# 2009 Self-Monitoring Program Report for Pond A18

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# Self-Monitoring Program

# 2009 Annual Report

# Pond A18 in Santa Clara County

Order No. R2-2005-0003

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# *I. Introduction*

This report summarizes results of the 2009 water quality sampling conducted for Pond A18 in Santa Clara County. Monitoring was conducted from May 1st 2009 through October 31st 2009. This monitoring was performed in accordance with Waste Discharge Requirements (WDR) Order No. R2-2005-0003 (Order) issued on February 16, 2005 by the San Francisco Bay Regional Water Quality Control Board (Regional Water Board).

This was the fifth year of monitoring following the initial release of water from former Salt Pond A18 on February 17, 2005 and the beginning of Continuous Discharge Operations on May 10, 2005. Initial adaptive pond management included measures to minimize the impact of low dissolved oxygen discharges on the immediate receiving water in Artesian Slough. Gate opening and closing procedures were streamlined in 2006 and 2007 to improve operational efficiency while also benefiting in-pond water quality by minimizing pond closures and maximizing flow through the pond. This operation was consistent with recommendations in the 2005 and 2006 Annual Self Monitoring Program Reports for Pond A18. Operations were further modified in 2008 and 2009 as part of the adaptive management process. The initial response to low pond DO in 2008 and 2009 was to initiate additional receiving water monitoring rather than immediately closing gates. This was in an effort to facilitate consistent flow through the pond and promote pond system stability.

Between 2006 and 2009, the City voluntarily performed supplemental monitoring to understand the dynamics of the Pond A18 system. This additional monitoring included sampling of nutrients, mercury/methyl mercury, suspended solids, extra chlorophyll *a* sampling at several pond sites, phytoplankton speciation, and incorporation of local irradiance measurements. A portion of the monitoring and analysis was conducted in collaboration with the U.S. Geological Survey (USGS) in Menlo Park, CA. This collaboration resulted in an estimation of primary production based on high resolution DO time series and correlations between shifts in pond water quality and environmental variables including solar irradiance and temperature. This additional investigation was initially presented at a scientific conference in November 2007, has been presented at additional technical venues, and was published in the September 2008 edition of *Wetlands* (Appendix V).

The City has continued to collaborate with the Regional Water Board and U.S. Fish and Wildlife Service (USFWS) by sharing weekly data and management strategies. Ponds A16 and A17 are managed by USFWS and are located on the opposite side of Artesian Slough from Pond A18. Pond A16 also discharges into Artesian Slough.

The City continues to develop a long term plan for future uses of Pond A18 through the San Jose/Santa Clara Water Pollution Control Plant Master Planning effort. Appendix IV is a status update on this process.

Figure 1 shows the location of Pond A18 intake and discharge structures, including sampling sites located in the pond and receiving water.

## A. Waste Discharge Requirements

The WDR requires the following three discharge limitations for Pond A18:

1. Salinity, dissolved oxygen, and pH requirements as shown in Table 1.

**Table 1. Pond A18 Discharge Requirements**

| Constituent | Instantaneous Maximum | Instantaneous Minimum | Units |
|---|---|---|---|
| Salinity for continuous circulation | 44 | | Ppt |
| Dissolved Oxygen[1] | | 5.0 | mg/L |
| pH[2] | 8.5 | 6.5 | |

[1] The Discharger may select discharge station A-A18-D, or receiving water station A-A18-5 to evaluate compliance with the dissolved oxygen limitation. In cases where receiving waters do not meet the Basin Plan objective, the Discharger must show, as described in its Operations Plan, that pond discharges do not further depress the dissolved oxygen level in the receiving water.

[2] The Discharger may select discharge station A-A18-D, or receiving water monitoring A-A18-5 to evaluate compliance with the pH limitation.

2. Pond waters discharging to Artesian Slough shall not exceed the natural temperature of the receiving waters by 20°F, or more.

3. Dissolved Oxygen Trigger. The Discharger shall monitor, report, and take corrective action measures, in accordance with the Operations Plan required by Provision D.2, if dissolved oxygen levels in Pond A18 at station A-A18-M fall below 1.0 mg/L during the continuous circulation period [note: the Regional Water Board has allowed the City to monitor A-A18-M at the discharge (D in Figure 1)].

## B. Monitoring Requirements

Monitoring requirements for the continuous circulation period are described in Table 2.

**Table 2. Continuous Circulation Monitoring for Pond A18**

| Sampling Station: | D.O. | pH | Temp | Salinity | Turbidity | Chlorophyll *a* | Metals/Water Column | Sample Function |
|---|---|---|---|---|---|---|---|---|
| A-A18-M | A | A | A | A | | A | | Management |
| A-A18-D | B | B | B | B | | | C<br>[Eliminated in 2006] | Discharge |
| A-A18-1 | D | D | D | D | D | | | Receiving Water |
| A-A18-2 | D | D | D | D | D | | | Receiving Water |
| A-A18-3 | D | D | D | D | D | | | Receiving Water |
| A-A18-4 | D | D | D | D | D | | | Receiving Water |
| A-A18-5 | E | E | E | E | | | | Receiving Water |

**LEGEND FOR TABLE 2**

A = Monitoring shall be conducted within Pond A18 monthly from May through October. Dissolved oxygen monitoring shall be conducted between 0800 and 1000 hours. Time of monitoring shall be reported. [Note: this can be taken at D].

B = Discharge monitoring shall be conducted before pond water mixes with receiving water using a continuous monitoring device from May through October. Downtime of continuous monitoring devices shall be minimized to the maximum extent feasible, and addressed annually in the Discharger's Operations Plan.

C = Water column samples for total and dissolved arsenic, chromium, nickel, copper, zinc, selenium, silver, cadmium, lead, and mercury shall be collected annually in August or September. When collecting metals samples, the Discharger shall also monitor for salinity, and total suspended solids. **[Note: This requirement was eliminated by the Regional Water Board in 2006 in a revision to the SMP included in a letter to the City dated May 9, 2006.].**

D = Receiving water monitoring shall be conducted at discrete locations from downstream to upstream monthly from May through October. The positions indicated on Figure 1 should be considered approximate. For days it monitors receiving water, the Discharger shall also (1) document if it monitors at flood tide, ebb tide, or slack tide (samples shall be collected as close to low tide as practicable), (2) monitor receiving water for dissolved oxygen, pH, temperature, salinity, and turbidity near the water surface and bottom, and (3) report standard observations, as described in Section D of the SMP.

E = Receiving water continuous monitoring for the purposes of determining compliance with the dissolved oxygen and pH limits shall be conducted from May through October at a location selected by the Discharger and approved by the Executive Officer at a point downstream of the discharge. Downtime of continuous monitoring devices shall be minimized to the maximum extent feasible, and addressed annually in the Discharger's Operations Plan.

In addition to the monitoring requirements listed in Table 2, annual sampling for Pond A18 sediment mercury and methyl mercury is required in August or September of each year.

# *II. Methods and Results*

This section summarizes 2009 monitoring activities.

## A. Quality Assurance/Quality Control

Instruments used for sampling Pond A18 were calibrated and maintained to ensure accurate data. Sonde units (continuous and discrete water quality monitors) were calibrated for dissolved oxygen, pH and conductivity prior to ambient deployment. Continuous sondes were cleaned and calibrated weekly. The discrete sonde unit was cleaned and calibrated prior to each use. Post-deployment calibration verification was performed on all sonde units after each use.

### Data Validation

As part of the Quality Control program, a target range of acceptable values was determined for pH, dissolved oxygen and conductivity prior to initiation of dry-season monitoring. During the post-deployment accuracy check, if a sonde unit's readings fell outside the specified range, the weekly data collected for that parameter was considered invalid and was not reported.

Dissolved oxygen was calibrated using percent saturation in either water-saturated air or air-saturated water (theoretical reading of 100% saturation). Weekly data with post-deployment readings within ±10% of the theoretical saturation level were accepted. Data with readings greater than ±10 but that did not exceed ±15% of theoretical were accepted or rejected based on best professional judgment. If an instrument had a post-deployment dissolved oxygen reading that exceeded ±15% of theoretical, all dissolved oxygen data since the instrument's last calibration were rejected as invalid and the cause of the QA/QC failure was investigated.

Calibrations for pH were performed using a 2-point calibration (pH 7 and pH 10 buffers) to establish a pH slope or an appropriate 1-point calibration following establishment of a pH slope. Since pH in Pond A18 tends to be higher (maximum of 9.7 in 2009), 1-point calibrations for units deployed in the pond were performed in a pH 10 buffer. Receiving water pH tends to be closer to neutral (range of 2009 receiving water pH was 6.8 – 8.6), so 1-point calibrations for units deployed in Artesian Slough were performed in a pH 7 buffer. Calibrations for conductivity were performed using either a 10,000 or 50,000 micro Sieman standard. Post-deployment accuracy checks were performed using the same standards. For both parameters, a target range within ±5% of the theoretical was established to determine data validity. Data outside this range were considered invalid for pH or Conductivity and were not reported. The cause of any such failure was investigated and steps to correct the error were taken including troubleshooting, probe replacement and sending the sonde unit into the manufacturer for repair.

There were two post-deployment verification failures for dissolved oxygen, two failures for pH, and four failures for conductivity during 2009. The data associated with these failures is invalid and is not reported, with the exception of a portion of the conductivity data. In addition, one sonde in Artesian Slough lost power resulting in a loss of some receiving water data from August 20 to August 25. Data collected prior to the power failure was retrieved and is reflected in the results of this report.

There were four consecutive weeks of post-deployment verification failures for conductivity by multiple sonde units deployed in Pond A18 from late August to September 2009. These were all caused by excessive biological fouling of the conductivity sensor by what appeared to be a diatom bloom in the pond. The post-deployment accuracy checks for conductivity for these four weeks were between 8.5% – 34.4% lower than theoretical. While each unit initially failed the post deployment verification, upon cleaning the probe, readings were within acceptable ranges so the fouling was interfering with the readings. Staff examined the data and determined that significant downward drift was occurring approximately 4 days (96 hours) after each deployment. Using best professional judgment, conductivity and salinity data from the first 96 hours of each week from 8/25/09 through 9/22/09 are included in this report, while the remainder of each week's conductivity data are invalid and not reported.

For the 2009 monitoring season, the post-deployment measurement error for reported water quality parameters was in the following ranges:

1. For dissolved oxygen: –6.2% to +8.4% (median +0.6%)
2. For pH: –4.0% to +3.6% (median +0.4%)
3. For conductivity: –4.4% to +2.0% (median -1.0%)

## B. Continuous Monitoring

Pond A18 discharge (Station D) was monitored continuously for temperature, practical salinity, pH, and dissolved oxygen during the dry season from May 1, 2009 to October 31, 2009. Receiving water in Artesian Slough (Station 5) was monitoring continuously for the same water quality parameters from May 12, 2009 to October 31, 2009. The slight delay in receiving water monitoring was due to a failure of the buoy mooring upon which the receiving water sonde is attached. This issue was corrected on May 12, 2009 by re-anchoring the buoy and receiving water monitoring began at that time. Figure 1 shows the location of both monitoring stations. Monitoring equipment consisted of YSI model 6600 sonde units fitted with appropriate sensors.

Sonde units were cleaned, serviced, calibrated, deployed, and retrieved on a weekly basis. Water quality was measured and recorded every 15 minutes. Following retrieval from the field, data was downloaded to a computer, validated, summarized, and evaluated with respect to discharge requirements and action triggers. Adaptive management actions such as additional receiving water monitoring or discharge gate opening and closing times for the upcoming week were determined using best professional judgment based on evaluation of weekly 10th percentile dissolved oxygen readings for the pond discharge and other water quality data. Data summaries were reported to Regional Water Board staff and appropriate City staff implemented adaptive management changes if needed.

### Temperature

Water temperature in the receiving water (Station 5; Figure 1) and at the Pond A18 discharge gate (Station D), under both discharge and non-discharge conditions, are shown in Table 3. Pond and receiving water temperatures tended to increase during the first four months of the monitoring season and decrease during the last two months of the season (Figure 3; Appendix II).

**Table 3. 2009 Continuous Temperature Monitoring Results (ºC)**

| Site/Condition | Minimum | Maximum | Mean | Median | # of Measurements (n) |
|---|---|---|---|---|---|
| Artesian Slough | 18.4 | 29.2 | 24.9 | 25.0 | 16089 |
| A18 Discharge | 12.1 | 29.0 | 22.7 | 23.2 | 16270 |
| A18 Non-Discharge | 13.4 | 28.9 | 23.6 | 23.9 | 1372 |

The WDR requires that discharges comply with the State's Thermal Plan. The Plan specifies that discharges shall not exceed the natural temperature of receiving waters by 20°F (~ 11ºC) and shall not cause temperatures to rise greater than 4°F above the natural temperature of the receiving water at any one time or place. To evaluate compliance, receiving water temperatures were compared to Pond A18 temperatures during pond discharges (non-discharge periods were excluded from this comparison). Differences for each concurrent 15-minute monitoring interval were determined by subtracting each discharge temperature from the corresponding receiving water temperature. Negative results indicate that the receiving water temperature was higher and positive results indicate that the pond discharge temperature was higher (Figure 4). Temperature differences ranged from -10.0ºC to 2.9ºC and averaged -2.0 ºC over 4,017 hours of monitored discharge. On average, pond temperatures were lower than receiving water temperatures (Figure 3). At no time was the temperature of the pond discharge greater than 11ºC above the corresponding receiving water temperature (Figure 4; Appendix II).

Pond temperatures at the discharge gate varied little between discharge and non-discharge periods (Table3; Figure 3).

## Salinity

Salinity of the receiving water (Station 5; Figure 1) and of water at Pond A18 discharge gate (Station D), under both discharge and non-discharge conditions, are shown in Table 4. Discharge salinity remained below 40 ppt at all times during the 2009 monitoring period (Table 4).

Salinity increased in Pond A18 until the middle of September, at which point pond salinity steadily decreased until the end of the monitoring season. Salinity in the receiving water showed a similar increasing trend until September followed by a slight decline at the end of the monitoring season (Figure 5; Appendix II). Receiving water salinity was much more variable than pond salinity with periodic spikes corresponding to incoming tides (Figure 7). These salinity increases in both the receiving water and pond were likely due to low freshwater tributary flows, dry weather, and high rates of evaporation during the summer months. Decreases in pond salinity in the fall (Figure 5; Appendix II) are likely due to decreased solar evaporation due to shorter day length, increased cloud cover and occasional rain events.

**Table 4. 2009 Continuous Salinity Monitoring Results (PSU[1])**

| Site/Condition | Minimum | Maximum | Mean | Median | # of Measurements (n) |
|---|---|---|---|---|---|
| Artesian Slough | 0.8 | 16.2 | 4.4 | 3.4 | 16089 |
| A18 Discharge | 18.9 | 29.4 | 24.9 | 25.4 | 15120 |
| A18 Non-Discharge | 18.9 | 29.0 | 25.0 | 25.7 | 1273 |

As noted in section II.A., four separate QA/QC failures occurred for conductivity due to excessive biological fouling of sondes deployed in the pond. From 8/25/09 through 9/23/09 (four consecutive monitoring weeks), sondes deployed in the pond were covered in a thick, dark brown biological growth believed to be from an abundance of diatoms. While this did not affect the data integrity of DO, pH or temperature, the fouling interfered with the accuracy of the conductivity probe readings. For these four weeks, all post deployment accuracy checks were low. However, examination of the data indicated that probe drift was gradual and conductivity measurements in the early part of each monitoring week were accurate based on a comparison to initial readings from each week and to the weeks bracketing this period. Staff used best professional judgement and included conductivity measurements from the initial 96 hours of each weekly deployment from 8/25/09 through 9/23/09 in this report. The remainder of each week's data was excluded.

### pH

The pH of the receiving water (Station 5; Figure 1) and of water at Pond A18 discharge gate (Station D), under both discharge and non-discharge conditions for 2009, are shown in Table 5. Pond pH levels were higher and more variable over the entire season than pH levels in the receiving water (Figure 6; Appendix II). Shorter-term, diurnal fluctuations of pH, which were much stronger in the receiving water (Figure 6; Appendix II), appear to reflect the daily salinity changes resulting from the natural tidal cycle (Figure 7).

**Table 5. 2009 Continuous pH Monitoring Results**

| Site/Condition | Minimum | Maximum | Mean | Median | # of Measurements (n) |
|---|---|---|---|---|---|
| Artesian Slough | 6.8 | 8.6 | 7.5 | 7.4 | 15430 |
| A18 Discharge | 7.8 | 9.7 | 8.9 | 8.8 | 15624 |
| A18 Non-Discharge | 8.1 | 9.7 | 8.9 | 8.9 | 1347 |

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[1] Practical Salinity Units (PSU) are a measurement of salinity from the specific conductance measured in water. An algorithm based on the ion composition of natural sea water converts specific conductance into PSU. One PSU is approximately equivalent to one part-per-thousand salinity.

The WDR requires that the pH objective of 6.5 to 8.5, as specified in the Basin Plan, be met either in the discharge or in the receiving water. During 2009 operations, pH in the receiving water rose above this range on two separate days (Table 13). Both of these events were brief (durations of 15 minutes and 45 minutes on 5/25/09 and 10/7/09 respectively) and corresponded to extremely low tides with shallow (3-4 feet) water depths. Based on 2005-2008 receiving water monitoring, these tidal conditions have characteristically been when the maximum surface water pH conditions have been measured.

The in-slough conditions during both of these events can be characterized as very low volume, shallow fresh water. The elevated pH appears to represent brief periods in which this low volume fresh water is more influenced by bottom slough water, which tends to have higher pH than surface water regardless of tide or pond discharge status (Tables 8 and 9). Pond A18 and Pond A16 discharge waters, both of which have higher pH than average ambient slough surface water, may also influence bottom pH at this time.

Despite the relatively elevated pH levels in the pond, and increased pond discharge time in 2009 compared to previous years, high pH pond discharges did not appear to cause occasional high pH levels measured in the receiving water (Figure 6; Appendix II). It is also interesting to note that pond pH levels in the early part of 2009 were similar to those measured throughout 2006 and in the early part of the 2007 and 2008 monitoring seasons with pond pH consistently at or above a pH of 9. However, similar to the declining pH trend observed in 2007 and 2008, by the first week of August 2009, pH levels in Pond A18 had decreased almost a full unit and were consistently below 9.0, and as low as 7.8, until the end of the monitoring season.

## Dissolved Oxygen

Dissolved oxygen (DO) concentrations in the receiving water (Station 5; Figure 1) and in pond water at Pond A18 discharge gate (Station D), under both discharge and non-discharge conditions, are summarized in Table 6. Weekly DO concentrations are shown graphically in Appendix I.

Dissolved oxygen levels in the receiving water fell below the Basin Plan objective of 5 mg/L on sixteen separate days during the 2009 monitoring season. The majority of these low DO incidents were relatively minor (DO was 4.6 – 4.9 mg/L) and occurred for brief periods (15 – 45 minutes). For example, on 23 September 2009, DO was below 5.0 mg/L for 15 minutes with a minimum DO concentration of 4.9 mg/L. This is typical of nearly all episodes of low DO in the receiving water for the 2009 monitoring season. All incidences were reported to the Regional Water Board and appropriate adaptive management strategies were considered. Because there was not a persistent low DO receiving water incident that coincided with low DO Pond A18 discharge, and discrete trigger monitoring did not indicate negative impacts to receiving waters, no additional management actions were implemented in 2009. There were two episodes (on 9/20/09 and 9/28/09) where low DO conditions in the receiving water persisted somewhat longer (1 hr to 3.5 hrs) and minimum DO concentrations were also somewhat lower at 4.0 and 4.3 mg/L respectively. The magnitude and duration of these events was minor compared to the 2008 episode that led to initiating timed discharges. In 2008 DO was below 5.0 mg/L for as long as 11 hours, spanning a range of tidal conditions, and reached a minimum concentration of 3.2 mg/L. Both 2009 low DO episodes are discussed in greater detail below.

**Table 6. 2009 Continuous Dissolved Oxygen Monitoring Results**

| Site/Condition | Minimum | Maximum | Mean | Median | # of Measurements (n) |
|---|---|---|---|---|---|
| Artesian Slough | 4.0 | 11.4 | 7.0 | 6.9 | 15401 |
| A18 Discharge | 0.1 | 23.2 | 7.1 | 7.5 | 15677 |
| A18 Non-Discharge | 0.1 | 20.9 | 7.9 | 8.4 | 1288 |

Receiving water exhibits two regular and predictable DO patterns based on diurnal and tidal cycles. DO tends to be low at night and higher during the day when photosynthesis is occurring. The tidal pattern is associated with spring and neap tides and demonstrates the influence of the volume of Bay water being pushed into Artesian Slough by the flooding tide. Spring tides, when tides and tidal currents are most extreme, are associated with the lowest DO periods. Slough conditions during high spring tides also contain the greatest volume of Bay water, which is evident even at the most upstream monitoring station. The lowest receiving water DO measurements occur during nighttime flooding spring tides when tidal currents reach their peak flow and photosynthesis is at a minimum.

Weekly measurements of Pond A18 DO levels, during both discharge and non-discharge periods, were plotted alongside Artesian Slough DO levels to evaluate the effect of the discharge on the receiving water (Appendix I, Weeks 1-27). Based on this comparison, there appears to be no causal effect of pond discharge on receiving water DO.

Weekly 10th percentile DO values were calculated for the pond's discharge and reported to the Regional Water Board (Table 7). The WDR requires implementation of adaptive management (corrective action) whenever weekly 10th percentile DO values fall below 3.3 mg/L. There were a total of 10 weeks (Tuesday to the following Tuesday) during which pond discharge DO levels fell below the weekly 10th percentile trigger of 3.3 mg/L. This is less than 2008 (15 tigger weeks) and is only slightly more than previous years (six triggering events in 2007 and seven events in 2006). Trigger incidents began in early August, which is approximately a month later than in previous years. The adaptive management strategy initially used to address low pond DO levels in prior years was to close the discharge gate 6-12 hours per day. While this strategy was effective at limiting the discharge of lower DO pond water into Artesian Slough, it was not beneficial at improving in-pond conditions, and may have even exacerbated the low DO conditions in the pond. Therefore, in 2008 and 2009, the City modified its response to DO trigger events to take into consideration the effects on in-pond biota. Rather than immediately closing the discharge valve upon triggering, the City instead continued discharges and monitored receiving water more frequently. Only when effects to receiving water were measured were valve closures initiated. Since there were no clear measured effects to receiving water from pond discharges, valve closures were not initiated in 2009.

## Low Dissolved Oxygen in Receiving Water

In 2009, there were two separate incidents in which DO in the receiving water was below 5.0 mg/L for what may be considered a longer duration. Both episodes occurred in late September and neither was of the duration or magnitude of the incident in 2008 that led to initiation of timed discharges. The 9/20/09 incident occurred during a high spring tide and was combined with regular overnight low DO patterns. Furthermore, because of the tidal stage (flooding to high tide), discharge flow from Pond A18 was minimal or not discharging at all. Discharge volume is greatest during low tide and least during high tide, so there was very little to no volume of pond water contributing to the receiving water for the duration of this high tide event. The minimal pond discharges during the 9/20/09 incident were also mixing with a greater volume of receiving water, which dilutes any influence from pond discharges. For these reasons, the incident on 9/20/09 was attributed to high spring tidal conditions and not to a pond discharge effect. The second incident was longer in duration (3.5 hrs) and occurred the following week on 9/28/09 with a minimum DO concentration of 4.3 mg/L. In contrast to the 9/20/09 episode, this incident did not occur during a spring tide, but did occur during a moderately high tide. It appears to be a direct result of lower prolonged irradiance due to persistent cloud cover from a mild storm front combined with a flooding high tide. While Pond A18 was discharging during this episode, discharge volume from the pond was again minimal. The incident was attributed to a short-term, weather-related decrease in irradiance and a flooding tide combined with the typical diurnal DO cycle. The short-term effect of decreased irradiance is discussed in greater detail later in this report in Section II.F. No pond management changes were implemented in response to these episodes as they did not appear to be caused by pond discharges.

## General Observations

Pond water color and clarity changed throughout the monitoring season. Initially the pond was moderately clear with a brownish green color. As the monitoring season progressed, water clarity declined and the pond color became an opaque dark green to blueish green by mid-June. In early August, pond water color changed rapidly from green to opaque brown. Concurrent with this color change was an increase in fouling of the continuous sondes in the pond. In August, this fouling was from detached aquatic grasses that wrapped around the units. In September, the fouling consisted of a dark brown mud like film covering the entire unit that appeared to be due to diatoms. This fouling interfered with the accuracy of conductivity readings and some conductivity data in September was compromised as a result. By early October, the pond color was a greenish brown to green and the sondes were no longer heavily fouled after a week’s deployment.

Filamentous macro-algae were less prevalent in 2009 than in some of the previous years (2006 and 2007 for example). Few algal mats were observed primarily along the northern edge of the pond between May and June 2009. Algal mats covered from 5 – 10% of the pond surface during this time compared to up to 40% coverage in 2007. These floating mats decreased as the season continued, with all filamentous algae absent from the pond surface by mid-August 2008. As these algal mats die, sink and decay, their decomposition may contribute to decreased dissolved oxygen levels.

There were no other unusual observations, odors or occurrences during continuous monitoring in 2009.

**Table 7. Weekly 10th Percentile Dissolved Oxygen (DO) Concentrations (mg/L) for Pond A18 Discharge (2009).** * Indicates values below the weekly trigger value of 3.3 mg/L. Gate Status/Corrective Action Column reflects action that was taken for the following week.

| Discharge Period | 10th Percentile DO (mg/L) | Gate Status/Corrective Action |
|---|---|---|
| May 1st through 5th (5 days) | 7.7 | Discharge gate fully open. |
| May 5th through 12th | 5.3 | Discharge gate fully open. |
| May 12th through 19th | 6.2 | Discharge gate fully open. |
| May 19th through 26th | 6.6 | Discharge gate fully open. |
| May 26th through June 2nd | 6.8 | Discharge gate fully open. |
| June 2nd through 9th | 7.7 | Discharge gate fully open. |
| June 9th through 16th | 7.8 | Discharge gate fully open. |
| June 16th through 23rd | 8.0 | Discharge gate fully open. |
| June 23rd through 30th | 7.8 | Discharge gate fully open. |
| June 30th through July 7th | 6.2 | Discharge gate fully open. |
| July 7th through 14th | 7.0 | Discharge gate fully open. |
| July 14th through 21st | 5.6 | Discharge gate fully open. |
| July 21st through 28th | 3.3 | Discharge gate fully open. |
| July 28th through August 4th | 1.7* | Discharge gate fully open.<br>Initiated weekly discrete monitoring at Artesian-02 beginning with 8/11/09 retrieval to evaluate effect on bottom DO in receiving water. |
| August 4th through 11th | 1.0* | Discharge gate fully open.<br>Discrete receiving water monitoring. No adverse effect from pond discharge. |
| August 11th through 18th | 0.1* | Discharge gate fully open.<br>Discrete receiving water monitoring. No adverse effect from pond discharge. |
| August 18th through 25th | N/A | Continued previous week's gate operations and discrete water quality monitoring..<br>Due to a sonde QA/QC failure, no DO data was available for this week.<br>Receiving water data indicated no adverse effects from pond discharge. |

**Table 7 (continued). Weekly 10th Percentile Dissolved Oxygen (DO) Concentrations (mg/L) for Pond A18 Discharge during the 2008 Monitoring Season.** * Indicates values below the weekly trigger value of 3.3 mg/L. Gate Status/Corrective Action Column reflects action that was taken for the following week.

| Discharge Period | 10th Percentile DO (mg/L) | Gate Status/Corrective Action |
|---|---|---|
| August 25th through September 1st | 0.5* | Discharge gate fully open.<br>Discrete receiving water monitoring.<br>No adverse effect from pond discharge. |
| September 1st through 8th | 1.1* | Discharge gate fully open.<br>Discrete receiving water monitoring.<br>No adverse effect from pond discharge. |
| September 8th through 15th | 0.4* | Discharge gate fully open.<br>Discrete receiving water monitoring.<br>No adverse effect from pond discharge. |
| September 15th through 22nd | 0.3* | Discharge gate fully open.<br>Discrete receiving water monitoring.<br>No adverse effect from pond discharge. |
| September 22nd through 29th | 0.2* | Discharge gate fully open.<br>Discrete receiving water monitoring.<br>No adverse effect from pond discharge. |
| September 29th through October 6th | 3.3 | Discharge gate fully open.<br>Continued discrete receiving water monitoring.<br>No adverse effect from pond discharge. |
| October 6th through 13th | 5.2 | Discharge gate fully open.<br>Continued discrete receiving water monitoring.<br>No adverse effect from pond discharge. |
| October 13th through 20th | 2.9* | Discharge gate fully open.<br>Discrete receiving water monitoring.<br>No adverse effect from pond discharge. |
| October 20th through 27th | 2.6* | Discharge gate fully open.<br>Discrete receiving water monitoring.<br>No adverse effect from pond discharge. |
| October 27th through 31st (5 days) | 4.4 | End of monitoring season. |

## C. Discrete Monitoring

### Discrete Receiving Water Monitoring

In addition to continuous water quality monitoring at Pond A18 discharge and in receiving water, the WDR requires discrete monthly sampling of water quality at four receiving water locations (Figure 1) during the monitoring season (Table 2). Surface and bottom measurements are summarized in Table 8. These receiving water transects of water quality in Artesian Slough help describe the mixing of fresh slough water with Bay salt water during tidal exchange. Measurements were taken while Pond A18 was discharging, as required by the WDR. The City deliberately conducted this discrete monitoring to document the effects of both ebbing and flooding tide.

### Discrete Trigger Monitoring

Additional discrete monitoring at station Artesian 02 began on 8/11/09 (Table 9) due to the 10th percentile weekly DO value in the pond falling below the 3.3 mg/L trigger for the previous week (Table 7). As stated in the City's supplement to the 2007 Report and in subsequent discussions with Water Board staff, the City adopted a modified approach to addressing the 3.3 mg/L DO trigger value. Rather than immediately implementing discharge valve closings as in prior years, the City continued the continuous circulation operations in Pond A18 and initiated additional receiving water quality monitoring (trigger monitoring). The purpose of the trigger monitoring was to determine whether continued discharges from Pond A18 during periods of hypoxia were negatively affecting the immediate receiving water. This modified response was implemented in consideration of the health of in-pond biota, due to an incident in 2007 where stressed fish were observed in the pond during a hypoxia event with the discharge valve closed. A strategy that maintains a more consistent flow through the pond under continuous circulation (rather than discharge valve timing) should create a more stable pond system, ameliorate the effects of low pond DO on pond biota, and possibly accelerate recovery from hypoxic events. However, discharge of low DO water from A18 could potentially cause decreases in receiving water DO. Increased monitoring in the receiving waters (trigger monitoring) is a protective measure to determine if low DO discharges are having negative impacts. If so, then additional adaptive management action would be necessary.

Under the revised management plan described in the City's Supplemental Report to the 2007 Pond A18 Annual Self-Monitoring Report, discharge valve timing or other adaptive management actions would only be implemented if surface receiving water was measured at less than 5.0 mg/L or bottom DO was less than 3.3 mg/L during a period when pond DO was below the 10th percentile trigger value and the low DO in the receiving water was due to discharge of low DO water from Pond A18. These conditions were not met at any time during 2009 dry season.

**Table 8. Artesian Slough Monthly Surface and Bottom Water Quality Measurements**

| Date and Time | Site | Tide | Depth | Temp (C) | Salinity (PSU) | pH | D.O. (mg/L) | Turbidity (NTU) | A18 Flow (cfs) |
|---|---|---|---|---|---|---|---|---|---|
| 5/26/09 14:51 | 1 | Flood | Bottom | 24.0 | 8.8 | 8.1 | 9.9 | 3.3 | 25.3 |
| 5/26/09 14:49 | 1 | Flood | Surface | 24.7 | 0.6 | 7.8 | 9.1 | 3.4 | 25.3 |
| 6/16/09 10:52 | 1 | Ebb | Bottom | 21.8 | 16.0 | 8.4 | 6.3 | 2.4 | 32.8 |
| 6/16/09 10:55 | 1 | Ebb | Surface | 24.6 | 0.6 | 8.2 | 7.4 | 1.6 | 34.1 |
| 7/28/09 9:34 | 1 | Ebb | Bottom | 25.0 | 16.6 | 8.2 | 3.3 | 16.7 | 33.1 |
| 7/28/09 9:34 | 1 | Ebb | Surface | 26.6 | 0.9 | 7.3 | 6.1 | 1.7 | 33.1 |
| 8/18/09 13:06 | 1 | Ebb | Bottom | 23.7 | 16.6 | 7.5 | 5.8 | 19.5 | 11.7 |
| 8/18/09 13:07 | 1 | Ebb | Surface | 27.0 | 0.8 | 7.9 | 7.5 | 1.3 | 11.7 |
| 9/15/09 13:33 | 1 | Ebb | Bottom | 23.7 | 14.2 | 7.6 | 5.0 | 4.9 | 23.6 |
| 9/15/09 13:35 | 1 | Ebb | Surface | 26.7 | 1.5 | 7.3 | 8.0 | 1.6 | 23.6 |
| 10/20/09 12:30 | 1 | Flood | Bottom | 21.0 | 18.8 | 8.1 | 6.1 | 12.4 | 33.8 |
| 10/20/09 12:32 | 1 | Flood | Surface | 24.9 | 1.2 | 7.3 | 7.8 | 1.8 | 33.8 |
| 5/26/09 14:26 | 2 | Flood | Bottom | 23.0 | 14.3 | 8.5 | 9.1 | 8.0 | 28.0 |
| 5/26/09 14:29 | 2 | Flood | Surface | 25.6 | 3.3 | 8.2 | 9.1 | 2.2 | 28.0 |
| 6/16/09 11:10 | 2 | Ebb | Bottom | 21.3 | 16.1 | 8.5 | 5.6 | 9.5 | 35.3 |
| 6/16/09 11:15 | 2 | Ebb | Surface | 24.6 | 1.5 | 8.0 | 7.0 | 1.7 | 35.3 |
| 7/28/09 10:06 | 2 | Ebb | Bottom | 24.8 | 18.6 | 8.4 | 2.8 | 26.0 | 36.1 |
| 7/28/09 10:06 | 2 | Ebb | Surface | 26.9 | 2.0 | 7.3 | 6.1 | 3.1 | 36.1 |
| 8/18/09 13:19 | 2 | Ebb | Bottom | 23.3 | 18.3 | 7.4 | 4.4 | 19.4 | 11.7 |
| 8/18/09 13:18 | 2 | Ebb | Surface | 26.7 | 3.4 | 7.7 | 6.9 | 3.1 | 11.7 |
| 9/15/09 13:44 | 2 | Ebb | Bottom | 23.7 | 16.1 | 7.6 | 6.0 | 9.8 | 26.3 |
| 9/15/09 13:45 | 2 | Ebb | Surface | 26.4 | 3.7 | 7.3 | 7.4 | 2.1 | 26.3 |
| 10/20/09 12:42 | 2 | Flood | Bottom | 20.1 | 19.9 | 8.1 | 5.3 | 17.6 | 28.4 |
| 10/20/09 12:45 | 2 | Flood | Surface | 24.4 | 3.7 | 7.3 | 8.9 | 5.7 | 28.4 |
| 5/26/09 14:02 | 3 | Flood | Bottom | 22.4 | 11.3 | 7.6 | 4.8 | 31.9 | 33.2 |
| 5/26/09 14:13 | 3 | Flood | Surface | 25.6 | 6.8 | 7.9 | 6.2 | 20.4 | 30.5 |
| 6/16/09 11:34 | 3 | Ebb | Bottom | 21.6 | 14.5 | 8.4 | 4.5 | 14.5 | 36.1 |
| 6/16/09 11:39 | 3 | Ebb | Surface | 24.3 | 2.3 | 7.8 | 6.5 | 2.4 | 37.3 |
| 7/28/09 9:56 | 3 | Ebb | Bottom | 23.4 | 18.5 | 8.3 | 1.5 | 46.0 | 36.1 |
| 7/28/09 9:56 | 3 | Ebb | Surface | 23.7 | 5.2 | 7.5 | 5.1 | 33.8 | 36.1 |
| 8/18/09 13:37 | 3 | Ebb | Bottom | 22.7 | 19.9 | 7.7 | 3.3 | 37.3 | 13.1 |
| 8/18/09 13:36 | 3 | Ebb | Surface | 24.6 | 16.6 | 7.7 | 3.9 | 15.1 | 13.1 |
| 9/15/09 14:01 | 3 | Ebb | Bottom | 23.1 | 14.7 | 7.5 | 2.3 | 12.1 | 29.6 |
| 9/15/09 14:02 | 3 | Ebb | Surface | 25.6 | 6.5 | 7.4 | 5.9 | 6.7 | 29.6 |
| 10/20/09 13:08 | 3 | Flood | Bottom | 18.7 | 16.8 | 7.4 | 4.0 | 41.2 | 16.4 |
| 10/20/09 13:10 | 3 | Flood | Surface | 19.0 | 16.0 | 7.4 | 4.2 | 41.0 | 16.4 |
| 5/26/09 13:53 | 4 | Flood | Bottom | 21.3 | 15.1 | 7.6 | 4.5 | 62.3 | 33.2 |
| 5/26/09 13:53 | 4 | Flood | Surface | 21.8 | 14.9 | 7.6 | 4.7 | 46.6 | 33.2 |
| 6/16/09 11:57 | 4 | Ebb | Bottom | 22.5 | 10.0 | 8.0 | 4.9 | 16.9 | 38.5 |
| 6/16/09 12:00 | 4 | Ebb | Surface | 23.8 | 4.4 | 7.7 | 6.1 | 8.7 | 38.5 |
| 7/28/09 9:45 | 4 | Ebb | Bottom | 22.5 | 16.6 | 7.5 | 2.4 | 141 | 34.6 |
| 7/28/09 9:45 | 4 | Ebb | Surface | 22.7 | 8.0 | 7.5 | 4.3 | 120 | 34.6 |
| 8/18/09 13:47 | 4 | Ebb | Bottom | 22.1 | 25.3 | 7.7 | 4.4 | 53.7 | 14.3 |
| 8/18/09 13:46 | 4 | Ebb | Surface | 23.2 | 21.8 | 7.8 | 4.1 | 37.1 | 14.3 |
| 9/15/09 14:14 | 4 | Ebb | Bottom | 22.9 | 13.2 | 7.5 | 1.9 | 24.1 | 31.9 |
| 9/15/09 14:15 | 4 | Ebb | Surface | 23.8 | 11.6 | 7.3 | 2.8 | 20.2 | 31.9 |
| 10/20/09 13:23 | 4 | Flood | Bottom | 18.0 | 24.9 | 7.5 | 5.0 | 127 | 16.4 |
| 10/20/09 13:26 | 4 | Flood | Surface | 18.1 | 23.4 | 7.5 | 4.9 | 88 | 8.2 |

**Table 9. 2009 Discrete Receiving Water Trigger Monitoring at Station Artesian-02.**

| Date and Time | Site | Tide | Depth | Temp (˚C) | Salinity (PSU) | pH | DO (mg/L) | A18 Flow (cfs) |
|---|---|---|---|---|---|---|---|---|
| 8/11/09 9:06 | 2 | Ebb/Lo | Bottom | 25.0 | 16.4 | 8.2 | 4.4 | 40.5 |
| 8/11/09 9:06 | 2 | Ebb/Lo | Surface | 26.0 | 4.7 | 7.9 | 5.7 | 40.5 |
| 8/18/09 13:19 | 2 | Flood | Bottom | 23.3 | 18.3 | 7.4 | 4.4 | 11.7 |
| 8/18/09 13:18 | 2 | Flood | Surface | 26.7 | 3.4 | 7.7 | 6.9 | 11.7 |
| 8/25/09 8:32 | 2 | Ebb | Bottom | 23.3 | 16.8 | 7.8 | 4.1 | 33.6 |
| 8/25/09 8:32 | 2 | Ebb | Surface | 25.2 | 3.2 | 7.6 | 6.3 | 33.6 |
| 9/1/09 14:27 | 2 | Ebb | Bottom | no data* | 18.0 | 8.0 | 5.9 | 26.8 |
| 9/1/09 14:38 | 2 | Ebb | Surface | 26.7* | 2.8 | 7.9 | 7.5 | 26.8 |
| 9/8/09 13:50 | 2 | Flood | Bottom | no data* | 21.6 | 7.5 | 6.4 | 28.0 |
| 9/8/09 13:50 | 2 | Flood | Surface | 26.9* | 3.8 | 7.3 | 7.8 | 28.0 |
| 9/15/09 13:44 | 2 | Ebb | Bottom | 23.7 | 16.1 | 7.6 | 6.0 | 26.3 |
| 9/15/09 13:45 | 2 | Ebb | Surface | 26.4 | 3.7 | 7.3 | 7.4 | 26.3 |
| 9/23/09 13:59 | 2 | Flood | Bottom | 25.3 | 21.0 | 7.8 | 5.4 | 34.7 |
| 9/23/09 13:59 | 2 | Flood | Surface | 27.5 | 5.8 | 7.6 | 8.3 | 34.7 |
| 9/29/09 10:23 | 2 | Flood | Bottom | 22.0 | 22.6 | no data* | no data* | 22.0 |
| 9/29/09 10:24 | 2 | Flood | Surface | 23.7 | 6.6 | no data* | no data* | 22.0 |
| 10/6/09 11:20 | 2 | Flood | Bottom | 18.9 | 20.5 | 8.5 | 9.2 | 42.5 |
| 10/6/09 11:20 | 2 | Flood | Surface | 24.3 | 3.7 | 7.4 | 8.3 | 42.5 |
| 10/13/09 10:48 | 2 | Flood | Bottom | 17.6 | 15.0 | 7.4 | 4.8 | 11.8 |
| 10/13/09 10:48 | 2 | Flood | Surface | 22.0 | 4.7 | 7.4 | 6.2 | 11.8 |
| 10/20/09 12:42 | 2 | Flood | Bottom | 20.1 | 19.9 | 8.1 | 5.3 | 40.1 |
| 10/20/09 12:45 | 2 | Flood | Surface | 24.4 | 3.7 | 7.3 | 8.9 | 40.1 |
| 10/27/09 13:41 | 2 | Ebb | Bottom | 21.3 | 5.5 | 7.4 | 5.4 | 49.8 |
| 10/27/09 13:41 | 2 | Ebb | Surface | 23.4 | 1.5 | 7.3 | 7.3 | 49.8 |

*Temperature data from the discrete monitor was not recorded for 9/1/09 or 9/8/09. Surface temperature reported here is taken from the continuous sonde reading. The discrete monitor failed post-deployment QA/QC on 9/29/09 for pH and DO so no data are reported for those parameters for that date.

## Discrete Pond Monitoring

Temperature, salinity, pH, dissolved oxygen, and chlorophyll *a* were measured monthly in Pond A18 discharge, as required by the WDR (indicated by "A" in Table 2). The WDR requires discrete dissolved oxygen measurement to be taken between 0800 and 1000 hours. The results below were taken from the continuous discharge monitor for the date and time of the Pond A18 chlorophyll *a* sample collection, which also occurred between 0800 and 1000 hours (Table 10).

**Table 10. Monthly Water Quality Measurements at A18 Discharge**

| Date and Time | Temperature (C) | Salinity (PSU) | pH | Dissolved Oxygen (mg/L) |
|---|---|---|---|---|
| 5/26/2009 08:30 | 20.71 | 20.50 | 9.2 | 8.4 |
| 6/17/2009 08:45 | 21.00 | 22.32 | 9.5 | 8.3 |
| 7/21/2009 08:45 | 23.66 | 25.80 | 9.1 | 4.2 |
| 8/25/2009 09:45 | 22.28 | 28.62 | 8.2 | 2.2 |
| 9/15/2009 09:45 | 22.32 | 28.82 | 8.4 | 1.2 |
| 10/20/2009 09:15 | 17.93 | 25.33 | 8.5 | 3.6 |

## Temperature

Water temperatures in Artesian Slough tended to decrease in a downstream direction. As expected, temperatures also tended to decrease with depth (Tables 8 and 9).

Pond A18 temperature is influenced by ambient air temperature and varied as expected for a large shallow, limited flow waterbody throughout the monitoring season (Table 10).

## Salinity

Vertical profiles of salinity were taken monthly at four stations in Artesian Slough (Figure 1; Table 8). These profiles indicate that the receiving water is fairly well mixed at Station 4 and often at Station 3, but that significant depth-related salinity differences can occur at Station 1 and Station 2 during flooding and ebbing tides. For example, on August 18th 2009, surface and bottom salinities, respectively, were 0.8 and 16.6 PSU (Station 1), 3.4 and 18.3 PSU (Station 2), 16.6 and 19.9 PSU (Station 3), and 21.8 and 25.3 PSU (Station 4). This pattern of upstream stratification and downstream mixing has been observed over the past four years during flooding tides regardless of whether Pond A18 was discharging (2007 Report; Table 9).

Pond A18 salinity gradually increased over the summer from about 19 PSU to a maximum of nearly 30 PSU in September 2009 (Table 10; Figure 5).

## pH

Vertical profiles of pH were taken monthly at four stations in Artesian Slough (Figure 1). Receiving water pH tended to be stratified at the upstream Stations 1 and 2 with bottom pH higher than surface pH regardless of tidal stage or pond discharge status (Tables 8 and 9). Downstream receiving water pH at Stations 3 and 4 was less stratified, similar to salinity patterns, and appeared more uniform and well-mixed throughout the water column.

Pond A18 pH levels (Table 10) were significantly higher than those in the receiving water until August 2009 (Table 8). The sudden drop in pond pH levels may indicate a community transition characterized by increased decomposition rates.

## Dissolved Oxygen

Monthly DO measurements at the four Artesian Slough stations (Figure 1; Table 8) indicate that surface DO levels were higher than bottom DO levels (Figure 8) along the length of the slough. Moving from upstream to downstream, surface DO levels declined from an average of 7.7 mg/L at Station 1 to 4.5 mg/L at Station 4. Bottom DO levels declined from an average of 6.1 mg/L at Station 1 to 3.9 mg/L at Station 4. Lower dissolved oxygen levels near the mouth of Artesian Slough are likely due to two factors. First, the solubility of oxygen decreases as salinity increases. Second, the Plant's freshwater input has a relatively high DO of roughly 7 mg/L, and the proportion of effluent in Artesian Slough is much greater at Station 1 than at Station 4. The lowest DO recorded at the bottom of the slough at Artesian 02 occurred on 7/28/09, which was prior to the first trigger event and before pond DO concentrations reached hypoxic levels.

The WDR requires the Discharger to monitor, report, and take corrective action if monthly discrete dissolved oxygen levels in Pond A18, taken between the 800 and 1000 hours at station A-A18-M [can be taken at station D], fall below 1.0 mg/L. Since monthly discrete DO levels in Pond A18 did not fall below 1.0 mg/L in 2009 (Table 10), no corrective action was required.

As part of the 2008 revised adaptive management strategy, the City began taking weekly discrete water column profiles for temperature, salinity, pH and dissolved oxygen at Station Artesian 02. This monitoring was initiated on August 11, 2009 when pond DO levels fell below the 3.3 mg/L trigger as a 10th percentile weekly value. Over 12 weeks of this monitoring, surface DO was never below 5.0 mg/L and bottom DO never below 3.3 mg/L (Table 9). Because there was not an observed decline in receiving water DO due to low DO pond discharges, additional adaptive management actions were not implemented in 2009.

### Turbidity

Turbidity was measured monthly at four stations in Artesian Slough in 2009. Turbidity increased in a downstream direction from Station 1 to Station 4 (Figure 9). As expected, turbidity was greater at the bottom than at the surface at each station. Greater downstream turbidity is due to lower TSS in Plant discharge and the greater effect of flooding tides on turbidity in the lower segments of Artesian Slough.

### General Observations

There were no unusual observations, odors or occurrences during discrete monitoring.

## D. Sediment Monitoring

Two sediment monitoring requirements were specified in the WDR: mercury and methyl mercury measurements from in-pond sediments, and a benthic macro-invertebrate community analysis from Artesian Slough sediments. The requirement for a benthic macro-invertebrate community analysis in Artesian Slough was fulfilled in 2006. Therefore, only in-pond sediment monitoring for mercury and methyl mercury was performed in 2009. The WDR states that sediment monitoring is to be performed in August or September of each year. Sediment monitoring for 2009 occurred on September 21, 2009.

### Mercury/Methyl Mercury

Pond A18 sediment was sampled at four in-pond locations (Figure 1) on September 21, 2009 by Kinnetic Laboratories Inc (KLI) to determine concentrations of total mercury and methyl mercury. Sediment samples were also analyzed for pH, total organic carbon (TOC), total sulfides, redox potential and particle size distribution. Total mercury, methyl mercury and percent solids analyses were performed by BrooksRand in Seattle, WA. Analyses of pH, TOC, total sulfide, redox potential and particle size were performed by Columbia Analytical Services in Kelso, WA. In addition, temperature, dissolved oxygen, pH, salinity and redox potential were measured in the overlying water at each sampling station using the following meters:

- Hydrolab Quanta Water Quality Monitoring System for temperature, dissolved oxygen, pH, and salinity.
- Oakton ORPtestr 10 meter for oxidation-reduction (redox) potential

Four sediment grab samples were collected at each of four sampling stations (16 separate grab samples), using a pre-cleaned stainless steel coring device. All samples were composited in their own pre-cleaned tefzel-coated compositing bucket. Very large chunks of gypsum and rock were removed during homogenization where possible. The top (<5 cm) portion of each station's core-collected sub-samples were composited. Composited, homogenized samples were placed into appropriate sample containers provided by each analytical laboratory.

Composited samples were immediately placed on ice and shipped overnight to the analytical laboratories. Analytical methods utilized by BrooksRand and Columbia Analytical services and QA/QC results are reported in Appendix III.

Complete results of the Pond A18 annual sediment mercury analysis are summarized in Table 4 of Appendix III. In 2009, total mercury in sediment samples ranged from 244 to 580 ng/g dry weight. This is less than the USEPA criteria for total mercury in sediment of 1000 ng/g dry weight. Methyl mercury in sediment ranged from 0.143 to 0.462 ng/g dry weight. Pond A18 total mercury concentrations in sediment for 2009 were comparable to those measured in past monitoring for all stations. Methyl mercury concentrations were comparable to, or less than, those measured in Pond A18 sediments since 2005. After five years of mercury and methyl mercury monitoring, concentrations show high inter-annual and spatial variability even when normalized to percent fines (Table 11). While spatial patterns may exist in a given year, such as uniform concentrations of both total mercury and methyl mercury in pond sediment for 2006 and 2008, these patterns have not been consistent from year to year.

**Table 11. Comparison of 2005 – 2009 Annual Sediment Mercury and Methyl Mercury Results from Four Locations in Pond A18.** Includes values normalized to percent fines. Station A18-1 is the most southern station and A18-4 is the most northern station.

| Year | Analyte | A18-1 | A18-2 | A18-3 | A18-4 |
|---|---|---|---|---|---|
| **2005** | Total Hg (ng/g) | 195 | 233 | 220 | 307 |
| | Me Hg (ng/g) | 0.421 | 0.638 | 2.095 | 3.373 |
| | Percent Fines (%) | 32.7% | 22.5% | 16.7% | 13.4% |
| | Hg normalized (ng/g) | 504 | 1036 | 1317 | 2291 |
| | Me Hg normalized (ng/g) | 1.088 | 2.836 | 12.545 | 25.172 |
| **2006** | Total Hg (ng/g) | 177 | 304 | 119 | 110 |
| | Me Hg (ng/g) | 0.305 | 0.253 | 0.353 | 0.282 |
| | Percent Fines (%) | 44.5% | 39.7% | 21.9% | 23.2% |
| | Hg normalized (ng/g) | 398 | 765 | 543 | 474 |
| | Me Hg normalized (ng/g) | 0.685 | 0.637 | 1.612 | 1.216 |
| **2007** | Total Hg (ng/g) | 304 | 512 | 66 | 216* |
| | Me Hg (ng/g) | 0.149 | 0.155 | 0.184 | 3.807* |
| | Percent Fines (%) | 11.4% | 16.3% | 7.84% | 25.0%* |
| | Hg normalized (ng/g) | 2667 | 3141 | 842 | 864* |
| | Me Hg normalized (ng/g) | 1.307 | 0.951 | 2.35 | 15.228* |
| **2008** | Total Hg (ng/g) | 558 | 573 | 417 | 446 |
| | Me Hg (ng/g) | 0.126 | 0.158 | 0.132 | 0.386 |
| | Percent Fines (%) | 61.8% | 13.7% | 53.7% | 21.2% |
| | Hg normalized (ng/g) | 951 | 4182 | 777 | 2103 |
| | Me Hg normalized (ng/g) | 0.204 | 1.153 | 0.246 | 1.821 |
| **2009** | Total Hg (ng/g) | 580 | 487 | 272 | 244 |
| | Me Hg (ng/g) | 0.230 | 0.149 | 0.143 | 0.462 |
| | Percent Fines (%) | 66.1% | 46.0% | 48.8% | 64.0% |
| | Hg normalized (ng/g) | 877 | 1058 | 557 | 381 |
| | Me Hg normalized (ng/g) | 0.348 | 0.324 | 0.293 | 0.722 |

* 2007 Results from Station A18-4 are the mean of duplicate samples taken at this location. Duplicate samples from A18-4 were sent to analytical laboratories blindly as A18-4 and A18-5.

## E. Chlorophyll *a*

Chlorophyll *a* was measured on a monthly basis in Pond A18 at the discharge point. Once per month, a 1-liter grab sample was collected and placed in a 1-liter amber glass jar. The sample was kept cool and out of direct light. Within 24 hours of collection, the sample was transferred to Basic Laboratory services in Redding, CA via courier. Analysis of all monthly chlorophyll *a* samples was performed by Basic Laboratory.

Chlorophyll *a* levels in Pond A18 peaked in September and October of 2009. The earlier months of the monitoring season demonstrated lower chlorophyll *a* concentrations, which was evident by the greater water clarity in the early months of 2009 dry season monitoring. A steady and fairly rapid increase in pond turbidity began in late July 2009. The final two months of 2009 monitoring had more opaque water clarity but there was a noticeable color change from green to brown September 2009, then back to green in October 2009. Despite low chlorophyll *a* concentrations in June and July 2009, chlorophyll *a* levels for the rest of the monitoring season (Table 12) were similar to those measured during the previous two years. As in years past, significant changes in chlorophyll *a* concentrations, water clarity, and changes in color throughout the season are usually indicative of a change in the pond's algal community.

**Table 12. Monthly Chlorophyll *a* Measurements at Pond A18 Discharge.** Salinity measurements are included for context as general changes in pond characteristics.

| Month (2008) | Date sampled | Salinity (PSU) | Chlorophyll *a* (µg/L) |
|---|---|---|---|
| May | 5/26/09 | 20.50 | 14 |
| June | 6/17/09 | 22.32 | 2 |
| July | 7/21/09 | 25.80 | 2 |
| August | 8/18/09 | 28.12 | 10 |
| September | 9/15/09 | 27.36 | 23 |
| October | 10/20/09 | 25.33 | 60 |

## F. Irradiance Measurements and Relationship to Dissolved Oxygen

City Staff obtained measurements for irradiance as solar radiation from the Union City CIMIS[2] station. Observations and analysis of trends over previous monitoring years indicated that irradiance is an important factor that controls pond DO levels. Long and short-term fluctuations in irradiance have affected pond community structure, the rate of photosynthesis and DO concentrations.

### Seasonal Irradiance Pattern

Seasonal irradiance patterns are predictable and are driven by day length. With fewer hours of daylight in late summer and early fall, daily solar radiation drops. This gradual transition can cause seasonal shifts in pond phytoplankton community structure. Such shifts have been documented in previous years, and 2009 was no exception. Decreases in solar radiation levels create conditions that favor more shade-tolerant phytoplankton species. Less shade-tolerant species die-off as they are replaced. The increased decomposition rates consume more oxygen, lowering DO levels further and may decrease pH.

From May through July 2009, Pond A18 DO levels were stable and relatively high (Appendix I; weeks 1-13). In early August and into the month of September 2009, pond DO dropped significantly with daily minimum DO measurements regularly below 2 mg/L. This drop in pond DO appears to have been caused by decreased rates of photosynthesis due to a drop in the average daily solar radiation (Figure 10). The normal, seasonal decrease in average daily solar radiation as day length shortens coincided with the apparent destabilization of the pond

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[2] California Irrigation Management Information Systems (CIMIS) at wwwcimis.water.ca.gov/cimis/data.jsp

community as observed by decreasing DO levels, decreasing pH (due to increased decomposition rates) and observed changes in water color and clarity.

Pond DO levels began to improve and stabilize starting in late September, 2009. This was likely due community stabilization as the transition in community structure neared completion. However, an aquatic community in transition is also susceptible to hypoxic events caused by short-term decreases in solar radiation as discussed below.

### Short Duration Changes in Daily Irradiance

While seasonal irradiance patterns are predictable and are driven by day length, short-duration changes in solar radiation are not. These short-term fluctuations can be caused by overcast skies, storms, or, as in 2008, unusual events such as prolonged hazy and smoky conditions due to wildfires burning across much of California. In 2009, there were two notable short-term drops in solar radiation that affected pond DO levels. The first occurred from September 27th to 30th due to several days of overcast conditions associated with a storm front passing through. While there was very little precipitation during this time, conditions were storm-like with daily irradiance dropping from a consistent 180-190 W/m$^2$ for the week prior to the event to 145 and 151 W/m$^2$ on 9/28/09 and 9/29/09 respectively (Figure 11). After seeming to recover from the more persistent low DO conditions caused by the seasonal decrease in irradiance, this sudden short-term drop in irradiance caused a corresponding drop in pond DO. However, the pond quickly recovered once irradiance levels were back to previous levels (Figures 11 and 12). This drop in irradiance coupled with low Bay DO from a flooding tide also caused a brief depletion of receiving water DO levels as mentioned in section II.B.

The second episode was much more dramatic and occurred during a significant storm event (more than 2.3 inches of rainfall in 24 hours as measured at the San Jose Weather Station) in mid-October. At this point in the monitoring season, Pond A18 appeared to have recovered from the persistent hypoxia associated with seasonal shifts in community structure. This event is an excellent example of how a short-term decrease in irradiance can affect a more stable pond system. The event lasted from October 10th through October 15th with both irradiance and pond DO reaching their minimum values on 10/13/09 at the height of the storm (Figure 12). Daily irradiance on 10/13/09 decreased to 7 W/m$^2$ and pond DO reached the lowest value (3.1 mg/L) measured in more than a week. These low DO conditions in Pond A18 were temporary and the pond recovered quickly as irradiance increased. By 10/15/09, increased irradiance coincided with an increase in pond DO levels.

# *III. Exceedances and Triggered Actions*

## A. Summary of Exceedances and Triggers

Table 13 summarizes the exceedances, triggers and corrective actions taken for 2009. All incidents were reported to the Regional Water Board.

## B. Summary of Corrective Action

There were several incidents where the dissolved oxygen in the receiving water fell below the 5.0 mg/L Basin Plan Objective (Table 13). All of the occurrences except for two (20 September 2009 and 28 September 2009) were brief and minor (receiving water DO was typically above 4.7 mg/L). Futhermore, all episodes including the two exceptions occurred at times when DO is naturally lower due to ecosystem processes. Some of the incidents (18 September 2009 to 22 September 2009) occurred while Pond A18 was not discharging or had minimal discharge flow. None of the excursions in 2009 were attributable to Pond A18 discharges, so no corrective action was taken.

Two more prolonged low DO incidents occurred in the receiving water in late September 2009. During this time, receiving water DO was below 5.0 mg/L for a maximum of 3.5 hours with a minimum measured DO of 4.3 mg/L. This is still a relatively brief period of lowered DO in the receiving water and the causes for these two events were attributed to tidal influence and low irradiance weather conditions. For both incidents, A18 discharge flow was low or zero due to high tide conditions. Because the low DO measured in the receiving water was not due to Pond A18 discharges, neither incident prompted the City to take corrective action and initiate Pond A18 discharge timing. These events were discussed in greater detail earlier in this report under Sections II.B. and II.F.

Twice during the monitoring season receiving water pH was measured above 8.5 (maximum of 8.6 on 5/25/09 and 10/7/09). As explained in section II.B., these brief and relatively minor increases are associated with extreme spring tides occurring in the early morning rather than Pond A18 discharges.

There were 10 weeks in which the weekly 10th percentile DO level in the discharge fell below the established trigger of 3.3 mg/L (Table 13). Prior to 2008, the corrective action following these trigger events was to close the discharge gate for varying periods of time during the night when DO levels were especially low. Beginning in 2008 the DO trigger initiated additional monitoring and evaluation, and no closing of gates. Only if possible negative effects to the receiving water were measured, would valve closures be implemented. Because no such effects were measured that could be attributed to Pond A18 discharge, valve closures were not implemented in 2009.

**Table 13, Exceedances of Water Quality Objectives, Triggers, and Corrective Action**

| Date(s) | Water Quality Excursions from Basin Plan Objective | Corrective Action |
|---|---|---|
| 5/25/09 | Receiving water pH > 8.5 for 15 minutes (pH was 8.6 at 11:15am during a flood tide with shallow water) | None. Event was brief, minor and related to tidal cycle. |
| 8/19 – 8/20/09 | Receiving water DO < 5.0 mg/L at surface both days for intervals of 15 to 60 minutes.<br>(min DO = 4.5 mg/L) | None. Events were brief, minor and related to tidal and diurnal cycles. Discrete monitoring indicated no adverse conditions in slough. |
| 9/18 – 9/22/09 | Receiving water DO < 5.0 mg/L at surface each day for intervals of 15 minutes to 1.75 hrs for each occurrence.<br>(min DO = 4.0 mg/L) | None. All events were related to tidal and diurnal cycles and occurred during no or minimal discharge from Pond A18. Discrete monitoring indicated no adverse conditions in slough. |
| 9/23 – 9/29/09 | Receiving water DO < 5.0 mg/L at surface on five separate days for intervals of 15 minutes to 3.5 hrs for each occurrence.<br>(min DO = 4.1 mg/L) | None. Most events were brief and minor. All events were related to tidal and diurnal cycles and influenced by significant, temporary decrease in solar radiation. |
| 10/7/09 | Receiving water pH > 8.5 for 45 minutes (pH was 8.6 at 23:00 to 23:45 during a flood tide with shallow water.) | None. Event was brief, minor and related to tidal cycle. |
| 10/15 – 10/17/09 | Receiving water DO < 5.0 mg/L at surface three times for 15 to 30 minutes.<br>(min DO = 4.6 mg/L) | None. Events were brief, minor and related to tidal and diurnal cycles. Pond A18 DO was > 5.0 mg/L for all three events. |
| 10/25/09 | Receiving water DO < 5.0 mg/L at surface once for 15 minutes.<br>(min DO = 4.6 mg/L) | None. Event was brief, minor and related to tidal and diurnal cycles. |
| **Date(s)** | **Dissolved Oxygen Trigger** | **Corrective Action** |
| 7/28 – 8/4/09 | 10th Percentile DO Concentration in the A18 discharge was 1.7 mg/L | Initiated weekly discrete trigger monitoring in receiving water. |
| 8/4 – 8/11/09 | 10th Percentile DO Concentration in the A18 discharge was 1.0 mg/L | No adverse effect measured. Continued trigger monitoring. |
| 8/11 – 8/18/09 | 10th Percentile DO Concentration in the A18 discharge was 0.1 mg/L | No adverse effect measured. Continued trigger monitoring. |
| 8/25 – 9/1/09 | 10th Percentile DO Concentration in the A18 discharge was 0.5 mg/L | No adverse effect measured. Continued trigger monitoring. |
| 9/1 – 9/8/09 | 10th Percentile DO Concentration in the A18 discharge was 1.1 mg/L | No adverse effect measured. Continued trigger monitoring. |
| 9/8 – 9/15/09 | 10th Percentile DO Concentration in the A18 discharge was 0.4 mg/L | No adverse effect measured. Continued trigger monitoring. |
| 9/15 – 9/22/09 | 10th Percentile DO Concentration in the A18 discharge was 0.3 mg/L | No adverse effect measured. Continued trigger monitoring. |

**Table 13 (continued). Exceedances of Water Quality Objectives, Triggers, and Corrective Action**

| Date(s) | Dissolved Oxygen Trigger | Corrective Action |
|---|---|---|
| 9/22 – 9/29/09 | 10th Percentile DO Concentration in the A18 discharge was 0.2 mg/L | No adverse effect measured. Continued trigger monitoring. |
| 10/13 – 10/20/09 | 10th Percentile DO Concentration in the A18 discharge was 2.9 mg/L | No adverse effect measured. Continued trigger monitoring. |
| 10/20 – 10/27/09 | 10th Percentile DO Concentration in the A18 discharge was 2.6 mg/L | No adverse effect measured. Continued trigger monitoring. |

## *IV. Supplemental Monitoring*

In an effort to increase our understanding of Pond A18 dynamics, the City initiated a supplemental monitoring program in September 2006. The monitoring required by the WDR is focused on water quality of the water discharged from the pond and any potential impacts that discharge may have on Artesian Slough receiving water. The supplemental monitoring was intended to provide additional information regarding spatial variability within the pond or the extent of the influence intake water may be having within the pond. This supplemental monitoring was done at the discretion of the City as staff time and budget allowed.

Supplemental monitoring results from 2006 were presented in the 2006 Annual Self-Monitoring Program Report for Pond A18. Under the first year of supplemental monitoring, discrete water quality readings and grab samples for a suite of analytical measurements were taken at two receiving water locations and seven locations in Pond A18 (Figure 2). The results indicated that the pond is well-mixed and homogenous with regard to aqueous concentrations of TSS, phosphate, sulfate, chloride, organic carbon, mercury and methyl mercury. Discrete measurements of temperature, pH and salinity also showed no spatial variability in the pond.

Chlorophyll *a* measurements and supplemental monitoring of phytoplankton species composition performed in 2006 were useful in characterizing changes in the phytoplankton community in the pond. The large algal biomass and dynamic phytoplankton community structure in the pond results in a highly productive system but also one that is very sensitive to climatic perturbations such as prolonged periods of high temperatures or decreased solar irradiance.

For the past three years, additional monitoring has focused on the most useful information gathered during 2006 supplemental monitoring. Tracking and characterizing changes in phytoplankton composition and algal biomass within the pond was a useful tool to document shifts in the pond ecology and as a measurement of pond productivity. Beginning in 2008, the City also included solar radiation measurements from the Union City, CA CIMIS station to correlate variations in daily solar radiation with pond DO levels through decreases in pond primary production. The major results from this supplemental monitoring and analysis for 2009 are presented in Section II.F.

# *V. Discussion and Interpretation of Results*

This section discusses 2009 monitoring season results and observations and provides comparison with those of previous years monitoring.

### Temperature

Pond and receiving water temperatures in 2009 (Table 3; Figure 3) were very similar to previous years. Average pond discharge temperatures were lower than receiving water temperatures in 2009 (Figure 4). Monthly comparisons of pond and receiving water temperatures are shown graphically in Appendix II. While average temperatures were similar, it is important to note that temperatures in Pond A18 and the receiving water during 2009 monitoring did not reach the highs that occurred in previous years due to a mild summer and late season storms. Prolonged hot weather, such as the heat wave in 2006, can have a negative effect on DO levels due to increased respiration rates.

### Salinity

During five years of dry season monitoring, salinity has been one of the most variable pond water quality parameter both within and between years. In 2005, Pond A18 salinity was lowered to 41 PSU by March 30th 2005 and averaged approximately 31 PSU during the continuous circulation period. There was a very different trend in pond salinity concentrations in 2006 with pond salinity steadily increasing throughout the summer from 4.5 PSU in May 2006 to 19.5 PSU late in the monitoring season. Due to unusually warm and dry winters, salinity in Pond A18 was approximately 19 PSU in May of 2007, 2008, and 2009. In all years, salinity reached its maximum level in late September (30.1 PSU in 2007, 29.9 PSU in 2008 and 29.4 PSU in 2009). Salinity fluctuations are not controllable on a fine scale in a system such as Pond A18. As a former commercial salt pond, the deliberate design of a shallow, large surface area pond is for high evaporation rates leading to increased salinity. In this respect, Pond A18 still functions as a system that concentrates salts through high evaporation rates. These uncontrollable salinity fluctuations may impact pond phytoplankton biomass, dynamics and stability as discussed in a later section.

Since average salinity levels in Pond A18's discharge in 2005 were significantly higher than 2006-2009 levels, some stratification of receiving water was observed in the early months of 2005. Particularly during and shortly after the initial release in 2005, the more saline pond water would sink to the bottom of Artesian Slough in the area immediately influenced by Pond A18 (up to station 2, Figure 1). However, this stratification was not observed by late summer of 2005 as pond salinity continued to decrease. Since late summer of 2005 there has been no observed vertical stratification of receiving waters as a result of Pond A18 discharge (Table 8). The differences between surface and bottom salinity at downstream stations are explained by tidal action in Artesian Slough (Figure 7). Artesian Slough is tidally influenced and twice per day, salt water from the Bay enters the slough with the flooding tide. The slough is dominated by San Jose/Santa Clara Water Pollution Control Plant (Plant) fresh water flows. The fresh water tends to float on top of heavier, more saline Bay water being pushed into the slough by the flooding tide. The effect of Pond A18 discharge on receiving water salinity is limited spatially due to immediate mixing of pond discharge water with freshwater effluent.

## pH

Pond pH increases as a result of intense photosynthesis when irradiance and temperatures are high. However, the buffering capacity of salt water appears to create an upper boundary on pond pH. Pond pH was temporarily quite high (9.0 – 9.7) at the beginning of the season when pond salinity was lowest (Figure 6). By early August 2009, pond pH had fallen below 9 and remained relatively low (7.8 – 8.9) compared to previous years and the early part of 2009. The timing of this decrease in pH corresponds to changes in the pond's algal community based on observed water color and clarity changes and chlorophyll *a* measurements. The drop in pH, which has been observed in previous years, is likely due to a decrease in photosynthesis and an increase in decomposition rates of algal cells as the pond's phytoplankton community transitions. Decomposition of algal cells lowers pond pH because the process releases carbonic acid.

Although high pond pH levels (maximum pH was 9.7) may result in some osmotic stress to fish and invertebrates, the slow rate of pH change in well-buffered pond water likely allows organisms to adjust. Increasing pond salinity may help stabilize or buffer pond pH levels, but, at the same time, steadily increasing salinity may negatively impact pond phytoplankton production and stability.

There is no apparent effect on pH in the receiving water from Pond A18 discharge. Rather, the regular fluctuations of receiving water pH are strongly associated with the tidal cycle (Figure 7) and show a diurnal pattern likely due to changes in rates of photosynthesis.

## Adaptive Management of Pond Dissolved Oxygen Levels

Similar to the previous three years, the primary pond management challenge in 2009 was to maintain dissolved oxygen concentrations (DO) at or above levels required in the WDR. Following initiation of adaptive management due to low pond DO levels in 2005, City staff opened the pond discharge gate each day only after first measuring the pond water dissolved oxygen concentration. The 2005 annual report concluded that this procedure "was perhaps too rigorous." Therefore, a more streamlined approach was initiated in 2006. The 2006 adaptive management strategy was to calculate the weekly 10th percentile pond discharge DO value, and, if the value was below the trigger of 3.3 mg/L, evaluate the current week's data to determine the best time period to close the discharge gate to limit the discharge of low DO water from the pond. The adjusted gate opening and closing times were then applied to the following week's pond maintenance schedule.

The 2006 streamlined adaptive management strategy resulted in no excursions below the Basin Plan DO objective of 5 mg/L in the receiving water due to Pond A18 discharge. The same streamlined adaptive management strategy was used in 2007. In 2008, the City adopted a strategy that focused more consideration to the health of Pond A18 biota. Shutting the pond discharge valve limits flushing in the pond. Doing so during a low-DO event likely exacerbates the hypoxia. This can cause negative effects to pond biota such as the stressed fish observed during the 2007 dry season. To avoid this situation, and based on monitoring demonstrating limited negative effects to receiving water quality from pond discharges, the City did not immediately implement valve closures as a result of falling below the DO trigger in 2008. Maximizing pond flow-through was a primary goal of the revised 2008 operations strategy described in the Supplement to the 2007 Pond A18 Report. Upon triggering, the City initiated weekly discrete receiving water monitoring in the nearest downstream station (Table 9). Valve closure was implemented only if DO measured at the surface was less than 5.0 mg/L or less than 3.3 mg/L at the bottom. This strategy maintained more consistent circulation in Pond A18 throughout the dry season, and there were no observations of stressed fish in 2008. This strategy was continued for the duration of the 2009 monitoring season with similar results.

There were no timed valve closures in 2009. In 2009, there were again no observations of stressed fish, and no negative effects to the receiving water as a result of increased discharges from the pond during low-DO periods (Appendix I; Weeks 1-27). This, combined with discrete trigger monitoring not measuring low receiving water DO resulted in no timed valve closures in 2009.

### Average discharge flow volume from Pond A18

Artesian Slough is dominated by tidal influence and continuous 100 MGD freshwater flows from the Plant. During flooding and high tides, salt water from San Francisco Bay provides most of the water volume in Artesian Slough as shown by the discrete transect receiving water monitoring (Table 8). The average discharge volume from Pond A18 during the 2009 monitoring season was 21.8 MGD and is relatively small by comparison. The pond's average daily flow from in 2009 was slightly higher than previous years (previous annual maximum was 19.5 MGD in 2008). The slight inter-annual variations in flow are due to modifications to discharge valve settings in order to maintain a consistent pond water depth.

The instantaneous flow from Pond A18 is highly variable depending on discharge gate settings, pond water level and tidal height in Artesian Slough. However, the average pond flow is only ~ 20% of the Plant's continuous daily freshwater flow. In addition to the relatively small discharge volume into Artesian Slough, there appears to be rapid mixing of pond discharge with receiving waters. These two factors likely account for the negligible or immeasurable effect of pond discharge on receiving water quality even at Artesian Slough Station 2 (Table 8), which is immediately downstream of the pond discharge point. Even immediately downstream of Pond A18 discharge, where the influence of the pond should be the greatest, variations in DO, pH and salinity are more influenced by interactions between Plant freshwater flow and tidal influence than discharge from Pond A18.

### Mercury and Methyl Mercury Analysis of Pond Sediment.

Mercury and methyl mercury concentrations in A18 sediments have been measured annually since 2005. After 5 years of mercury sediment monitoring, there has not been a consistent spatial pattern within the pond from year to year. Some years (2005 and 2007 for example) mercury concentrations have exhibited a distinct gradient of high to low from north to south. Other years, including 2009, mercury and methyl mercury concentrations have appeared more uniform throughout the pond. Despite the lack of a clear spatial trend, five years of pond mercury concentrations can begin to characterize general mercury concentrations in Pond A18 as a system. This characterization provides a useful comparison to other sediment mercury concentrations such as those found in San Francisco Bay.

Mean (± SE) sediment mercury and methyl mercury concentrations in Pond A18 from five years of monitoring data are 317 ± 36 ng/g and 0.69 ± 0.24 ng/g, respectively. Compared to the most recent available Regional Monitoring Program (RMP) data[3] for mercury concentrations in nearby Bay sediments, mean total mercury and mean methyl mercury concentrations are similar to those in Pond A18 (Table 14). While mean concentrations are similar, mercury in A18 sediments has been much more variable than in Lower South Bay sediments as shown by the higher standard error for pond data. The somewhat smaller sample size for pond sediment mercury data may account for some of the greater statistical variability. However, mercury concentrations in pond sediments span a greater range of values than those measured in the Bay.

**Table 14. Comparison of Mean (± SE) Mercury and Methyl Mercury Concentrations in A18 Sediments to South Bay Concentrations from RMP Data[4]**

| Data Source | Total Mercury (ng/g) | n | Methyl Mercury (ng/g) | n |
|---|---|---|---|---|
| A18 sediment | 317 ± 36 | 20 | 0.69 ± 0.24 | 20 |
| South Bay sediment (RMP) | 267 ± 10 | 27 | 0.85 ± 0.06 | 27 |

### Pond Primary Production

In partnership with the U.S. Geological Survey (USGS), the City analyzed Pond A18 samples collected in 2006 to characterize the pond ecology with respect to pond primary productivity and estimated the pond's carrying capacity to support biota in two idealized food-webs. This analysis was presented[4] at the national conference of the Estuarine Research Federation, November 2007 in Providence, RI (Appendix V), at the 2008 Salt Pond Science Symposium, 2008 Calfed Bay Delta Conference, and at the 2009 State of the Estuary Conference. A companion paper on this research that is unique to the former salt ponds of San Francisco Bay was published in the peer-reviewed journal, *Wetlands*[5] (Appendix V).

Due to low water levels (approximately 2 feet) in Pond A18, high summer irradiance, low flow-through rates, and availability of nutrients, phytoplankton blooms were common in 2005 and 2006. There were no dramatic phytoplankton blooms observed in 2007, 2008 or 2009 (Table 12), but chlorophyll *a* levels did increase from initial dry season concentrations (from 14 µg/L to

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[3] 2005 – 2007 Regional Monitoring Program Status and Trends data for Bay sediment mercury and methyl mercury concentrations for stations located south of the Dumbarton Bridge.

[4] J. Thèbault, Schraga, T.S., Cloern, J.E,, and Dunlavey, E.G. Funky Green Biomass Machines: The Former Salt Ponds of South San Francisco Bay, CA. Poster Presentation at 2007 Estuarine Research Federation Conference, Providence, RI.

[5] J. Thèbault, Schraga, T.S., Cloern, J.E,, and Dunlavey, E.G. 2008. Primary Production and Carrying Capacity of Former Salt Ponds after Reconnection to San Francisco Bay. Wetlands 28:841-851.

a maximum of 60 μg/L in October 2009). Particularly in 2009, while a dramatic bloom did not occur, the increase in chlorophyll *a* coupled with observed water color changes and various fouling situations in the pond are indicative of a transition in pond community structure.

While extreme variations in chlorophyll *a* were not observed in 2009, the physical properties of the pond, high irradiance and low flow through rates result in a highly productive system. Based on high resolution continuous dissolved oxygen data collected in Pond A18 for 2006, mean Gross Primary Production (GPP) is estimated to be 8.2 g $O_2$ /$m^2$/day. This very high rate of photosynthesis is double that of some of the world's most productive estuaries, such as the Chesapeake Bay[6]. Dissolved oxygen data from 2009 is similar to that of 2006. Therefore, 2006 estimates of GPP are a likely approximation for those of 2009.

High rates of photosynthesis, which cause the extremely high dissolved oxygen levels measured in the pond (maximum of 23.2 mg/L, Table 6), are balanced by high rates of ecosystem respiration (ER) by pond algae, zooplankton, benthic invertebrates and fish. High respiration rates, particularly at night when photosynthesis ceases, can cause extremely low dissolved oxygen levels (minimum of 0.1 mg/L, Table 6). The extremes of GPP and ER in Pond A18 provide a beneficial food supply function. However, the extreme levels and apparent tight coupling of GPP and ER also result in a system that is highly susceptible to hypoxic events when irradiance decreases (decreases photosynthetic rates), temperature increases (increases metabolism and respiration) and possibly during seasonal and monthly swings in salinity that may induce changes in phytoplankton species dominance. Events such as a succession of overcast days or conditions with increased smoke, haze or particulate matter like those experienced for several weeks beginning in early July 2008 due to the California wildfires can dramatically affect GPP rates by decreasing daily irradiance.

In 2006, Chlorophyll *a* results indicated a rapid decline in pond phytoplankton biomass in July 2006. This corresponded to an observed color change in Pond A18 and to the prolonged heatwave that occurred in the Bay area. It was suspected that this was due to a die-off of pond phytoplankton. Corresponding declines in pH and DO provided further evidence that a die-off occurred in 2006. Dead algal cells would be expected to decompose and the decomposition process would use up oxygen and release carbonic acid. To better understand pond phytoplankton dynamics, the City decided to sample the pond periodically for phytoplankton species composition and abundance in 2007 and 2008.

This documented a shift in phytoplankton species abundance despite the absence of an apparent dramatic phytoplankton die-off in those years. Declines in pond pH levels and more extreme swings in the diurnal DO cycle have also coincided with the above observed transitions in pond community structure. Because of the preponderance of data characteristic of these transitions, in 2009 the City relied on chlorophyll *a* monitoring, water color and clarity observations, general observations, changes in pH, irradiance measurements and changes in DO patterns to determine when such a transition was occurring.

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[6] Kemp, W.M, E.M Smith, M. Marvin-DiPasquale and W.R. Boynton. 1997. Organic carbon balance and net ecosystem metabolism in Chesapeake Bay. Marine Ecology Progress Series 150:229-248.

## Nuisance filamentous macro-algae

The presence of filamentous macro-algae in Pond A18 varies from year to year. Filamentous algae consist of macroscopic filaments which are of little value to pond productivity since filter-feeding zooplankton (copepods, cladocerans, rotifers, shrimp, aquatic insects) are not able to utilize them effectively. Filamentous algal mats also block light penetration into the water column, thereby decreasing phytoplankton production and overall pond productivity.

In 2009, there was little evidence of floating filamentous green algae in Pond A18. This is similar to observations in 2005 and is in sharp contrast to other South Bay Salt Ponds that have reported problems with these nuisance algae.

In 2006, filamentous algae in Pond A18 became more noticeable, especially during the latter half of the season. The increase in filamentous algae in 2006 may have been due to the phytoplankton die-off. With decreased phytoplankton abundance, there was a corresponding decrease in shade competition, which may be a favorable condition for macro-algae establishment. In 2007, there were noticeably more filamentous algae in Pond A18 (maximum coverage estimated at 40%), especially in the early months of the monitoring season (May and June 2007). Salinity, pH and chlorophyll *a* concentrations in early 2007 were similar to those at the end of 2006. These conditions appear to be favorable for the growth of nuisance algal mats. Early 2008 conditions were also similar to those of early 2007 with slightly elevated salinity and pH. However, filamentous algae were much less abundant in 2008 compared to 2007, and the reasons for this are not readily apparent. A maximum of approximately 15% of Pond A18 was covered by filamentous algae in 2008.

Filamentous macro-algae can potentially cause widespread and persistent poor water quality conditions in the pond. Die-off of algal mats could contribute to decreases in pH, DO and observed changes in the phytoplankton community structure. If the changes in the abundance of filamentous algae, phytoplankton composition and chlorophyll *a* observed in 2006 and 2007 were due to uncontrollable factors such as variations in irradiance, temperature or increasing pond salinity in a pond designed for high evaporation rates, such changes may be unavoidable.

## *VI. Lessons Learned and Recommendations*

(1) In 2009, Pond A18 discharge averaged approximately 20% of the Plant flow. There was no definitive observable effect on receiving water from Pond A18 discharge on any water quality parameter despite continuous pond discharges compared to previous years and despite continued discharges after DO levels fell below the 3.3 mg/L trigger.

**Recommendation:** Continue the 2009 operations and management strategy using the DO trigger as an early warning signal to initiate additional weekly receiving water column monitoring at Station Artesian 02. Adaptive management will only be performed when both the receiving water and Pond A18 (measured by discrete monitors or continuous monitors) do not meet the DO water quality standard as a result of Pond A18 discharges.

(2) The effect of tides and ambient dissolved oxygen concentrations is greater than the effect of Pond A18 discharge on Artesian Slough DO levels. Bottom DO concentrations at Artesian Slough stations nearest the Pond A18 discharge are higher than surface DO concentrations further downstream in Artesian Slough (Figure 8).

Salinity stratification in Artesian Slough occurs during flood tides as a result of freshwater discharge flowing over denser incoming saltwater. During ebb tides near low tide, when Pond A18 has significant discharge, there is less salinity stratification in Artesian Slough, probably due to dilution of pond water with Plant flows.

**Recommendation:** Continue the 2009 operations and management strategy. This is further evidence of the minimal spatial impact Pond A18 discharge has in Artesian Slough and the greater effect of ambient Bay water entering the slough during flooding tides.

(3) Sampling chlorophyll *a* and tracking irradiance provided useful information for characterizing variability of the Pond A18 phytoplankton community and how climatic and water quality factors affect pond stability. The most important factor affecting dramatic changes in pond DO levels (lows and highs) may be irradiance. Pond conditions were affected by seasonal shifts in irradiance, weather patterns and conditions affecting irradiance such as late summer and early fall storms.

**Recommendation:** Continue monitoring chlorophyll a and tracking changes in irradiance to determine the effect on pond DO and influences on pond phytoplankton community structure.

(4) Pond A18 has very high primary productivity due to the large biomass of phytoplankton. Because of this high productivity, decreases in irradiance on shorter temporal scales (hours or days) due to cloud cover, rain events or other conditions can cause temporary periods of low dissolved oxygen due to decreased rates of photosynthesis.

**Recommendation:** Changes in irradiance are natural or uncontrollable and likely independently affect pond DO and receiving water DO. Shutting the discharge valve as a result of temporary low DO due to decreased irradiance may exacerbate a low DO incident due to stagnation of pond water. No adverse effects on receiving water DO have been measured in five years of monitoring. As long as adverse affects to the receiving water due to pond discharges are not measured, continuous discharges should continue to benefit pond biota.

(5) After five years of monitoring mercury and methyl mercury in Pond A18 sediments, no consistent pattern between years or among stations is evident. However, five years of monitoring indicate that mercury and methyl mercury concentrations in A18 sediment are similar to those in Lower South Bay sediments.

**Recommendation:** Continued annual monitoring of mercury and methyl mercury concentrations in Pond A18 sediment is unlikely to provide additional useful information. This monitoring is no longer necessary on an annual frequency since A18 sediment mercury concentrations are equivalent to proximate Bay sediment concentrations. This monitoring should be repeated every other year to confirm concentrations are not changing substantially.

**Figure 1. Artesian Slough and Pond A18 Monitoring Stations**

Pond stations are referred to in the text as 1,2,3, & 4 (yellow squares). Artesian Slough stations (green circles) and Pond stations D and M are abbreviated in this figure. For example, station A-A18-1 is abbreviated as 1, A-A18-D is abbreviated as D, etc. Stations 2 (for discrete monitoring) and 5 (for continuous monitoring) are located at the same site in Artesian Slough.

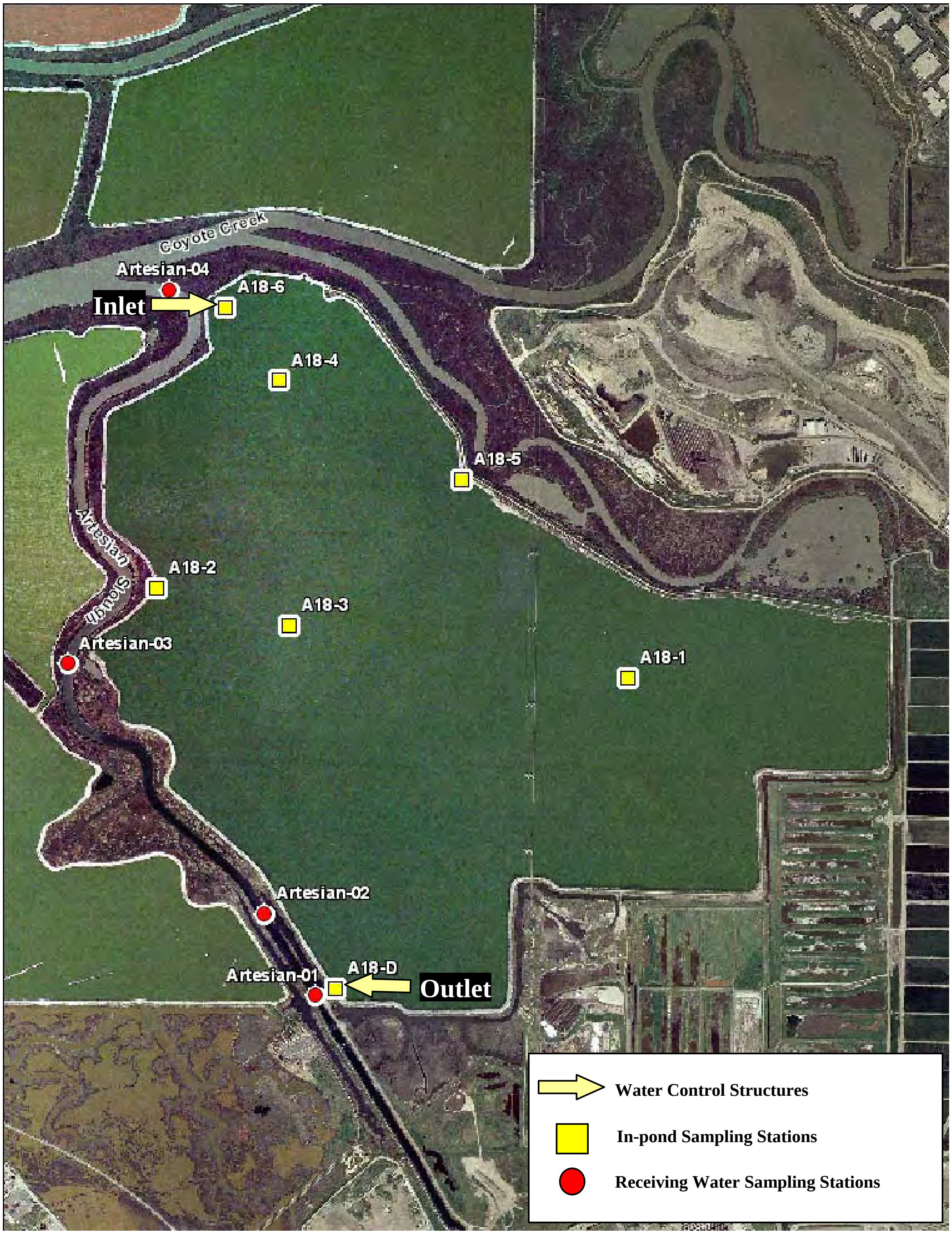
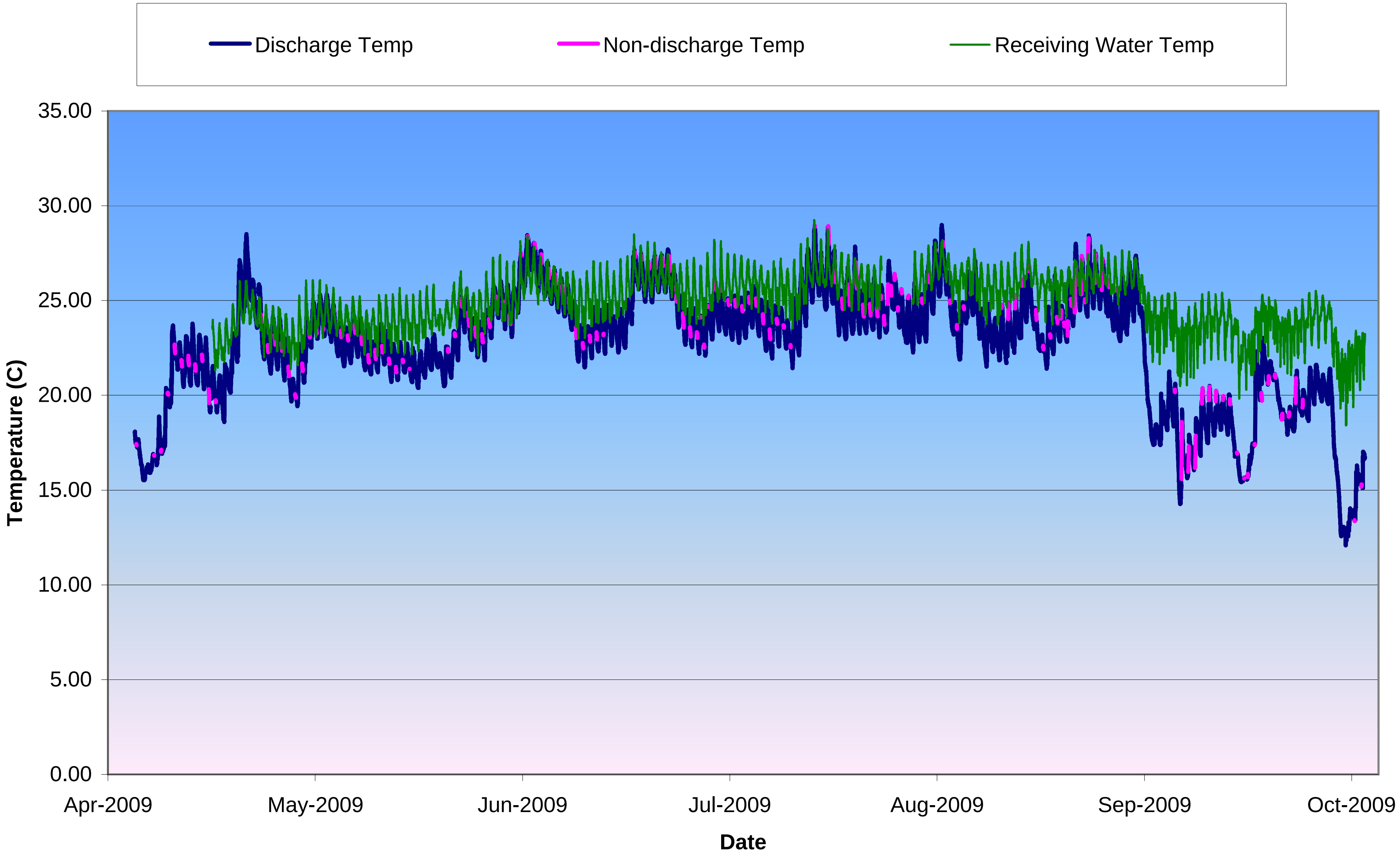


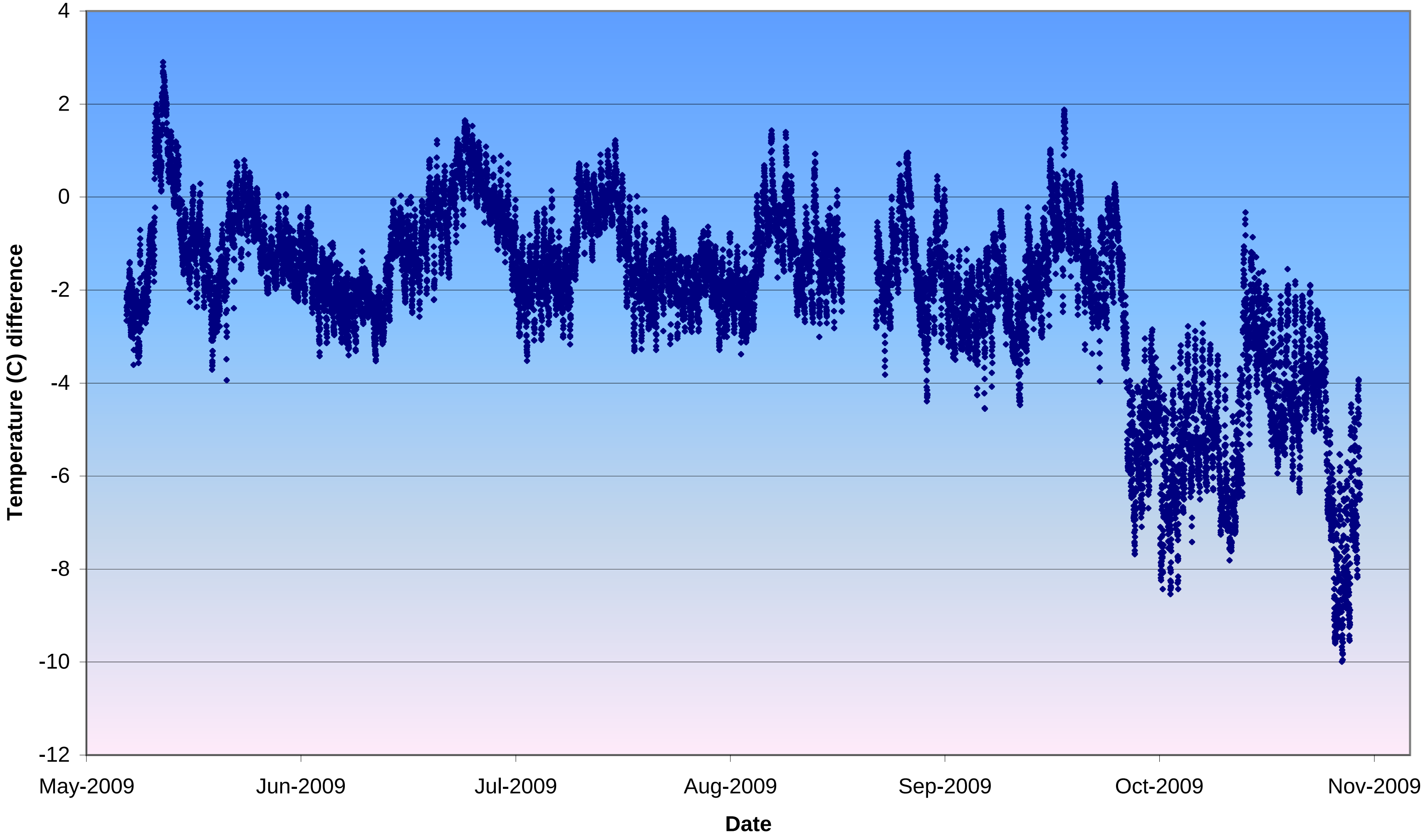
**Figure 2. Artesian Slough and Pond A18 Supplemental Monitoring Stations from 2006 Supplemental Monitoring.**

## Figure 3. 2009 Dry Season Temperature Profiles of Pond A18 and Artesian Slough

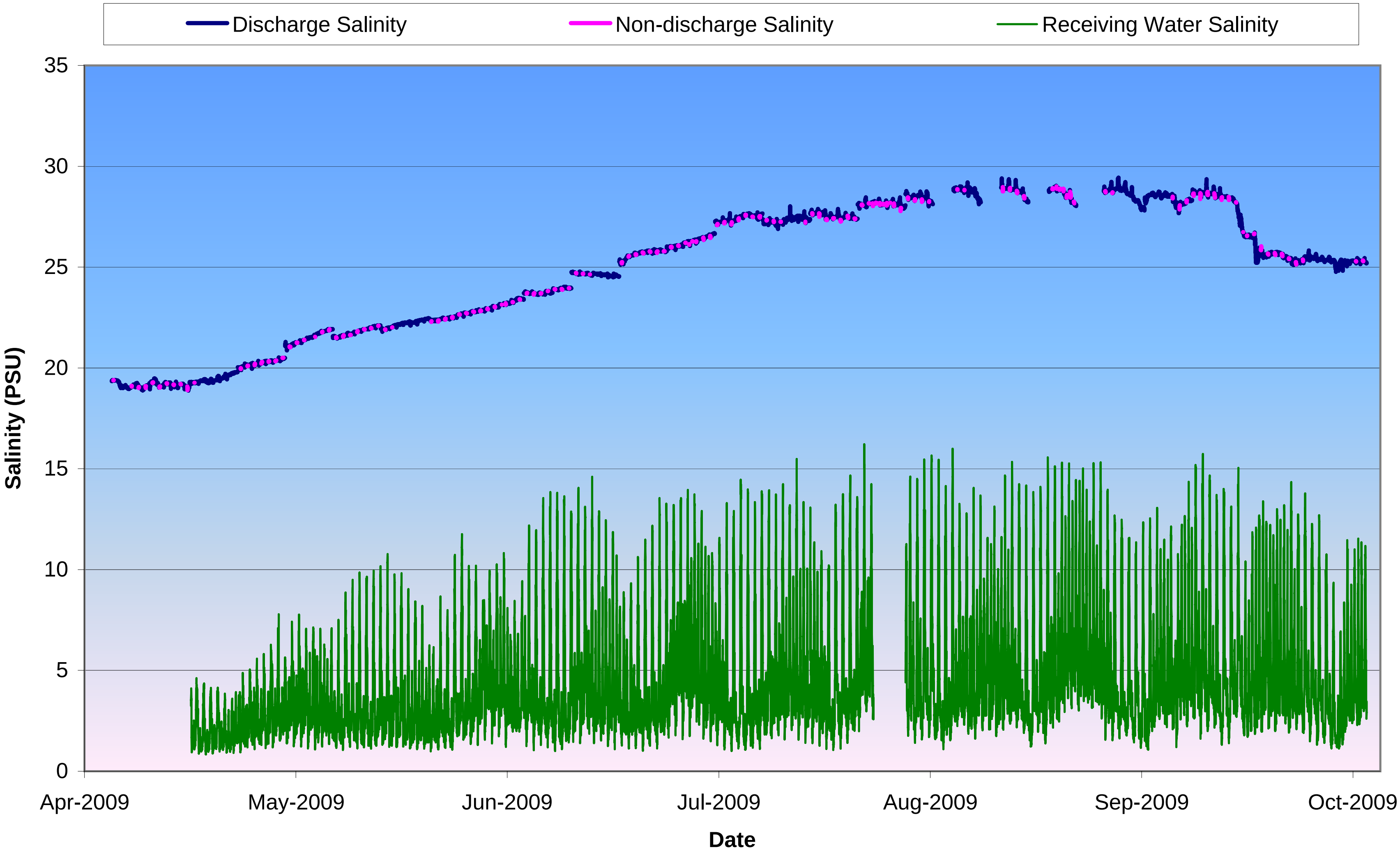


## Figure 4. 2009 Temperature Differences Between A18 Discharge and Artesian Slough

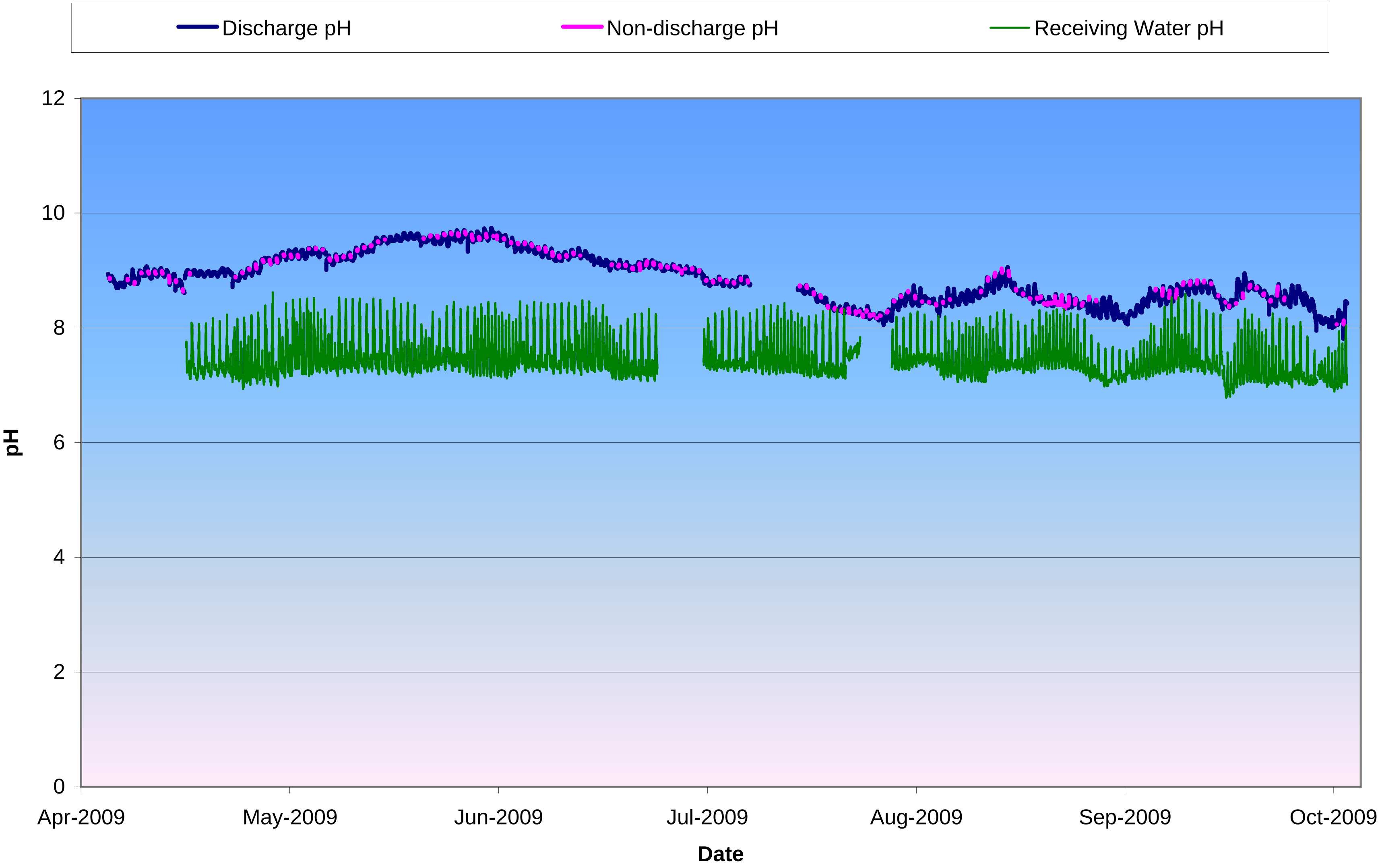
### Negative values indicate that Pond A18 discharge temperature is less than Artesian Slough



## Figure 5. 2009 Dry Season Salinity Profiles of Pond A18 and Artesian Slough



## Figure 6. 2009 Dry Season pH Profiles of Pond A18 and Artesian Slough



## Figure 7. Effect of Tidal Cycle on Salinty and pH of Artesian Slough

Example taken from week 11 of receiving water data

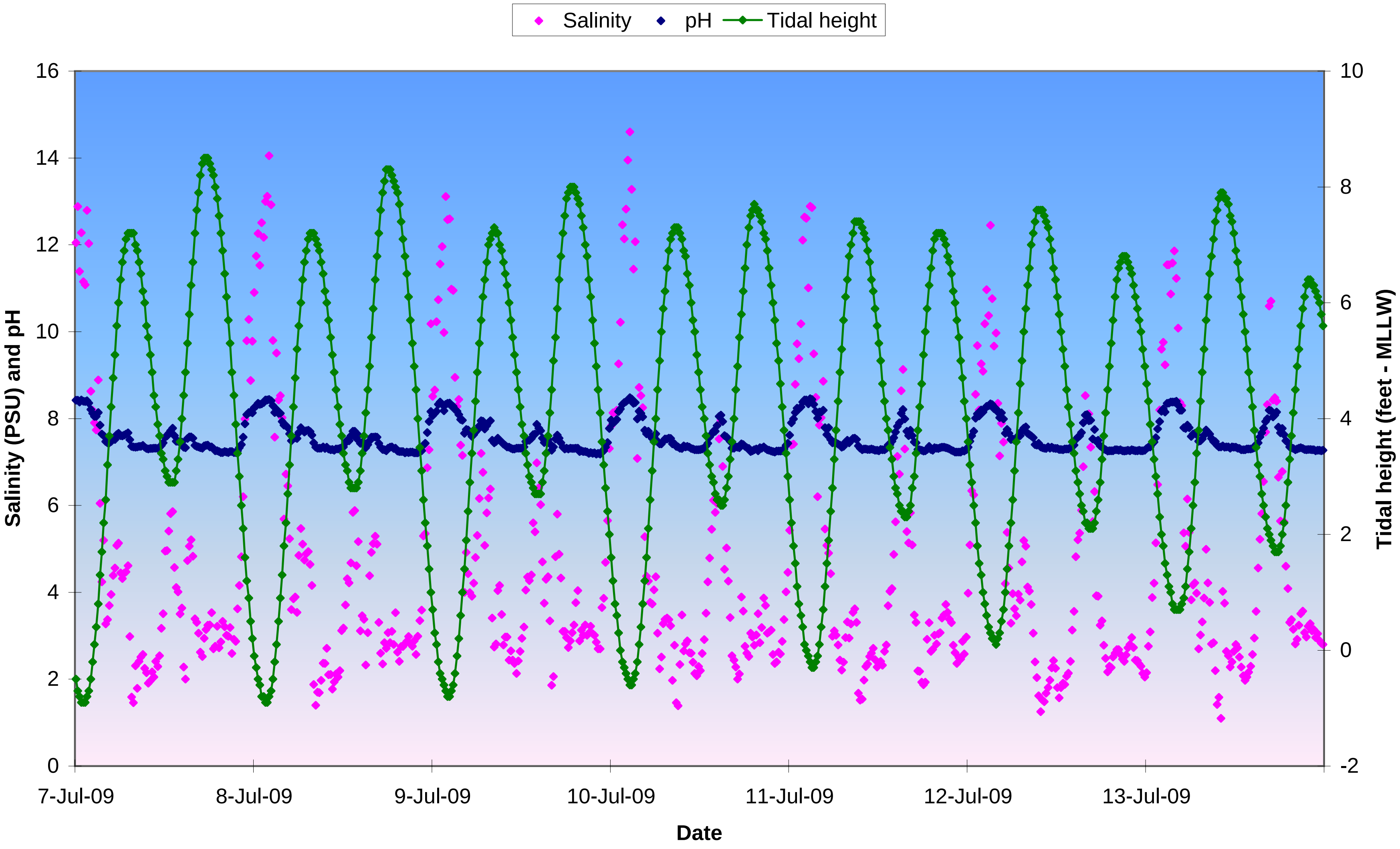
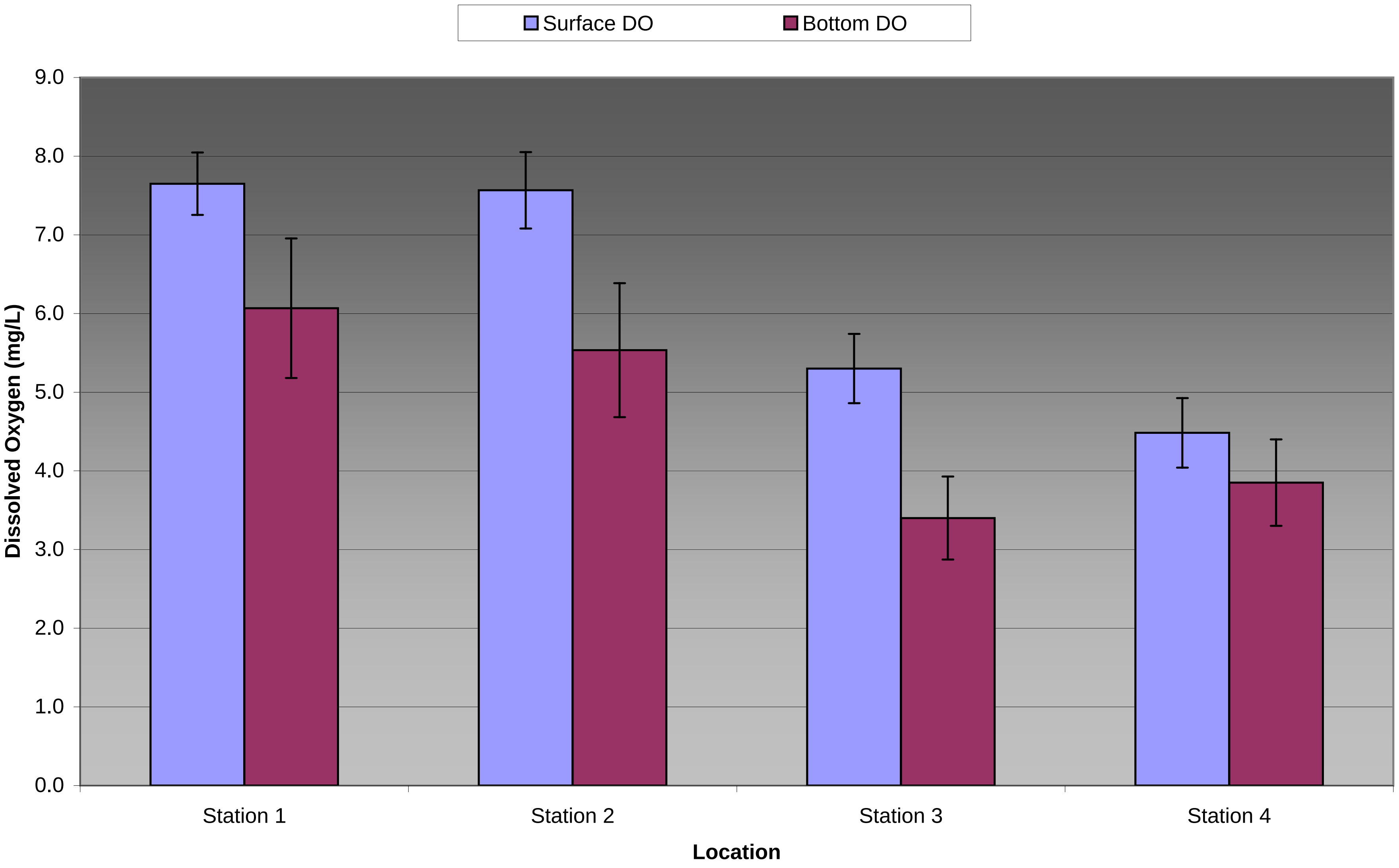
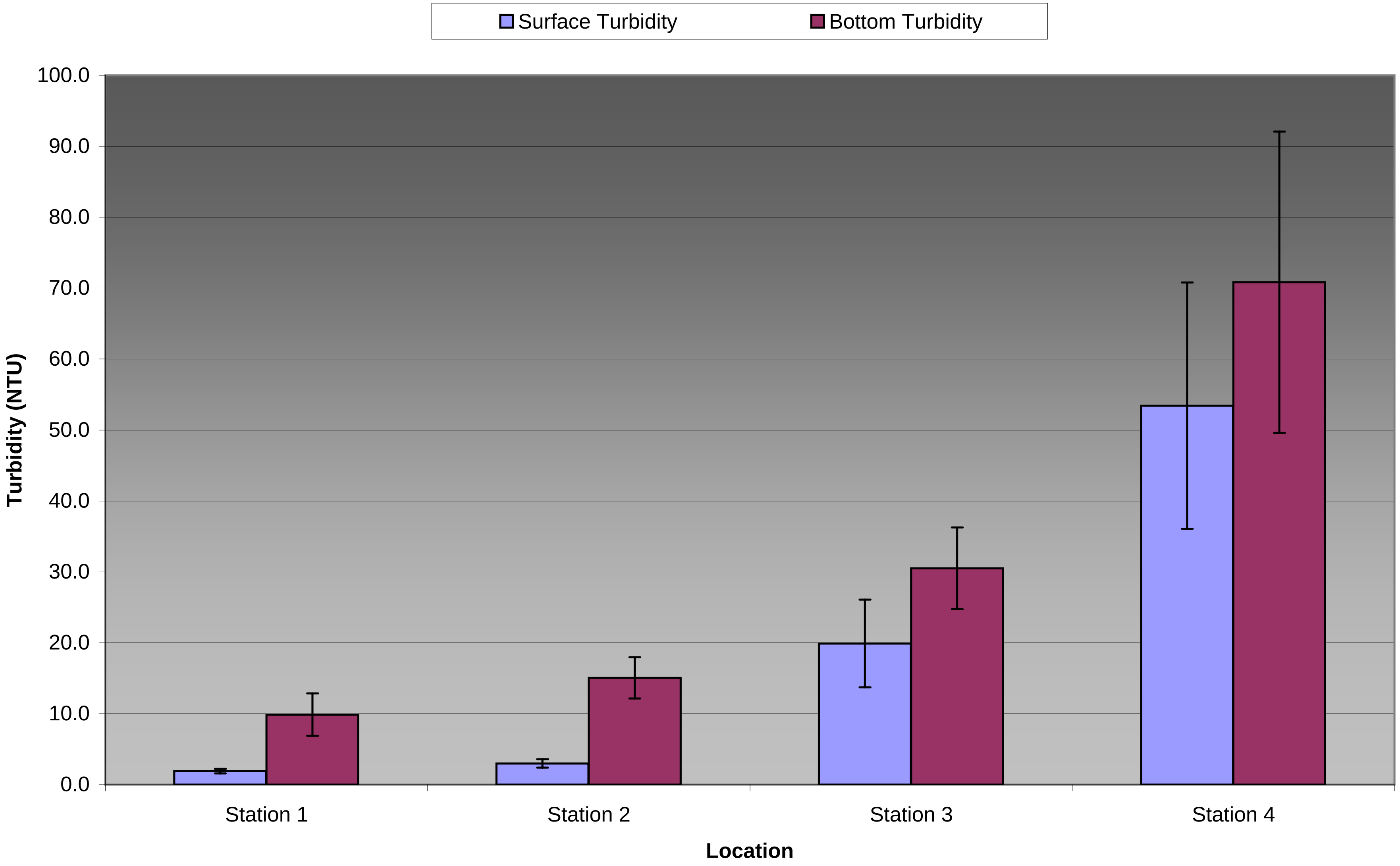


Figure 8.  Mean (+ SE) Monthly Dissolved Oxygen in Artesian Slough for 2009

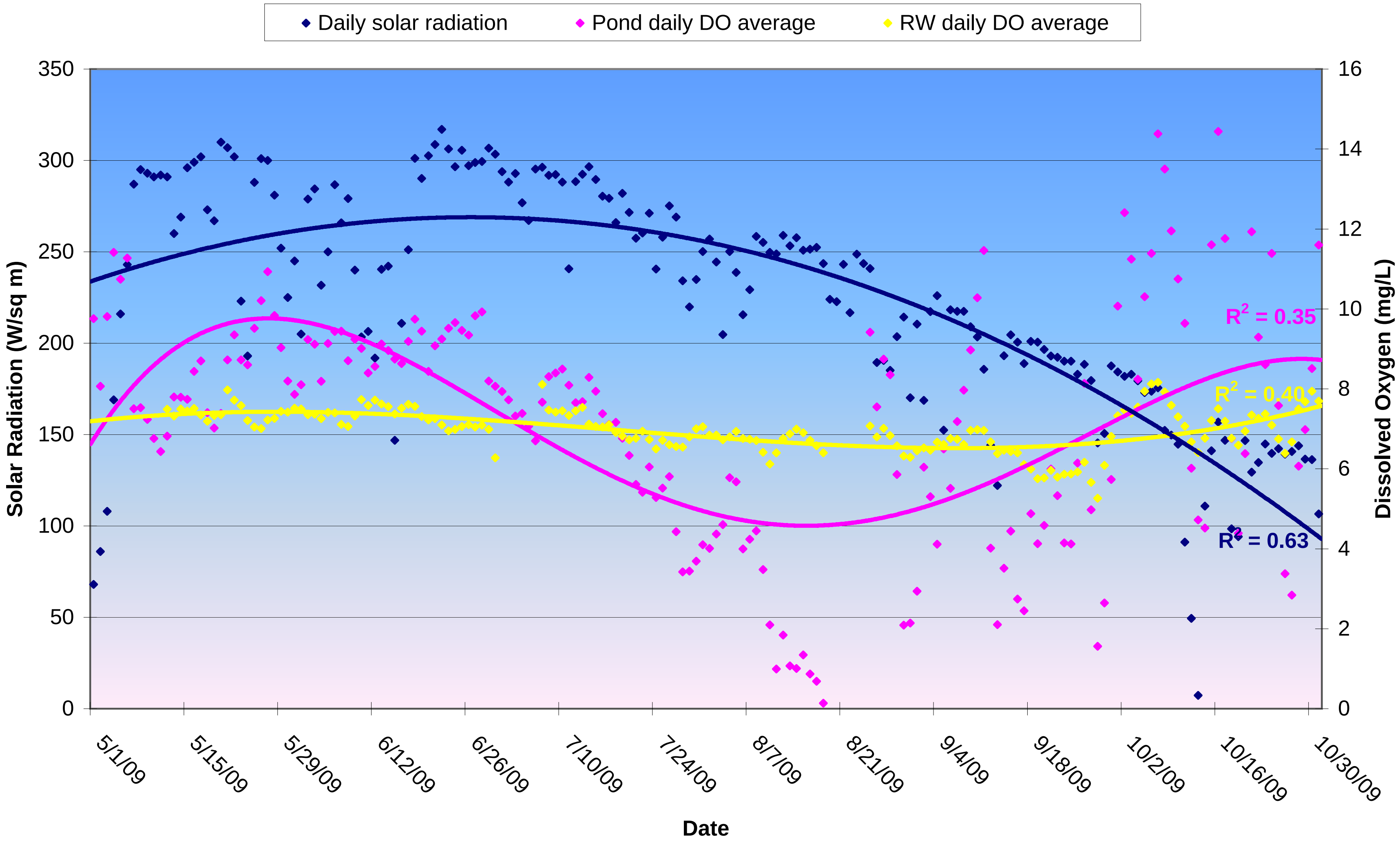


## Figure 9. Mean (± SE) Monthly Turbidity in Artesian Slough for 2009

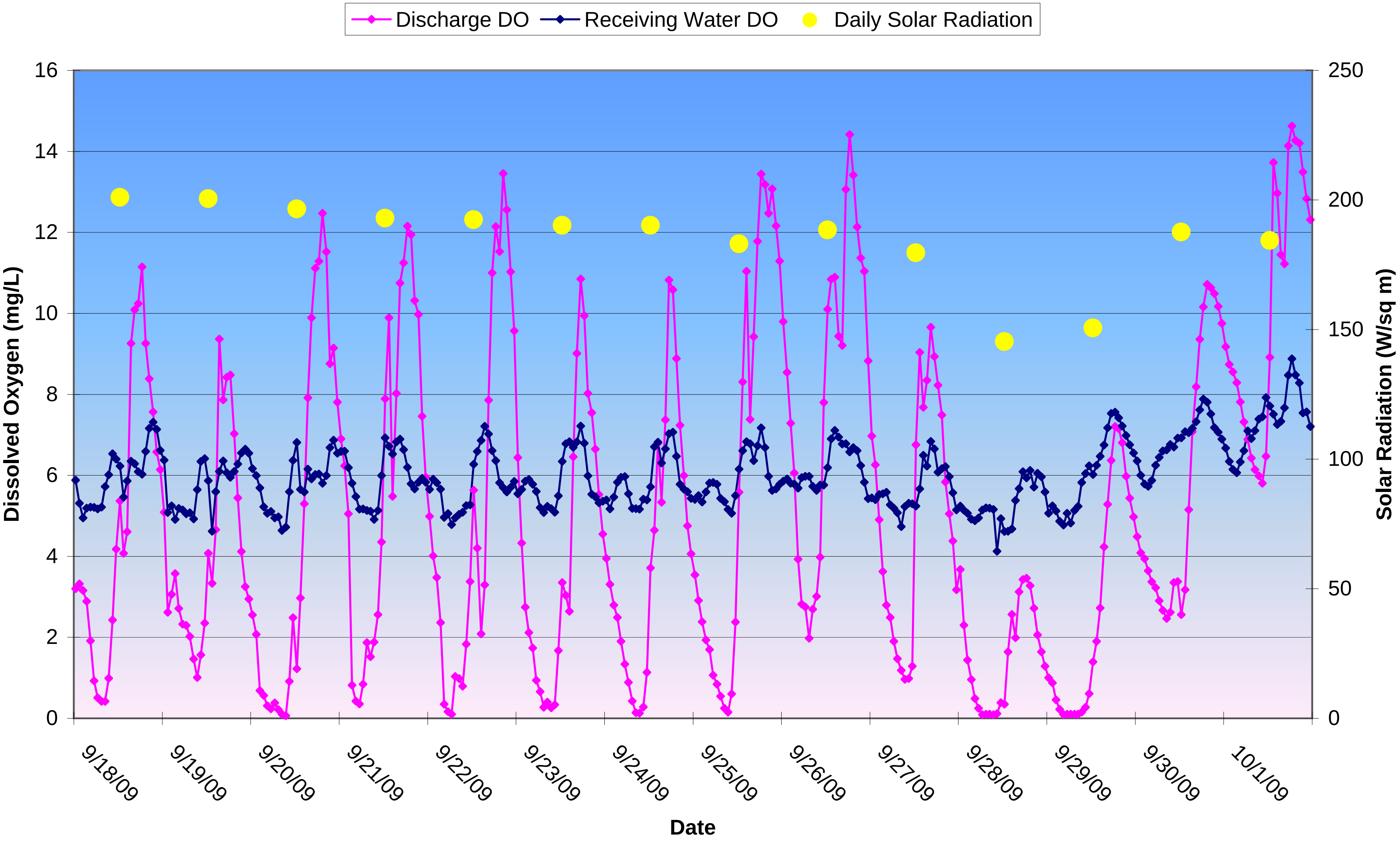


## Figure 10. 2009 Long Term Seasonal Daily Solar Radiation and DO Trends

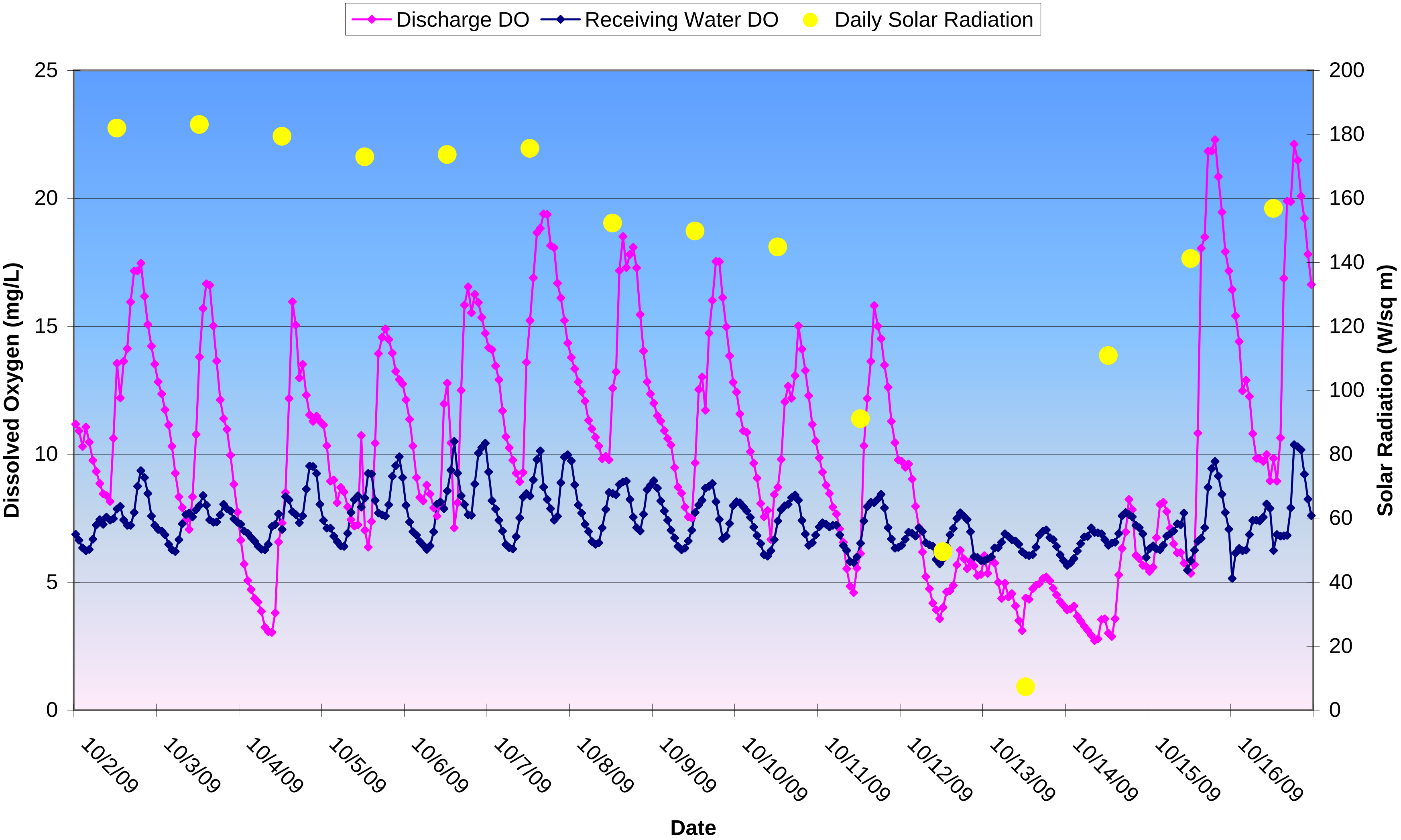
**Daily solar radiation peaked in mid-June when day length was greatest. Declines in pond DO coincided with gradually shortened day length and resulting decreases in solar radiation.**



## Figure 11. Short Term Effects of Temporary Declines of Solar Radiation on Pond A18 and Artesian Slough Dissolved Oxygen Concentrations - Weeks 21 and 22



## Figure 12. Storm Related Short Term Effects of Temporary Declines of Solar Radiation on Pond A18 Dissolved Oxygen Concentrations - Weeks 23 and 24



# Appendix I. Continuous Monitoring of Dissolved Oxygen in Pond A18 and in Artesian Slough

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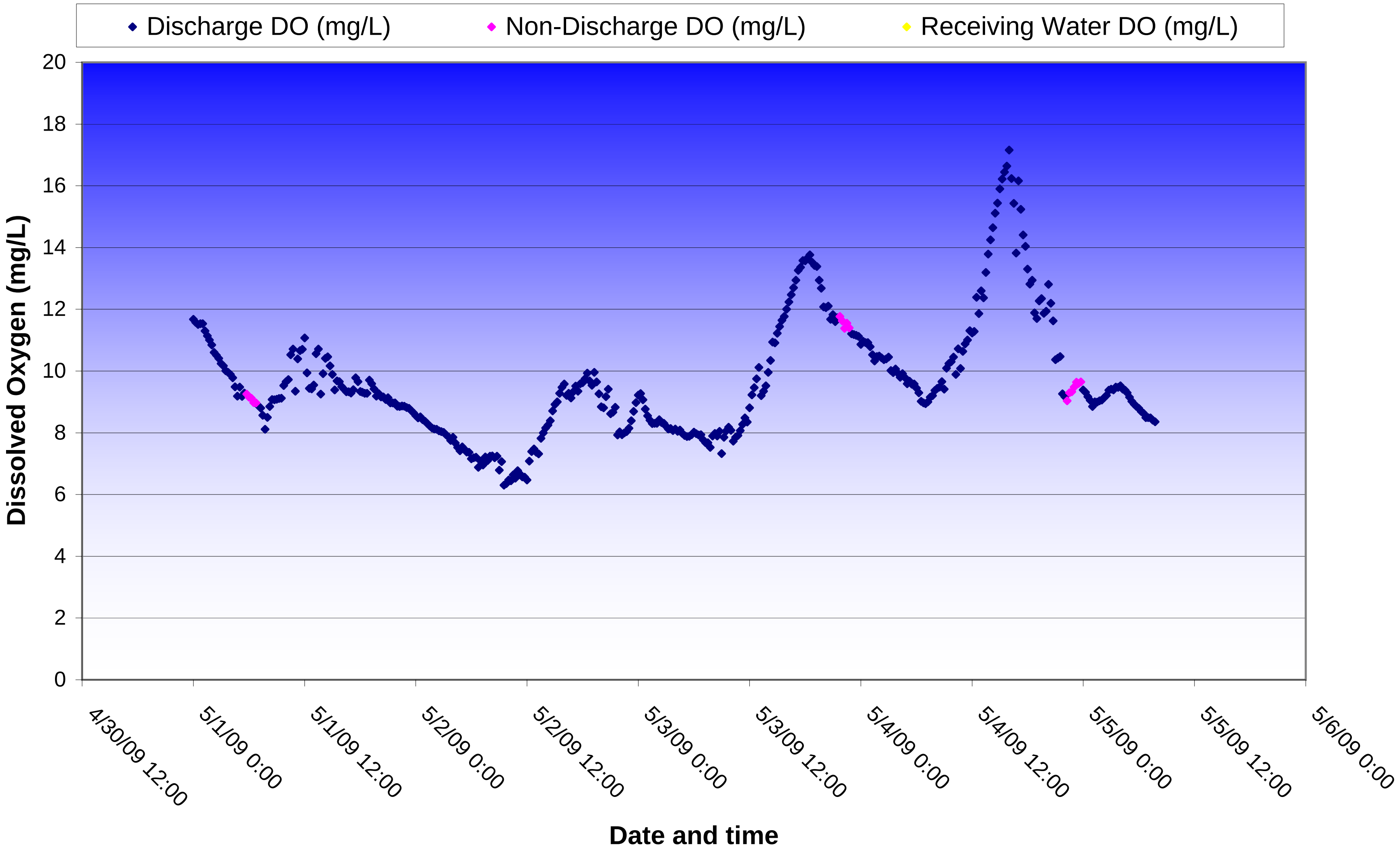
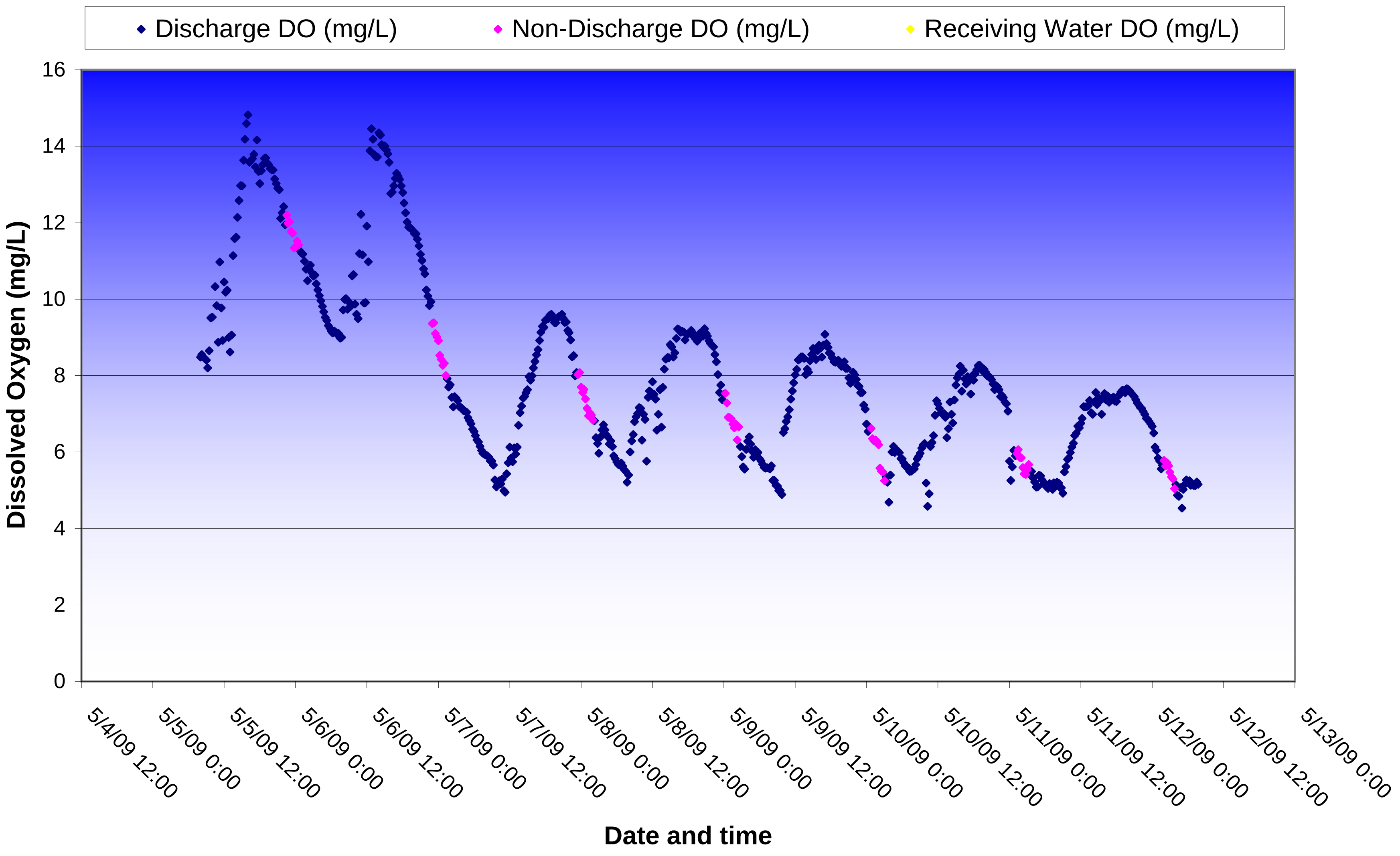
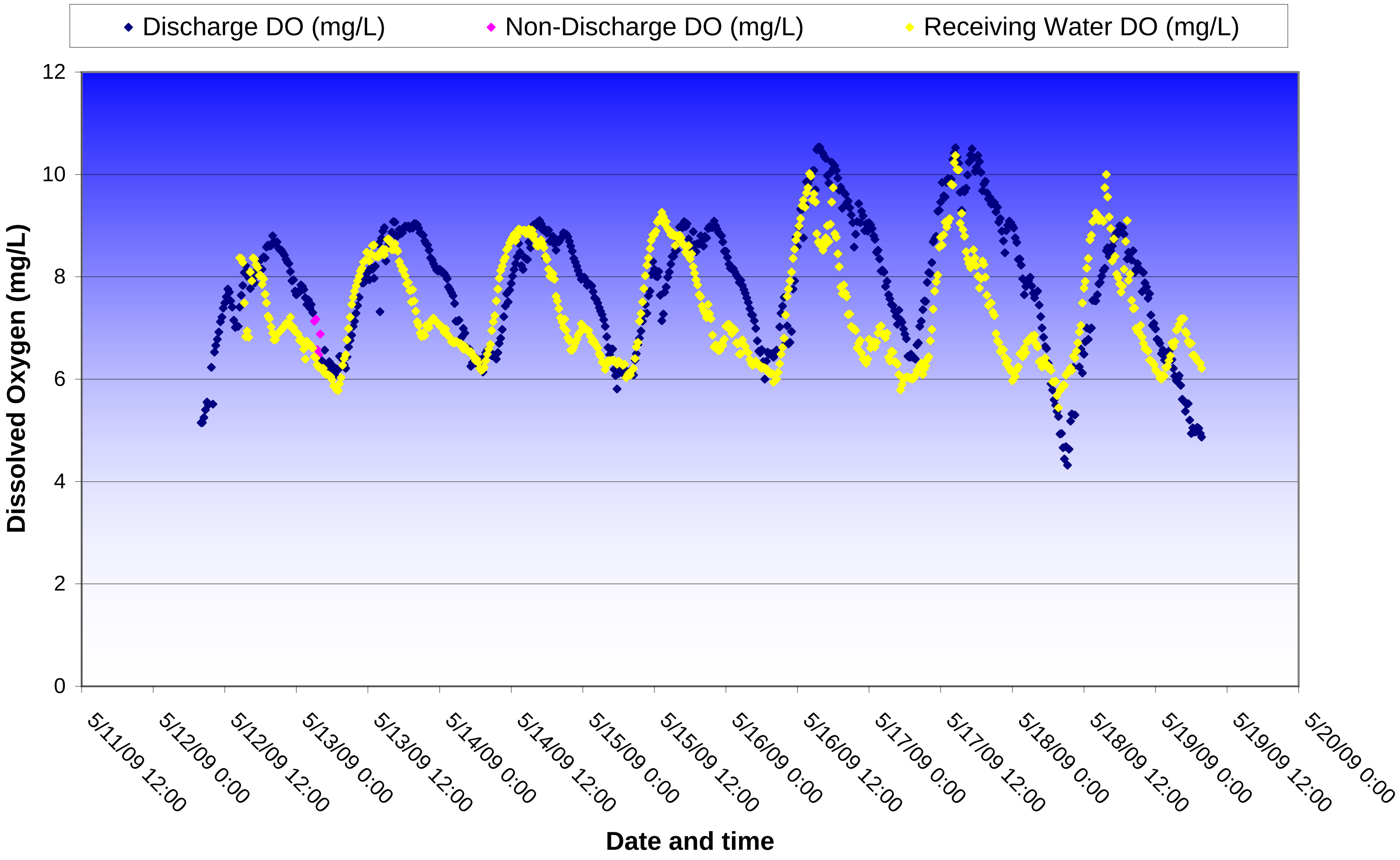
## Pond A18 and Artesian Slough Dissolved Oxygen Comparisons
## Week 1 - 4/30/09 to 5/5/09

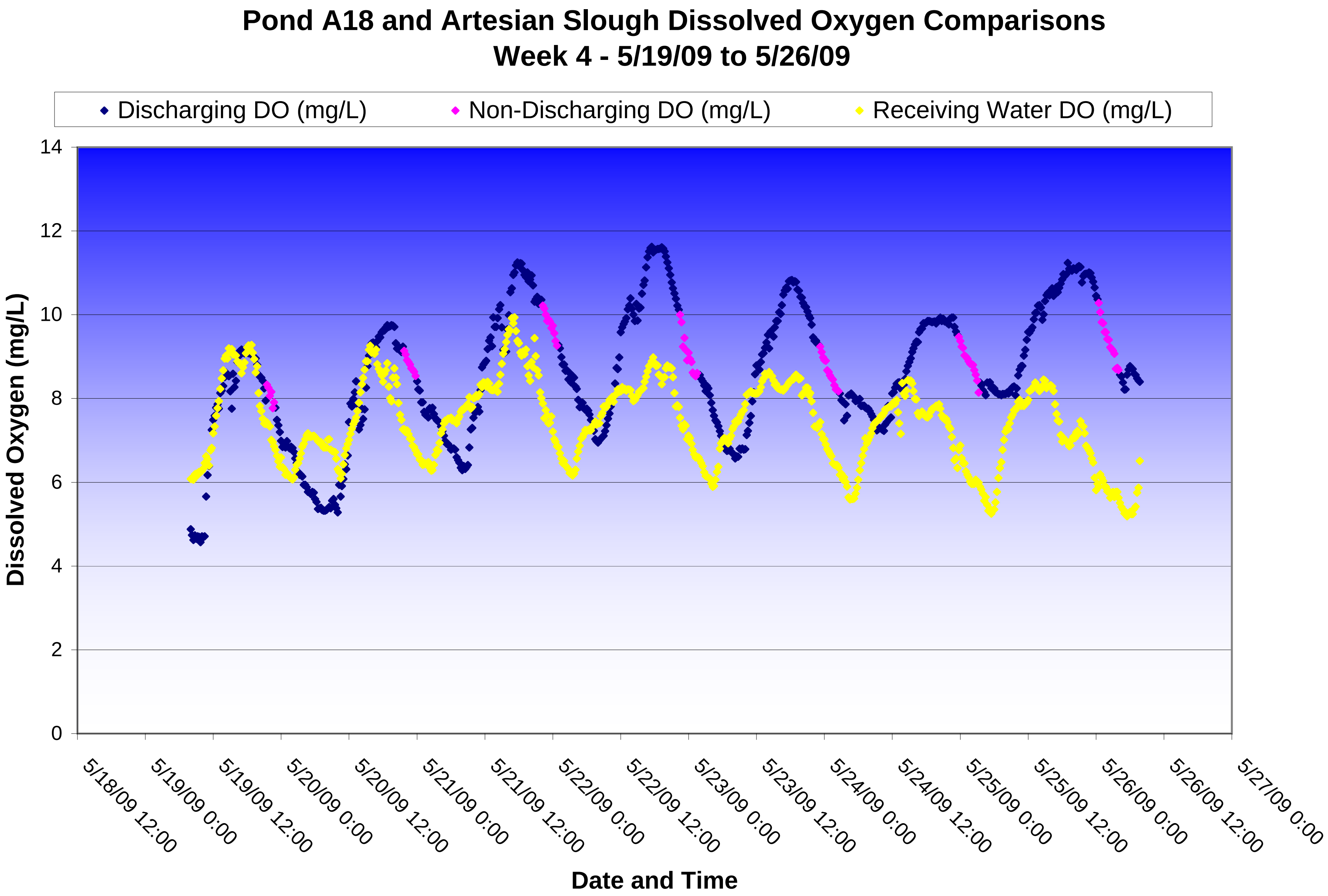


## Pond A18 and Artesian Slough Dissolved Oxygen Comparisons
## Week 2 - 5/5/09 to 5/12/09

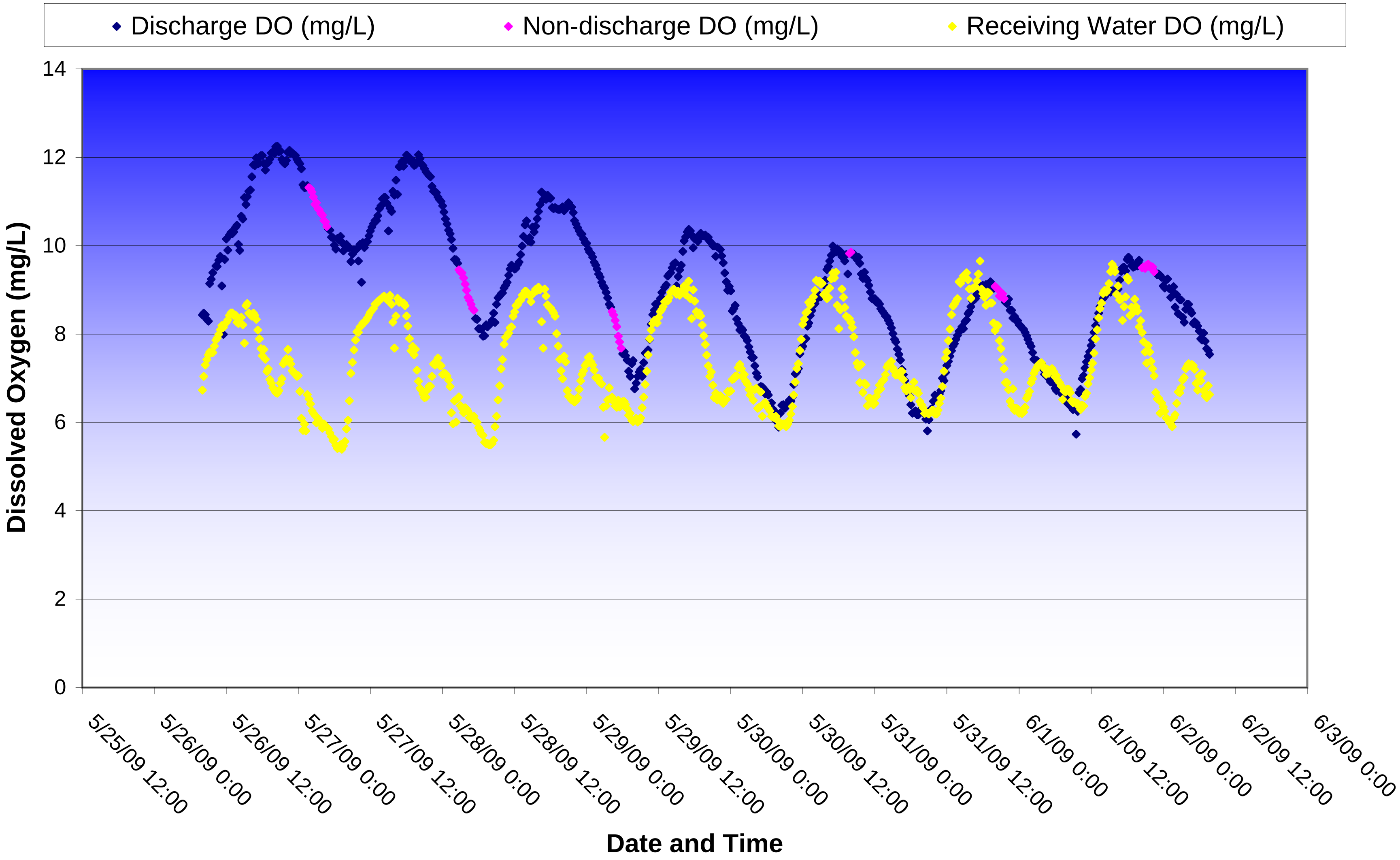


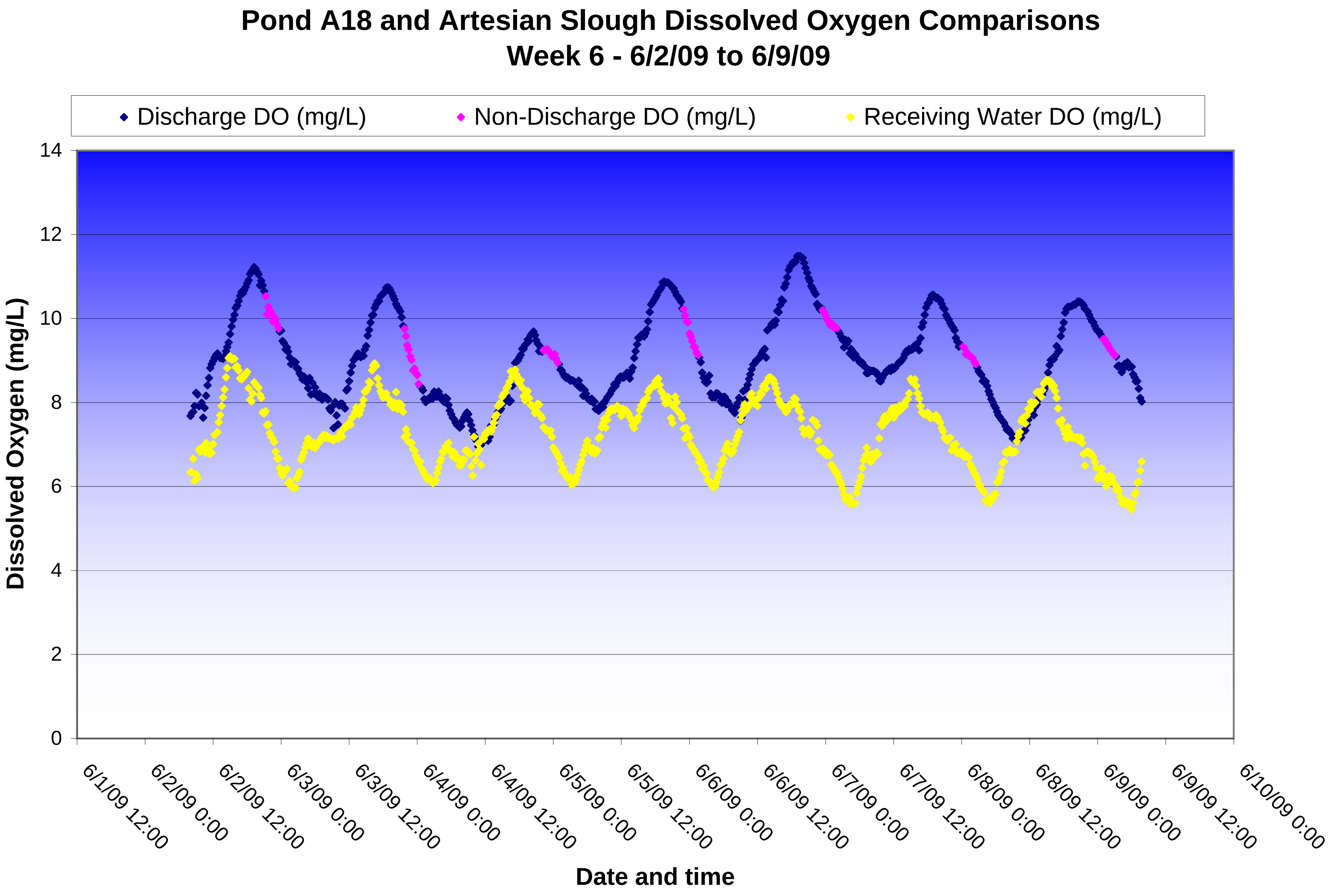
## Pond A18 and Artesian Slough Dissolved Oxygen Comparisons
## Week 3 - 5/12/09 to 5/19/09

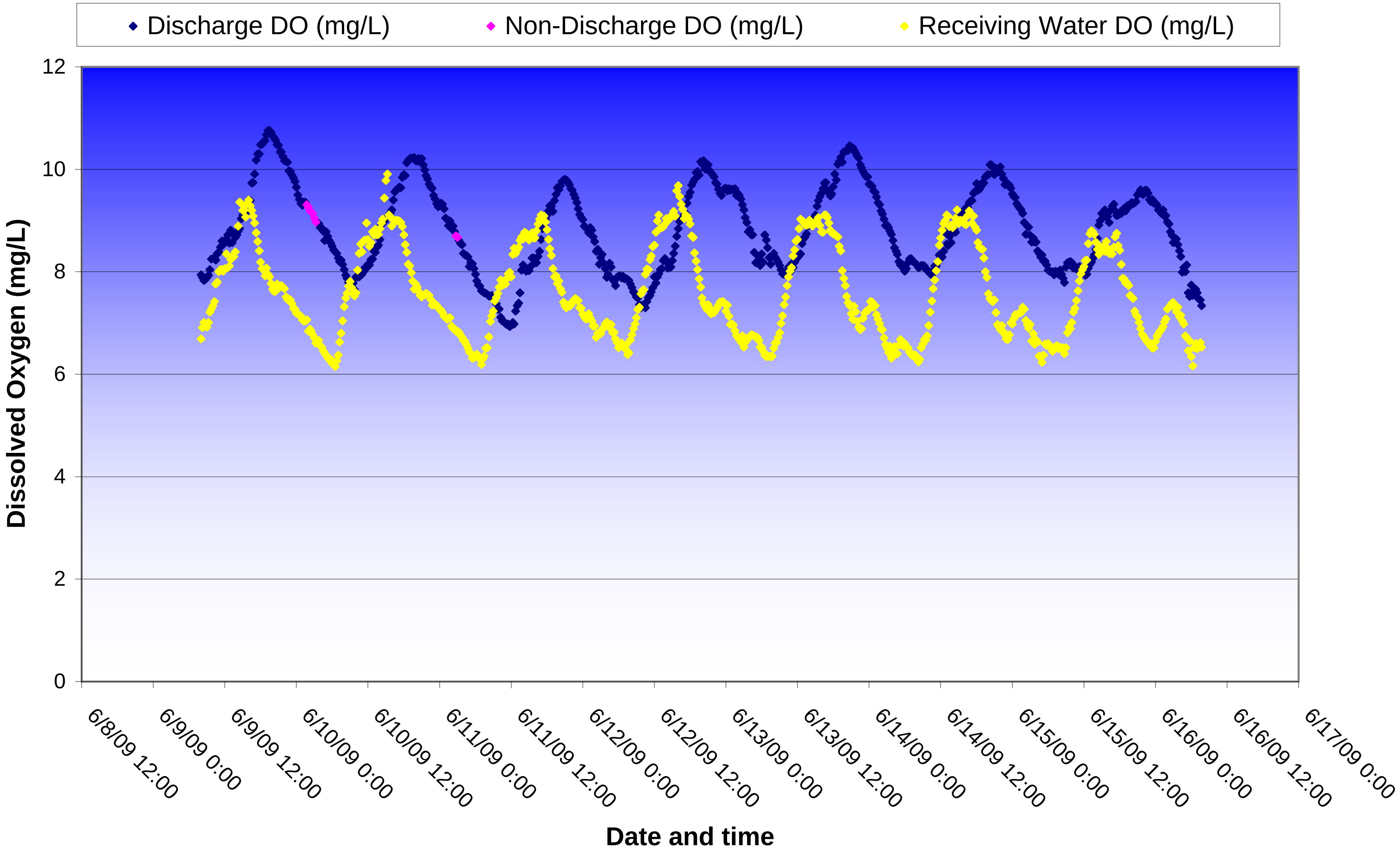



Pond A18 and Artesian Slough Dissolved Oxygen Comparisons
Week 4 - 5/19/09 to 5/26/09
Discharging DO (mg/L)
Non-Discharging DO (mg/L)
Receiving Water DO (mg/L)
Dissolved Oxygen (mg/L)
14
12
10
8
6
4
2
0
5/18/09 12:00
5/19/09 0:00
5/19/09 12:00
5/20/09 0:00
5/20/09 12:00
5/21/09 0:00
5/21/09 12:00
5/22/09 0:00
5/22/09 12:00
5/23/09 0:00
5/23/09 12:00
5/24/09 0:00
5/24/09 12:00
5/25/09 0:00
5/25/09 12:00
5/26/09 0:00
5/26/09 12:00
5/27/09 0:00
Date and Time

## Pond A18 and Artesian Slough Dissolved Oxygen Comparisons
## Week 5 - 5/26/09 to 6/2/09

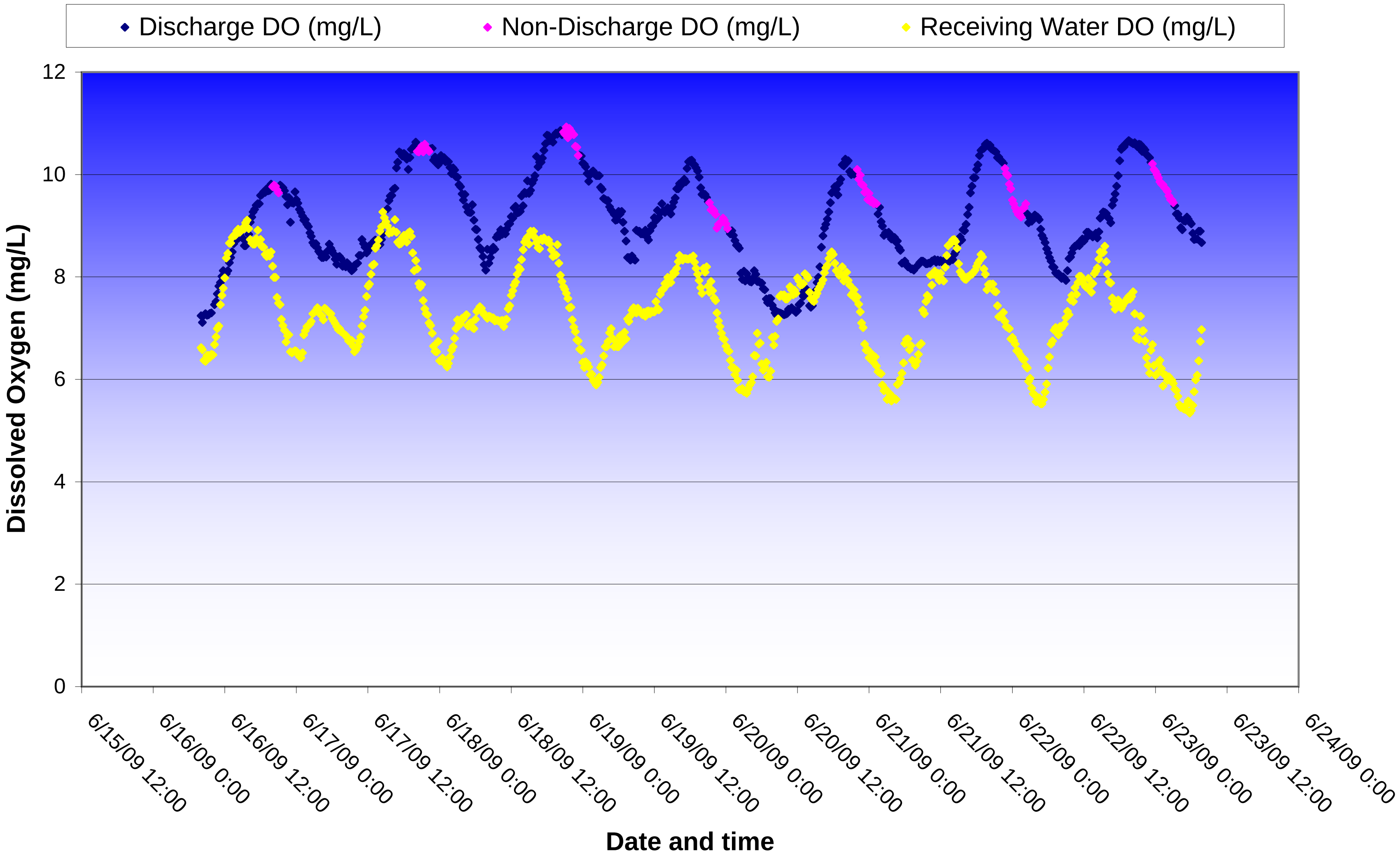


Pond A18 and Artesian Slough Dissolved Oxygen Comparisons
Week 6 - 6/2/09 to 6/9/09
◆ Discharge DO (mg/L)
◆ Non-Discharge DO (mg/L)
◆ Receiving Water DO (mg/L)
Dissolved Oxygen (mg/L)
14
12
10
8
6
4
2
0
6/1/09 12:00
6/2/09 0:00
6/2/09 12:00
6/3/09 0:00
6/3/09 12:00
6/4/09 0:00
6/4/09 12:00
6/5/09 0:00
6/5/09 12:00
6/6/09 0:00
6/6/09 12:00
6/7/09 0:00
6/7/09 12:00
6/8/09 0:00
6/8/09 12:00
6/9/09 0:00
6/9/09 12:00
6/10/09 0:00
Date and time

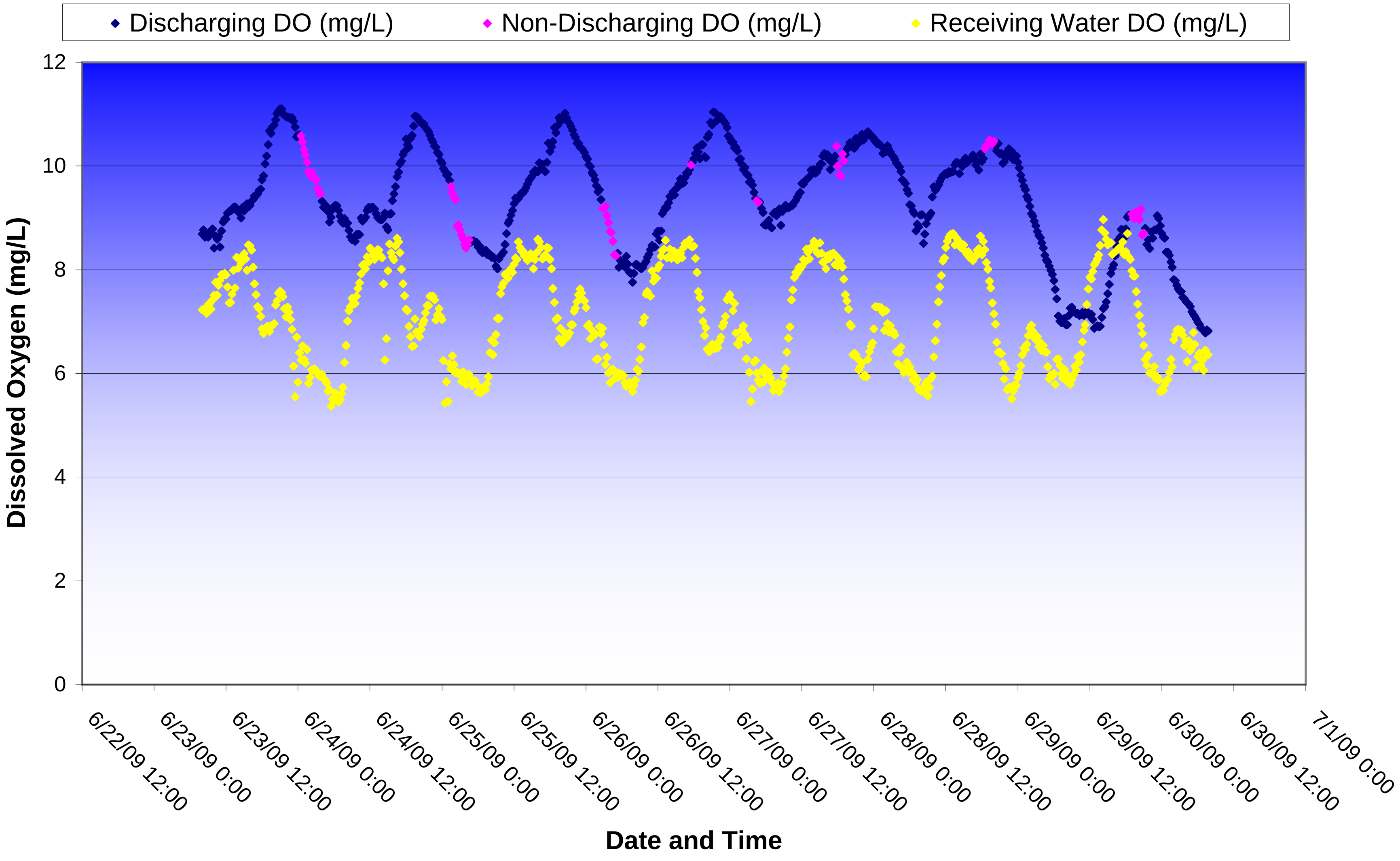


Pond A18 and Artesian Slough Dissolved Oxygen Comparisons
Week 7 - 6/9/09 to 6/16/09

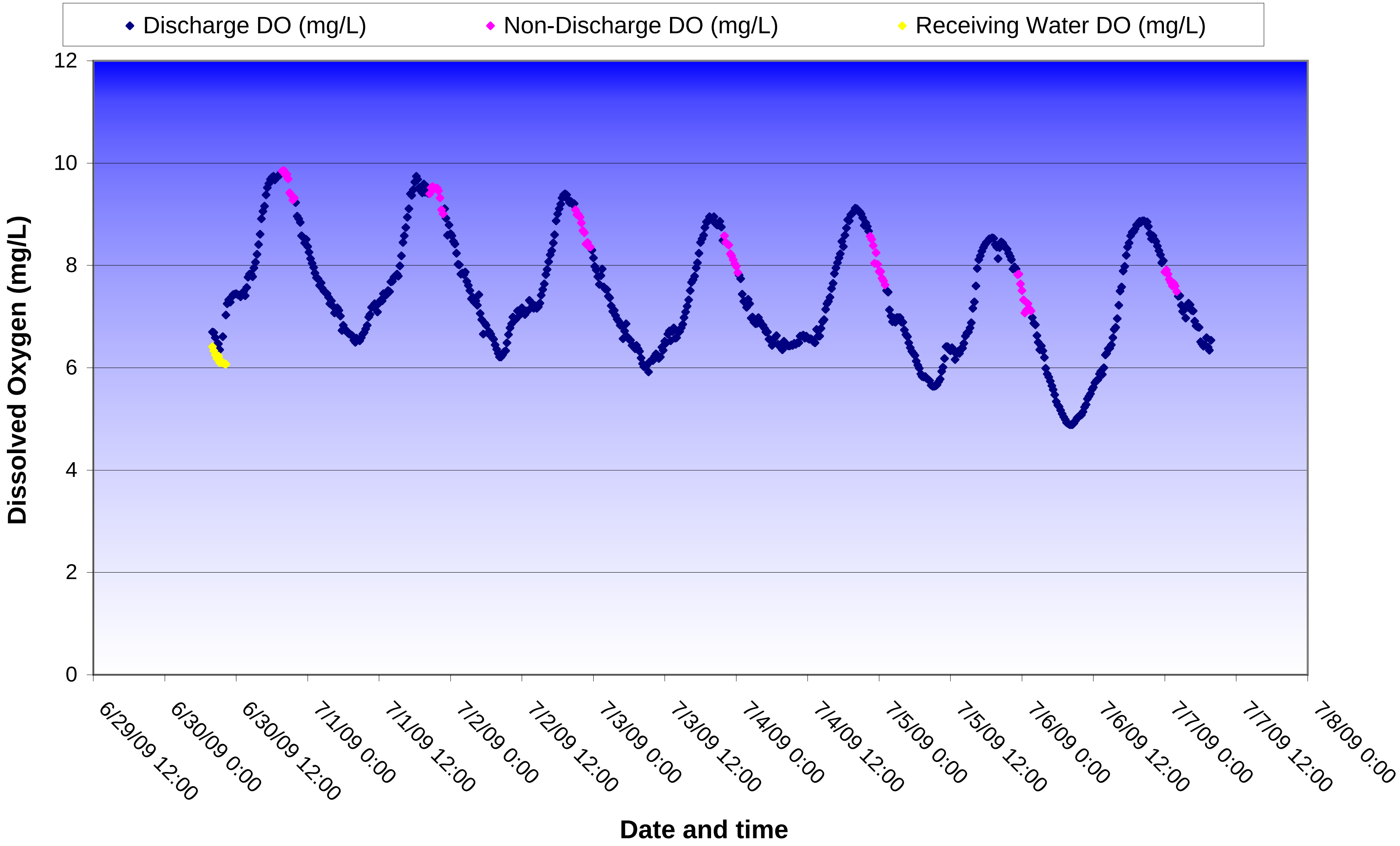
# Pond A18 and Artesian Slough Dissolved Oxygen Comparisons
## Week 8 - 6/16/09 to 6/23/09

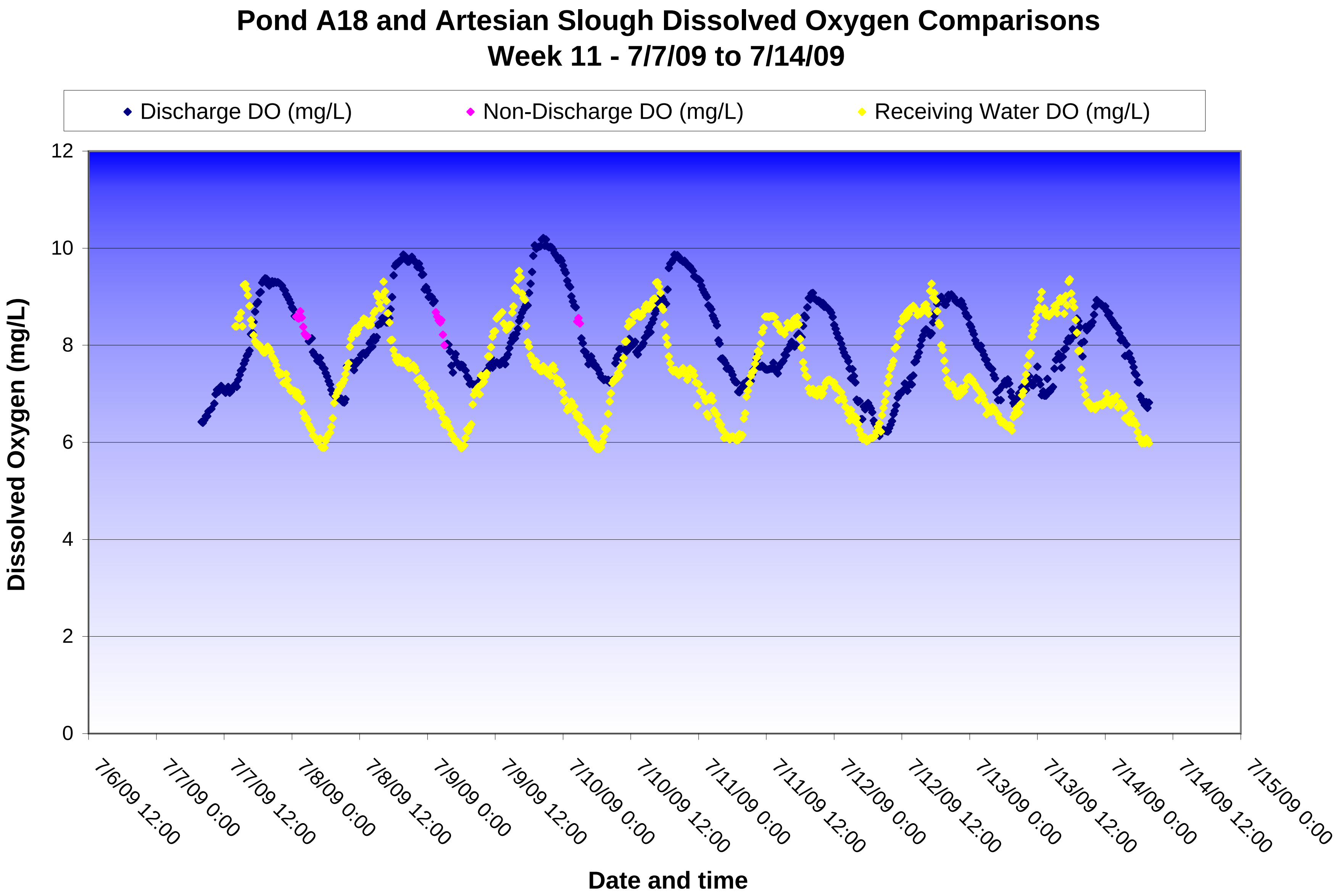


# Pond A18 and Artesian Slough Dissolved Oxygen Comparisons
## Week 9 - 6/23/09 to 6/30/09

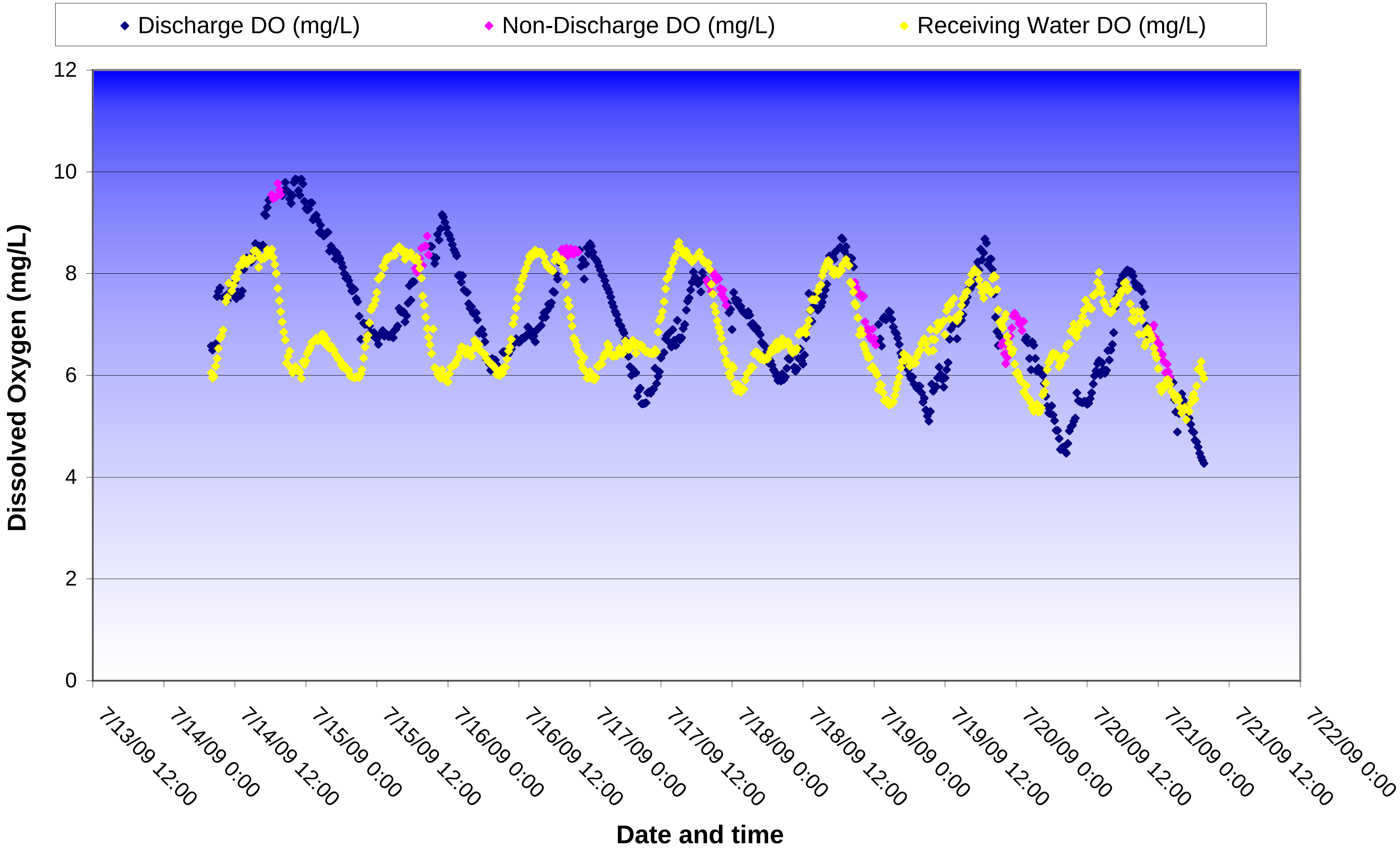


## Pond A18 and Artesian Slough Dissolved Oxygen Comparisons
## Week10 - 6/30/09 to 7/7/09

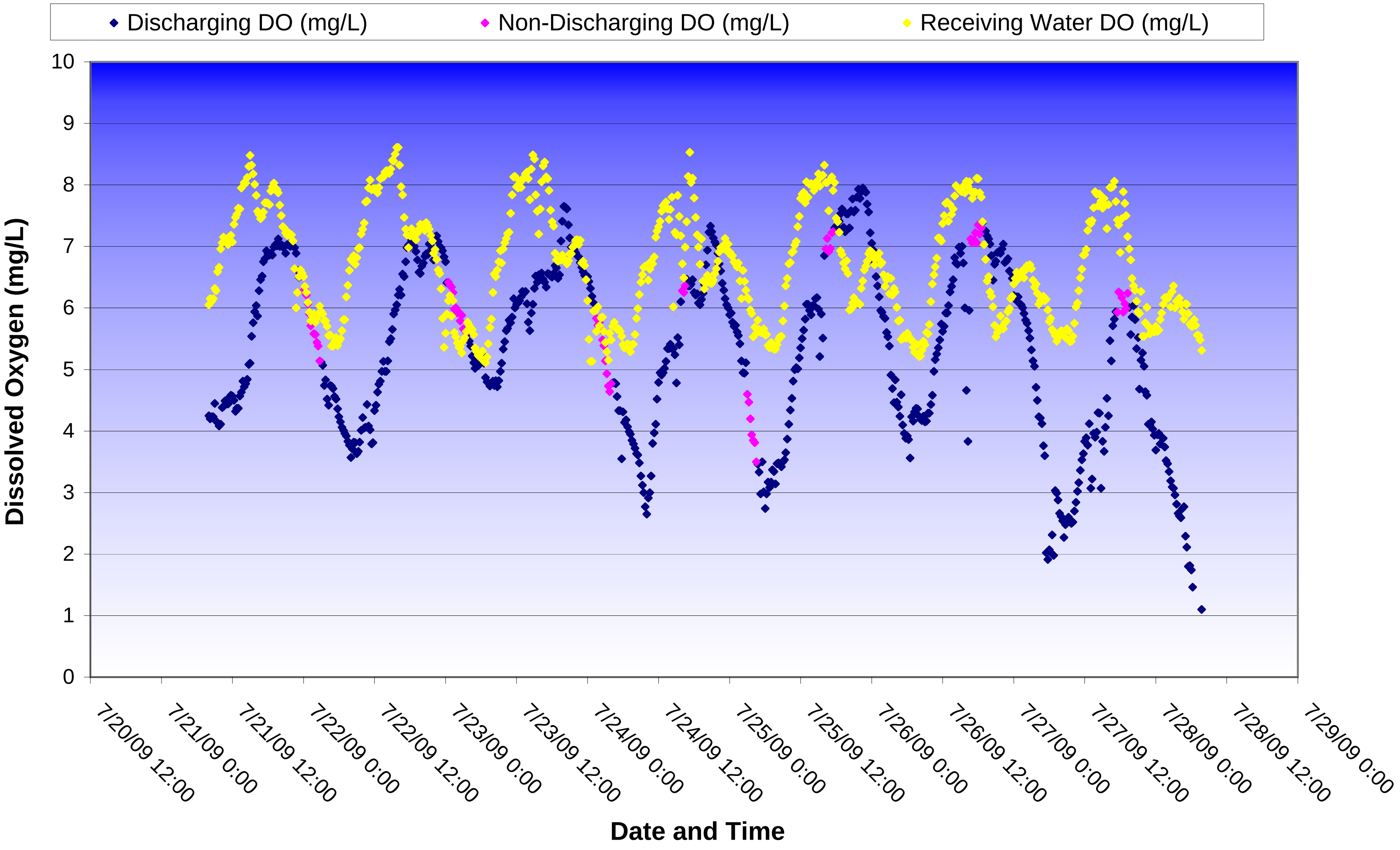


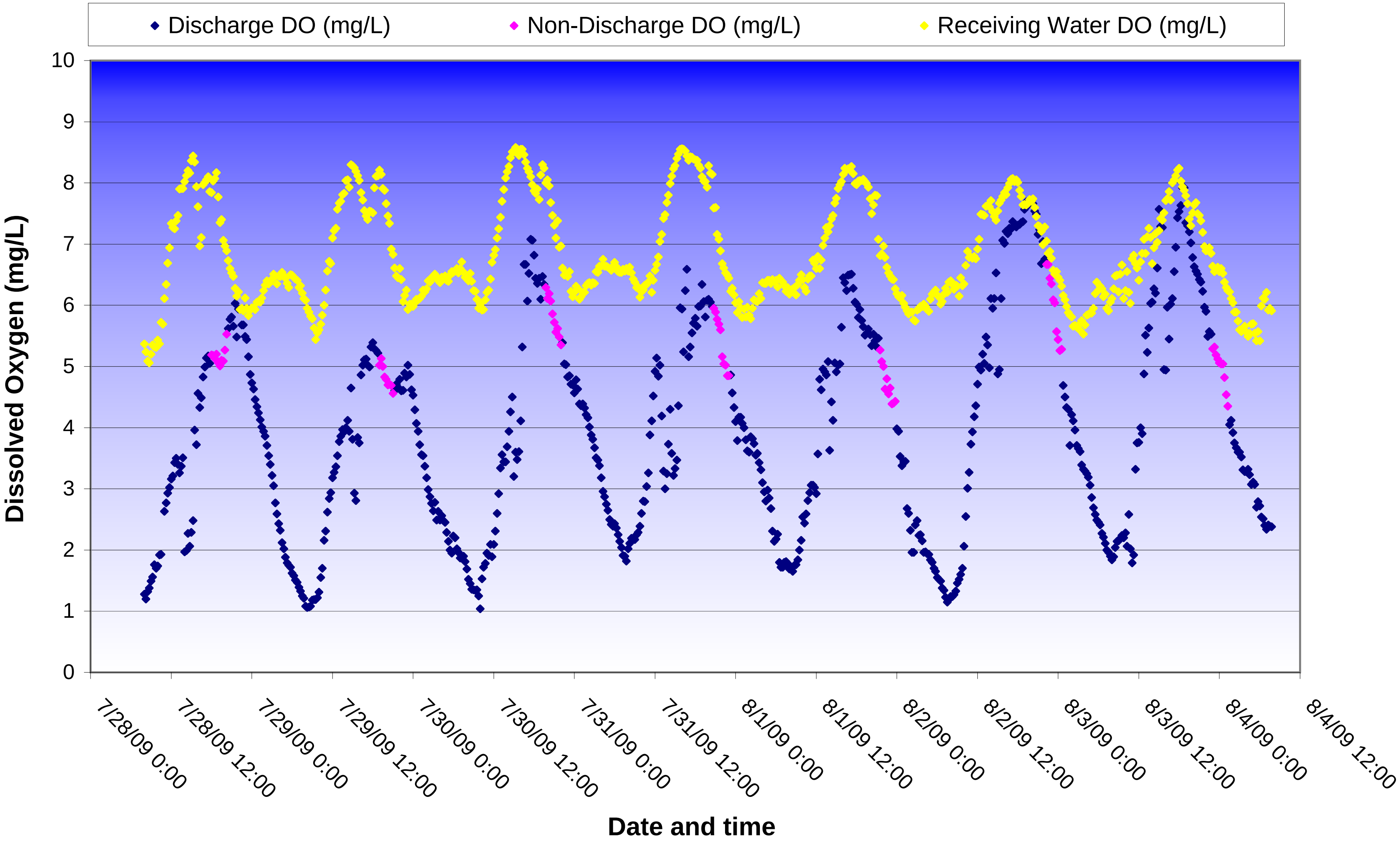

Pond A18 and Artesian Slough Dissolved Oxygen Comparisons
Week 11 - 7/7/09 to 7/14/09
◆ Discharge DO (mg/L)
◆ Non-Discharge DO (mg/L)
◆ Receiving Water DO (mg/L)
Dissolved Oxygen (mg/L)
12
10
8
6
4
2
0
7/6/09 12:00
7/7/09 0:00
7/7/09 12:00
7/8/09 0:00
7/8/09 12:00
7/9/09 0:00
7/9/09 12:00
7/10/09 0:00
7/10/09 12:00
7/11/09 0:00
7/11/09 12:00
7/12/09 0:00
7/12/09 12:00
7/13/09 0:00
7/13/09 12:00
7/14/09 0:00
7/14/09 12:00
7/15/09 0:00
Date and time

# Pond A18 and Artesian Slough Dissolved Oxygen Comparisons
## Week 12 - 7/14/09 to 7/21/09



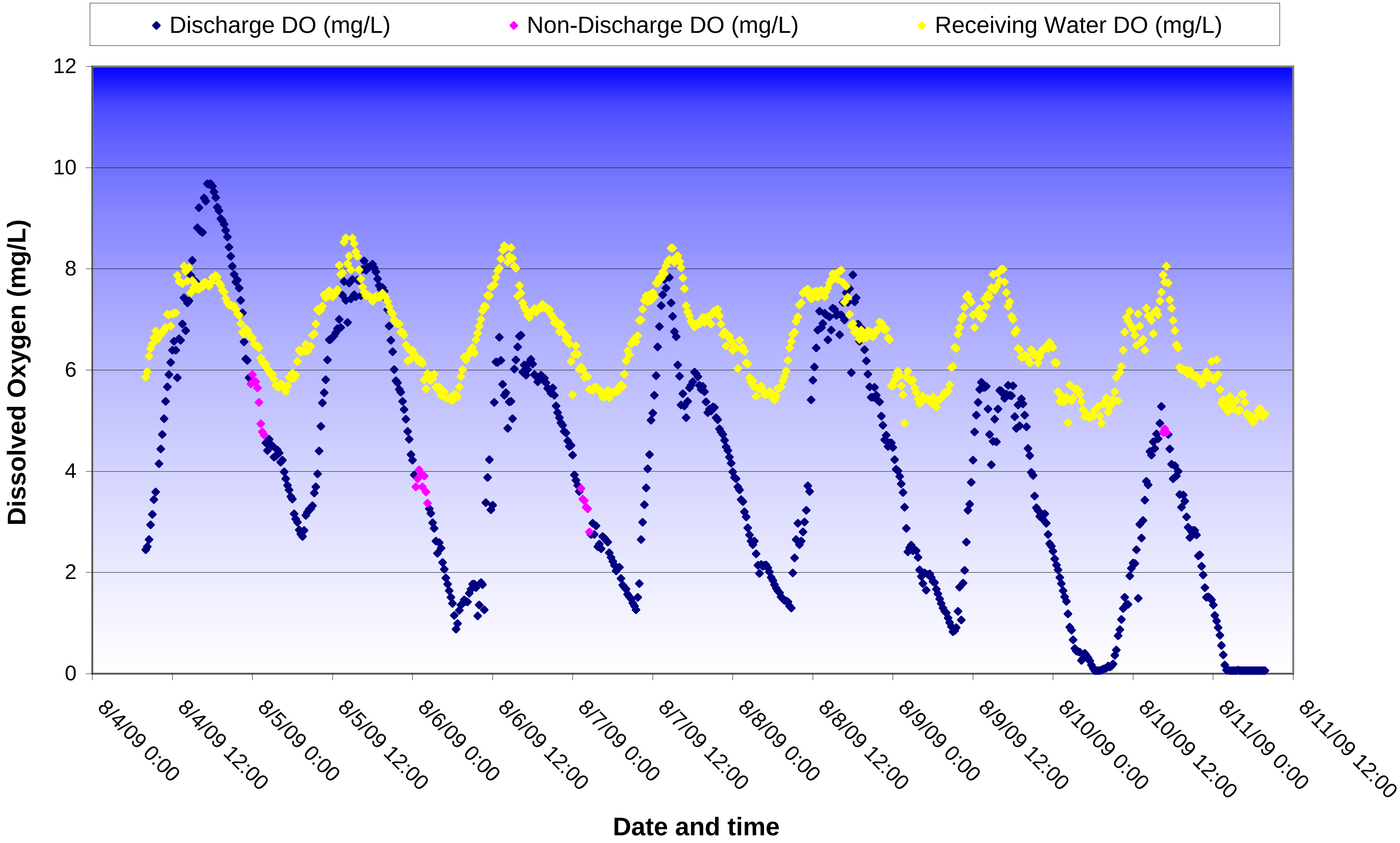
# Pond A18 and Artesian Slough Dissolved Oxygen Comparisons
## Week 13 - 7/21/09 to 7/28/09



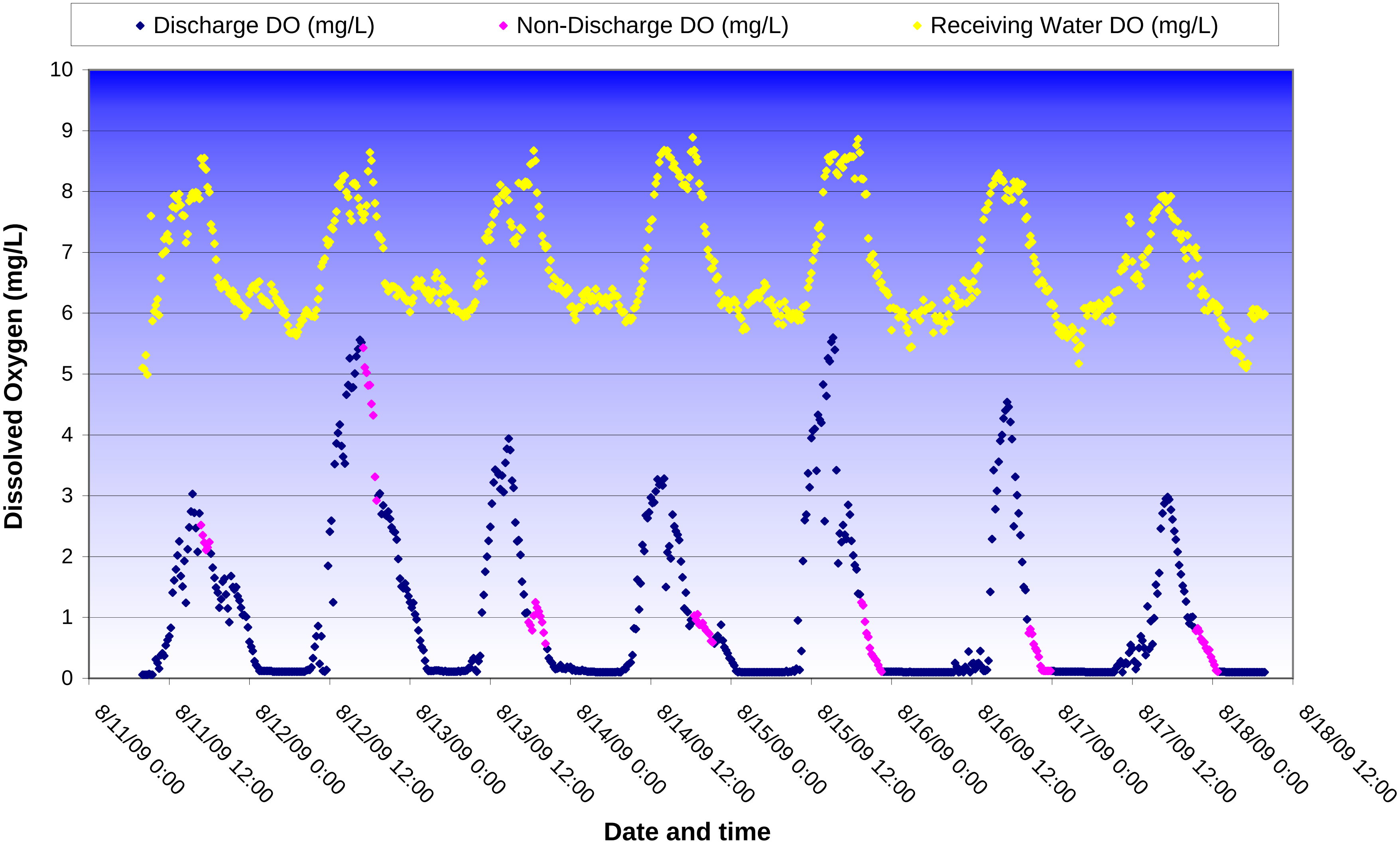


Pond A18 and Artesian Slough Dissolved Oxygen Comparisons
Week 14 - 7/28/09 to 8/4/09

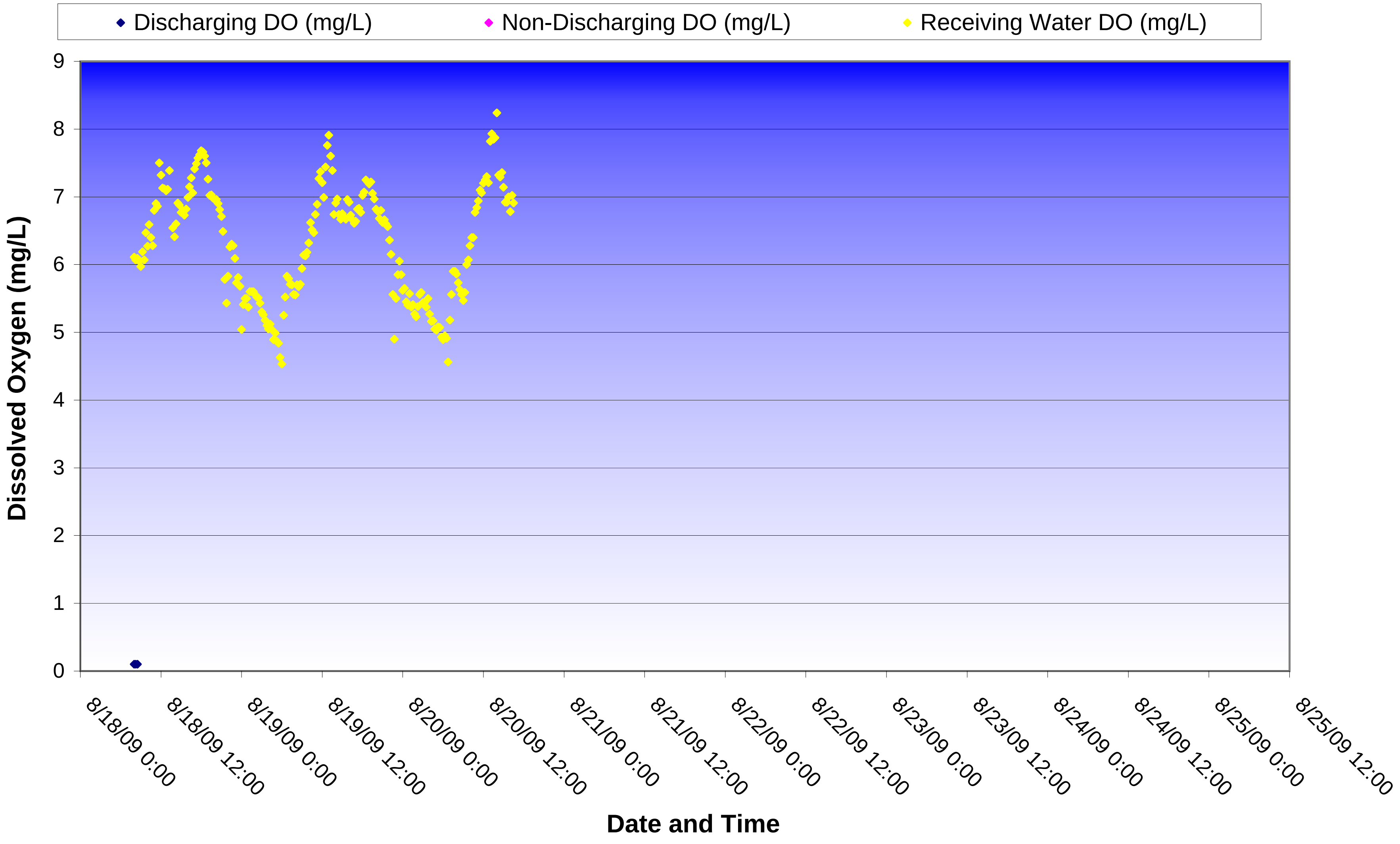
# Pond A18 and Artesian Slough Dissolved Oxygen Comparisons
## Week 15 - 8/4/09 to 8/11/09



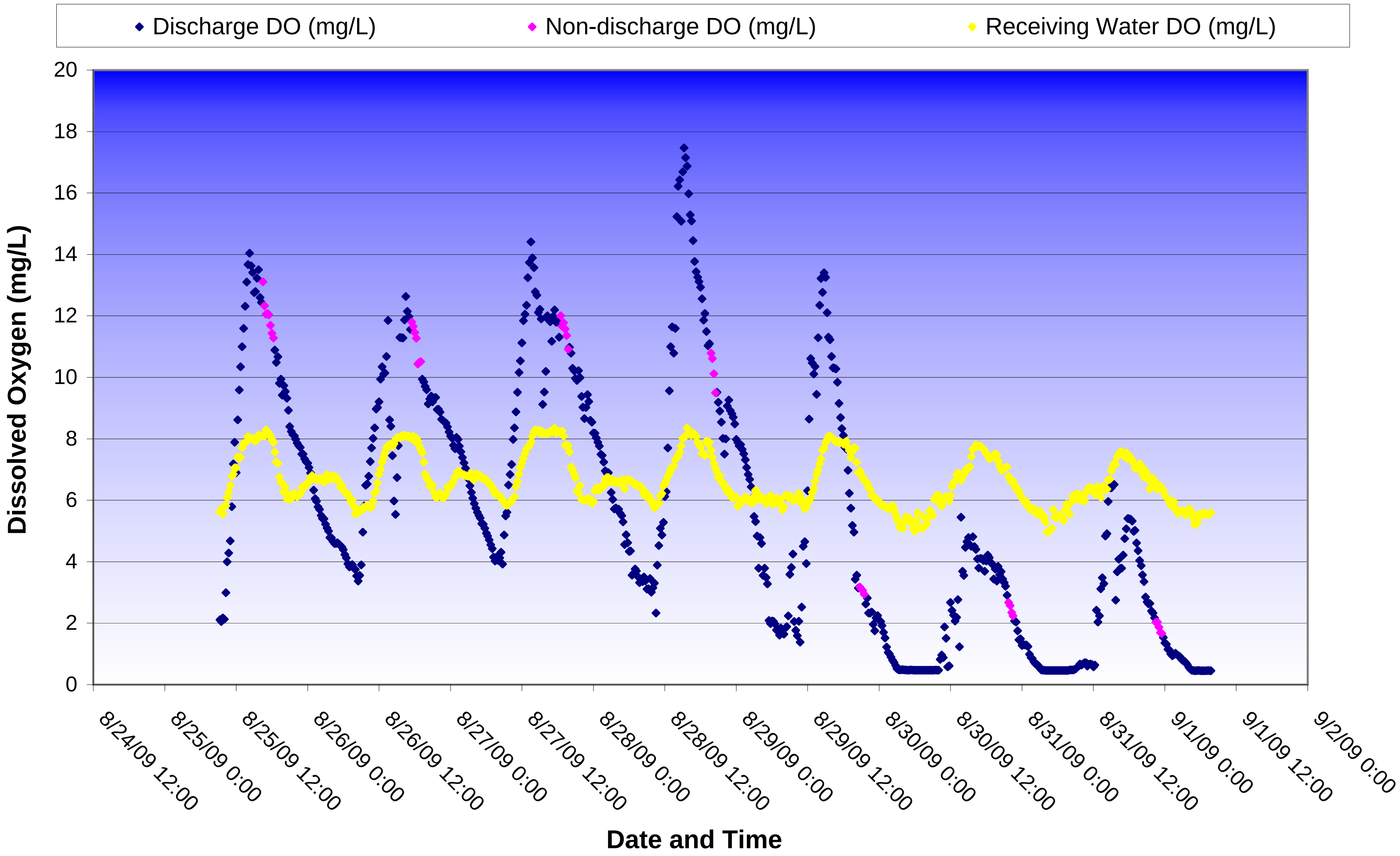
# Pond A18 and Artesian Slough Dissolved Oxygen Comparisons
## Week 16 - 8/11/09 to 8/18/09



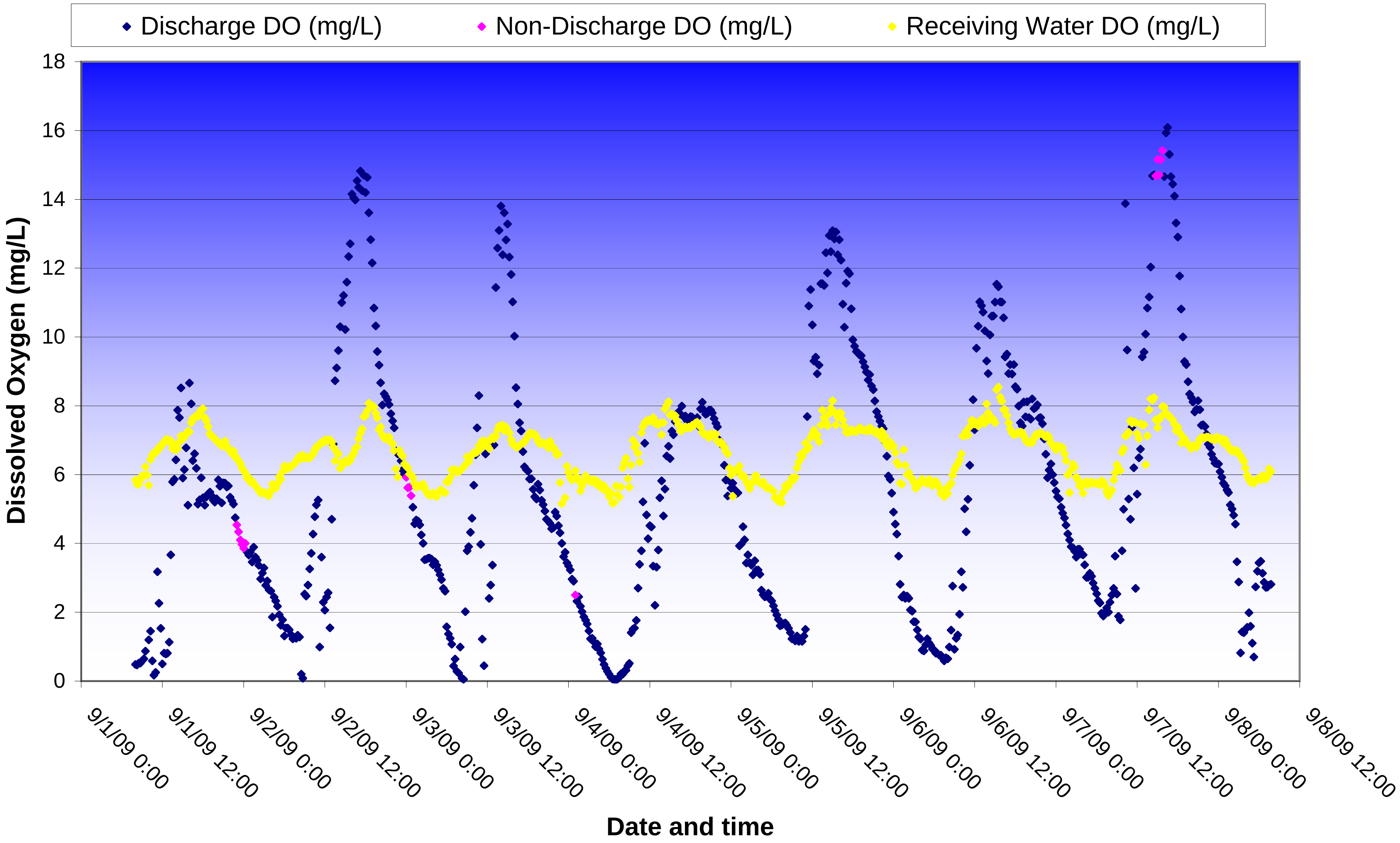
# Pond A18 and Artesian Slough Dissolved Oxygen Comparisons
## Week 17 - 8/18/09 to 8/25/09

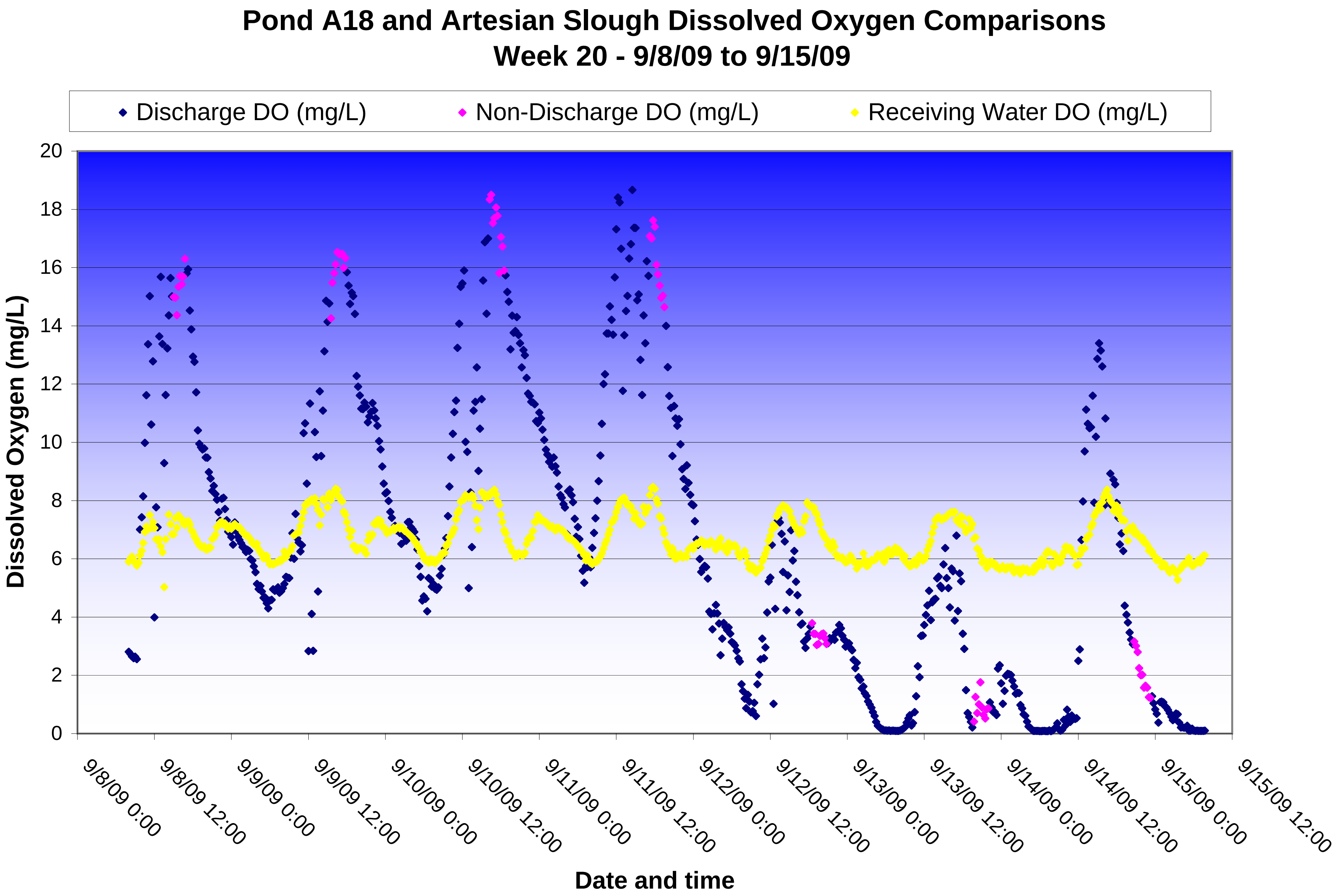


# Pond A18 and Artesian Slough Dissolved Oxygen Comparisons
## Week 18 - 8/25/09 to 9/1/09

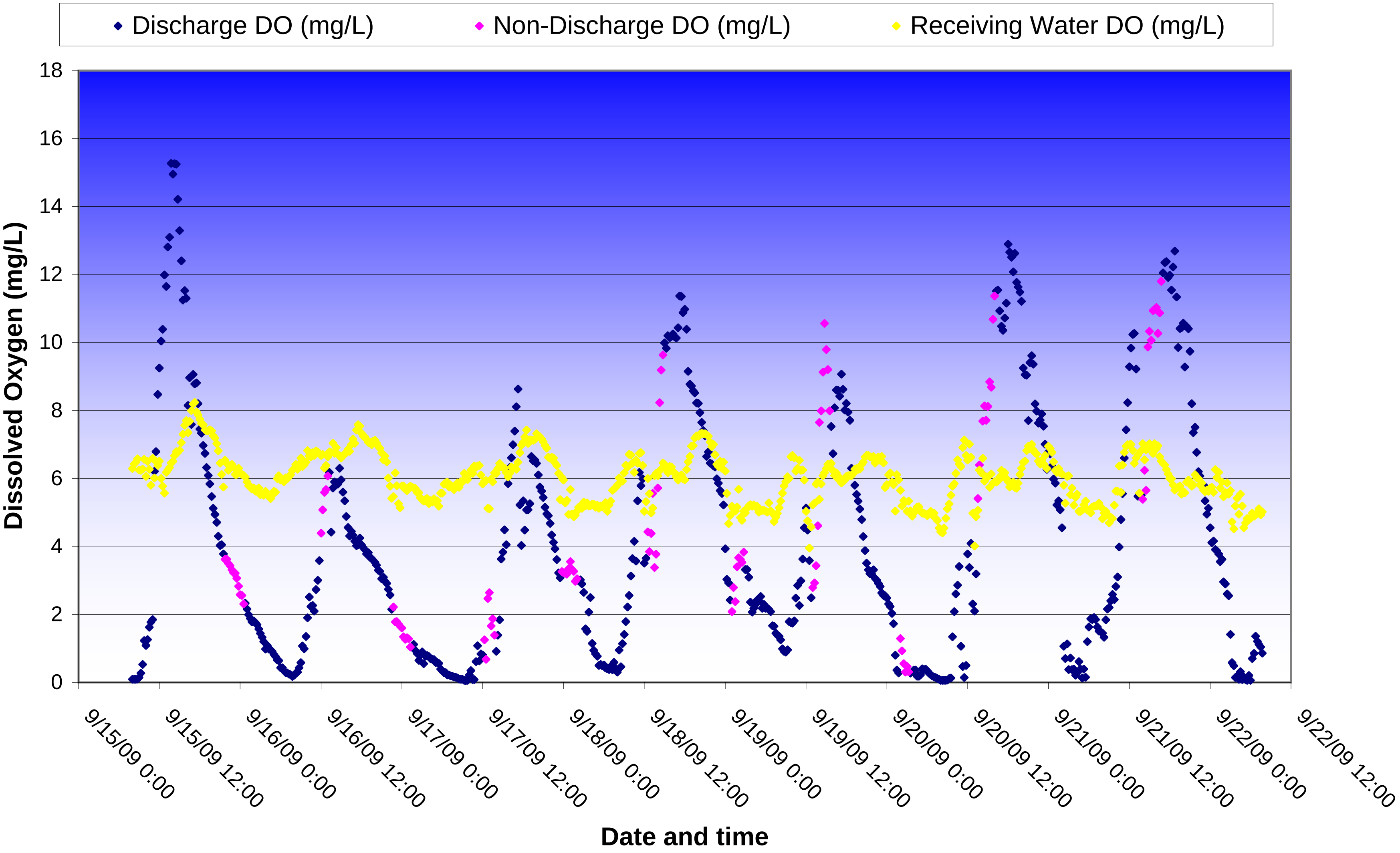


## Pond A18 and Artesian Slough Dissolved Oxygen Comparisons
## Week 19 - 9/1/09 to 9/8/09

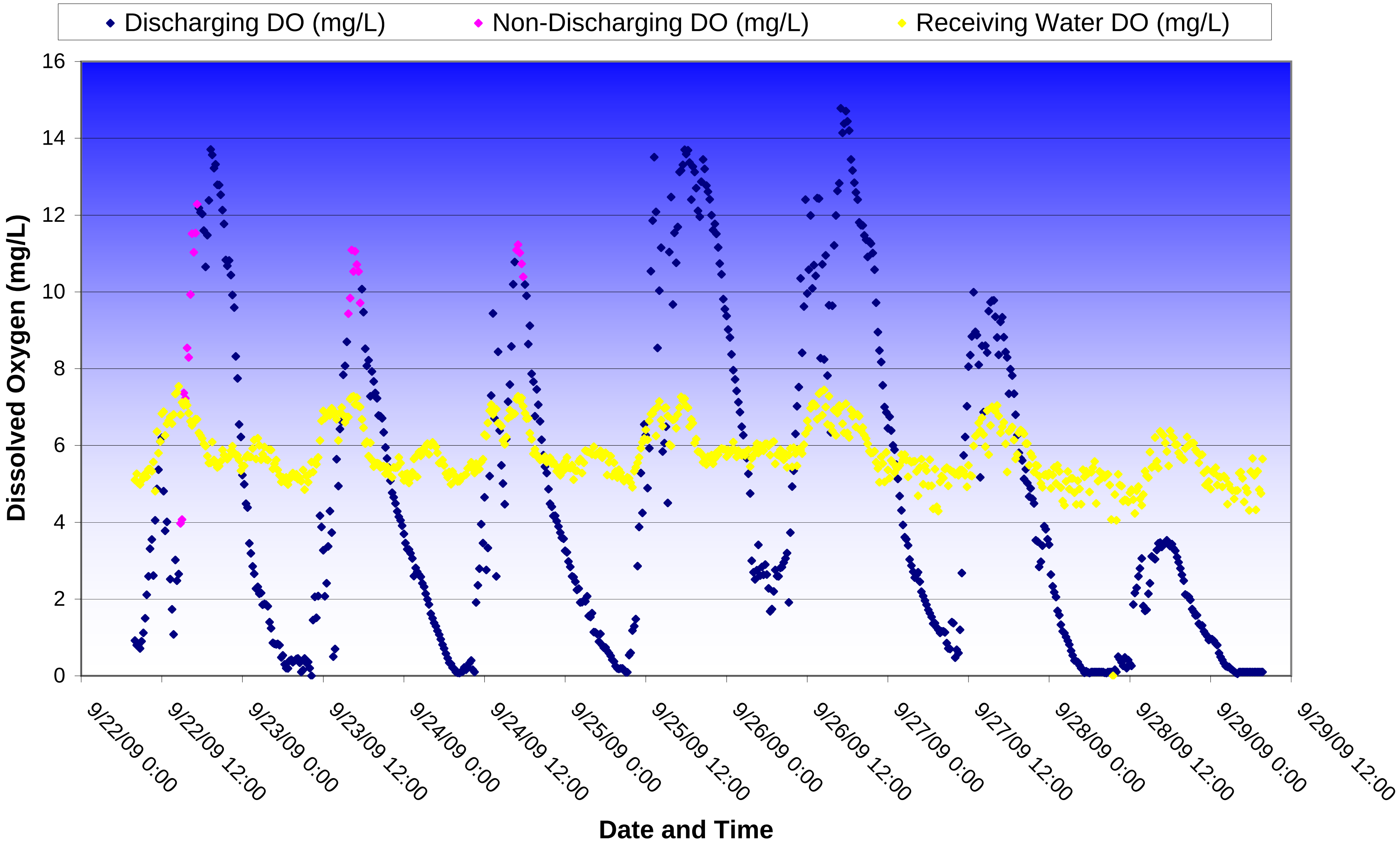




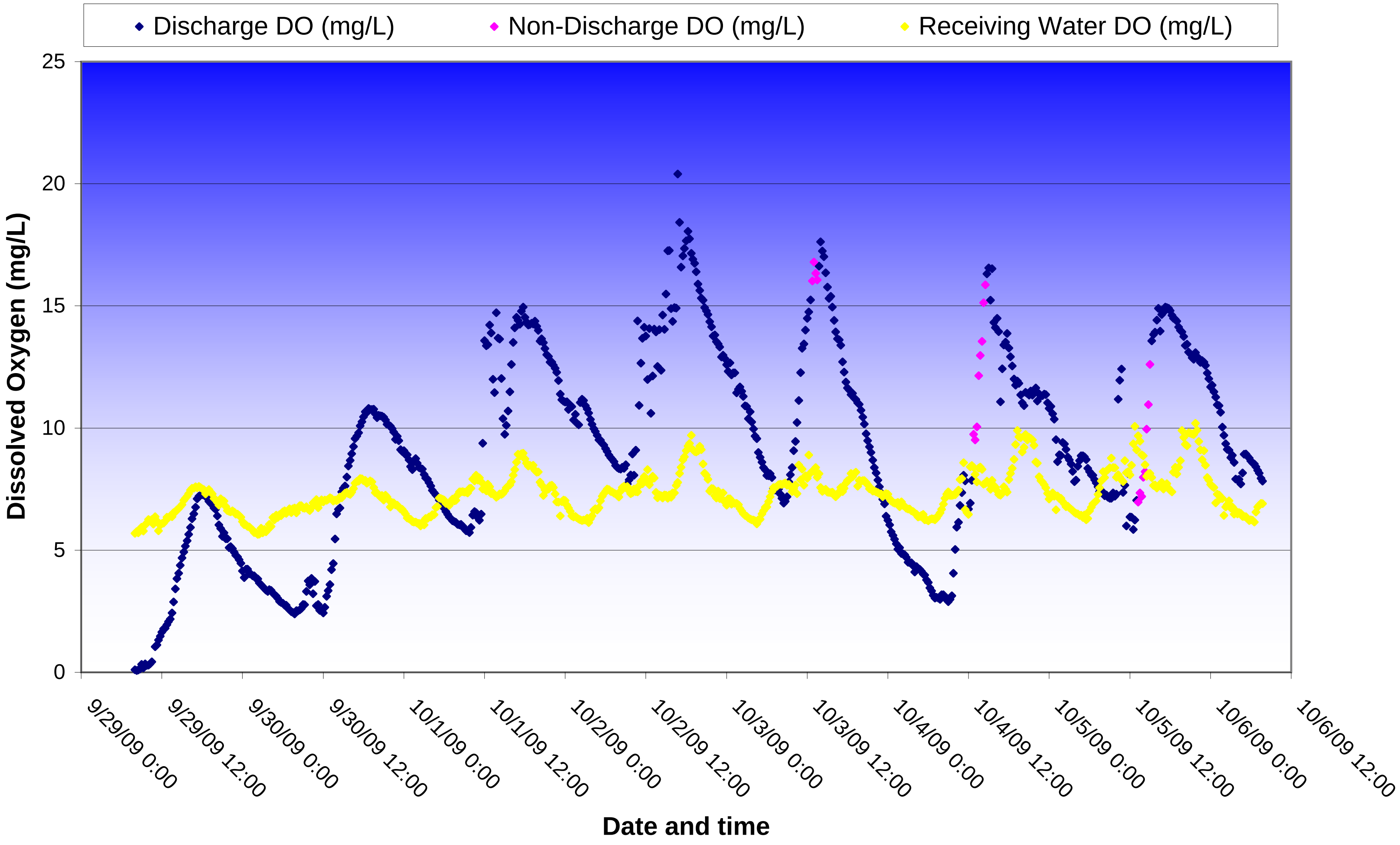
## Pond A18 and Artesian Slough Dissolved Oxygen Comparisons
## Week 21 - 9/15/09 to 9/22/09



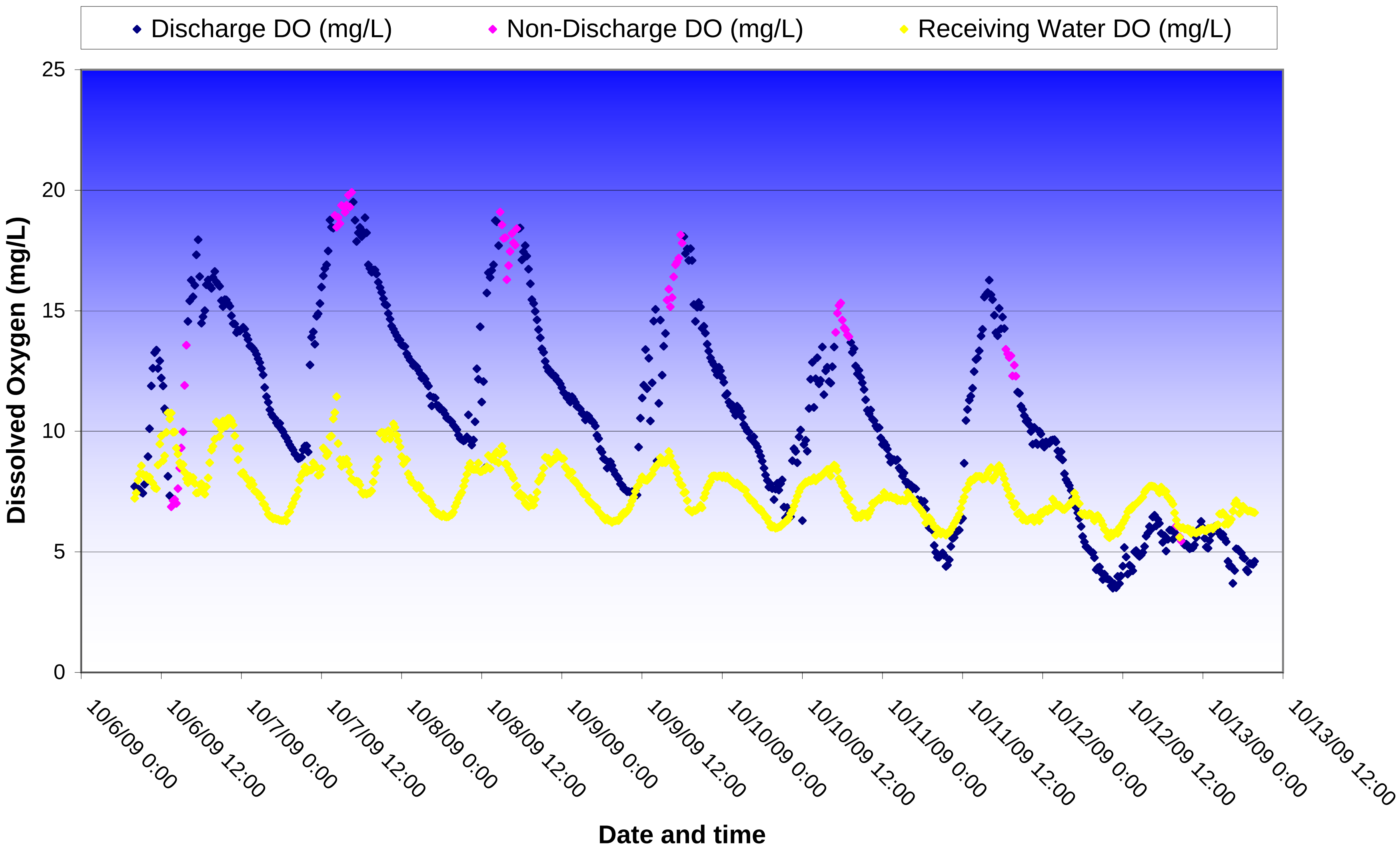
## Pond A18 and Artesian Slough Dissolved Oxygen Comparisons
## Week 22 - 9/22/09 to 9/29/09



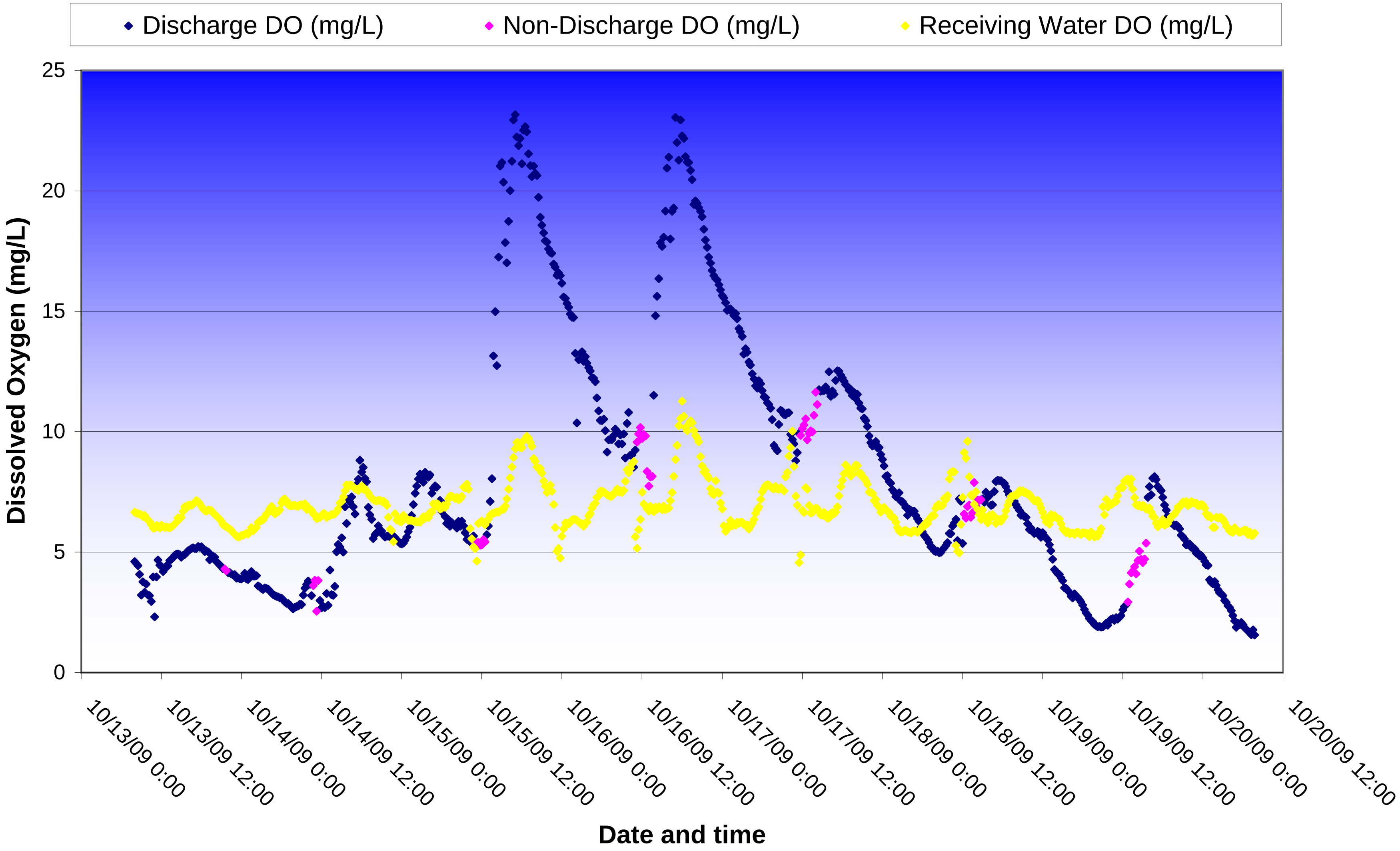
## Pond A18 and Artesian Slough Dissolved Oxygen Comparisons
## Week 23 - 9/29/09 to 10/6/09

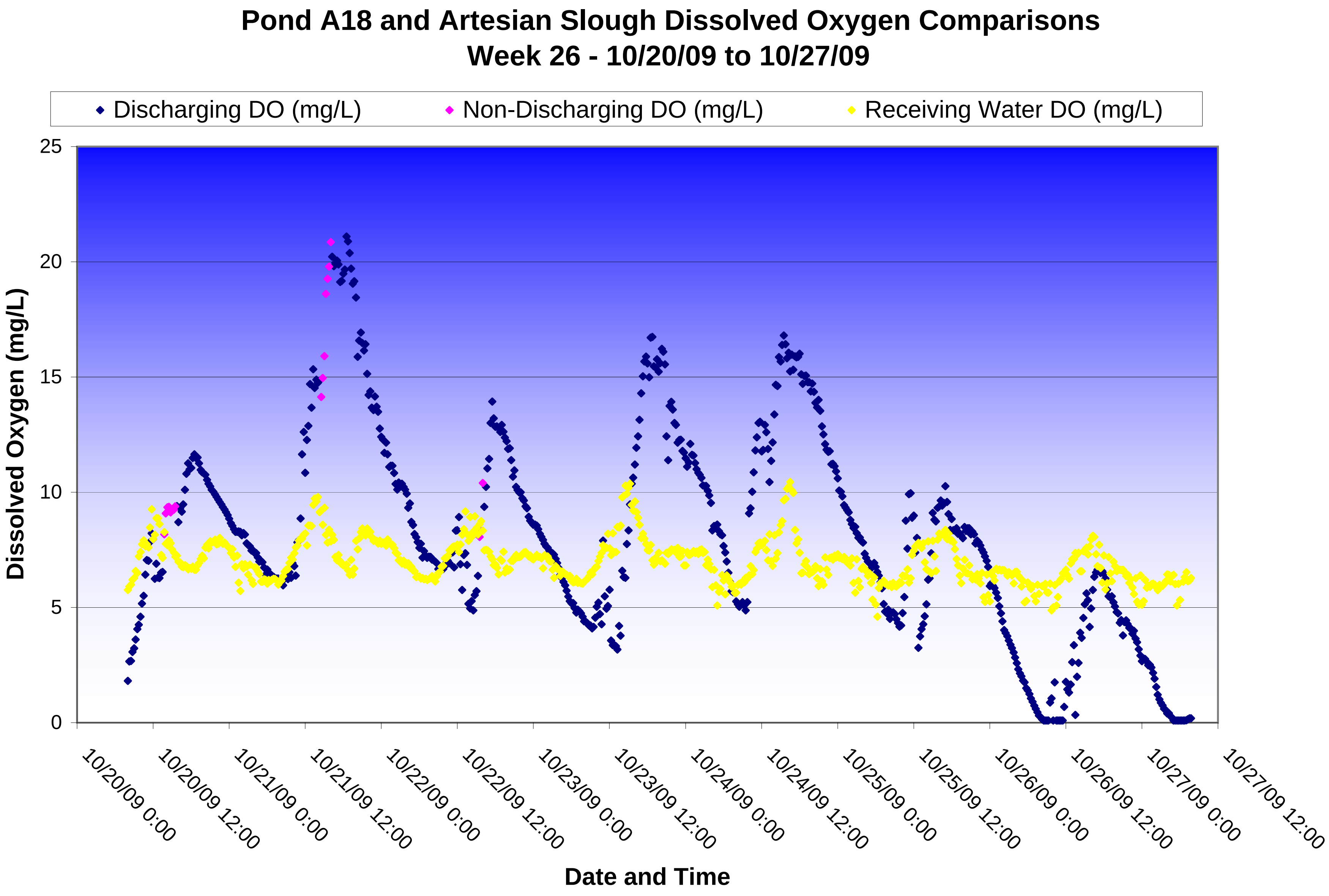


## Pond A18 and Artesian Slough Dissolved Oxygen Comparisons
## Week 24 - 10/6/09 to 10/13/09

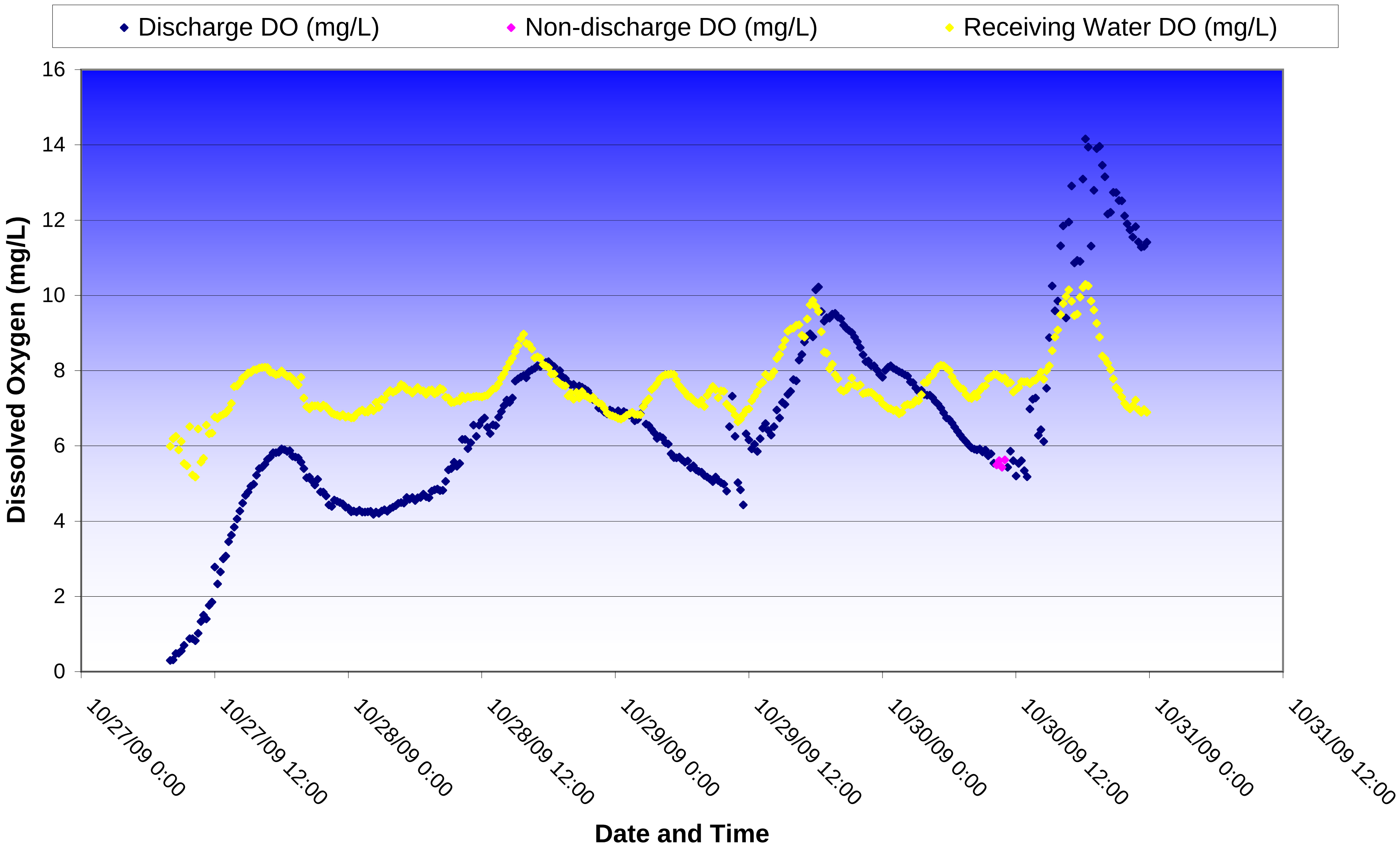


# Pond A18 and Artesian Slough Dissolved Oxygen Comparisons
## Week 25 - 10/13/09 to 10/20/09

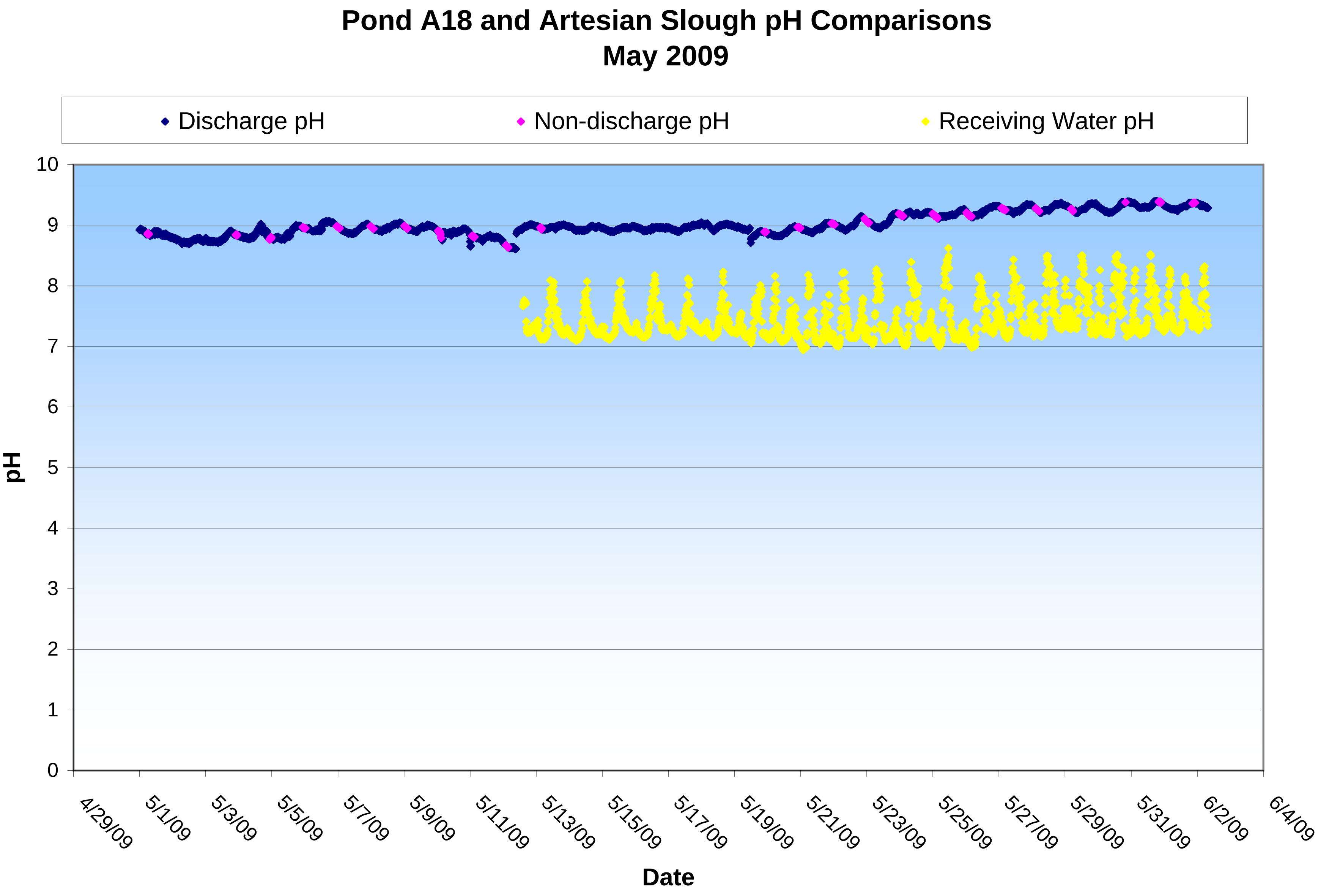


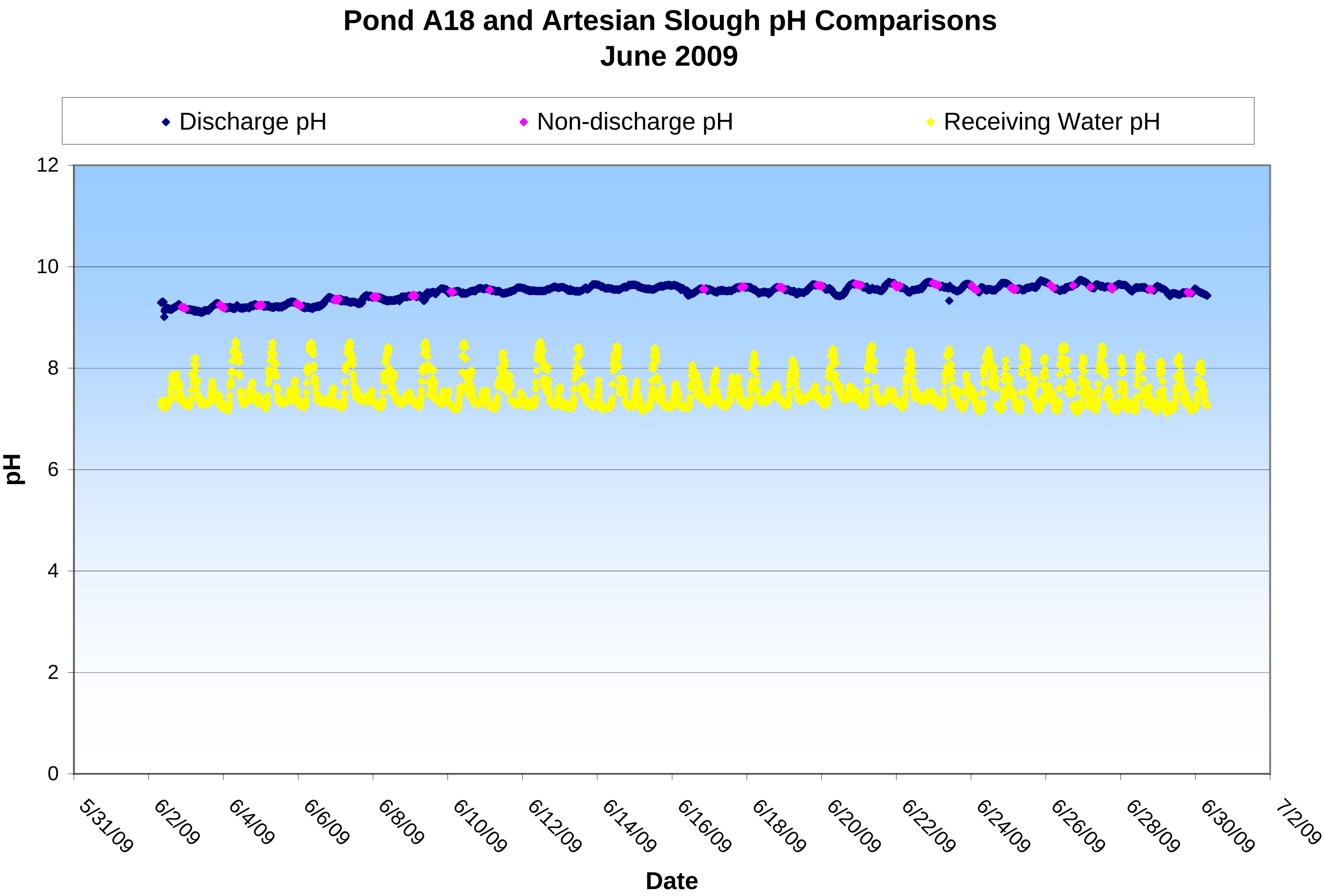

Pond A18 and Artesian Slough Dissolved Oxygen Comparisons
Week 26 - 10/20/09 to 10/27/09
◆ Discharging DO (mg/L)
◆ Non-Discharging DO (mg/L)
◆ Receiving Water DO (mg/L)
Dissolved Oxygen (mg/L)
25
20
15
10
5
0
10/20/09 0:00
10/20/09 12:00
10/21/09 0:00
10/21/09 12:00
10/22/09 0:00
10/22/09 12:00
10/23/09 0:00
10/23/09 12:00
10/24/09 0:00
10/24/09 12:00
10/25/09 0:00
10/25/09 12:00
10/26/09 0:00
10/26/09 12:00
10/27/09 0:00
10/27/09 12:00
Date and Time

# Pond A18 and Artesian Slough Dissolved Oxygen Comparisons
## Week 27 - 10/27/09 to 10/31/09: final week; partial



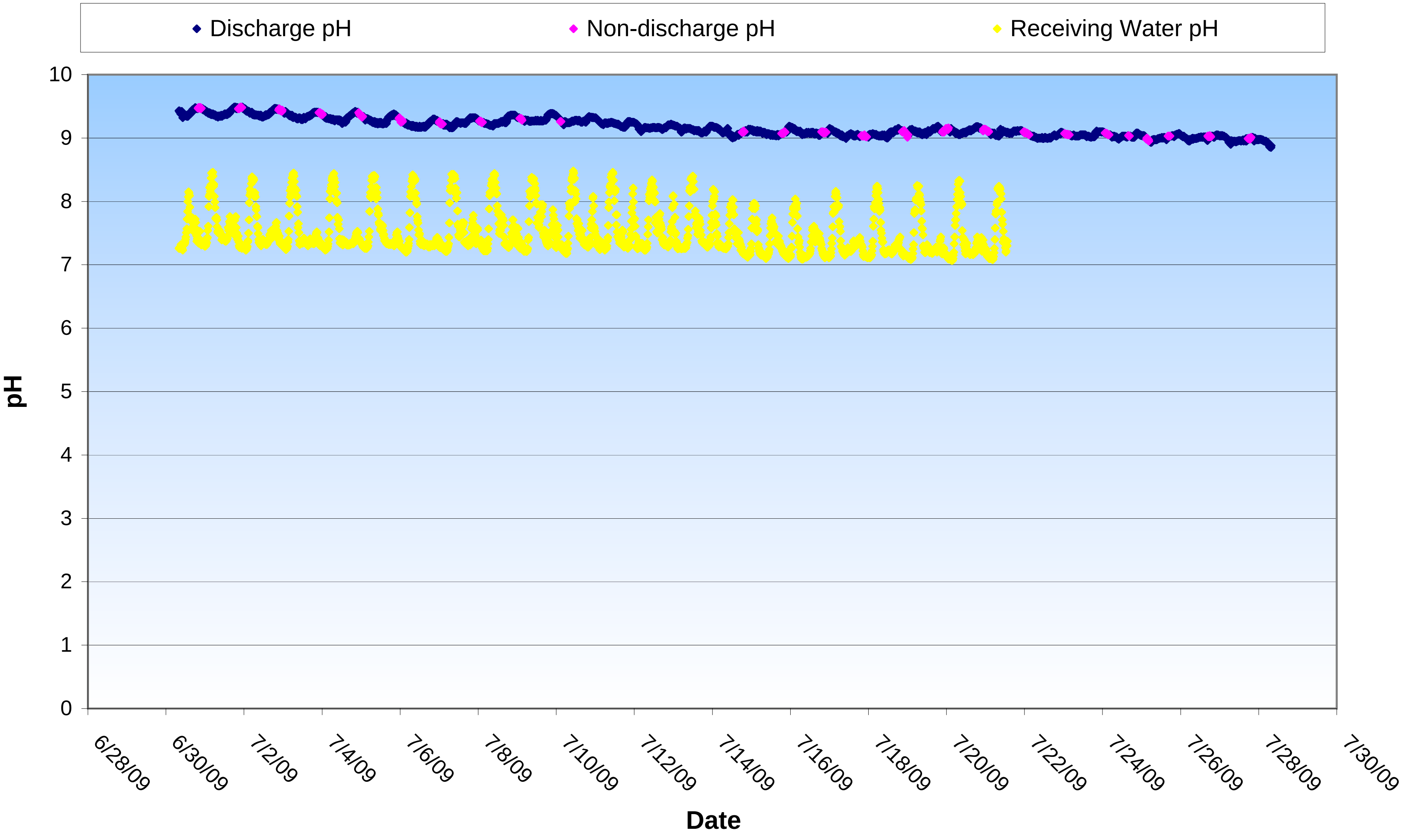
# Appendix II. Comparative Profiles of pH, Salinity and Temperature in A18 and Artesian Slough for Each Month of 2009 Monitoring Season.


Pond A18 and Artesian Slough pH Comparisons
May 2009
◆ Discharge pH
◆ Non-discharge pH
◆ Receiving Water pH
pH
10
9
8
7
6
5
4
3
2
1
0
4/29/09
5/1/09
5/3/09
5/5/09
5/7/09
5/9/09
5/11/09
5/13/09
5/15/09
5/17/09
5/19/09
5/21/09
5/23/09
5/25/09
5/27/09
5/29/09
5/31/09
6/2/09
6/4/09
Date

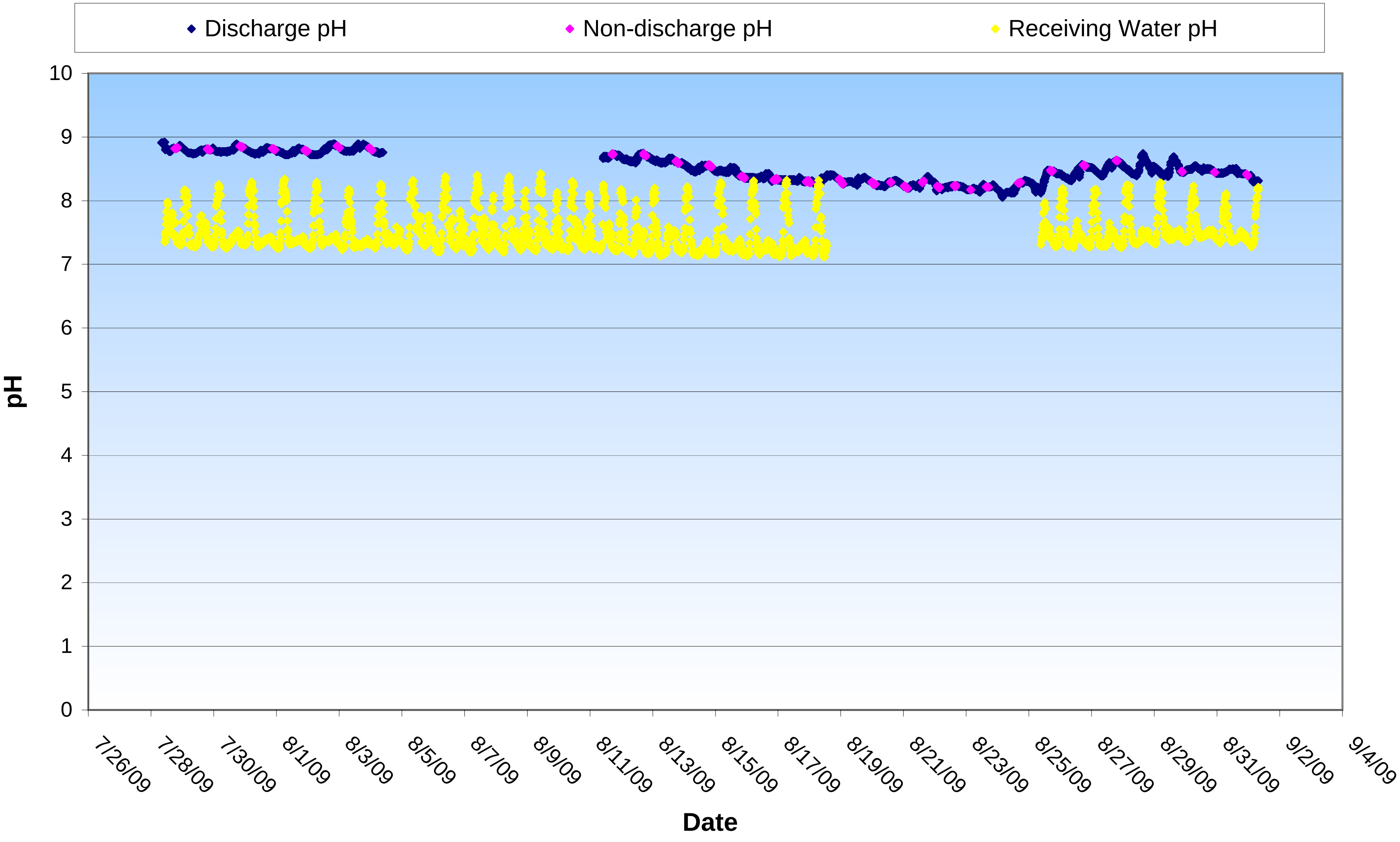


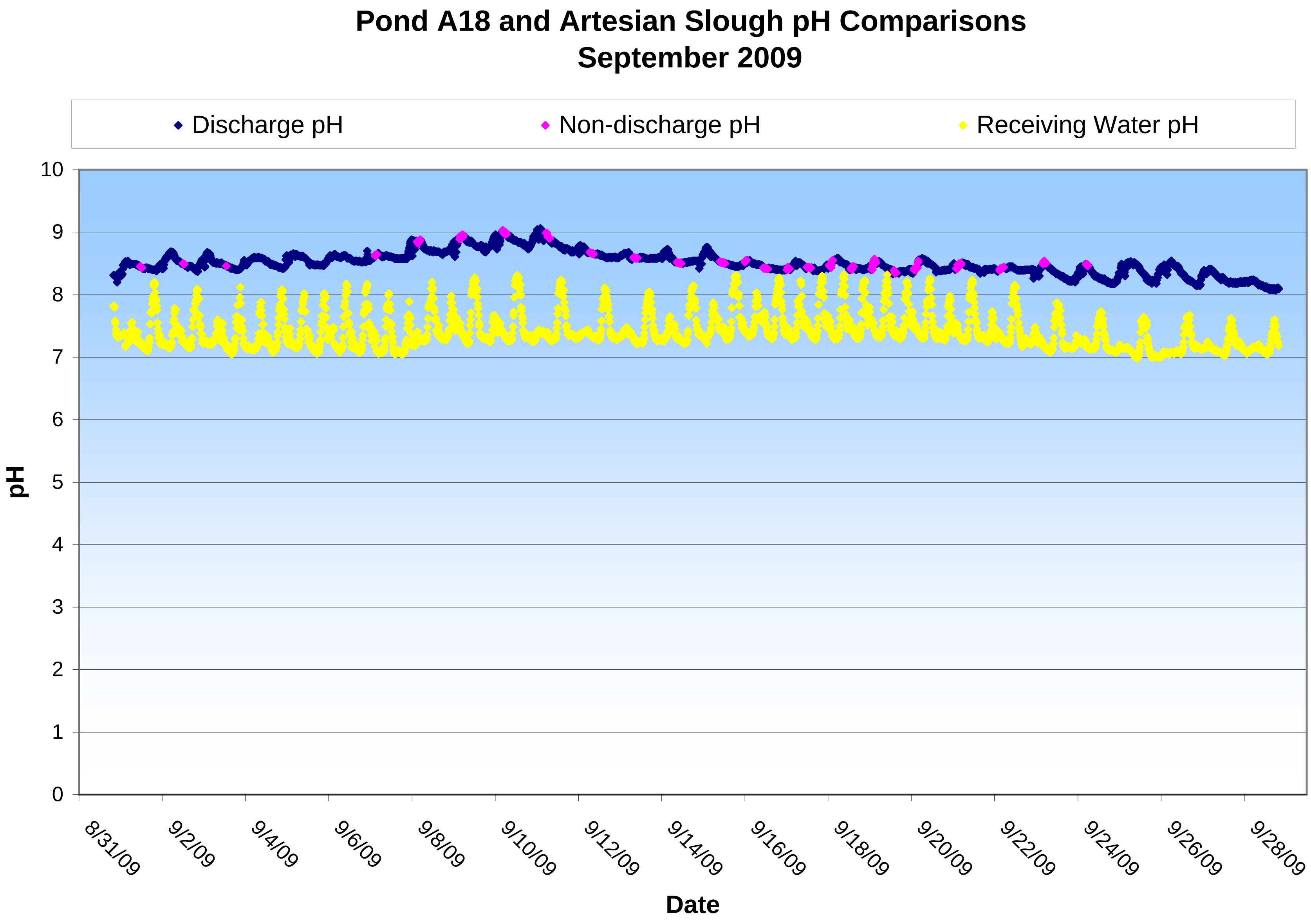
Pond A18 and Artesian Slough pH Comparisons
June 2009

**Pond A18 and Artesian Slough pH Comparisons**
**July 2009**

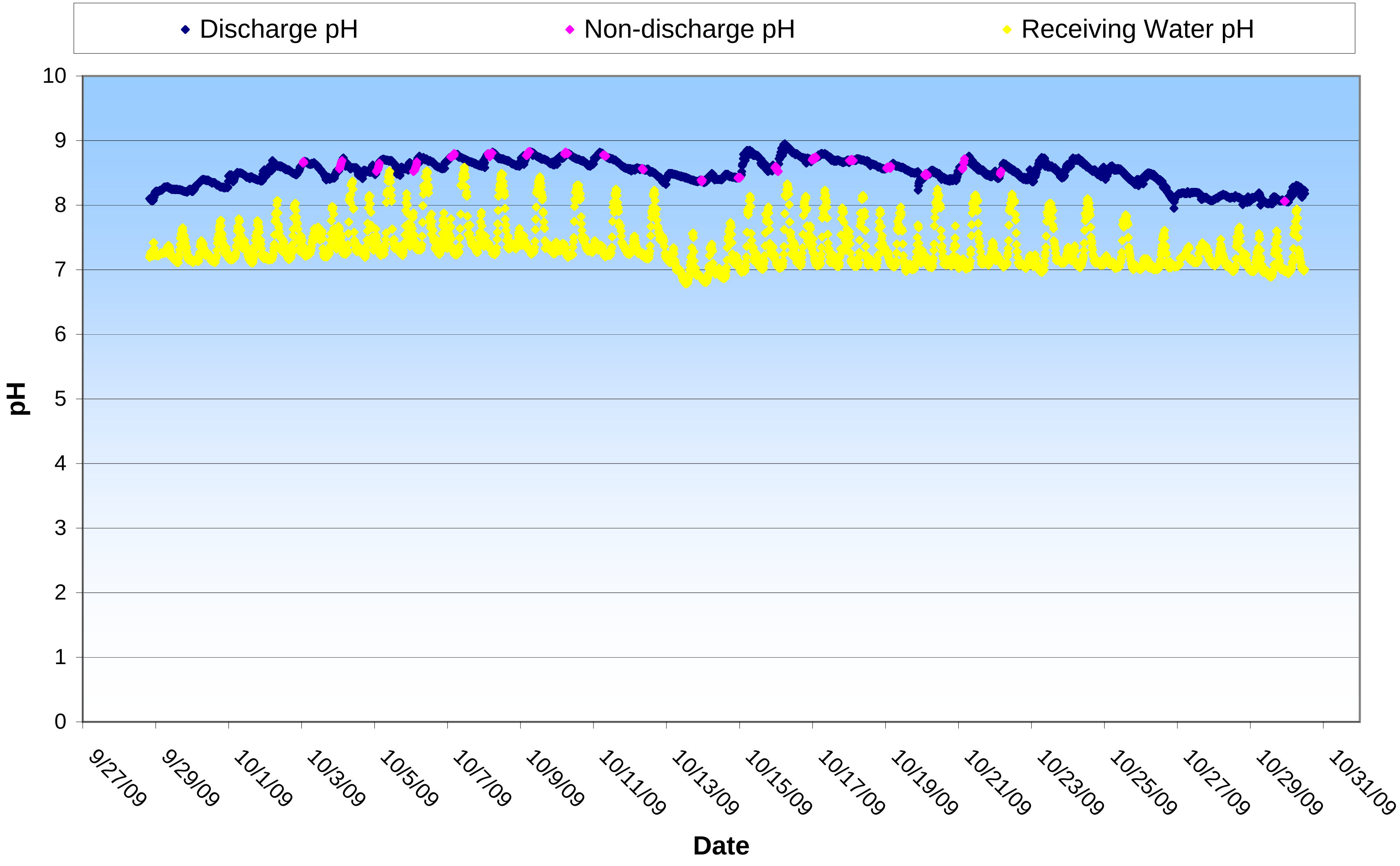


## Pond A18 and Artesian Slough pH Comparisons
## August 2009

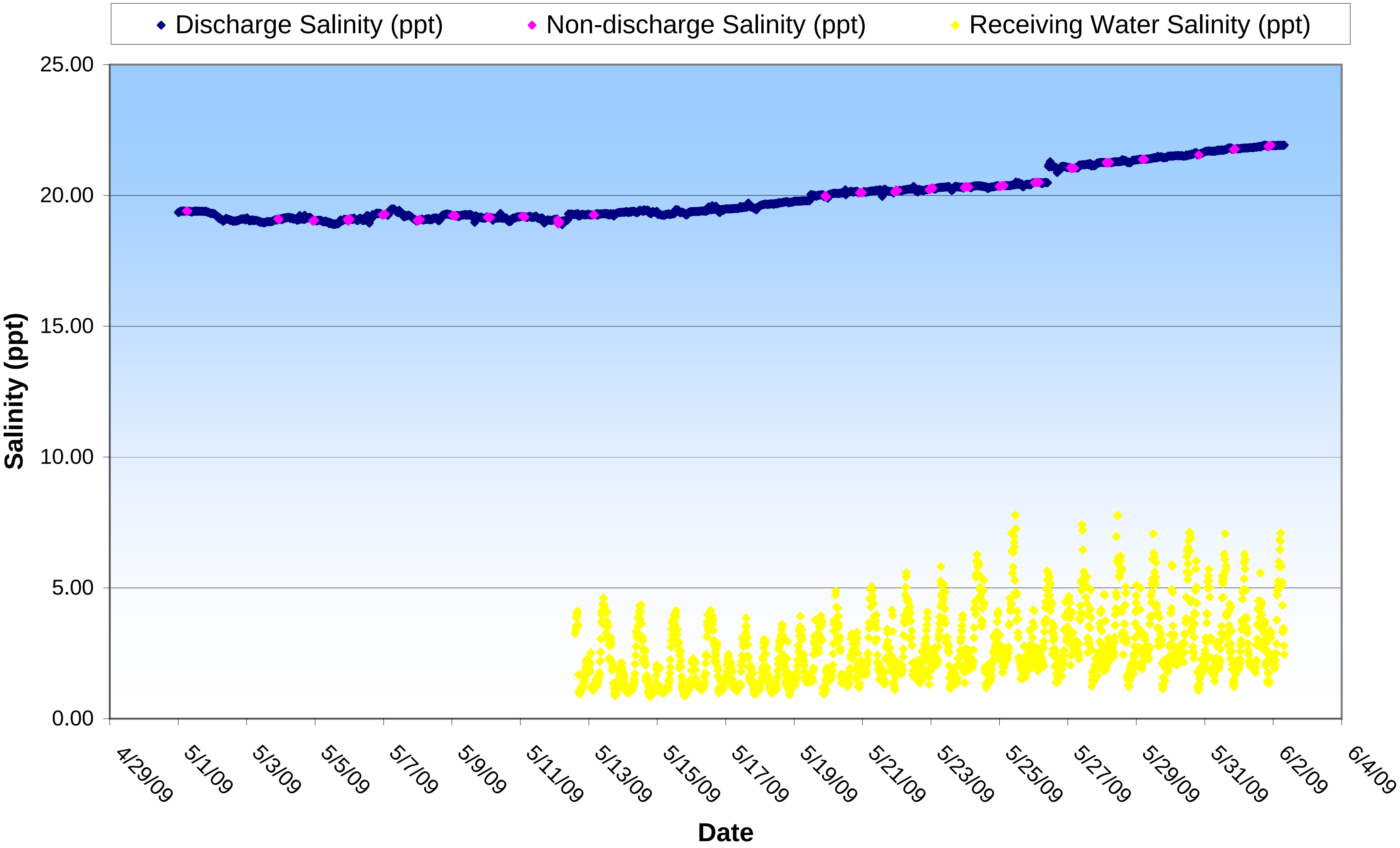



Pond A18 and Artesian Slough pH Comparisons
September 2009

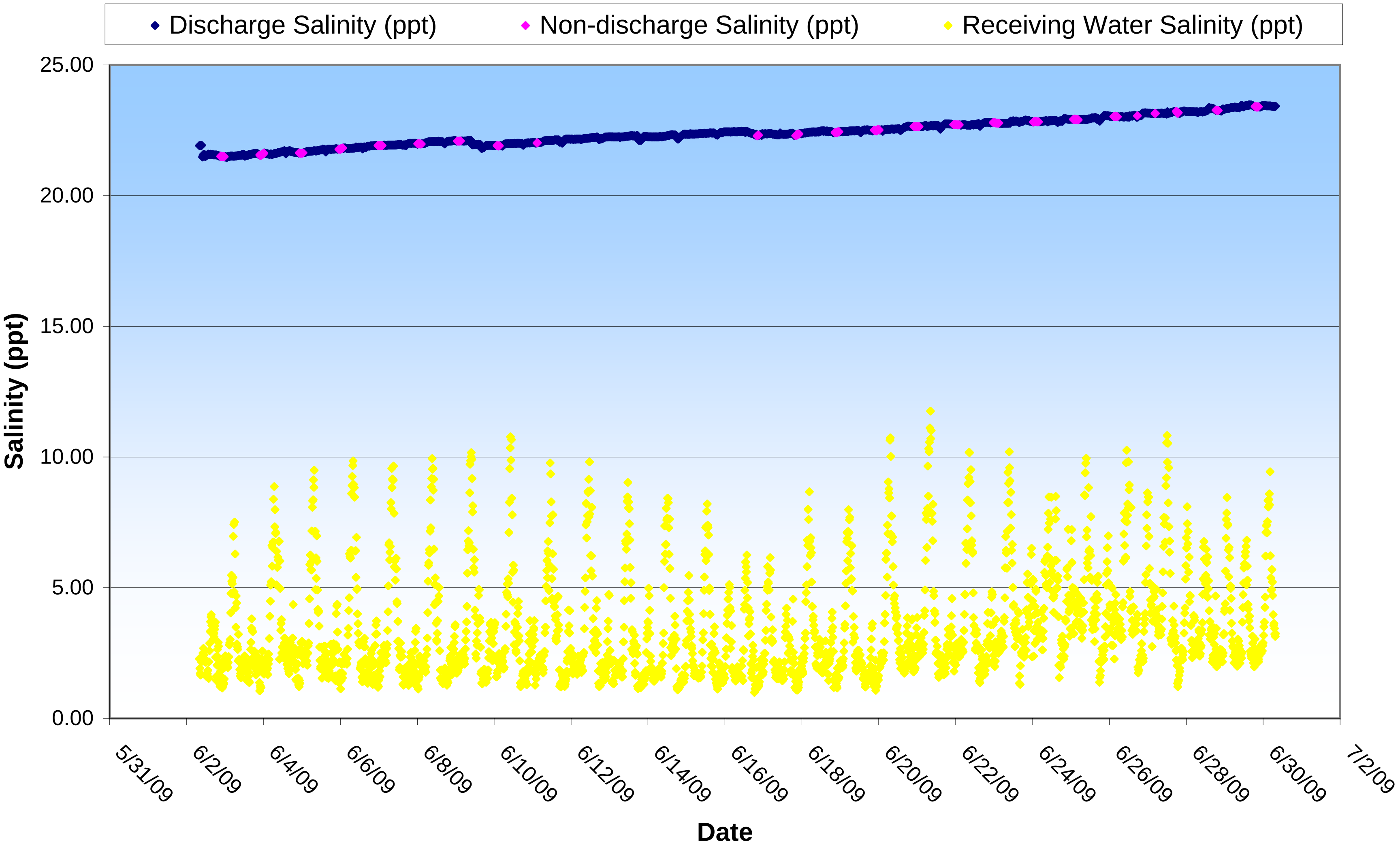
# Pond A18 and Artesian Slough pH Comparisons
## October 2009

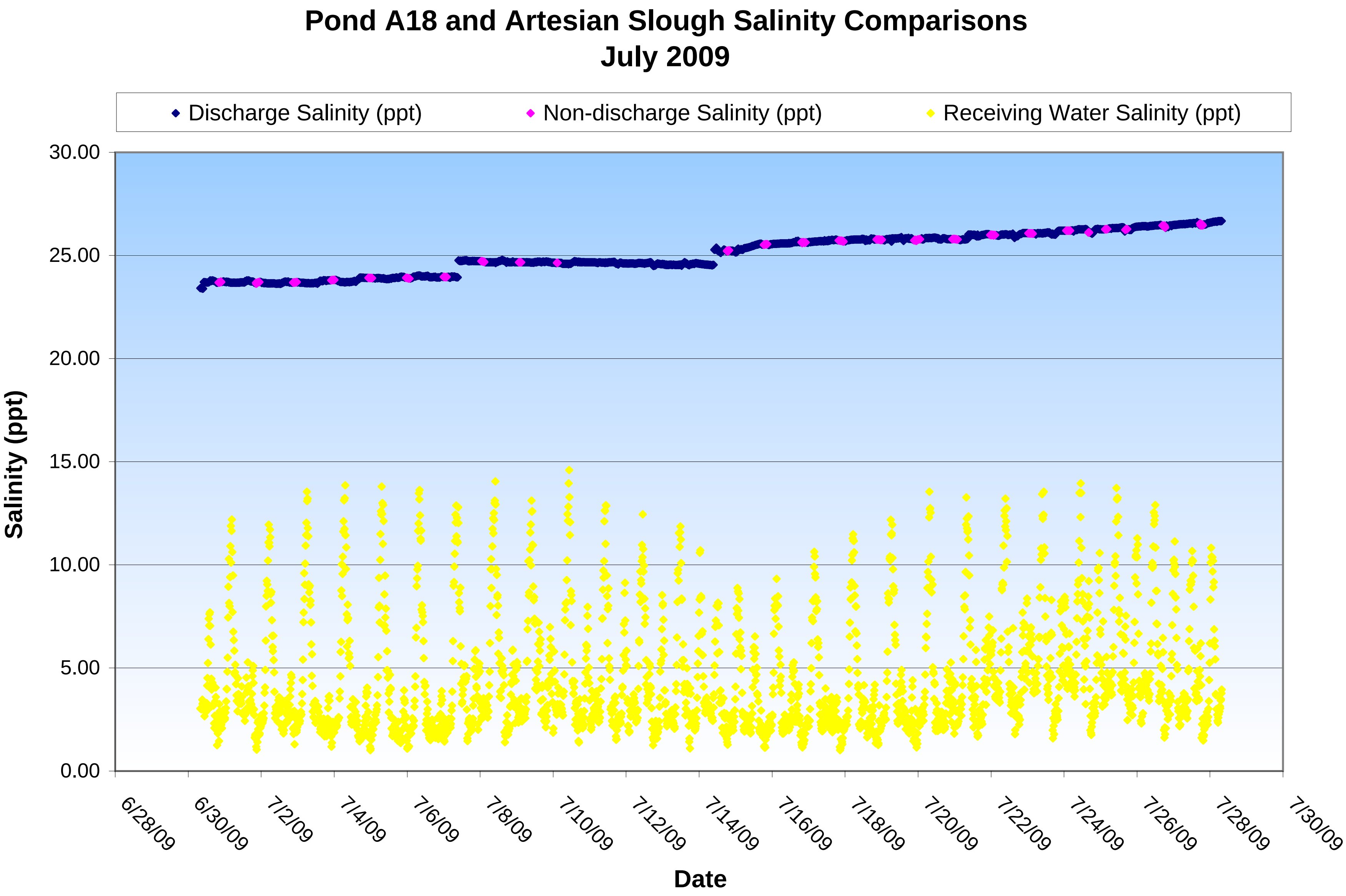


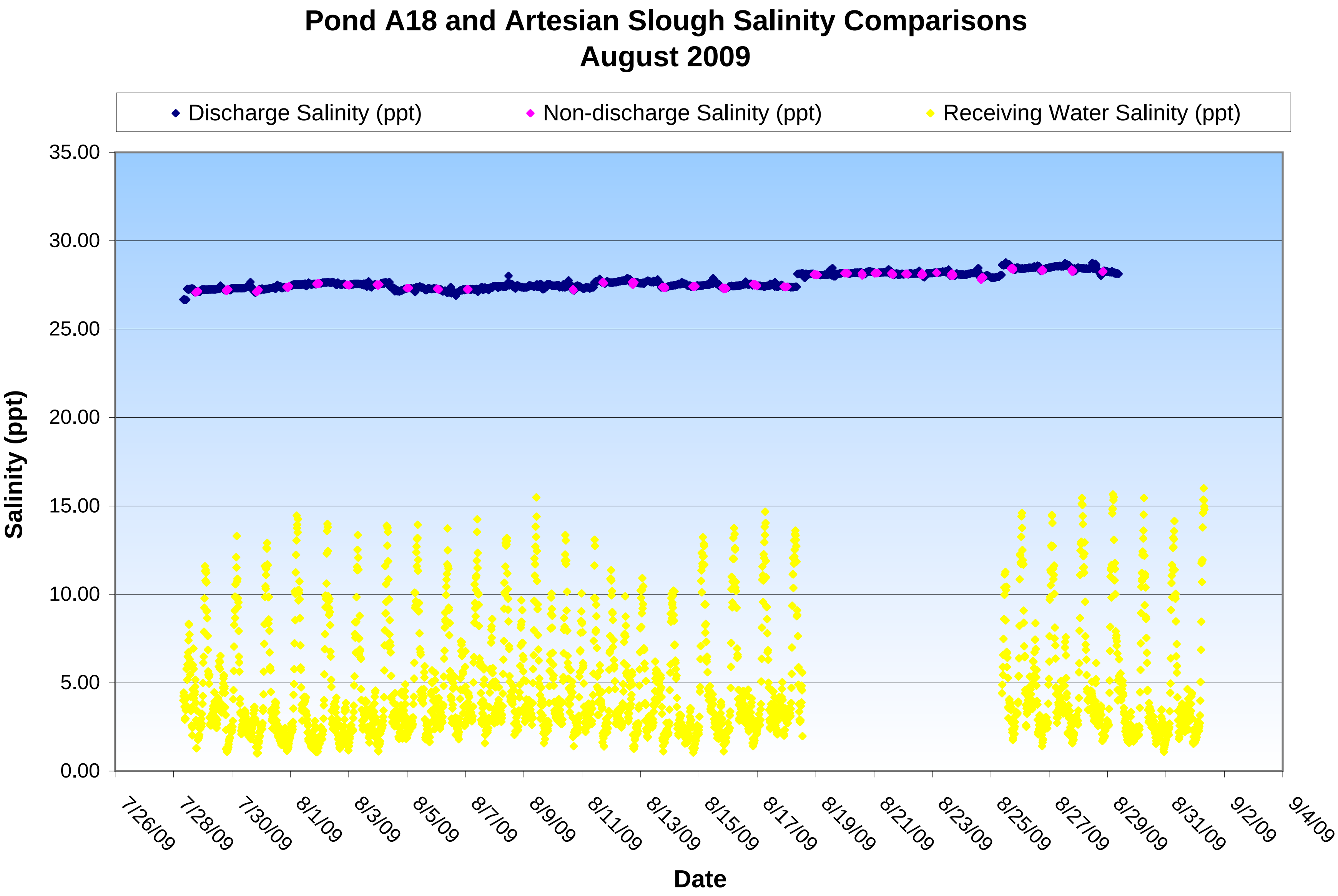
# Pond A18 and Artesian Slough Salinity Comparisons
## May 2009

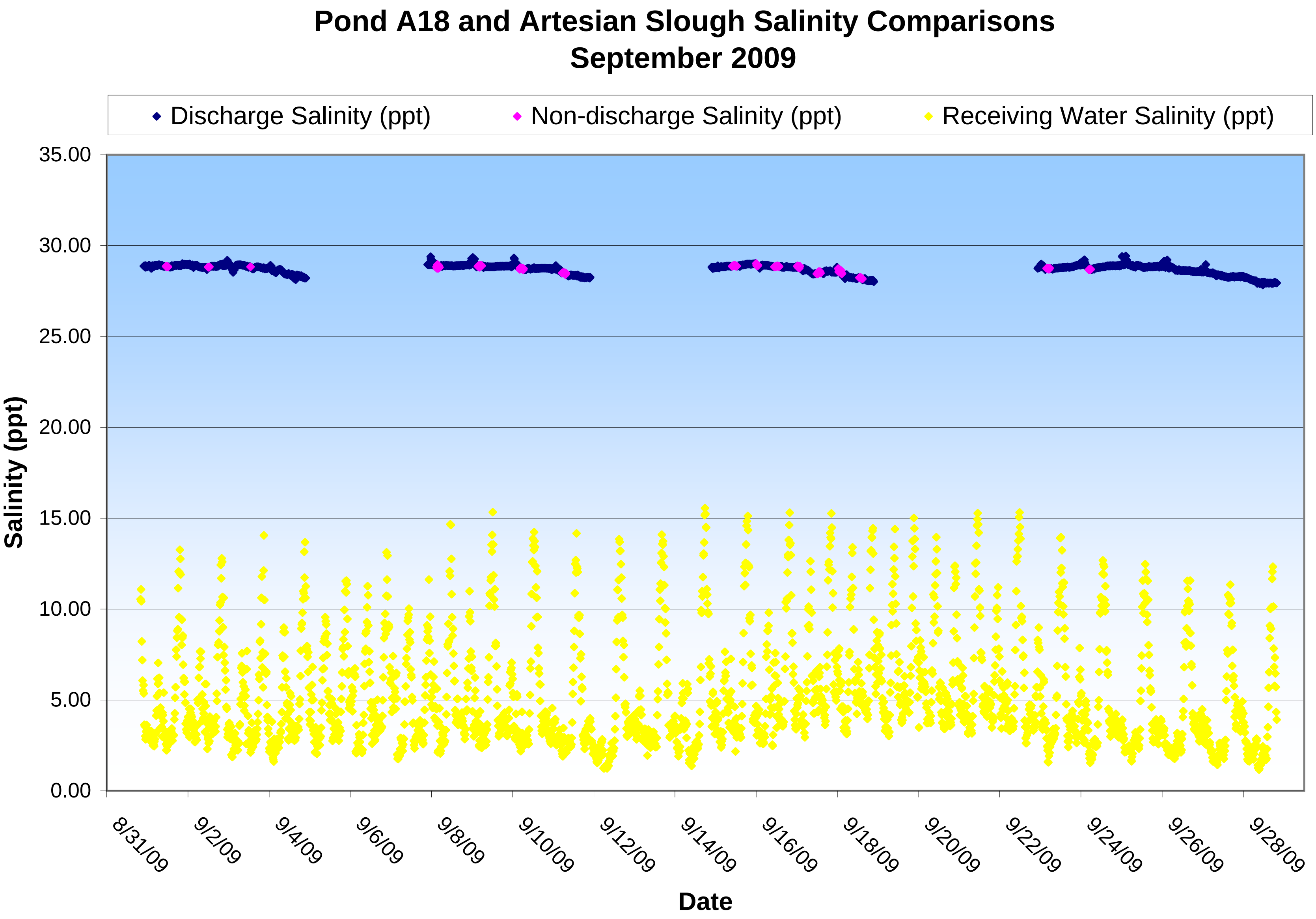


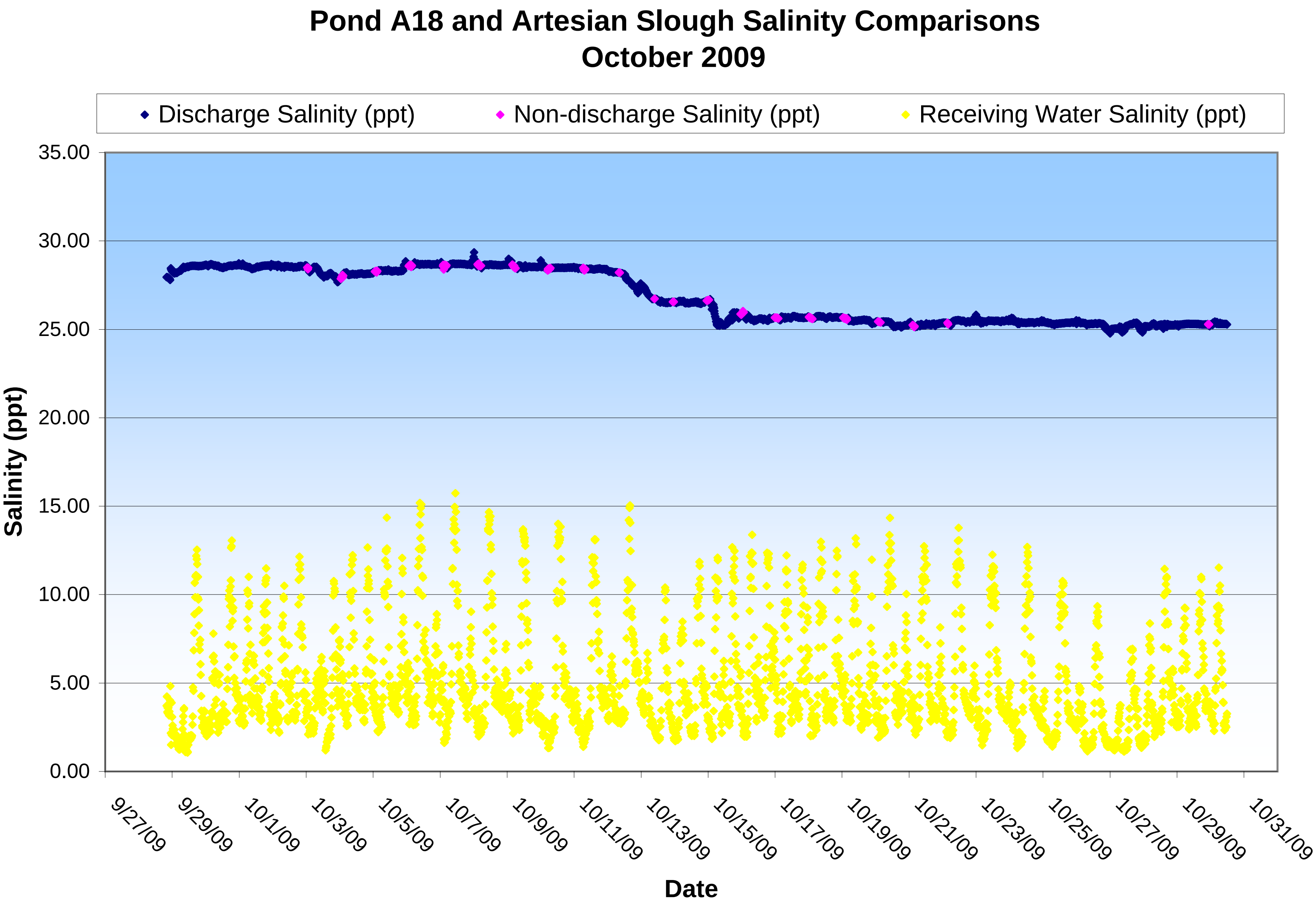
# Pond A18 and Artesian Slough Salinity Comparisons
# June 2009



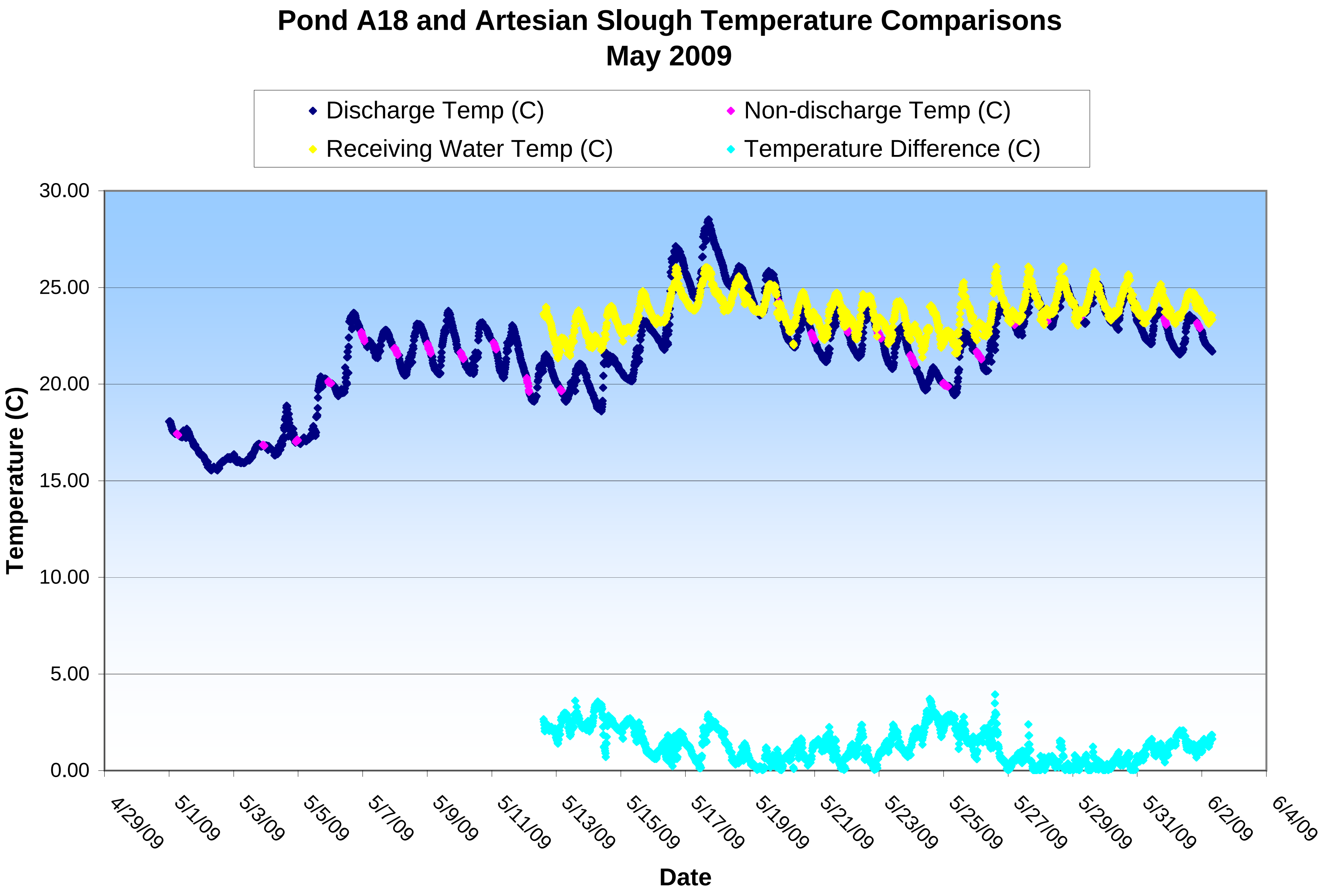

Pond A18 and Artesian Slough Salinity Comparisons
July 2009
◆ Discharge Salinity (ppt)
◆ Non-discharge Salinity (ppt)
◆ Receiving Water Salinity (ppt)
Salinity (ppt)
30.00
25.00
20.00
15.00
10.00
5.00
0.00
6/28/09
6/30/09
7/2/09
7/4/09
7/6/09
7/8/09
7/10/09
7/12/09
7/14/09
7/16/09
7/18/09
7/20/09
7/22/09
7/24/09
7/26/09
7/28/09
7/30/09
Date


Pond A18 and Artesian Slough Salinity Comparisons
August 2009
◆ Discharge Salinity (ppt)
◆ Non-discharge Salinity (ppt)
◆ Receiving Water Salinity (ppt)
Salinity (ppt)
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
7/26/09
7/28/09
7/30/09
8/1/09
8/3/09
8/5/09
8/7/09
8/9/09
8/11/09
8/13/09
8/15/09
8/17/09
8/19/09
8/21/09
8/23/09
8/25/09
8/27/09
8/29/09
8/31/09
9/2/09
9/4/09
Date

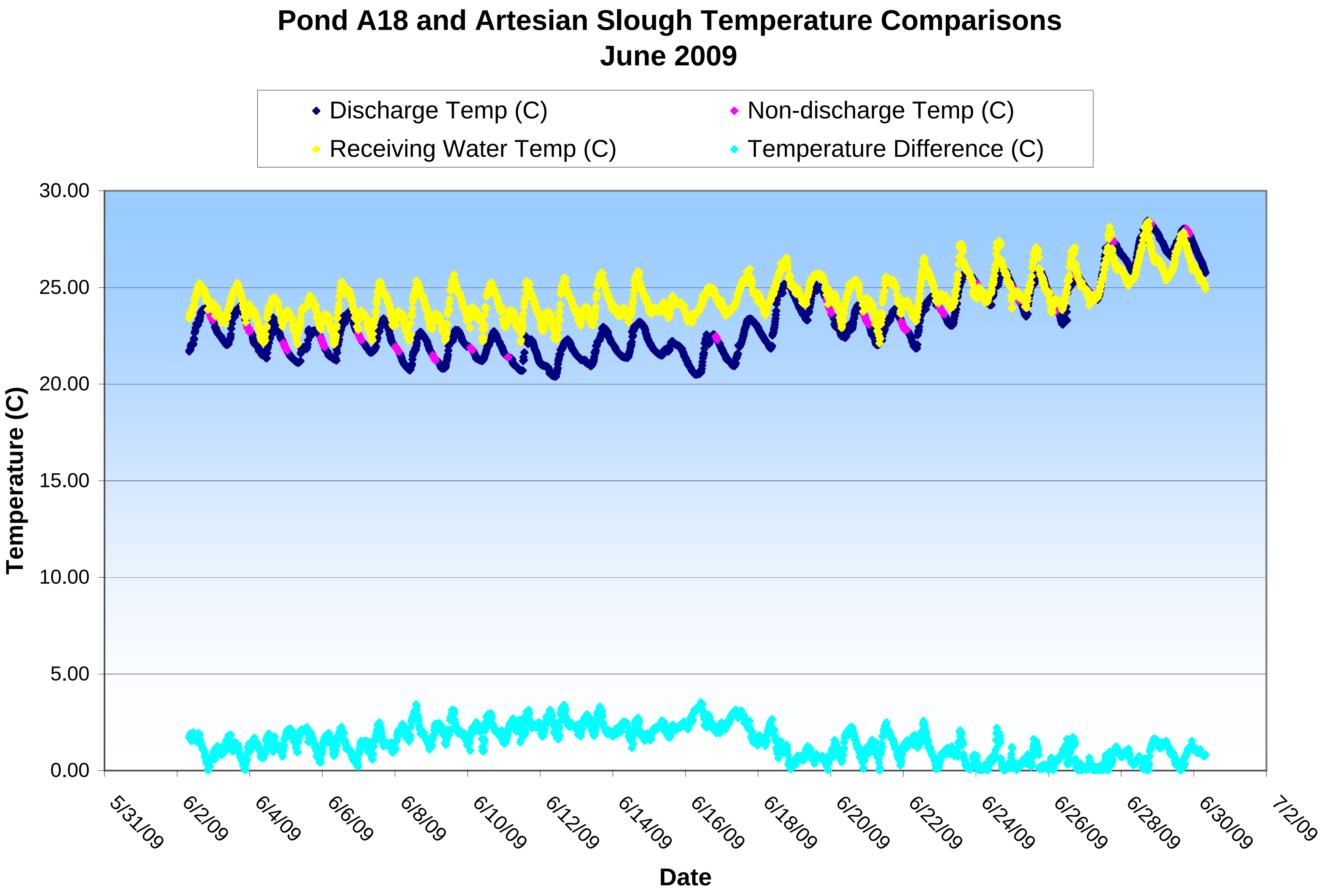

Pond A18 and Artesian Slough Salinity Comparisons
September 2009
Discharge Salinity (ppt)
Non-discharge Salinity (ppt)
Receiving Water Salinity (ppt)
Salinity (ppt)
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
8/31/09
9/2/09
9/4/09
9/6/09
9/8/09
9/10/09
9/12/09
9/14/09
9/16/09
9/18/09
9/20/09
9/22/09
9/24/09
9/26/09
9/28/09
Date

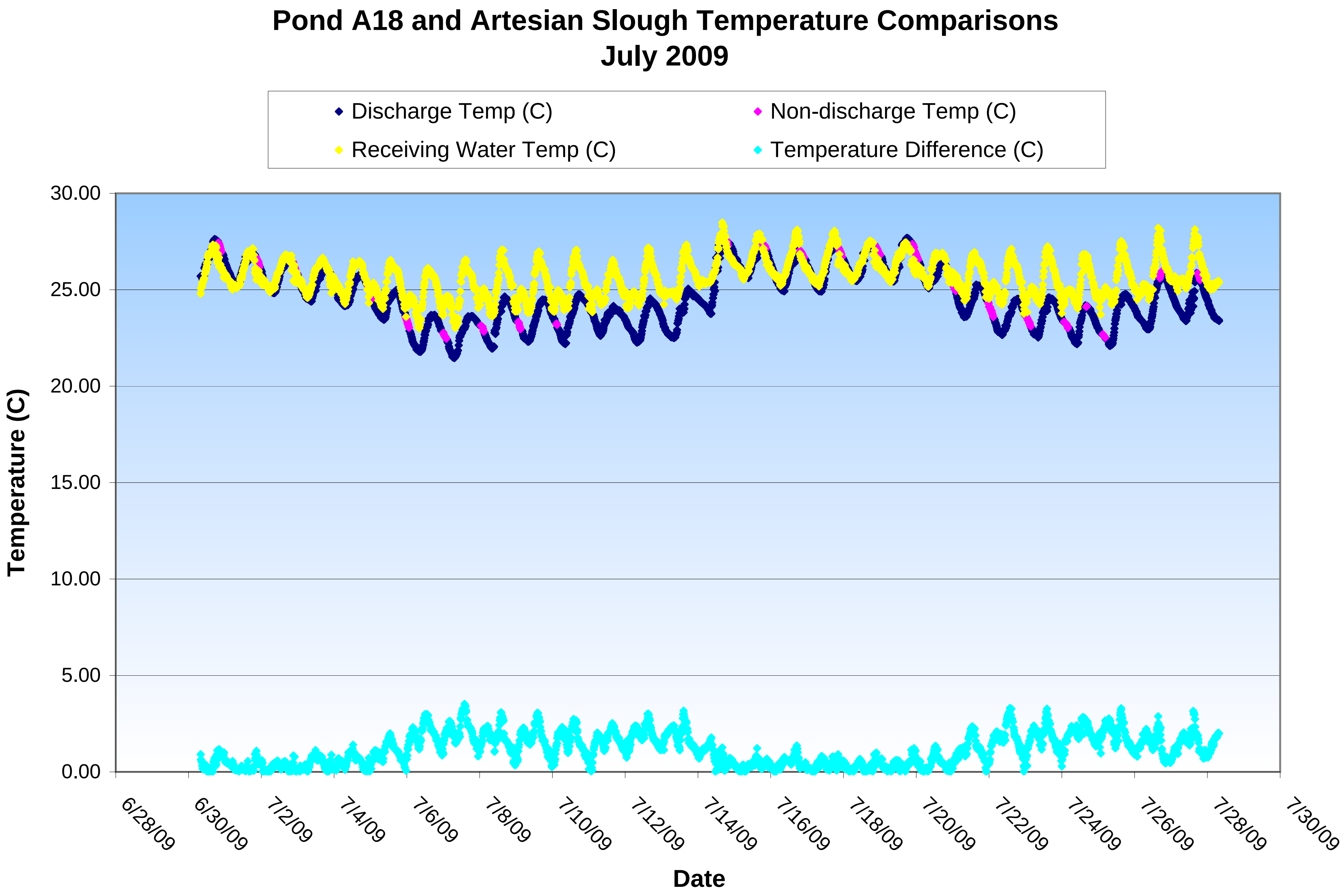


Pond A18 and Artesian Slough Salinity Comparisons
October 2009



Pond A18 and Artesian Slough Temperature Comparisons
May 2009
◆ Discharge Temp (C)
◆ Non-discharge Temp (C)
◆ Receiving Water Temp (C)
◆ Temperature Difference (C)
Temperature (C)
30.00
25.00
20.00
15.00
10.00
5.00
0.00
4/29/09
5/1/09
5/3/09
5/5/09
5/7/09
5/9/09
5/11/09
5/13/09
5/15/09
5/17/09
5/19/09
5/21/09
5/23/09
5/25/09
5/27/09
5/29/09
5/31/09
6/2/09
6/4/09
Date


Pond A18 and Artesian Slough Temperature Comparisons
June 2009
◆ Discharge Temp (C)
◆ Non-discharge Temp (C)
◆ Receiving Water Temp (C)
◆ Temperature Difference (C)
Temperature (C)
30.00
25.00
20.00
15.00
10.00
5.00
0.00
5/31/09
6/2/09
6/4/09
6/6/09
6/8/09
6/10/09
6/12/09
6/14/09
6/16/09
6/18/09
6/20/09
6/22/09
6/24/09
6/26/09
6/28/09
6/30/09
7/2/09
Date


Pond A18 and Artesian Slough Temperature Comparisons
July 2009
Discharge Temp (C)
Non-discharge Temp (C)
Receiving Water Temp (C)
Temperature Difference (C)
Temperature (C)
30.00
25.00
20.00
15.00
10.00
5.00
0.00
6/28/09
6/30/09
7/2/09
7/4/09
7/6/09
7/8/09
7/10/09
7/12/09
7/14/09
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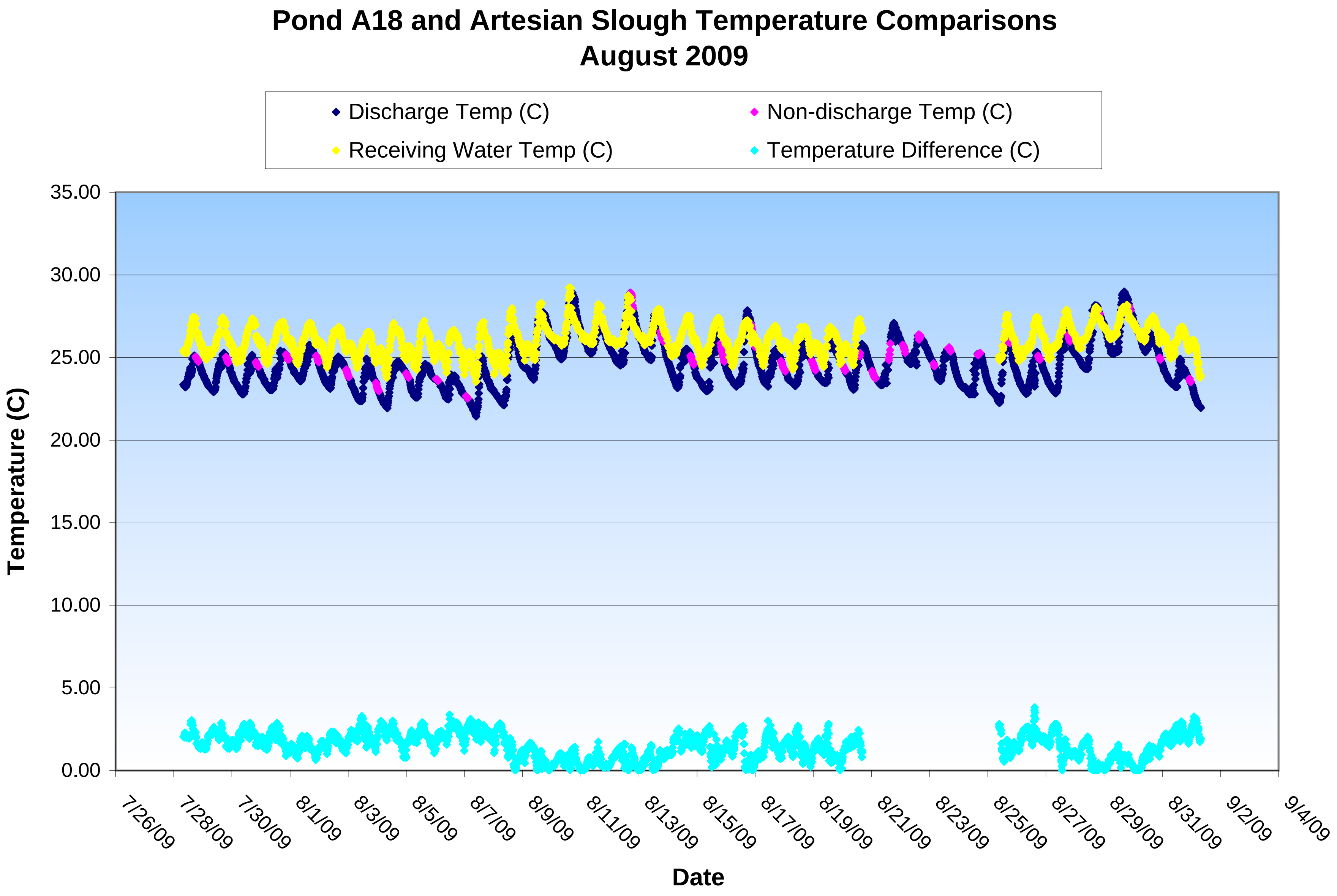
7/28/09
7/30/09
Date


Pond A18 and Artesian Slough Temperature Comparisons
August 2009
◆ Discharge Temp (C)
◆ Non-discharge Temp (C)
◆ Receiving Water Temp (C)
◆ Temperature Difference (C)
Temperature (C)
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
7/26/09
7/28/09
7/30/09
8/1/09
8/3/09
8/5/09
8/7/09
8/9/09
8/11/09
8/13/09
8/15/09
8/17/09
8/19/09
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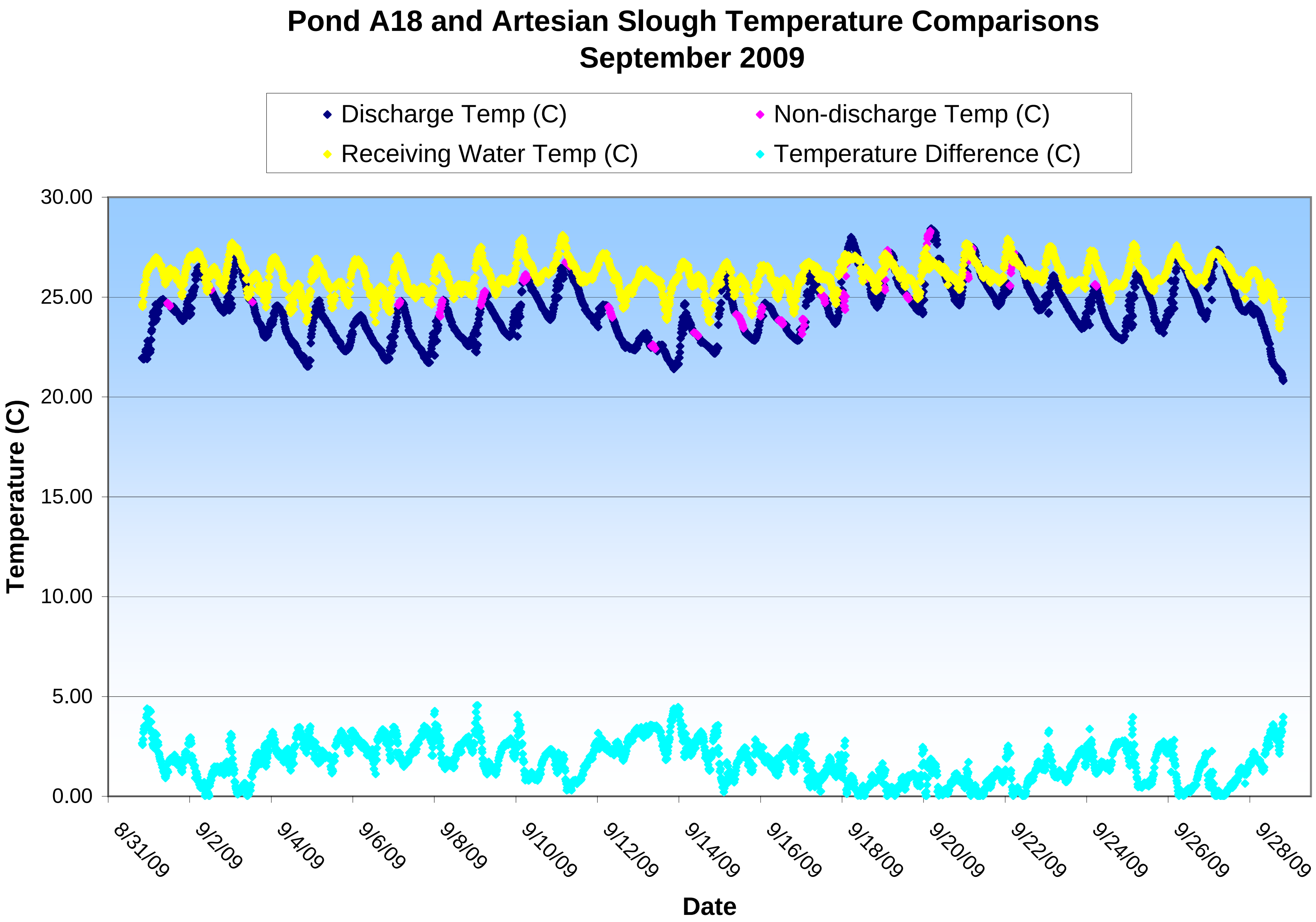
8/27/09
8/29/09
8/31/09
9/2/09
9/4/09
Date


Pond A18 and Artesian Slough Temperature Comparisons
September 2009
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◆ Non-discharge Temp (C)
◆ Receiving Water Temp (C)
◆ Temperature Difference (C)
Temperature (C)
30.00
25.00
20.00
15.00
10.00
5.00
0.00
8/31/09
9/2/09
9/4/09
9/6/09
9/8/09
9/10/09
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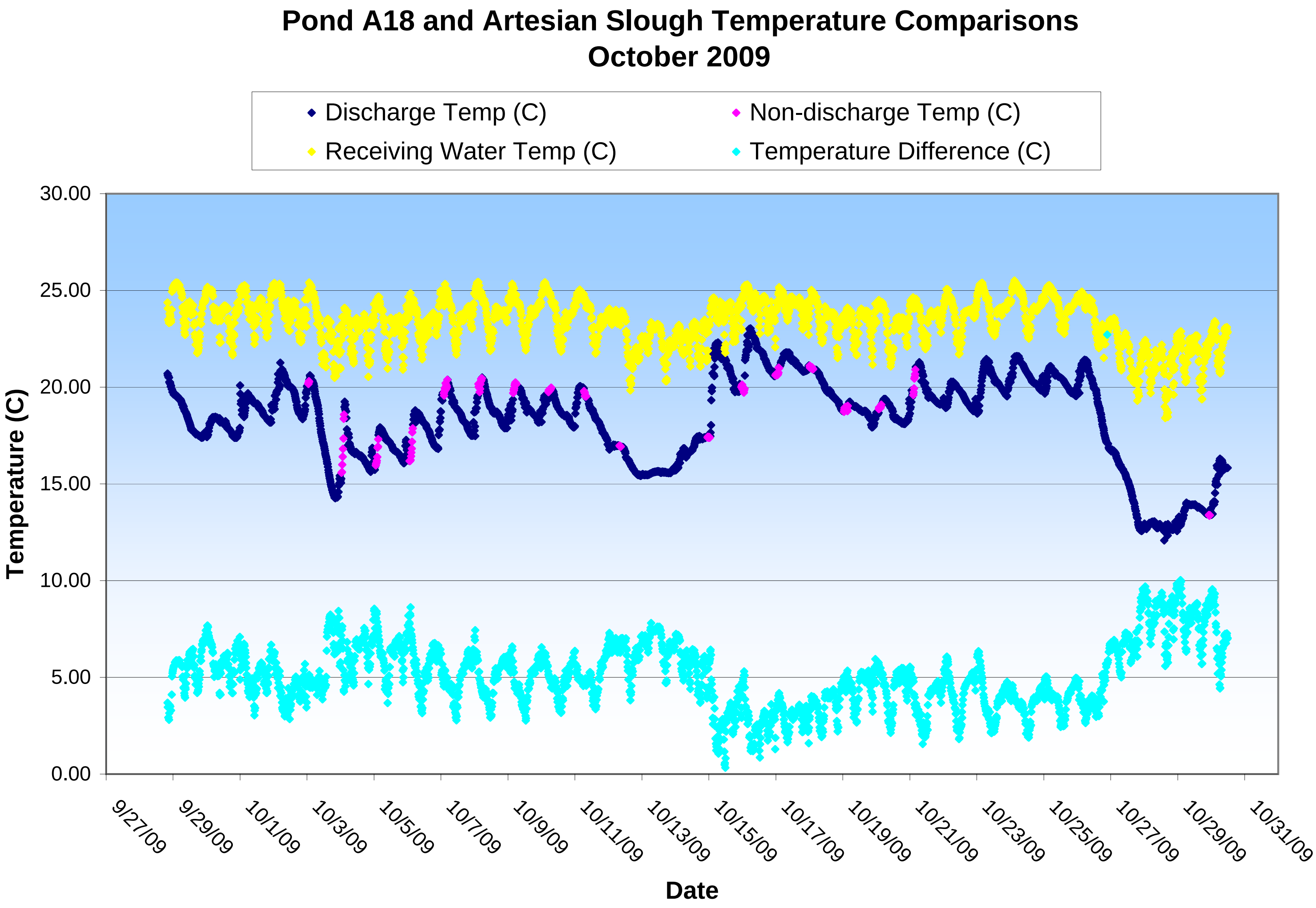
9/28/09
Date


Pond A18 and Artesian Slough Temperature Comparisons
October 2009
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◆ Non-discharge Temp (C)
◆ Receiving Water Temp (C)
◆ Temperature Difference (C)
Temperature (C)
30.00
25.00
20.00
15.00
10.00
5.00
0.00
9/27/09
9/29/09
10/1/09
10/3/09
10/5/09
10/7/09
10/9/09
10/11/09
10/13/09
10/15/09
10/17/09
10/19/09
10/21/09
10/23/09
10/25/09
10/27/09
10/29/09
10/31/09
Date

# Appendix III. Pond A18 Sediment Mercury Report - 2009

# POND A18 SEDIMENT MERCURY REPORT – 2009

*Prepared for:*

**The City of San Jose**
**Environmental Services Department**
**700 Los Esteros Road**
**San Jose, CA 95134**

*Prepared by:*

KINNETIC LABORATORIES INCORPORATED

**307 Washington Street**
**Santa Cruz, CA 95060**

**16 December 2009**

# Pond A18 Sediment Mercury Report – 2009

**Kinnetic Laboratories, Inc.**
**16 December 2009**

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# Pond A18 Sediment Mercury Report – 2009

**Kinnetic Laboratories, Inc.**
**16 December 2009**

## 1.0 INTRODUCTION

In 2005, The City of San Jose purchased Salt Pond A18 from Cargill and has been managing the pond since October 2005. As part of the requirements in the A18 Waste Discharge Order (WDO), the City is required to perform in-pond sampling of A18 sediment to be analyzed for mercury, methyl mercury concentrations and related chemistry. The Self Monitoring Program (SMP) specifically states: *"The Discharger shall collect annual samples for mercury and methyl mercury in August or September of each year from Pond A18. In collecting mercury samples, the Discharger shall follow the guidelines in Section C of the SMP, and monitor for pH, TOC, sulfides and redox potential. Further, the Discharger shall report concentrations of mercury in mg/kg dry weight."*

## 2.0 METHODS

Sediment samples were collected from four locations (Figure 1) in Pond A18 on 21 September 2009. A 14-foot Jon Boat was used to access all sites. Sample locations were determined and recorded using a Garmin 76 handheld WAAS enabled GPS. Samples were collected using a 4" stainless steel hand auger at all sampling sites. A minimum of five cores were collected at each site and the top 5-cm of each core was placed in a Tefzel-coated compositing bucket.

Each sample was composited in a separate pre-cleaned Tefzel-coated compositing bucket. Very large chunks of gypsum and rock, where possible, were removed during the homogenization of the sample. It was still obvious that pieces of large material remained in the homogenized sample. The homogenized samples were then allocated into the appropriate pre-labeled sample jars using a stainless steel spoon. All sediment samples were analyzed for total mercury, methyl mercury, percent solids, pH, total organic carbon (TOC), total sulfides, redox potential (ORP), and particle size distribution. Each analytical laboratory provided sample containers for their appropriate analyses. A 4 oz. jar was provided for the total mercury, methyl mercury, and percent solids (for dry weight calculation). A 4 oz. jar (with zinc acetate preservative) was provided for the total sulfides. Zinc acetate preservative was added to the sample handling by the analytical laboratory to prevent sulfide loss and increase accuracy of results. This preservative was not used for sulfide sample processing during the previous two years (2007 and 2008). Sampling and processing of sulfide samples were the same as in previous years with the exception of the added preservative and allocating the sample to its' own jar. A 16 oz. jar was provided for the pH, total organic carbon (TOC), redox potential, particle size, and percent solids (again for dry weight calculation). Samples were immediately placed on ice and then shipped under strict chain-of-custody procedures to the appropriate analytical laboratories on 22 September 2009. All samples were received by the analytical laboratories by 09:08 AM on 23 September 2009.

Total mercury (EPA 1631 Appendix), methyl mercury (EPA 1630 Mod.), and percent solids (EPA 160.3) were analyzed by Brooks Rand of Seattle, Washington. Percent solids (EPA 160.3M), pH (SM 9045C), TOC (ASTM D4129-82M), total sulfides (EPA 9030B Mod.), redox potential (ASTM D1498-00), and particle size distribution (ASTM D422 Mod.) were analyzed by Columbia Analytical Services, Inc. of Kelso, Washington.

Overlying water at each sampling location was sampled for temperature, dissolved oxygen (D.O.), pH, salinity, and redox potential. A Hydrolab Quanta Water Quality Monitoring System was used to measure temperature (ºC), pH (units), salinity (ppt), and D.O. in both mg/L and percent saturation. An Oakton ORPtestr 10 ORP meter was used to measure oxidation-reduction (redox) potential (mV).

**Figure 1. Sampling Locations for Pond A18, 21 September 2009.**

## 3.0 RESULTS

Stations were located and sampled on 21 September 2009 between 11:00 and 12:30 PDT (Table 1). Station water characteristics were recorded at each sampling site (Table 2). Water turbidity was high at all stations. Water color was brownish red at three stations and brown at one. No unusual odors, trash, or any oil and grease sheen was observed.

**Table 1. Station Locations and Sampling Times.**

| STATION | TIME (PDT) | LATITUDE | LONGITUDE |
|---|---|---|---|
| A18-1 | 12:30 | 37º 26' 42.7" | 121º 57' 02.6" |
| A18-2 | 12:10 | 37º 26' 56.2" | 121º 57' 19.3" |
| A18-3 | 11:40 | 37º 27' 14.3" | 121º 57' 35.1" |
| A18-4 | 11:00 | 37º 27' 32.9" | 121º 57' 38.7" |

**Table 2. Station Water Characteristics.**

| STATION | TURBIDITY | OIL & GREASE SHEEN | TRASH | COLOR | ODORS |
|---|---|---|---|---|---|
| A18-1 | HIGH | NONE | NONE | BROWN | NONE |
| A18-2 | HIGH | NONE | NONE | BROWNISH RED | NONE |
| A18-3 | HIGH | NONE | NONE | BROWNISH RED | NONE |
| A18-4 | HIGH | NONE | NONE | BROWNISH RED | NONE |

### 3.1 Water Quality Parameter Field Measurements:

Overlying water quality field measurements are presented in Table 3. Depth ranged from 2 feet at station A18-4 to 3 feet at A18-2. pH ranged from 8.1 (A18-4) to 8.5 (A18-1 and A18-2). Temperature increased slightly going from north (A18-4 at 22.2 ºC) to south (A18-1 at 24.8 ºC) but may likely be a reflection of warming water temperatures during the day as sampling was conducted in the same direction. Dissolved oxygen varied from 2.6 mg/L (36% saturation) at A18-3 to 6.3 mg/L (92% saturation) at A18-2. ORP ranged from 73 mV (A18-3) to 94 mV (A18-4). Salinity increased from north to south ranging from 27.9 ppt (A18-4) to 29.2 and 29.1 ppt (A18-2 and A18-1 respectively).

**Table 3. Station Water Quality Parameter Field Measurements.**

| STATION | WATER DEPTH (feet) | pH (units) | TEMP. (ºC) | D.O. (mg/L) | D.O. (% Saturation) | ORP (mV) | SALINITY (ppt) |
|---|---|---|---|---|---|---|---|
| A18-1 | 2.25 | 8.5 | 24.8 | 4.1 | 59 | 82 | 29.1 |
| A18-2 | 3.00 | 8.5 | 24.1 | 6.3 | 92 | 81 | 29.2 |
| A18-3 | 2.50 | 8.2 | 22.4 | 2.6 | 36 | 73 | 28.7 |
| A18-4 | 2.00 | 8.1 | 22.2 | 3.0 | 30 | 94 | 27.9 |

### 3.2 Sediment Quality Analytical Measurements:

Analytical results for sediment samples are presented in Table 4. Total mercury in sediment ranged from 0.244 mg/kg (dry wt.) at A18-4 to 0.580 mg/kg (dry wt.) at A18-1. Methyl mercury in sediment ranged from 0.000143 mg/kg (dry wt.) at A18-3 to 0.000462 mg/kg (dry wt.) at A18-4. The percent of total weight recovered for sample A18-2 particle size determination was outside of laboratory acceptance limits of 90-110%. The sample was reanalyzed (duplicate values can be found in laboratory replicates section below) but produced similar results. The analytical laboratory attributed the high recovery to organic material present in the sample.

**Table 4. Analytical Results for Sediment Samples.**

| | SAMPLING STATIONS | | | |
|---|---|---|---|---|
| ANALYTE | A18-1 | A18-2 | A18-3 | A18-4 |
| **Total Mercury** | | | | |
| mg/kg dry weight | 0.580 | 0.487 | 0.272 | 0.244 |
| ng/g dry weight | 580 | 487 | 272 | 244 |
| **Methyl Mercury** | | | | |
| mg/kg dry weight | 0.000230 | 0.000149 | 0.000143 | 0.000462 |
| ng/g dry weight | 0.230 | 0.149 | 0.143 | 0.462 |
| % Solids (Brooks Rand – Mercury Samples) | 37.8 | 30.7 | 22.7 | 30.1 |
| % Solids (Columbia Analytical – Conventionals) | 35.1 | 25.1 | 23.5 | 27.3 |
| TOC (% dry wt.) | 2.57 | 4.27 | 6.35 | 3.57 |
| ORP (millivolts) | -241 | -276 | -219 | -294 |
| pH (units) | 7.94 | 7.65 | 7.63 | 7.60 |
| Total Sulfide (mg/kg dry wt.) | 24.1 | 29.3 | 19.4 | 23.1 |

**Table 4. Analytical Results for Sediment Samples (continued).**

| ANALYTE | SAMPLING STATIONS<br>A18-1 | A18-2 | A18-3 | A18-4 |
|---|---|---|---|---|
| **Particle Size Distribution (%)** | | | | |
| Gravel, Medium | 16.7 | 41.1 | 0.00 | 0.00 |
| Gravel, Fine | 7.45 | 14.3 | 6.22 | 7.93 |
| Sand, Very Coarse | 5.73 | 10.6 | 20.7 | 17.1 |
| Sand, Coarse | 3.97 | 6.24 | 11.7 | 7.47 |
| Sand, Medium | 2.58 | 4.33 | 6.47 | 5.07 |
| Sand, Fine | 3.43 | 5.24 | 7.75 | 5.19 |
| Sand, Very Fine | 0.95 | 1.24 | 1.58 | 1.02 |
| Silt | 61.6 | 30.5 | 34.2 | 62.7 |
| Clay | 4.54 | 15.5 | 14.6 | 1.30 |

## 4.0 QUALITY ASSURANCE/QUALITY CONTROL

Kinnetic Laboratories conducts its activities in accordance with formal QA/QC procedures. The objectives of the QA/QC Program are to fully document the field and laboratory data collected, to maintain data integrity from the time of field collection to storage at the end of the project, and to produce the highest quality data possible. The program is designed to allow data to be assessed by the following parameters: Precision, Accuracy, Comparability, Representativeness, and Completeness.

Field Quality Control includes adherence to formal sample documentation and tracking. Analytical chemistry Quality Control is formalized by EPA and State Certification agencies, and involves internal quality control checks such as method blanks, matrix spike/matrix spike duplicates (MS/MSDs), blank spike/blank spike duplicates, laboratory replicates, calibration standards, and certified reference materials (CRMs). All analytical data collected for this sediment-testing program underwent QA/QC evaluation according to EPA National Functional Guidelines for inorganic data review (USEPA, 2002).

### 4.1 Holding Times

All analytical tests, with the exception of sediment ORP, were performed within holding times. Columbia Analytical Services, Inc. stated that the samples were received past the recommended holding time (24- hours) for ORP. They have been performing this analysis since 2005 including two reports by S.R. Hansen and Associates (2005 and 2006) and by Kinnetic Laboratories (2007 through 2009). Reviewing the 2007 and 2008 reports show that, although not reported by the laboratory, analyses did not take place within 24-hours. It is likely that this analysis has always missed the recommended 24-hour hold time.

### 4.2 Blanks

Method blanks were run to assess contamination introduced in the laboratory. In all cases, procedural blanks for sediment did not contain any quantifiable concentrations indicating the methods and equipment used were free of or did not introduce contamination. Mercury was detected in three of four method blanks and methyl mercury was detected in all method blanks performed by Brooks Rand (Table 5). In the case of mercury, the average of the method blanks was less than two times the MDL (Method Detection Limit), the standard deviation was less than two-thirds the MDL, and highest method blank was less than one-tenth of the associated sample results, satisfying all acceptance criteria. In the case of methyl mercury, the average of method blanks was less than two times the MDL and the standard deviation was less than two-thirds of the MDL satisfying both of the primary acceptance criteria. Method blanks performed by Columbia Analytical Services, Inc. for total sulfide and TOC were all non-detects (Table 6).

**Table 5. Method Blank Results for Brooks Rand Sediment Sample Analyses.**

| METHOD BLANK | MERCURY (ng/g) | METHYL MERCURY (ng/g) | PERCENT SOLIDS (%) |
|---|---|---|---|
| MB1 | 0.24 | 0.001 | -0.03 |
| MB2 | 0.09 | 0.001 | -0.06 |
| MB3 | 0.02 | 0.001 | - |
| MB4 | 0.00 | 0.001 | - |
| Average | 0.09 | 0.001 | -0.05 |
| Standard Deviation | 0.11 | 0.000 | - |
| **Method Detection Limit** | 0.35 | 0.008 | 0.10 |
| **Criteria** | Avg.<2X MDL, Std Dev <2/3 MDL or Results >10X Highest Blank | Avg.<2X MDL, Std Dev <2/3 MDL | <MDL or <1/10th sample |

**Table 6. Method Blank Results for Columbia Analytical Services, Inc. Sediment Sample Analyses.**

| METHOD BLANK | TOTAL SULFIDE (mg/kg) | TOTAL ORGANIC CARBON (%) |
|---|---|---|
| MB1 | ND | ND |
| **Method Reporting Limit** | 2.2 | 0.05 |

ND = analyte not detected at or above the associated method reporting limit.

## 4.3 Laboratory Replicates

Laboratory replicates, with the exception of pH, were performed on field sediment samples (Table 7). pH laboratory replicate was performed on a sample that was batched with this projects samples. Relative Percent Difference (RPD) of all analyses met QA/QC objectives. Normally, a laboratory replicate is not performed on a particle size distribution sample but sample A18-2 was problematic where it contained, as stated earlier, a large amount of organic material. As there is no established evaluation guideline for this type of laboratory replicate, a general field duplicate guideline was used where RPDs greater than 50% were considered to be of potential concern.

**Table 7. Laboratory Replicate Results.**

| ANALYTE | SAMPLE VALUE | DUPLICATE VALUE | AVERAGE VALUE | DUPLICATE RPD | CONTROL LIMITS |
|---|---|---|---|---|---|
| Mercury (ng/g – dry weight) – Dup1 | 580.0 | 588.3 | 584.2 | 1% | ≤ 30% |
| Mercury (ng/g – dry weight) – Dup2 | 487.0 | 448.9 | 468.0 | 8% | ≤ 30% |
| Methyl Mercury (ng/g – dry weight) | 0.230 | 0.214 | 0.222 | 7% | ≤ 35% |
| Percent Solids (%)(Brooks Rand) | 37.79 | 37.04 | 37.42 | 2% | ≤ 15% |
| Percent Solids (%)(Columbia Analytical) | 27.3 | 29.0 | 28.2 | 6% | ≤ 20% |
| pH (units)* | 4.08 | 4.04 | 4.06 | < 1% | ≤ 20% |
| ORP (mV) | -241 | -243 | -242 | < 1% | ≤ 20% |
| Total Sulfide (mg/kg) | 24.1 | 21.9 | 23.0 | 10% | ≤ 20% |
| Total Organic Carbon (%) | 2.57 | 2.53 | 2.55 | 2% | ≤ 20% |
| **Particle Size Distribution (%)** | | | | | |
| Gravel, Medium | 41.1 | 37.0 | 39.1 | 10% | ≤ 50% |
| Gravel, Fine | 14.3 | 18.4 | 16.4 | 25% | ≤ 50% |
| Sand, Very Coarse | 10.6 | 10.4 | 10.5 | 2% | ≤ 50% |
| Sand, Coarse | 6.24 | 6.21 | 6.23 | 0% | ≤ 50% |
| Sand, Medium | 4.33 | 4.43 | 4.38 | 2% | ≤ 50% |
| Sand, Fine | 5.24 | 5.48 | 5.36 | 4% | ≤ 50% |
| Sand, Very Fine | 1.24 | 0.83 | 1.04 | 40% | ≤ 50% |
| Silt | 30.5 | 31.8 | 31.2 | 4% | ≤ 50% |
| Clay | 15.5 | 14.0 | 14.8 | 10% | ≤ 50% |

[1] NA = not applicable **Bolded** value exceeds control limit

### 4.4 Laboratory Control Samples

Laboratory Control Samples (LCSs) were run by Brooks Rand Labs for methyl mercury (laboratory fortified blank) and Columbia Analytical Services, Inc. for pH, ORP, total sulfide, and TOC (Table 8). All LCS recoveries were within established Control Limits indicating proper analytical performance in the absence of matrix effects.

**Table 8. Laboratory Control Sample Results.**

| ANALYTE | TRUE VALUE | RESULT | PERCENT RECOVERY | CONTROL LIMITS |
|---|---|---|---|---|
| Methyl Mercury (ng/g) | 1.000 | 0.968 | 97% | 65-135% |
| pH (units) | 5.81 | 5.78 | 99% | 85-115% |
| ORP (mV) | 480 | 482 | 100% | 85-115% |
| Total Sulfide (mg/kg) | 6.4 | 4.1 | 64% | 55-130% |
| Total Organic Carbon (%) | 0.550 | 0.487 | 89% | 82-119% |

### 4.5 Spike Samples

Matrix Spike and Matrix Spike Duplicates (MS/MSD) percent recoveries were evaluated to determine acceptable accuracy based on method-specific percent recoveries. The general rule is that when spikes are reported below the accepted range they indicate a low bias to the results and when reported above the accepted range they indicate a high bias. However, if the spike concentration was low in comparison with the sample concentration, a poor recovery is not in itself indicative of a QC problem.

All MS/MSD recoveries met established QC objects (Table 9). As another measure of precision, the RPD between MS/MSD recovery results were evaluated. Since RPD values were not provided for total sulfide and TOC, control limits for duplicate sample results of ≤ 20% was used. In all cases, calculated RPDs were below their associated Control Limits.

**Table 9. Matrix Spike/Matrix Spike Duplicate Results.**

| ANALYTE | MATRIX SPIKE | | | | MATRIX SPIKE DUPLICATE | | | | CONTROL LIMITS | |
|---|---|---|---|---|---|---|---|---|---|---|
| | SAMP. VALUE | SPIKED VALUE | MEASUR. VALUE | % RECOV. | SPIKED VALUE | MEASUR. VALUE | % RECOV. | DUP. RPD (%) | % RECOV. | RPD |
| Mercury (ng/g-wet wt.) | 580.0 | 2490 | 3223 | 106% | 2430 | 3169 | 107% | 2% | 70-130% | ≤ 30% |
| Mercury (ng/g-wet wt.) | 487.0 | 3119 | 3717 | 104% | 3146 | 3941 | 110% | 6% | 70-130% | ≤ 30% |
| Methyl Mercury (ng/g-wet wt.) | 0.230 | 0.6257 | 0.857 | 100% | 0.6158 | 0.826 | 97% | 4% | 65-135% | ≤ 35% |
| Total Sulfide (mg/kg) | ND[1] | 1360 | 1540 | 111% | 1350 | 1390 | 101% | 9% | 34-166% | ≤ 20% |
| Total Organic Carbon (%) | 2.57 | 7.54 | 9.77 | 95% | 7.51 | 9.87 | 97% | 2% | 77-155% | ≤ 20% |

[1] – ND = non-detect

### 4.6 Certified Reference Material

All certified reference material (CRM) percent recoveries for this project were well within QC limits indicating proper analytical performance in the absence of matrix effects (Table 10).

**Table 10. Certified Reference Material Results.**

| ANALYTE | CRM ID | CERTIFIED VALUE | MEASURED VALUE | % RECOVERY | CONTROL LIMITS |
|---|---|---|---|---|---|
| Mercury (ng/g – wet weight) | MESS-3 | 91.00 | 98.50 | 108% | 75-125% |
| Methyl Mercury (ng/g – wet weight) | CC-580 | 75.00 | 59.88 | 80% | 65-135% |
| Methyl Mercury (ng/g – wet weight) | CC-580 | 75.00 | 59.73 | 80% | 65-135% |

### 4.7 QA/QC Conclusions

A careful review of the results confirmed that the laboratories met QA/QC requirements. Overall evaluation of the QA/QC data indicates that the chemical data are within established performance criteria and can be used for general characterization of sediments in the proposed project area. No data were subjected to qualification as a result of quality control objectives not being met.

# Appendix IV. Update on A18 Future Use Planning and Long-term Operations.

## Status Report on A18 Planning Process and Long-term Operations

This section provides an update on efforts to determine the future uses of Pond A18 within the context of the Master Planning effort for the San Jose/Santa Clara WPCP (Plant).

### Plant Master Planning

The Plant Master Planning effort, which includes planning for A18, is now in its second year. Major progress included development of draft technical alternatives for liquids, solids, and energy management, as well as a robust community engagement process, including public workshop and Community Advisory Group meetings. Carollo Engineers and Brown & Caldwell are the consultant team assisting the City. The City's vision is to balance environmental, economic, and community considerations, achieve energy self sufficiency, and have Plant lands become a special place, serving as a transition zone between the heart of Silicon Valley and the Bay, with A18 being the Bay-side portion of that transition.

### Stakeholder Engagement, Coordination and Outreach

Outreach to the public is an integral part of the Plant Master Planning effort. Since tours were started again in May 2008, about 6,000 people toured the Plant. More than 100 people attended a community workshop on May 16, 2009 and their participation in a values survey launched the first phase of public involvement. Since then, nearly 1,500 public values surveys were collected at the workshop, through Plant tours, and through the project Web site.

The Community Advisory Group (CAG) developed a work plan and meeting schedule for 2009-2010. CAG discussed biosolids disposition options at the November meeting and social land use opportunities (parks, trails, etc.) and constraints in December. Environmental and economic land use opportunities and constraints will be discussed at the January meetings. View all meeting agendas and meeting summaries at *www.sanjoseca.gov/esd/plantmasterplan*

City staff also met with Regional Board staff on September 15, 2009 to discuss Master Plan concepts, including the planning effort for A18. In addition, City staff and the consultant team have met with other regulatory and resource agency stakeholders, including, the U.S. Army Corps of Engineers, Santa Clara Valley Water District, California State Coastal Conservancy, California Department of Fish and Game, San Francisco Bay Conservation and Development Commission, and U.S. Fish and Wildlife Service to provide updates on the project status and discuss assumptions with respect to land uses, particularly for Pond A18 (the 860-acre former salt production pond).

### Land Use Analysis

Skidmore, Owings, and Merrill (SOM), and Hargreaves and Associates are the land use planning consultants developing concepts for potential plant land uses, including A18, the biosolids area, and the buffer lands along Highway 237. The consultant team is using input from the first land use workshop attended by City and Tributary agency staff, the outcome of the community workshop on May 16, 2009, survey data from the public tours and Web site, as well as the information gathered from our agency partners over the summer and fall to develop preliminary land use alternatives for discussion at a second staff-level workshop scheduled for December 2009. Economic analysis, including job generation and revenue to the City, the Tributary Agencies, and the region, will be major components of the potential alternatives along with environmental and social sustainability. The purpose of the workshop is to review and comment on the preliminary land use alternatives and to develop a recommended vision and principles guiding future use of the site. The land use alternatives will then be refined and presented to the public in spring 2010. The alternative development has focused on natural and performative water-based uses for Pond A18.

### Sea-Level Rise Analysis

The consultant team performed an analysis of the likely impact of sea-level rise on the Plant site. Nearly all of the Plant's land, including the operations area and biosolids treatment area, would be flooded by the South San Francisco Bay (Bay) under all sea-level rise projections. Protecting the facility's ability to continue to treat the region's wastewater will be a central component of the Master Plan. Understanding the relationship of Pond A18 to the Bay and the surrounding lands will be a crucial component towards developing a flexible and resilient strategy to accommodate sea-level rise.

### Technical Analysis

Based on projections and information from the scenarios included in the Envision San Jose 2040 General Plan update and other sources, the consultant team completed a detailed evaluation of the Plant's ability to handle future flows and loads as well as potential future regulatory requirements. The consultant team has narrowed the technical options for liquids and solids treatment, as well as optimization of energy production and use based on these findings.

A second technical workshop with wastewater industry experts was held on October 1, 2009, to review the planning assumptions and analysis of future treatment options. These experts comprise the Plant Master Plan's Technical Advisory Group (TAG) and represented expertise in liquids, solids, energy, constructed wetlands and overall process. Bruce Wolfe, Executive Officer of the San Francisco Bay Regional Water Quality Control Board, is one of the TAG members who provided valuable input into future regulatory scenarios.

Appendix V. Pond A18 Primary Productivity Publication in September 2008 volume of *Wetlands* and Poster Presentation displayed at multiple national, state and regional conferences.

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# PRIMARY PRODUCTION AND CARRYING CAPACITY OF FORMER SALT PONDS AFTER RECONNECTION TO SAN FRANCISCO BAY

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*Abstract:* Over 6,110 ha of the commercial production salt ponds surrounding South San Francisco Bay, CA, have been decommissioned and reconnected to the bay, most as part of the largest wetlands restoration program in the western United States. These open water ponds are critical habitat for millions of birds annually and restoration program managers must determine the appropriate balance between retention of ponds versus re-conversion to tidal salt marsh, knowing that both are essential ecosystems for endangered bird species. Our study describes the ecological value of the new open water pond ecosystems as feeding habitats for birds. We used the oxygen rate of change method to determine ecosystem metabolic parameters from high resolution time-series of dissolved oxygen concentration. Areal gross primary production (8.17 g $O_2$ $m^{-2}$ $d^{-1}$) was roughly double the world's most productive estuaries. High rates of phytoplankton photosynthesis were balanced by equally high rates of community respiration (8.25 g $O_2$ $m^{-2}$ $d^{-1}$). Metabolic equilibrium was delicately poised: sharp irradiance and temperature shifts triggered short term photosynthesis reduction resulting in oxygen depletion. We converted net primary production (NPP) into potential carrying capacity of the forage biota that support targeted pond waterbirds. NPP was processed through both a pelagic food web, resulting in forage biota for piscivorous birds and a benthic food web, resulting in forage biota for shorebirds and diving benthivores. Both food webs included efficient algal-based and inefficient detrital trophic pathways. The result of all primary production being routed through simple food webs was high potential forage production and energy supply to waterbirds, equivalent to 11–163 million planktivorous fish or 19–78 billion small estuarine clams within the 330-ha pond between May and October. Food quantity does not necessarily equal quality and these systems have the potential to produce toxic or inedible algae. Our study provides the first measurement of primary production in the open water ponds of San Francisco Bay and presents a novel approach for transforming primary production into forage production as a metric of an ecosystem's energetic carrying capacity.

*Key Words:* birds, dissolved oxygen concentration, ecosystem restoration, food webs, forage biota, net ecosystem metabolism, phytoplankton

## INTRODUCTION

San Francisco Bay has been named the urbanized estuary (Conomos 1979) because of its geographic setting within the densely populated metropolitan area between San Francisco, Oakland, and Silicon Valley. Landscape transformations of the bay began immediately after California's population explosion was launched by the 1849 gold rush (Nichols et al. 1986), and included diking and conversion of native salt marsh around the South Bay (Figure 1) into shallow ponds managed for solar evaporation salt production. The commercial salt pond network grew to encompass approximately 10,500 ha of former tidal wetlands south of the San Mateo Bridge. The ponds are now of primary importance to migratory waterbirds, and also provide year round foraging habitat for a number of resident species. In all, at least 70 endangered, rare, and common bird species inhabit, breed, or feed on the ponds, and the annual

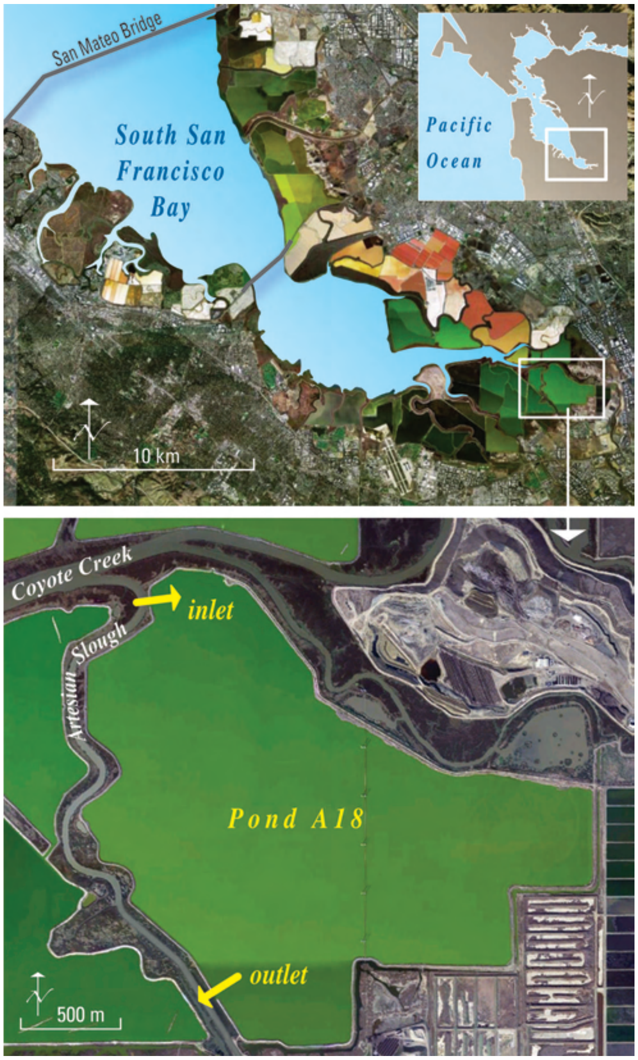

Figure 1. Upper panel: map of South San Francisco Bay ringed with ponds, note color variations in ponds due to bacteria and phytoplankton species, San Francisco Bay inset. Lower panel: map of Pond A18 including inlet and outlet water control structures. Satellite images courtesy of NASA (images altered for ease of viewing). Bay area inset and image design courtesy of Jeanne DiLeo (USGS).

bird use of ponds numbers in the millions (Warnock et al. 2002).

Beginning in 2004, a significant portion of the production salt ponds (6,110 ha) were decommissioned and opened to exchange with water from the bay or adjacent sloughs. The decommissioned ponds are presently managed as non-tidal or minimally tidal open water systems, most as part of the South Bay Salt Pond Restoration Project (SBSPRP; http://www.southbayrestoration.org). This is the largest program of wetland restoration in the western United States, conceived to rebuild wetland habitats to sustain endangered species of plants, birds, and mammals. Program managers face a critical decision about how to adaptively manage these ponds to meet multiple ecological goals, namely determine the appropriate balance between newly restored salt marshes that are home to endemic birds such as the endangered California clapper rail (*Rallus longirostris obsoletus*) and Alameda song sparrow (*Melospiza melodia pusillula*) versus retention of salt ponds that over the past century have increased populations of permanent and migratory waterbirds such as the American white pelican (*Pelecanus erythrorhynchos*) and the endangered western snowy plover (*Charadrius alexandrinus*). Eliminating artificial salt pond habitats without concomitantly restoring natural salt ponds and tidal salt marshes with pans could reduce or even extirpate some of these species from the bay (Takekawa et al. 2006). Moreover, questions remain about which open ponds to maintain and which ones to restore.

An important criterion to inform the decision-making process is the ecological value of pond and salt marsh habitats (Lopez et al. 2006). Fundamental ecological parameters such as primary production have not been measured in these high-biomass shallow habitats, a first step in quantifying the pond's ecological functioning and contribution to the greater system. In this paper we explore quantity and quality of local production that sustains food webs in one South San Francisco Bay pond. We calculate primary production and ecosystem metabolism from high resolution dissolved oxygen measurements using the oxygen curve method first described by Odum (1956) and subsequently applied in numerous studies (McKenna 2003, Caffrey 2004, Russell and Montagna 2007). Using a novel approach, we convert the primary production via simple food webs into estimates of potential carrying capacity of forage organisms that support the target bird species. Carrying capacity is expressed in units that are meaningful for restoration project managers, providing tangible ecological metrics for valuating different habitat types and understanding the outcomes of adaptive management decisions.

## METHODS

### Site Description

Pond A18 (37°27′N, 121°57′W) is one of the largest (330 ha) decommissioned salt ponds in South San Francisco Bay. The pond's levees are bounded by three tidal channels connected to San Francisco Bay: Artesian Slough to the west, Coyote Creek to the north, and Coyote Creek Bypass Channel to the northeast (Figure 1). Artesian Slough receives 386 million liters of treated wastewater daily from the San Jose/Santa Clara Water Pollution Control Plant (City of San Jose 2007a). Wastewater inputs contribute to the very high nutrient concentrations in lower South San Francisco Bay and its ponds. For example, analyses across 25 ponds in May and June of 2003 and 2006 measured concentrations of dissolved inorganic nitrogen (DIN) and soluble reactive phosphorus (SRP) that always exceeded levels that limit phytoplankton growth (mean DIN = 84 μM with 91% as $NH_4$; mean SRP = 2.6 μM; A. K. Miles, USGS, pers. comm.).

The City of San Jose purchased Pond A18 in 2005 and manages the pond's connectivity through one inlet and one outlet constructed as 1.22-m diameter culverts having one-way tide gates. The inlet is located in the northwest corner (Figure 1) where mixtures of water from Artesian Slough and South San Francisco Bay enter the pond. The outlet is in the southwestern corner (Figure 1) where pond water discharges into Artesian Slough. Water exchange with the pond is unidirectional: intake in the north, discharge in the south. Tides are predominantly semidiurnal, thus water enters and exits the pond twice daily when tide heights are below the outlet and above the intake. Pond A18 functions as a nearly closed system rather than an open flow-through system, as evidenced by hydraulic residence time estimated between 15 and 50 days (City of San Jose, Environmental Services Department, unpubl.).

Bathymetry of Pond A18 is characteristic of other South Bay salt ponds, with an expansive shallow (mean depth = 0.7 m) area rimmed by a narrow trench (1.2–1.8 m deep) created by excavation for levee construction. All of these shallow open water ponds are bounded by levees that separate them from the surrounding bay and brackish sloughs. Pond A18 is used as foraging and roosting habitat by the same communities of birds observed in other ponds having comparable salinity range (Takekawa et al. 2006). It is an example of an isolated high salinity pond (salinity before 2005 = 110) that has been transformed by breaching its bounding levee, and as such it is a representative system for understanding ecological functions of shallow ponds with newly established tidal connectivity to San Francisco Bay.

### Water Quality Measurements in Pond A18

Conductivity, temperature, and dissolved oxygen (DO) were measured at 15 minute intervals from May 1 to October 31, 2006, using YSI model 6600 datasondes deployed inside Pond A18 at the pond discharge location (City of San Jose 2007b). DO was measured with YSI rapid-pulse probes (membrane technology) from May to August, and YSI Reliable Optical DO probes (optical technology) from August through October. Simultaneous measurements from the two probes agreed within 1% in side-by-side comparisons. Salinity, reported using the practical salinity scale, was determined automatically from sonde conductivity and temperature readings according to algorithms in Clesceri et al. (1998). Conductivity calibrations were performed using standards of 10,000 μS $cm^{-1}$ and 50,000 μS $cm^{-1}$. DO sensors were calibrated to percent saturation using 100% standards of air saturated water (bubbled for 12 h) or water saturated air (moist, vented calibration cup). The sondes were retrieved and replaced with a newly calibrated instrument at the end of each week. Data were downloaded to a computer and post-deployment calibration verification was conducted in the laboratory. DO data were accepted if the post-deployment sensor readings were within ± 10% of the standard. Conductivity data were accepted for the week if the post-deployment sensor readings were within ± 5% of the standard. Weekly data that did not meet the calibration confidence limits were discarded and these data gaps are reflected in our results.

Phytoplankton biomass was measured monthly as chlorophyll *a* concentration (Chl *a*) in surface water at the discharge point. Samples were collected into 1 L bottles and stored in the dark on ice and transported to a laboratory within 4 hours for filtration and analysis (Clesceri et al. 1998). Phytoplankton species composition was determined by microscopic analyses of samples collected on August 18, September 13, and October 19 at the discharge point inside of the pond and on September 13 and October 19 at the mouth of Artesian Slough.

### Weather Data

We used weather data measured at Union City and provided by the California Irrigation Management Information System (CIMIS: http://wwwcimis.water.ca.gov/cimis/data.jsp). Wind speed (m $s^{-1}$), water vapor pressure (kPa), air temperature (°C), and total solar radiation (W $m^{-2}$) were recorded. We converted total solar radiation into photosynthetically active radiation (PAR, mol quanta $m^{-2}$ $d^{-1}$), assuming 1 W $m^{-2}$ = 0.4 mol quanta $m^{-2}$ $d^{-1}$ and PAR = 46% of total irradiance (Baker and Frouin 1987). The Union City CIMIS station did not provide sea level atmospheric pressure, therefore we used hourly data (hPa) interpolated from measurements recorded every 3 h at San Francisco International Airport (NOAA, National

Climatic Data Center). All data are reported as Pacific Standard Time (GMT-8).

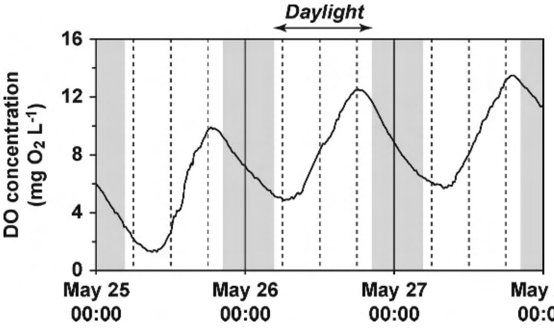

Figure 2. Diel cycles of DO concentration in Pond A18 from May 25 to May 28, 2006.

### Primary Production, Respiration, and Ecosystem Metabolism

We used the DO rate of change method first proposed by Odum (1956) to calculate daily gross primary production, ecosystem respiration, and net ecosystem metabolism from the continuous measurements of DO in Pond A18. Hourly rates of DO change were calculated from the 15 minute interval DO data (see Figure 2 for an example of diel DO variations). The rate of DO change is determined by rates of photosynthesis, respiration, accrual of other water sources, and atmospheric exchange. We assumed that accrual of DO from other water sources is negligible because of the pond's long residence time. Then, the measured rate of DO change each hour is described by the mass balance equation:

$$\frac{\mathrm{d}C}{\mathrm{d}t} = P - R + D \tag{1}$$

where $C$ is DO concentration in the pond (mg O$_2$ L$^{-1}$), $t$ is time (h), $P$ is rate of photosynthesis, $R$ is the respiration rate, and $D$ is the rate of oxygen uptake by diffusion across the air-water interface ($P$, $R$, and $D$ units mg O$_2$ L$^{-1}$ h$^{-1}$).

Wind produces turbulence in stationary water bodies, facilitating gas exchange processes which increase with wind speed (Liss and Merlivat 1986). This relationship is represented as:

$$D = k_a(C_s - C) \tag{2}$$

where $k_a$ is the volumetric reaeration coefficient (h$^{-1}$) and $C_s$ is the DO saturation concentration (mg O$_2$ L$^{-1}$). We calculated $k_a$ hourly using three different functions of wind speed (O'Connor 1983, Hartman and Hammond 1985, Ro and Hunt 2006) as an approach for estimating uncertainty in the rate of air-water oxygen exchange. Detailed methodology of these calculations is presented in Appendix A. The DO saturation concentration, which is dependent on water salinity and temperature, was calculated hourly using the algorithm of Benson and Krause (1984):

$$\begin{aligned}\ln C_s = {} & -135.29996 + 1.572288 \times 10^5 \times T^{-1} \\ & - 6.637149 \times 10^7 \times T^{-2} + 1.243678 \\ & \times 10^{10} \times T^{-3} - 8.621061 \times 10^{11} \times T^{-4} \\ & - \left(0.020573 - 12.142 \times T^{-1} \right. \\ & \left. + 2363.1 \times T^{-2}\right) \times S \end{aligned} \tag{3}$$

where $C_s$ is expressed in μmol O$_2$ kg$^{-1}$, $T$ is water temperature (K), and $S$ is water salinity. The calculated $C_s$ was then converted to mg O$_2$ L$^{-1}$:

$$\begin{aligned} C_s(\text{mg O}_2\ \text{L}^{-1}) = {} & C_s(\mu\text{mol O}_2\ \text{kg}^{-1}) \\ & \times \rho_w \times 31.9988 \times 10^{-6} \end{aligned} \tag{4}$$

where $\rho_w$ is the density of seawater (kg m$^{-3}$) calculated hourly from atmospheric pressure, water temperature, and salinity according to the International Equation of State of Seawater IES-80 (UNESCO 1981).

Net ecosystem metabolism (NEM) is the difference between photosynthesis and respiration, which we computed (from rearrangement of Eq. 1) as:

$$NEM = P - R = \frac{\mathrm{d}C}{\mathrm{d}t} - D. \tag{5}$$

For each day we calculated daily NEM by summing hourly diffusion-corrected rates of DO change (d$C$/d$t$ − $D$) over 24 h, starting and ending at sunrise. We next calculated hourly respiration rate $R$ as the average of nighttime (solar radiation = 0) diffusion-corrected rates of DO change. By convention, respiration is expressed as a positive number, thus nighttime hourly diffusion-corrected rates of DO change were multiplied by −1. We computed daily respiration as 24 × $R$, assuming respiration during the daytime is the same as at night. Hourly photosynthesis $P$ was calculated by subtracting $R$ from diffusion-corrected rates of DO change during the daylight period (solar radiation > 0). We computed daily photosynthesis by summing $P$ from sunrise to sunset. We multiplied these volumetric rates by mean pond depth ($H$ = 0.7 m) to yield areal rates (g O$_2$ m$^{-2}$ d$^{-1}$) of daily gross primary production (GPP = [daily $P$] × $H$), ecosystem respiration (ER = [daily $R$] × $H$), and net ecosystem metabolism (NEM = GPP − ER).

These areal rates were also expressed in C units (g C m$^{-2}$ d$^{-1}$). Based on nutrient surveys demonstrating that most of the DIN in South Bay ponds is in the recycled form of ammonium, we assumed a photosynthetic quotient of 1.1 ($O_2$:$CO_2$ molar) characteristic of recycled production (Laws 1991). A respiratory quotient of 1 mole $O_2$ consumed per mole of C respired was used.

### Estimation of Autotrophic and Heterotrophic Respiration

Measures of phytoplankton biomass and photosynthesis allowed us to estimate rates of autotrophic respiration, based on the assumption that phytoplankton are the dominant autotrophs in Pond A18. We first calculated biomass-specific photosynthetic rates $P^B$ (mg C (mg Chl *a* d)$^{-1}$) for each day when Chl *a* was measured:

$$P^B = 1000 \times \frac{GPP}{H} \times \frac{1}{[Chl]} \qquad (6)$$

where $[Chl]$ is the Chl *a* concentration (mg Chl *a* m$^{-3}$). We used 7-d mean values of GPP (g C m$^{-2}$ d$^{-1}$), centered on Chl *a* sampling dates, to smooth the variability of production caused by the daily fluctuations in weather. Next we calculated biomass-specific autotrophic respiration rate $r_{auto}$ (d$^{-1}$) using Eq. 9 in Cloern et al. (1995):

$$r_{auto} = 0.15 \times P^B \times (Chl : C) + 0.015. \qquad (7)$$

The phytoplankton Chl:C ratio (mg Chl *a* (mg C)$^{-1}$) was calculated using Eq. 15 in Cloern et al. (1995):

$$\begin{aligned} Chl : C = {} & 0.003 + 0.0154 \times e^{0.05T} \\ & \times e^{-0.059 \times (I/(kH)) \times \left(1 - e^{-kH}\right)} \\ & \times \frac{N}{K_N + N} \end{aligned} \qquad (8)$$

where $T$ is 7-d centered mean pond temperature (°C), $I$ is 7-d centered mean daily PAR, $N$ is the average total DIN concentration (84 μM) from past surveys of South Bay ponds (A.K. Miles, USGS, pers. comm.), $K_N$ is the half-saturation constant (= 1 μM; Cloern et al. 1995) that defines phytoplankton growth as a function of DIN concentration, and $k$ is the light attenuation coefficient (= 2.97 m$^{-1}$). Light attenuation was calculated as a linear function of total suspended solid concentration (Cloern 1987) using a mean value of 41 mg L$^{-1}$ in Pond A18 (City of San Jose 2007b). Daily areal rates of autotrophic respiration $R_{auto}$ (g C m$^{-2}$ d$^{-1}$) were calculated as:

$$R_{auto} = 0.001 \times r_{auto} \times H \times \frac{[Chl]}{Chl : C}. \qquad (9)$$

Finally, the difference between ecosystem respiration and autotrophic respiration is the heterotrophic respiration rate $R_{hetero}$ (g C m$^{-2}$ d$^{-1}$):

$$R_{hetero} = ER - R_{auto}. \qquad (10)$$

We subtracted the percent of GPP represented by $R_{auto}$ from total GPP to obtain net primary production (NPP). We routed total NPP from the 6 month period of measurement through hypothetical food webs as carbon transferred to pelagic or benthic consumers. Percent of carbon transferred was calculated based on fixed gross growth assimilation efficiencies (GGE = annual production/ingestion) of different consumer groups based on the following published measurements: protistan GGE = 0.28 and metazoan zooplankton GGE = 0.23 (Straile 1997); heterotrophic bacteria GGE = 0.25 (Sobczak et al. 2002); benthic invertebrates GGE = 0.22 (Sprung 1995, Ikeda and Shiga 1999); and planktivorous fish GGE = 0.25 (Present and Conover 1992).

## RESULTS

### Environmental Survey

Diel variation of DO concentration ($DO_{max} - DO_{min}$, based on hourly measurements) ranged from 1.78–16.82 mg $O_2$ L$^{-1}$ (average = 6.73 mg $O_2$ L$^{-1}$). Representative DO curves illustrating the diel variations are presented in Figure 2. Mean daily DO concentration was also highly variable throughout the study period, ranging from 0.5–14.4 mg L$^{-1}$. Hypoxia events (i.e., DO concentration $< 2$ mg $O_2$ L$^{-1}$; Dauer et al. 1992) occurred the third week of May (1.47 mg $O_2$ L$^{-1}$), second week of June (0.60 mg $O_2$ L$^{-1}$), and mid-to-late July (0.45 mg $O_2$ L$^{-1}$) (Figure 3).

Mean daily water temperature in Pond A18 ranged from 17.1–31.7°C and exhibited a clear seasonal cycle with maximum values in mid-to-late July (Figure 3). Solar radiation decreased 2-fold from mid-July to late October (Figure 3). Episodes of low mean daily irradiance were observed the third week of May, mid-June, and early and mid October. Pond salinity continuously increased throughout the study period, ranging from 4.6 in early May to 19.4 in late October 2006. Mean daily wind speeds ranged from 0.73–3.30 m s$^{-1}$ with no strong seasonal pattern.

Phytoplankton biomass was very high, with Chl *a* ranging from 270 mg m$^{-3}$ in mid-July to 22 mg m$^{-3}$ in late September 2006 (Figure 4). This is contrasted by Chl *a* values between 3 and 10 mg m$^{-3}$ in adjacent San Francisco Bay (http://sfbay.wr.usgs.gov/access/wqdata/) during the same period, and 1–8 mg m$^{-3}$ in Artesian Slough during September and October. Six species of toxin-producing or harmful phytoplankton were abundant

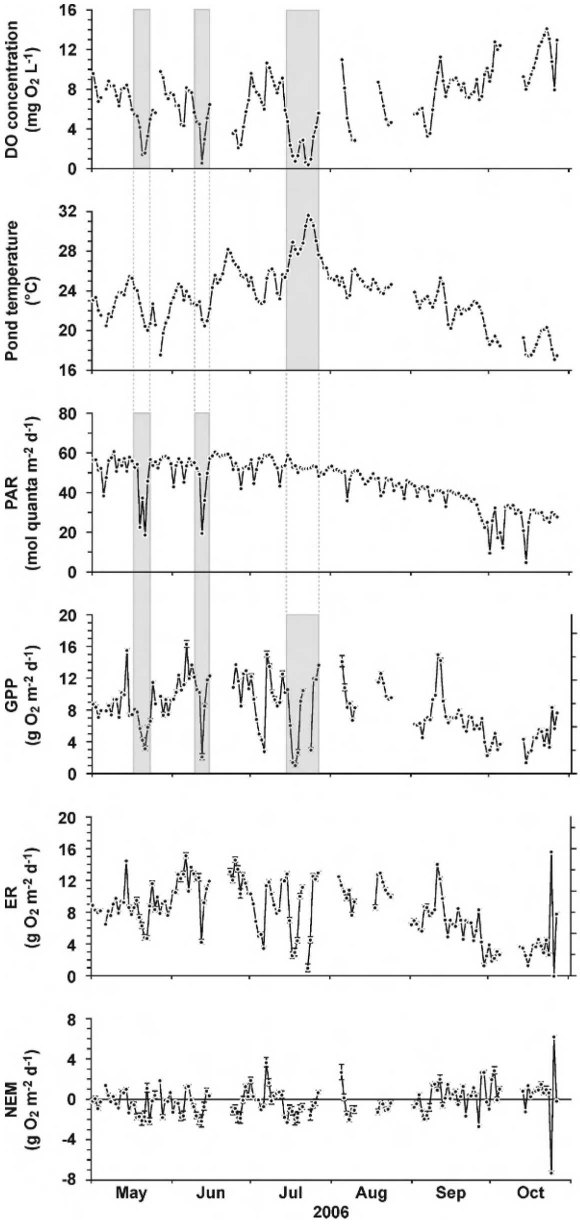

Figure 3. Pond A18 May–October 2006 daily mean DO concentration, pond temperature, photosynthetically active radiation, gross primary production (± 1 s.d.), ecosystem respiration (± 1 s.d.), and net ecosystem metabolism (± 1 s.d.). Shaded areas highlight periods of low DO and GPP coincident with extreme high pond temperature or low PAR. Standard deviations are derived from three different equations used for the computation of the reaeration coefficient. Data gaps are due to discarded DO data.

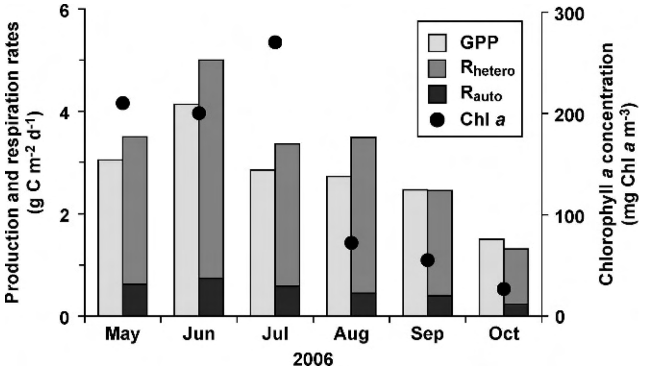

Figure 4. Monthly measurements (May–October 2006) of chlorophyll *a* concentration, estimates of autotrophic respiration ($R_{auto}$), heterotrophic respiration ($R_{hetero}$) and gross primary production (GPP; 7-d mean values centered on Chl *a* sampling dates) in Pond A18.

in more than one sample collected in Pond A18: *Alexandrium* sp., *Aureococcus anophagefferens* (Hargraves et Sieburth), *Chattonella marina* (Subrahmanyan), *Karenia mikimotoi* (Mikyake et Kominami), *Anabaenopsis* sp., and *Anabaena* sp. Of these six harmful species, only *C. marina* and *K. mikimotoi* were also present outside the pond in Artesian Slough, and both species had substantially lower biomass in the slough than within the pond.

## Ecosystem Metabolism Parameters

Daily rates of gross primary production and ecosystem respiration ranged from 1.06–16.34 g $O_2$ $m^{-2}$ $d^{-1}$ (May–October average = 8.17 g $O_2$ $m^{-2}$ $d^{-1}$ ≡ 2.79 g C $m^{-2}$ $d^{-1}$), and 0.01–15.64 g $O_2$ $m^{-2}$ $d^{-1}$ (average = 8.25 g $O_2$ $m^{-2}$ $d^{-1}$ ≡ 3.10 g C $m^{-2}$ $d^{-1}$), respectively (Figure 3). Production and respiration covaried seasonally and were highly correlated ($r^2 = 0.82$; $p < 0.001$). Estimates of GPP and ER were the same regardless of which reaeration coefficient equation was used (see Appendix A); average standard deviations between equations were 0.13 and 0.16 g $O_2$ $m^{-2}$ $d^{-1}$ for GPP and ER, respectively. We report metabolic rates using an average diffusion term.

Daily gross primary production appeared to be partly controlled by irradiance (positive linear relationship; $r^2 = 0.32$; $p < 0.001$). Specifically, sharp drops in GPP and DO concentration in May and June coincided with sharp drops in solar radiation (shaded areas on Figure 3). The decreasing trend of GPP starting in early August occurred synchronously with the late summer decrease in irradiance (Figure 3). DO depletion was also linked to weather events. A severe drop of GPP and DO concentration during the third week of July coincided with a heat wave and abrupt increase in pond temperature above 28°C (Figure 3).

Monthly autotrophic and heterotrophic respiration rates ranged from 0.23–0.74 g C $m^{-2}$ $d^{-1}$ (mean = 0.46 g C $m^{-2}$ $d^{-1}$; s.d. = 0.20), and from 1.00–4.26 g C $m^{-2}$ $d^{-1}$ (mean = 2.40 g C $m^{-2}$ $d^{-1}$;

s.d. = 1.15), respectively (Figure 4). This implies that $R_{auto}$ represented between 12.9% and 18.4% (mean = 16.4%; s.d. = 1.9%) of ecosystem respiration, and between 15.6% and 20.6% (mean = 17.4%; s.d. = 2.1%) of gross primary production. As the pond was not colonized by vascular plants or macroalgae, and no benthic microalgae species, easily re-suspended from the sediments by wind waves, were observed in our water samples, we attribute all $R_{auto}$ to phytoplankton.

Pond A18 tended to be mostly net heterotrophic (ER > GPP) from May to August and either balanced or net autotrophic (GPP = ER or GPP > ER) in September and October (Figure 4). This seasonal shift is reflected in the trend of increasing DO concentration from August to October, concurrent with decreasing GPP and ER (Figure 3).

Net ecosystem metabolism ranged from $-7.27$ to $6.22 \text{ g } O_2 \text{ m}^{-2} \text{ d}^{-1}$ ($\equiv -3.01$ to $1.95 \text{ g C m}^{-2} \text{ d}^{-1}$) with a May–October average of $-0.09 \text{ g } O_2 \text{ m}^{-2} \text{ d}^{-1}$ ($\equiv -0.31 \text{ g C m}^{-2} \text{ d}^{-1}$; Figure 3). Thus, Pond A18 had a balanced net metabolism over the study period. The total GPP during 6 months of observation in Pond A18 was $519 \text{ g C m}^{-2}$ ($\equiv 1521 \text{ g } O_2 \text{ m}^{-2}$). Over the 330 ha of the pond, this translates to 1,713 metric tons of organic carbon produced.

## DISCUSSION

### Photosynthesis and Respiration in Pond A18

Continuous DO measurements in Pond A18 showed that the shallow ponds connected to San Francisco Bay sustain areal gross primary productivity ($8.17 \text{ g } O_2 \text{ m}^{-2} \text{ d}^{-1}$) roughly double the magnitude of the world's most productive estuaries, such as Chesapeake Bay ($4.8 \text{ g } O_2 \text{ m}^{-2} \text{ d}^{-1}$; Kemp et al. 1997), and on par with highly productive tidal marsh creeks (Caffrey 2004). In the pond, primary production was realized in 0.7 m average depth as compared with 7 m average depth in Chesapeake Bay. Thus, on a volumetric basis ($\text{g } O_2 \text{ m}^{-3} \text{ d}^{-1}$), Pond A18 was 17-fold more productive than Chesapeake Bay. Primary production in Pond A18 was more than 5-fold that in shallow subtidal habitats of South San Francisco Bay, even during the spring bloom ($1.55 \text{ g } O_2 \text{ m}^{-2} \text{ d}^{-1}$; Caffrey et al. 1998). From a regional perspective, these ponds are important sources of organic matter and energy to fuel production in aquatic food webs. This result is not surprising because the ponds are shallow, high-light and high-nutrient habitats that sustain fast phytoplankton growth and high biomass accumulation. The median phytoplankton growth rate in Pond A18 ($0.91 \text{ d}^{-1}$) corresponded to a biomass doubling time of only 18.3 hours, so these ponds function as bioreactors that produce new biomass at rates approaching the maximum capacity of algal cells to divide.

Our study further showed that the high rates of phytoplankton photosynthesis were balanced by equally high rates of community respiration. The synchronous and proportional responses of ER to decreases in GPP suggest that respiration was tightly linked to autochthonous production, so exogenous sources of organic matter contribute little to system metabolism. This finding is similar to that of Caffrey et al. (1998) who showed that photosynthesis in South San Francisco Bay is nearly balanced by benthic and pelagic respiration. This result was expected for Pond A18 where levees prevent organic matter inputs from surrounding wetlands and the volume of estuarine water entering at each tide is negligible compared to the pond's volume. Although there were small seasonal changes, net ecosystem metabolism of Pond A18 was approximately balanced over daily and seasonal time scales (Figures 3, 4). However, this equilibrium is delicately poised because short-term disruptions of photosynthesis led to rapid depletions of oxygen that persisted for days. These hypoxic events were probably linked to weather events: cloudiness from storms in late May and mid June when daily solar radiation dropped abruptly, and a heat wave in July when pond temperatures rose above 28°C for 10 consecutive days (Figure 3). The inhibitory effect of high temperature on phytoplankton photosynthesis is well documented, and temperatures above 30°C inhibit growth or cause mortality of many temperate phytoplankton species (Butterwick et al. 2005).

### Ecological Valuation of Ponds as Feeding Habitats for Birds

Most of the oxygen consumption in Pond A18 was heterotrophic respiration. This implies high potential production rates of consumers, including invertebrates and fish used as the forage base by millions of shorebirds and waterfowl that flock to San Francisco Bay's ponds (Warnock et al. 2002). The carrying capacity of shallow pond habitats is determined by the pathways and efficiencies of carbon (and energy) transfer from phytoplankton to consumers, which are unknown. However, we can estimate bounds on the carrying capacity measured as potential production rates of forage organisms in Pond A18. Our approach routed algal NPP through a simple pelagic food web leading to production of small planktivorous fish that are harvested by piscivorous birds (e.g., American white pelican, double-crested cormorant *Phalacrocorax auritus*, Caspian tern *Hydroprogne caspia*, Forster's tern *Sterna forsteri*), or a benthic food web producing invertebrates harvested by probing shorebirds (western sandpiper *Calidris mauri*) and diving benthivores (lesser scaup *Aythya affinis*, greater scaup *Aythya marila*, ruddy duck *Oxyura jamaicensis*, eared grebe *Podiceps nigricollis*). Knowing that autotrophic respiration rate represented on average 17.4% of GPP, we estimated NPP over the study period to be 82.6% of GPP, i.e. 428.8 g C $m^{-2}$. We assumed fixed GGEs based on published measurements. Given the complexity of real food webs and high variability of growth efficiencies, we addressed the uncertainty of forage production by comparing efficient algal-based food webs with inefficient detrital food webs in which all algal production is routed through heterotrophic bacteria and then to benthic suspension feeders or protistans before it becomes available to metazoan zooplankton and finally to planktivorous fish. True forage production probably falls between these extremes, so our approach estimated bounds on the potential forage production of different consumer groups. However, bacterial production is small relative to algal production in nutrient-rich water bodies (Berglund et al. 2007), so the true forage production in habitats such as Pond A18 may be close to the upper bounds presented here.

Results showed that potential production of planktivorous fish was between 1.7 and 24.7 g C $m^{-2}$ within a 6 month period, assuming that all primary production is routed through the pelagic food web (Figure 5). This range brackets measures of fish yield as a fraction of primary production in marine ecosystems (Nixon 1988) and the mean fish productivity (10.9 g C $m^{-2}$ $y^{-1}$) measured in 10 estuaries (Houde and Rutherford 1993). The wet-weight mass of small planktivorous fish, such as year-old Atlantic silverside (*Menidia menidia*), is about 10 g (Conover and Ross 1982), corresponding to about 0.5 g C. Therefore, if all the primary production in Pond A18 is routed through a simple pelagic food web it can support production equivalent to 3–49 small planktivorous fish per square meter, or between 11 and 163 million fish within the 330-ha pond in this 6 month period. Similar calculations yield estimates of potential invertebrate production in the shorter, more efficient benthic food web of 23.6–94.3 g C $m^{-2}$ in 6 months (Figure 5), a range comparable to measured productivity of estuarine bivalves (see Table 7 in Wilson 2002). Using 0.004 g C as the tissue biomass of small bivalves, such as the Asian clam *Corbula amurensis* (Cole et al. 1992), this calculation implies a pond-scale secondary production equivalent to 19–78 billion clams from May through October. The high algal primary production of Pond A18 implies high rates of forage production for the diverse assemblages of birds that feed in these pond habitats around San Francisco Bay.

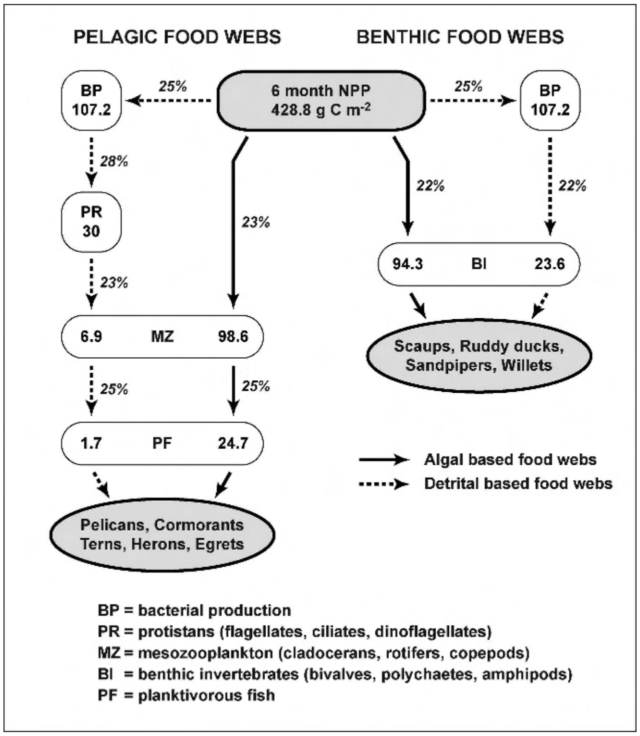

Figure 5. Idealized food webs and potential forage production (g C $m^{-2}$) in Pond A18 based on net primary production of 428.8 g C $m^{-2}$ over the 6 month sampling period. Carbon is transferred to pelagic or benthic consumers through algal-based (plain arrows) and bacterial-based (dashed arrows) food webs. Percentages next to arrows are gross growth efficiencies.

Our approach illustrates how easily measured primary production can be transformed into estimates of forage production as a measure of the energetic carrying capacity of estuarine ponds. Carrying capacity is expressed in units (production of fish and clams) that are meaningful for restoration-project managers. Application of this approach across different habitat types can provide project designers a method for comparing the ecological value of those habitats and an objective basis for setting target allocations of newly created habitats by the functions they provide.

## Caveats and Hypothesis for Adaptive Restoration Actions

Our study provides the first measurement of primary production in the former salt ponds of

San Francisco Bay, and it reveals a high potential forage production and energy supply to shorebirds and waterfowl. However, measures of production and carbon supply to consumers do not provide the complete information required for ecological valuation of habitats, and we offer three caveats. First, carrying capacity is determined by the quality and packaging of organic carbon produced as well as carbon supply rate. Most of the algal biomass in Pond A18 was in the form of phytoplankton. However, some other shallow ponds around San Francisco Bay are colonized by dense macroalgal beds, i.e., biomass packaged in a form that is not easily accessible to consumers and accumulates to degrade water and habitat quality. Success in attaining habitat goals of this restoration project requires new knowledge to identify which pond habitat types promote growth of macroalgae and which promote growth of phytoplankton. Second, there is great variability among phytoplankton species in their accessibility and food value to consumers. Some species in Pond A18 are of high nutritional value such as diatoms (*Nitzschia closterium*, *Cyclotella* spp.), cryptophytes, and *Mesodinium rubrum*. However, other species are toxic (dinoflagellates *Alexandrium* sp., *K. mikimotoi*) or impair feeding and metabolism of animals (*A. anophagefferens*). These taxa often occur in habitats such as Pond A18 with long residence time and high organic content (Gobler et al. 2005). This is in contrast to the waters of San Francisco Bay which have not historically supported harmful algal blooms (Cloern and Dufford 2005). Third, although high algal biomass can support high rates of animal production (Figure 5), it also leads to high system metabolism and susceptibility to episodes of hypoxia when weather events, such as storms and heat waves, trigger declines in photosynthetic oxygen supply (Figure 3). This can lead to hypoxia events in the adjacent sloughs and in the bay.

Shallow estuarine ponds are high-productivity bioreactors that are functionally analogous to aquaculture ponds, except their invertebrate and fish production are harvested by birds instead of humans. From a restoration perspective, these habitats are beneficial because of their food supply function, but detrimental because of their potential to produce toxic or inedible algae and their susceptibility to hypoxic events. Adaptive management of San Francisco Bay's former salt ponds provides an opportunity to determine, empirically, how algal biomass and quality respond to hydraulic manipulations through their control of flushing rate and residence time. We conclude with a testable hypothesis that emerges from our study and can guide adaptive management as the restoration process evolves: algal biomass and food quality in shallow tidal ponds vary with tidal flushing rate; organic content, prevalence of toxic and harmful species, and occurrences of anoxia/hypoxia decrease as flushing rate increases; algal biomass can be manipulated through hydraulic controls to optimize the food supply to consumers and minimize the harmful consequences of excess biomass accumulation.

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## APPENDIX A

Here we detail the methodology used to calculate volumetric reaeration coefficients $k_a$. O'Connor (1983) developed a relationship between the transfer coefficient of sparingly soluble gases and wind velocity, based on the liquid film and surface renewal concepts:

$$K_L = \left(\frac{D_w}{v_w}\right)^{2/3} \times \left(\frac{\rho_a}{\rho_w}\right)^{1/2} \times \frac{\kappa^{1/3}}{\Gamma_0,} \times U^* \qquad \text{(A1)}$$

where $K_L$ is the liquid-phase oxygen mass transfer coefficient (m d$^{-1}$), $v_w$ is the kinematic viscosity of water calculated from Eq. A2–A4 (m$^2$ s$^{-1}$), $D_w$ is the diffusivity of $O_2$ in water calculated from Eq. A5

($m^2\ s^{-1}$), $\rho_a$ is the density of air calculated from Eq. A6 ($kg\ m^{-3}$), $\rho_w$ is the density of water calculated according to IES-80 ($kg\ m^{-3}$, UNESCO 1981), $\kappa$ is the dimensionless Von Karman constant (= 0.4), $\Gamma_0$ is the dimensionless viscous sublayer thickness (= 6.5 for most lakes and reservoirs; Wool et al. 2001), and $U^*$ is the wind shear velocity calculated from Eq. A7 ($m\ d^{-1}$).

The kinematic viscosity of water is the ratio of the dynamic viscosity ($\mu_w$, in $kg\ m^{-1}\ s^{-1}$) and the density of water and was calculated hourly:

$$v_w = \frac{\mu_w}{\rho_w}. \quad \text{(A2)}$$

The dynamic viscosity of water was calculated hourly according to Sündermann (1986):

$$\mu_w = \mu_{pw} \times \Big(1 + \big(5.185 \times 10^{-5} \times T + 1.0675 \times 10^{-4}\big) \times \left(\frac{\rho_w \times S}{1806.55}\right)^{1/2} + \big(3.3 \times 10^{-5} \times T + 2.591 \times 10^{-3}\big) \times \left(\frac{\rho_w \times S}{1806.55}\right)\Big) \quad \text{(A3)}$$

where $\mu_{pw}$ is the dynamic viscocity of pure water ($kg\ m^{-1}\ s^{-1}$), $S$ is water salinity, $T$ is water temperature (°C).

The dynamic viscocity of pure water, expressed as a function of water temperature, was calculated hourly according to Sündermann (1986):

$$\mu_{pw} = 1.002 \times 10^{-3} \times 10^{\left(\frac{1.1709 \times (20 - T) - 1.827 \times 10^{-3} \times (T - 20)^2}{T + 89.93}\right)}. \quad \text{(A4)}$$

The diffusivity of $O_2$ in water was calculated hourly according to Cussler (1984):

$$D_w = \frac{k_B \times T}{4\P \times \mu_w \times R_o} \quad \text{(A5)}$$

where $k_B$ is the Boltzmann's constant (= $1.3806503 \times 10^{-23}\ m^2\ kg\ s^{-2}\ K^{-1}$), $T$ is water temperature (K), and $R_o$ is the radius of the $O_2$ molecule (= $1.72 \times 10^{-10}$ m; Cussler 1984).

The density of air was calculated hourly using the following formula:

$$\rho_a = \frac{P_{atm} - P_v}{R_d \times T_{air}} + \frac{P_v}{R_v \times T_{air}} \quad \text{(A6)}$$

where $P_{atm}$ is the atmospheric pressure (Pa), $P_v$ is the water vapor pressure (Pa), $R_d$ is the gas constant for dry air (= $287.05\ J\ kg^{-1}\ K^{-1}$), $R_v$ is the gas constant for water vapor (= $461.495\ J\ kg^{-1}\ K^{-1}$), and $T_{air}$ is air temperature (K).

Wind shear velocity was calculated hourly using the following equation:

$$U^* = \sqrt{C_d} \times U_{10} \times 86400 \quad \text{(A7)}$$

where $C_d$ is the dimensionless drag coefficient (= 0.0011) and $U_{10}$ is the wind speed at 10 m height ($m\ s^{-1}$), calculated according to Eq. A8. Union City wind speed data were normalized to 10 m assuming the logarithmic wind profile (Ro and Hunt 2006):

$$U_{10} = U_z \times \frac{\ln\left(\frac{10}{z_0}\right)}{\ln\left(\frac{z}{z_0}\right)} \quad \text{(A8)}$$

where $z$ is the height of actual wind speed measurement (= 6.9 m in Union City), $U_z$ is the wind speed measured in Union City ($m\ s^{-1}$), and $z_0$ is the surface roughness length (= $10^{-5}$ m for smooth water surface; Ro and Hunt 2006).

Hartman and Hammond (1985) compiled gas exchange rates measured in San Francisco Bay with those for other wind-dominated systems and derived an equation for predicting the gas transfer coefficient in wind-dominated systems:

$$K_L = 34.6 \times R_{visc} \times \left(D_{w,20^\circ C} \times 10^4\right)^{1/2} \times U_{10}^{3/2} \quad \text{(A9)}$$

where $R_{visc}$ is the ratio of the kinematic viscosity of pure water at 20°C to the kinematic viscosity of water at the measured temperature and salinity (calculated using Eq. A2–A4) and $D_{w,20^\circ C}$ is the diffusivity of $O_2$ at 20°C calculated using Eq. A5 ($m^2\ s^{-1}$).

Ro and Hunt (2006) recently published a new, unified equation for oxygen mass transfer coefficients based on gas transfer data published during the last 50 yr:

$$K_L = 0.24 \times 170.6 \times \left(\frac{D_w}{v_w}\right)^{1/2} \times \left(\frac{\rho_a}{\rho_w}\right)^{1/2} \times U_{10}^{1.81}. \quad \text{(A10)}$$

We finally calculated volumetric reaeration coefficients ($k_a$, $h^{-1}$) according to Cox (2003):

$$k_a = \frac{1}{24} \times \frac{K_L}{H} \quad \text{(A11)}$$

where $H$ is the mean depth of the pond (= 0.7 m).

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science for a changing world

# Funky Green Biomass Machines: The Former Salt Ponds of South San Francisco Bay, CA

Julien Thébault[2], Tara S. Schraga[1], James E. Cloern[1], and Eric G. Dunlavey[3]

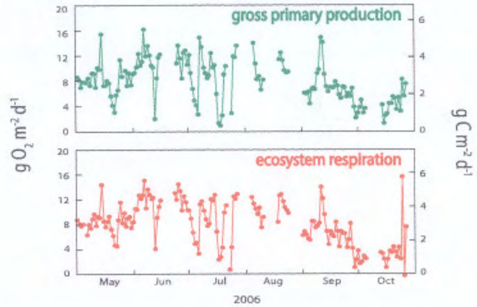
## Mysterious new habitats

Over 6110 ha of the salt ponds surrounding South San Francisco Bay have been decommissioned, most as part of the largest wetlands restoration program in the western United States. These open water ponds are critical habitat for millions of birds, and program managers must determine the appropriate balance between ponds versus salt marsh, knowing both are essential habitats for endangered bird species. There is little information available on the ecosystem functions provided by these habitats, such as primary production.

We explored local production in Pond 18A as a representative system. Prior to opening in 2005, pond salinity was 110, presently the salinity ranges 2-22. Pond A18 is surrounded by a levy system with openings for the inlet and outlet.

## What we discovered

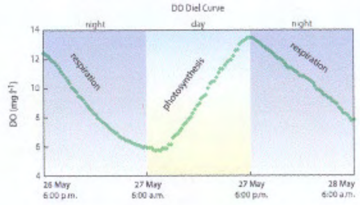
Remarkably high gross primary production (GPP mean = 8.2 g $O_2$ $m^{-2}$ $d^{-1}$), DOUBLE the rate of the world's most productive estuaries!



- High rates of photosynthesis were balanced by equally high rates of ecosystem respiration suggesting tight coupling and turnover of GPP.
- 84% of the respiration was heterotrophic implying high production rates of invertebrates and fish used as the forage base by waterbirds.

## How we calculated primary production

We converted high-resolution timeseries of dissolved oxygen (O2) into daily gross primary production and whole-ecosystem respiration (ER).



dissolved oxygen rate of change
$dO_2/dt = GPP - ER + D$

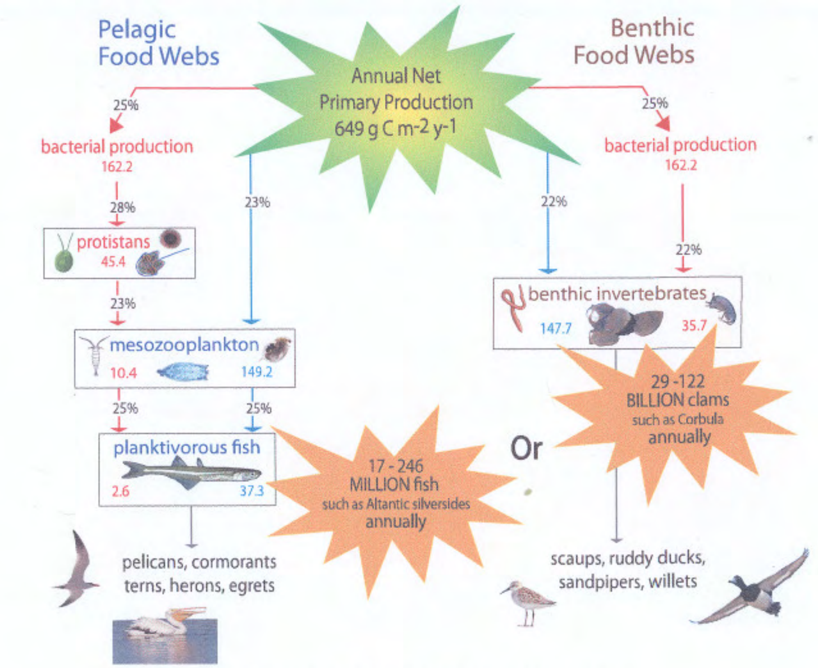
where D = atmospheric $O_2$ exchange. We assumed accrual from other water sources to be negligible due to the pond's long residence time (15-50 days).

GPP was calculated as the average of **daytime diffusion-corrected rates of oxygen change** and ER was calculated as average of **nighttime diffusion-corrected rates of oxygen change**. Volumetric rates were multiplied by mean pond depth (0.7 m) to yield areal rates presented here.

Calculations are detailed in the handout.

## These ponds are for the birds

Idealized food webs and potential production of bird forage biota in Pond A18 based on annual net primary production (NPP). We transfer all NPP to either pelagic or benthic consumers through efficient algal-based (⟶) and inefficient bacterial-based (⟶) food webs, resulting in upper and lower bounds on carrying capacity. Percentages represent growth efficiencies, numbers represent production in grams Carbon $m^{-2}$ $y^{-1}$.



Pelagic Food Webs

Annual Net Primary Production 649 g C $m^{-2}$ $y^{-1}$

Benthic Food Webs

25%
bacterial production 162.2
28%
protistans 45.4
23%
23%
mesozooplankton 10.4 149.2
25%
25%
planktivorous fish 2.6 37.3

17 - 246 MILLION fish such as Altantic silversides annually

pelicans, cormorants terns, herons, egrets

25%
bacterial production 162.2
22%
22%
benthic invertebrates 147.7 35.7

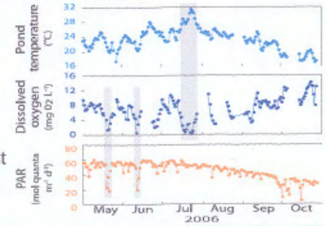
Or

29 -122 BILLION clams such as Corbula annually

scaups, ruddy ducks, sandpipers, willets

## Quantity does not equal quality

- The fast system metabolism is susceptible to weather events, such as storms and heat waves, triggering photosynthesis interruption resulting in oxygen depletion and hypoxia events
- Some phytoplankton in Pond A18 are toxic taxa that occur in habitats with long residence time and high organic content.
- Other ponds are densely colonized by macroalgae - biomass that is not easily accessible to consumers and degrades water quality.



## What to take home

- These first measurements of primary production in the former salt ponds of San Francisco Bay quantify the high potential forage production and energy supply to shorebirds and waterfowl.
- The ponds are high-productivity bioreactors that are functionally analogous to aquaculture ponds, except their invertebrate and fish production are harvested by birds instead of humans.
- From a restoration perspective, these habitats are beneficial because of their food supply function, but detrimental because of their potential to produce toxic or inedible algae and susceptibility to hypoxic events. Adaptive management of San Francisco Bay's former salt ponds provides an opportunity to learn how algal biomass and quality respond to hydraulic manipulations through their control of flushing rate and residence time.

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