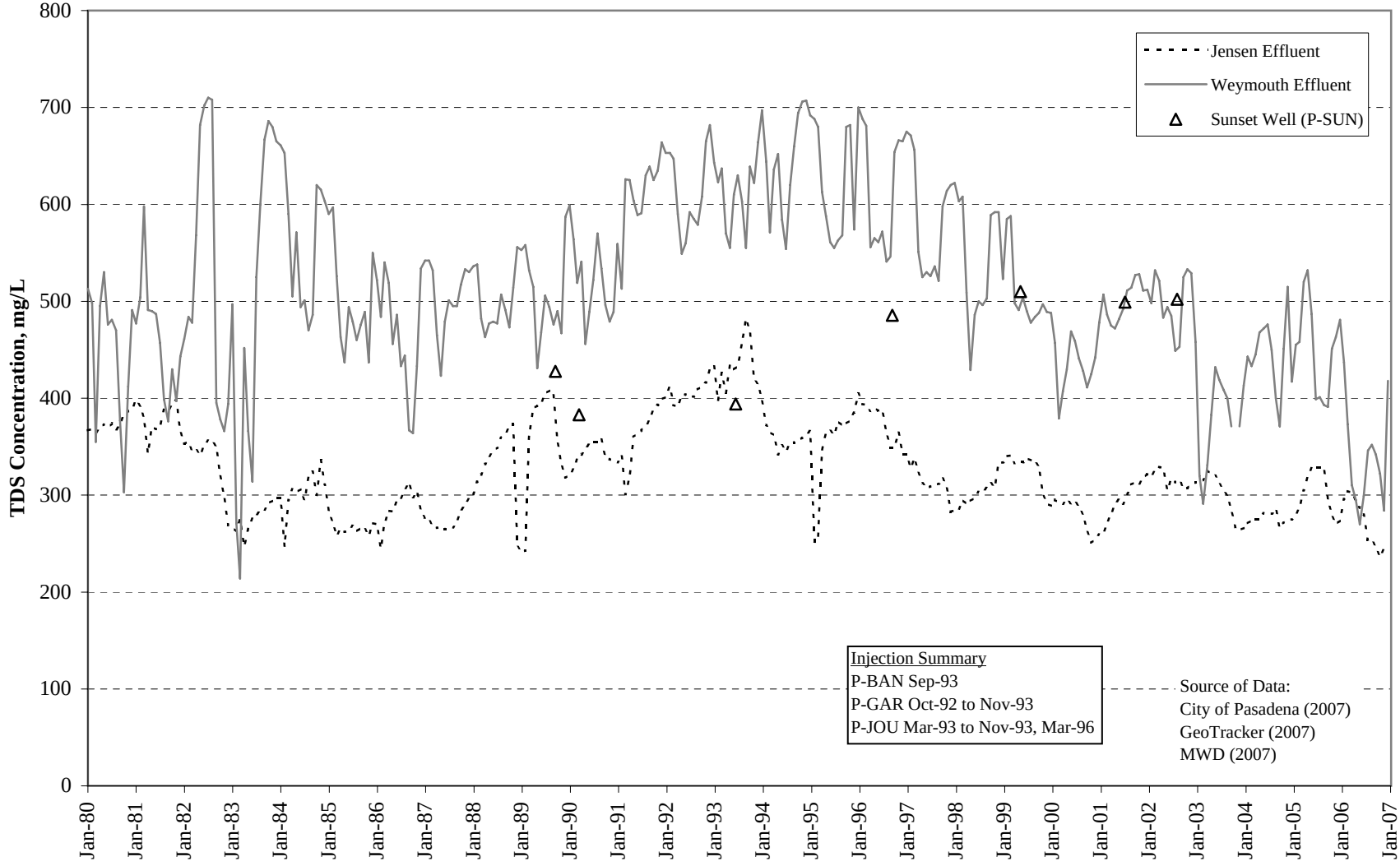

Figure 23

Monthly Average Total Dissolved Solids Concentrations in Imported Water and Bangham Well (P-BAN)

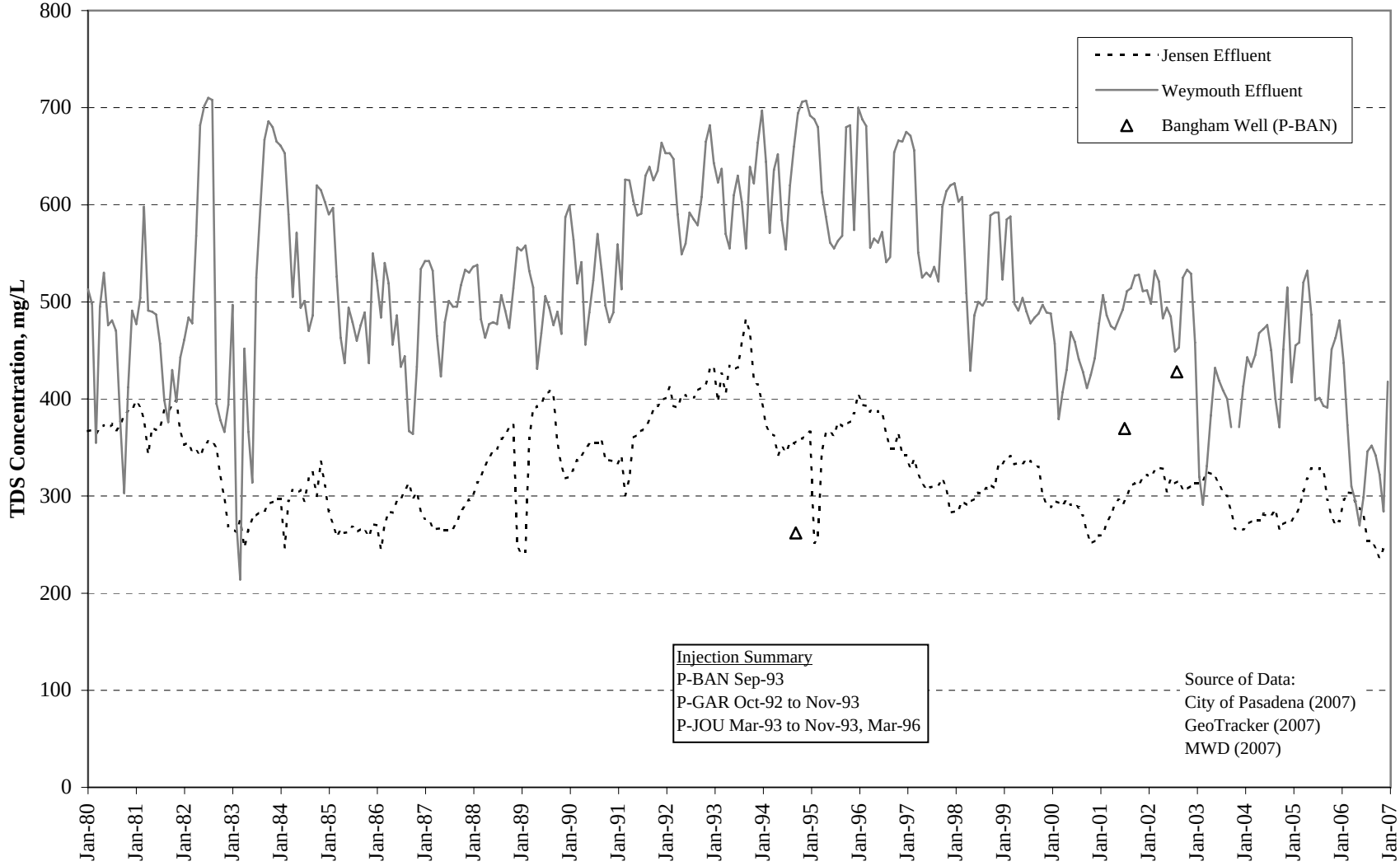

Figure 24

Monthly Average Total Dissolved Solids Concentrations in Imported Water and Copelin Well (P-COP)

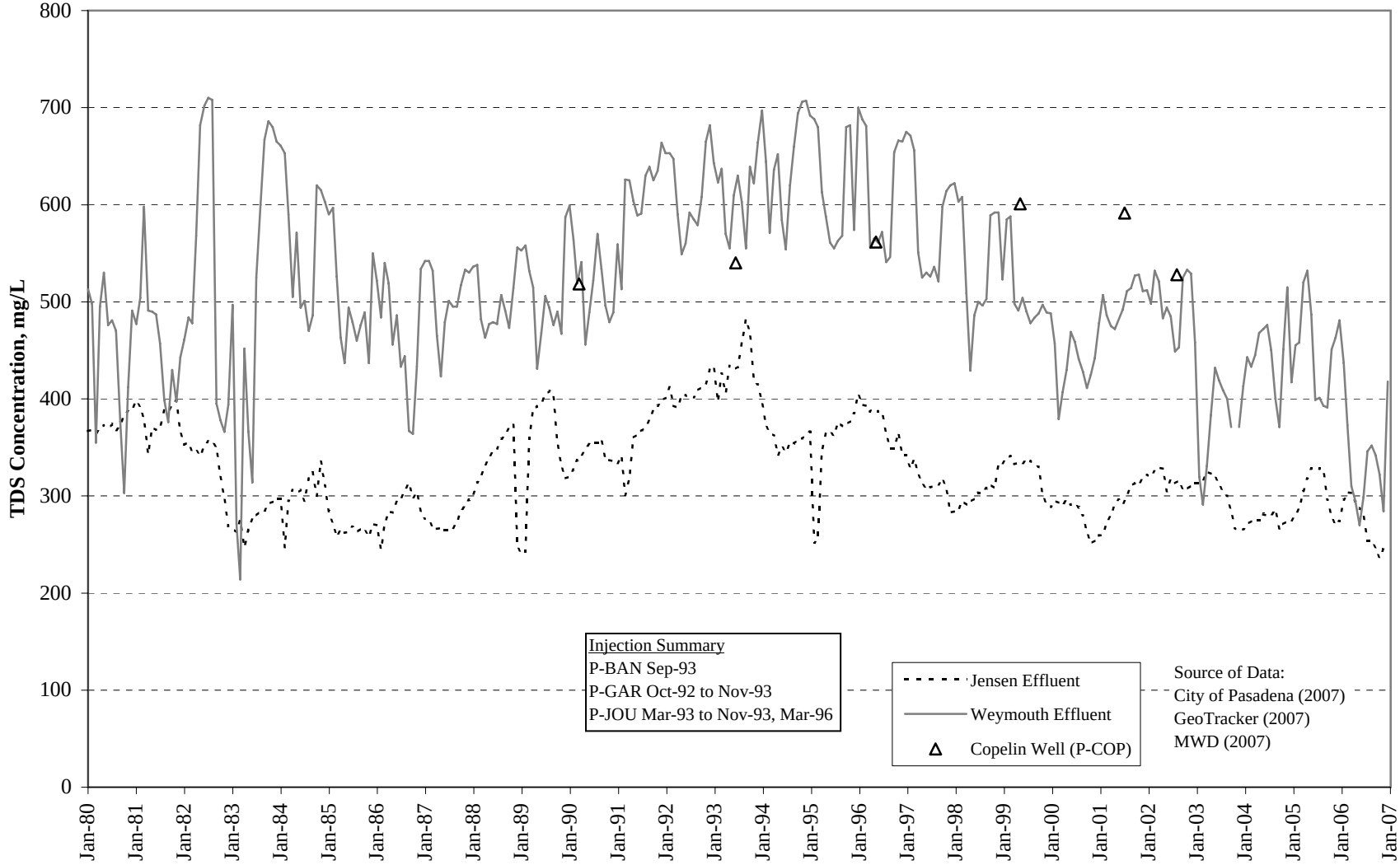

Figure 25

Monthly Average Total Dissolved Solids Concentrations in Imported Water and Villa Well (P-VIL)

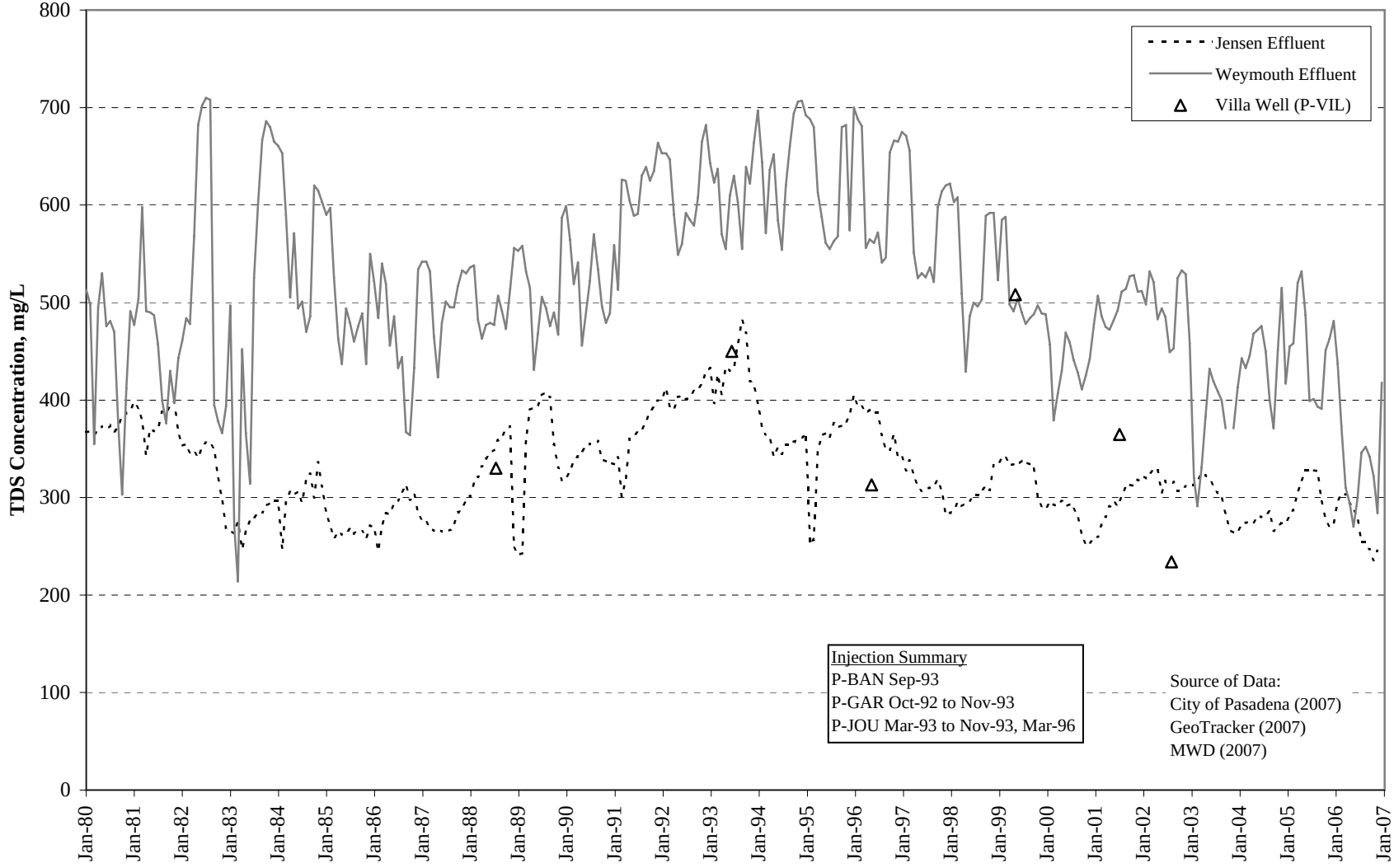

Figure 26

Monthly Average Total Dissolved Solids Concentrations in Imported Water and Garfield Well (P-GAR)

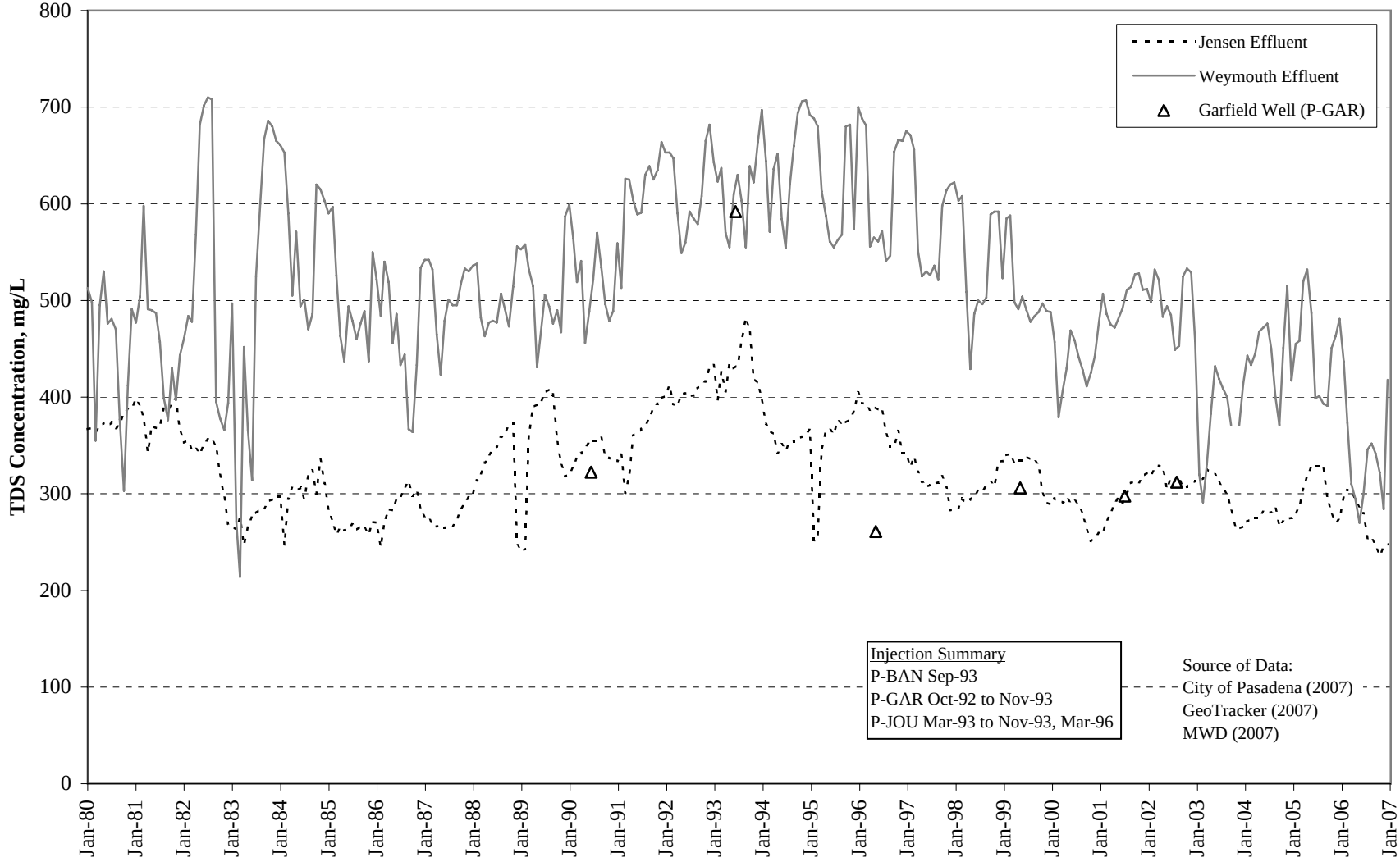

Figure 27

Monthly Average Total Dissolved Solids Concentrations in Imported Water and Valley Water Company Well 1

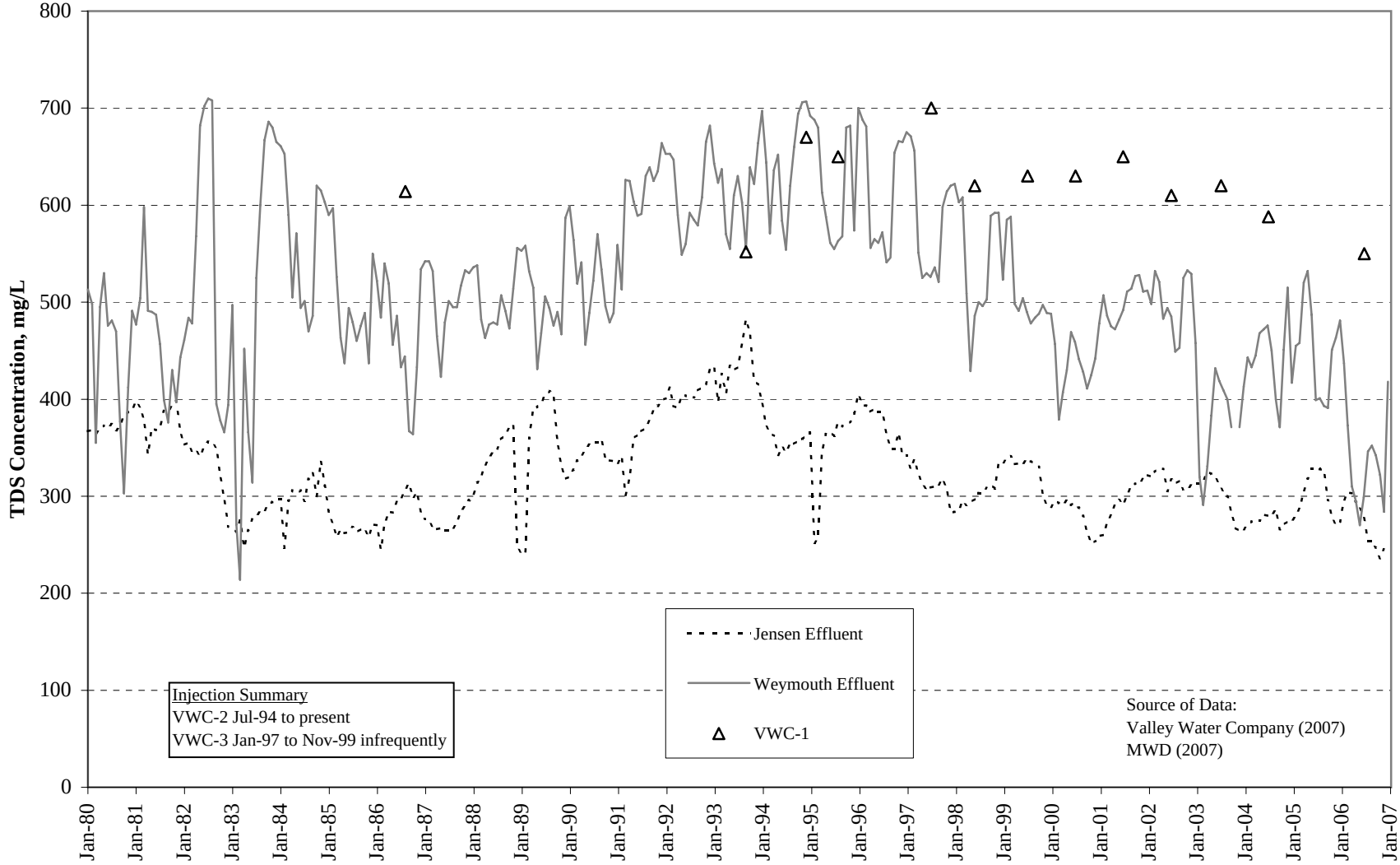

Figure 28

Monthly Average Total Dissolved Solids Concentrations in Imported Water and Valley Water Company Well 2

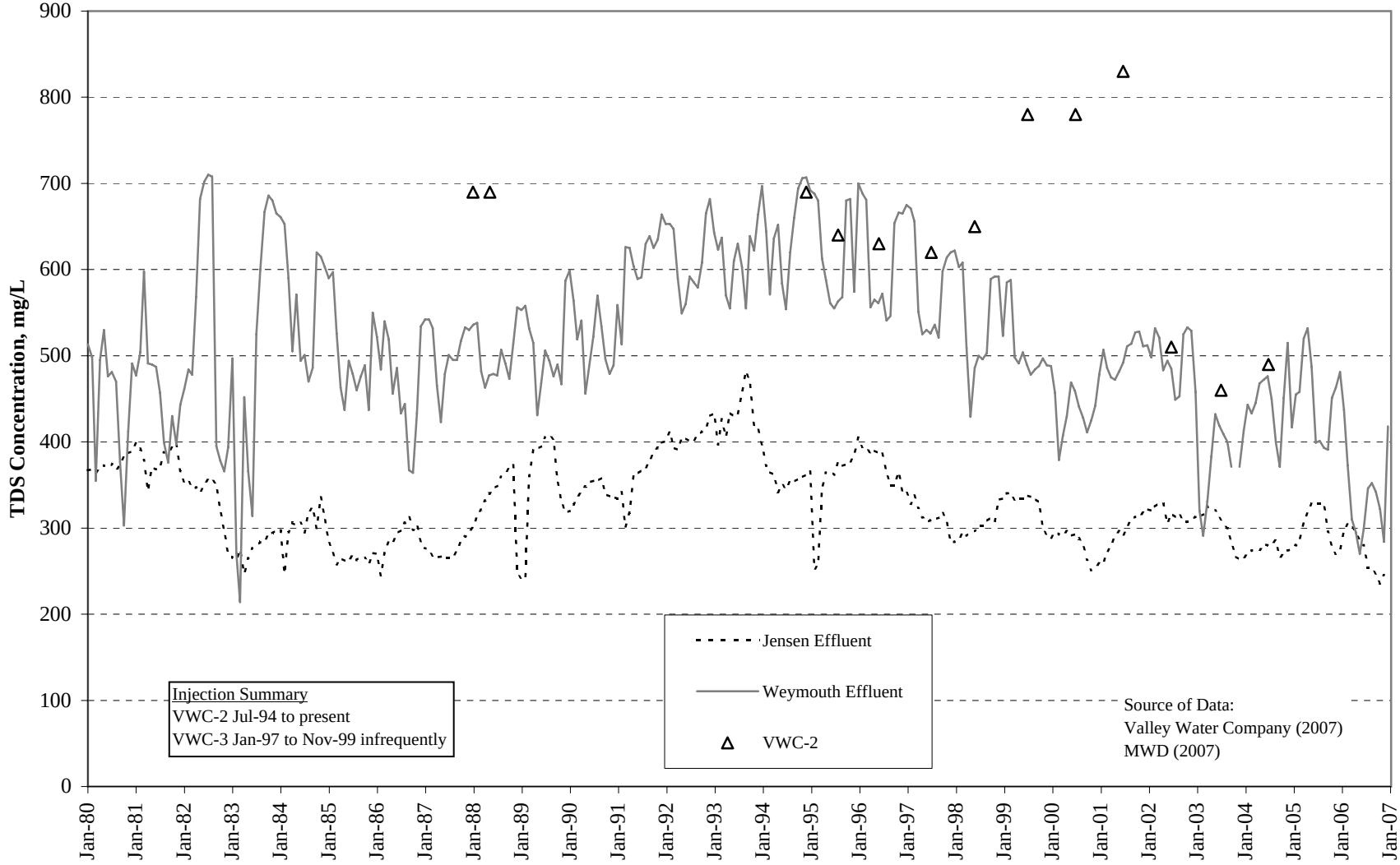

Figure 29

Monthly Average Total Dissolved Solids Concentrations in Imported Water and Valley Water Company Well 3

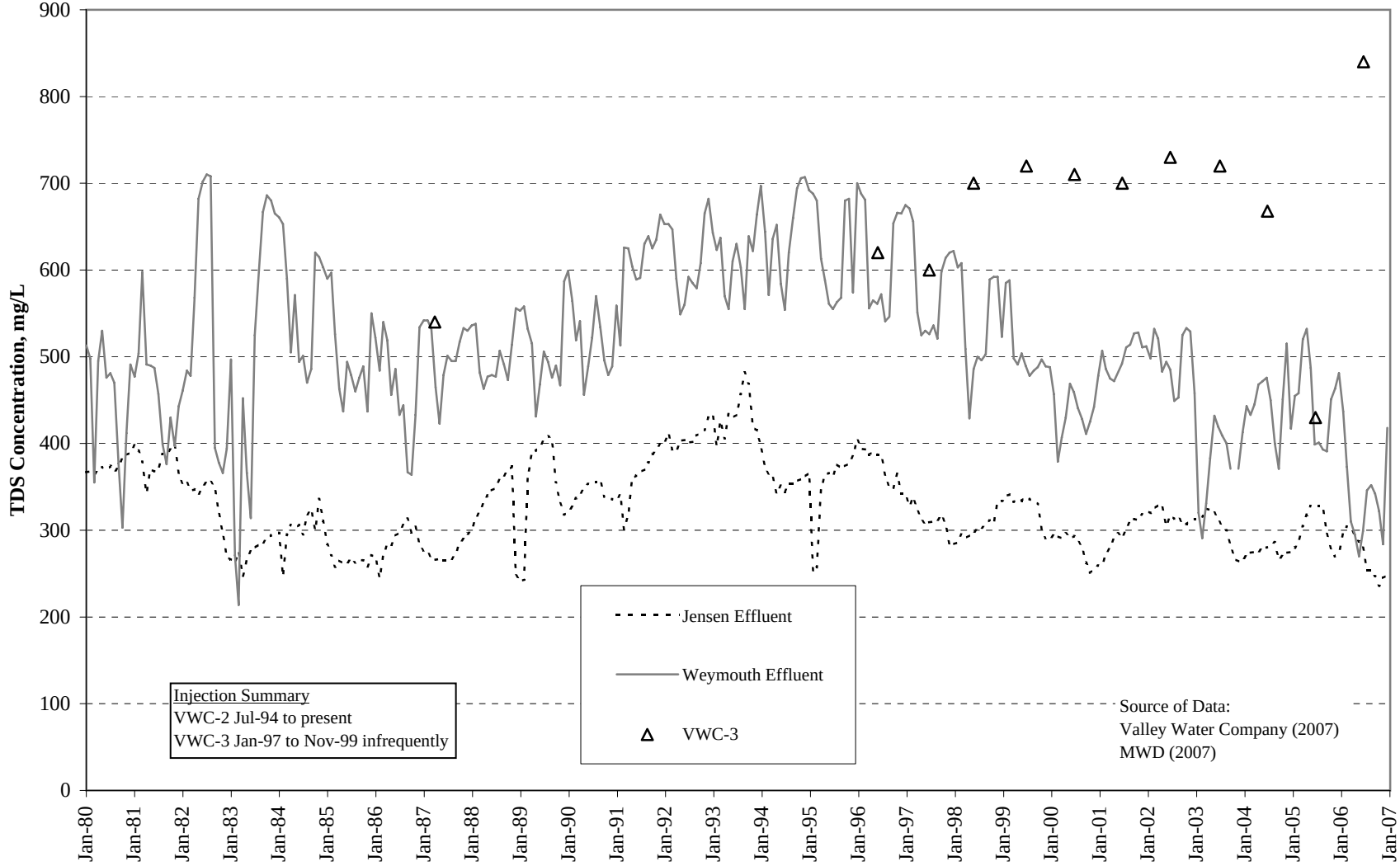

Figure 30

Monthly Average Total Dissolved Solids Concentrations in Imported Water and Valley Water Company Well 4

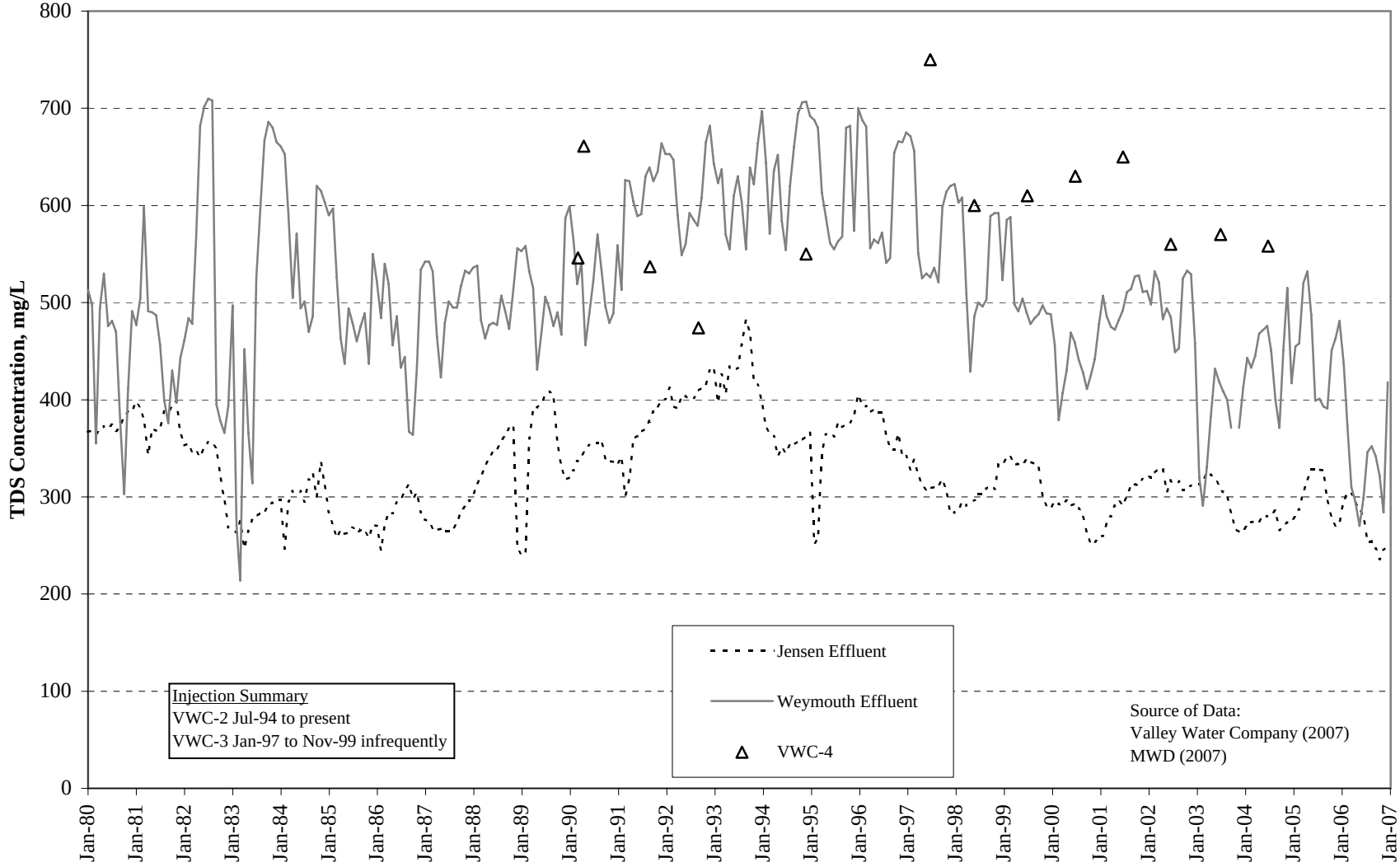

Figure 31

Monthly Average Perchlorate Concentrations in Imported Water and Sunset Well (P-SUN)

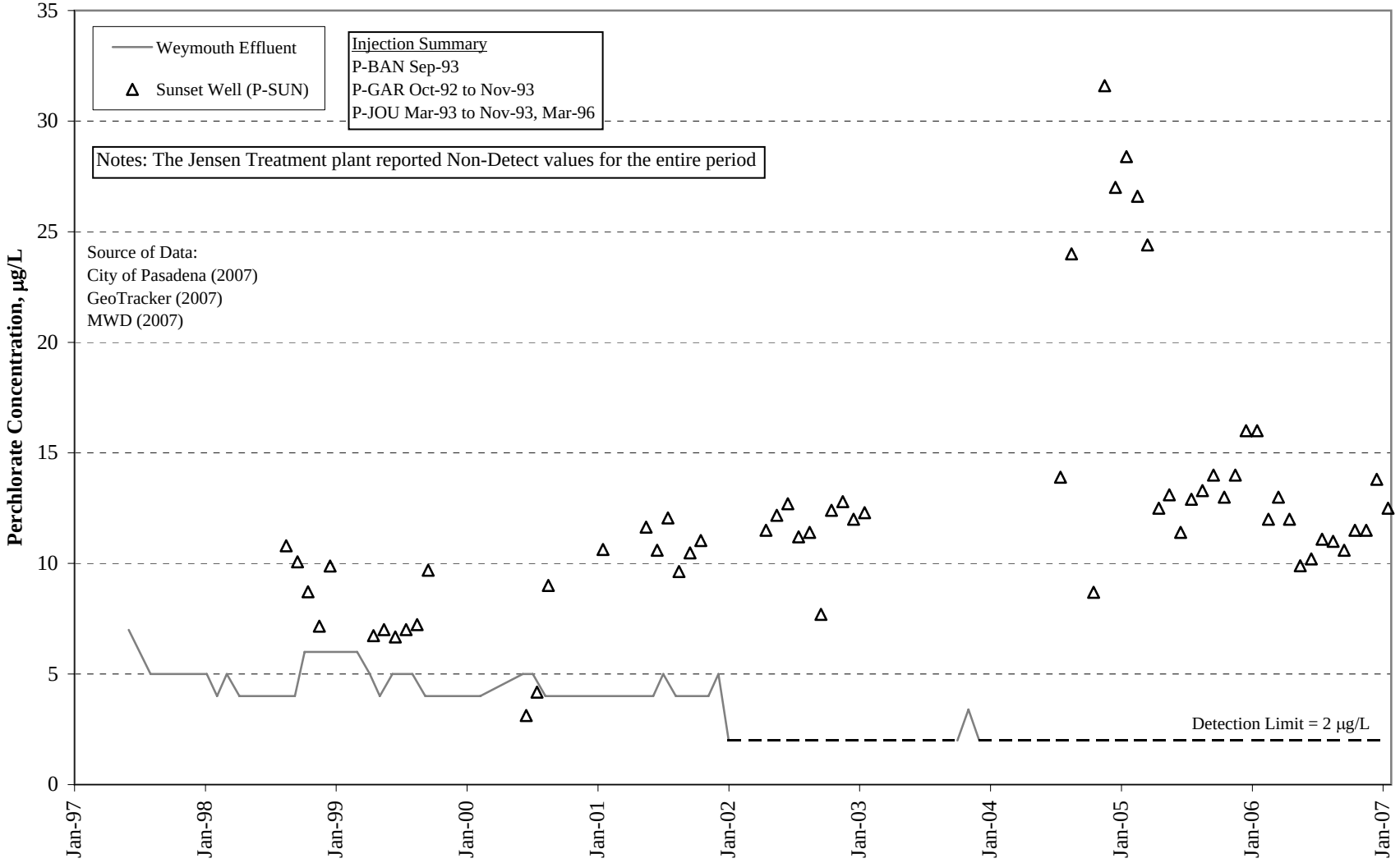

Figure 32

Monthly Average Perchlorate Concentrations in Imported Water and Bangham Well (P-BAN)

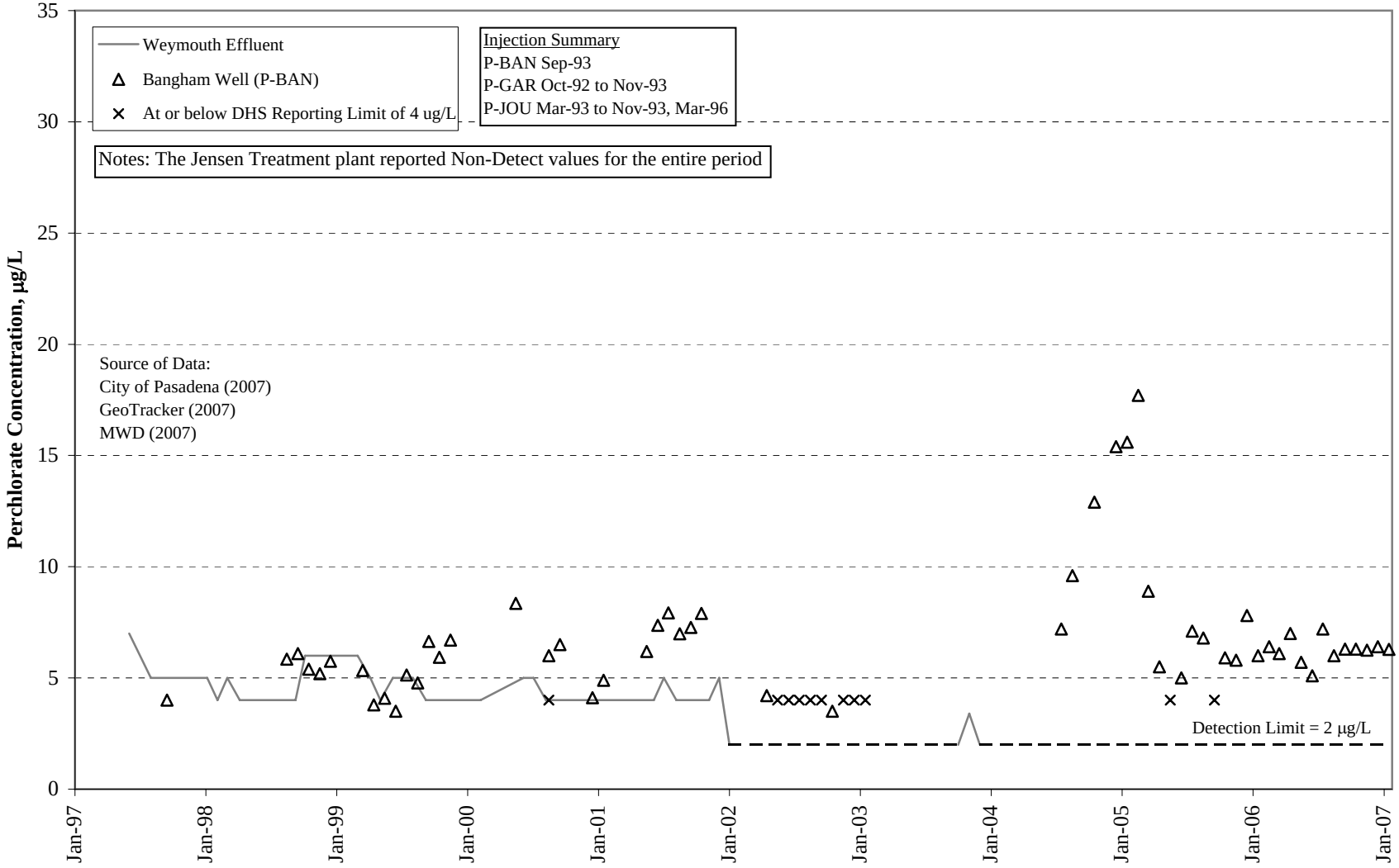

Figure 33

Monthly Average Perchlorate Concentrations in Imported Water and Copelin Well (P-COP)

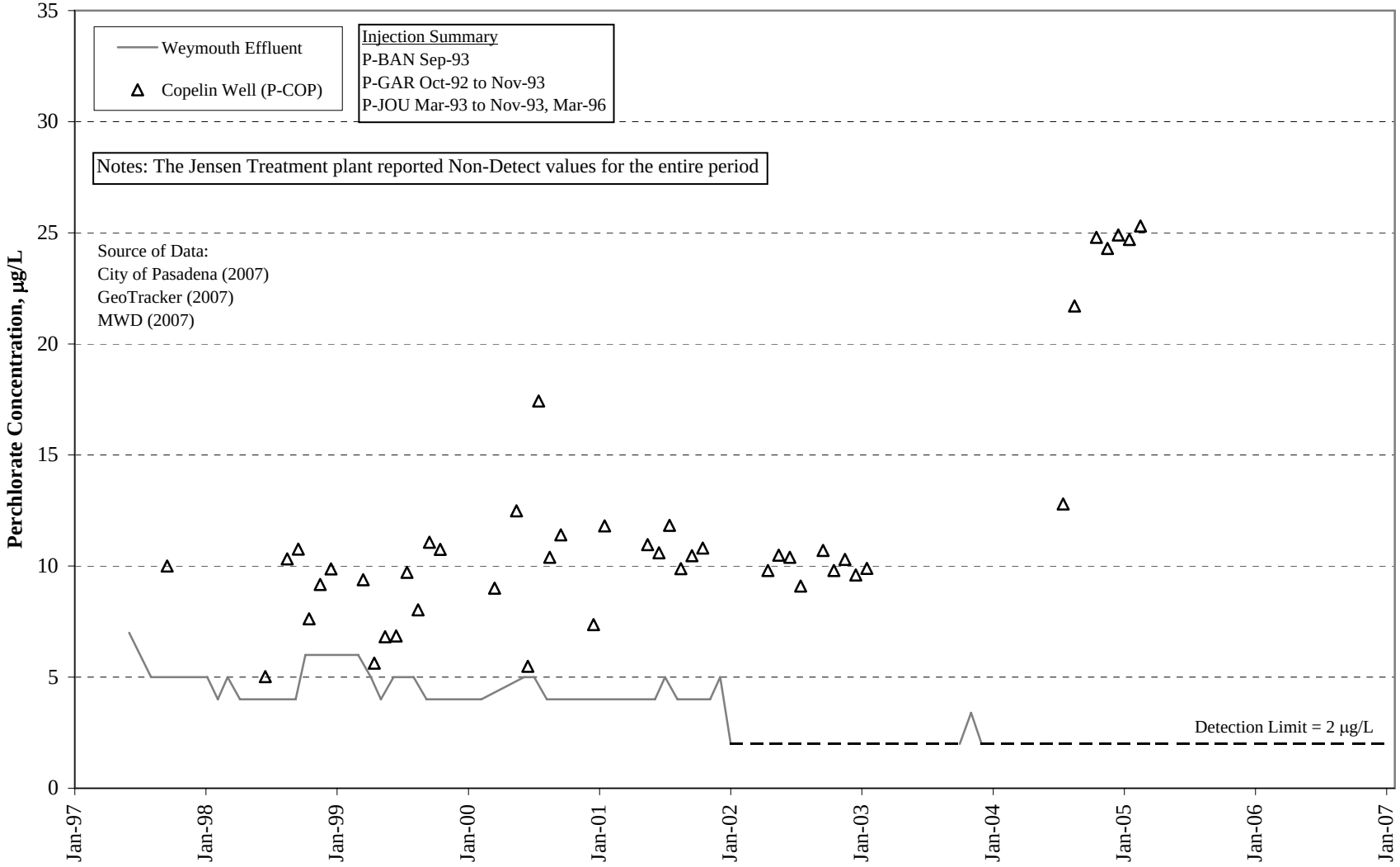

Figure 34

Monthly Average Perchlorate Concentrations in Imported Water and Villa Well (P-VIL)

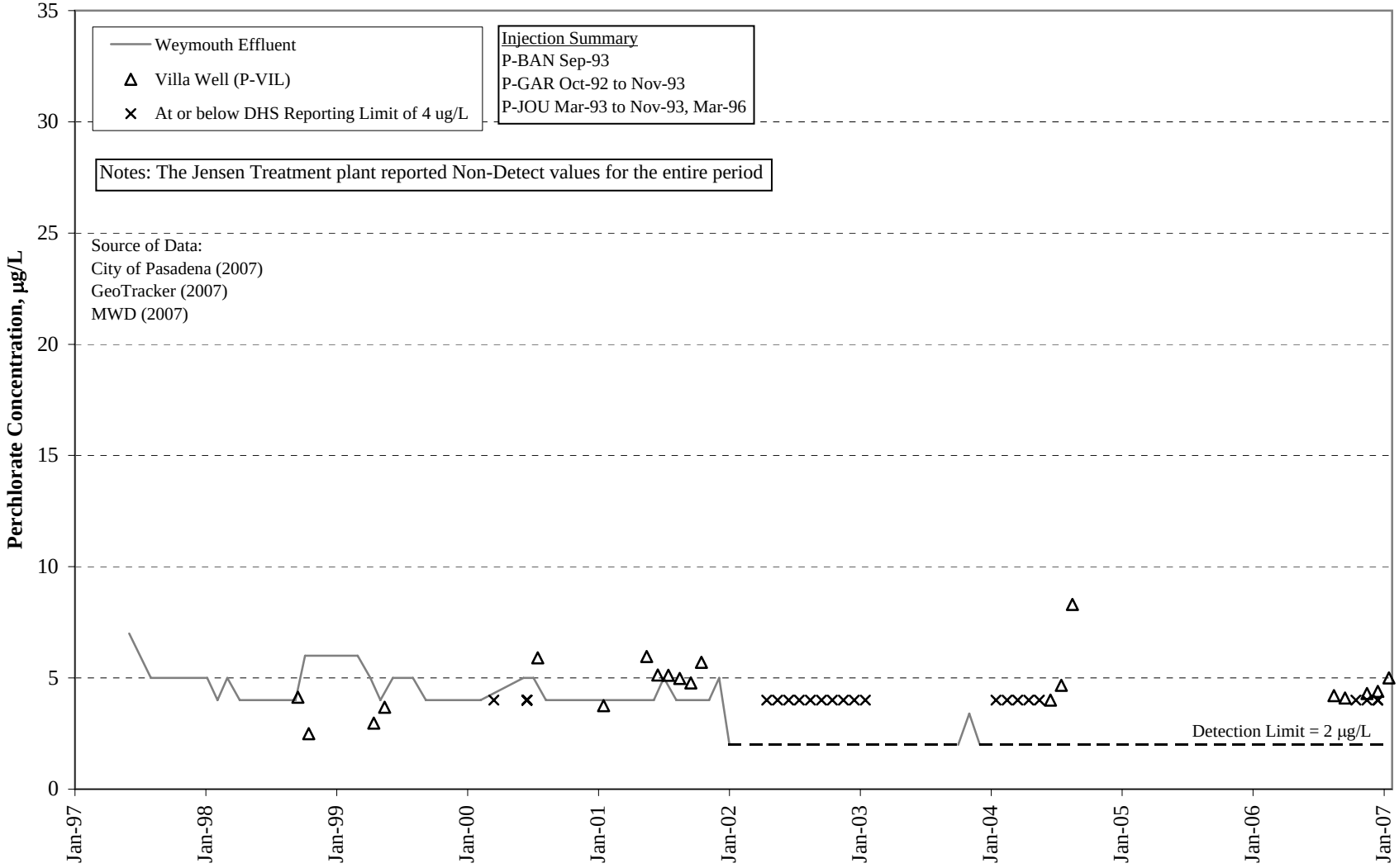

Figure 35

Monthly Average Perchlorate Concentrations in Imported Water and Garfield Well (P-GAR)

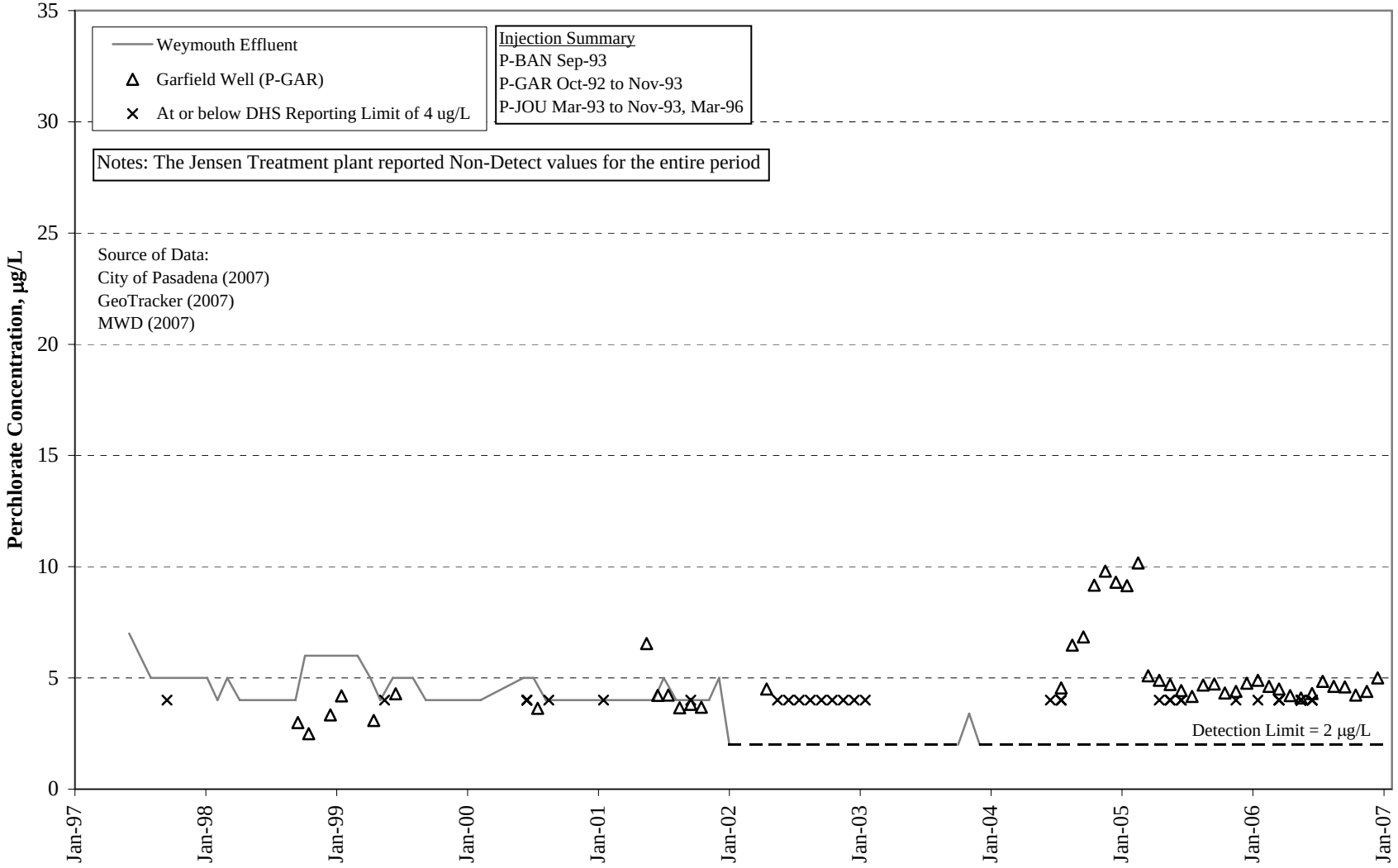

Figure 36

Monthly Average Perchlorate Concentrations in Imported Water and Valley Water Company Well 1

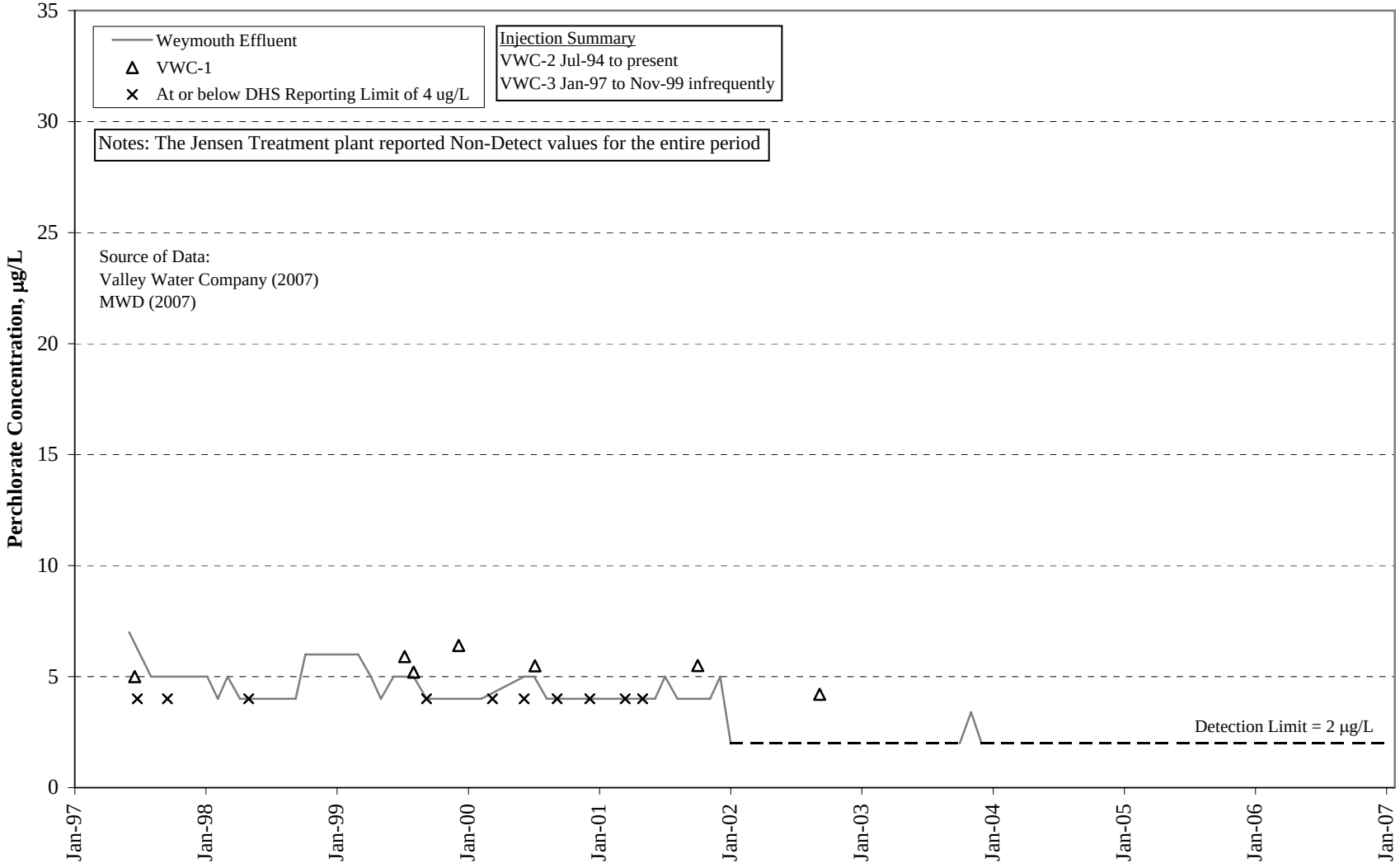

Figure 37

Monthly Average Perchlorate Concentrations in Imported Water and Valley Water Company Well 2

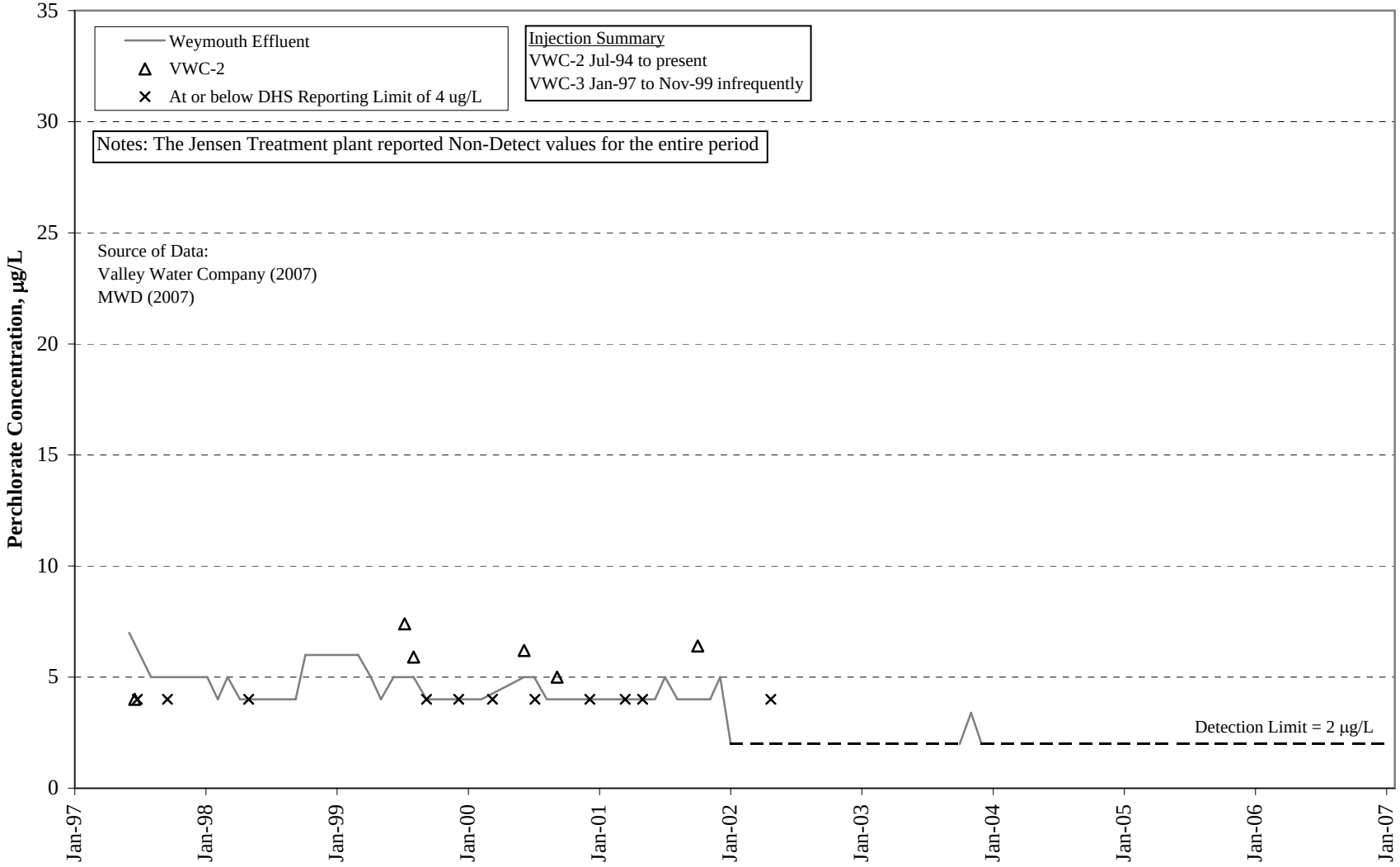

Figure 38

Monthly Average Perchlorate Concentrations in Imported Water and Valley Water Company Well 3

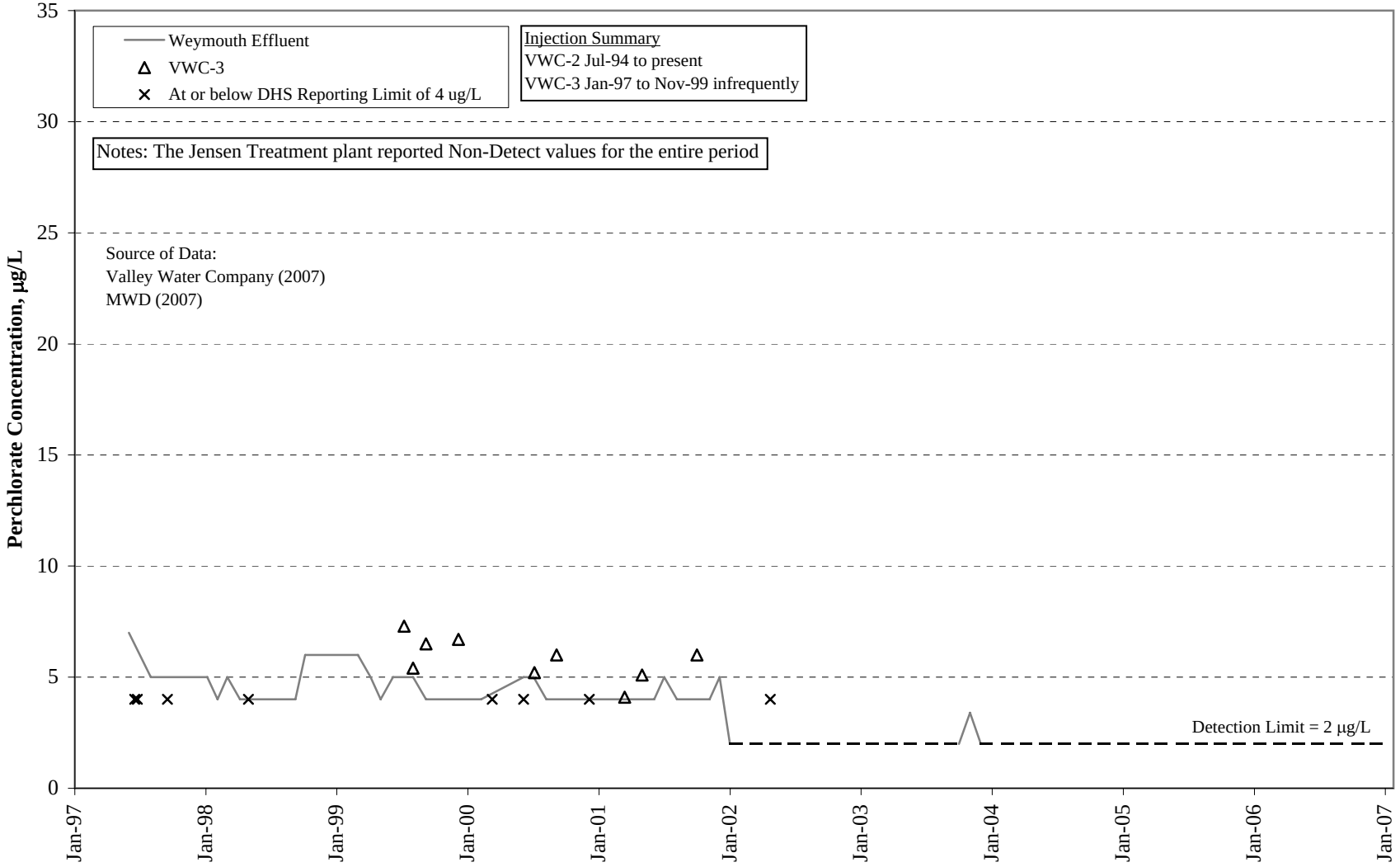

Figure 39

Monthly Average Perchlorate Concentrations in Imported Water and Valley Water Company Well 4

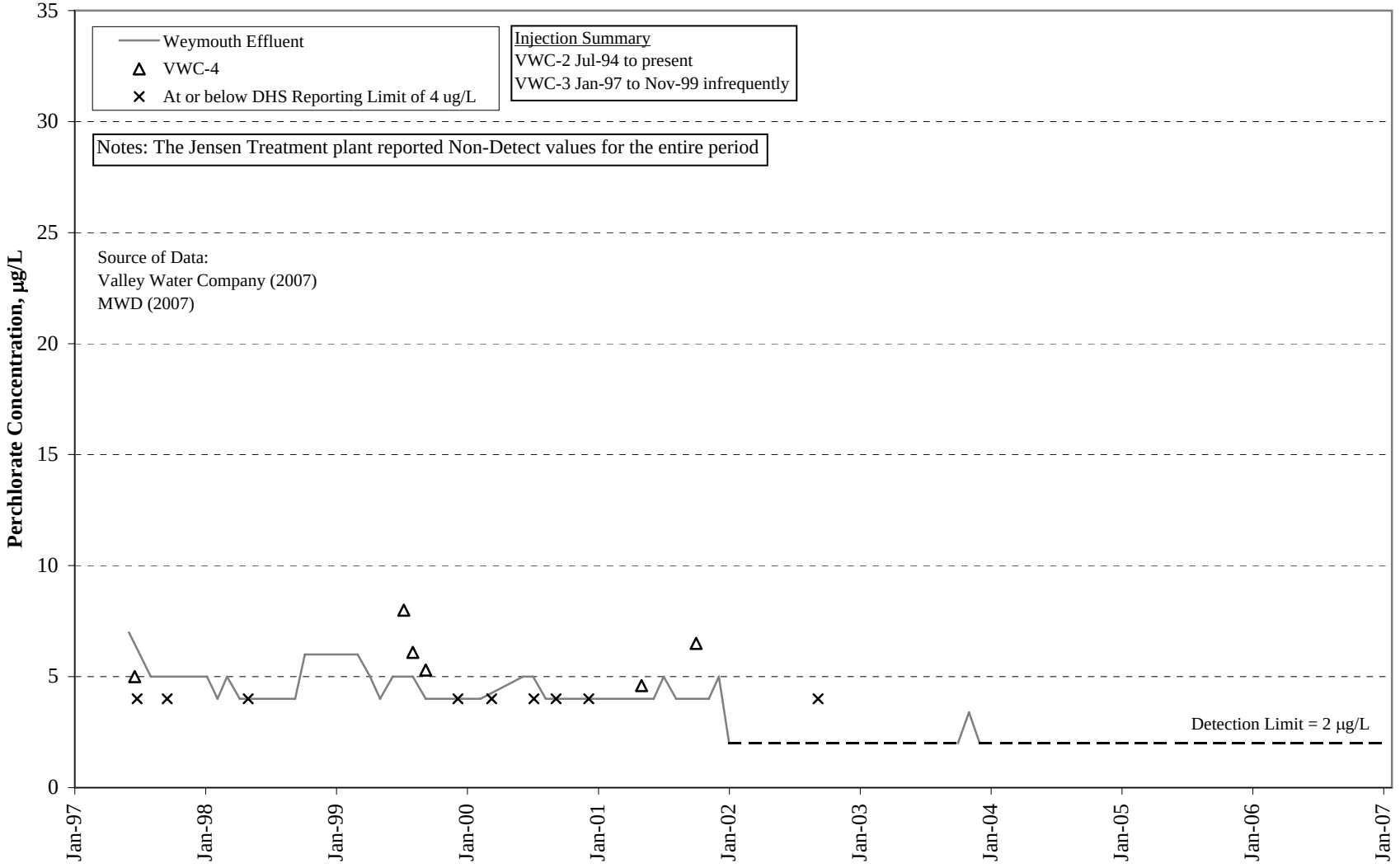

Figure 40