# Water Resources Center
# Annual Technical Report
# FY 2007

# Introduction

The Rhode Island Water Resources Center has supported one information transfer project, "Clean Drinking Water in Rhode Island" and one research project "Enhancing Drinking Water Supply by Better Understanding Surface Water – Ground Water Interaction." The information transfer project consisted of a camp for Middle and High School science teachers to prepare the teachers to develop lesson plans on water resources for their science students. The research project results will assist the University of Rhode Island in evaluating their water supply as well as provide data to allow the PIs to apply for other sources of funding to expand their research efforts.

# Research Program Introduction

The research project entitled "Enhancing Drinking Water Supply by Better Understanding surface Water − Ground Water Interaction," was funded by the Rhode Island Water Resources Center. The researchers sought to develop analytical and computational tools to determine the zone of influence of a freshwater pond to a nearby well. Their study was conducted using the main well of the University of Rhode Island and a nearby pond on campus. This research can have application to other well/surface water systems and provide guidance for selecting treatment processes.

Funding for this project provided support for a graduate student to complete her Master's Thesis. Information generated in this project assisted the PIs in obtaining funding for a 2 year $190,000 project entitled "Clean Water by Riverbank Filtration" funded by the World Bank. The PIs are also preparing a proposal to be submitted to US AID.

# Enhancing Drinking Water Supply by better Understanding Surface Water – Ground Water Interaction

## Basic Information

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|---|---|
| **Title:** | Enhancing Drinking Water Supply by better Understanding Surface Water – Ground Water Interaction |
| **Project Number:** | 2007RI68B |
| **Start Date:** | 3/1/2007 |
| **End Date:** | 2/28/2008 |
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| **Descriptors:** | |
| **Principal Investigators:** | Thomas Boving, Anne Veeger |

## Publication

# Enhancing Drinking Water Supply by Better Understanding Surface Water – Ground Water Interaction

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**June 2008**

## Abstract

Rhode Island's ground-water resources are one of the state's most valuable natural resources supplying drinking water to as much as 100% of its population in some portions of the state. The University of Rhode Island is no exception where 100 % of its drinking water is pumped from a network of three wells. These high-production wells (up to 1000 gpm) are located within 100ft from a surface water body. The close proximity to surface water together with the geologic setting of the well field led us to hypothesize that the URI well field may be under the influence of surface water and therefore at potential risk of contamination in the event of a contamination event affecting the surface water. Our principal objective was to address this hypothesis from both the hydrologic and regulatory viewpoints. To achieve our objective we used tools such as hydrogeochemical fingerprinting, temperature profiles, a stable isotope mass balance approach and microscopic particulate analysis (MPA). Although the study is still proceeding, the current available results suggest that there is potential for surface water infiltration to occur at this site.

## Introduction

Rhode Island's ground-water resources are one of the state's most valuable natural resources supplying drinking water to approximately 25% of the statewide population and as much as 100% of the population in the southern and western portions of the State. The protection of ground-water resources from pollution is therefore a top priority and is addressed by the Rhode Island Wellhead Protection (WHP) Program. According to RIDEM (2005), the goal of this program is to protect the ground water within the area contributing water to a public drinking water well. This area is referred to as "wellhead protection area" (WHPA).

Within the WHPA, ground water is recharged by percolating precipitation and infiltration from surface water. Surface water is defined as any water that is open to the atmosphere and is subject to surface runoff. This includes perennial streams, rivers, ponds, lakes, ditches, and some wetlands, as well as intermittent streams and natural or artificial surface impoundments that receive water from runoff.

IN Rhode Island, ground- and surface water systems are typically interconnected, with ground water commonly providing the baseflow component of streamflow. Hence, if a well is drilled near a surface water body, it is possible that a portion of the extracted water originates from surface water drawn inot the subsurface by the induced hydraulic gradient. Ground-water sources that are *under the direct influence of surface water* (GWUDI) are considered to be at risk from waterborne pathogens. The U.S. Environmental Protection Agency (USEPA) defines *GWUDI* as any water below the surface of the ground with:

1.) significant occurrence of insects or other microorganisms, algae, organic debris, or large-diameter pathogens such as *Giardia lamblia*; or
2.) significant and relatively rapid shifts in water characteristics such as turbidity, temperature, conductivity, or pH which closely correlate to climatological or surface-water conditions.

Part (1) of the definition is aimed at determining if there are particulates present that are indicative of surface water. This may be determined using *Microscopic Particulate Analysis* (MPA) which analyzes for significant numbers of large macro-organisms, algae and surrogate indicators of surface water presence. Part (2) of the definition is aimed at establishing whether there is a well established hydraulic connection between the ground-water source and surface water. The rapid changes in the ground-water chemistry are attributed to the contribution of surface water. This implies that if ground water is rapidly recharged by surface water, then microbial pathogens can readily enter the ground water source presenting a potential health risk (NSEL, 2002).

The Surface Water Treatment Rule (SWTR) promulgated in 1989 by the EPA (40 CFR Part 141, Subpart H) requires that public water supplies derived from GWUDI receive the same treatment as water supplies derived directly from surface water sources (Chin and Qi., 2000). In 1998, the *Interim Enhanced Surface Water Treatment Rule* (IESWTR) added *Cryptosporidium* to the definition of GWUDI and requires 2-log removal of *Cryptosporidium* by conventional or alternative treatment (40 CFR Parts 9, 141, and 142). This change in definition applies to public water systems (PWS) that serve 10,000 or more people.

The GWUDI status of a drinking water well is generally determined at the state level and GWUDI assessment approaches vary greatly. Guidance in GWUDI determination is provided by the USEPA (1991) and the American Water Works Association (AWWA, 1986 and 2001), among others. As a rule of thumb, wells more than 61 m (200 ft) from surface waters and cased to depths exceeding 15 m (50 ft) are usually considered to be adequately protected from surface water (AWWA, 1991). In Rhode Island, the Department of Health (RIDOH) determines GWUDI status by taking into account the distance between a well and the nearest surface water body, the well construction, and the historical fecal bacteria data from the supply well (RIDOH, pers. Comm.). For instance, deep wells with a separation distance of least 150 to 200 ft (45 – 60 m), depending on the type of well, from the nearest surface water and no history of bacteria contamination are not considered GWUDI.

The approach currently used in Rhode Island is practical, cost effective and consistent with USEPA GWUDI guidance. The USEPA emphasis on the potential threat of pathogens however, at least in part, masks the risk associated with transport of harmful solutes, such as dissolved organic pollutants spilled into the surface water. Hence, this approach may oversimplify the hydraulic and hydrogeologic processes that govern the interaction between surface and ground water and could cause a rapid breakthrough of non-biological pollutants. This assessment is supported by Wilson et al. (1996), who concluded that the classification of ground water as GWUDI should rely on a group of indicators, such as physical indicators (e.g., temperature and electrical conductance correlations with surface waters), hydrogeologic indicators (e.g., time of travel, natural filtration, hydraulic connection), and biological indicators (e.g., microscopic particle analysis). Overall, the potential health risks associated with the breakthrough of surface water pollutants into drinking-water wells suggests that an approach that addresses both pathogen and solute occurrence would add an additional margin of safety to the characterization of surface water contributions to ground-water withdrawals in Rhode Island.

Using the URI well field as a study site, the principal goal of this project was *to collect and synthesize the data necessary for understanding the interaction between ground and surface water and interpret the results in the context of current regulatory benchmarks*. This goal was supported by the following objectives:

1. Collect chemical, physical, and biological data that are indicative of a possible connection between surface and ground water.
2. Estimate the percentage of ground water withdrawal attributable to induced surface water recharge.
3. Synthesize the data and assess current approach to GWUDI on the background of Rhode Island specific hydrogeologic conditions.
4. Disseminate findings to the public.

We realize that this project has research components and utilizes advanced tools (e.g. isotopic analysis) that go well beyond what can reasonably be expected as part of the day-to-day GWUDI decision making process.  We also recognize that designation as GWUDI triggers a mandatory treatment response designed for pathogens, not solutes. We accounted for these limitations when comparing ours to current regulatory approaches.

## Setting

This project was conducted around the University of Rhode Island well field located at the western end of the campus.  All of URI's drinking water is pumped from three major pumping wells that range from 95 to 138 feet deep and are about 50 to 200 feet from Thirty Acre Pond (Figure 1).  Both Thirty Acre Pond and the URI wells are located in the Chipuxet Aquifer which consists of mostly glacially stratified material (Dickerman, 1984).  The bottom of Thirty Acre Pond is also covered by a low permeability organic layer that is about 40 feet thick near the center of the pond and thins out closer to shore (Dickerman, 1984, Figure 2).

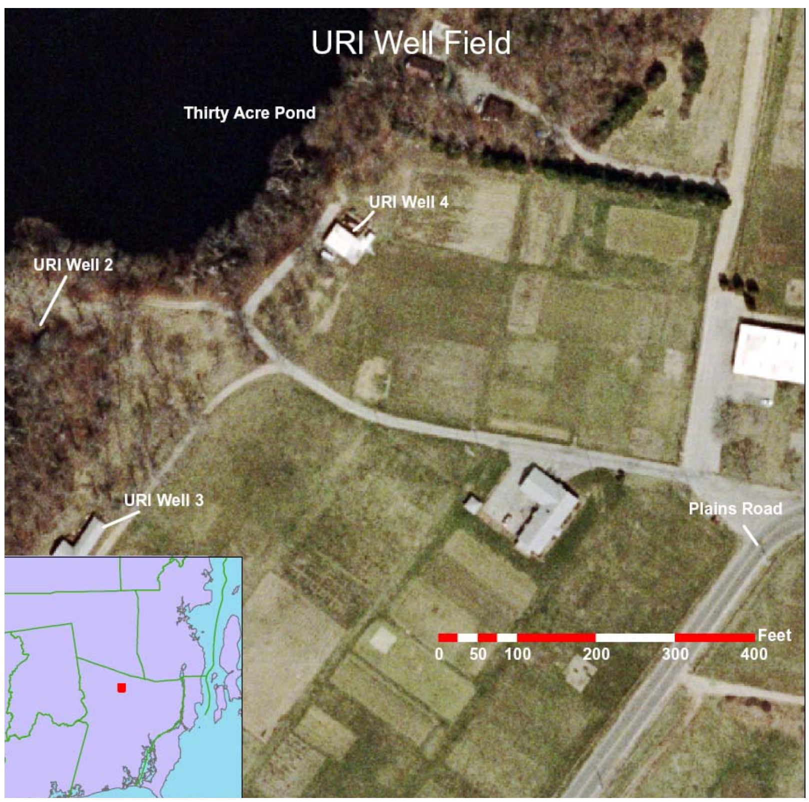


**Figure 1**: Location of the major pumping wells in the URI well field relative to Thirty Acre Pond (RIGIS).

## Methods

Based on existing hydrogeologic information and supported by data collected by us prior to this study, we hypothesized that *at least a fraction of the URI well water is derived from Thirty Acre Pond.* To test this hypothesis, our experimental plan involved a step-by-step approach. Plan elements included a combination of chemical, physical, and biological indicators and hydraulic considerations to:

1. Characterize ground and surface water using chemical, physical, and biological indicators.
2. Develop a conceptual understanding of the hydraulic relationships between surface water and ground water at this study site.

*Well selection criterion:* The most productive of all three URI wells (#2 through #4) is Well #4; therefore, Well #4 was the focus of this project. Well #4 was drilled in 1974 and is a 24-x18-inch gravel packed well, screened from 75 to 85ft with 160-slot Johnson screen and from 85 to 95ft with 240-slot screen (Dickerman, 1984). It produces 1000 gpm, and feeds water through a 16-inch main into a 1,000,000 gal storage tank. URI has the capability to chlorine-disinfect the water, but the quality of the well water has been high and currently does not warrant pre-treatment, filtration, or desinfection. The water pH (approx. 5.9) is adjusted with lime for erosion control. Lime is added to the water immediately downgradient from the well head. Figure 2 is an east west cross section through the Thirty Acre Pond area showing the location of Well #4 relative to the pond.

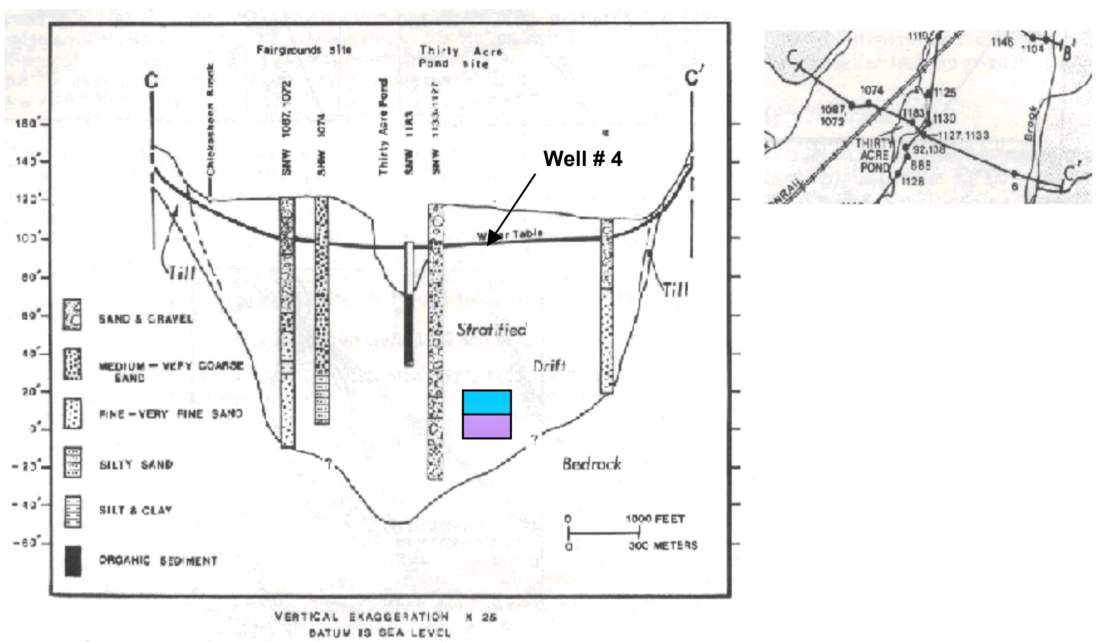


**Figure 2:** The location of Well #4 relative to Thirty Acre Pond in cross section. The blue and purple boxes represent the area of the well that is screened. Notice the thick layer of organic sediment at the bottom of Thirty Acre Pond.

*Chemical, physical, and biological indicators*: A connection between surface and ground water manifests itself in chemical, physical, and/or biological indicators. Our experimental plan covered each of these indicators.

Chemical Indicators: Seasonal variations in surface water, ground water, and precipitation composition were characterized based on field parameters (dissolved oxygen, pH, electrical conductance, and temperature), and major dissolved constituents (Ca, Mg, Na, K, Cl, $SO_4$, $HCO_3$, F, $NO_3$, $PO_4$, $SiO_2$), which were measured/sampled for weekly. Analyses of these samples were completed in-house with a Dionex DX-120 Ion Chromatograph, and a Shimadzu spectrophotometer. These analyses were used to provide the basis for fingerprinting surface water and ground water and identifying seasonal variations in compositions associated with varying source contributions.

Isotope Mass-Balance Approach: The isotopic ratios of stable oxygen and hydrogen isotopes have been successfully used to quantify recharge water and surface-water contributions to well discharge (Muir and Coplen, 1981; Maloszewski, 1987) and to characterize the interaction between surface water and ground water (Yager and Kappel, 1998; Molloy et al, 1994). Previous research shows that the isotopic composition of precipitation in southern RI during June 1999 to August 2000 exhibited a strong seasonal variation with winter precipitation on average yielding significantly lighter isotopic compositions than summer precipitation (Veeger and Merrit, 2001). The average isotopic composition of the ground water (-7.3 $\delta^{18}O$, -44 $\delta D$) was consistent with the isotopic composition of precipitation during the period October to March, suggesting a strong seasonal bias in ground-water recharge. Surface water samples were also collected from 18 sites in the Pawcatuck River Watershed and the Chipuxet River, yielding a June-to-November average isotopic composition of –5.5 $\delta^{18}O$, -36.4 $\delta D$. Most importantly, the average ground - water isotopic composition is significantly lighter than that of all the surface-water samples collected during same sampling period (Veeger and Merrit, 2001). Isotopic fingerprinting and quantification of surface-water contributions to ground water withdrawals is therefore possible in this watershed using a mass-balance mixing model.

Stable isotope water samples were collected weekly from well #4, and Thirty Acre Pond, and monthly for precipitation intercepted at the well field. Budgetary constraints limited the number of samples that could be analyzed however, and a total of 32 samples have been analyzed to date by the Isotope Laboratory at the University of Arizona, Tucson. The isotopic data was supplemented by meteorological data (precipitation, temperature, pan evaporation) collected at the URI weather station located adjacent to the well field site. The isotopic composition of the water was used as a conservative tracer, permitting calculation of the percentage of ground-water withdrawal attributable to a surface-water source.

Physical Indicators: The physical indicators hydraulic head and heat were used to evaluate a possible hydraulic connection between Thirty Acre Pond and the stratified glacial-sediment aquifer below. The head distribution below the pond was measured with four piezometers that were installed at different depths and locations by a direct-push method. Figure 3 shows the location of these piezometers. Piezometers were also equipped with water level loggers to record water level and pressure changes. The loggers were set to take readings every ten minutes. Measurements were also taken weekly by means of a manually operated water level meter.

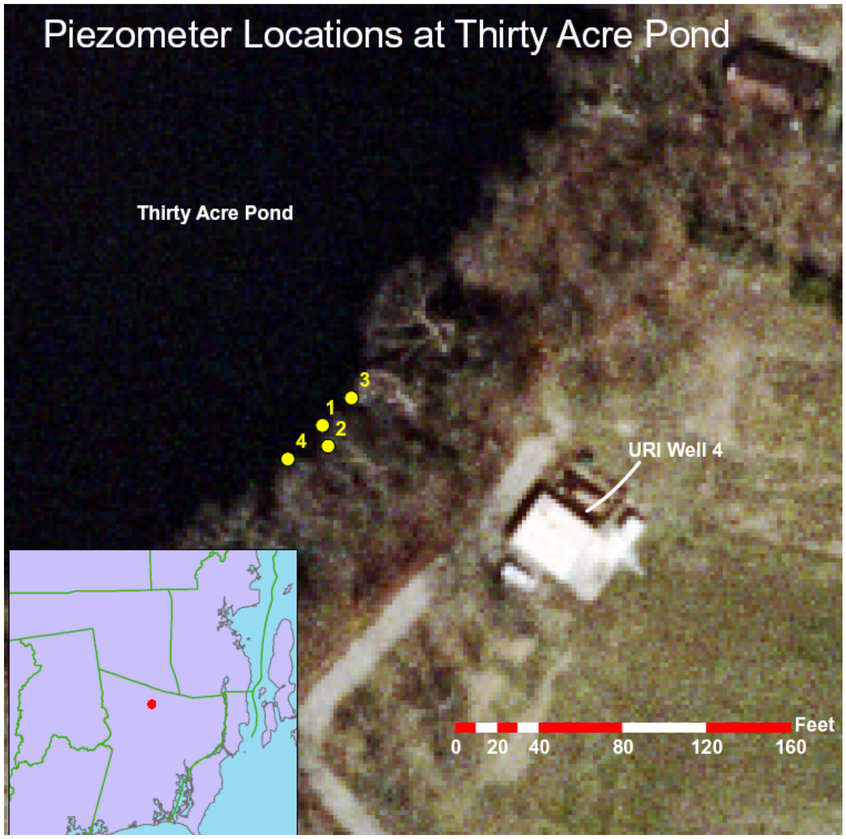


**Figure 3**: The locations of the four piezometers installed in Thirty Acre Pond. Piezometer 1 was the only piezometer where a LevelTroll was installed.

In addition heat was used as a natural tracer. This approach is useful in environments where diurnal or seasonal changes in temperatures at the land surface are measured in local ground water or infiltrating water (Stonestrom and Constanz, 2003; Conant, 2004; Burow, et al., 2005). Ground water maintains a temperature close to the local mean annual air temperature (10-12 °C in southern Rhode Island) while surface water temperature varies in relation to air temperature (0°C to about 25°C in Rhode Island). This temperature contrast permitted us to use temperature profiles to identify the presence of infiltrating surface water at Thirty Acre Pond. Infiltration of seasonally warmed or cooled surface water produces a readily identifiable sub-bottom temperature profile. The depth to which temperature variations occur is an indication of the magnitude of flow across the surface-water/ground-water interface (Stonestrom and Constanz, 2003). The temperature of the ground water and surface water were measured every half hour using Thermocron iButtons (DS1921G), manufactured by Dallas Semiconductor. We have successfully used iButtons in Rhode Island for surface-water and ground-water temperature monitoring (Allen and Boving, 2006) and for identification of infiltrating surface water in seasonal ponds (Ware et al., 2006). The ibuttons were installed on 6 wooden stakes at 15 cm increments. These stakes were then placed into the pond (Figure 4) at various depths and locations. Each stake contained three to four ibuttons (2-3 below the pond bottom and 1 in the surface column) and data was downloaded from the ibuttons every one to three weeks.


**Figure 4**: The location of the six stakes installed in Thirty Acre Pond. As stated above, these stakes contain three to four ibuttons.

<u>Biological Indicators:</u> Our biological indicator was the *Microscopic Particulate Analysis* (MPA), which is one of several factors that states may consider in making the determination of whether or not a supply is GWUDI. MPA sampling relies on specialized equipment necessary to sample a large volume of water. Recommended sample volume is 1,000 gallons collected over an 8 to 24 hour period at a flow rate of 1 gpm. MPA sampling units were rented from Analytical Services in Williston, VT. Two samples were collected from Well #4, one in December 2007 and one in May 2008. The samples were refrigerated at 2 to 5 °C for up to 15 hours before shipped in blue-ice cooled containers to Analytical Services, Inc. where they were analyzed. This lab is accredited by USEPA to perform MPA analysis. The MPA data was evaluated using the USEPA risk based approach (USEPA, 1992).

## Results & Discussion

At the time of the release of this draft report (June 2008), sampling was still going on and will continue until at least one year's worth of data has been collected. Hence, only the results from July of 2007 to May of 2008 were included in this draft report.

*<u>Chemical Indicators</u>***:** Results for anions ($Cl^-$, $F^-$, $NO_3^-$, $PO_4^{-3}$, and $SO_4^{-2}$), cations ($Na^+$, $K^+$, $Mg^{+2}$, $Ca^{-2}$), dissolved silica and alkalinity (as $CaCO_3$) are shown in Figures 5, 6 and 7. Please note that $F^-$ and $PO_4^{-3}$ were not present at detectable levels. Tables of all chemical data are provided in Appendix A.

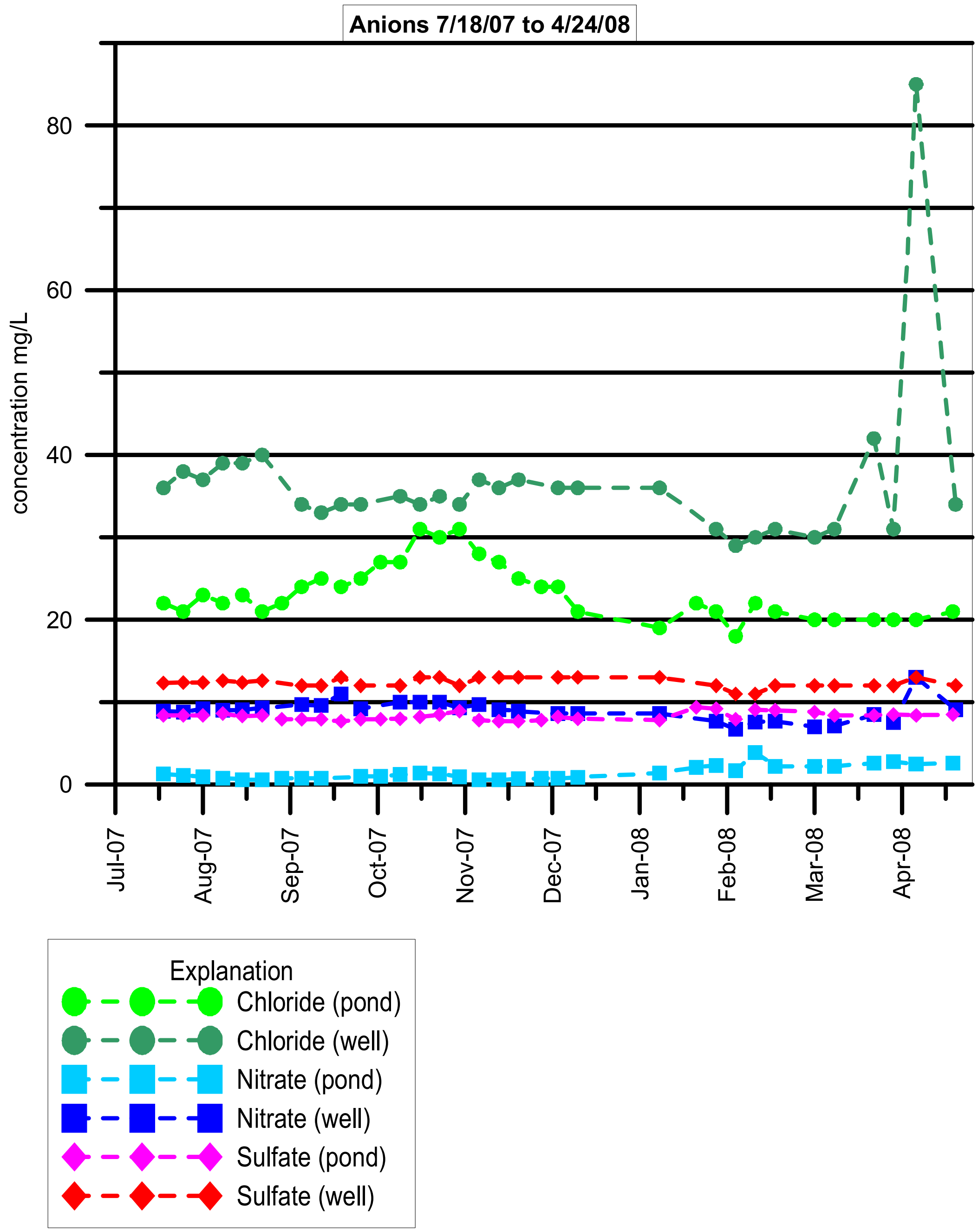


**Figure 5:** Concentration versus time for anions detected in Thirty Acre Pond and at URI Well #4.

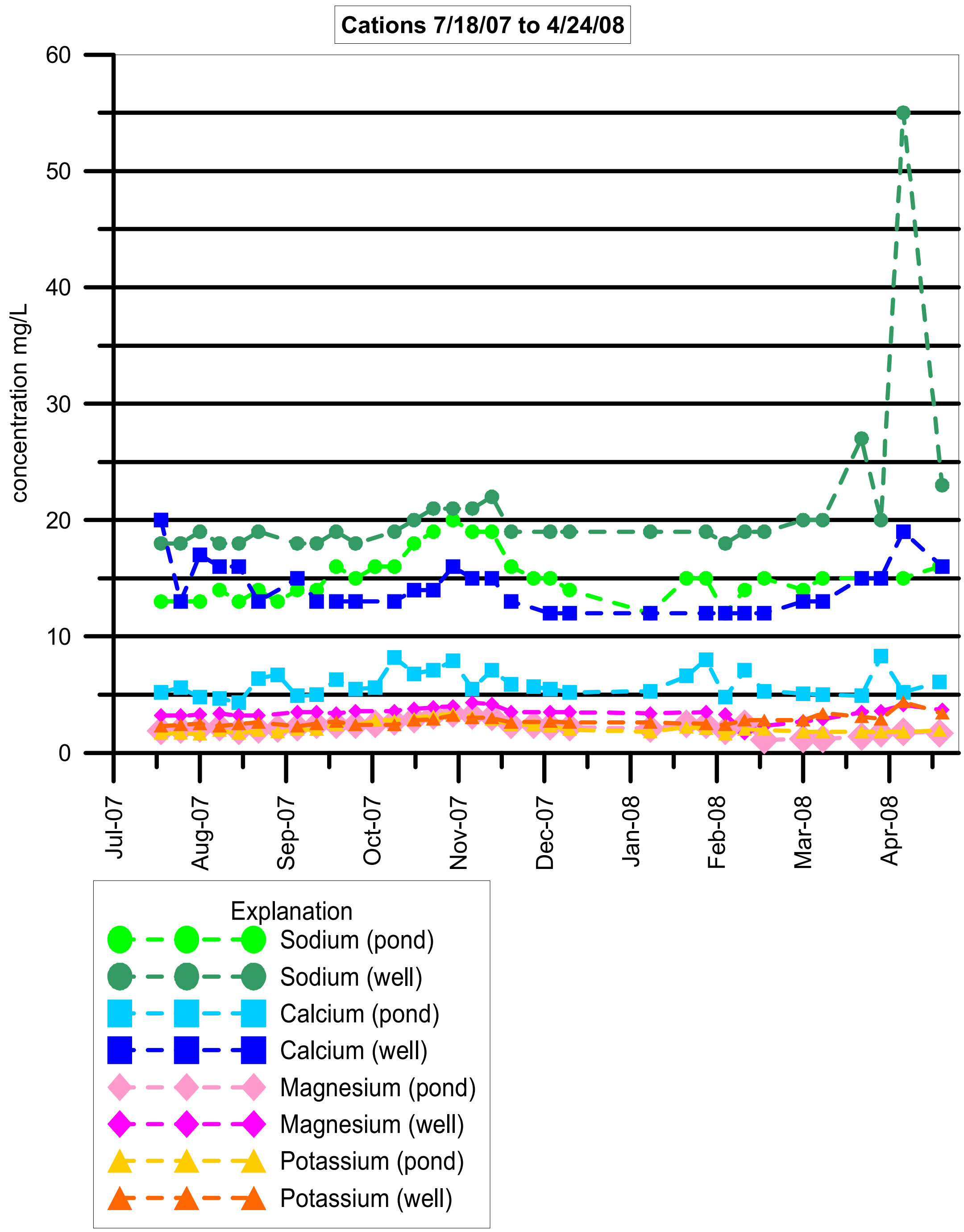


**Figure 6:** Concentration versus time for cations detected at Thirty Acre Pond and URI Well #4.

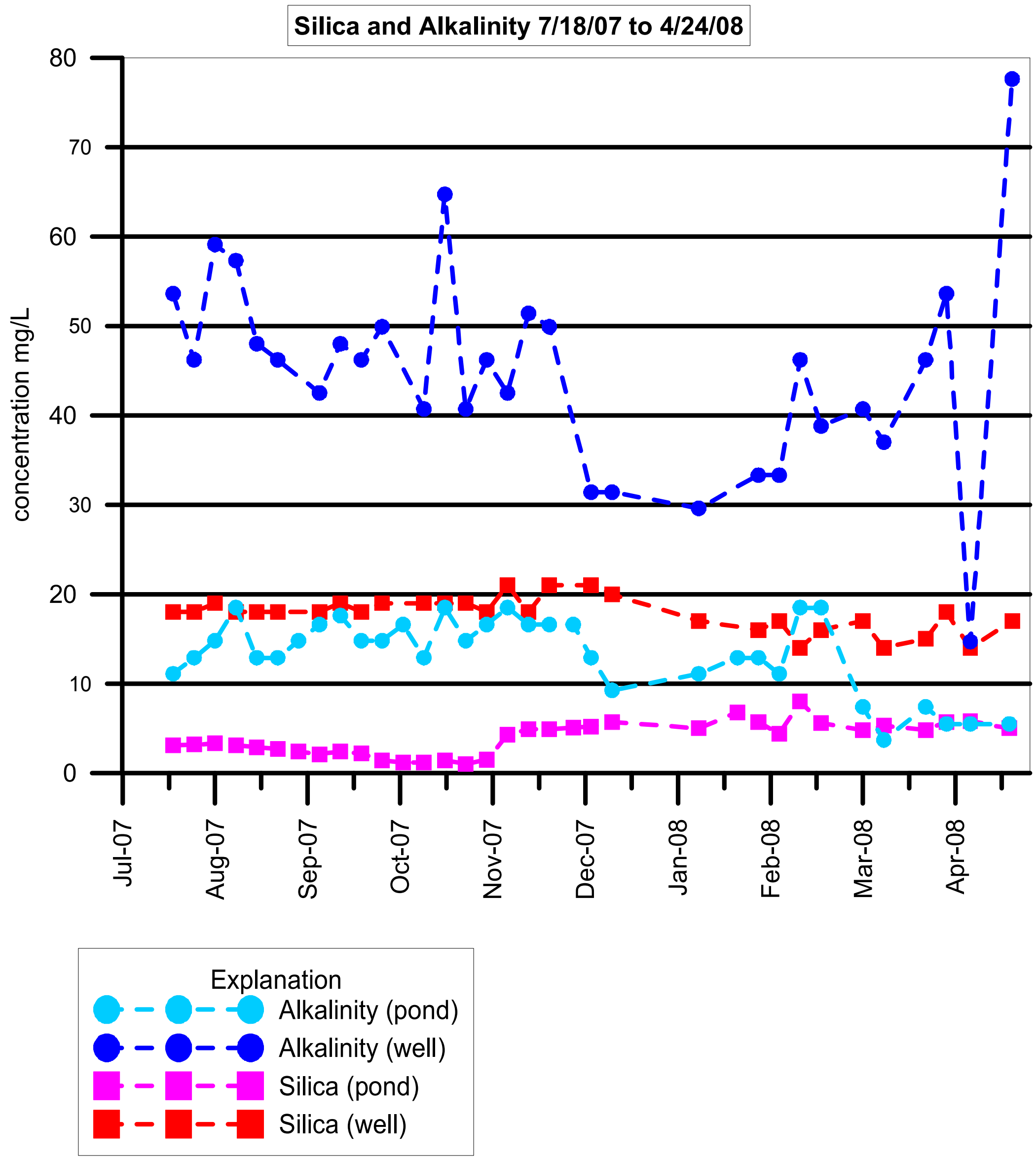


**Figure 7:** Concentration versus time for dissolved silica and alkalinity as $CaCO_3$ at Thirty Acre Pond and Well #4.

Chemical constituents can be used to develop a chemical fingerprint of the water bodies being studied. If the background concentrations are different, mixtures of the waters can then be identified when the composition of one water shifts toward the composition of the other. The robustness of the determination depends on the number of constituents used and level to which a distinct chemical signature can be assigned to each water body.

From the above figures, potassium, sulfate, nitrate, and dissolved silica concentrations show similar patterns for both the well and the pond, with little to no temporal variation throughout the reporting period. The observed similarities therefore preclude their use for identifying mixing between surface and ground water at this study site. Chloride, calcium, and sodium concentrations, on the other hand, show seasonal variations in both the well and the pond, with lower concentrations consistently associated with the surface water and higher concentrations present in the ground water. Significant infiltration of surface water could therefore, be evidenced by a drop in the concentration of these constituents in the ground water. Chloride, the only conservative constituent in this group, may show evidence of this effect in September 2007 when significant pumping, triggered by the return of students to the University may have induced surface-water infiltration potentially causing the observed drop in chloride concentrations. This same trend is not apparent, however, in the concentrations of calcium and sodium. It should also be noted that application of this geochemical fingerprinting technique in this setting is particularly challenging because the surface-water composition is expected to shift seasonally as the contribution of ground water to surface-water baseflow comprises an increasing proportion of the total streamflow. During the summer and early fall months, the composition of surface water is therefore expected to shift toward that of shallow ground water. Sodium concentrations may show evidence of this trend as the concentration rises from late August 2007 into November 2007.

The alkalinity of the well water also varies considerably throughout the study period; however this most likely is not the result of surface water infiltration. Although the well field operators report that the water from the sampling tap in the well house is untreated with lime, we believe it is possible that when the well pump is not running, the tap may draw treated water from the main distribution system causing water treated with lime to mix with the untreated water. This scenario is corroborated by data collected on 4/10/08 when maintenance was carried out at the well. On this date there is a large positive spike in both chloride and calcium concentrations as well as a significant negative spike in alkalinity – all of which could be explained by the maintenance operations.

Samples for dissolved organic carbon (DOC) have been collected but not yet been analyzed. Results for these samples will be included in a Master's Thesis by Patricia H Logan from the Department of Geosciences and in the upcoming final project report.

Isotopes: A total of 32 isotope samples taken over the course of the study period were analyzed for stable isotopes of oxygen and hydrogen. Figure 8 shows the results of these analyses.

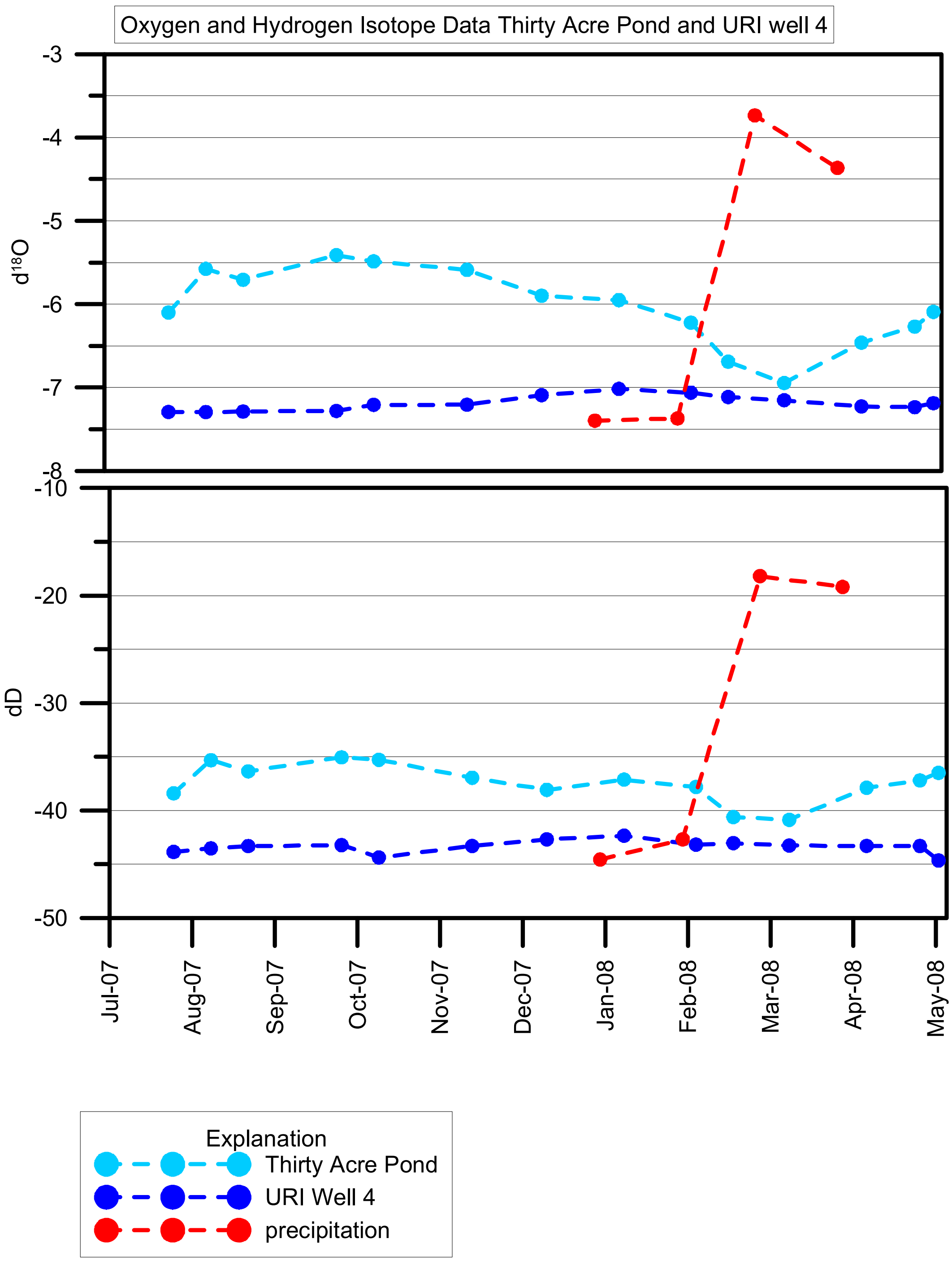


**Figure 8:** Isotopic composition (per mil) versus time for $\delta^{18}O$ (top graph) and $\delta D$ (bottom graph) for precipitation, Thirty Acre Pond and URI well 4 from July of 2007 to May of 2008.

Oxygen and hydrogen isotopic data in Thirty Acre Pond exhibit a strong seasonal variation with compositions varying from -5.4‰ $\delta^{18}O$ and -35‰ $\delta D$ to -6.9‰ $\delta^{18}O$ and -41‰ $\delta D$. Isotopic compositions are heavier throughout the summer and early fall, getting continuously lighter until late February to early March, and becoming heavier again throughout the spring. This trend is consistent with both a seasonal change in the isotopic composition of precipitation (lighter in winter, heavier in summer) and with evaporative enrichment that occurs throughout the summer and early fall. In well samples, isotopic compositions are nearly constant throughout the entire study period with $\delta^{18}O$ ranging from -7.0 to -7.3‰ and $\delta D$ ranging from -42 to -45‰. These compositions are similar to those exhibited by winter precipitation and are close to the average composition of ground water reported by Veeger et al (2001).

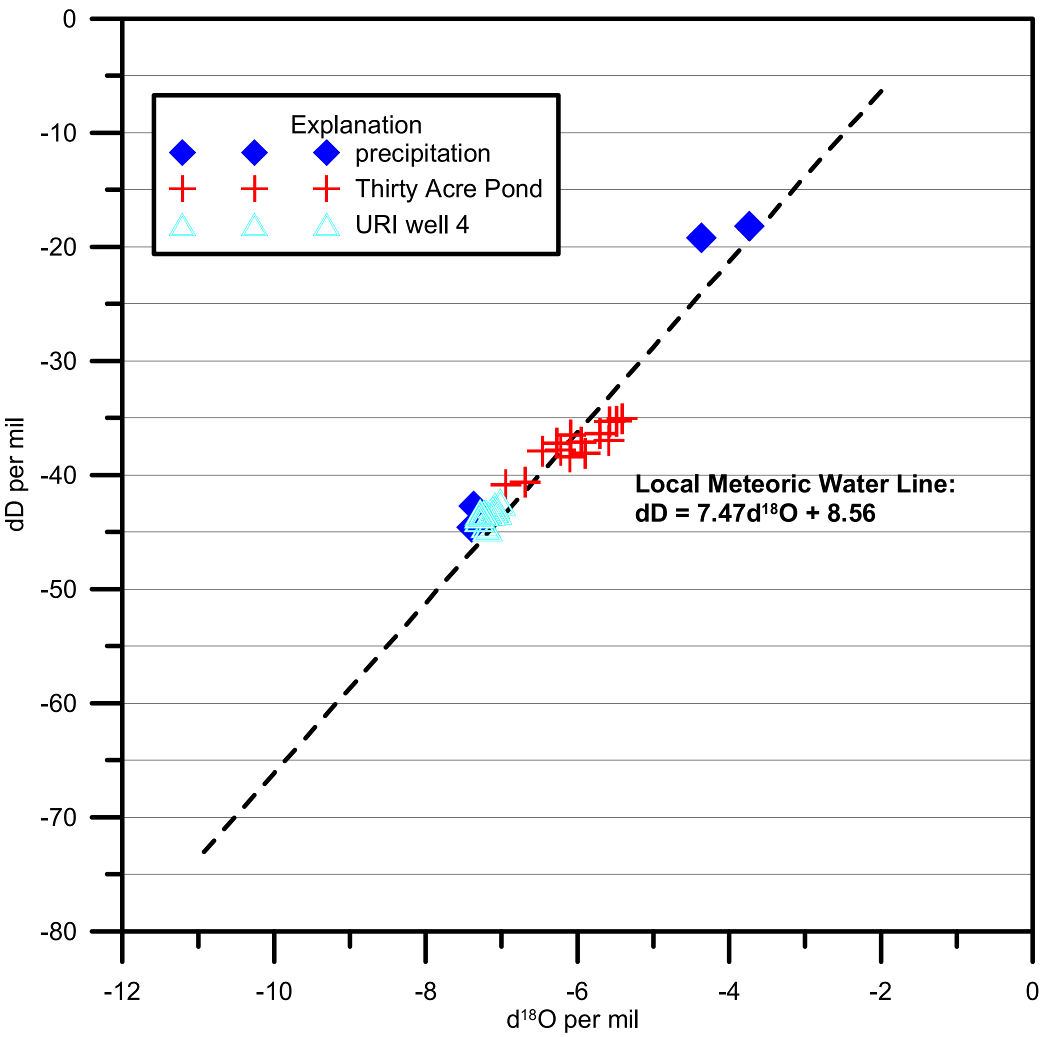


**Figure 9:** $\delta D$ as a function of $\delta^{18}O$ for samples from Thirty Acre Pond, URI well #4 and precipitation.

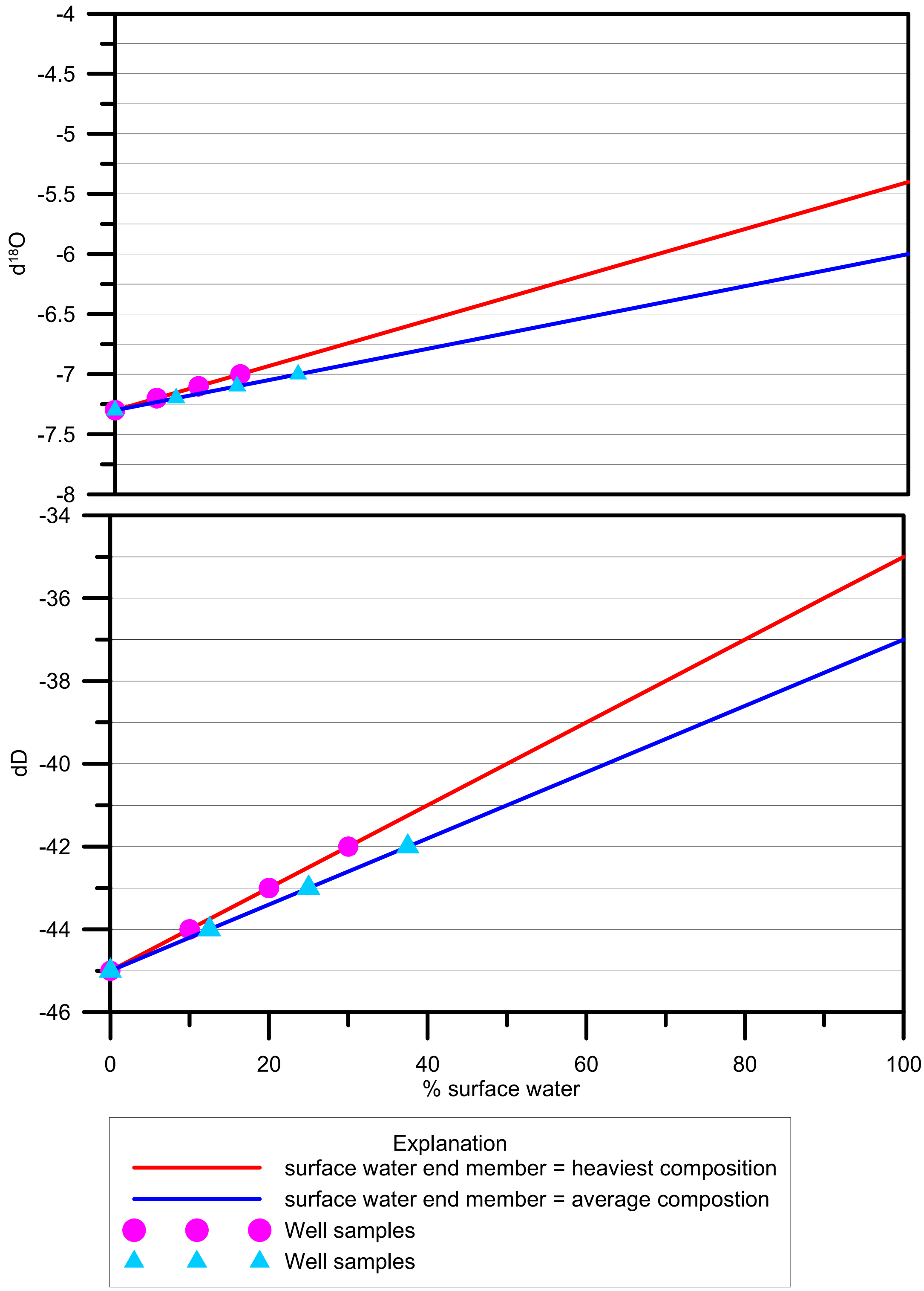


**Figure 10**: Isotope mass balance showing the percent surface water present in the well samples for two different scenarios. All lines have the same ground-water end member that represents 100% ground water (-7.3‰ $\delta^{18}O$ and -45‰ $\delta D$) and each line has a different surface-water end member, which represents 100% surface water. The data points on each line show the % surface water potentially present in the well samples for each scenario.

Figure 9 shows all samples plotted along the local meteoric water line (Veeger et al, 2001). Surface water samples plot where expected showing a slight evaporation trend to the right of the meteoric water line in the late spring and summer. Ground-water samples plot directly on the meteoric water line coincident with winter precipitation. The pronounced difference between surface water and ground water in the summer/fall, coupled with the relatively uniform isotopic composition of the ground-water samples suggests that little surface water is infiltrating into ground water. To quantify this assessment, a mass balance was performed using both $\delta^{18}O$ and $\delta D$.

The mass balance approach assumes that the isotopic composition of water is conservative and preserves the signature of each source. A simple mixing model can therefore be applied to quantify the contribution of each source. Because the isotopic composition of surface water varies seasonally, two surface-water end member scenarios are illustrated in Figure 10. The heaviest surface-water end member (-5.4 per mil $\delta^{18}O$ and -35 per mil $\delta D$) corresponds to the late summer/early fall period when evaporative enrichment results in the greatest difference between surface-water and ground-water isotopic compositions. The lighter end member corresponds to the average surface water isotopic composition (-6.0 per mil $\delta^{18}O$ and -37 per mil $\delta D$) which is representative of both early summer and early winter. The isotopic composition of the ground water covered a small range and the lightest composition (-7.3 per mil $\delta^{18}O$ and -45 per mil $\delta D$) was assumed to be representative of 100% ground water. This composition is approximately equivalent to the average isotopic composition for ground water in this watershed as determined by Veeger et al, (2001). The percent of surface water present is calculated using a weighting function:

$$\%SW = \frac{\partial^{18}O_{sample} - \partial^{18}O_{GW}}{\partial^{18}O_{SW} - \partial^{18}O_{GW}} \bullet 100$$

Where,
$\%SW$ = percentage of surface water contribution,
$\delta^{18}O_{sample}$ = oxygen isotopic composition of the well water sample,
$\delta^{18}O_{GW}$ = oxygen isotopic composition of the local ground water, and
$\delta^{18}O_{SW}$ = oxygen isotopic composition of the surface water body.

The results of the oxygen isotope mixing model for both scenarios are presented in Table 1. Because the isotopic composition of surface water changes seasonally, the application of a single surface-water end member may result in disproportionately large surface water contributions during certain time periods. Applying the mixing model to each time period separately however, is problematic due to the expected lag time between infiltration and breakthrough at the wellhead. Nevertheless, the model results suggest that a small portion of surface water is likely present in the discharge from well #4. The observed pattern suggests that the greatest surface-water contribution occurs in late fall to early winter, coincident with the maximum water-table decline that occurs in late fall to early winter. The absence of a surface water contribution during the summer months is consistent with the decreased water use by the University during this period.

**Table 1. Potential surface water contributions to discharge from URI well #4 based on an oxygen isotope mass-balance model. Surface-water end members: heavy = -5.4 per mil $\delta^{18}O$; average = -6.0 per mil $\delta^{18}O$.**

| | URI WELL #4 | | % SW Contribution δ18O mixing model | |
|---|---|---|---|---|
| Date | δ18O‰ | δD‰ | Heavy | Average |
| 7/25/2007 | -7.3 | -44 | 0.0 | 0.0 |
| 8/8/2007 | -7.3 | -44 | 0.0 | 0.0 |
| 8/22/2007 | -7.3 | -43 | 0.0 | 0.0 |
| 9/26/2007 | -7.3 | -43 | 0.0 | 0.0 |
| 10/10/2007 | -7.2 | -44 | 5.3 | 7.7 |
| 11/14/2007 | -7.2 | -43 | 5.3 | 7.7 |
| 12/12/2007 | -7.1 | -43 | 10.5 | 15.4 |
| 1/10/2008 | -7.0 | -42 | 15.8 | 23.1 |
| 2/6/2009 | -7.1 | -43 | 10.5 | 15.4 |
| 2/20/2008 | -7.1 | -43 | 10.5 | 15.4 |
| 3/12/2008 | -7.2 | -43 | 5.3 | 7.7 |
| 4/10/2008 | -7.2 | -43 | 5.3 | 7.7 |
| 4/30/2008 | -7.2 | -43 | 5.3 | 7.7 |
| 5/7/2008 | -7.2 | -45 | 5.3 | 7.7 |

*Physical Indicators*:

Hydraulic Head: Results from measuring hydraulic head in the piezometers installed at Thirty Acre Pond are presented in Figures 11 and 12. Figure 11 shows the measurements that were taken by hand with a water level meter each week along with the water level of the pond for that week. Measurements began in early March after ice was no longer present and ice heaving would no longer be an issue. For the first few measurements, piezometer water levels were above the height of the pond water level indicating a vertical gradient upward (ground water discharging into surface water). From late March to the end of April, water levels steadily decreased below that of the water level in the pond indicating a vertical gradient downward (surface water recharging the ground water). Water levels from the end of April to early May steadily increased until they are slightly above the water level of the pond (transition from vertical gradient downward to vertical gradient upward). This pattern might represent the pattern of pumping at the URI well field. The first few measurements were recorded during spring break when the campus was less populated. Upon the return of the students toward the end of March, daily pumping resumed and towards the end of the year pumping decreased as classes ended in early May and students left campus by the second week of May.

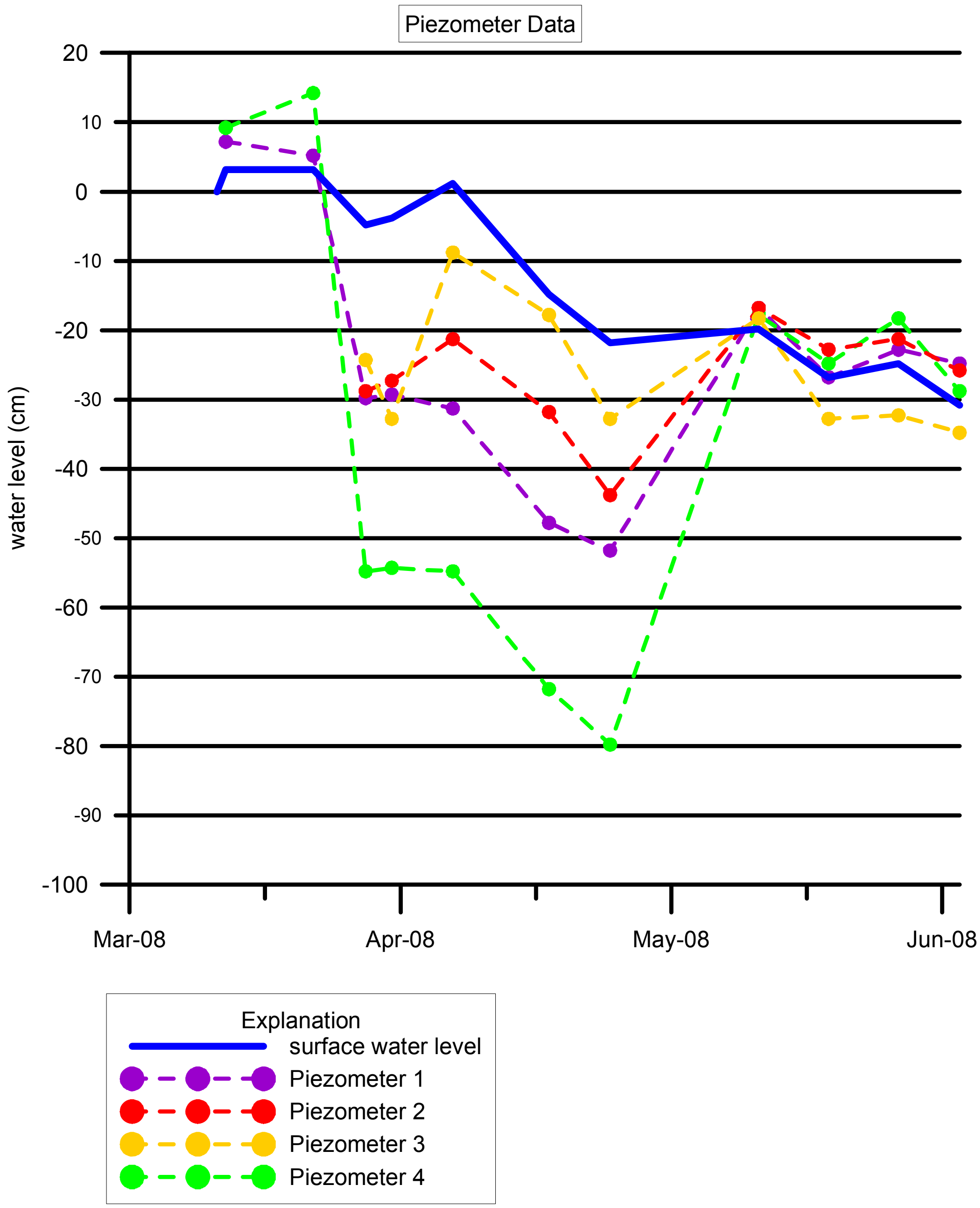


**Figure 11:** Weekly measurements of water levels inside the four piezometers installed at Thirty Acre Pond relative to the water level of the pond.

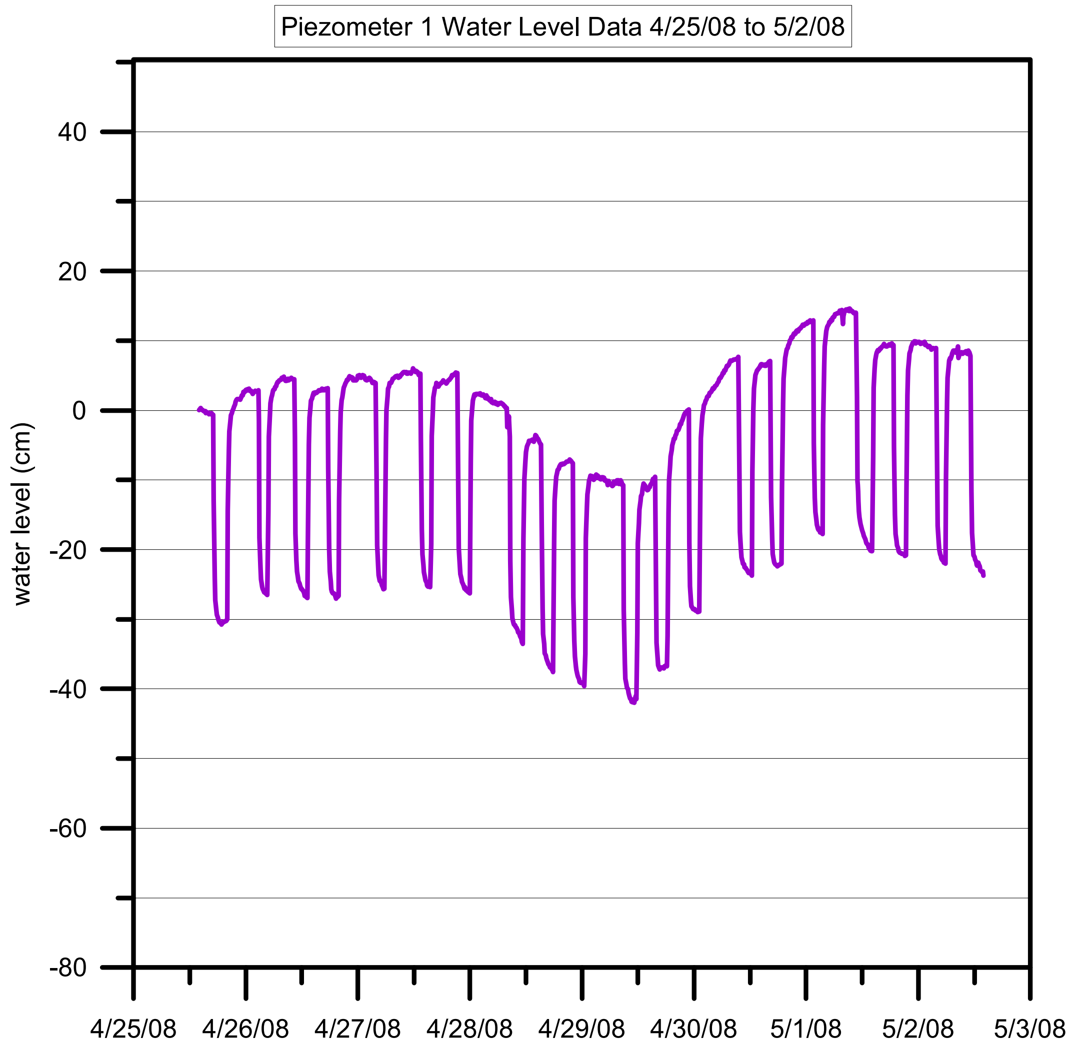


**Figure 12:** Water level fluctuations over a time period of one week for Piezometer 1 at Thirty Acre Pond measured with the In-situ LevelTroll 500. Measurements were taken every 10 minutes from 4/25/08 to 5/2/08.

Continuous water level measurements were recorded beginning in late April 2008. The continuous records show similar overall water level trends with lower water levels in late April and steadily increasing levels up through May coincident with the end of classes. A notable feature however, is the pronounced diurnal variation in water levels that introduces a rapid fluctuation of approximately 30 cm (Figure 12). There are also pronounced daily fluctuations that appear to reflect times when the pump is being turning on and off. According to well maintenance reports, this occurs two to three times each day and is dependent on the water level in the water tower. The hydraulic data clearly demonstrate that pumping of URI well #4 has a strong a rapid impact on the distribution of head beneath Thirty Acre pond. The rapid decline observed in the piezometers indicates that the potential exists for surface water to migrate along this induced vertical gradient toward the well.

<u>Temperature Data</u>: Temperature data from the ibuttons were graphed versus time to screen for the presence of thermal pulses potentially associated with infiltrating surface water.

Graphs of temperature data for the full study period are presented in Appendix B. Depths of the ibuttons ranged above the lake bottom (surface water) to about 30 to 50 cm below the lake bottom. Depths changed somewhat over the study period due to freeze/thaw effects during the winter. In general, ground-water temperature appears to be affected by infiltrating surface water to a depth of about 40 cm for stakes that are further out in the pond and about 45 cm for stakes that are closer to land. Below these depths the temperature signature disappears. Two examples are shown in Figures 13 and 14.

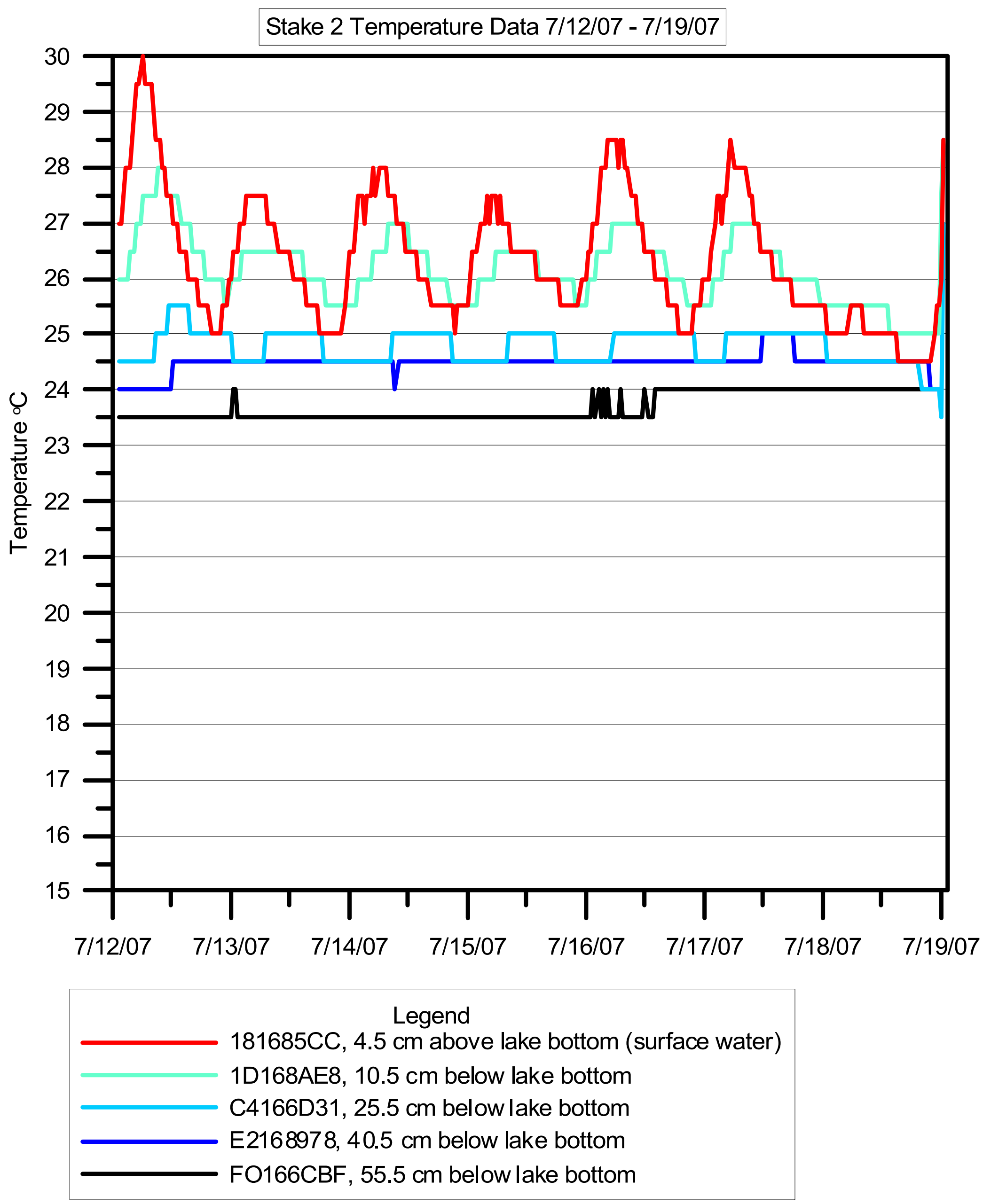


**Figure 13:** Temperature data for Stake 2 from 7/12/07 to 7/19/07.

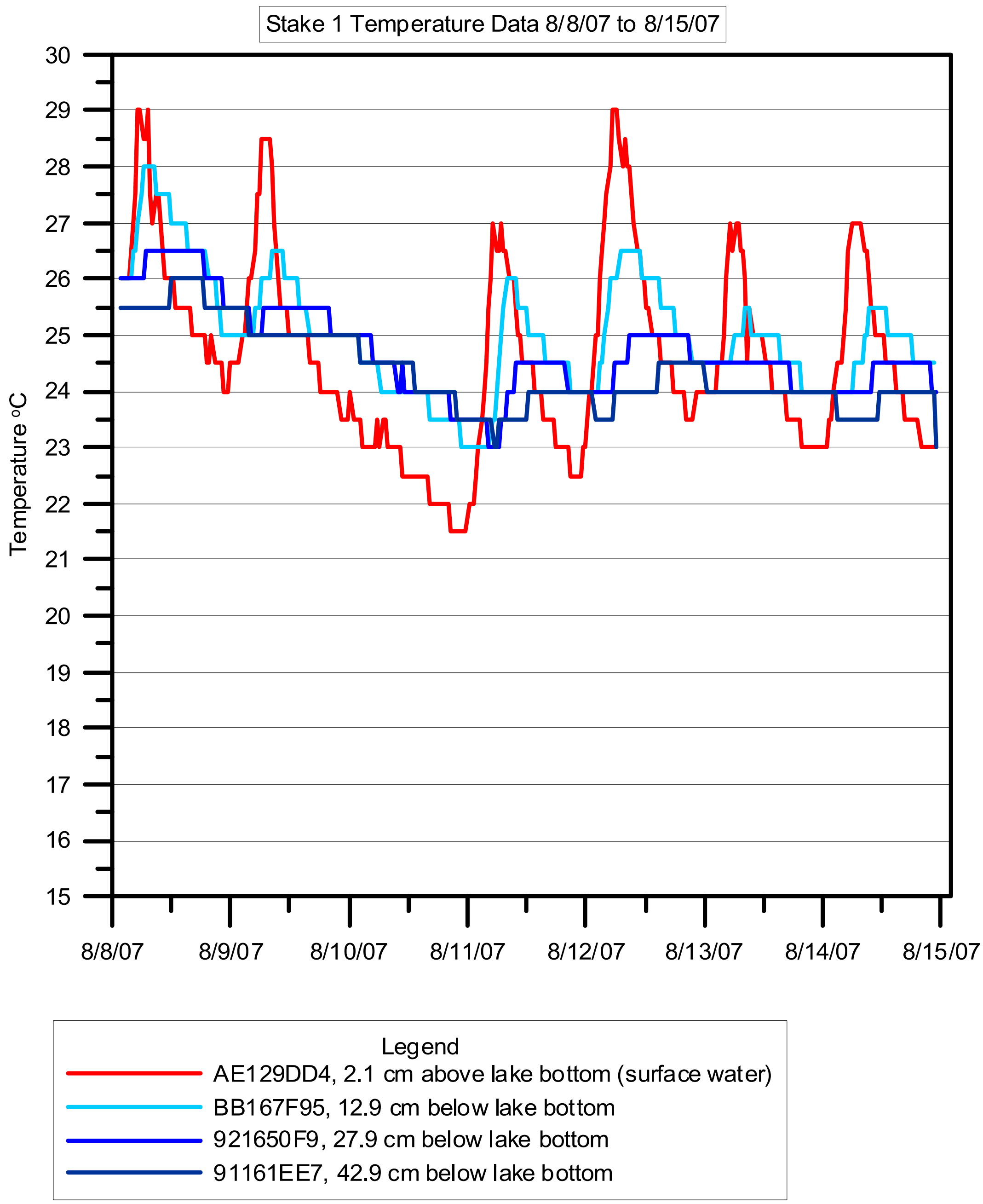


**Figure 14:** Temperature Data for Stake 1 from 8/8/07 to 8/15/07.

Figure 13 shows data from Stake 2, which was installed about 2 m offshore and at a maximum depth of 55.5 cm. Temperature variability decreases with depth from the surface water towards the deepest i-button, with no significant temperature variability observed at a depth of 55 cm. Data from Stake 1, which was installed closer to shore and at a maximum depth of 42.9 cm, is shown in Figure 14. In this case a fairly strong temperature signature was recorded at each depth. These findings suggest that surface water infiltration is occurring particularly close to the shoreline. Addition studies of heat transfer are planned that will attempt to quantify this inflow and distinguish between heat transfer be advection and heat transfer by conduction.

*Biological Indicators*: The results from the two MPA analyses (Dec 2007, May 2008) are shown in Figure 15 and Appendix C. Algae were the most common particulate detected on both occasions. Significant numbers of protozoa were also detected. Diatoms, which were not detected in the December 2007, test were detected at a level of 170 organism per 100 gallons in May. Based on the MPA results, the water is scored on a scale 0 to greater than 20. A score of <9 indicates a low risk, a score of 10 to 19 moderate risk, and a score of >20 a high risk. If the well receives a score of 20 or greater, it automatically is classified as GWUDI. According to Analytical Services, Inc., the samples from well #4 scored 14 for both tests, putting it in the moderate risk category. This means that surface water infiltration is likely and the well should be continually monitored.

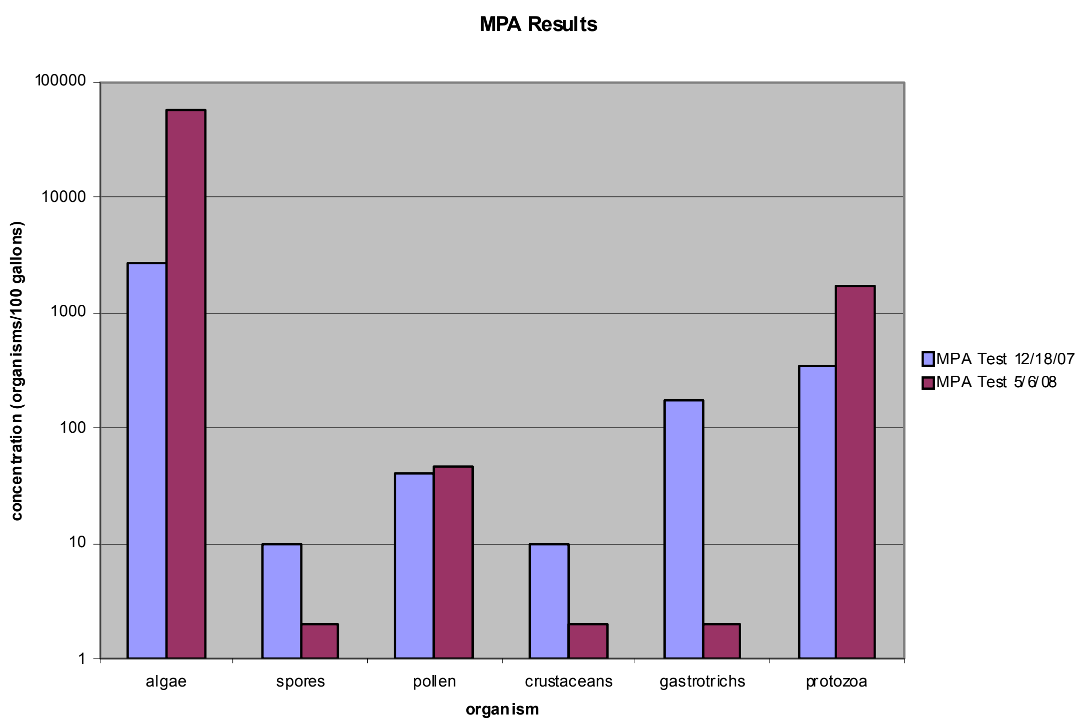


**Figure 15:** Results from MPA analyses. Organisms that were tested for that were not included on this graph were not present at significant levels. Please see Appendix C for full results.

*Conceptual Model:* The geology and hydrogeology of this area has been well documented in several reports, including Dickerman (1984) and Johnston and Dickerman (1986). Well #4 and Thirty Acre Pond are considered to be hydraulically connected to one another suggesting that major pumping from the well will have an effect on the movement of ground water and surface water in this system. Although temperature and hydraulic head data in combination with isotopic data suggest surface water infiltration is occurring at the study site, there is another factor that must be taken into account. As stated earlier, the bottom of Thirty Acre Pond is covered by a low permeability organic layer that can be as thick as 40 feet in the center of the pond but thins out closer to shore. Because hydraulic and temperature measurements were collected where the organic cover was thin (i.e. near the edge of the pond), the substantial thickness of this layer over most of the pond area is expected to hinder ground-water movement toward the well when pumping is occurring. This could partially explain why solute data and isotope data point towards little to no infiltration where as these physical parameters show the potential for infiltration.

Based on the research performed in this area, we conclude that the ground water withdrawn from Well #4 contains at a small percentage of surface water. However the low permeability layer below the pond possibly obstructs the movement of ground water from the pond to the well limiting the total flux despite the presence of a pronounced pumping-induce vertical gradient. The magnitude of the flux will be explored in more detail in the Master's Thesis by Patricia Logan (ongoing).

*Assessment of current approach of GWUDI based on research:* Although the current approach to GWUDI classification used by RIDOH is effective and follows EPA guidelines, including an analysis of chemical, physical and biological indicators similar to the analysis done here would further strengthen the approach. In Rhode Island, many ground-water-based public supply systems are similar to the one studied here in that they are derived from unconfined, unconsolidated, aquifers in close proximity to surface-water bodies or wetlands. The different indicators of ground-water/surface-water interaction examined by us allow for a better understanding of a connection between ground water and surface water. A better understanding of possible surface/ground water interaction in Rhode Island not only minimizes the risk of drinking water contamination from the surface, but may open wells and new well field locations previously considered GWUDI for safe development. In addition, identifying wells that derive a portion of their water from a surface-water body, but have no existing water-quality problems, will provide valuable background information for use in the event of a catastrophic event that affects surface-water quality.

Other states have adopted some of these approaches in their assessment of GWUDI. The Montana Department of Environmental Quality risk-based GWUDI assessment protocol is a typical example. At its core is a step-wise approach to GWUDI classification, beginning with a preliminary screening that rates the vulnerability of a well to contamination from surface water based on a scoring matrix. If a numerically defined risk level is reached, further assessment of the well is required, i.e. hydrogeologic assessment, water quality assessment, and microscopic particulate analysis (MPA). A pass/fail criterion is used to determine the ultimate status of the well. In general, wells that have no evidence of existing or potential hydraulic connection with surface water are considered non-GWUDI. Wells that have a hydraulic connection and a medium or high risk MPA score are considered GWUDI. Evidence that a well is GWUDI is usually more conclusive than evidence that a well is non-GWUDI.

## Conclusions

Chemical, physical and biological indicators show potential for being useful for GWUDI determination in this glacial aquifer setting. Chemical indicators, including chloride, sodium, calcium and environmental isotopes, show promise as good tools however the constant flux in surface water composition creates some complications. Environmental isotopes appear to be the most reliable indicator in this study. Physical indicators including hydraulic head and temperature, demonstrate the potential for surface water infiltration however factors such as pond stratigraphy and environmental effects such as heat conduction need to be considered before a significant flux of infiltrating surface water is assumed to exist. Biological indicators measured by an MPA test, provide conclusive evidence that particulates associated with surface water are being transported to the well, but again the flux of surface water can't be quantified using this method.

Nevertheless, when these factors are used in conjunction with one another they provide useful tools to better understand ground-water/surface-water interaction in a specific location and may be considered helpful in determining GWUDI status. Data collection and analysis will continue until the end of this year and a full data set will be presented in a Master's Thesis by Patricia Logan.

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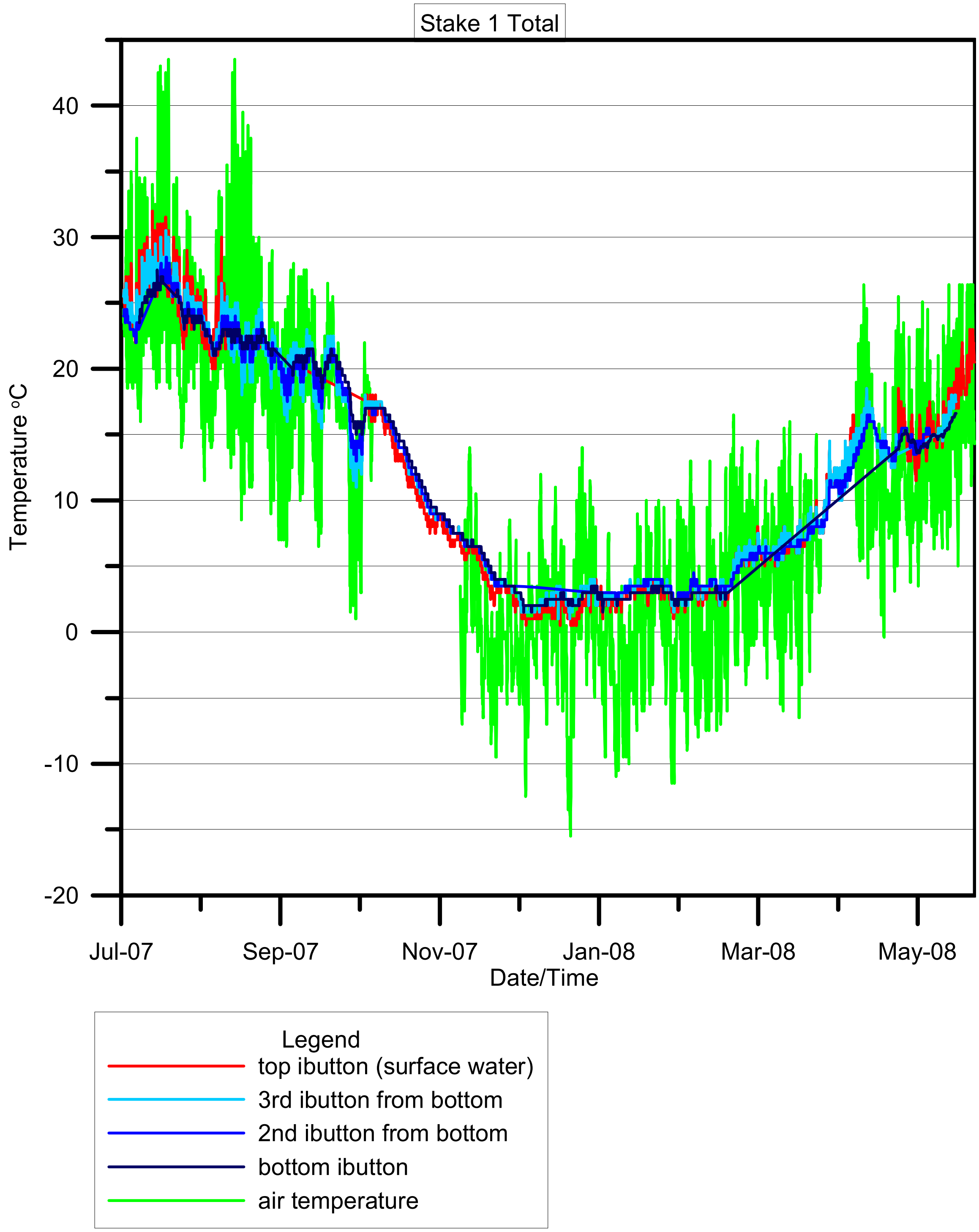
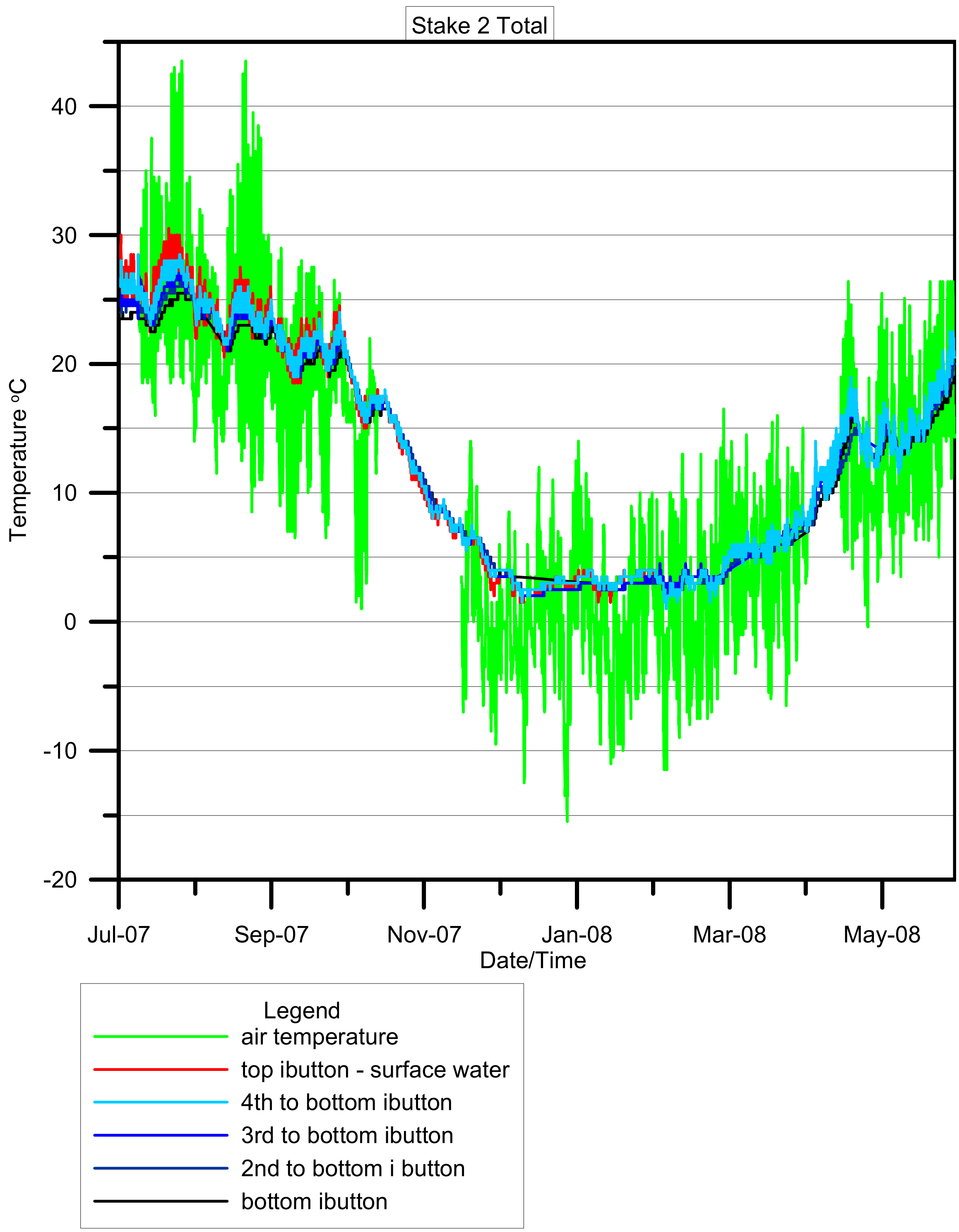
**Appendix A: Solute Concentrations and Isotopic Signatures for Thirty Acre Pond and URI Well #4 from 7/18/07 to 6/4/08**

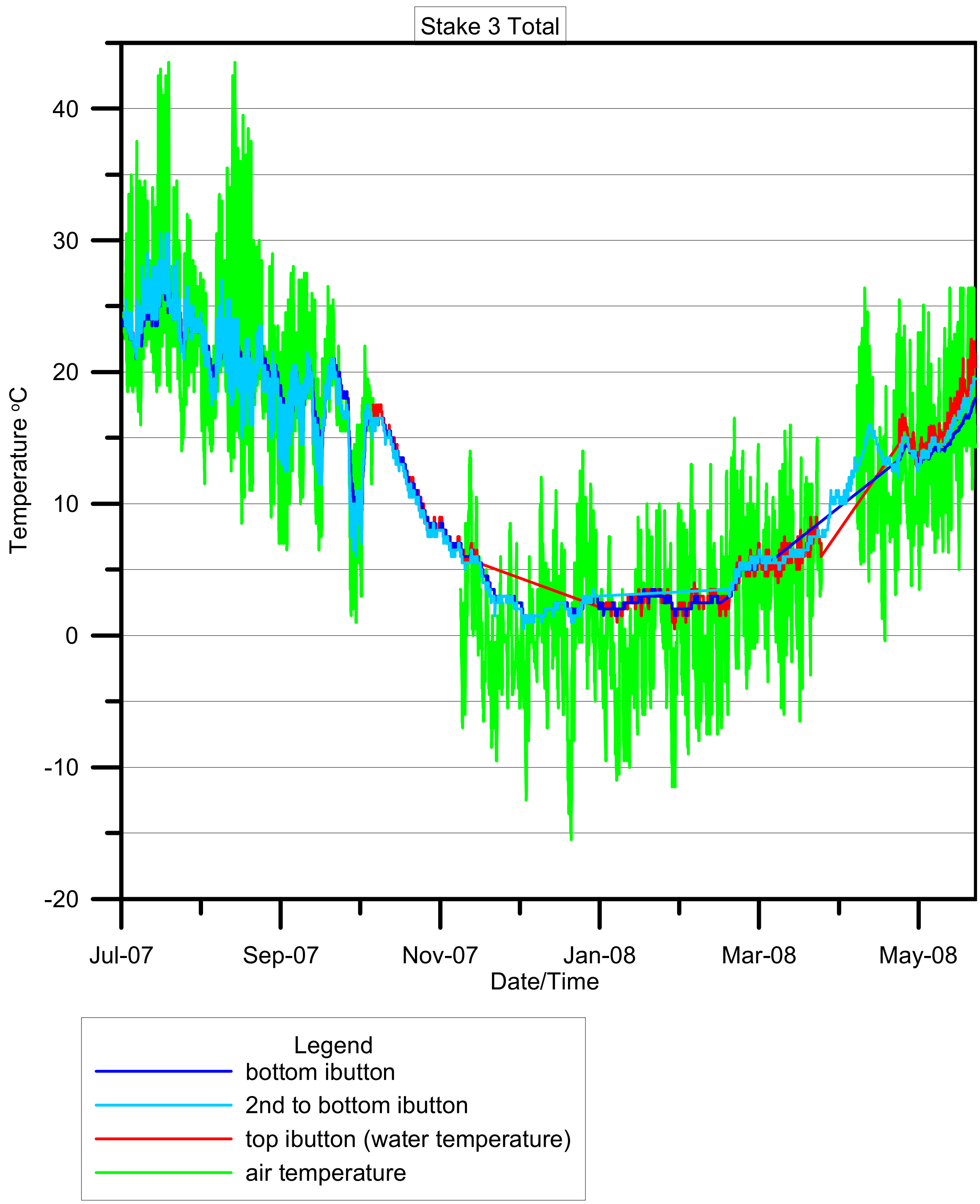
| Major Constituents -Thirty Acre Pond (mg/L) | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $Cl^-$ | $F^-$ | $NO3^-$ | $SO4^{2-}$ | $PO4^{3-}$ | Na+ | $Ca^{2+}$ | $Mg^{2+}$ | $K^+$ | $SiO_2$ | $HCO_3$ | $\delta^{18}O$‰ | δD‰ |
| 7/18/2007 | 22 | n/a | 1.3 | 8.4 | | 13 | 5.2 | 1.9 | 1.7 | 3.1 | 11.1 | | |
| 7/25/2007 | 21 | n/a | 1.1 | 8.4 | | 13 | 5.6 | 2 | 1.7 | 3.2 | 12.9 | -6.1 | -38 |
| 8/1/2007 | 23 | 0.28 | 0.94 | 8.4 | | 13 | 4.8 | 2.1 | 1.6 | 3.3 | 14.8 | | |
| 8/8/2007 | 22 | 0.28 | 0.78 | 8.6 | | 14 | 4.7 | 2.2 | 1.9 | 3.1 | 18.5 | -5.6 | -35 |
| 8/15/2007 | 23 | 0.27 | 0.6 | 8.3 | | 13 | 4.3 | 1.9 | 1.7 | 2.9 | 12.9 | | |
| 8/22/2007 | 21 | 0.27 | 0.58 | 8.4 | | 14 | 6.4 | 2 | 1.9 | 2.7 | 12.9 | -5.7 | -36 |
| 8/29/2007 | 22 | 0.21 | 0.76 | 7.9 | | 13 | 6.7 | 2.1 | 1.8 | 2.4 | 14.8 | | |
| 9/5/2007 | 24 | 0.2 | 0.75 | 7.9 | | 14 | 4.9 | 2.2 | 2 | 2.1 | 16.6 | | |
| 9/12/2007 | 25 | 0.21 | 0.75 | 7.9 | | 14 | 5 | 2.4 | 2 | 2.4 | 17.6 | | |
| 9/19/2007 | 24 | n/a | n/a | 7.7 | | 16 | 6.3 | 2.4 | 2.4 | 2.2 | 14.8 | | |
| 9/26/2007 | 25 | n/a | 0.97 | 7.9 | | 15 | 5.5 | 2.4 | 2.4 | 1.4 | 14.8 | -5.4 | -35 |
| 10/3/2007 | 27 | n/a | 1 | 7.9 | | 16 | 5.6 | 2.5 | 2.8 | 1.2 | 16.6 | | |
| 10/10/2007 | 27 | n/a | 1.2 | 8 | | 16 | 8.2 | 2.7 | 2.8 | 1.2 | 12.9 | -5.5 | -35 |
| 10/17/2007 | 31 | n/a | 1.4 | 8.2 | | 18 | 6.8 | 2.9 | 3 | 1.4 | 18.5 | | |
| 10/24/2007 | 30 | n/a | 1.3 | 8.5 | | 19 | 7.1 | 3.2 | 3.2 | 1 | 14.8 | | |
| 10/31/2007 | 31 | n/a | 0.95 | 8.9 | 0.54 | 20 | 7.9 | 3.4 | 3.4 | 1.5 | 16.6 | | |
| 11/7/2007 | 28 | n/a | 0.59 | 7.8 | | 19 | 5.5 | 3.2 | 3.1 | 4.3 | 18.5 | | |
| 11/14/2007 | 27 | n/a | 0.55 | 7.7 | | 19 | 7.1 | 3.1 | 2.9 | 4.9 | 16.6 | -5.6 | -37 |
| 11/21/2007 | 25 | n/a | 0.71 | 7.7 | | 16 | 5.9 | 2.4 | 2.4 | 4.9 | 16.6 | | |
| 11/29/2007 | 24 | n/a | 0.73 | 7.8 | | 15 | 5.7 | 2.4 | 2.4 | 5.1 | 16.6 | | |
| 12/5/2007 | 24 | n/a | 0.76 | 8.2 | | 15 | 5.5 | 2.3 | 2.3 | 5.2 | 12.9 | | |
| 12/12/2007 | 21 | n/a | 0.89 | 8 | | 14 | 5.2 | 2.2 | 2 | 5.7 | 9.24 | -5.9 | -38 |
| 1/10/2008 | 19 | n/a | 1.4 | 7.8 | | 12 | 5.3 | 2.1 | 1.8 | 5 | 11.1 | -6 | -37 |
| 1/23/2008 | 22 | n/a | 2.1 | 9.4 | | 15 | 6.6 | 2.5 | 2.2 | 6.8 | 12.9 | | |
| 1/30/2008 | 21 | n/a | 2.3 | 9.2 | | 15 | 8 | 2.4 | 2.1 | 5.7 | 12.9 | | |
| 2/6/2008 | 18 | n/a | 1.7 | 7.9 | | 12 | 4.8 | 1.9 | 1.6 | 4.4 | 11.1 | -6.2 | -38 |
| 2/13/2008 | 22 | n/a | 3.9 | 9.1 | | 14 | 7.1 | 2.5 | 2 | 8 | 18.5 | | |
| 2/20/2008 | 21 | n/a | 2.2 | 9 | | 15 | 5.3 | 1.1 | 2 | 5.6 | 18.5 | -6.7 | -41 |
| 3/5/2008 | 20 | n/a | 2.2 | 8.8 | | 14 | 5.1 | 1.2 | 1.8 | 4.8 | 7.4 | | |
| 3/12/2008 | 20 | n/a | 2.2 | 8.4 | | 15 | 5 | 1.2 | 1.8 | 5.3 | 3.7 | -6.9 | -41 |
| 3/26/2008 | 20 | n/a | 2.6 | 8.4 | | 15 | 4.9 | 1.4 | 1.8 | 4.8 | 7.4 | | |
| 4/2/2008 | 20 | n/a | 2.8 | 8.5 | 1.6 | 15 | 8.3 | 1.7 | 1.8 | 5.7 | 5.5 | | |
| 4/10/2008 | 20 | n/a | 2.5 | 8.4 | | 15 | 5.2 | 1.8 | 1.8 | 5.8 | 5.5 | -6.5 | -38 |
| 4/23/2008 | 21 | n/a | 2.6 | 8.5 | | 16 | 6.1 | 1.7 | 1.9 | 5 | 5.5 | | |
| 4/30/2008 | | | | | | | | | | 5.1 | 5.5 | -6.3 | -37 |
| 5/7/2008 | | | | | | | | | | 3.2 | 7.4 | -6.1 | -37 |
| 5/21/2008 | | | | | | | | | | | 12 | | |
| 5/28/2008 | | | | | | | | | | | 7.4 | | |
| 6/4/2008 | | | | | | | | | | | 9.2 | | |
| | | | | | | | | | | | | | |
| | | | | | | | | | | | | | |
| | | | | | | | | | | | | | |

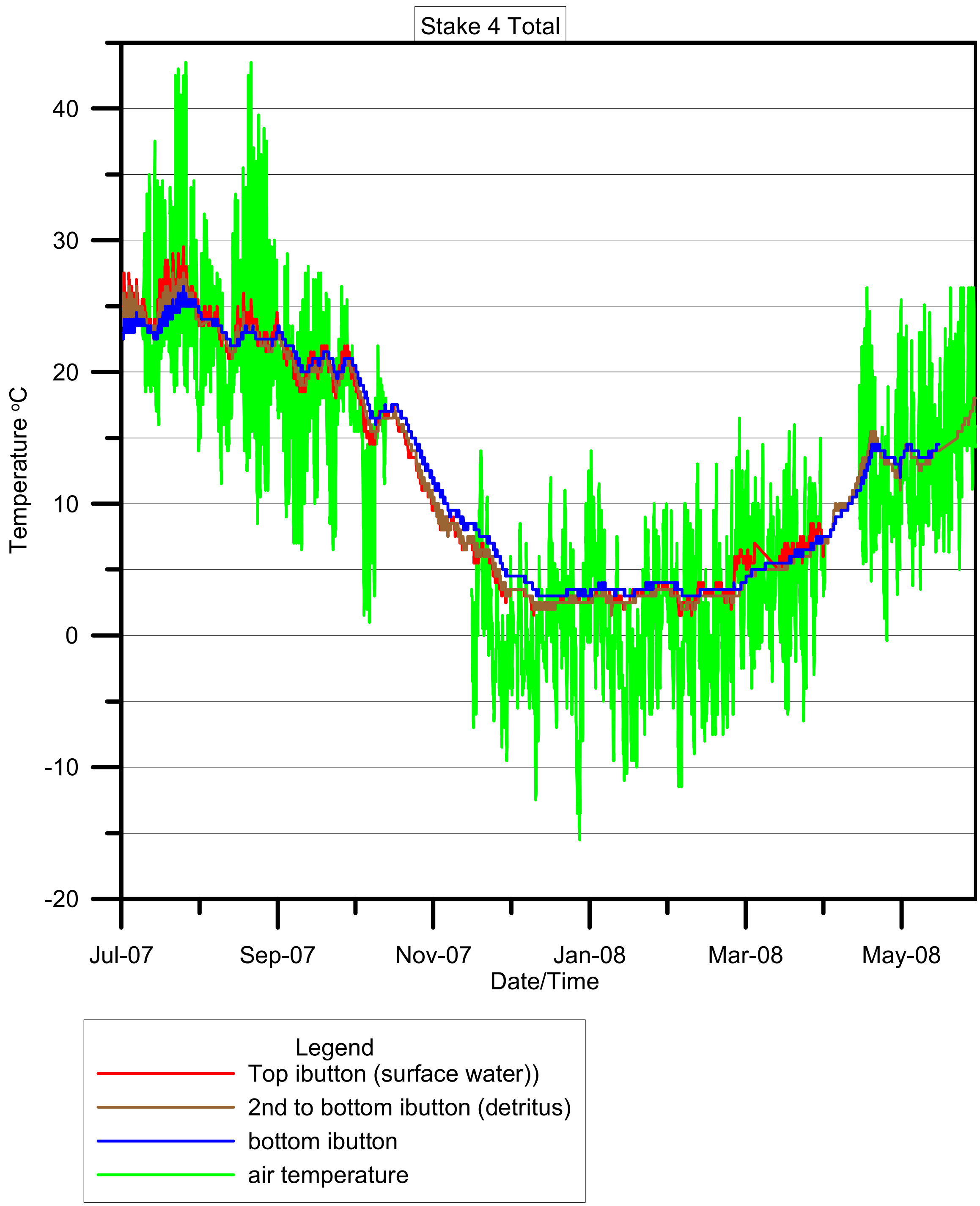
| Major Constituents - URI well 4 (mg/L) | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $Cl^-$ | $F^-$ | $NO3^-$ | $SO4^{2-}$ | $PO4^{3-}$ | Na+ | $Ca^{2+}$ | $Mg^{2+}$ | $K^+$ | $SiO_2$ | $HCO_3^-$ | $\delta^{18}O$‰ | δD‰ |
| 7/18/2007 | 36 | 0.51 | 8.9 | 12.3 | | 18 | 20 | 3.2 | 2.3 | 18 | 53.6 | | |
| 7/25/2007 | 38 | 0.54 | 8.8 | 12.4 | | 18 | 13 | 3.2 | 2.4 | 18 | 46.2 | -7.3 | -44 |
| 8/1/2007 | 37 | 0.57 | 9.2 | 12.4 | | 19 | 17 | 3.3 | 2.5 | 19 | 59.1 | | |
| 8/8/2007 | 39 | 0.56 | 9 | 12.6 | | 18 | 16 | 3.4 | 2.3 | 18 | 57.3 | -7.3 | -44 |
| 8/15/2007 | 39 | 0.53 | 9.1 | 12.4 | | 18 | 16 | 3.2 | 2.5 | 18 | 48 | | |
| 8/22/2007 | 40 | 0.59 | 9.3 | 12.6 | | 19 | 13 | 3.2 | 2.6 | 18 | 46.2 | -7.3 | -43 |
| 8/29/2007 | | | | | | | | | | | | | |
| 9/5/2007 | 34 | 0.58 | 9.7 | 12 | | 18 | 15 | 3.5 | 2.3 | 18 | 42.5 | | |
| 9/12/2007 | 33 | 0.51 | 9.6 | 12 | | 18 | 13 | 3.5 | 2.5 | 19 | 48 | | |
| 9/19/2007 | 34 | 0.61 | 11 | 13 | | 19 | 13 | 3.4 | 2.7 | 18 | 46.2 | | |
| 9/26/2007 | 34 | 0.58 | 9.2 | 12 | | 18 | 13 | 3.6 | 2.4 | 19 | 49.9 | -7.3 | -43 |
| 10/3/2007 | | | | | | | | | | | | | |
| 10/10/2007 | 35 | 0.44 | 10 | 12 | | 19 | 13 | 3.6 | 2.4 | 19 | 40.7 | -7.2 | -44 |
| 10/18/2007 | 34 | 0.45 | 10 | 13 | | 20 | 14 | 3.8 | 2.8 | 19 | 64.7 | | |
| 10/24/2007 | 35 | 0.45 | 10 | 13 | | 21 | 14 | 3.9 | 2.9 | 19 | 40.7 | | |
| 10/31/2007 | 34 | 0.5 | 9.3 | 12 | | 21 | 16 | 4 | 3.2 | 18 | 46.2 | | |
| 11/7/2007 | 37 | 0.45 | 9.7 | 13 | | 21 | 15 | 4.3 | 3 | 21 | 42.5 | | |
| 11/14/2007 | 36 | 0.5 | 9.1 | 13 | | 22 | 15 | 4.2 | 3 | 18 | 51.4 | -7.2 | -43 |
| 11/21/2007 | 37 | 0.47 | 8.9 | 13 | | 19 | 13 | 3.5 | 2.6 | 21 | 49.9 | | |
| 11/23/2007 | | | | | | | | | | | | | |
| 11/29/2007 | | | | | | | | | | | | | |
| 12/5/2007 | 36 | 0.53 | 8.6 | 13 | | 19 | 12 | 3.5 | 2.7 | 21 | 31.4 | | |
| 12/12/2007 | 36 | 0.53 | 8.6 | 13 | | 19 | 12 | 3.5 | 2.6 | 20 | 31.4 | -7.1 | -43 |
| 1/10/2008 | 36 | 0.54 | 8.6 | 13 | | 19 | 12 | 3.4 | 2.6 | 17 | 29.6 | -7.0 | -42 |
| 1/23/2008 | | | | | | | | | | | | | |
| 1/31/2008 | 31 | 0.33 | 7.7 | 12 | | 19 | 12 | 3.5 | 2.5 | 16 | 33.3 | | |
| 2/6/2008 | 29 | n/a | 6.7 | 11 | | 18 | 12 | 3.3 | 2.4 | 17 | 33.3 | -7.1 | -43 |
| 2/13/2008 | 30 | 0.33 | 7.6 | 11 | | 19 | 12 | 1.7 | 2.8 | 14 | 46.2 | | |
| 2/20/2008 | 31 | 0.32 | 7.7 | 12 | | 19 | 12 | 2.3 | 2.8 | 16 | 38.8 | -7.1 | -43 |
| 3/5/2008 | 30 | 0.12 | 7 | 12 | | 20 | 13 | 2.7 | 2.8 | 17 | 40.7 | | |
| 3/12/2008 | 31 | 0.1 | 7.1 | 12 | | 20 | 13 | 2.9 | 3.4 | 14 | 37 | -7.2 | -43 |
| 3/26/2008 | 42 | 0.1 | 8.5 | 12 | | 27 | 15 | 3.5 | 3.1 | 15 | 46.2 | | |
| 4/2/2008 | 31 | 0.1 | 7.5 | 12 | 1 | 20 | 15 | 3.6 | 2.9 | 18 | 53.6 | | |
| 4/10/2008 | 85 | n/a | 13 | 13 | | 55 | 19 | 4.1 | 4.4 | 14 | 14.7 | -7.2 | -43 |
| 4/24/2008 | 34 | 0.26 | 9.1 | 12 | | 23 | 16 | 3.7 | 3.4 | 17 | 77.6 | | |
| 4/30/2008 | | | | | | | | | | 16 | 55.4 | -7.2 | -43 |
| 5/7/2008 | | | | | | | | | | 17 | 61 | -7.2 | -45 |
| 5/21/2008 | | | | | | | | | | | 70 | | |
| 5/28/2008 | | | | | | | | | | | 61 | | |
| 6/4/2008 | | | | | | | | | | | 47 | | |
| | | | | | | | | | | | | | |

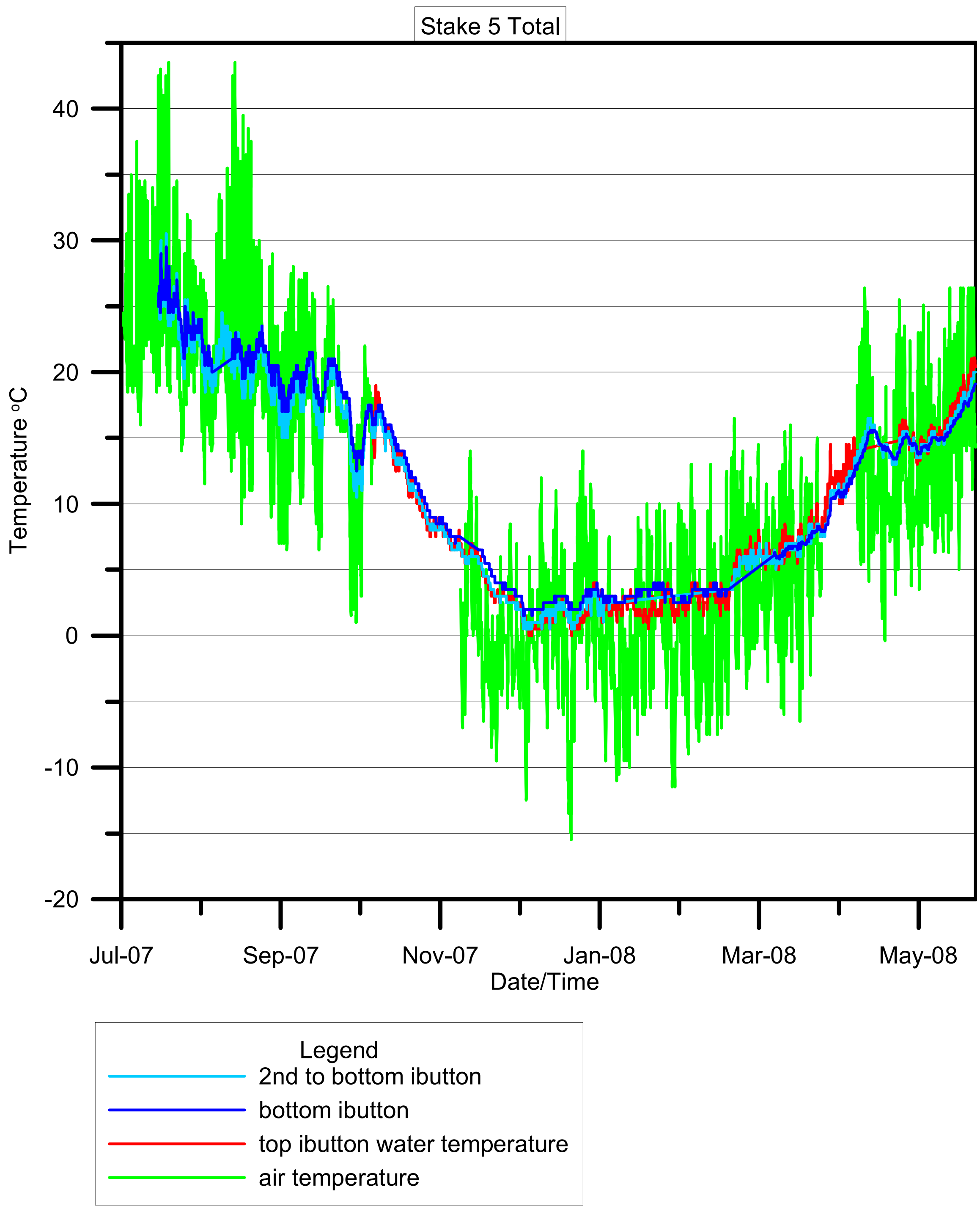
**Appendix B: Temperature Results and LevelTroll results for entire study period**



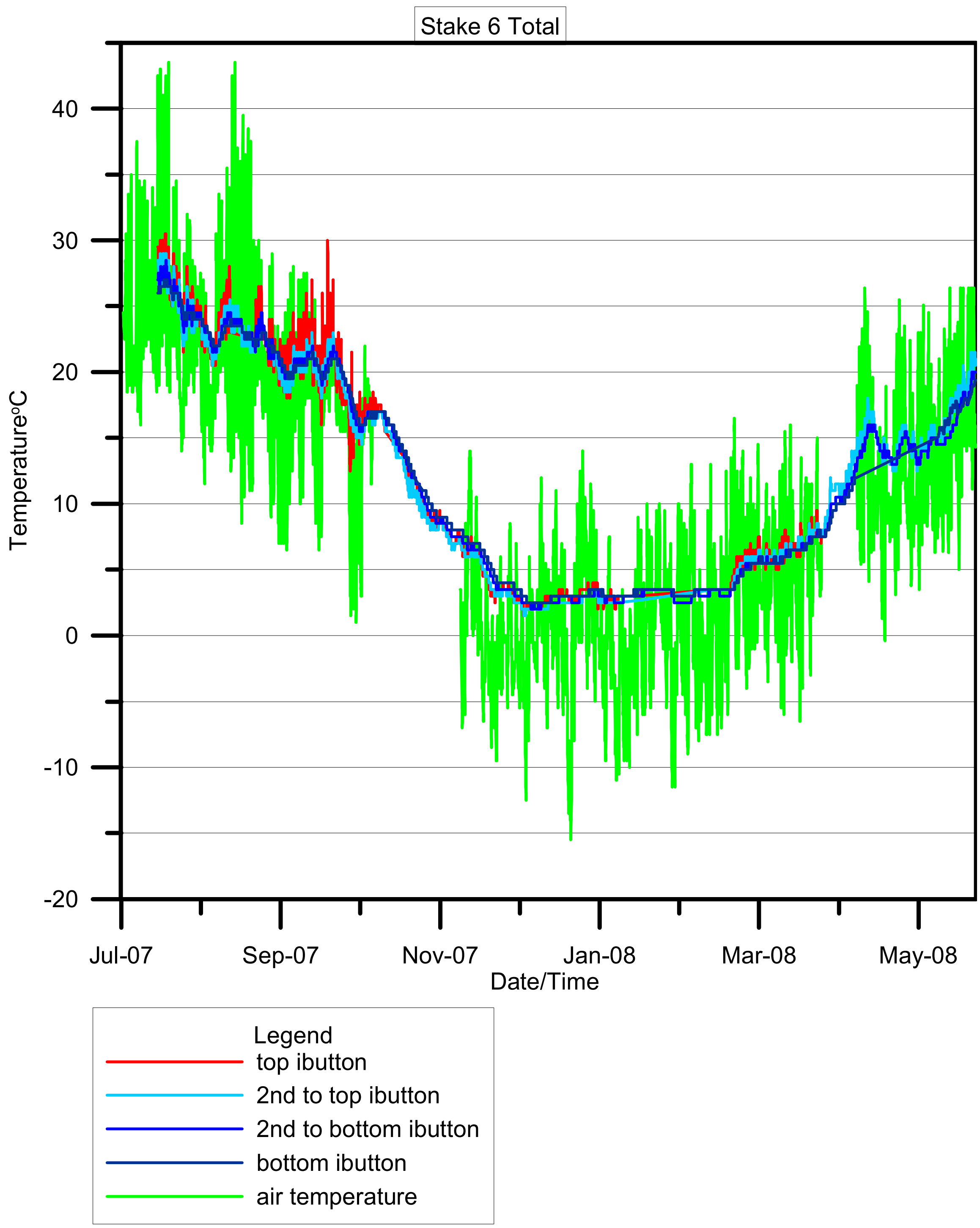

Stake 2 Total
40
30
20
10
0
-10
-20
Temperature °C
Jul-07
Sep-07
Nov-07
Jan-08
Mar-08
May-08
Date/Time
Legend
air temperature
top ibutton - surface water
4th to bottom ibutton
3rd to bottom ibutton
2nd to bottom i button
bottom ibutton

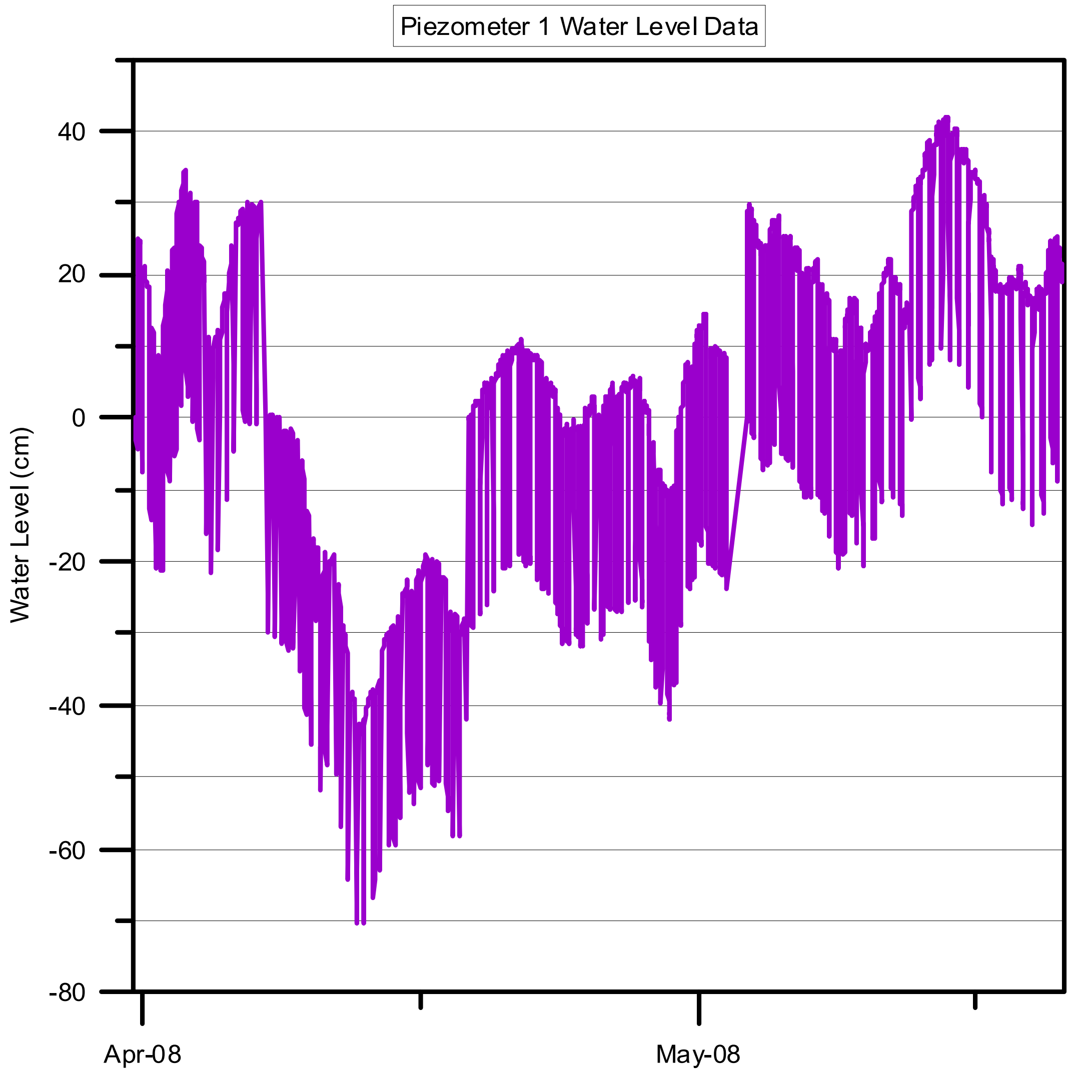

Stake 3 Total
Temperature °C
40
30
20
10
0
-10
-20
Jul-07
Sep-07
Nov-07
Jan-08
Mar-08
May-08
Date/Time
Legend
bottom ibutton
2nd to bottom ibutton
top ibutton (water temperature)
air temperature


Stake 4 Total
Temperature °C
40
30
20
10
0
-10
-20
Jul-07
Sep-07
Nov-07
Jan-08
Mar-08
May-08
Date/Time
Legend
Top ibutton (surface water))
2nd to bottom ibutton (detritus)
bottom ibutton
air temperature



Stake 5 Total
Temperature °C
40
30
20
10
0
-10
-20
Jul-07
Sep-07
Nov-07
Jan-08
Mar-08
May-08
Date/Time
Legend
2nd to bottom ibutton
bottom ibutton
top ibutton water temperature
air temperature


Stake 6 Total
Temperature°C
40
30
20
10
0
-10
-20
Jul-07
Sep-07
Nov-07
Jan-08
Mar-08
May-08
Date/Time
Legend
top ibutton
2nd to top ibutton
2nd to bottom ibutton
bottom ibutton
air temperature



Piezometer 1 Water Level Data
Water Level (cm)
40
20
0
-20
-40
-60
-80
Apr-08
May-08

## Appendix C: MPA Results

| MPA Analytical Results 5/6/08 | | | | | |
|---|---|---|---|---|---|
| Amorphous Debris | uniformly distributed | Crustaceans | <2 | Giardia | ND |
| Vegetative Debris | | Crustacean parts | <2 | Cryptosporidium | ND |
| With Chlorophyll | 2 | Crustacean eggs | <2 | | |
| Without Chlorophyll | 8 | Water mites | <2 | | |
| Diatoms | | Gastrotrichs | <2 | | |
| With Chlorophyll | $<1.7*10^3$ | Tardigrades | <2 | | |
| Without Chlorophylll | $<1.7*10^3$ | Nematodes | <2 | | |
| Other Algae | $5.8*10^4$ | Nematode eggs | <2 | | |
| Rotifers | <2 | Invertebrate eggs | <2 | | |
| Rotifer Eggs | <2 | Annelids | <2 | | |
| Spores | <2 | Amoebae | 2 | | |
| Pollen | $4.6*10^1$ | Protozoa | $<1.7*10^3$ | | |
| Iron Bacteria | ND | Insects/larvae | <2 | | |
| **Total Score: 14** | | | | | |

| MPA Analytical Results 12/17/07 | | | | | |
|---|---|---|---|---|---|
| Amorphous Debris | uniformly distributed | Crustaceans | $1*10^1$ | Giardia | ND |
| Vegetative Debris | | Crustacean parts | $<1*10^1$ | Cryptosporidium | ND |
| With Chlorophyll | $<1*10^1$ | Crustacean eggs | $<1*10^1$ | | |
| Without Chlorophyll | $<1*10^1$ | Water mites | $<1*10^1$ | | |
| Diatoms | | Gastrotrichs | $1.7*10^2$ | | |
| With Chlorophyll | $<1.7*10^2$ | Tardigrades | $<1*10^1$ | | |
| Without Chlorophylll | $<1.7*10^2$ | Nematodes | $<1*10^1$ | | |
| Other Algae | $2.7*10^3$ | Nematode eggs | $<1*10^1$ | | |
| Rotifers | $<1*10^1$ | Invertebrate eggs | $<1*10^1$ | | |
| Rotifer Eggs | $<1*10^1$ | Annelids | $<1*10^1$ | | |
| Spores | $1*10^1$ | Amoebae | $<1*10^1$ | | |
| Pollen | $4.0*10^1$ | Protozoa | $3.4*10^2$ | | |
| Iron Bacteria | present | Insects/larvae | $<1*10^1$ | | |
| **Total Score: 14** | | | | | |

# Information Transfer Program Introduction

The information transfer program funded by the RI Water Resources Center had the overall objective of teaching High School and Middle School Science teachers about the opportunities and water related issues in Water Resources. This was accomplished by teacher participation in a summer camp with laboratory, field sampling and field trips to treatment facilites.

# Clean Drinking Water in Rhode Island

## Basic Information

| | |
|---|---|
| **Title:** | Clean Drinking Water in Rhode Island |
| **Project Number:** | 2007RI60B |
| **Start Date:** | 3/1/2007 |
| **End Date:** | 2/28/2008 |
| **Funding Source:** | 104B |
| **Congressional District:** | Two |
| **Research Category:** | Water Quality |
| **Focus Category:** | Water Quality, Education, None |
| **Descriptors:** | |
| **Principal Investigators:** | Harold Knickle |

## Publication

# Clean Drinking Water in Rhode Island

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The project focuses on information transfer and education utilizing two major outreach activities, a meeting and workshop on clean water and a summer workshop for middle and high school teachers to promote interest in clean water careers. The objectives were as follows:

1. Run a summer workshop for Middle School and High School Teachers on Clean Water
2. Host a Meeting and Workshop on Clean Water

The Summer Workshop on Clean Water for Middle and High School Teachers Camp was presented in the Department of Civil and Environmental Engineering Laboratory in Bliss Hall on the campus of the University of Rhode Island. Teachers from several RI schools including Central Falls, East Greenwich, North Kingstown, Pawtucket and the Times 2 Academy applied and were accepted. All experiments were conducted under the supervision of the PI and several graduate and undergraduate student mentors.

Middle and High school science teachers were encouraged to participate in a week of lectures, lab activities and field trips that focused on clean water. The schedule for the workshop was from Monday to Friday during the week of July 23 to July 27, 2007. Teachers arrived at 9:00 am and left at 3:30 pm. The academic content of this camp was such that several of the teachers applied to the RI Department of Education for CEUs.

Activities included presentations of the water cycle, chemistry of water, water quality and treatment, sewage treatment and biological treatment technology, runoff and storm water, industrial water pollution, pollution prevention, and the Blackstone River cleanup. Laboratory exercises included water quality sampling and testing, pH and dissolved oxygen measurement, bacteria pollution testing, conductivity testing, acid rain analysis, aeration, adsorption and a lecture on health effects. Laboratory experience also included use of some of the major equipment in the Environmental Laboratory including organic and trace metal analysis To ensure that the material presented in this camp could be transferred to the students that the teachers taught during the academic year the Rhode Island Statewide Curriculum Lesson Planning template was followed whenever possible.

Field work included the collection of samples from various locations and water bodies. Field trips were made to fresh water treatment facilities and a sewage treatment plant.
Each teacher wrote a brief laboratory report for each laboratory exercise which was graded and returned. Also, each teacher developed a lesson plan to integrate this subject matter into their courses.

**Clean Water Workshop 2007**
**Five Day Schedule**

**Day 1 July 23, 2007**
Pre Assessment Survey
Introduction to the Water Cycle
Introduction to Water Chemistry and Water Quality Treatment
Drinking Water Sample Collection
Lunch
Drinking Water Quality Testing
Laboratory Report

**Day 2 July 24, 2007**
East Greenwich Sewage Treatment Plant, Presentation by Mile Pacillo, Operator
Lunch
Introduction to Sewage Treatment and Biological Technology
Biological Testing Laboratory
Laboratory Report

**Day 3 July 25, 2007**
Introduction to Surface Water, Water Runoff and Storm Water
Settling Laboratory
pH Laboratory
Lunch
Pond Water Runoff
DVD: The Pond
Introduction to Aeration
Settling Laboratory Continued
Activated Carbon adsorption Laboratory
Dissolved Oxygen Measurement Laboratory
Laboratory Report

**Day 4 July 26, 2007**
Introduction to Chemical and Physical Adsorption
Visit to URI Water Wells
Water Tower, Flow Rates and Pressure Head
Introduction to Health Effects Associated with Water Quality
Introduction to Chemical and Physical Adsorption
Lunch
Introduction to Pollution Prevention
Adsorption Laboratory
Laboratory Report

**Day 5 July 27, 2007**
Visit to Scituate Reservoir
Introduction to Blackstone River Cleanup Point Sources and Non-Point Sources
Blackstone River Samples
Field Trip to URI Water Supply System
Lunch
Essay Writing
Post Assessment Survey

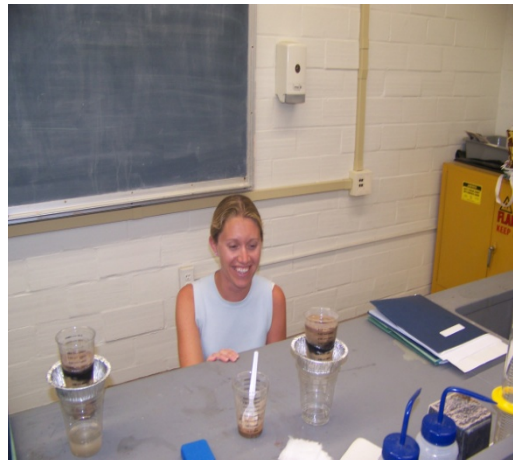
Awarding of Certificates

**Results**

Eight teachers signed up for the workshop.  Most developed curriculum plans and two requested follow-up conferences.  The plant visits were well received.  These included a modern wastewater treatment plant in East Greenwich, Rhode Island.  That plant is typical of wastewater treatment plants in their primary treatment. In their secondary treatment they use rotary filters and for their final step before discharging into Narragansett Bay the use ultraviolet lams to kill any bacteria left in the discharge stream.  Another important plant trip was to visit the University of Rhode Island fresh water system.  This included the pond which supplies the aquifer from which water is pumped.  These steps are followed by the addition of lime to neutralize the water.  The water is then pumped up to a large storage tank followed by gravity feed to the academic buildings.  A notable plant trip included the Scituate Reservoir and the Providence Water Supply Board Water treatment plant.  The plant provides water to more than 60% of the residents of the State of Rhode Island.  The water treatment plant includes a number of import steps including settling, aeration and chlorination.  The plant visits were enhanced with lecture and laboratory experiences outlined in the schedule for the week event.  A series of photographs follows.

The following pictures are from the Scituate Reservoir and Providence Water Supply Treatment Plant

**The following picture depict lab experiments with sand and activated carbon filtration and a guest lecturer (Dr. Barnett)**

**The following pictures depict the URI Fresh Water System.**

## Meeting and Workshop on Clean Water

At the meeting and workshop, the Keynote speaker, Harold Mantius, was from the Ocean Spray Cranberry Cooperative. He discussed the reduction in usage of fresh water in production plants. Following the presentation by the keynote speaker there was an extended workshop discussing recycling, conservation and changing processing methods.

**Fresh cranberries picked, washed and ready for processing/sorting**

# Student Support

| Student Support | | | | | |
|---|---|---|---|---|---|
| **Category** | **Section 104 Base Grant** | **Section 104 NCGP Award** | **NIWR−USGS Internship** | **Supplemental Awards** | **Total** |
| **Undergraduate** | 2 | 0 | 0 | 0 | 2 |
| **Masters** | 4 | 0 | 0 | 0 | 4 |
| **Ph.D.** | 0 | 0 | 0 | 0 | 0 |
| **Post−Doc.** | 0 | 0 | 0 | 0 | 0 |
| **Total** | 6 | 0 | 0 | 0 | 6 |

# Notable Awards and Achievements

The Rhode Island Water Resources Center project entitled "Clean drinking Water in Rhode Island" sponsored a Clean Water Workshop for Middle School and High School Teachers. The purpose was to encourage the teachers to include water resources topics in their science classes. The hands−on experiments that the teachers performed were designed to be able to be performed by their students in their classes. This was the first time that the Rhode Island Water Resources Center sponsored a Teacher Workshop. The positive comments from the teachers about including the material in science courses will help to encourage careers in the water resources area.

# Publications from Prior Years

1. 2006RI45B ("Assessment of Downstream Hazard Potential for Dam Failure in Rhode Island") − Dissertations − Madsen, R, "Assessment of Downstream hazard Potential for Dam Failure in Rhode Island," a Masters Thesis, May 2007.