

NASA Comments on the August 2012 PWP Technical Memoranda

PWP Statement/Conclusion	NASA's Comments
<b>NASA's Comments on the Pasadena Water and Power (PWP) Cover Letter</b>	
<p><b>Page 1, Last Paragraph:</b> "PWP believes that the existing data is quite extensive and more than sufficient to permit determination of JPL as a definite source of perchlorate contamination of the Sunset Reservoir Wells. Further data collection would not be productive and would not change the appropriate conclusion of this issue."</p>	<p>NASA's review of PWP's May 2012 Technical Memorandum demonstrated that PWP's conclusions were not supported by all available data. The PWP memorandum misrepresented NASA's statements, presented unsubstantiated opinions, and did not consider all available data in an integrated manner.</p> <p>Dr. Sturchio's evaluation of PWP's May 2012 Technical Memorandum concluded, "<b><i>The opinions of PWP are found to be based on flawed assumptions and incogent arguments leading to erroneous and unfounded conclusions regarding the origin of perchlorate in the Sunset Reservoir wells. The PWP (2012) opinions that there is a single source of perchlorate (BMI complex) in the Sunset Reservoir wells, that Chilean nitrate fertilizer could not have contributed perchlorate to the Sunset Reservoir wells, and that all of the perchlorate in the Sunset Reservoir wells is from JPL are inconsistent with the perchlorate isotopic data and other evidence presented by NASA (2007). The available data presented by NASA (2007) indicate clearly that at least three separate types of perchlorate must have contributed to the Sunset Reservoir wells, including mostly synthetic perchlorate (of which the majority is most likely from the BMI complex via imported Colorado River water) along with locally significant amounts of residual perchlorate from Chilean nitrate fertilizer and indigenous natural perchlorate from regional atmospheric deposition. The available data do not require the presence of any JPL-sourced perchlorate in the Sunset Reservoir wells, and the NASA (2007) report makes a reasonable case that all JPL sourced perchlorate is contained in the Monk Hill sub-basin.</i></b>"</p> <p>It is worth noting that in March 2010, NASA's AI study was published in the peer-reviewed journal <i>Environmental Forensics</i>.<sup>1</sup> This supports the technical validity of NASA's findings.</p>
<p><b>Page 2, First Paragraph:</b> "PWP believes it is time to set a meeting between the interested parties. The month of September 2012 seems reasonable, and we request that the meeting occur in Pasadena."</p>	<p>NASA also believes it would be beneficial to have a meeting between interested parties. NASA continues to welcome technical discussions of both our Additional Investigation (AI)<sup>2</sup> and Responses to Comments (RTC)<sup>3</sup>, and that such technical discussions are key to moving forward productively.</p>
<b>NASA's Comments on PWP's Technical Memorandum on the Monk Hill Treatment System After One Year of Operation (August 2012)</b>	
<p><b>Page 2, Last Paragraph:</b> La Cañada – Flintridge Production Wells, "There does not appear to be</p>	<p>Considering La Cañada Irrigation District (LCID) and Valley Water Company (VWC) wells are located up-gradient of the OU-1, OU-2, and OU-3 systems, there is no potential for remedial activities at JPL to</p>

<sup>1</sup> Steve Slaten, Keith A. Fields, Susan Santos, Andrew Barton, Heather V. Rectanus, and Mohit Bhargava. 2010. "Integrated Environmental Forensics Approach for Evaluating the Extent of Dissolved Perchlorate Originating from Multiple Sources." *Environmental Forensics*, 11:72-93. March.

<sup>2</sup> NASA. 2007. *Technical Memorandum, Additional Investigation Results, National Aeronautics and Space Administration, Jet Propulsion Laboratory, Pasadena, California*. Prepared by Battelle for the National Aeronautics and Space Administration. January.

<sup>3</sup> NASA. 2008. *Responses to Comments on the Additional Investigation Results, National Aeronautics and Space Administration, Jet Propulsion Laboratory, Pasadena, California*. Prepared by Battelle for the National Aeronautics and Space Administration. December.

### NASA Comments on the August 2012 PWP Technical Memoranda

PWP Statement/Conclusion	NASA's Comments
any change in concentration based on changes in operation of the three operable units."	impact concentrations in these wells. Current and historical chemical levels from the La Cañada-Flintridge area need to be evaluated concerning perchlorate in the Sunset Reservoir Wells based on the flow paths and travel times. In particular, one must consider the historical data from MW-21 presented in NASA's AI Technical Memorandum, indicating a more significant source of perchlorate upgradient of JPL.
<b>Page 3, First Paragraph:</b> La Cañada – Flintridge Monitoring Wells, "There does not appear to be any change in concentration based on changes in operation of the three operable units."	Considering MW-14 is located up-gradient and MW-21 is located cross-gradient of the OU-1, OU-2, and OU-3 systems, there is no potential for remedial activities at JPL to impact concentrations in these wells. Current and historical chemical levels from the La Cañada-Flintridge area need to be evaluated concerning perchlorate in the Sunset Reservoir Wells based on the flow paths and travel times. In particular, one must consider the historical data from MW-21 presented in NASA's AI Technical Memorandum, indicating a more significant source of perchlorate upgradient of JPL.
<b>Page 3, Last Paragraph:</b> JPL Monitoring Wells West of the Arroyo Seco, "The decline in concentration of perchlorate in the monitoring wells that had very high concentrations of perchlorate (MW-7, MW-16, and MW-24) and were located near the disposal sites were clearly associated with the operation of OU-1 which began in 2005. Other monitoring wells, located further from the disposal sites and having overall lower concentrations of perchlorate, have not shown decreases, whether located west (MW-6) or east. Interestingly MW-3-2 and MW-3-3 show exactly inverted curves, with the concentration dropping to <DLR for one and rising above it for the other in late 2001, early 2002. This coincides with the Monk Hill Wells being taken out of operation."	<p>NASA concurs with PWP's statement that the OU-1 Source Area Groundwater Treatment System has reduced chemical levels in MW-7, MW-16, and MW-24. All three of these monitoring wells are located within the treatment zone of the OU-1 system.</p> <p>Perchlorate concentrations in MW-6 have generally remained below the California Maximum Contaminant Level (MCL) from Aug/Sep 1996 – Apr/May 2012 with two exceptions: 15.4 µg/L (April/May 2002) and 9.9 µg/L (Mar/April 2006). MW-6 is cross-gradient of the OU-1 treatment system and outside the treatment zone, so changes in chemical levels are most likely not associated with operation of the OU-1 system.</p> <p>Prior to initiating treatment, dissolved chemical mass was migrating southeast from the source area toward the Arroyo Well, Well 52, and the LAWC wells. The OU-2 system addressed volatile chemicals in the unsaturated zone, thus reducing chemical mass migrating downward to groundwater. The OU-1 Source Area Groundwater Treatment System addresses source area groundwater near MW-7, MW-16, and MW-24. Monitoring data show that chemicals had already migrated outside the source area before the OU-1 system was brought online in early 2005. Therefore, an increase, and a subsequent decrease, in perchlorate concentrations could be expected at certain wells (e.g., MW-3, MW-4, and MW-12) as the dissolved plume migrates down-gradient in the direction of the MHTS and LAWC system capture zones. In particular, MW-3-2 shows increasing concentrations beginning in 2003, peaking in 2008 (at 270 µg/L), and then dropping to low or non-detectable concentrations by 2012. This is a typical distribution of dissolved chemical mass migrating past a fixed point (Gaussian distribution curve)<sup>4</sup>.</p>
<b>Page 4, First Paragraph:</b> East Monk Hill Sub-Basin Production Wells, "...it would appear that the	Over the next 10 years, NASA expects that implementation of the OU-1, OU-2, and OU-3 systems will significantly lower perchlorate concentrations in Arroyo Well, Well 52, LAWC#3, and LAWC#5. The

<sup>4</sup> 2012. Kueper, Bernar. *Princeton Remediation Course*. Lecture and course materials. <http://www.princeton-groundwater.com/remediation-course.htm>.

### NASA Comments on the August 2012 PWP Technical Memoranda

PWP Statement/Conclusion	NASA's Comments
operation of OU-1 and OU-2 did not have any impact on the perchlorate concentrations of these production wells."	capture zones of these four wells intersect the JPL site. The capture zones of Ventura Well and Las Flores Water Company Well No. 2 (LFWC#2) are not within the JPL plume, so there is no potential for remedial activities at JPL to impact concentrations in these wells.
<b>Page 4, Second Paragraph:</b> East Monk Hill Sub-Basin Monitoring Wells, "The lowering concentrations seen on the JPL site do not appear to have impacted the monitoring or production wells east of the Arroyo Seco; however, shutting off the Monk Hill Wells seems to have resulted in increasing concentrations in some monitoring wells, but not others."	<p>NASA expects chemical concentrations in MW-18 and MW-17 to decrease with time as a result of the OU-1, OU-2, and OU-3 treatment systems.</p> <p>Chemical concentrations in MW-19 have generally been low and are representative of groundwater from La Cañada-Flintridge, flowing to the south of the JPL facility.</p> <p><b>It is important to note that the August 2012 PWP technical memorandum omits evaluation of chemical data from MW-20, MW-26, and the Rubio Cañon Land and Water Association (RCLWA) wells, which support NASA's technical analysis that the leading edge of the JPL plume has been established and is contained within the Monk Hill Subarea<sup>3</sup>.</b></p>
<b>Page 5, First Paragraph:</b> Sunset Reservoir Wells, "The travel time for water moving from the Monk Hill Sub-Basin to western Pasadena Sub-Basin is anywhere from seven to 21 years (Figure 10). Further, the Pasadena Sub-Basin is considerably longer, wider, and deeper and has considerably larger volume of water in it (Figure 11). Thus it would be entirely reasonable to expect that even if the Monk Hill wells were shut down for nine years (2002-2011) that there would be no measurable impact upon the concentrations of perchlorate in the Sunset Reservoir Wells even if there once had been containment."	<p>NASA has discussed extensively that two independent groundwater flow models have demonstrated that the Monk Hill production wells (in particular Arroyo Well, Well 52, LAWC#3, and LAWC#5) effectively contain groundwater from the JPL source area<sup>2,3</sup>. Furthermore, particle tracking results from the RBMB Groundwater Model show that the Sunset Reservoir Wells capture groundwater from the La Cañada-Flintridge area, and not from the vicinity of the JPL source area.</p> <p>NASA has several questions/observations regarding Figure 10:</p> <ol style="list-style-type: none"> <li>1. It is unclear as to how the groundwater flow transit paths and travel times/flow velocities were estimated. A detailed explanation of the assumed pumping conditions (i.e., which wells are operational) and the assumed groundwater/chemical flow conditions (i.e., advective conditions or attenuated flow) used to perform the transit path and travel timeframe estimates are needed to establish the technical validity of Figure 10.</li> <li>2. It appears that the groundwater transit paths were drawn by hand (i.e., not using groundwater flow model particle tracking), and that the transit paths ignore operation of Monk Hill production wells.</li> <li>3. Particle tracking simulations performed using the JPL and RBMB groundwater flow models show that the starting locations of the middle two transit paths are within the capture zone of the Well 52; even if these transit paths originate further downgradient, they would be captured by the LAWC or RCLWA wells (note, both LAWC wells and RCLWA#7 are not shown in Figure 10).</li> <li>4. The far left transit path would be representative of water flow from La Cañada-Flintridge, not JPL<sup>2</sup>.</li> </ol> <p>Regarding Figure 11, it would be useful to include the location of this cross section line on a plan view</p>

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<p><b>Page 5, First Paragraph:</b> Sunset Reservoir Wells, "However, these results are entirely consistent with PWP's contention that no containment had ever been achieved and that the steady levels of perchlorate over time represent the fact that there was as much blending of water from La Cañada Flintridge with Monk Hill area water before the shutdown of Monk Hill wells and after."</p>	<p>map to illustrate the location of the Pasadena sub-basin in relation to the Monk Hill production wells and JPL source area.</p> <p>PWP's contention is based on several flawed assumptions that were presented in PWP's May 2012 Technical Memorandum. Specifically:</p> <ol style="list-style-type: none"> <li>1. PWP does not account for containment by production wells in Monk Hill Subarea discussed extensively in NASA's 2008 RTC<sup>3</sup>.</li> <li>2. PWP does not consider evidence that the leading edge of NASA's perchlorate plume has been established, discussed extensively in NASA's 2008 RTC<sup>1</sup>.</li> <li>3. PWP does not account for historical data from MW-21 presented in NASA's AI Technical Memorandum indicating a more significant source of perchlorate in the La Cañada-Flintridge area.</li> <li>4. PWP does not consider the perchlorate isotope data collected by NASA, which does not support their contention.</li> <li>5. PWP does not account for other potential sources of perchlorate in the Sunset Reservoir wells, including Chilean Nitrate fertilizers. PWP's underlying assumption is that there are only two sources of perchlorate in the basin (JPL and La Cañada-Flintridge). The perchlorate isotope data indicate that this is not true. PWP does not consider that perchlorate associated with imported water could have entered the aquifer near the Sunset Reservoir wells from areas other than La Cañada-Flintridge (e.g., the golf course near the Rose Bowl).</li> </ol> <p>The results observed at the Sunset Reservoir Wells are consistent with NASA's conclusions<sup>2,3</sup>. Specifically, the perchlorate in the Sunset Reservoir Wells had not originated from the JPL, but was a mix of one or more non-JPL, synthetic source(s) along with a substantial amount of naturally occurring perchlorate.</p>
<p><b>NASA's Comments on PWP's Technical Memorandum on Stable Isotope Analysis of Industrial Sources of Perchlorate, Raymond Basin Well Samples, and Biodegradation (August 2012)</b></p>	
<p><b>Page 2, Second Paragraph:</b> "This brief memorandum will attempt to demonstrate two points: 1) the normal process of manufacturing perchlorate (electrolysis followed by anodic oxidation) normally produces a range of <math>\delta^{18}\text{O}</math> through mass-dependent fractionation and that any manufacturer will produce products with that same range...2) even if were possible, biodegradation of perchlorate in groundwater would alter those "fingerprints."</p>	<p>NASA asked Dr. Neil Sturchio (the author or co-author of every peer-reviewed article cited by PWP in this technical memorandum) to review PWP August 2012 memorandum. Dr. Sturchio's review, provided as Attachment A, concludes, "...PWP's position that different manufacturers do not produce isotopically distinct perchlorate is completely untenable in view of the available data," and, with regard to biodegradation of perchlorate, "PWP (August 2012) has made a fatal error in their analysis of these data. They apparently do not understand the definition of <math>\Delta^{17}\text{O}</math>."</p>

**NASA Comments on the August 2012 PWP Technical Memoranda**

PWP Statement/Conclusion	NASA's Comments
<p><b>Page 6, First Paragraph:</b> Conclusions, "Contrary to the assertions of NASA's 2007 TM, using the <math>\delta^{18}\text{O}</math> cannot distinguish on industrial source from another...Since there is naturally very little variability in <math>\Delta^{17}\text{O}</math>, it is the most sensitive measure of anaerobic biodegradation. Using this tool, there is clear evidence that anaerobic biodegradation is occurring."</p>	<p>Regarding PWP's conclusion, Dr. Sturchio remarked (see Attachment A), "<i>the elevated <math>\Delta^{17}\text{O}</math> values discussed by PWP (August 2012) and shown in their Figure 5 have absolutely no relationship to biodegradation or any other mass-dependent fractionation process; rather, they clearly indicate the presence of a natural perchlorate contribution to groundwater in these Raymond Basin wells.</i>"</p>

## **Attachment A**

**Dr. Neil Sturchio's Comments on Pasadena Water and Power's August 2012 "Technical Memorandum on Stable Isotope Analysis of Industrial Sources of Perchlorate, Raymond Basin Well Samples, and Biodegradation"**

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COMMENTS ON PASADENA WATER AND POWER'S "TECHNICAL MEMORANDUM ON  
STABLE ISOTOPE ANALYSIS OF INDUSTRIAL SOURCES OF PERCHLORATE, RAYMOND  
BASIN WELL SAMPLES, AND BIODEGRADATION"

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NEIL C. STURCHIO, PH.D.

**Prepared for:** Tidewater, Inc.  
**Date:** August 30, 2012



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Neil C. Sturchio, Ph.D.

## 1.0 Introduction

The Pasadena Water and Power Company (PWP) produced a 14-page document in August 2012 titled “*Technical Memorandum on Stable Isotope Analysis of Perchlorate, Raymond Basin Well Samples, and Biodegradation*”. In that memorandum, PWP argues against the conclusions of NASA as presented in the January 2007 document titled “*Technical Memorandum: Additional Investigation Results*” [hereafter referred to as NASA (2007)]. Specifically, PWP (August 2012) attempts to discredit NASA’s (2007) conclusions based on stable isotope analysis of perchlorate from the Raymond Basin wells. In this commentary, it is shown that PWP (August 2012) makes unfounded and erroneous assertions regarding the interpretation of stable isotope data for perchlorate in the Raymond Basin wells.

## 2.0 PWP (August 2012) Discussion Points

PWP (August 2012) organized its arguments into discussions of two separate points, as follows:

Discussion Point 1: “*The normal process of manufacturing perchlorate (electrolysis followed by anodic oxidation) normally produces a range of  $\delta^{18}\text{O}$  through mass-dependent fractionation and that any manufacturer will produce products with that same range. Thus, the degree of depletion of  $\delta^{18}\text{O}$  cannot be used to “fingerprint” the manufacturer of one perchlorate sample as opposed to another*”.

Discussion Point 2: “*Even if it were possible [to fingerprint manufacturers], biodegradation of perchlorate in groundwater would alter those “fingerprints”. Anaerobic bacteria consume  $^{16}\text{O}$  preferentially over  $^{18}\text{O}$ , changing the ratio ( $\delta^{18}\text{O}$ ) “smudging” the SIA fingerprint. This process can be clearly seen when examining the ratio of  $^{17}\text{O}$  to  $^{16}\text{O}$  ( $\Delta^{17}\text{O}$ ). There is a pronounced difference in the depletion of  $\Delta^{17}\text{O}$  between industrial samples and samples collected from wells in the Raymond Basin.*”

### 2.1 Response to PWP (August 2012) Discussion Point #1

PWP asserts that the normal perchlorate manufacturing process produces perchlorate having a range of  $\delta^{18}\text{O}$  values, such that perchlorate from any perchlorate manufacturer would be indistinguishable from that of any other perchlorate manufacturer. PWP notes that the range in perchlorate  $\delta^{18}\text{O}$  values presented in Figures 16 and 17 of the NASA (2007) is similar to the range in  $\delta^{18}\text{O}$  values of perchlorate in laboratory reagents and production materials reported by Sturchio et al. (2006). PWP then states “*What this data strongly suggests is that the range of  $\delta^{18}\text{O}$  seen in the Raymond Basin well samples does not represent a series of different unique ranges from different manufacturers, but is simply the natural range of the industrial process for the production of perchlorate.*”

There are several obvious problems with PWP’s position. First, PWP does not cite any data in support of its argument that all perchlorate manufacturers produce perchlorate having the same range in isotopic composition. Second, not all of the perchlorate reagents and production materials analyzed by Sturchio et al. (2006) were from the same manufacturer, and the two

identified manufacturing localities in that study produced isotopically distinct perchlorate. For example, the perchlorate samples manufactured by Western Electrochemical at their Cedar City, Utah plant have a narrow range in  $\delta^{18}\text{O}$ , from -22.3 to -20.4 ‰, and the isotopic fractionation of oxygen during production of a single batch of perchlorate in June 2004 yielded a difference of -7 ‰ in  $\delta^{18}\text{O}$  between the water used in the reaction and the perchlorate product. This indicates that perchlorate should generally have a  $\delta^{18}\text{O}$  value that is systematically related to that of the local water supply used by the manufacturer. Sturchio et al. (2006) also give isotopic data for perchlorate extracted from groundwater at the former BMI Complex site in Henderson, NV and from surface water from Las Vegas Wash, and these two samples had similar values of  $\delta^{18}\text{O}$  (-15.0 and -14.5 ‰, respectively), which are significantly different from those of the perchlorate manufactured later in Cedar City, Utah. Furthermore, unpublished data from archived BMI complex samples show typical  $\delta^{18}\text{O}$  values of -16.9 to -15.4 ‰, and unpublished data for perchlorate extracted from groundwater wells at the Arkema, Inc. site (formerly Pennsalt Chemicals Corp., which manufactured perchlorate from 1958-1965 in Portland, OR) show relatively low  $\delta^{18}\text{O}$  values of -23.8 to -22.9 ‰ (ESTCP Project 200509). The perchlorate sample from EM Corp. having a distinct  $\delta^{37}\text{Cl}$  value of -3.1 (Sturchio et al., 2006) was manufactured in Darmstadt, Germany by an affiliate of Merck (personal communication, B. Gu, Oak Ridge National Laboratory). Thus, from the four known perchlorate manufacturers we can identify  $\Delta$  with certainty (BMI Complex in Nevada, Western Electrochemical in Utah, Pennsalt in Oregon, and Merck in Germany), we see four isotopically distinct sources of perchlorate. Therefore, **PWP's position that different manufacturers do not produce isotopically distinct perchlorate is completely untenable in view of the available analytical data.**

PWP (August 2012) asserts that because the Sturchio et al. (2006) study was published 2006, *"long after the BMI Complex in Henderson NV was destroyed, it is unlikely that any of these samples originated at that facility"*. PWP has no factual basis for making this speculative statement. Some of the perchlorate reagents analyzed by Sturchio et al. (2006) may have in fact been manufactured at the BMI Complex, because they were obtained by me from laboratory shelves at Argonne National Laboratory which contained materials dating back at least to the early 1960's, based on hand-written notes on some of the bottle labels. In particular, the perchlorate reagents from Sigma-Aldrich and Mallinckrodt have isotopic compositions indistinguishable from those of archived perchlorate samples from Kerr-McGee Co. and PEPCON that were manufactured in Henderson NV (ESTCP Project 200509).

PWP offers no viable explanation for the dissimilarity in isotopic composition of perchlorate in groundwater from the JPL-sourced samples (from the JPL site and the nearby Monk-Hill sub-basin area) and perchlorate from samples in the remainder of the Raymond Basin study area of NASA (2007). The simplest explanation for this observation is that these two areas have perchlorate from different sources, as discussed by NASA (2007).

## **2.2 Response to PWP (August 2012) Discussion Point #2**

PWP (August 2012) attempts to use a correlation between  $\Delta^{17}\text{O}$  and  $\delta^{18}\text{O}$  values to argue that perchlorate in all of the Raymond Basin wells has been affected by biodegradation. They state that *" $\Delta^{17}\text{O}$  probably is the most sensitive measure of biodegradation as it has the least variation in among the industrial samples by a considerable bit"*. In their Figure 5, they plot  $\Delta^{17}\text{O}$  vs.

$\delta^{18}\text{O}$  values for “solids from Sturchio et al., 2006” and “groundwater from the Raymond Basin”, and the data shown in this figure appear to be for isotopic analyses of perchlorate although not identified as such in the figure. PWP argues that the positive correlation between  $\Delta^{17}\text{O}$  and  $\delta^{18}\text{O}$  values exhibited by the groundwater samples from the Raymond Basin (slope = 3.0) as compared with the lack of correlation shown by the industrial samples (slope = 0.07) indicates that anaerobic biodegradation or another mass-dependent fractionation process has affected all of the groundwater samples. They state “the difference between the groundwater samples and the industrial samples is very clear and indicates biodegradation”.

PWP (August 2012) has made a fatal error in their analysis of these data. They apparently do not understand the definition of  $\Delta^{17}\text{O}$ . The definition of  $\Delta^{17}\text{O}$  is given in Sturchio et al. (2011) as follows: *In systems where isotopic fractionation is strictly mass-dependent,  $\delta^{17}\text{O} \approx 0.52 \times \delta^{18}\text{O}$  and is not normally reported. However, natural  $\text{ClO}_4$  commonly has  $^{17}\text{O}$  in excess of this relationship (Bao and Gu 2004; Böhlke et al. 2005) and the  $^{17}\text{O}$  anomaly commonly is reported as a deviation from the abundance expected for mass-dependent fractionation, according to the approximation (Thiemens 2006):*

$$\Delta^{17}\text{O} = \delta^{17}\text{O} - 0.52 \times \delta^{18}\text{O}$$

Based on the definition of  $\Delta^{17}\text{O}$ , the effect of mass-dependent isotopic fractionation of oxygen is normalized out, and any remaining deviation of  $\Delta^{17}\text{O}$  from a value of  $0.0 \pm 0.1$  indicates a non-mass-dependent  $^{17}\text{O}$  abundance in the material being analyzed. As first reported by Bao and Gu (2004), and confirmed subsequently by Bohlke et al. (2005), Sturchio et al. (2006), and Jackson et al. (2010), there is no  $^{17}\text{O}$  anomaly in synthetic perchlorate but all natural perchlorate samples have positive  $^{17}\text{O}$  anomalies as indicated by  $\Delta^{17}\text{O}$  values  $> 0.0$ . Therefore, **the elevated  $\Delta^{17}\text{O}$  values discussed by PWP (August 2012) and shown in their Figure 5 have absolutely no relationship to biodegradation or any other mass-dependent fractionation process; rather, they clearly indicate the presence of a natural perchlorate contribution to the groundwater in these Raymond Basin wells.**

### 3.0 Cited References

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