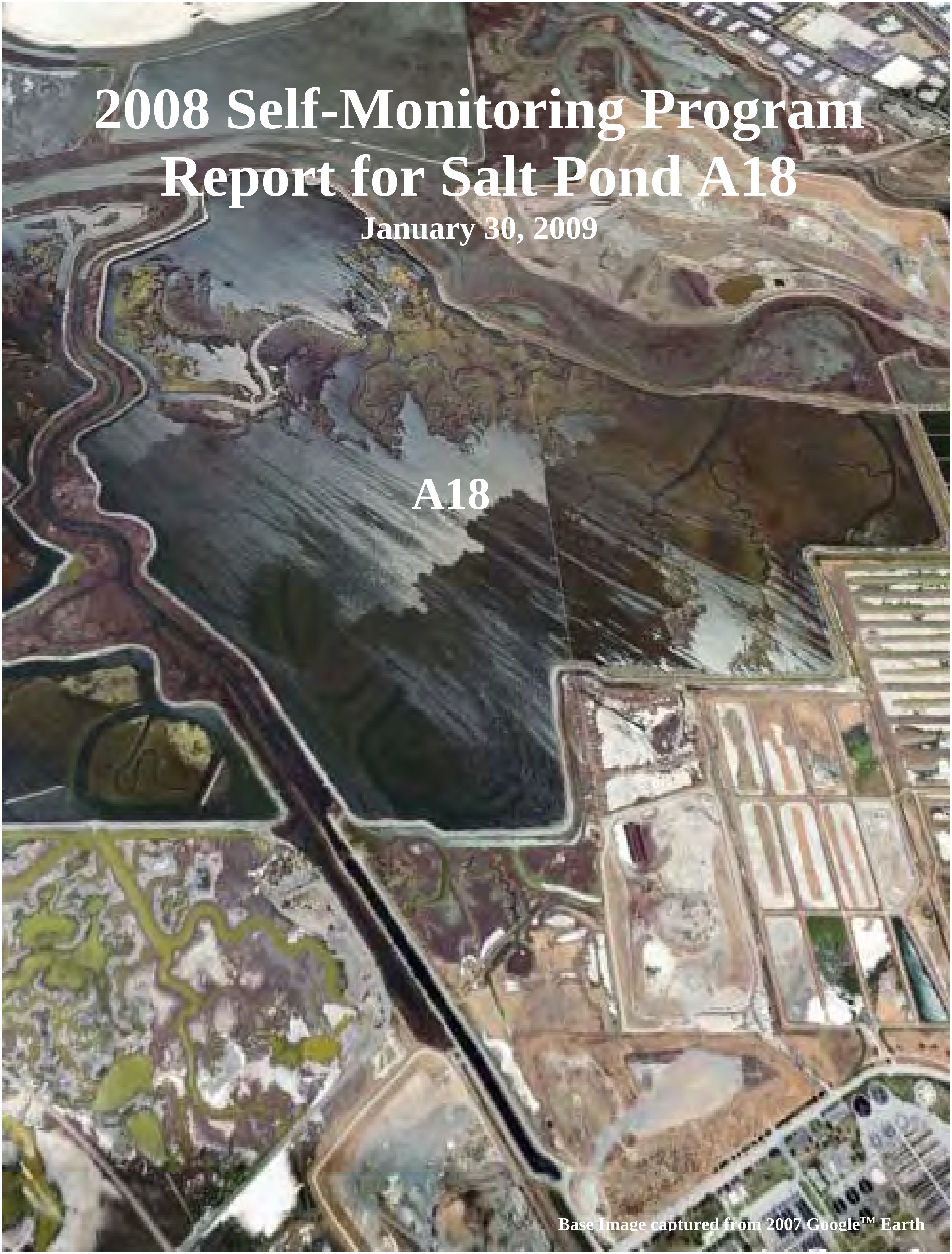
2008 Self-Monitoring Program Report for Salt Pond A18

January 30, 2009



Base Image captured from 2007 Google™ Earth

Self-Monitoring Program

2008 Annual Report

Salt Pond A18 in Santa Clara County

Order No. R2-2005-0003

Prepared for:

California Regional Water Quality Control Board
San Francisco Bay Region
1515 Clay Street, Suite 1400
Oakland, CA 94560

Prepared by:

City of San Jose
Environmental Services Department
200 E. Santa Clara, 10th Floor
San Jose, CA 95113

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I. Introduction

This report summarizes the results of the 2008 water quality sampling conducted for Salt Pond A18 in Santa Clara County. Monitoring activities occurred from May 1st 2008 through October 31st 2008. This monitoring was performed by City of San Jose staff according to 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 fourth year of monitoring following the initial release of water from Salt Pond A18 on February 17, 2005 and the beginning of Continuous Discharge Operations on May 10, 2005. Adaptive pond management included measures begun in 2005 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 to improve operational efficiency and minimize pond closures to maintain in-pond water quality and maximize flow through the pond. This operation was consistent with the recommendations in the 2005 Annual Self Monitoring Program Report for Salt Pond A18. The streamlined gate operations procedures implemented in 2006 were again employed in 2007, resulting in similar levels of success. However, operations in 2008 differed from those in the previous two years of operation. Now the initial response to low pond DO was to initiate additional receiving water monitoring rather than immediately closing gates.

Between 2006 and 2008, the City voluntarily performed supplemental monitoring in an effort to gain a better understanding of pond dynamics. This additional monitoring included sampling of nutrients, mercury/methyl mercury, suspended solids and extra chlorophyll *a* sampling at several pond sites. 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 dynamics and 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 VI).

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. Salt Ponds A16 and A17 are managed by USFWS and are located on the opposite side of Artesian Slough from Salt Pond A18. Salt Pond A16 also discharges into Artesian Slough. City staff also communicated via teleconference with the Regional Water Board to discuss the 2007 Annual Report and a follow-up submittal to the 2007 Report. Appendix IV contains a summary 2008 communications related to management of Salt Pond A18.

Figure 1 shows the location of Salt 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 Salt Pond A18:

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

Table 1. Salt 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. Salt 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 Salt 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 Salt 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 [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 Salt Pond A18 sediment mercury and methyl mercury is required in August or September of each year.

II. Methods and Results

This section summarizes 2008 monitoring activities.

A. Quality Assurance/Quality Control

Instruments used for sampling Salt 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 calibration 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.

Calibrations for pH were performed using a 2-point calibration (pH 7 and pH 10 buffers) to establish a pH slope. Calibrations for conductivity were performed using either a 10,000 micro Sieman or a 50,000 micro Sieman standard. Post-deployment calibration verifications for pH and conductivity were performed using the same standards. For both parameters, a target range within ±5% of the theoretical was established to determine data validity. Data that fell outside of this range were considered invalid for pH or Conductivity and were not reported.

There were no post-deployment verification failures during 2008. However, sonde malfunctions occurred during two weeks (July 1 through July 8 and September 2 though September 9) and continuous data collected during those weeks was not immediately retrievable. These sonde malfunctions occurred with units deployed in Salt Pond A18 and were attributed to water leaking into the sonde body or the data connection port of the sonde unit. In both instances, YSI repair technicians recovered a portion of the logged data later and this recovered data is included in the data summaries of this report. Please note that post-deployment accuracy checks were not performed for these two data sets since the sondes were non-responsive. In addition, immediate management decisions could not be made from these data in 2008 since the information was recovered several weeks following collection. However, data variability and ranges appeared normal and reasonable and these two data sets were included based on best professional judgment.

For the 2008 monitoring season, the post-deployment measurement error for reported water quality parameters was in the following ranges:

1. For dissolved oxygen: –4.0% to +3.8% (median +0.5%)
2. For pH: –2.2% to +3.3% (median +0.4%)
3. For conductivity: –3.8% to +1.2% (median +1.3%)

B. Continuous Monitoring

Receiving water in Artesian Slough (Station 5) and Salt Pond A18 discharge (Station D) were monitored continuously for temperature, practical salinity, pH, and dissolved oxygen during the dry season from May 1, 2008 to October 31, 2008 (Figure 1). Monitoring equipment consisted of YSI model 6600 sonde units fitted with the appropriate sensors. This equipment was chosen for its accuracy and reliability in monitoring dissolved oxygen concentrations in environments having variable salinities and biological fouling. As in previous years, City staff maintained a rigorous cleaning and maintenance schedule of this normally reliable equipment. The problems with dissolved oxygen measurements encountered in the early part of 2006 were corrected in 2007 and 2008 by installation of state-of-the-art, optical-based dissolved oxygen sensors (ROX™) on all continuous sonde units. This equipment upgrade prevented any loss of dissolved oxygen data due to equipment fouling or probe failure for 2007 and 2008.

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 strategies and 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 collected data and evaluating weekly 10th percentile dissolved oxygen readings for the pond discharge. Weekly data summaries were reported to Regional Water Board staff (usually Tuesdays or Wednesdays) and appropriate City staff implemented adaptive management changes.

Temperature

Water temperature in the receiving water (Station 5; Figure 1) and at the Salt Pond A18 discharge gate (Station D), under both discharge and non-discharge conditions, are shown in Table 3. Salt 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. 2008 Continuous Temperature Monitoring Results (ºC)

Site/Condition	Minimum	Maximum	Mean	Median	# of Measurements (n)
Artesian Slough	19.2	29.9	24.9	25.1	17645
A18 Discharge	13.8	30.6	22.6	23.1	15392
A18 Non-Discharge	14.7	30.3	22.8	23.0	1923

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 Salt 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 -9.3ºC to 2.8ºC and averaged -2.3 ºC over 3,848 hours of monitored discharge. On average, pond temperatures were found 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).

Salt 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 Salt 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 2008 monitoring period (Table 4).

Table 4. 2008 Continuous Salinity[2] Monitoring Results (PSU[1])

Site/Condition	Minimum	Maximum	Mean	Median	# of Measurements (n)
Artesian Slough	0.9	18.6	3.5	3.0	17645
A18 Discharge	18.0	29.9	25.6	26.8	15392
A18 Non-Discharge	18.2	29.8	26.1	28.2	1922

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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.

Salinity increased in Salt 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 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.

pH

The pH of the receiving water (Station 5; Figure 1) and of water at Salt Pond A18 discharge gate (Station D), under both discharge and non-discharge conditions for 2008, are shown in Table 5. Salt 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. 2008 Continuous pH Monitoring Results

Site/Condition	Minimum	Maximum	Mean	Median	# of Measurements (n)
Artesian Slough	6.9	8.9	7.4	7.3	17645
A18 Discharge	8.1	9.9	8.8	8.6	15397
A18 Non-Discharge	8.1	9.8	8.7	8.5	1917

The WDR requires that the pH objective of 6.5 to 8.5 be met either in the discharge or in the receiving water. During 2008 operations, pH in the receiving water rose above this range specified in the Basin Plan Objectives on seven separate days (Table 13), all of which occurred in the first half of the monitoring season. This is in contrast to previous monitoring years when all requirements for pH were satisfied during the entire dry season. Each of these events was brief (durations ranged from 15 minutes to 2 hrs) and corresponded to extremely low tides with shallow (3 feet) water depths. These tidal conditions have characteristically been when the maximum surface water pH conditions have been measured. The most significant of these events occurred from 5/8/08 through 5/11/08 with elevated pH over short durations measured in the receiving water on each day during extreme low tides.

The in-slough conditions during each of these events can be characterized as very low volume, shallow fresh water. Based on the duration and conditions during these events, 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 levels than surface water regardless of tide or pond discharge status (Tables 8 and 9). Salt Pond A18 and Salt Pond A16 discharge waters, both of which have higher pH than average ambient slough surface water, may also influence bottom pH at this time.

Based on the high pH event on 7/4/08, it is most likely the greater signal from higher pH bottom slough water that is responsible for the elevated pH readings at the surface. On 7/4/08, pH at the surface of the receiving water was measured at 8.6 at 9:45am and remained at 8.5 for more than an hour. The tide was an extremely low at the time (-2.0 MLLW at 9:56am) and Salt Pond A18 was discharging at approximately 47.6 cfs. In addition, by 7/4/08, Salt Pond A18 pH had dropped to 8.4, which is less than the measured slough pH at this time. So for the 7/4/08 event, which had identical tidal conditions to the other six pH events, it appears that Salt Pond A18 discharge was not causing receiving water pH to rise above 8.5. The Water Quality Control Plan for San Francisco Bay (Basin Plan) states that discharges shall not cause pH levels changes more than 0.5 units from ambient. Compared to similar tidal conditions in previous years (extreme low spring tides), surface pH conditions were not elevated more than 0.5 pH units under these conditions. The typical pH levels have been 8.3 – 8.4 units during daytime low spring tide conditions.

Unlike 2006 and 2007 when pond pH remained elevated during the summer months, pH was only elevated in Salt Pond A18 until late June 2008. During the first week of July 2008, there was a sharp decline in pH from 9.5 to 8.5 over one week (Figure 6) beginning on 7/1/08.

Despite the relatively elevated pH levels in the pond, and increased pond discharge time in 2008 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 2). It is also interesting to note that pond pH levels in the early part of 2008 were similar to those measured throughout 2006 and in the early part of the 2007 monitoring season with pond pH consistently at or above a pH of 9. However, similar to the declining pH trend observed in 2007, by the first week of July 2008, pH levels in Salt Pond A18 had decreased almost of a full unit and were consistently between 8.2 and 8.5 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 Salt 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 six times during the 2008 monitoring season. Five of these six low DO incidents were minor and occurred for brief periods. For example, on 19 May 2008, DO was below 5.0 mg/L for 30 minutes with a minimum DO concentration of 4.8 mg/L. All six incidents were reported to the Regional Water Board and appropriate adaptive management strategies were implemented as described below. The more persistent low DO receiving water incident is discussed below.

Table 6. 2008 Continuous Dissolved Oxygen Monitoring Results

Site/Condition	Minimum	Maximum	Mean	Median	# of Measurements (n)
Artesian Slough	3.2	10.3	6.6	6.6	17641
A18 Discharge	0.1	17.8	6.0	5.8	15365
A18 Non-Discharge	0.1	13.8	5.4	4.5	1920

Receiving water exhibits two regular and somewhat predictable DO patterns based on diurnal and tidal cycles. The diurnal pattern is one of lower DO at night and higher DO during the day when photosynthesis is occurring. The tidal pattern is associated with spring and neap tides and demonstrates the influence of variations in the volume of Bay water being pushed into Artesian Slough by the flooding tide. Spring tides, when high and low tides are most extreme and tidal currents are greatest, 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. Each of the incidences in 2008 occurred during or within one day of spring tides and were combined with regular overnight low DO patterns. Furthermore, because of the tidal stage during these times (flooding to high tides), discharge flow from Salt Pond A18 was lower in volume (discharge volume is greatest during low tide) and pond discharges were also mixing with a greater volume of receiving water, which dilutes any influence from pond discharges. Finally, one incident was observed in late August to early September where staff measured prolonged periods of low DO in the receiving water over five days.

Weekly measurements of Salt 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 1-26). 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 15 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 represents a substantial increase in trigger events compared to previous monitoring (six triggering events in 2007 and seven events in 2006). As exhibited in 2007, the 2008 trigger incidents occurred from the middle of July and after. 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, 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, and only when effects to receiving water were measured were the valve closures initiated.

Low Dissolved Oxygen Incident in Receiving Water

Between 29 August 2008 and 2 September 2008, staff observed a more significant occurrence of low DO concentrations in receiving waters. This period coincided with a new moon spring tide. Overnight DO was consistently below 5.0 mg/L reaching a minimum of 3.2 mg/L at the surface. As part of a separate ambient monitoring program, the City also conducted DO measurements in lower South Bay on 28 August 2008, consistently measuring low DO at locations far removed from Salt Pond A18 discharge influence. During this monitoring exercise, a minimum DO was observed at 2.3 mg/L in lower San Francisco Bay and 52% of DO measurements were found to be below 5.0 mg/L. Other researchers conducting monitoring in Lower South Bay confirmed the lower DO trend (personal communication, T. Schraga, USGS on 9/2/08). Salt Pond A18 DO was also extremely low during this time. However, this data was only retrieved well after the monitoring season due to a sonde malfunction. Despite not having pond water quality data immediately available, the City initiated discharge valve closures as an adaptive response due to the magnitude of the low DO in the receiving water. However, in light of the ambient Bay data and tidal stage, it is unlikely that Salt Pond A18 discharges contributed significantly to the low DO in the receiving water during this 5-day period. The low DO observed appears to have been a system-wide incident which also affected DO in Salt Pond A18. In addition to the data from Lower South Bay indicating a system-wide condition, current literature and scientific studies have documented that the distribution and intensity of hypoxia in estuaries is increasing worldwide.[2]

General Observations

Salt Pond water color and clarity changed throughout the monitoring season. Initially the pond was relatively clear compared to previous monitoring and exhibited a light brownish color. As the monitoring season progressed, water clarity declined and the pond color became greenish brown by mid-July and was observed green with some brown by the end of the monitoring season.

Filamentous macro-algae were less prevalent in 2008 than in 2007. Some algal mats were observed primarily along the eastern edge of the pond between May and June 2008. Algal mats covered from 5 – 15% 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. City staff updated the Regional Water Board regarding the amount of visible macro-algae in Salt Pond A18 via weekly email correspondence (Appendix IV).

There were no other unusual observations, odors or occurrences during continuous monitoring in 2008.

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[2] Tyler, R.M., D.C. Brady, T.E. Targett. 2008. Temporal and Spatial Dynamics of Diel-Cycling Hypoxia in Estuarine Tributaries. Estuaries and Coasts 32:123-145.

Table 7. Weekly 10th Percentile Dissolved Oxygen (DO) Concentrations (mg/L) for Pond A18 Discharge (2008). * 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 6th (6 days)	8.3	Discharge Gate fully open.
May 6th through 13th	7.5	Discharge Gate fully open.
May 13th through 20th	8.5	Discharge Gate fully open.
May 20th through 27th	6.4	Discharge Gate fully open.
May 27th through June 3rd	7.1	Discharge Gate fully open.
June 3rd through 10th	6.0	Discharge Gate fully open.
June 10th through 17th	6.7	Discharge Gate fully open.
June 17th through 24th	6.1	Discharge Gate fully open.
June 24th through July 1st	3.3	Discharge Gate fully open.
July 1st through 8th	N/A (0.2 based on recovered data)	Discharge Gate fully open. Due to a sonde malfunction, data for this week was not recovered until the end of monitoring season.
July 8th through 15th	0.2*	Discharge Gate fully open. Initiated weekly discrete monitoring at Artesian-02 to evaluate effect on bottom DO in receiving water. No adverse effect measured
July 15th through 22nd	1.8*	Discharge Gate fully open. Discrete receiving water monitoring. No adverse effect from pond discharge.
July 22nd through 29st	0.9*	Discharge Gate fully open. Discrete receiving water monitoring. No adverse effect from pond discharge.
July 29st through August 5th	2.3*	Discharge Gate fully open. Discrete receiving water monitoring. No adverse effect from pond discharge.
August 5th through 12th	2.6*	Discharge Gate fully open. Discrete receiving water monitoring. No adverse effect 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 12th through 19th	1.2*	Discharge Gate fully open. Discrete receiving water monitoring. No adverse effect from pond discharge.
August 19th through 26th	1.2*	Discharge Gate fully open. Discrete receiving water monitoring. No adverse effect from pond discharge.
August 26th through September 2nd	0.1*	Initiated 5 hr per night valve closure on 9/2/08 due to receiving water surface DO <5.0 mg/L from continuous sonde. Discrete receiving water monitoring. No adverse effect from pond discharge.
September 2nd through 9th	N/A	Continued discharge valve timing due to receiving water DO < 5.0 mg/L at the surface from continuous sonde. Due to a sonde malfunction, only some pond discharge data for this week was recovered at the end of the monitoring season. Discrete receiving water monitoring. No adverse effect from pond discharge.
September 9th through 16th	1.9*	Continued discharge valve timing. Discrete receiving water monitoring. No adverse effect from pond discharge.
September 16th through 23rd	2.9*	Discharge Gate fully open. Discrete receiving water monitoring. No adverse effect from pond discharge.
Septebmer 23rd through 30th	1.6*	Discharge Gate fully open. Discrete receiving water monitoring. No adverse effect from pond discharge.
September 30th through October 7th	1.5*	Discharge Gate fully open. Discrete receiving water monitoring. No adverse effect 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
October 7th through 14th	3.0*	Discharge Gate fully open. Discrete receiving water monitoring. No adverse effect from pond discharge.
October 14th through 21st	5.3	Discharge Gate fully open. Discrete receiving water monitoring. No adverse effect from pond discharge.
October 21st through 28th	1.3*	Discharge Gate fully open. Discrete receiving water monitoring. No adverse effect from pond discharge.
October 28th through 31st (4 days)	2.3	End of monitoring season

C. Discrete Monitoring

In addition to continuous water quality monitoring at Salt 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 have been summarized in Table 8. Although the WDR requires monitoring water quality parameters (temperature, salinity, DO, & pH) at the surface and bottom only, the entire water column was monitored at 1-foot intervals. These depth profiles 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 Salt 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.

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)
5/28/08 10:14	1	Ebb	Bottom	20.6	13.6	8.8	11.5	3.3	30.0
5/28/08 10:18	1	Ebb	Surface	23.5	0.9	7.3	10.2	2.1	30.0
6/18/08 15:05	1	Hi	Bottom	24.9	16.6	8.4	9.0	9.4	14.3
6/18/08 15:09	1	Hi	Surface	26.1	1.3	7.4	12.9	2.2	14.3
7/8/08 11:24	1	Lo	Bottom	26.7	0.7	7.4	7.5	6.9	51.5
7/8/08 11:25	1	Lo	Surface	26.7	0.6	7.4	7.9	4.8	51.5
8/19/08 14:20	1	Flood	Bottom	25.5	12.0	7.9	6.1	18.4	20.9
8/19/08 14:24	1	Flood	Surface	27.0	0.8	7.5	7.2	15.9	16.7
9/16/08 13:02	1	Flood	Bottom	24.2	10.1	7.8	6.3	11.9	17.9
9/16/08 13:04	1	Flood	Surface	26.4	0.9	7.5	7.1	1.7	17.9
10/21/08 12:00	1	Ebb	Bottom	19.9	20.4	8.2	6.0	6.2	30.8
10/21/08 12:02	1	Ebb	Surface	24.9	0.6	7.4	7.5	0.8	30.8
5/28/08 9:57	2	Ebb	Bottom	20.7	10.6	8.5	8.6	5.5	28.5
5/28/08 10:04	2	Ebb	Surface	23.1	1.7	7.3	9.5	3.0	28.5
6/18/08 14:35	2	Flood	Bottom	24.8	17.2	8.8	12.1	11.6	17.0
6/18/08 14:40	2	Flood	Surface	26.3	2.1	7.5	12.9	2.8	15.2
7/8/08 11:05	2	Ebb	Bottom	26.5	15.5	8.5	6.7	14.4	50.1
7/8/08 11:07	2	Ebb	Surface	26.7	6.0	7.8	7.1	3.2	50.1
8/19/08 13:53	2	Flood	Bottom	24.4	21.0	8.2	3.5	16.1	24.5
8/19/08 13:58	2	Flood	Surface	27.1	2.7	7.6	7.4	3.4	24.5
9/16/08 11:49	2	Flood	Bottom	22.8	19.7	8.3	5.7	11.9	36.3
9/16/08 11:53	2	Flood	Surface	25.5	4.3	7.7	7.1	5.0	32.8
10/21/08 12:10	2	Ebb	Bottom	20.5	15.8	8.4	8.0	16.4	32.2
10/21/08 12:13	2	Ebb	Surface	24.4	2.2	7.5	7.1	1.9	32.2
5/28/08 9:40	3	Ebb	Bottom	20.9	11.2	8.6	6.4	10.5	27.5
5/28/08 9:44	3	Ebb	Surface	22.5	2.4	7.3	8.8	3.6	27.5
6/18/08 14:18	3	Flood	Bottom	23.6	13.8	7.8	7.7	21.2	18.7
6/18/08 14:23	3	Flood	Surface	25.0	10.9	7.7	8.4	14.7	17.0
7/8/08 10:52	3	Ebb	Bottom	26.1	10.2	8.0	4.7	22.1	50.1
7/8/08 10:56	3	Ebb	Surface	26.5	7.7	7.8	5.5	11.7	50.1
8/19/08 13:35	3	Flood	Bottom	23.7	13.5	7.6	2.8	25.4	31.6
8/19/08 13:42	3	Flood	Surface	23.9	13.6	7.6	3.0	19.8	28.2
9/16/08 12:45	3	Flood	Bottom	21.8	14.6	7.7	3.6	44.0	21.9
9/16/08 12:49	3	Flood	Surface	22.0	14.3	7.7	3.5	28.5	21.9
10/21/08 12:35	3	Ebb	Bottom	20.0	17.5	8.2	3.9	16.3	33.1
10/21/08 12:41	3	Ebb	Surface	23.7	3.8	7.5	6.6	4.5	34.0
5/28/08 9:24	4	Ebb	Bottom	19.7	10.2	7.7	5.2	19.0	25.8
5/28/08 9:28	4	Ebb	Surface	20.9	6.1	7.6	6.7	13.0	25.8
6/18/08 13:53	4	Flood	Bottom	22.7	16.8	7.9	7.5	37.5	20.9
6/18/08 13:59	4	Flood	Surface	22.9	16.3	7.9	7.9	22.5	20.9
7/8/08 10:36	4	Ebb	Bottom	26.2	7.5	7.5	4.0	40.0	47.9
7/8/08 10:39	4	Ebb	Surface	26.2	7.4	7.5	4.2	26.4	49.0
8/19/08 13:16	4	Flood	Bottom	23.0	17.2	7.6	3.2	68.4	34.6
8/19/08 13:20	4	Flood	Surface	23.3	16.8	7.6	3.3	33.9	34.6
9/16/08 12:25	4	Flood	Bottom	20.9	18.6	7.8	3.5	59.0	26.0
9/16/08 12:31	4	Flood	Surface	21.0	18.3	7.8	3.4	32.6	26.0
10/21/08 12:51	4	Ebb	Bottom	20.4	13.0	7.8	3.3	18.5	34.0
10/21/08 12:55	4	Ebb	Surface	22.7	6.6	7.6	5.7	11.7	34.8

Discrete trigger monitoring

Additional discrete monitoring at station Artesian 02 began on 7/22/08 due to the 10th percentile weekly DO value in the pond falling below the 3.3 mg/L trigger for the previous week (Table 9). 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 in 2008. Rather than immediately implementing discharge valve closings as in prior years, the City continued the continuous circulation operations in Salt Pond A18 as well as initiating additional receiving water quality monitoring (trigged monitoring). The purpose this trigged monitoring was to determine whether continued discharges from Salt Pond A18 during periods of hypoxia were negatively affecting receiving water quality. This modification operation 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. 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 and ameliorate the effects of low pond DO on pond biota.

Under the revised management plan described in the City's Supplemental Report to the 2007 Salt 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.

Table 9. 2008 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)
7/22/08 9:52	2	Low	Bottom	22.5	18.3	8.5	6.6	55.4
7/22/08 9:54	2	Low	Surface	24.9	4.8	7.7	7.7	55.4
7/29/08 10:15	2	Flood	Bottom	24.0	18.3	8.1	5.1	36.8
7/29/08 10:18	2	Flood	Surface	25.7	3.8	7.5	7.6	36.8
8/5/08 13:23	2	Flood	Bottom	24.1	19.2	8.3	7.0	45.5
8/5/08 13:26	2	Flood	Surface	26.4	3.7	7.6	8.1	45.5
8/12/08 10:45	2	Flood	Bottom	25.1	16.2	8.1	7.4	29.6
8/12/08 10:51	2	Flood	Surface	26.5	2.9	7.5	10.6	29.6
8/19/08 13:53	2	Flood	Bottom	24.4	21.0	8.2	3.5	24.5
8/19/08 13:58	2	Flood	Surface	27.1	2.7	7.6	7.4	24.5
8/26/08 11:07	2	Flood	Bottom	23.7	22.9	8.4	2.7	16.7
8/26/08 11:13	2	Flood	Surface	26.0	4.0	7.6	6.9	16.7
9/2/08 11:54	2	Low	Bottom	23.8	19.6	8.2	5.4	45.5
9/2/08 11:57	2	Low	Surface	26.0	7.4	7.8	7.3	45.5
9/9/08 10:37	2	Flood	Bottom	24.2	21.2	8.1	4.3	21.9
9/9/08 10:41	2	Flood	Surface	26.1	3.3	7.6	7.5	20.0
9/16/08 11:49	2	Flood	Bottom	22.8	19.7	8.3	5.7	36.3
9/16/08 11:53	2	Flood	Surface	25.5	4.3	7.7	7.1	36.3
9/23/08 10:47	2	Hi/Ebb	Bottom	22.4	18.5	8.2	3.4	20.0
9/23/08 10:52	2	Hi/Ebb	Surface	25.3	3.8	7.4	6.1	20.0
9/30/08 12:37	2	Flood	Bottom	23.1	19.0	8.2	3.6	19.0
9/30/08 12:43	2	Flood	Surface	26.1	3.5	7.5	6.9	19.0
10/7/08 14:32	2	Low	Bottom	23.1	21.4	8.3	6.5	41.4
10/7/08 14:36	2	Low	Surface	26.3	2.0	7.5	7.7	41.4
10/14/08 11:12	2	Hi/Ebb	Bottom	18.3	18.4	7.8	5.2	16.1
10/14/08 11:15	2	Hi/Ebb	Surface	24.1	2.7	7.4	7.5	16.1
10/21/08 12:10	2	Ebb	Bottom	20.5	15.8	8.4	8.0	32.2
10/21/08 12:13	2	Ebb	Surface	24.4	2.2	7.5	7.1	32.2
10/28/08 13:38	2	Hi/Ebb	Bottom	20.0	15.8	7.8	3.4	0.0*
10/28/08 13:40	2	Hi/Ebb	Surface	24.3	3.3	7.5	6.7	0.0*
11/4/08 12:29	2	Low	Bottom	17.4	18.4	8.0	6.9	39.7
11/4/08 12:32	2	Low	Surface	23.6	1.3	7.4	7.4	39.7

*Flow from Pond A18 during monitoring on 10/28/08 was 0.0 cfs due to a high tide. The water quality values taken on this date represent conditions dominated by the high tide water (primarily Bay water) with freshwater input from the SJ/SC WPCP. Lower DO at the bottom of the slough is from more saline Bay water compared to the higher DO freshwater from the Plant.

Temperature, salinity, pH, dissolved oxygen, and chlorophyll *a* were measured monthly in Salt 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 reported below were taken from the continuous discharge monitor for the date and time of the Salt 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)
5/28/2008 09:00	18.93	20.51	9.6	9.4
6/18/2008 09:45	24.10	23.21	9.7	9.9
7/8/2008 09:30	26.91	25.24	8.5	2.3
8/19/2008 09:45	22.90	28.01	8.4	2.0
9/16/2008 09:45	21.00	29.46	8.3	3.1
10/21/2008 09:45	17.63	28.42	8.6	4.8

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).

Salt 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 19th 2008, surface and bottom salinities, respectively, were 0.8 and 12.0 PSU (Station 1), 2.7 and 21.0 PSU (Station 2), 13.6 and 13.5 PSU (Station 3), and 16.8 and 17.2 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 Salt Pond A18 was discharging (2007 Report; Table 9).

Salt Pond A18 salinity gradually increased over the summer from about 19 PSU to a maximum of nearly 30 PSU in September 2008(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 Stations 3 and 4 were less stratified with respect to pH and, similar to salinity patterns appeared uniform and well-mixed throughout the water column.

Salt Pond A18 pH levels (Table 10) were significantly higher than those in the receiving water until the first week of July 2008 (Table 8). The sudden decline in pond pH levels may be indicative of a community transition characterized by increased decomposition rates (see Phytoplankton section later).

Dissolved Oxygen

Monthly vertical profiles from 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 8.8 mg/L at Station 1 to 5.2 mg/L at Station 4. Bottom DO levels declined from an average of 7.7 mg/L at Station 1 to 4.5 mg/L at Station 4. Lower dissolved oxygen levels near the mouth of Artesian Slough are likely a result of 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 WDR requires the Discharger to monitor, report, and take corrective action if monthly discrete dissolved oxygen levels in Salt 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 Salt Pond A18 did not fall below 1.0 mg/L in 2008 (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 July 15, 2008 when pond DO levels fell below the 3.3 mg/L trigger as a 10th percentile weekly value. Over 16 weeks of this discrete monitoring, surface DO was never below 5.0 mg/L and bottom DO was only below 3.3 mg/L once on 8/26/08 (Table 9). At the time of the 8/26/08 monitoring, flow from Salt Pond A18 was relatively low (16.7 cfs). The lowest bottom DO measurements (2.7 - 3.4 mg/L) at Station Artesian 02 were recorded during times when low (9/23/08) or no (10/28/08) flow was coming from the pond indicating that low DO Bay water is likely the causative factor rather than pond discharges. These lower DO bottom water measurements are associated with flooding or high tides. At these times, the volume of water and water depth in Artesian Slough is the greatest and salinity is relatively high due to the higher proportion of Bay water brought in by the tide. Lower oxygen solubility due to increased salinity and decreased photosynthesis due to greater light attenuation at increased water depth are some probable causes of this trend.

Turbidity

Turbidity was measured monthly at four stations in Artesian Slough in 2008 and 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, which was also observed in previous monitoring, was presumably due to lower TSS in Plant discharge and the greater effect of flooding tides on turbidity in the lower reaches 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 2008. The WDR states that sediment monitoring is to be performed in August or September of each year. Sediment monitoring for 2008 occurred on August 27, 2008.

Mercury/Methyl Mercury

Salt Pond A18 sediment was sampled at four in-pond locations (Figure 1) on August 27, 2008 by Kinnetic Labortories 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:

- YSI Model 63 handheld instrument for temperature, pH and salinity
- YSI Model 58 portable meter for dissolved oxygen
- 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 appropriate analytical laboratories. Details of the analytical methods utilized by BrooksRand and Columbia Analytical services, QA/QC results and calibration of the YSI sonde are reported in Appendix III.

Complete results of the Salt Pond A18 annual sediment mercury analysis are summarized in Table 1 of Appendix III. In 2008, total mercury in sediment samples ranged from 417 to 573 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 samples ranged from 0.126 to 0.386 ng/g dry weight. Salt Pond A18 mercury concentrations in sediment for 2008 were somewhat greater than those measured in past monitoring for all stations. However, methyl mercury concentrations were comparable to, or less than, those measured in Salt Pond A18 sediments since 2005. After four 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 the upper 5 cm of pond sediment north to south in 2006 and 2008, these patterns have not been consistent from year to year.

Table 11. Comparison of 2005 – 2008 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

* 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. See Appendix III for a discussion of the field duplicate sample.

E. Chlorophyll *a*

Chlorophyll *a* was measured on a monthly basis in Salt Pond A18 at the discharge point. Once per month, a 1-liter grab sample was collected and placed in a 1-liter plastic jar. The sample was kept cool and out of direct light. Within 4 hours of collection, the sample was transferred to TestAmerica Analytical Testing Corporation in Morgan Hill, CA via courier. Analysis of all monthly chlorophyll *a* samples was performed by TestAmerica. There is no chlorophyll *a* data for May 2008 as the sample was lost in transport to the laboratory. Conditions in May 2008 were very similar to those of mid June 2008 in terms of water color, clarity and phytoplankton composition. Based on these observations, June 2008 chlorophyll *a* concentration is the best approximation available for May chlorophyll *a* levels.

Chlorophyll *a* levels in Salt Pond A18 peaked in July and August of 2008. The earlier months of the monitoring season demonstrated low chlorophyll *a* concentrations, which was evident by the increased water clarity compared to any other time in the past four years. A steady and fairly rapid increase in pond turbidity occurred beginning in the second week of July 2008. The final two months of 2008 monitoring had similar water clarity but there was a noticeable color change from brown in July and August 2008 to a greenish brown in September and October 2008. Despite low chlorophyll *a* concentrations in June and likely May 2008, 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 throughout the season coupled with observed changes in water clarity and color 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 a potential cause of changes in chlorophyll *a*.

Month (2008)	Date sampled	Salinity (PSU)	Chlorophyll *a* (μg/L)
May	5/20/08	20.51	*
June	6/18/08	23.21	7
July	7/8/08	25.24	42
August	8/19/08	28.01	60
September	9/16/08	29.46	16
October	10/21/08	28.42	26

*Due to a clerical error, the May Chlorophyll-a sample was not transferred to the contract laboratory. Based on general observations of pond water color and phytoplankton species composition, the expected chlorophyll a concentration in May should be approximately that of June.

F. Phytoplankton Species Composition

An additional sample for phytoplankton species composition analysis was collected concurrently with the monthly pond chlorophyll *a* samples. This sampling is not required by the WDR, but is a useful qualitative monitoring tool for detecting changes in the pond's autotrophic community. The monthly phytoplankton sample was collected into a 125 mL plastic bottle, immediately preserved with lugols solution and archived in order to provide targeted opportunities to analyze the phytoplankton community structure during suspected periods of transition within the pond.

For 2008, the City had phytoplankton species composition analysis performed on samples collected in June, August and October to represent the range of early, transitional and late season community structure. In general, based on density (cells/mL), phytoplankton species data show there was no clear dominant species in the early part of the monitoring season and species richness or diversity was low with only nine species recorded compared to 26 and 19 species recorded in August and October 2008 respectively. The latter months were dominated by a solitary green algae (*Nannochloropsis sp*) and a photosynthetic cryptomonad (*Hemiselmis virescens*). Both of these species were detected in June 2008 but at densities that were two to three orders of magnitude less than August or October 2008 densities. The much lower density of phytoplankton and lower species diversity in June 2008 is in agreement with the higher water clarity and low chlorophyll *a* measurements also measure in June.

G. Irradiance Measurements and Relationship to Dissolved Oxygen

City Staff obtained measurements for irradiance as solar radiation from the Union City CIMIS[3] station. Observations and analysis of trends over previous monitoring years indicated that irradiance is an important factor that controls pond DO levels because fluctuations in irradiance can affect the rate of photosynthesis.

During May and June 2008, Salt Pond A18 DO levels were stable and relatively high (Appendix I; weeks 1-9). In late June and through the month of July 2008, pond DO dropped significantly with daily minimum DO measurements regularly below 2 mg/L. This drop in pond DO may have been caused by a number of factors, among them decreased rates of photosynthesis due to a drop in the average daily solar radiation. Beginning in late June and continuing through the month of July 2008, wildfires were burning across much of California. Air quality was poor during this time with continued air quality advisories and extremely smoky and hazy conditions. Such high, constant particulate matter attenuates the amount of light penetrating the atmosphere and the result is less solar radiation to fuel photosynthesis. The solar radiation obtained for 2008, shows a measurable drop in daily irradiance that corresponds to the measured drop in DO as a daily average (Figure 10).

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

III. Exceedances and Triggered Actions

A. Summary of Exceedances and Triggers

Table 13 summarizes the exceedances, triggers and corrective actions taken for 2008. 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 one (29 August 2008 to 2 September 2008) were brief, minor (receiving water DO was typically above 4.7 mg/L) and occurred at times when DO is naturally lower due to ecosystem processes. Some of the incidents (6 September 2008 and 24 September 2008) occurred while Salt Pond A18 was not discharging. All of these brief and minor excursions were not attributable to Salt Pond A18 discharges so no corrective action was taken.

A more prolonged low DO incident in the receiving water in late August to early September 2008 prompted the City to take corrective action and initiate Salt Pond A18 discharge timing. During this 5 day period, receiving water surface DO fell well below the 5.0 mg/L objective for 3 to 11 hrs each day. Low DO incidents occurred overnight and during flooding tides, which follows the typical DO pattern in this and previous years monitoring. Because of the magnitude of these lower DO measurements during this period, the City's response of timed discharges as an adaptive management measure was appropriate even though discrete trigger monitoring did not measure surface DO below 5 mg/L or bottom DO below 3.3 mg/L (Table 9). However, in hindsight, given additional information regarding DO levels in the Lower South Bay measured by other researchers (USGS, Menlo Park), the timing (nighttime) and the tidal conditions (spring flood tide), it is likely that this was a region-wide Lower South Bay event rather than an effect from Salt Pond A18 discharges. This incident is also discussed in section II.B of this Report under Low Dissolved Oxygen Incident in Receiving Water.

Early in the monitoring season, there were multiple occasions when receiving water pH was measured above 8.5 (maximum of 8.9 on 5/8/08). As explained in section II.B. under pH, these brief and relatively minor increases in receiving water pH are associated with extreme spring tides occurring in the early morning rather than Salt Pond Pond A18 discharges.

There were 14 weeks in which the weekly 10th percentile DO level in the discharge fell below the established trigger of 3.3 mg/L (Table 13) which could be evaluated and responded to immediately. After data was recovered for Week 10 (1 July – 8 July), there were a total of 15 weeks, but Week 10 data was only recovered after the monitoring season ended so no management actions were taken. In previous years, 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. However, in 2008 the DO trigger initiated additional monitoring and evaluation, and no closing of gates. Only when possible negative effects to the receiving water were measured (in August and September, 2008), were valve closures implemented. The closure time in 2008 was 5 hours from 3am to 8am in order to limit discharges of low DO pond water overnight. This adaptive management was successful insofar as it maximized pond discharge time while minimizing discharges of overnight low DO water from Salt Pond A18. While this resulted in more triggering incidents, there were no clear negative effects on receiving water due to continued pond discharges. The strategy likely benefited the Salt Pond A18 ecosystem by improving pond circulation during periods of hypoxia, which should reduce recovery times.

Table 13: Exceedances of Water Quality Objectives & Triggers and Corrective Action

Date(s)	Water Quality Excursions from Basin Plan Objective	Corrective Action
5/8 – 5/11/08	Receiving water pH > 8.5 on each day for between 15 minutes to 2.75 hrs on a given day (max pH = 8.9)	None. Each event was brief and appeared to be tidally related
5/19/08	Receiving water DO < 5.0 mg/L at surface for 30 minutes (min DO = 4.8 mg/L)	None. Event was brief, minor and related to tidal and diurnal cycles. Minimal pond discharge flow.
5/23/08	Receiving water pH>8.5 for 15 minutes (max pH = 8.6)	None. Event was brief and related to tidal cycle.
6/3/08	Receiving water DO < 5.0 mg/L at surface for 15 minutes (min DO = 4.9 mg/L)	None. Event was brief, minor and related to tidal and diurnal cycles.
6/15 – 6/17/08	Receiving water DO < 5.0 mg/L at surface on each day for between 1.5 hrs and 15 minutes (min DO = 4.1 mg/L)	None. Events were brief, minor and related to tidal and diurnal cycles.
6/18/08	Receiving water pH>8.5 for 30 hrs (max pH = 8.6)	None. Event was brief and related to tidal cycle.
7/3/08	Receiving water DO < 5.0 mg/L at surface for 2.25 hrs (min DO = 4.7 mg/L)	None. Event was brief, minor and related to tidal and diurnal cycles.
7/4/08	Receiving water pH>8.5 for 15 minutes (max pH = 8.6)	None. Pond A18 pH was 8.4.
8/29 – 9/2/08	Receiving water DO < 5.0 mg/L at surface for each day for between 11 hrs and 15 minutes (min DO = 3.2 mg/L)	Initiated timed discharges from A18 with 5 hr per night discharge valve closures.
9/6/08	Receiving water DO < 5.0 mg/L at surface for 30 minutes (min DO = 4.6 mg/L)	None. Pond A18 was not discharging. Event related to tidal and diurnal cycles.
9/24 – 9/30/08	Receiving Water DO < 5.0 mg/L at surface on 3 separate days for 15 or 30 minutes each event (min DO = 4.4 mg/L)	None. Pond A18 was not discharging during some events. All were brief, minor and related to tidal and diurnal cycles.
10/2/08	Receiving water DO < 5.0 mg/L at surface for 15 minutes (min DO = 4.8 mg/L)	None. Event was brief, minor and related to tidal and diurnal cycles.
10/4/08	Receiving water DO < 5.0 mg/L at surface for 15 minutes (min DO = 4.9 mg/L)	None. Event was brief, minor related to tidal and diurnal cycles.

Date(s)	Dissolved Oxygen Trigger	Corrective Action
7/8 – 7/15/08	10th Percentile DO Concentration in the A18 discharge was 0.2 mg/L	Initiated weekly discrete trigger monitoring in receiving water.
7/15 – 7/22/08	10th Percentile DO Concentration in the A18 discharge was 1.8 mg/L	No adverse effect measured. Continued trigger monitoring.
7/22 – 7/29/08	10th Percentile DO Concentration in the A18 discharge was 0.9 mg/L	No adverse effect measured. Continued trigger monitoring.

Table 13 (continued): Pond A18 Exceedances of Water Quality Objectives & Trigger Levels and Corrective Action

Date(s)	Dissolved Oxygen Trigger	Corrective Action
7/29 – 8/5/08	10th Percentile DO Concentration in the A18 discharge was 2.3 mg/L	No adverse effect measured. Continued trigger monitoring.
8/5 – 8/12/08	10th Percentile DO Concentration in the A18 discharge was 2.6 mg/L	No adverse effect measured. Continued trigger monitoring.
8/12 – 8/19/08	10th Percentile DO Concentration in the A18 discharge was 1.2 mg/L	No adverse effect measured. Continued trigger monitoring.
8/19 – 8/26/08	10th Percentile DO Concentration in the A18 discharge was 1.2 mg/L	No adverse effect measured. Continued trigger monitoring.
8/26 – 9/2/08	10th Percentile DO Concentration in the A18 discharge was 0.1 mg/L	Initiated timed discharges due to surface receiving water < 5.0 mg/L from continuous sonde.
9/9 – 9/16/08	10th Percentile DO Concentration in the A18 discharge was 1.9 mg/L	Continued timed discharges for further evaluation and caution.
9/16 – 9/23/08	10th Percentile DO Concentration in the A18 discharge was 2.3 mg/L	Ceased timed discharges. No adverse effect measured. Continued discrete trigger monitoring.
9/23 – 9/30/08	10th Percentile DO Concentration in the A18 discharge was 1.6 mg/L	No adverse effect measured. Continued trigger monitoring.
9/30 – 10/7/08	10th Percentile DO Concentration in the A18 discharge was 1.5 mg/L	No adverse effect measured. Continued trigger monitoring.
10/7 – 10/14/08	10th Percentile DO Concentration in the A18 discharge was 3.0 mg/L	No adverse effect measured. Continued trigger monitoring.
10/21 – 10/28/08	10th Percentile DO Concentration in the A18 discharge was 1.3 mg/L	No adverse effect measured. Continued trigger monitoring.

IV. Supplemental Monitoring

In an effort to increase our understanding of Salt 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 Salt 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 Salt Pond A18 (Figure 2). The monitoring 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.

Due to the lack of spatial variability in the pond as well as staff and budgetary constraints, supplemental monitoring was reduced in 2007 and 2008. For the past two 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 has been a useful tool to document shifts in the pond ecology and as a measurement of pond productivity. For 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 2008 are presented in Section II.F and II.G of this report.

V. Discussion and Interpretation of Results

This section discusses 2008 monitoring season results and observations and provides comparison with those of previous years monitoring.

Temperature

Salt Pond and receiving water temperatures measured in 2008 (Table 3; Figure 3) were very similar to previous years. As in previous monitoring, average pond discharge temperatures were lower than receiving water temperatures in 2008 (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 Salt Pond A18 and the receiving water during 2008 monitoring did not reach the highs that occurred in 2006, due to the milder summer in 2008 compared to 2006. Prolonged hot weather can have a negative effect on DO levels due to increased respiration rates.

Salinity

During four years of dry season monitoring, salinity has been the most variable water quality parameter measured in the pond both within and between years. In 2005, Salt 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. Salinity trends in 2007 and 2008 demonstrated a different pattern than previous monitoring. Due to unusually warm and dry winters, salinity in Salt Pond A18 was at 19.1 PSU in May 2007 and 18.3 PSU in May 2008. In both years, salinity reached its maximum level in late September (30.1 PSU in 2007, 29.9 PSU in 2008). Salinity fluctuations are not controllable on a fine scale in a system such as Salt 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, Salt Pond A18 still functions as a system that concentrates salts through high evaporation rates. These uncontrollable salinity fluctuations may significantly impact pond phytoplankton biomass, dynamics and stability as discussed in a later section.

Since average salinity levels in Salt Pond A18's discharge in 2005 were significantly higher than 2006-2008 levels, some stratification of receiving water was observed in the early months of 2005. Particularly during and shortly after the initial release period in 2005, the more saline pond water would sink to the bottom of Artesian Slough in the area immediately influenced by Salt Pond A18 (up to station 2, Figure 1). However, this stratification was not evident in the 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 Salt Pond A18 discharge as reported in monthly discrete receiving water monitoring (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 Salt Pond A18 discharge on receiving water salinity is limited spatially due to immediate mixing of pond discharge water with freshwater effluent.

pH

Salt Pond pH levels increase during periods of intense photosynthesis, when irradiance and temperatures are high. However, there appears to be an upper boundary on pond pH due to the buffering capacity of salt water. Buffering capacity increases with increased salinity. Salt Pond pH levels were temporarily quite high (9.4 – 9.9) at the beginning of the season when pond salinity was at its lowest (Figure 6). By July 2008, pond pH had fallen below a pH of 9 and remained relatively low (8.1 – 8.6) compared to previous years and the early part of 2008. The timing of this measured decrease in pond pH corresponds to observed changes in the pond's algal community based on observed water color, chlorophyll *a* measurements and phytoplankton species composition data.

Although somewhat high pond pH levels (range for the season of 8.1 – 9.9) may result in some osmotic stress to fish and invertebrates, the slow rate of pH change in a well-buffered pond water likely allows pond organisms to adjust. Also, while increasing pond salinity may help to stabilize or buffer pond pH levels, steadily increasing salinity may have a negative impact on pond phytoplankton production and stability.

There is no apparent effect on pH in the receiving water from Salt 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 2008 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. This procedure was cumbersome and time consuming. The 2005 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 dataset 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 streamlined adaptive management strategy utilized in 2006 was successful in that there were no excursions below the Basin Plan DO objective of 5 mg/L in the receiving water due to Salt Pond A18 discharge. The same streamlined adaptive management strategy initiated in 2006 was used in 2007. In 2008, the City adopted a strategy that focused more consideration to the health of Salt Pond A18 biota. Since shutting the pond discharge valve limits the amount of flushing in the pond, doing so during a low-DO event could possibly prolong and exacerbate the hypoxia.

This can cause negative effects to pond biota such as the stressed fish observed during the 2007 dry season. In an effort 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 Salt Pond A18 Report. Upon triggering, the City initiated weekly discrete receiving water monitoring in the nearest downstream station (Table 9). Additional adaptive management actions were 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 was effective in maintaining a more consistent circulation pattern in Salt Pond A18 throughout the dry season and there were no instances of observed stressed fish in 2008. Furthermore, there were no negative effects to the receiving water measured as a result of increased discharges from the pond during low-DO periods (Appendix I; Weeks 10 and 11).

As in the previous years monitoring, receiving water DO levels do not appear to be affected, either positively or negatively, by the Salt Pond A18 discharge (Appendix I; Weeks 1-26). For example, from July 8 -15, 2008 DO in the pond discharge fell below 2 mg/L for several hours each day and rose above 9 mg/L twice, with no apparent effect on receiving water (Appendix I; Week 11). Two additional examples of this lack of cause-and-effect are provided in the DO charts for Week 3 and Week 17 (Appendix I). Neither prolonged, very high DO discharges (Week 3), nor did low DO discharges (Week 17) appear to affect receiving water DO in a positive or negative direction.

The usual diurnal pattern of pond DO levels is a sinusoidal curve of up-and-down swings in DO due to algal photosynthesis during the day and organism respiration at night in the absence of photosynthesis (Appendix I; Week 7). Past events such as apparent phytoplankton die-offs (July 2006) and changes in phytoplankton community structure (July - September 2007 and July 2008), can cause DO levels to decline rapidly (Appendix I; Weeks 9 - 11). In some cases, such as a hypoxic event in 2007, conditions can result in stress to pond biota, especially when combined with climatic perturbations such as decreased irradiance due to cloud cover leading to decreased rates of photosynthesis.

Average discharge flow volume from Salt Pond A18

Artesian Slough is dominated by continuous freshwater flows from the Plant of approximately 100 MGD. In contrast, the average discharge volume from salt Pond A18 during the 2008 monitoring season was 19.5 MGD. This average daily flow from the pond in 2008 is slightly greater than that of 2006 and 2007 (17.6 MGD and 14.4 MGD, respectively). 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 flow from Salt 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 Salt 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 Salt Pond A18. As noted above, adaptive management of discharge flows in previous years resulted in longer periods of gate closure throughout the monitoring season compared to 2008.

Mercury and Methyl Mercury Analysis of Pond Sediment.

In 2005, there was a noticeable difference in mercury and methyl mercury concentrations spatially within pond sediment. Concentrations in 2005 for mercury and methyl mercury in sediments were greater in the northern areas of the pond. Methyl mercury concentrations in particular were as much as 23-times greater at the extremes (Station 1 and Station 4) when concentrations were normalized to percent clay. In contrast, 2006 pond sediment mercury and methyl mercury concentrations appeared fairly uniform, especially when normalized to percent clay. Mercury and methyl mercury concentrations in pond sediment in 2007 showed yet another trend with total mercury concentrations in pond sediment higher in the southern portions. This was in direct contrast to the apparent spatial trend for total mercury observed in 2005. In 2008, both total mercury and methyl mercury were again fairly uniform throughout the pond. Methyl mercury concentrations in pond sediments showed slightly more variability than total and were nominally higher in the most northern station (A18-4). Data is too limited to determine what may account for the inter-annual or occasional spatial variability over the past four years. The complexity of mercury methylation and lack of information on sediment dynamics in Salt Pond A18 further confound this issue.

Mean (±SE) sediment mercury and methyl mercury concentrations in Salt Pond A18 from four years of monitoring data are 292 ±38 ng/g and 0.98 ± 0.33 ng/g, respectively. Compared to the most recent available RMP data[4] for mercury concentrations in nearby Bay sediments, mean total mercury and mean methyl mercury concentrations are very similar to those in salt Pond A18 (Table 14). While mean concentrations are similar, mercury in Salt Pond A18 sediments has been much more variable than in Lower South Bay sediments as shown by the higher standard error for pond data. The smaller sample size for pond sediment mercury data may be a factor affecting this statistical variability. However, mercury concentrations in pond sediments span a greater range of values than those measured in the Bay.

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[4] 2004 – 2006 Regional Monitoring Program Status and Trends data for Bay sediment mercury and methyl mercury concentrations for stations located south of the Dumbarton Bridge.

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	292 ± 38	17	0.98 ± 0.33	17
South Bay sediment (RMP)	251 ± 8	30	0.85 ± 0.06	30

Pond Primary Production

In partnership with the U.S. Geological Survey (USGS), the City analyzed Salt 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[5] at the national conference of the Estuarine Research Federation, November 2007 in Providence, RI (Appendix VI) and at the 2008 Salt Pond Science Symposium. A companion paper on this research and analysis that is unique to the former salt ponds of San Francisco Bay was published in the peer-reviewed journal, *Wetlands*[6] (Appendix VI).

Due to low water levels (approximately 2 feet) in Salt Pond A18, high summer irradiance, low flow-through rates, and availability of nutrients, phytoplankton blooms were common in 2005 and 2006. There were no phytoplankton blooms observed in 2007 or 2008 (Table 12), but chlorophyll *a* levels did increase from initial dry season concentrations (from 7 μg/L to a maximum of 60 μg/L in August 2008).

While extreme variations in chlorophyll *a* were not observed in 2008, 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 Salt Pond A18 for 2006, mean Gross Primary Production (GPP) is estimated to be 8.2 g O_2 /m^2/day. This indicates very high rates of photosynthesis in the pond and is double the rate of some of the world's most productive estuaries, such as the Chesapeake Bay[7]. Dissolved oxygen data from 2008 is similar to that of 2006. Therefore, 2006 estimates of GPP are a likely approximation for those of 2008.

High rates of photosynthesis, which cause the extremely high dissolved oxygen levels measured in the pond (maximum of 17.8 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

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[5] 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.

[6] 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.

[7] 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.

oxygen levels (minimum of 0.1 mg/L, Table 6). The extremes of GPP and ER in Salt 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 during periods of decreased irradiance (decreases photosynthetic rates), prolonged increased temperature (increases metabolism and respiration) and possibly 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 effect GPP rates by decreasing daily irradiance.

Chlorophyll *a* results from 2006 indicated a rapid decline in pond phytoplankton biomass in July 2006. This corresponded to an observed color change in Salt 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 would use up oxygen and release carbonic acid. To better understand pond phytoplankton dynamics, the City determined that it would be helpful to sample the pond periodically for phytoplankton species composition and abundance. Such analyses could better describe what may be occurring during an algal bloom and/or crash and the reason for any crash event that may take place in Salt Pond A18 in the future.

Additional phytoplankton sampling was implemented in 2007 and 2008. While there did not appear to be a dramatic die-off of phytoplankton in 2008 based on chlorophyll *a* data, a transition likely occurred in Salt Pond A18 based on water clarity observations, chlorophyll *a* changes and phytoplankton species changes. Chlorophyll *a* trends in 2008 were similar to those of 2007, but dramatic declines in pH and DO in the first week of July 2008 suggest a more rapid transition. Steady increases in chlorophyll *a* throughout the season along with simultaneous observed color changes from light brown to darker brown to greenish brown, also suggest a change in community structure. An analysis of the phytoplankton species composition of the pond before, during and after the period in question confirms that the pond did indeed transition from a low diversity, low-density autotrophic community with no dominant species to one dominated by a solitary green alga (*Nannochloropsis sp*) and a cyrptomonad (*Hemiselmis virescens*). Densities of the green algae were greatest in October 2008 when it was the dominant species, which would have caused to observed greenish color change in Salt Pond A18 and contributed to the stability of the pond system.

In 2008, the dramatic decreases in pond DO and pH along with an observed color changes corresponded to several weeks of hazy, smoky conditions with high particulate matter in the air due to wildfires raging across the state of California. The decreased irradiance from smoky conditions and potential increased particulates settling into the pond by deposition, which would increase water column shading could have decreased photosynthesis rates. Such conditions would favor more shade tolerant producers and could have caused a rapid die-off of less shade tolerant phytoplankton.

Nuisance filamentous macro-algae

In 2005, there was little evidence of floating filamentous green algae in Salt Pond A18. This was in sharp contrast to other South Bay Salt Ponds that reportedly had a rather large presence of these nuisance algae. 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 2006, filamentous algae in Salt 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. In 2007, there were noticeably more filamentous algae in Salt Pond A18 (maximum coverage estimated at 40%), especially in the early months of the monitoring season (May and June 2007). Conditions in early 2007 with respect to salinity, pH and chlorophyll *a* concentrations 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. Filamentous algae were much less abundant in 2008 compared to 2007, and the reasons for this are not readily apparent since salinity and pH difference were slight. A maximum of approximately 15% of Salt Pond A18 was covered by filamentous algae in 2008. Die-off of algal mats could also 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

- In 2008, Salt Pond A18 discharge averaged approximately 20% of the Plant flow. There was no definitive observable effect on receiving from Salt Pond A18 discharge on any water quality parameter despite much more frequent pond discharges compared to previous years and despite continued discharges after DO levels fell below the 3.3 mg/L trigger.

  Recommendation: Continue operations and management strategy followed in 2008 where the DO trigger acts as an early warning signal and initiates additional weekly receiving water column monitoring at Station Artesian 02. Only when both the receiving water and Salt Pond A18 (measured by discrete monitors or continuous monitors) do not meet the DO water quality standard should additional adaptive measures occur.

- 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 Salt 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 operations and management strategy followed in 2008. This is further evidence of the minimal spatial impact Salt Pond A18 discharge has in Artesian Slough.

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

  Recommendation: Continue operations and management strategy followed in 2008. This is further evidence of the minimal spatial impact Salt Pond A18 discharge has in Artesian Slough and the greater effect of ambient Bay water entering the slough during flooding tides.

- Supplemental monitoring performed in 2006-2008 provided useful information for characterizing variability of the Salt Pond A18 phytoplankton community and how climatic and water quality factors may affect pond stability.

  Recommendation: As time, staff resources, and budget allow, continue voluntary supplemental monitoring of Pond A18 including monthly phytoplankton species composition sampling and tracking changes in irradiance to determine the effect on pond DO.

- The most important factor affecting dramatic changes in pond DO levels (lows and highs) may be irradiance. Pond conditions were affected by weather patterns and conditions affecting irradiance such as state-wide wildfires.

  Recommendation: Continue to use irradiance measurements taken locally at weather stations or through reliable quality controlled irradiance monitoring programs during the A18 monitoring season to correlate irradiance and DO levels.

- Salt Pond A18 is 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 four 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.

- After four years of monitoring mercury and methyl mercury in Salt Pond A18 sediments, no consistent pattern between years or among stations is evident.

  Recommendation: Continue annual monitoring of mercury and methyl mercury concentrations in sediment as required in the WDR.

- Pond phytoplankton community structure and dynamics may be directly affected by salinity. Pond salinity increases throughout the dry season, may tend to destabilize the phytoplankton community and cause shifts in species dominance. Phytoplankton biomass and overall stability can greatly affect pond DO levels through high photosynthesis and respiration rates. An unstable phytoplankton community can cause very extreme DO concentrations with extremely high DO during peak photosynthetic activity and hypoxia at night in the absence of photosynthesis. Increased oxidation and decomposition of lysed cells due to changes in community structure can also contribute to decreased DO concentrations.

  Recommendation: Continue to track and characterize pond phytoplankton blooms and general community structure through sampling of chlorophyll *a*, phytoplankton species abundance and composition, and nutrients.

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.

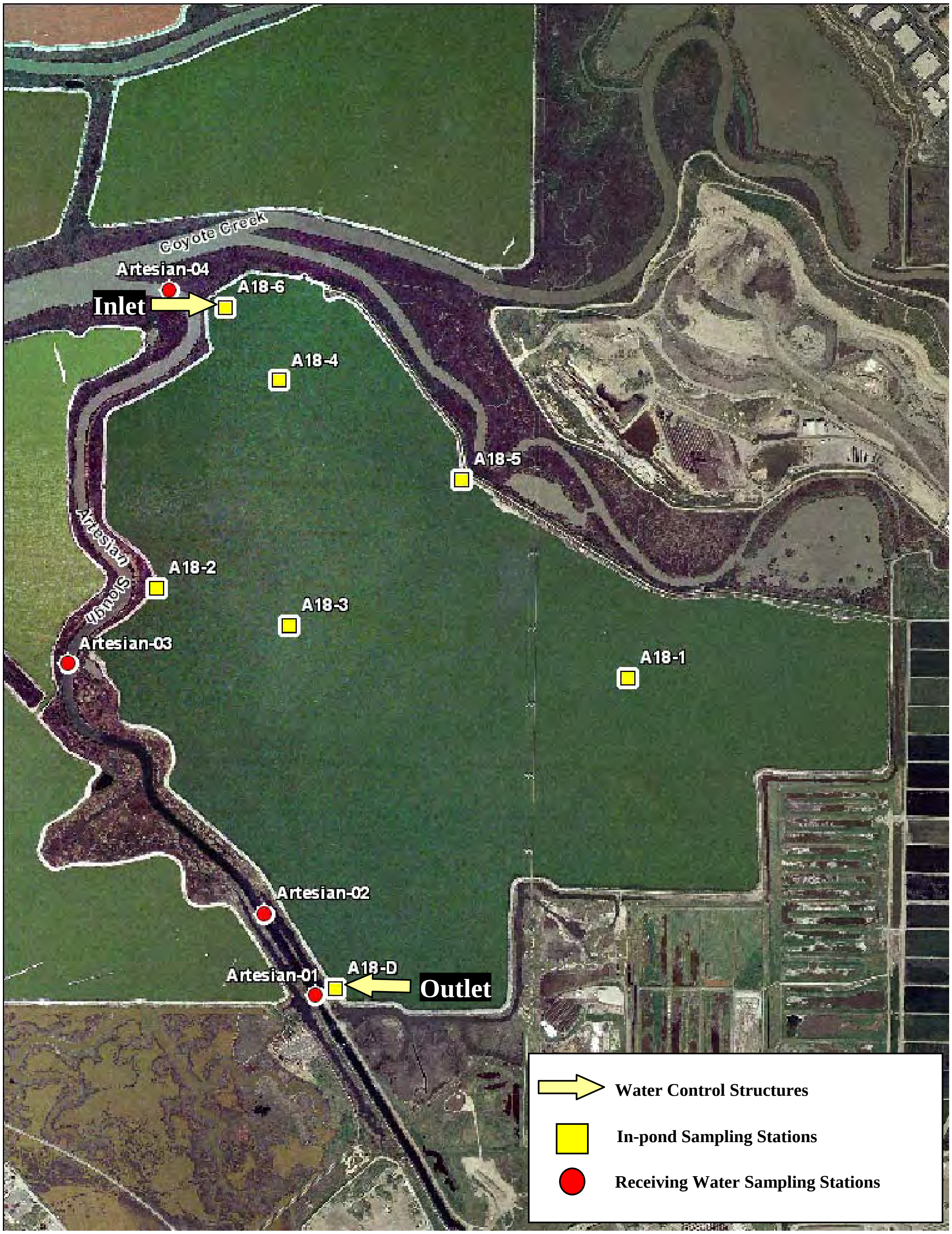


Figure 2. Artesian Slough and Pond A18 Supplemental Monitoring Stations from 2006 Supplemental Monitoring.

Figure 3. 2008 Dry Season Temperature Profiles of Pond A18 and Artesian Slough

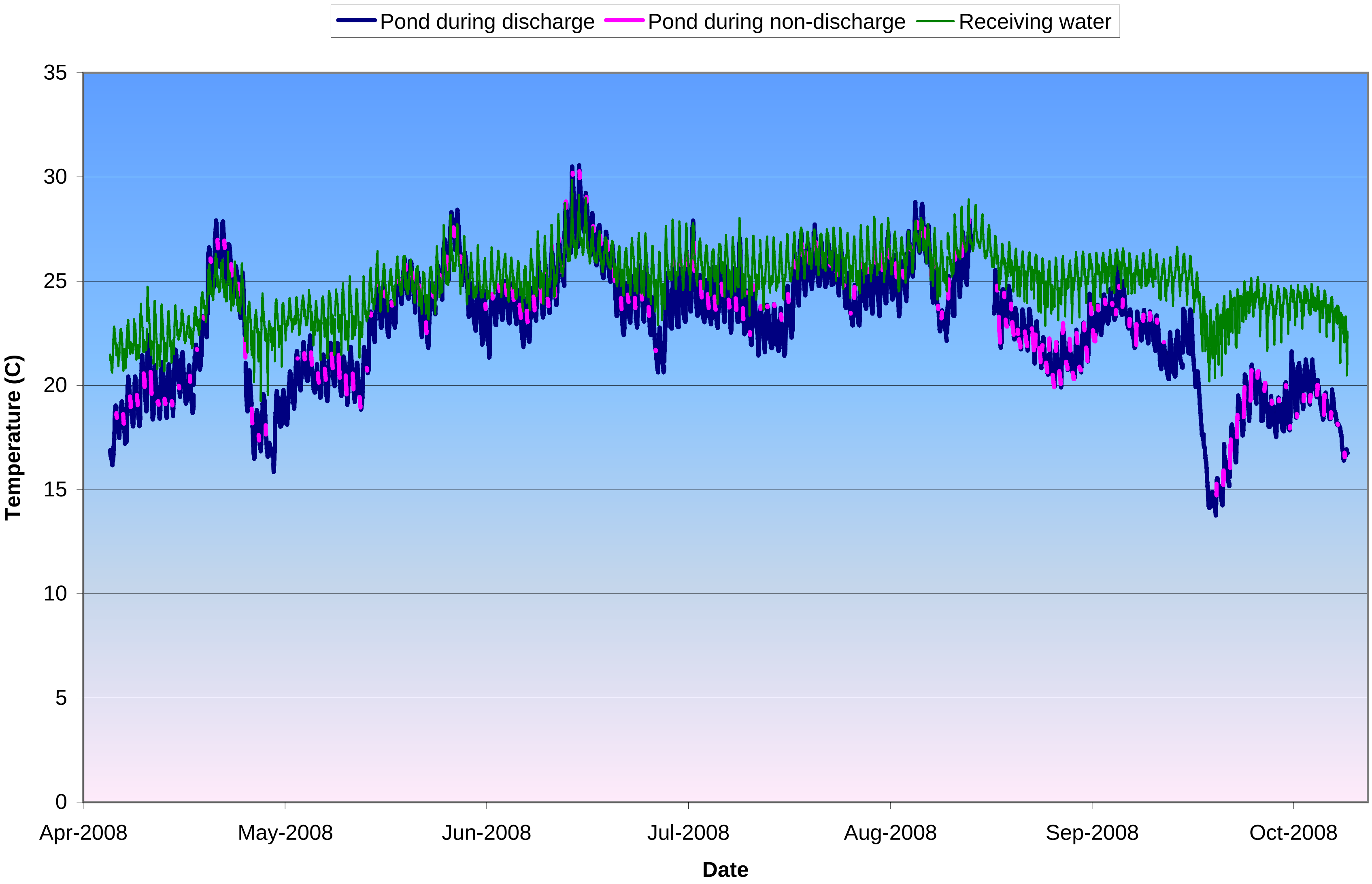


Figure 4. 2008 Temperature Difference between A18 Discharge and Artesian Slough

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

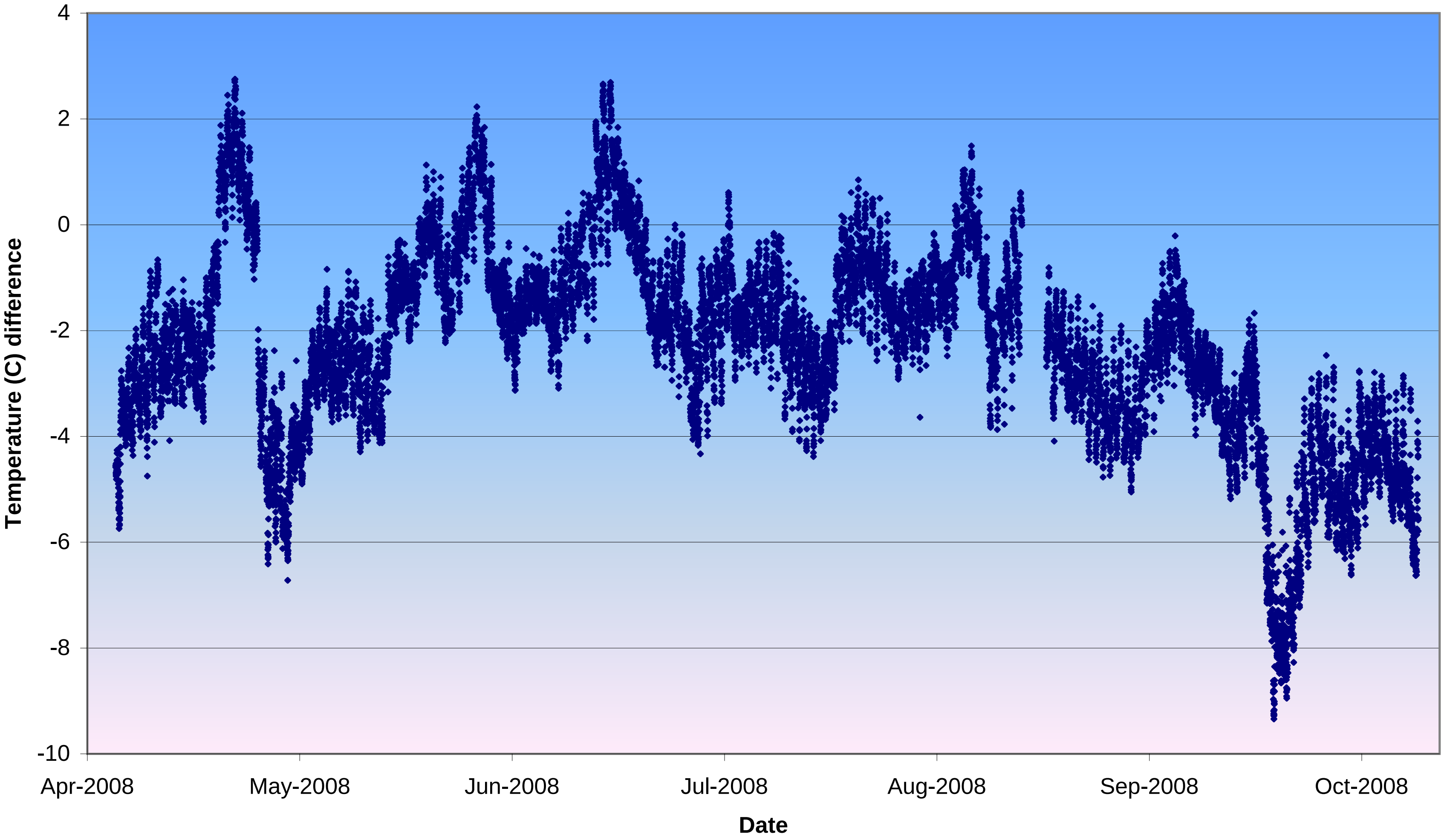


Figure 5. 2008 Dry Season Salinity Profiles of Pond A18 and Artesian Slough

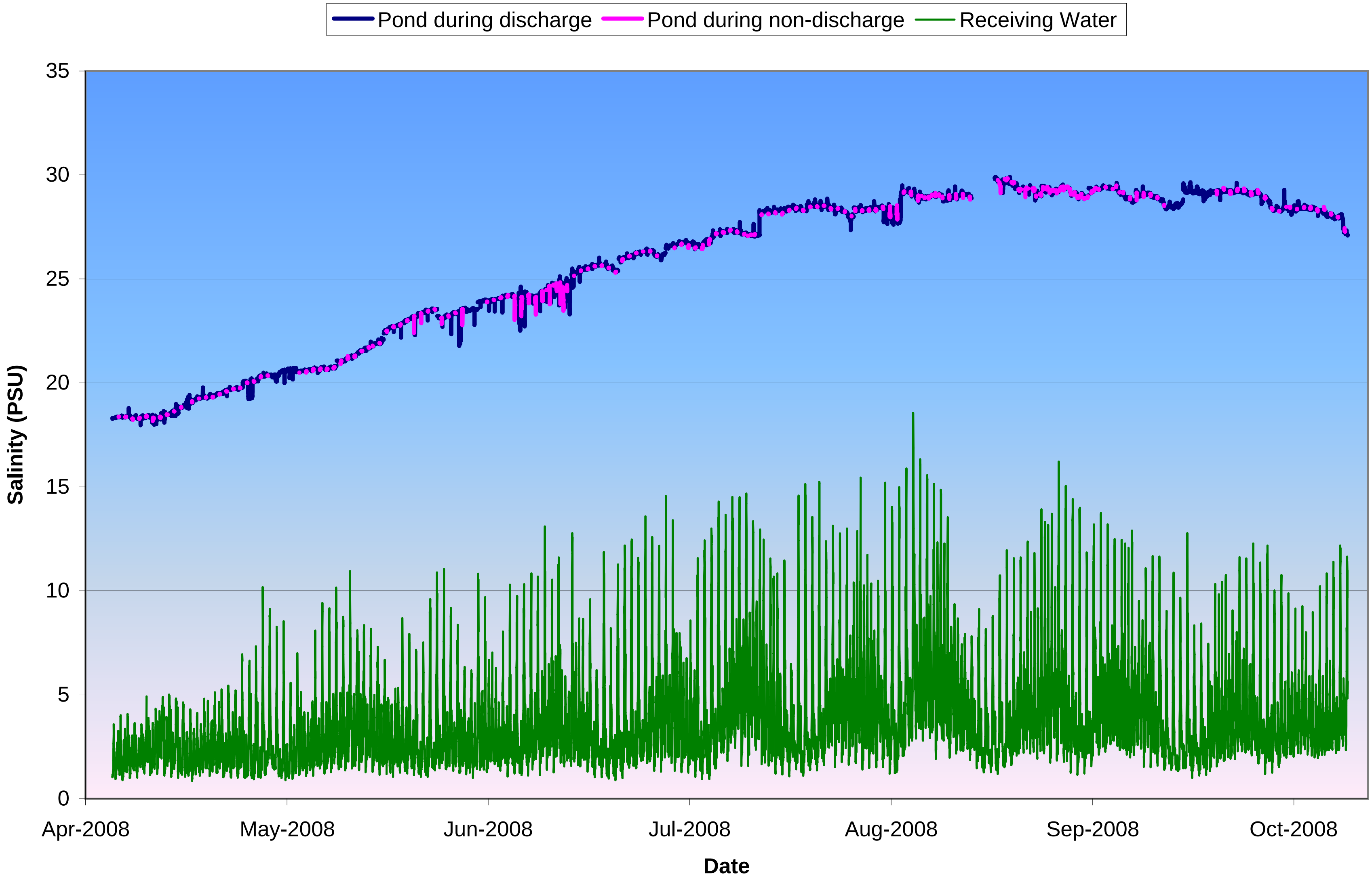


Figure 6. 2008 Dry Season pH Profiles of Pond A18 and Artesian Slough

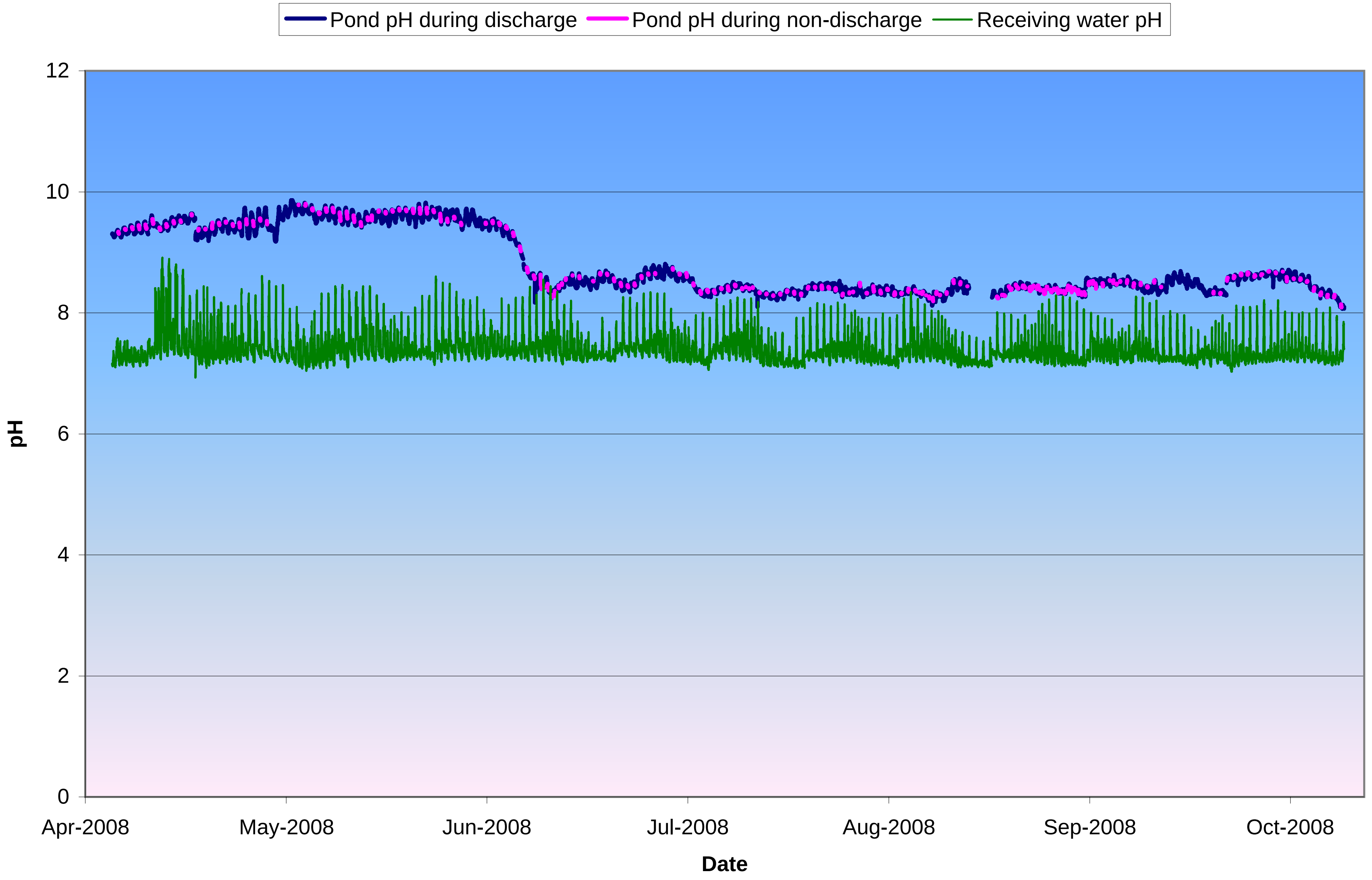


Figure 7. Effect of Tidal Cycle on Salinity and pH of Artesian Slough

Example taken from Week 23 of Receiving Water data

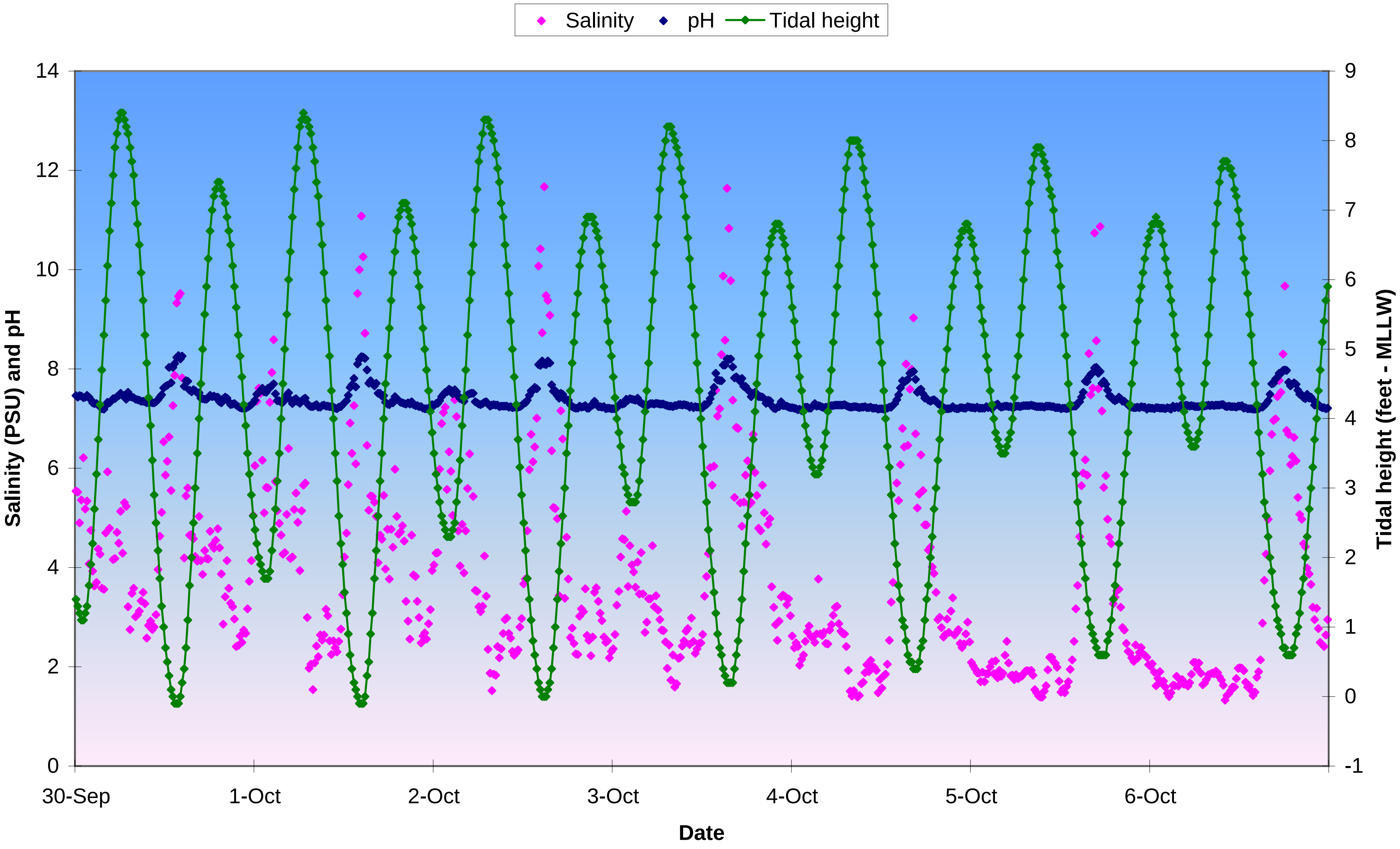


Figure 8. Mean (+ SE) Monthly Dissolved Oxygen in Artesian Slough for 2008

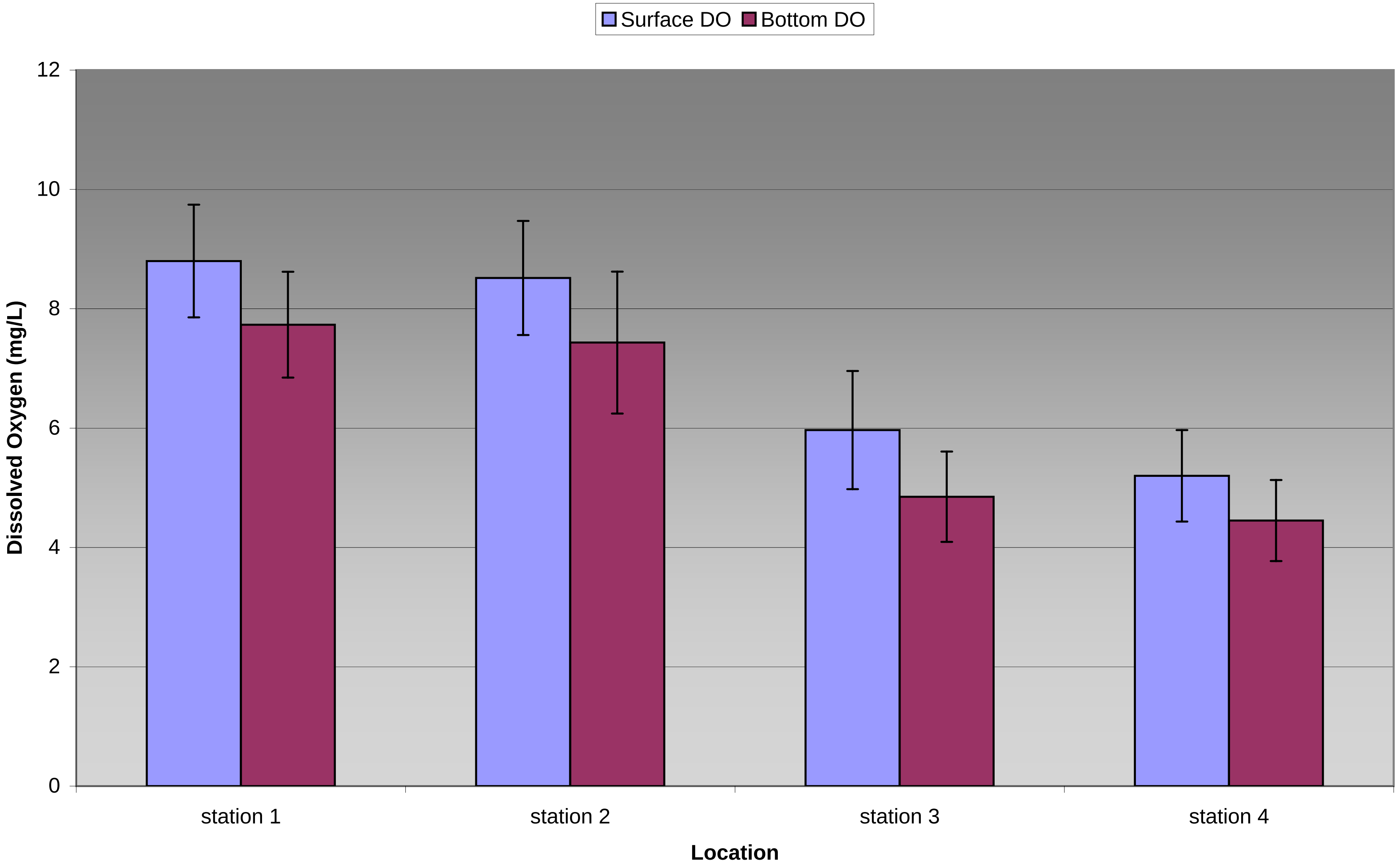


Figure 9. Mean (± SE) Monthly Turbidity in Artesian Slough for 2008

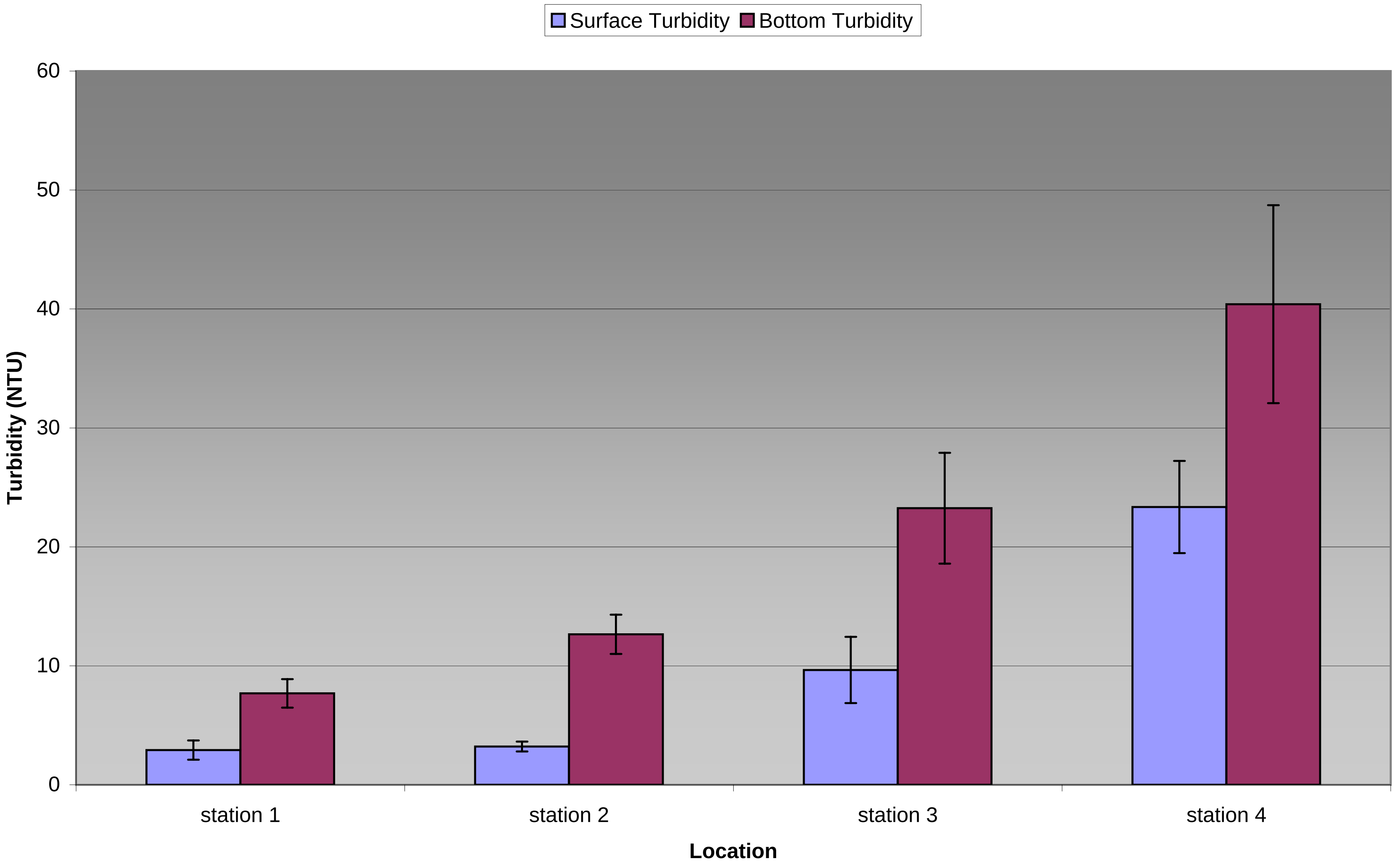
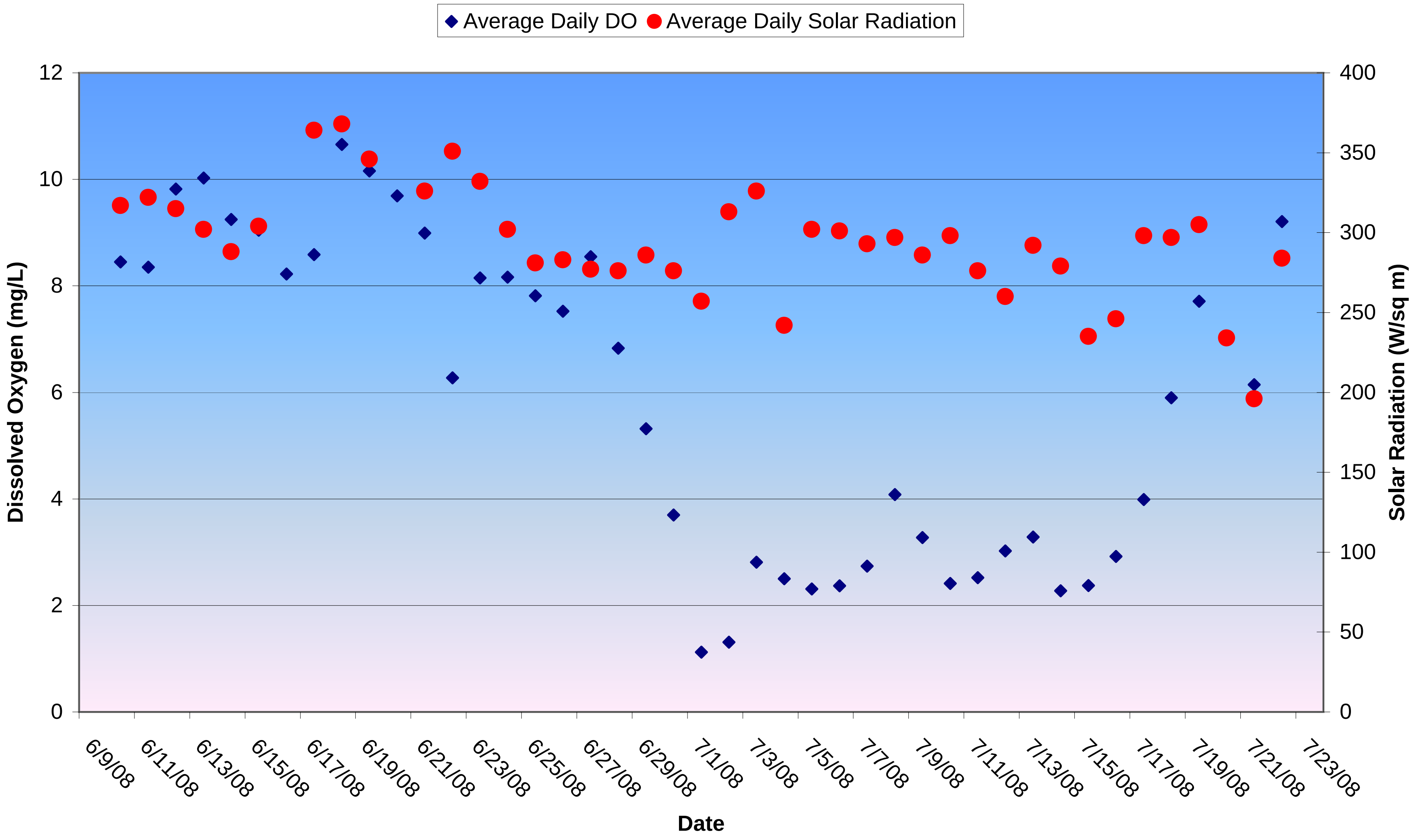
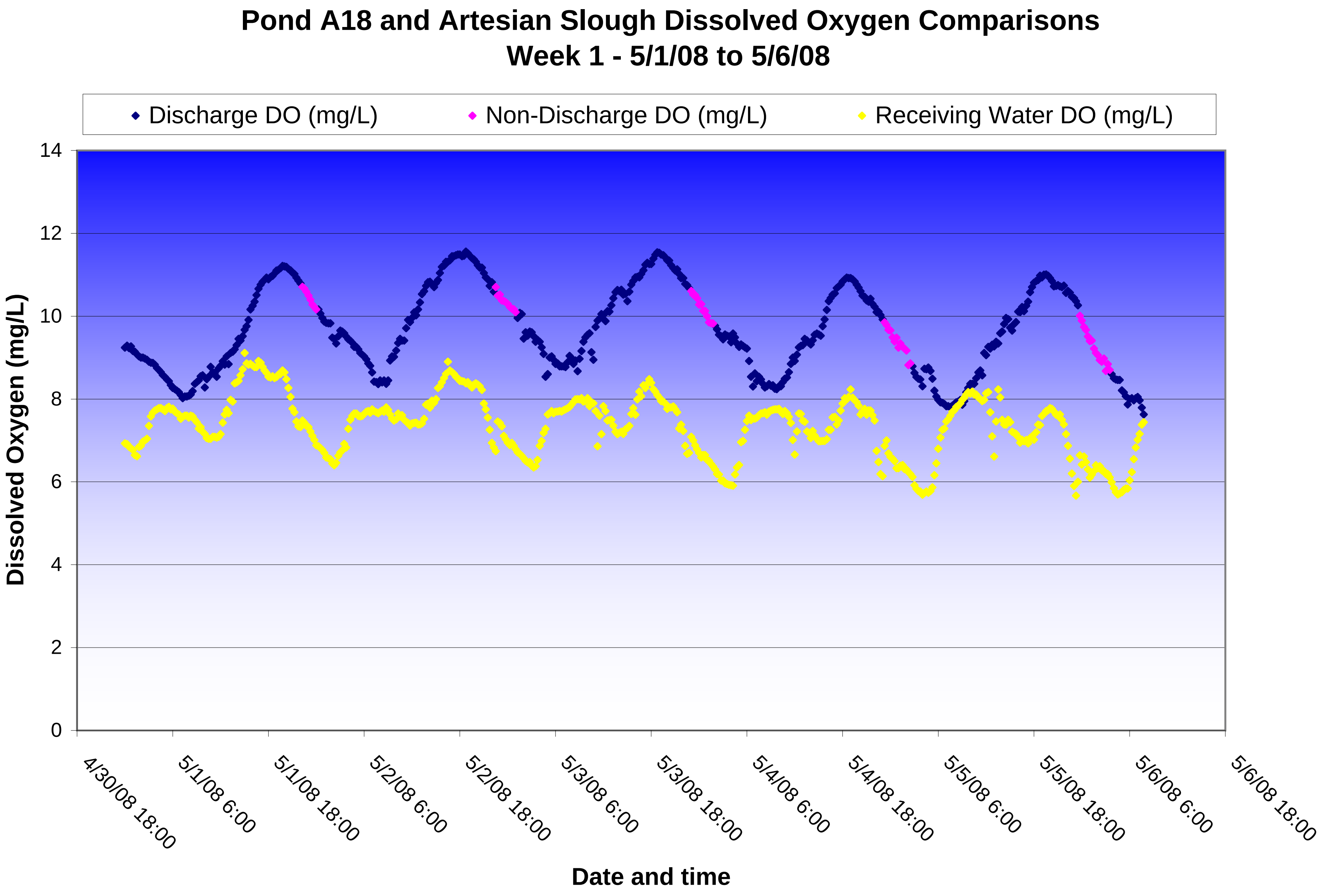


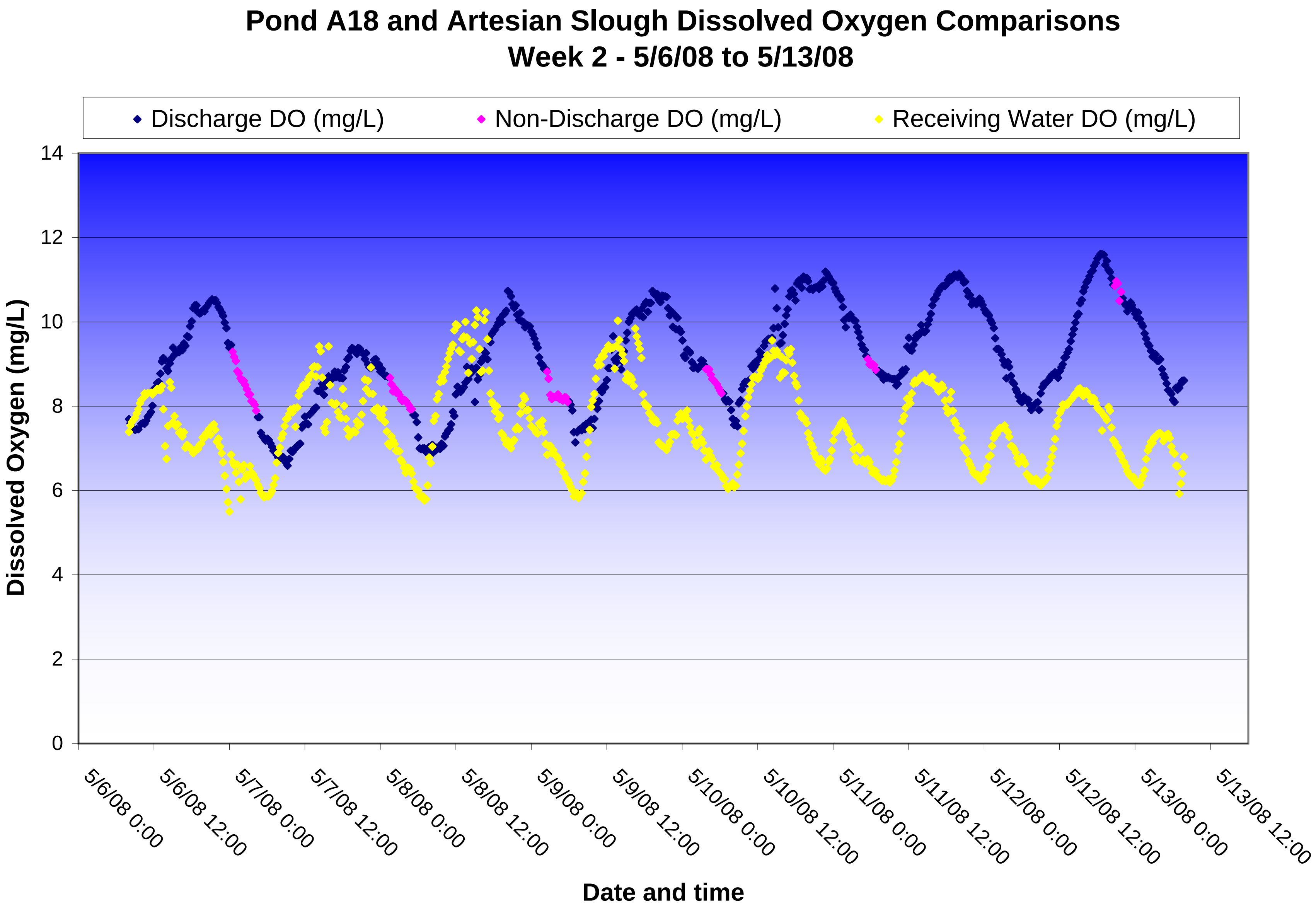
Figure 10. June and July 2008 Average Daily Solar Radiation and Pond DO

Drop in Solar radiation on 6/24 - 6/25 corresponds to the onset of smoky and hazy conditions from CA wildfires. These conditions persisted into August, 2008

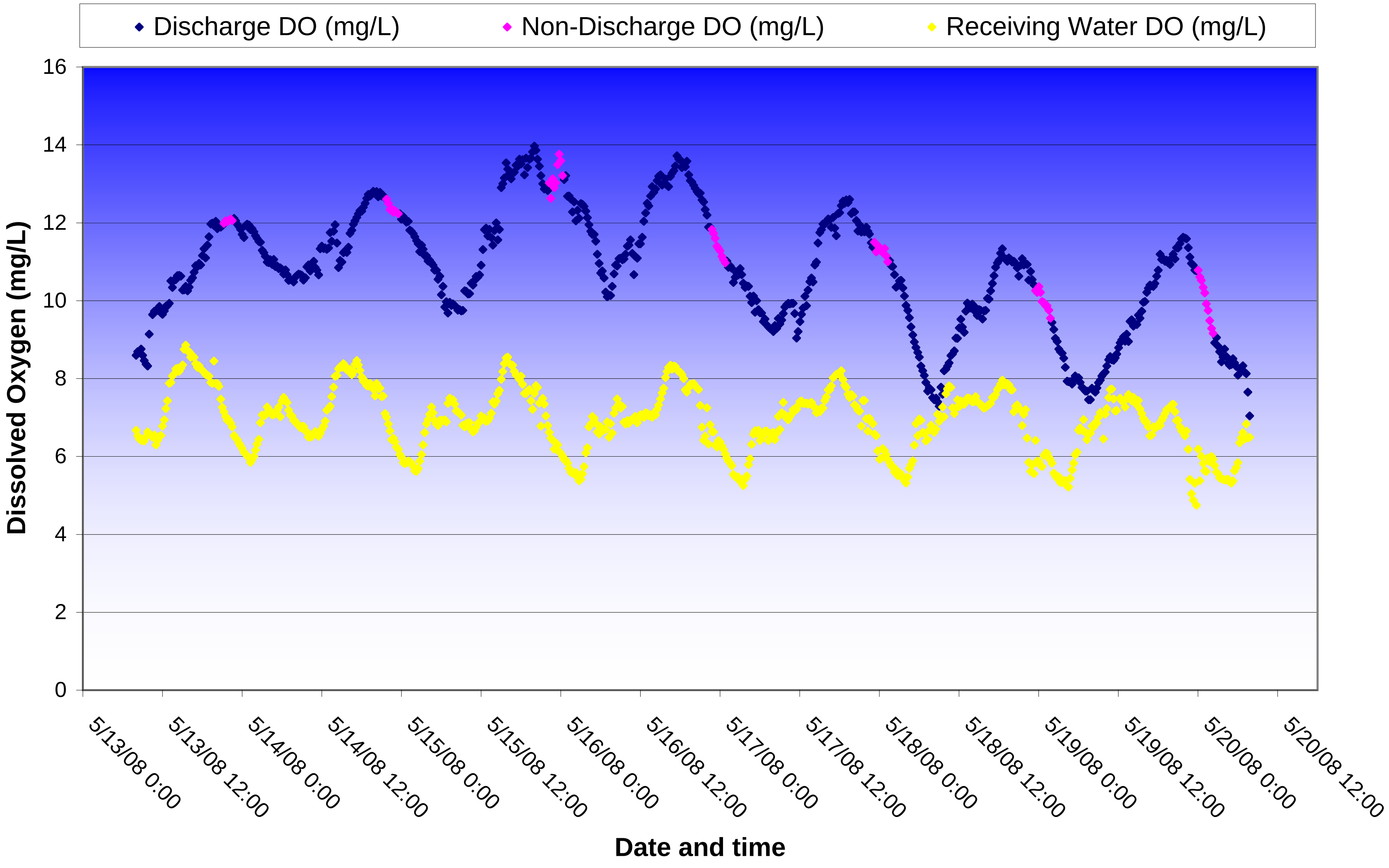


Appendix I. Continuous Monitoring of Dissolved Oxygen in Pond A18 and in Artesian Slough

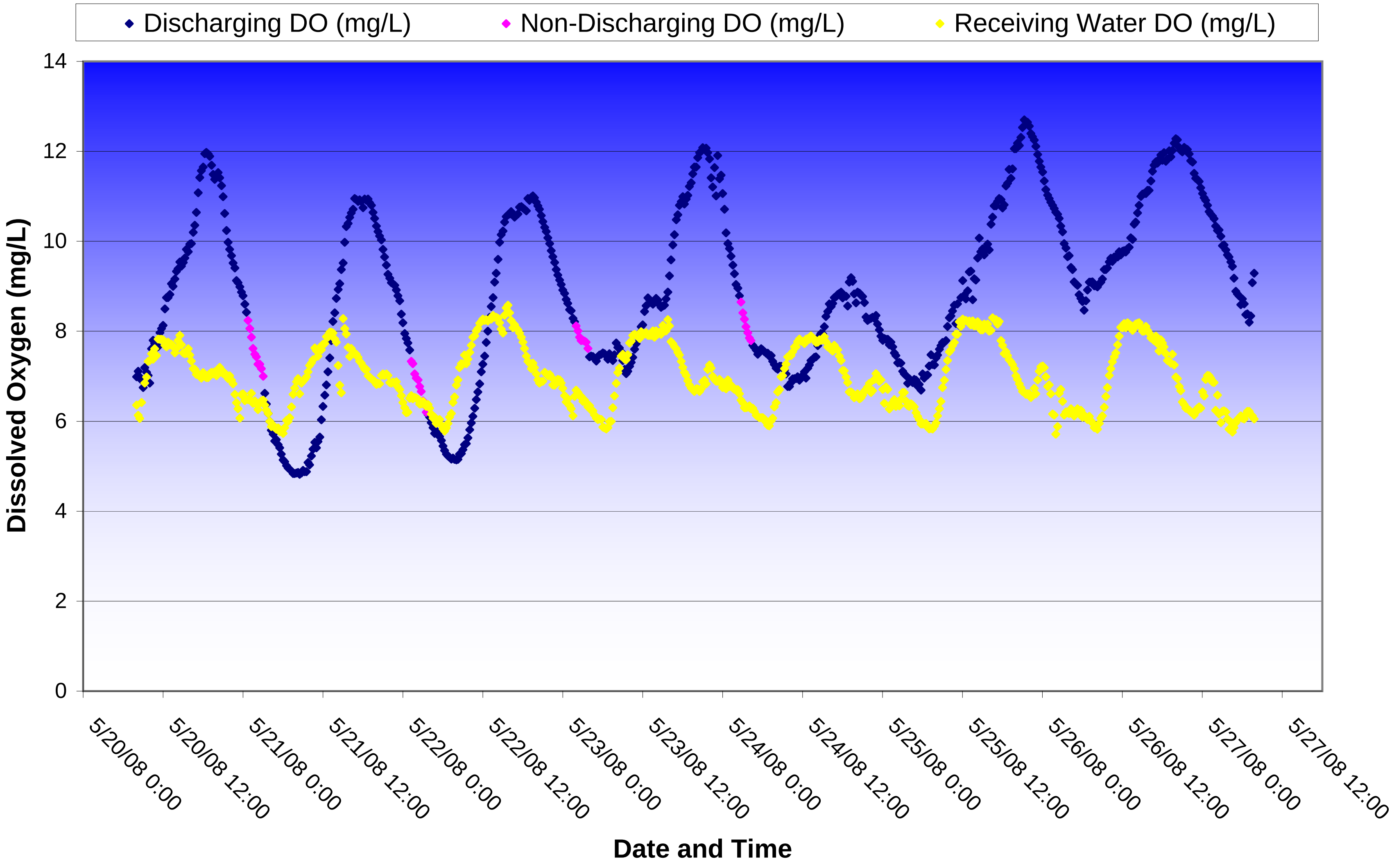

Pond A18 and Artesian Slough Dissolved Oxygen Comparisons
Week 1 - 5/1/08 to 5/6/08
◆ Discharge DO (mg/L)
◆ Non-Discharge DO (mg/L)
◆ Receiving Water DO (mg/L)
Dissolved Oxygen (mg/L)
14
12
10
8
6
4
2
0
4/30/08 18:00
5/1/08 6:00
5/1/08 18:00
5/2/08 6:00
5/2/08 18:00
5/3/08 6:00
5/3/08 18:00
5/4/08 6:00
5/4/08 18:00
5/5/08 6:00
5/5/08 18:00
5/6/08 6:00
5/6/08 18:00
Date and time


Pond A18 and Artesian Slough Dissolved Oxygen Comparisons
Week 2 - 5/6/08 to 5/13/08
◆ 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
5/6/08 0:00
5/6/08 12:00
5/7/08 0:00
5/7/08 12:00
5/8/08 0:00
5/8/08 12:00
5/9/08 0:00
5/9/08 12:00
5/10/08 0:00
5/10/08 12:00
5/11/08 0:00
5/11/08 12:00
5/12/08 0:00
5/12/08 12:00
5/13/08 0:00
5/13/08 12:00
Date and time

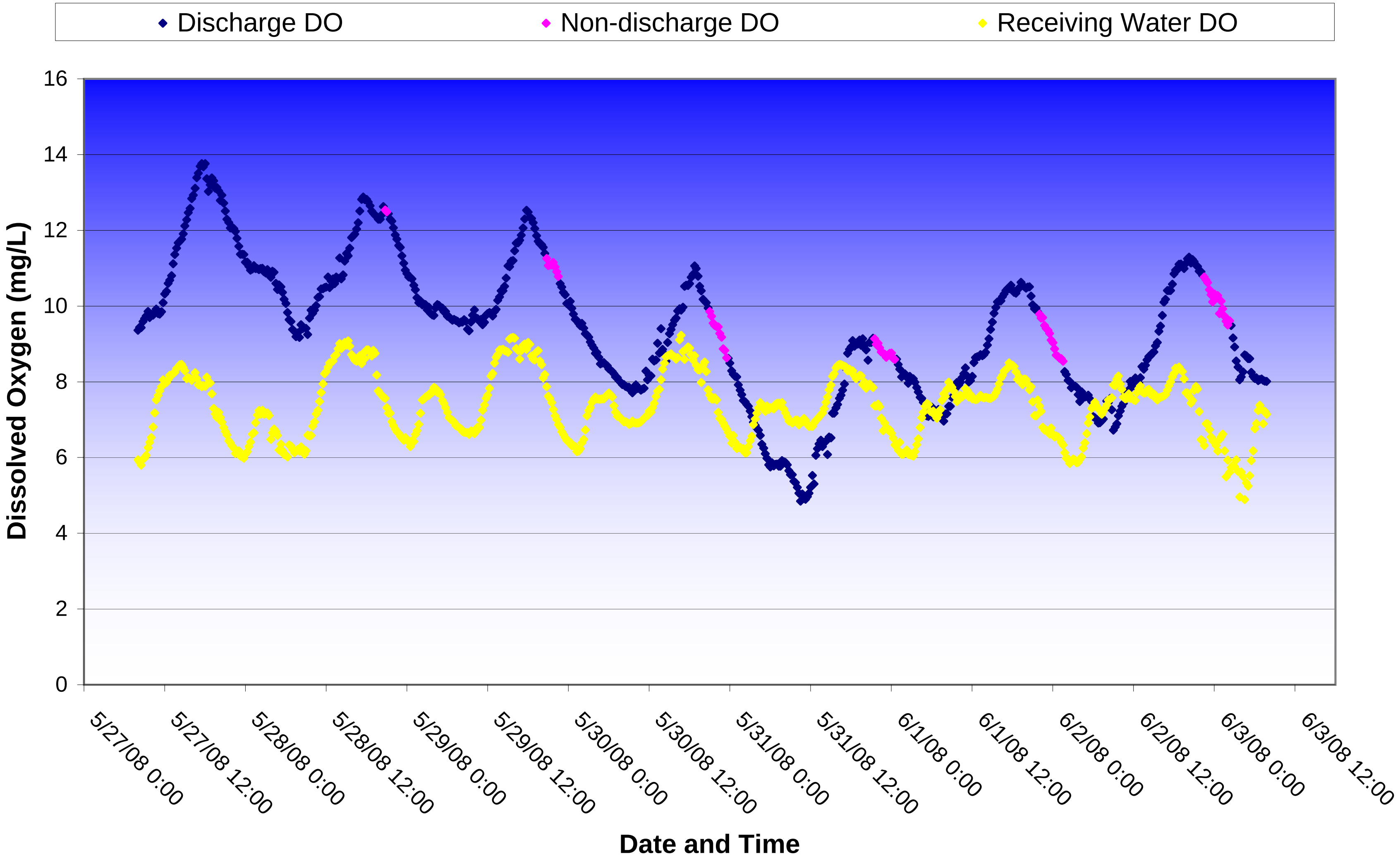
Pond A18 and Artesian Slough Dissolved Oxygen Comparisons
Week 3 - 5/13/08 to 5/20/08



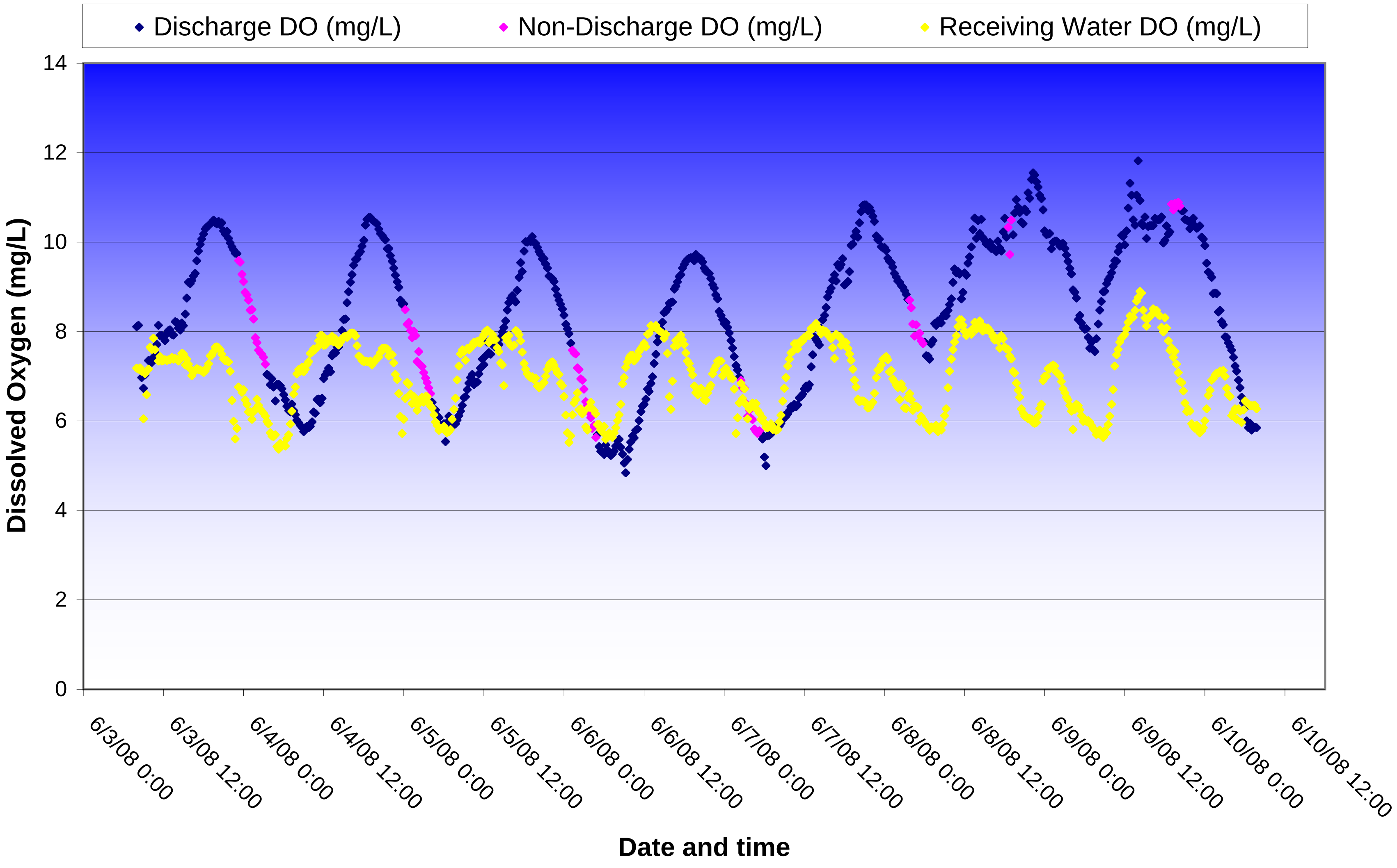
Pond A18 and Artesian Slough Dissolved Oxygen Comparisons
Week 4 - 5/20/08 to 5/27/08

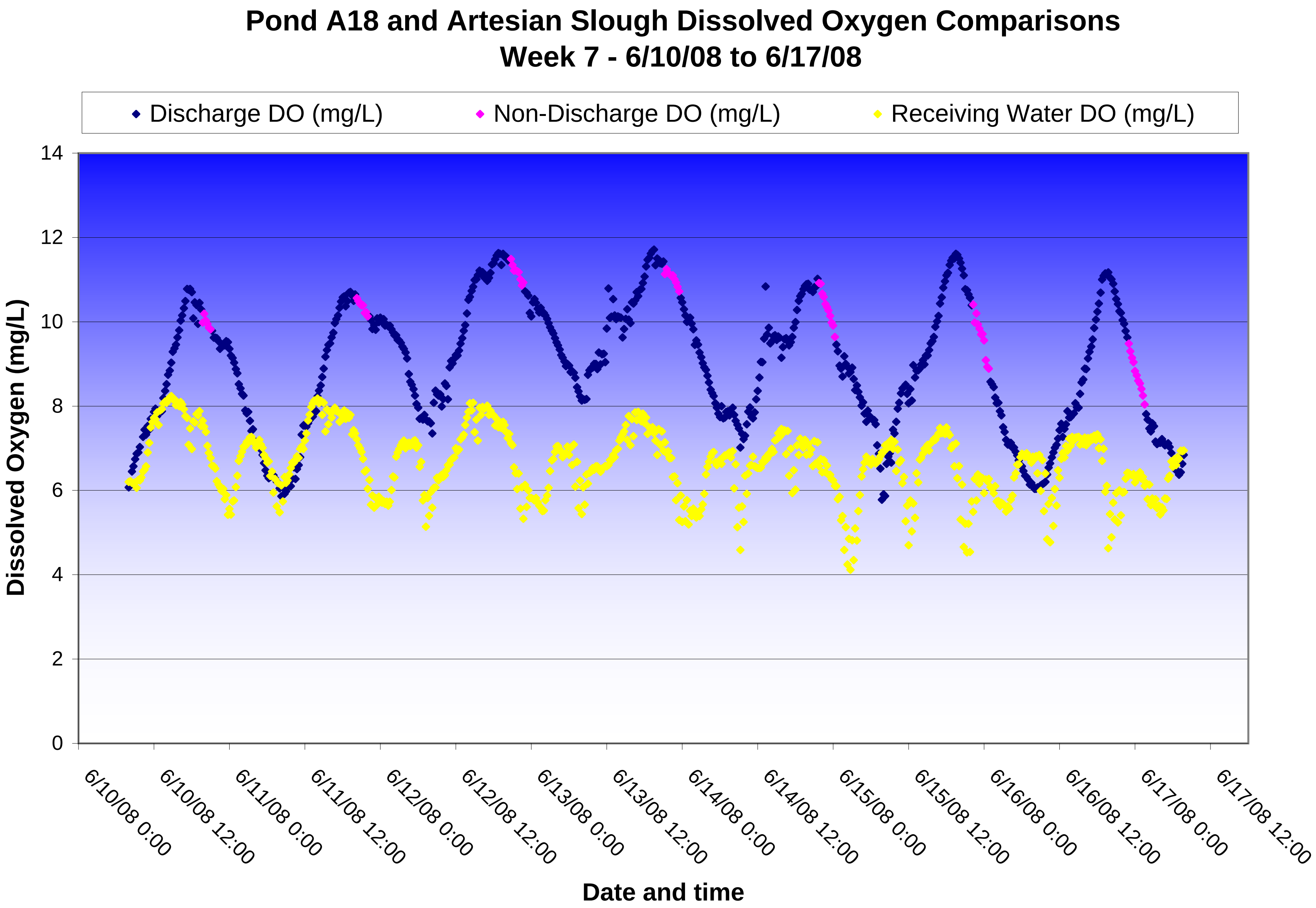


Pond A18 and Artesian Slough Dissolved Oxygen Comparisons
Week 5 - 5/27/08 to 6/3/08

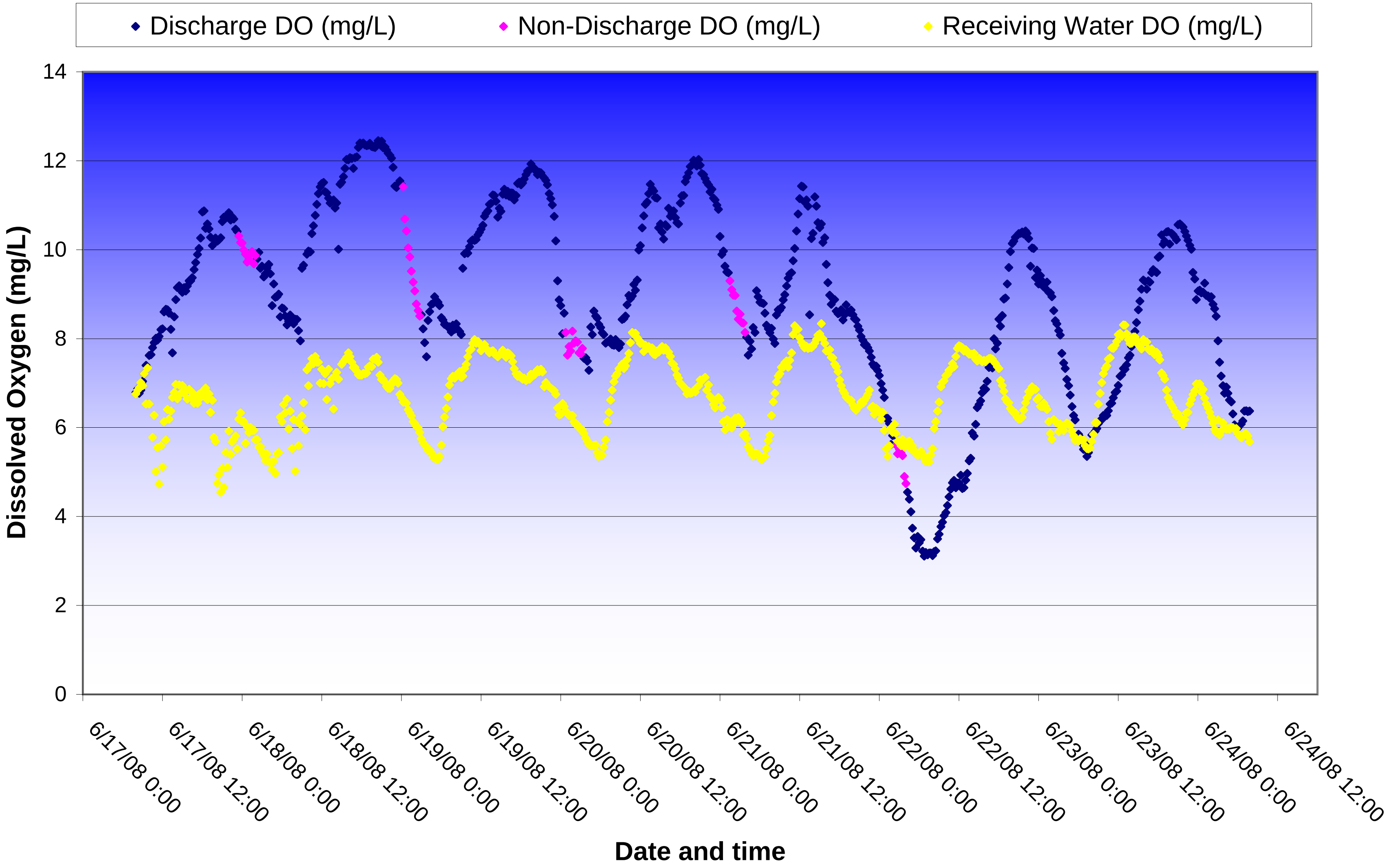


Pond A18 and Artesian Slough Dissolved Oxygen Comparisons
Week 6 - 6/3/08 to 6/10/08

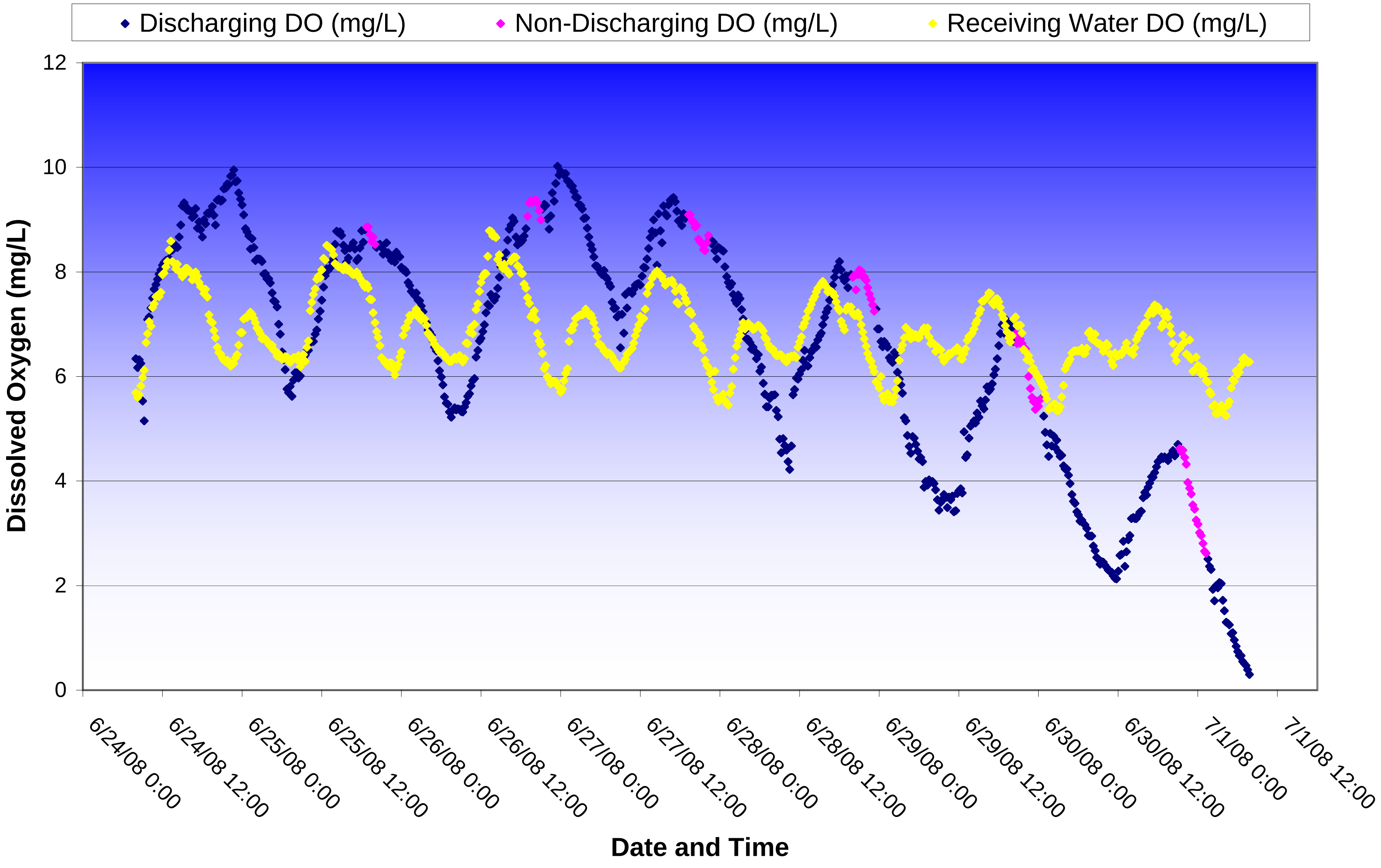



Pond A18 and Artesian Slough Dissolved Oxygen Comparisons
Week 7 - 6/10/08 to 6/17/08
◆ Discharge DO (mg/L)
◆ Non-Discharge DO (mg/L)
◆ Receiving Water DO (mg/L)
Dissolved Oxygen (mg/L)
14
12
10
8
6
4
2
0
6/10/08 0:00
6/10/08 12:00
6/11/08 0:00
6/11/08 12:00
6/12/08 0:00
6/12/08 12:00
6/13/08 0:00
6/13/08 12:00
6/14/08 0:00
6/14/08 12:00
6/15/08 0:00
6/15/08 12:00
6/16/08 0:00
6/16/08 12:00
6/17/08 0:00
6/17/08 12:00
Date and time

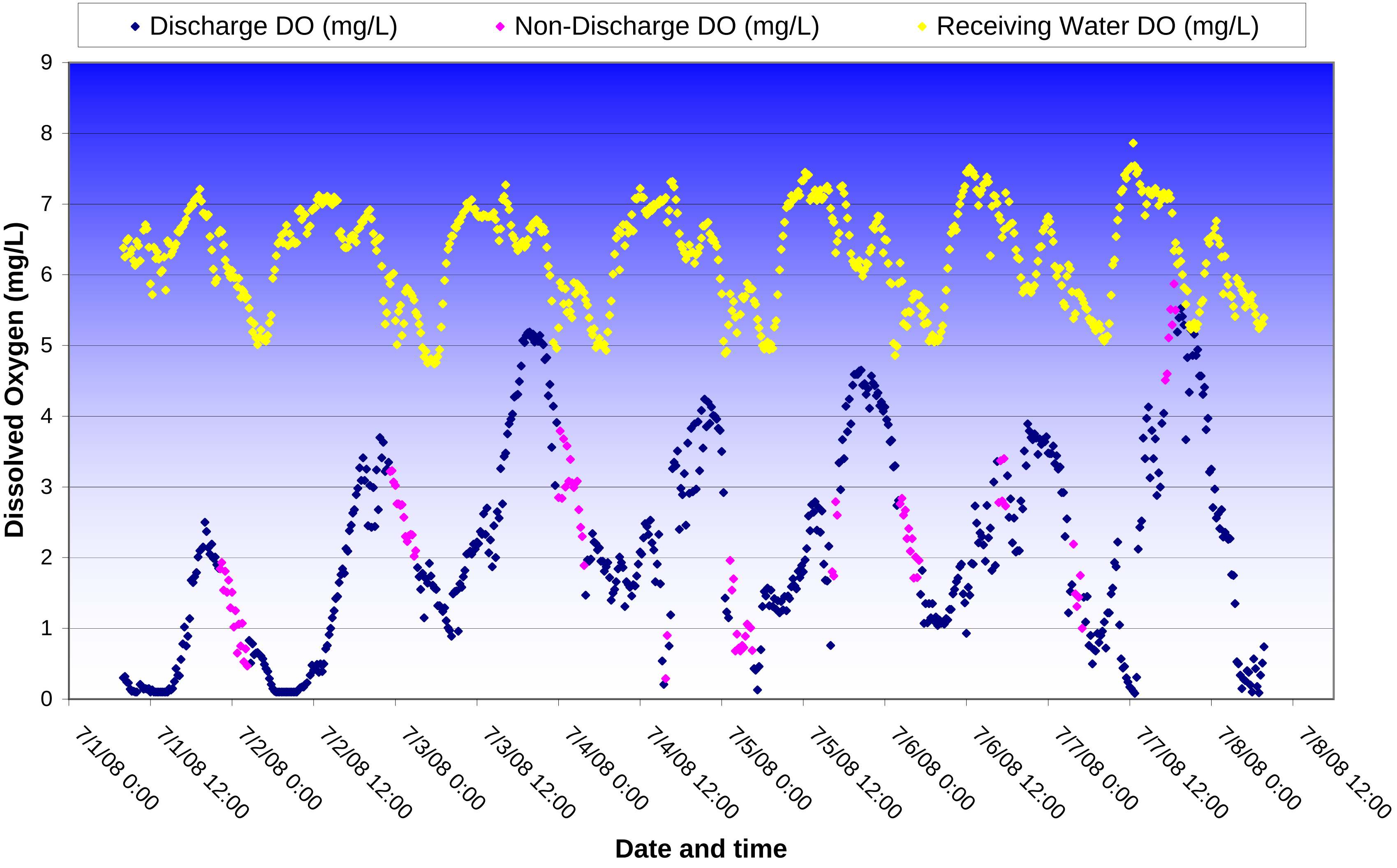
Pond A18 and Artesian Slough Dissolved Oxygen Comparisons
Week 8 - 6/17/08 to 6/24/08

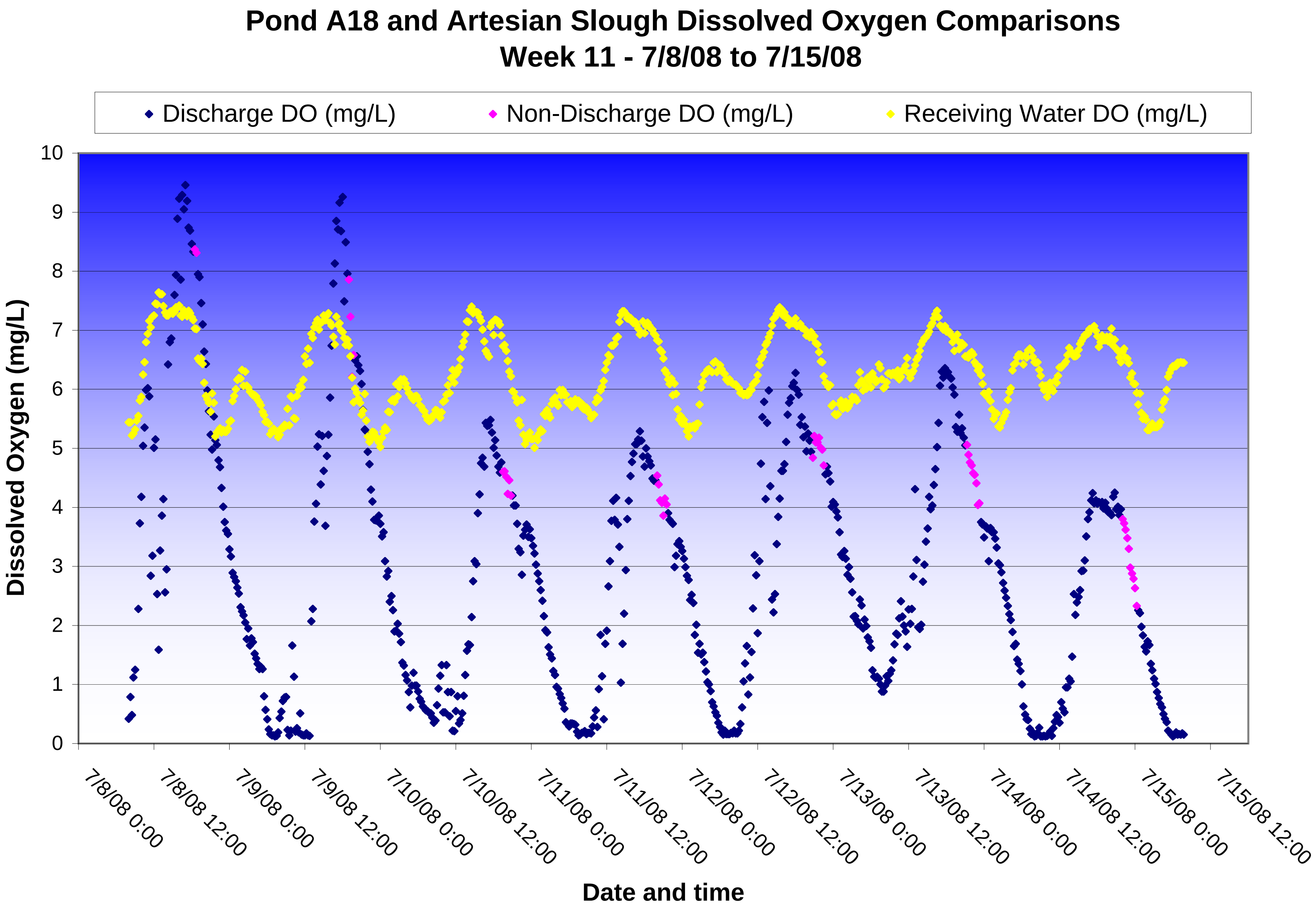


Pond A18 and Artesian Slough Dissolved Oxygen Comparisons
Week 9 - 6/24/08 to 7/1/08



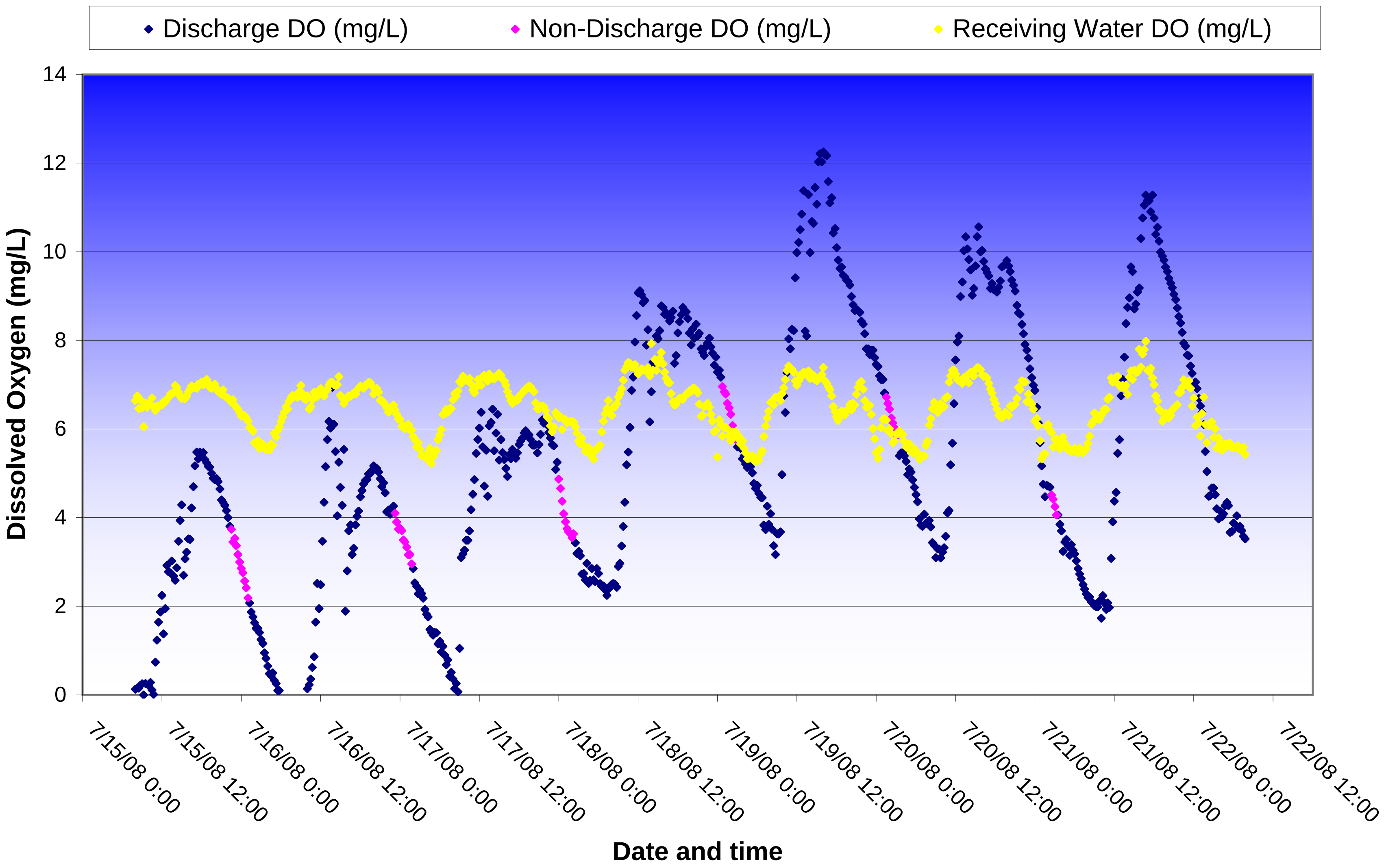
Pond A18 and Artesian Slough Dissolved Oxygen Comparisons
Week 10 - 7/1/08 to 7/8/08



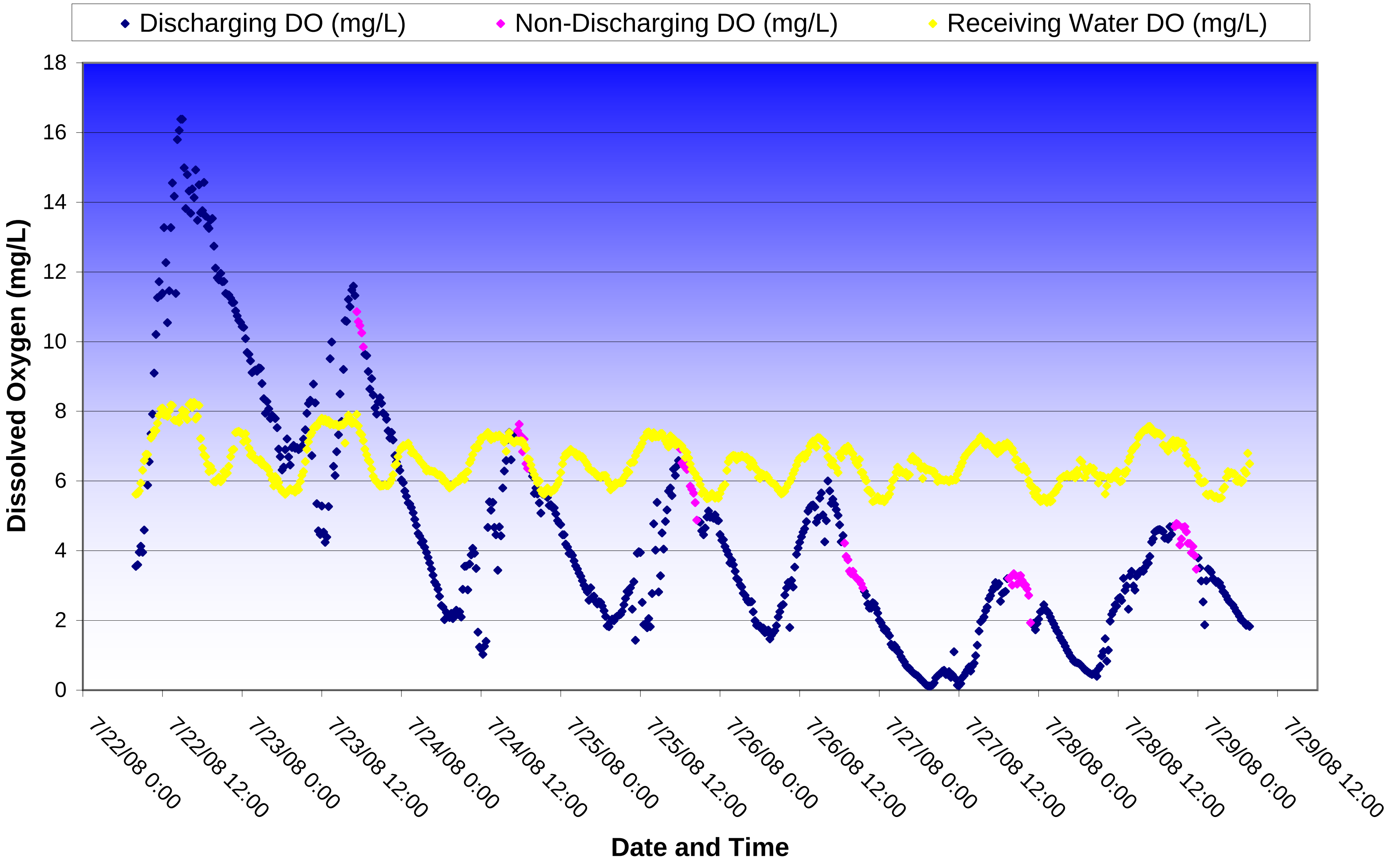


Pond A18 and Artesian Slough Dissolved Oxygen Comparisons
Week 11 - 7/8/08 to 7/15/08
◆ Discharge DO (mg/L)
◆ Non-Discharge DO (mg/L)
◆ Receiving Water DO (mg/L)
Dissolved Oxygen (mg/L)
10
9
8
7
6
5
4
3
2
1
0
7/8/08 0:00
7/8/08 12:00
7/9/08 0:00
7/9/08 12:00
7/10/08 0:00
7/10/08 12:00
7/11/08 0:00
7/11/08 12:00
7/12/08 0:00
7/12/08 12:00
7/13/08 0:00
7/13/08 12:00
7/14/08 0:00
7/14/08 12:00
7/15/08 0:00
7/15/08 12:00
Date and time

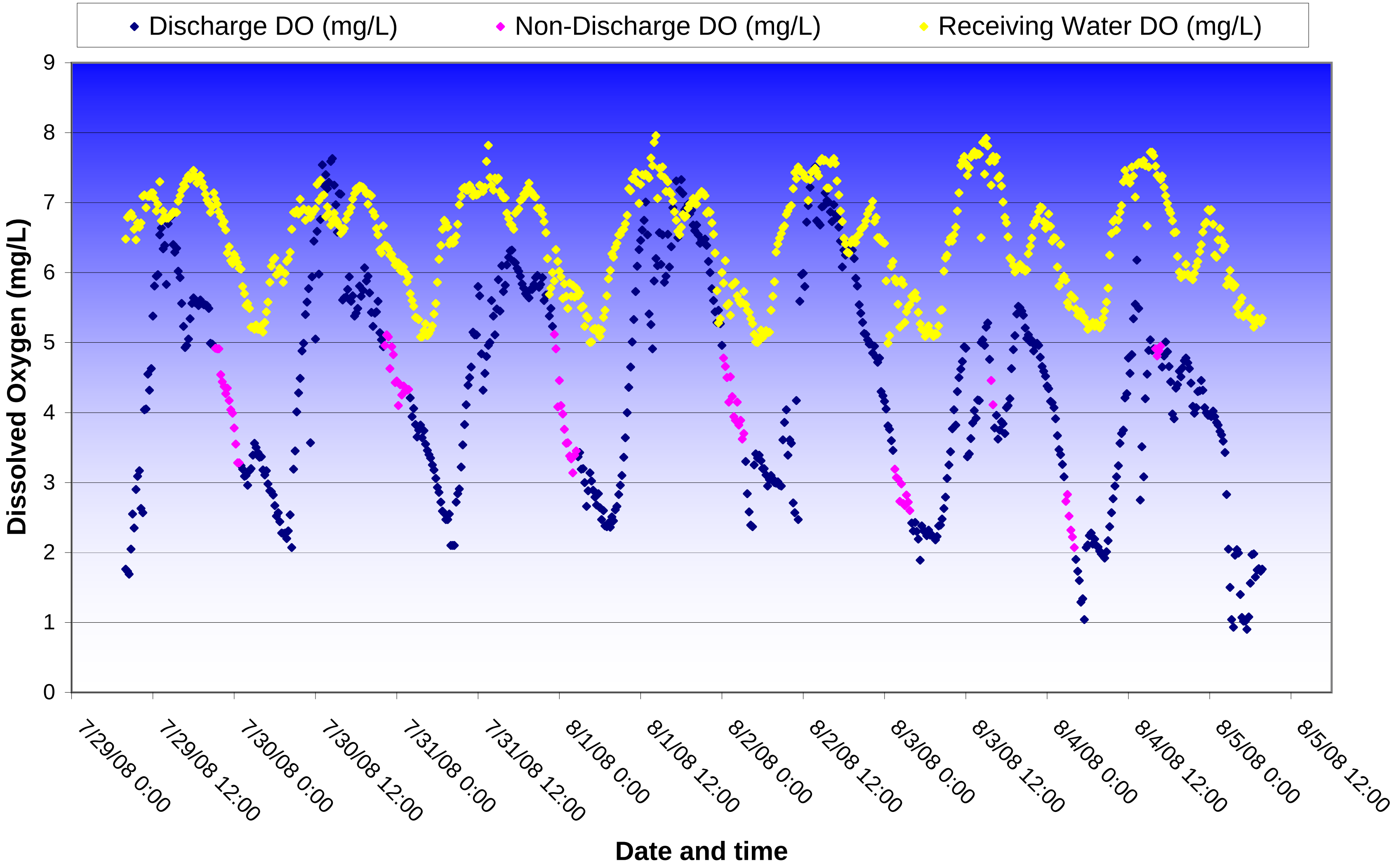
Pond A18 and Artesian Slough Dissolved Oxygen Comparisons
Week 12 - 7/15/08 to 7/22/08



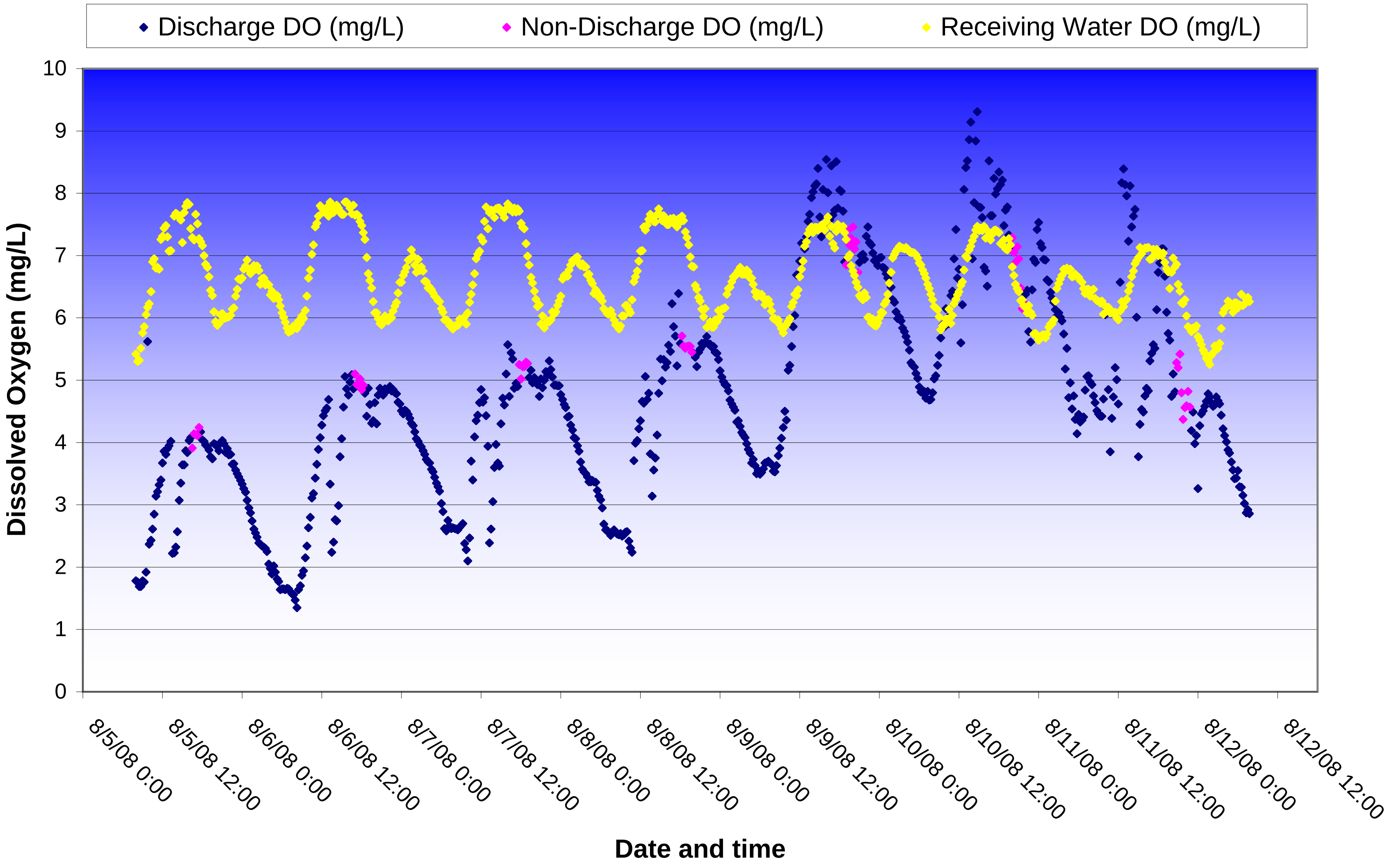
Pond A18 and Artesian Slough Dissolved Oxygen Comparisons
Week 13 - 7/22/08 to 7/29/08



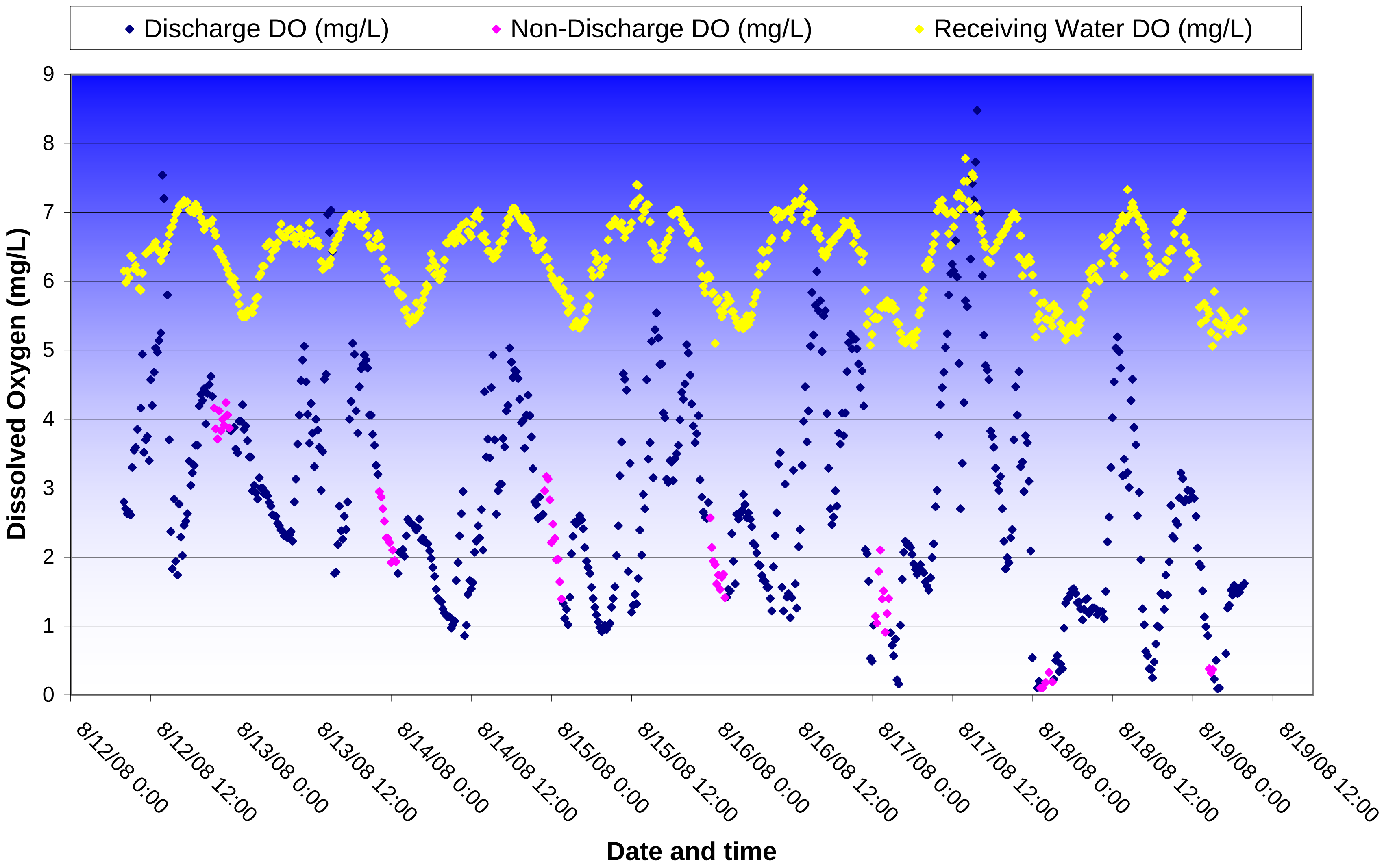
Pond A18 and Artesian Slough Dissolved Oxygen Comparisons
Week 14 - 7/29/08 to 8/5/08

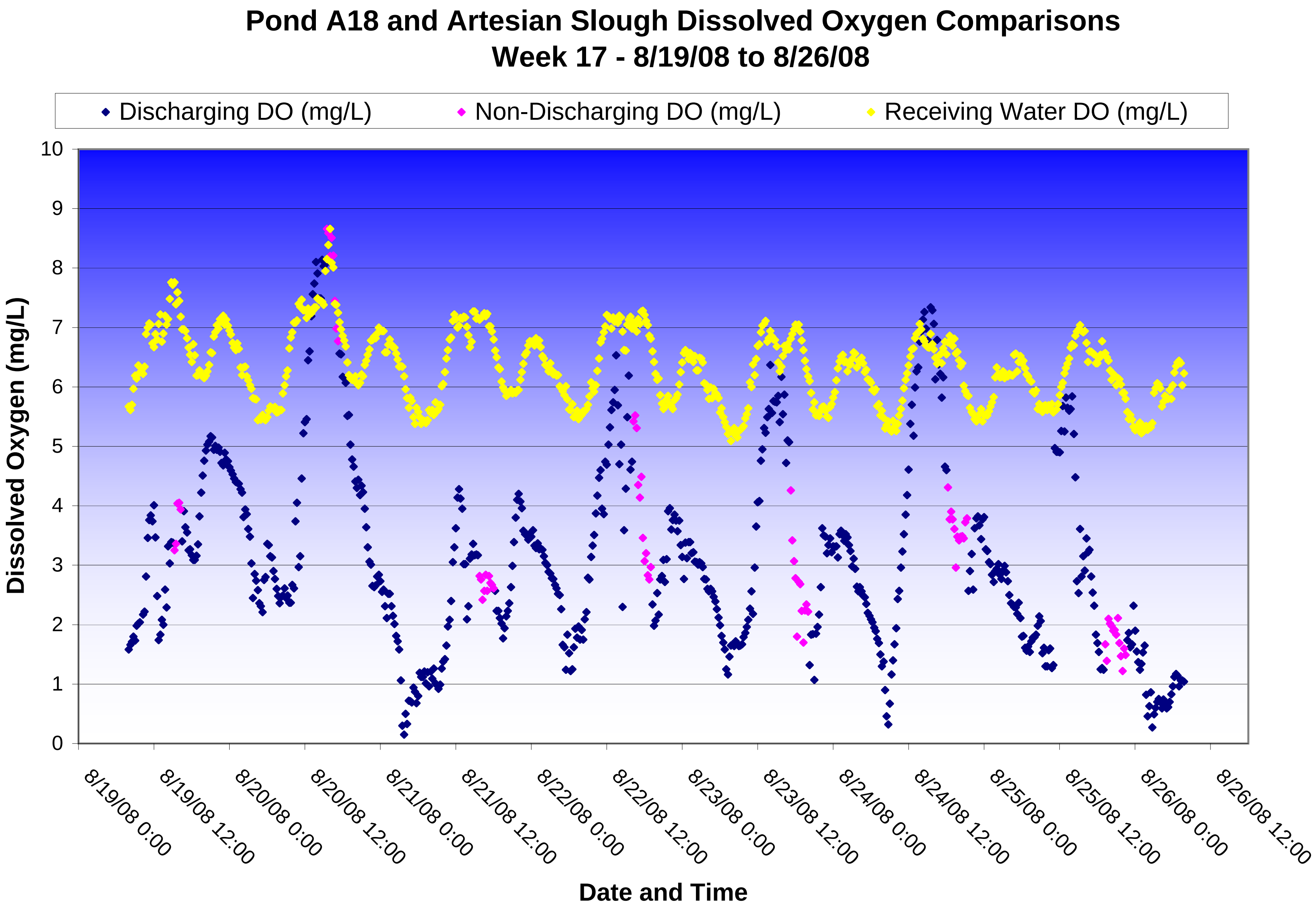


Pond A18 and Artesian Slough Dissolved Oxygen Comparisons
Week 15 - 8/5/08 to 8/12/08



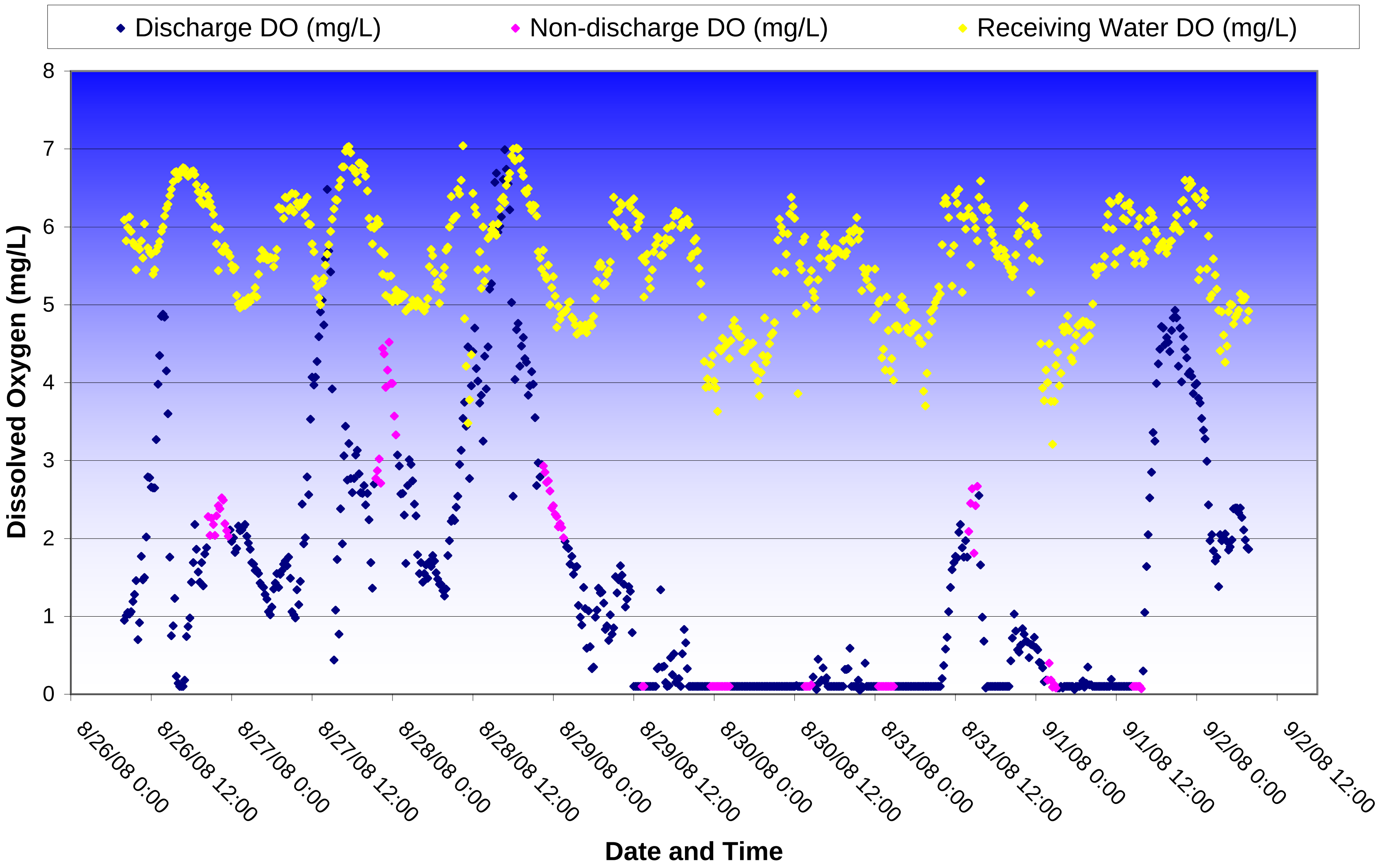
Pond A18 and Artesian Slough Dissolved Oxygen Comparisons
Week 16 - 8/12/08 to 8/19/08

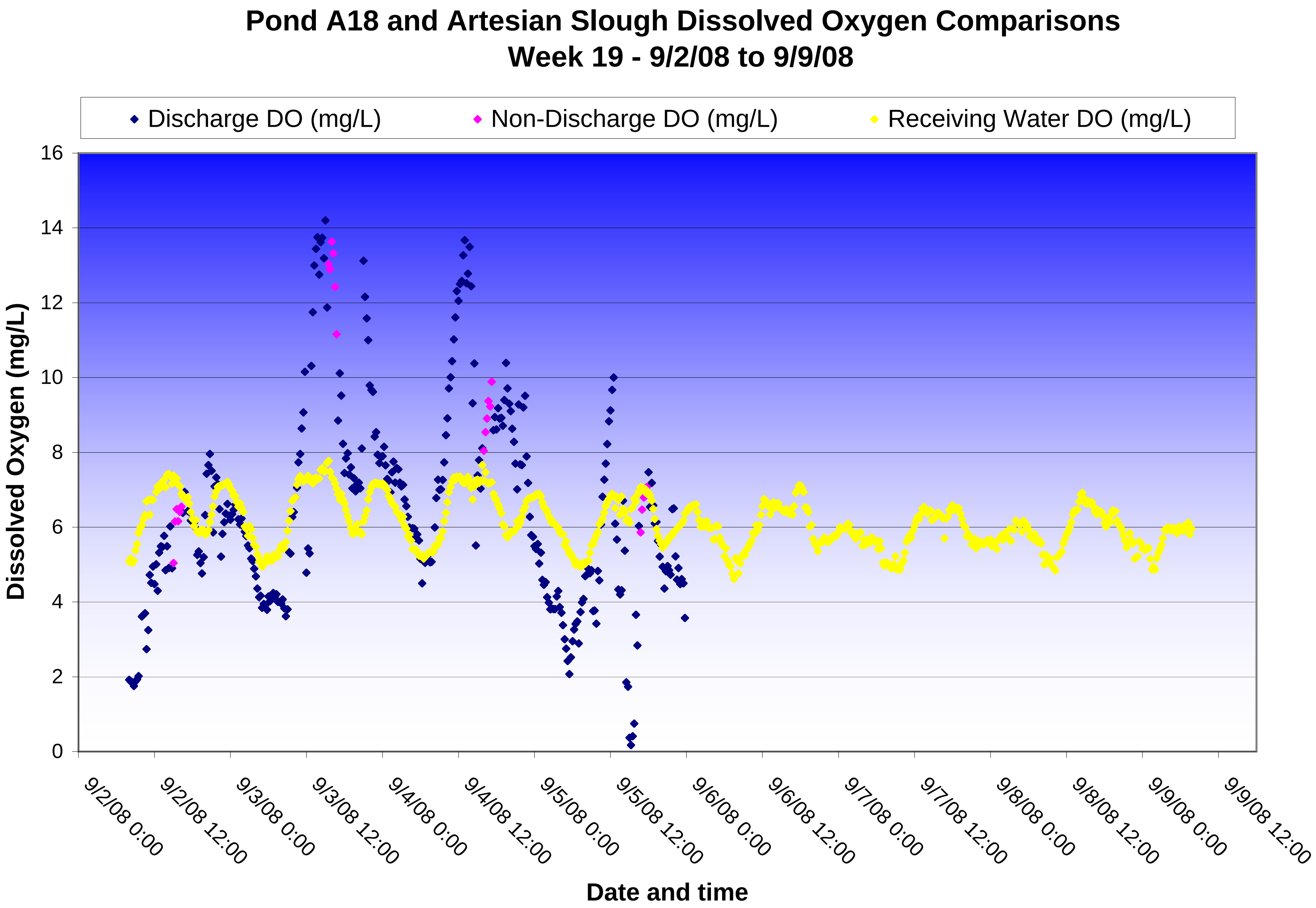




Pond A18 and Artesian Slough Dissolved Oxygen Comparisons
Week 17 - 8/19/08 to 8/26/08

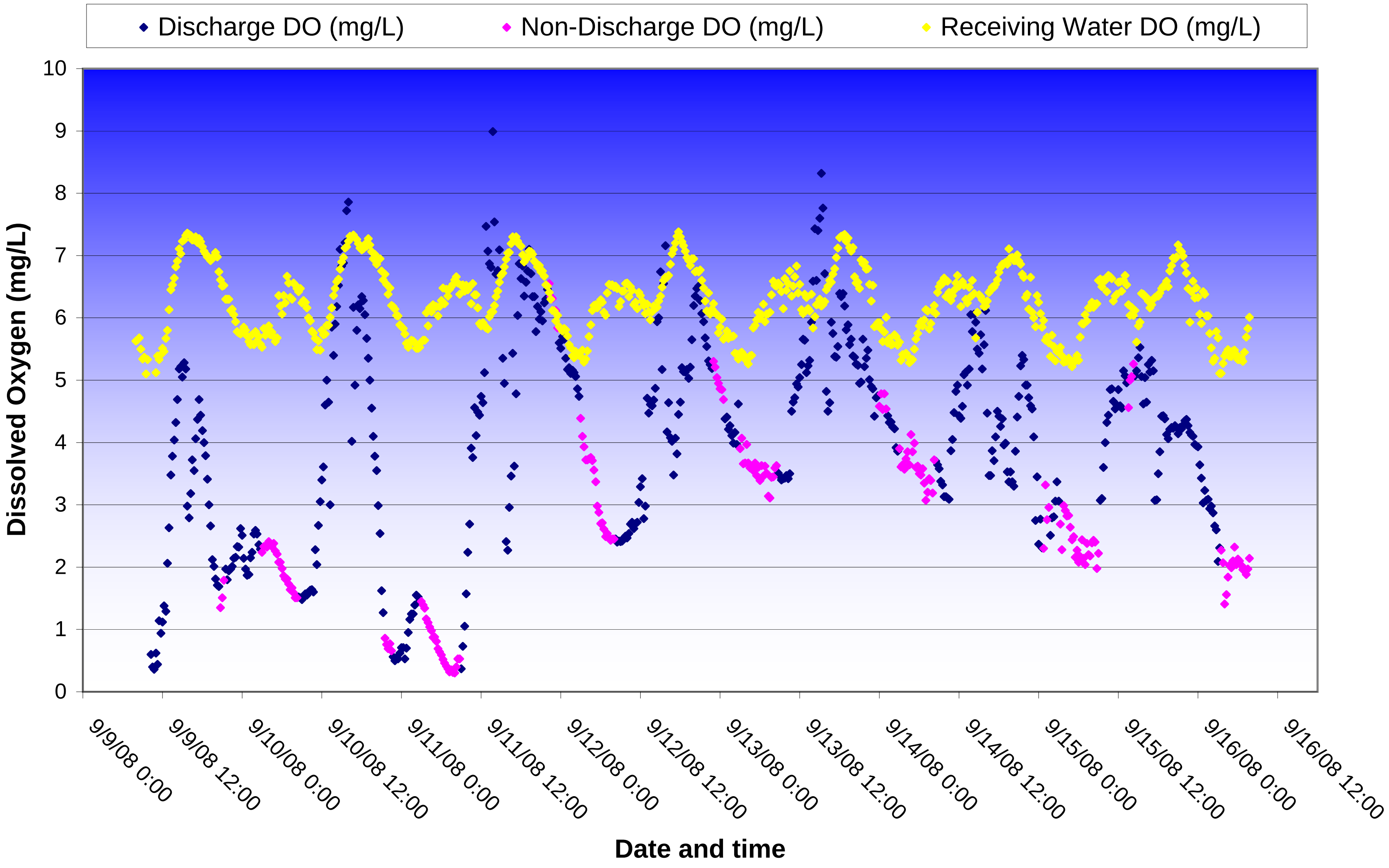
Pond A18 and Artesian Slough Dissolved Oxygen Comparisons
Week 18 - 8/26/08 to 9/2/08



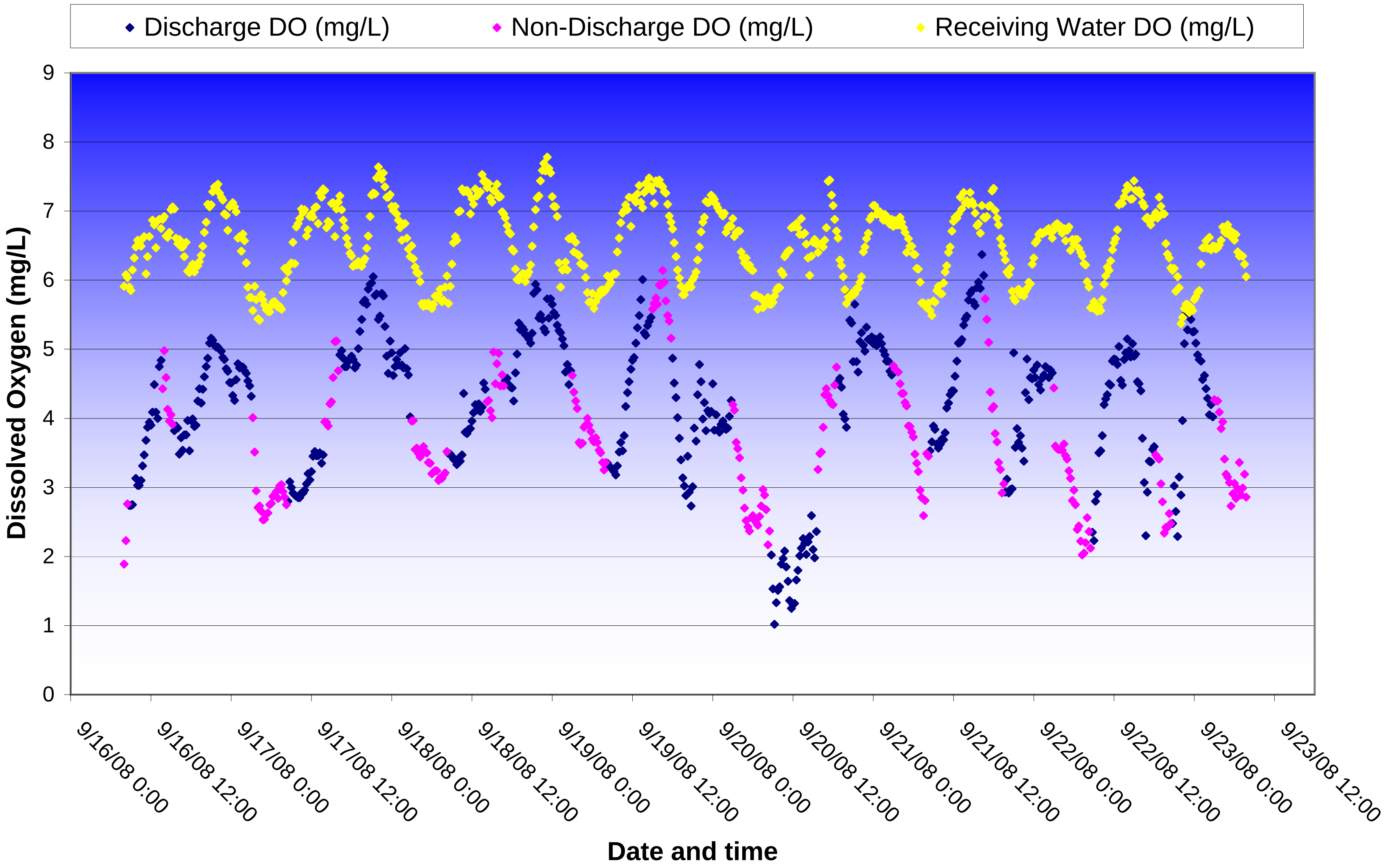


Pond A18 and Artesian Slough Dissolved Oxygen Comparisons
Week 19 - 9/2/08 to 9/9/08
◆ Discharge DO (mg/L)
◆ Non-Discharge DO (mg/L)
◆ Receiving Water DO (mg/L)
Dissolved Oxygen (mg/L)
16
14
12
10
8
6
4
2
0
9/2/08 0:00
9/2/08 12:00
9/3/08 0:00
9/3/08 12:00
9/4/08 0:00
9/4/08 12:00
9/5/08 0:00
9/5/08 12:00
9/6/08 0:00
9/6/08 12:00
9/7/08 0:00
9/7/08 12:00
9/8/08 0:00
9/8/08 12:00
9/9/08 0:00
9/9/08 12:00
Date and time

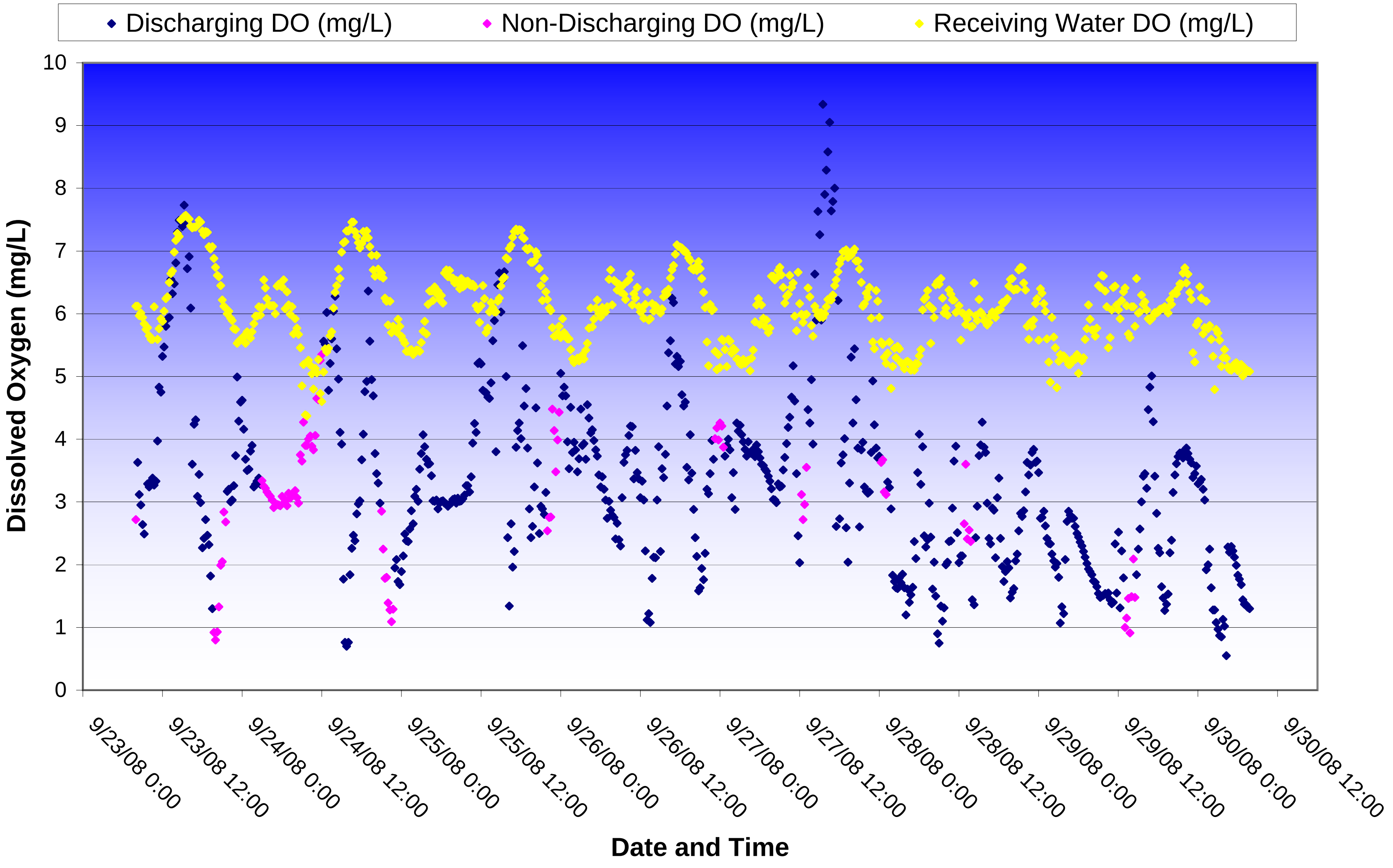
Pond A18 and Artesian Slough Dissolved Oxygen Comparisons
Week 20 - 9/9/08 to 9/16/08



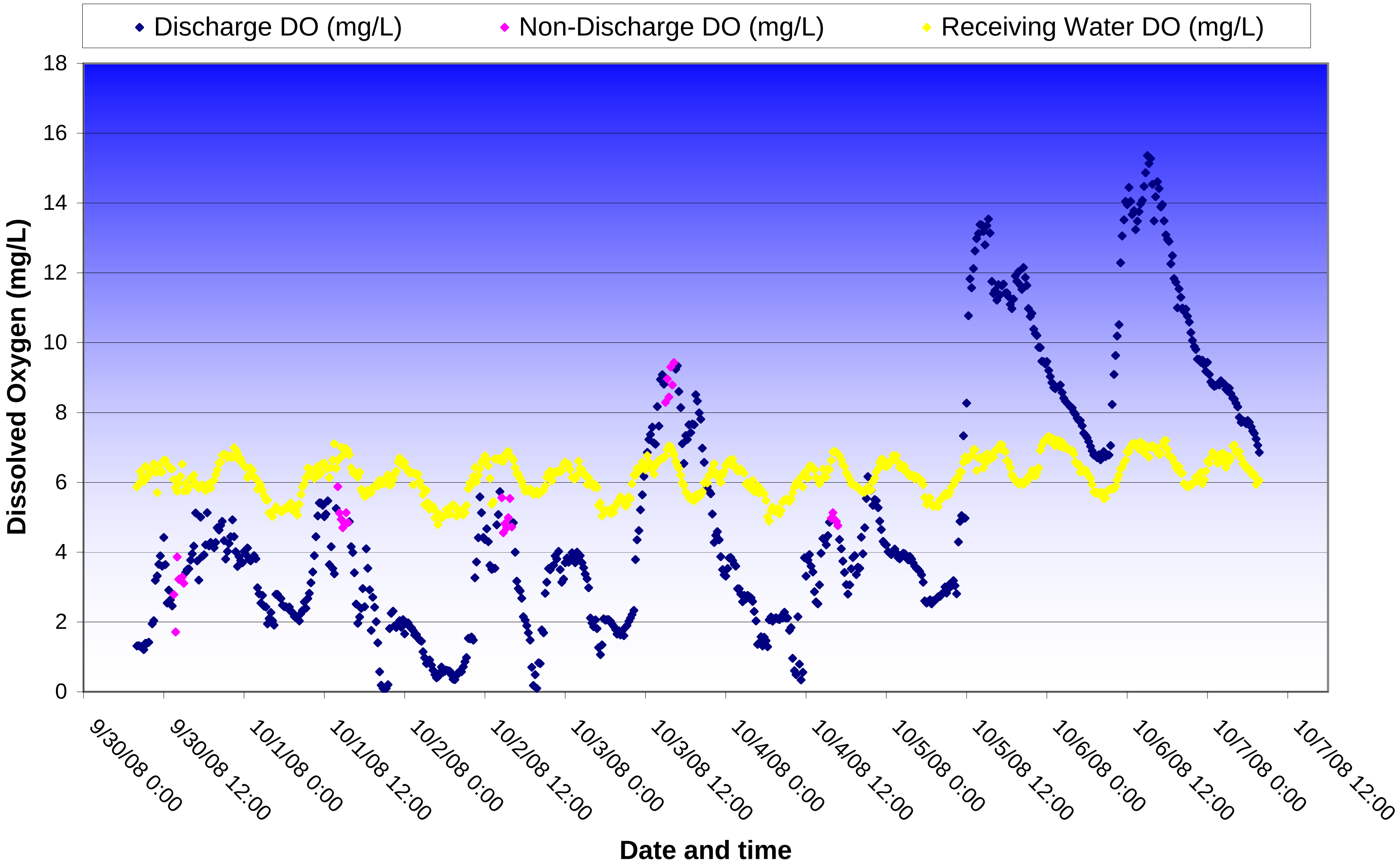
Pond A18 and Artesian Slough Dissolved Oxygen Comparisons
Week 21 - 9/16/08 to 9/23/08



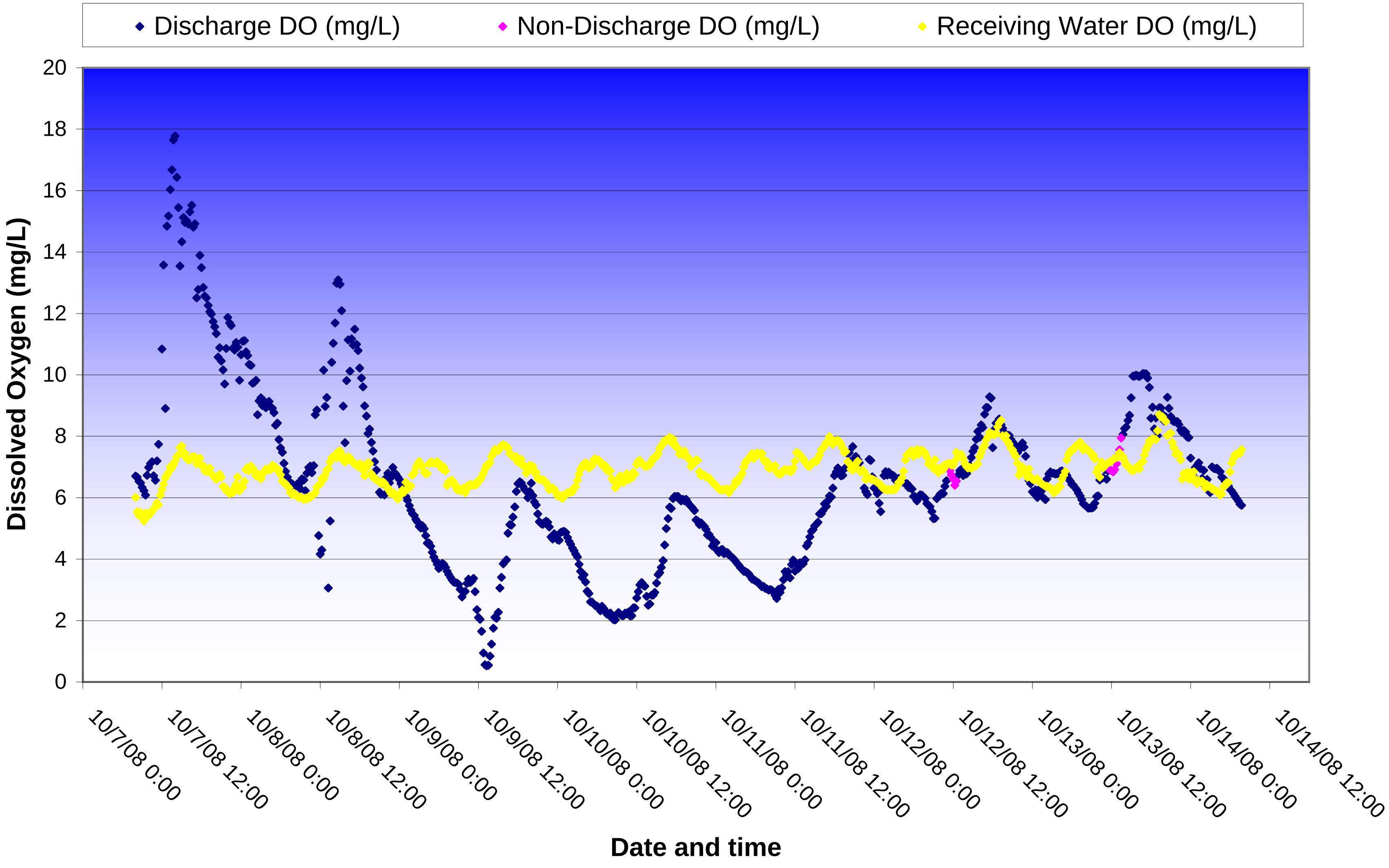
Pond A18 and Artesian Slough Dissolved Oxygen Comparisons
Week 22 - 9/23/08 to 9/30/08



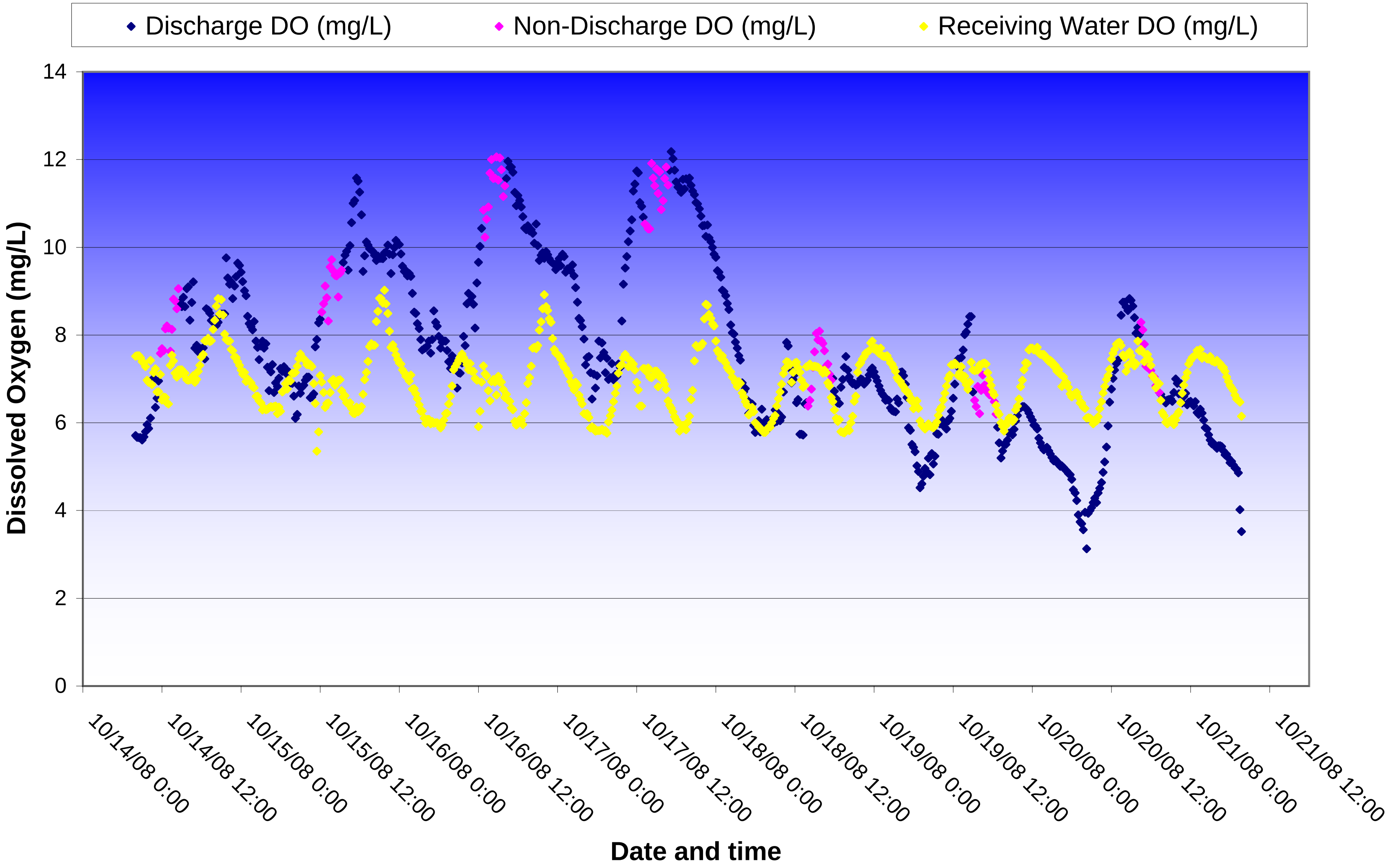
Pond A18 and Artesian Slough Dissolved Oxygen Comparisons
Week 23 - 9/30/08 to 10/7/08



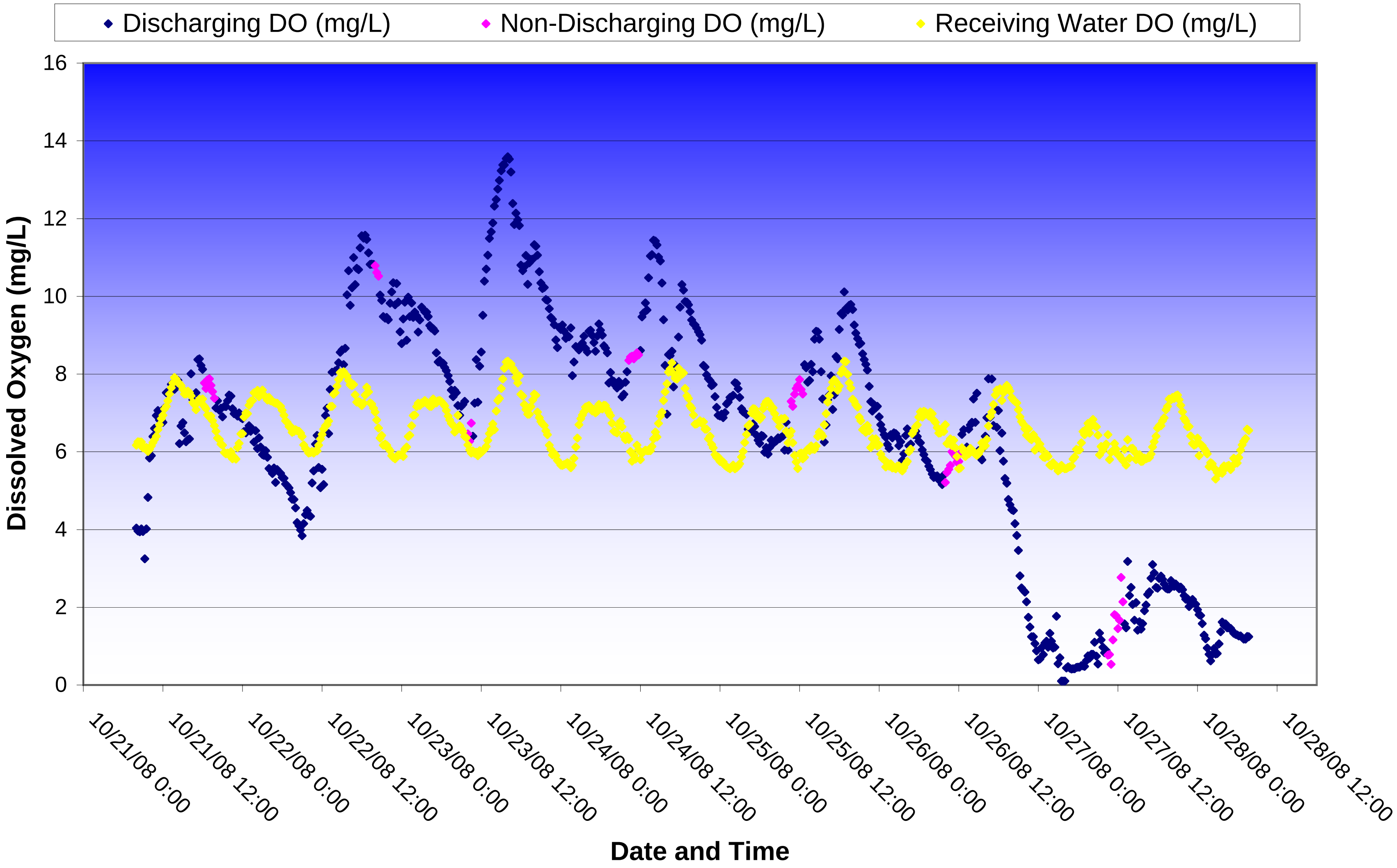
Pond A18 and Artesian Slough Dissolved Oxygen Comparisons
Week 24 - 10/7/08 to 10/14/08



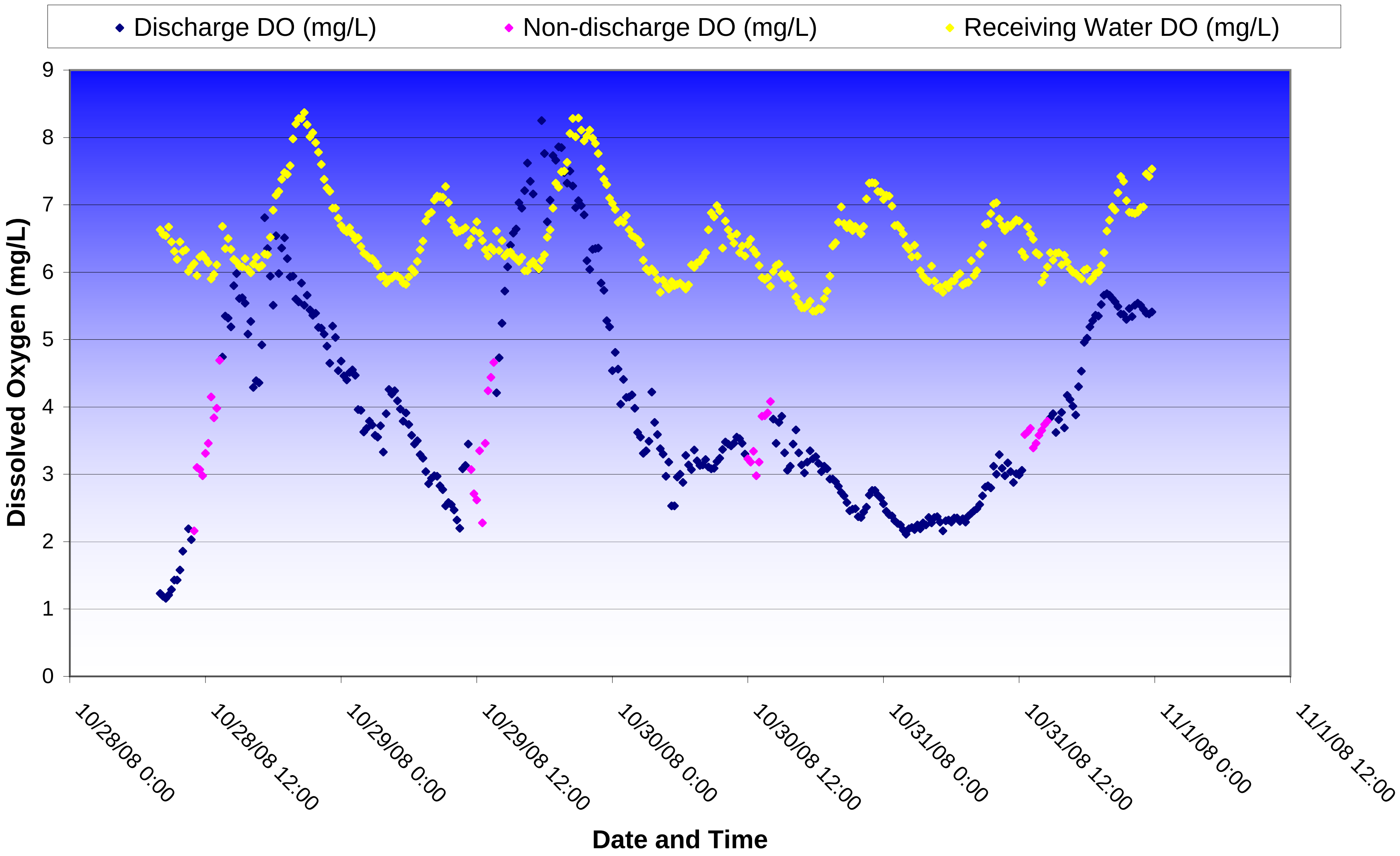
Pond A18 and Artesian Slough Dissolved Oxygen Comparisons
Week 25 - 10/14/08 to 10/21/08



Pond A18 and Artesian Slough Dissolved Oxygen Comparisons
Week 26 - 10/21/08 to 10/28/08

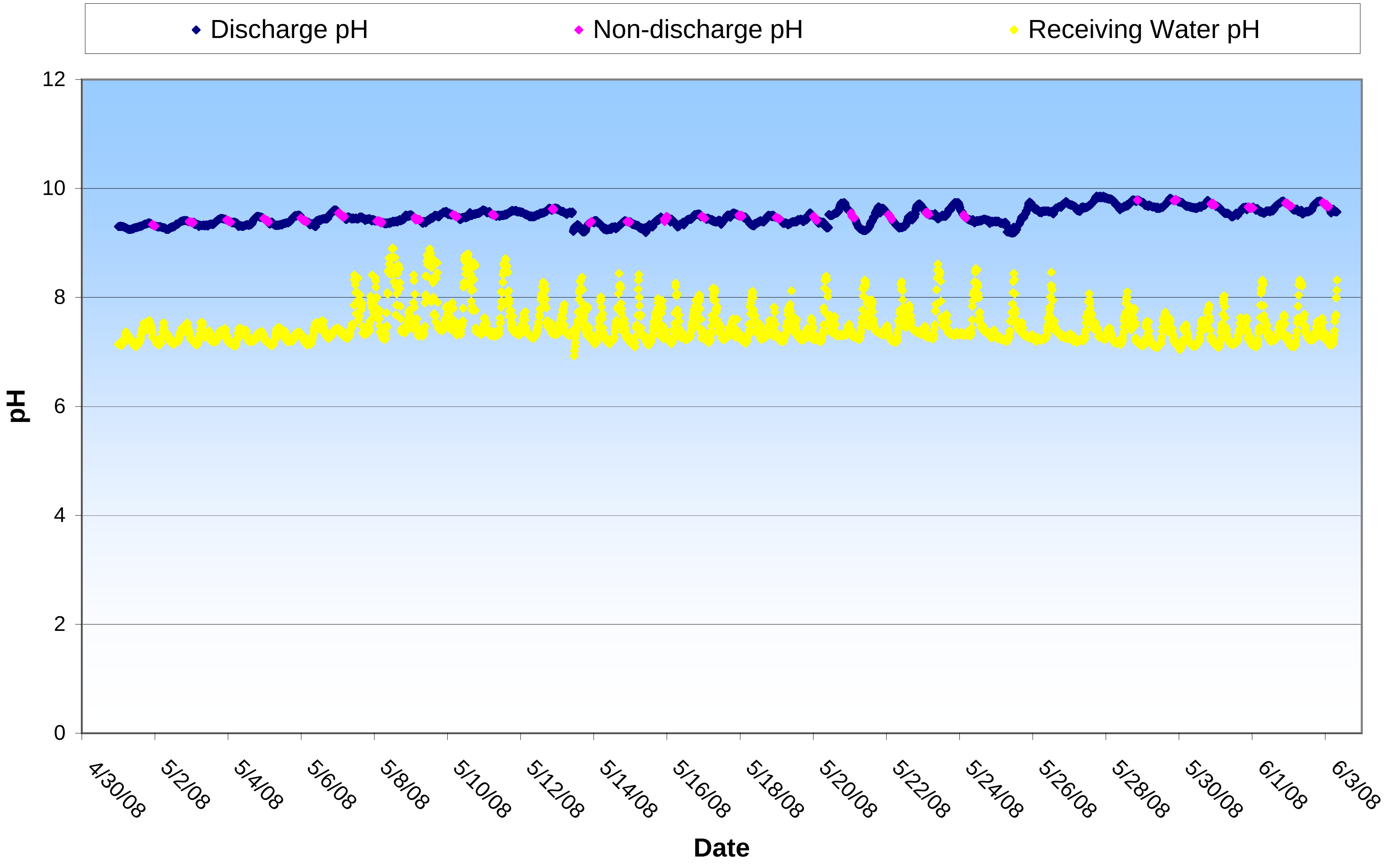


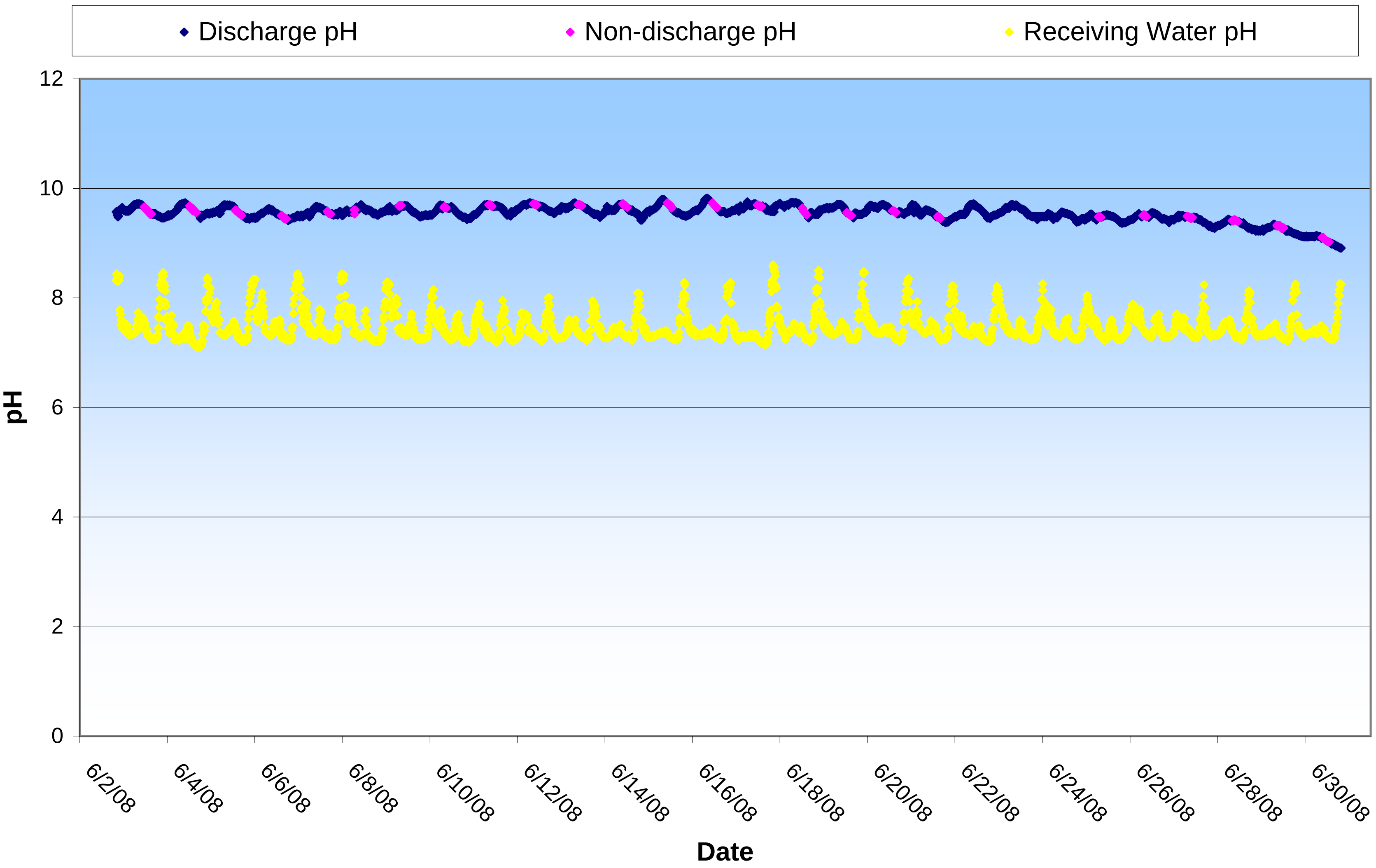
Pond A18 and Artesian Slough Dissolved Oxygen Comparisons
Week 27 - 10/28/08 to 10/31/08: final week; partial



Appendix II. Comparative Profiles of pH, Salinity and Temperature in A18 and Artesian Slough for Each Month of 2008 Monitoring Season.

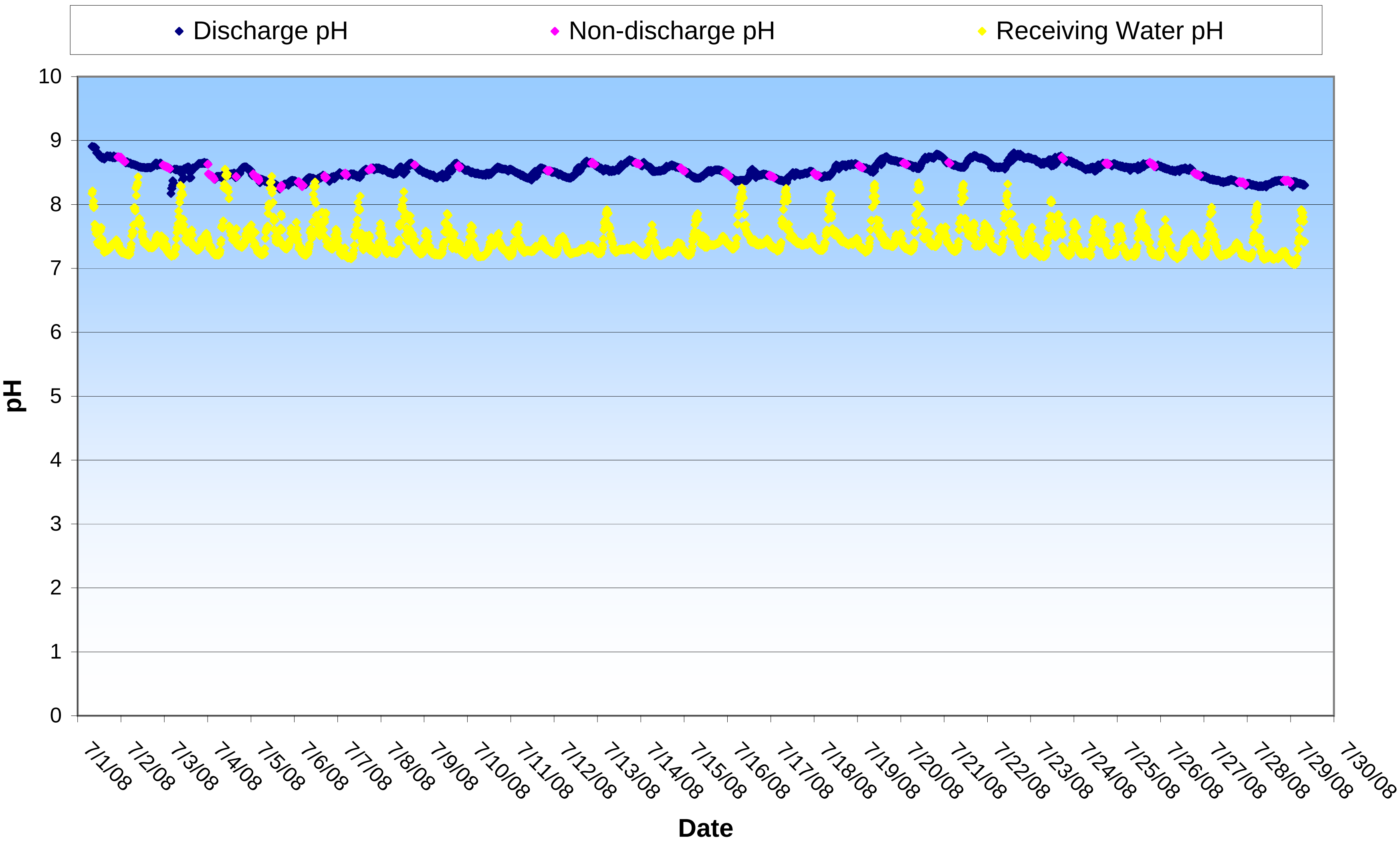
Pond A18 and Artesian Slough pH Comparisons
May 2008

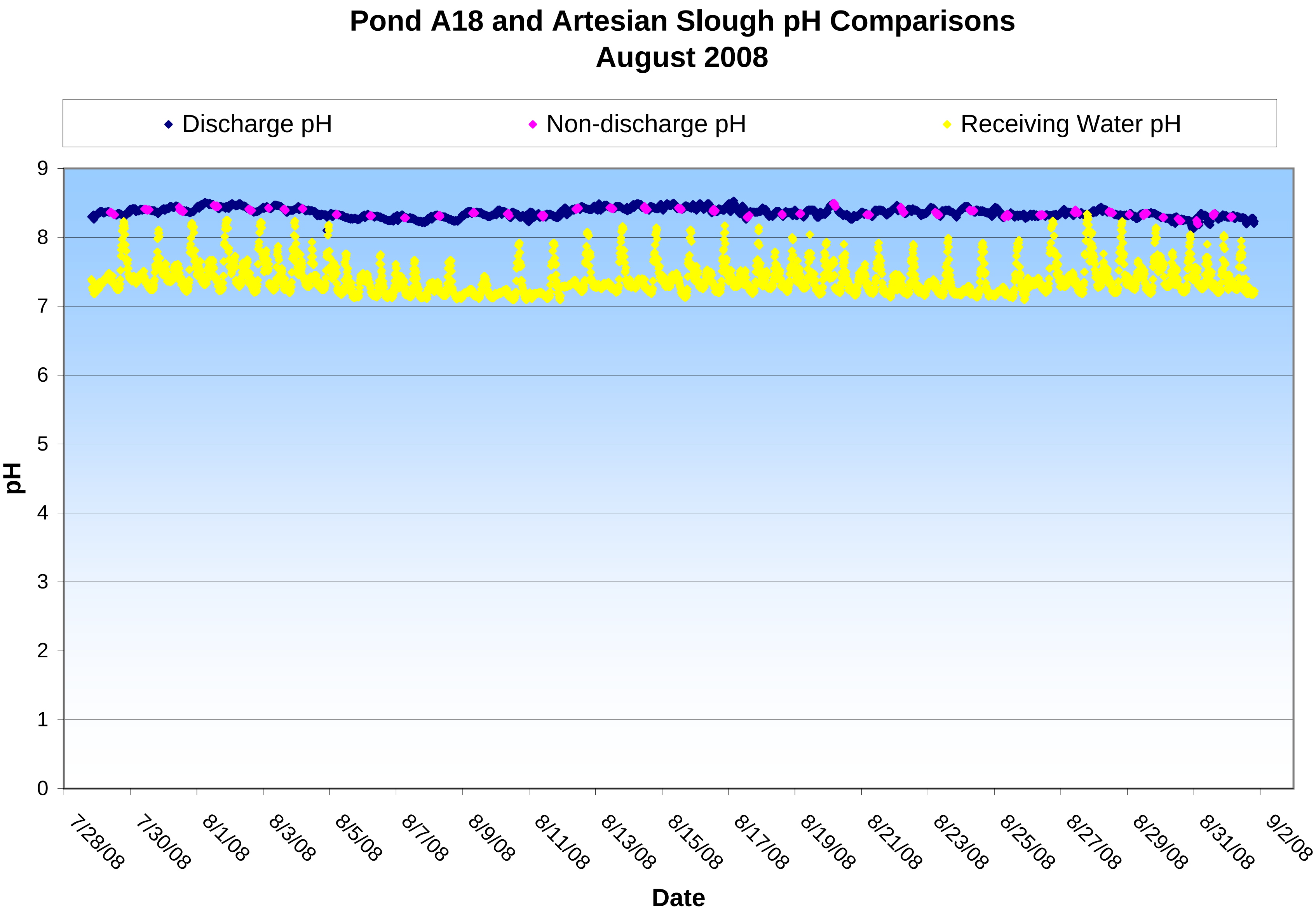




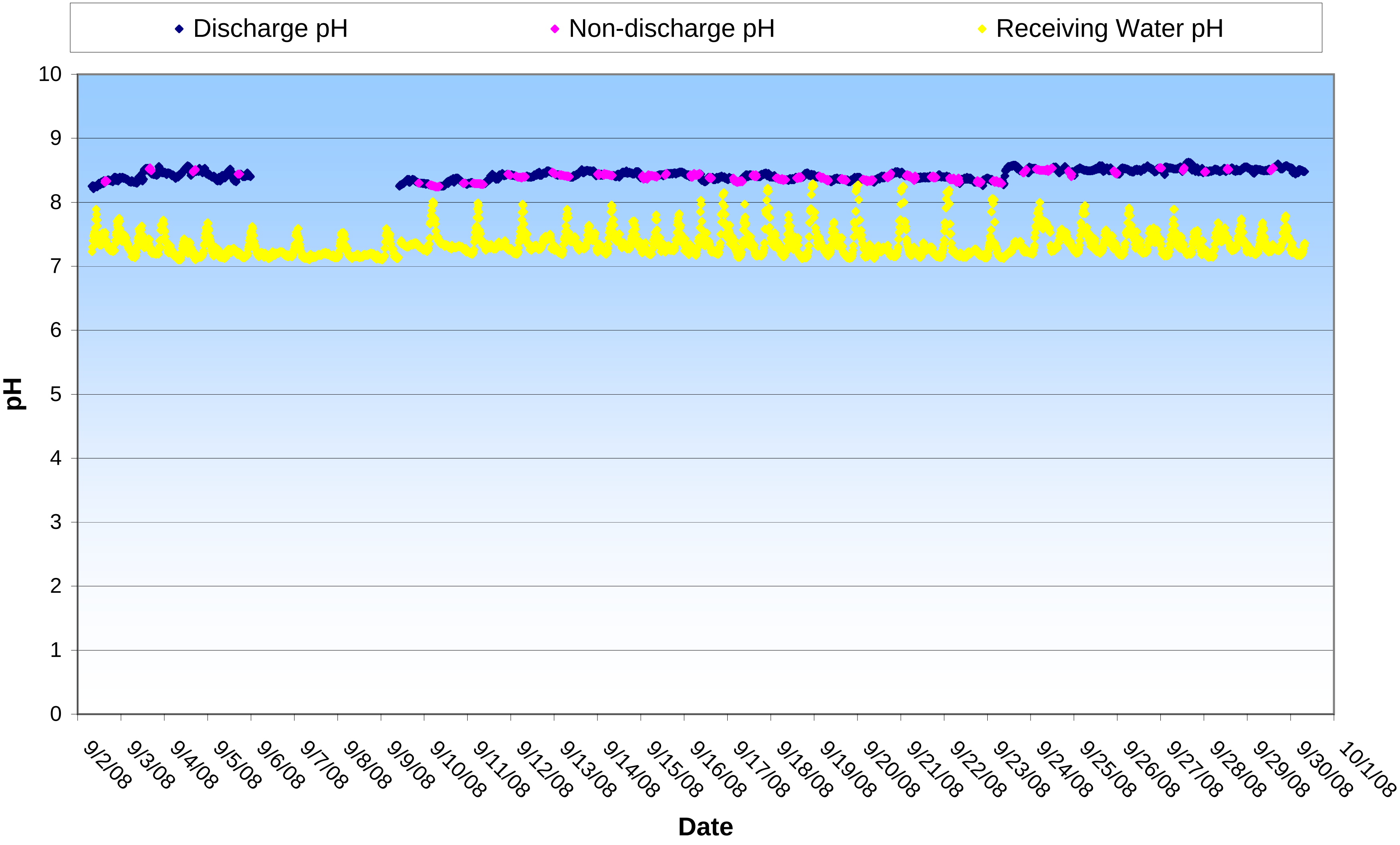
Pond A18 and Artesian Slough pH Comparisons
June 2008

Pond A18 and Artesian Slough pH Comparisons
July 2008

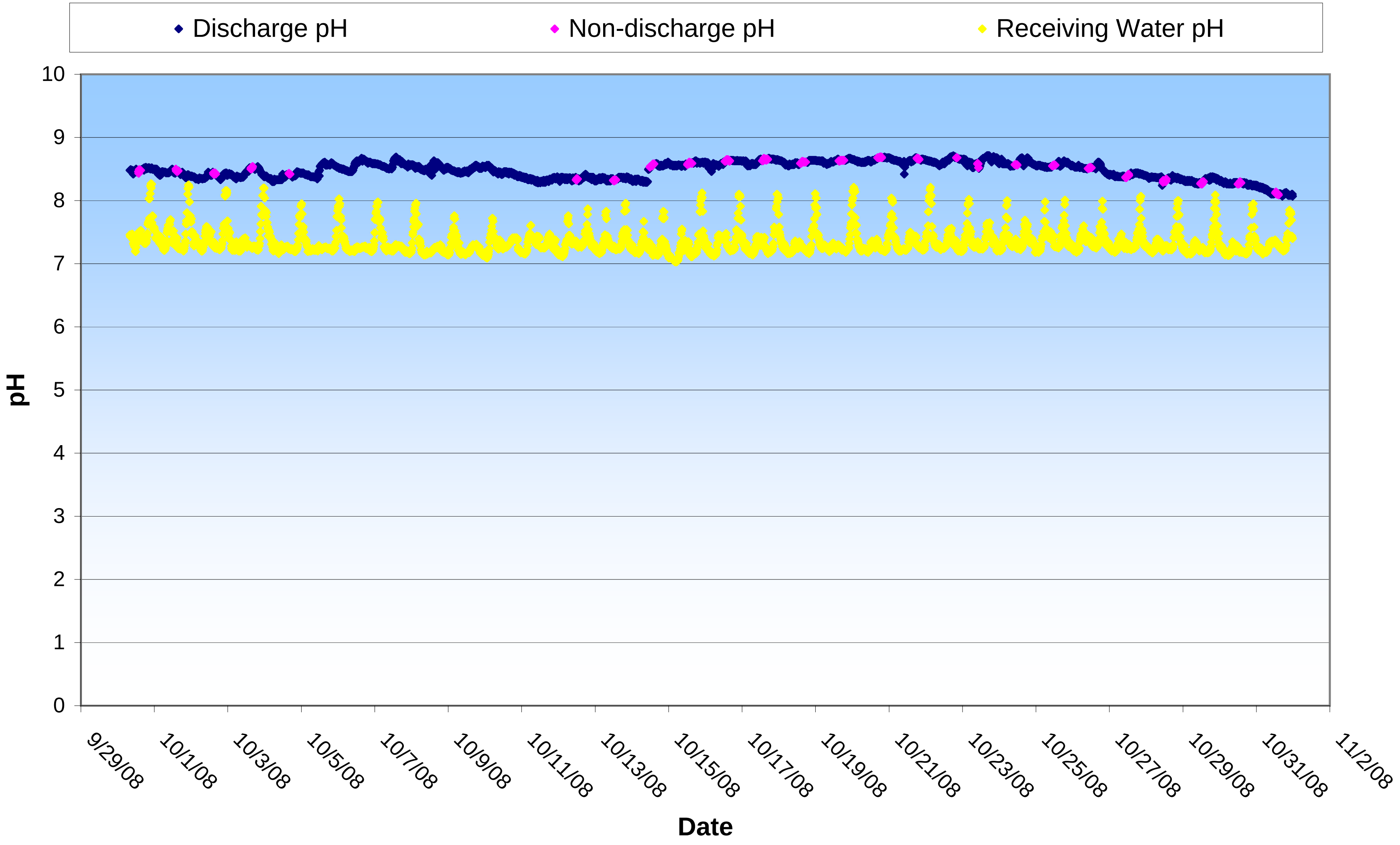



Pond A18 and Artesian Slough pH Comparisons
August 2008
◆ Discharge pH
◆ Non-discharge pH
◆ Receiving Water pH
pH
9
8
7
6
5
4
3
2
1
0
7/28/08
7/30/08
8/1/08
8/3/08
8/5/08
8/7/08
8/9/08
8/11/08
8/13/08
8/15/08
8/17/08
8/19/08
8/21/08
8/23/08
8/25/08
8/27/08
8/29/08
8/31/08
9/2/08
Date

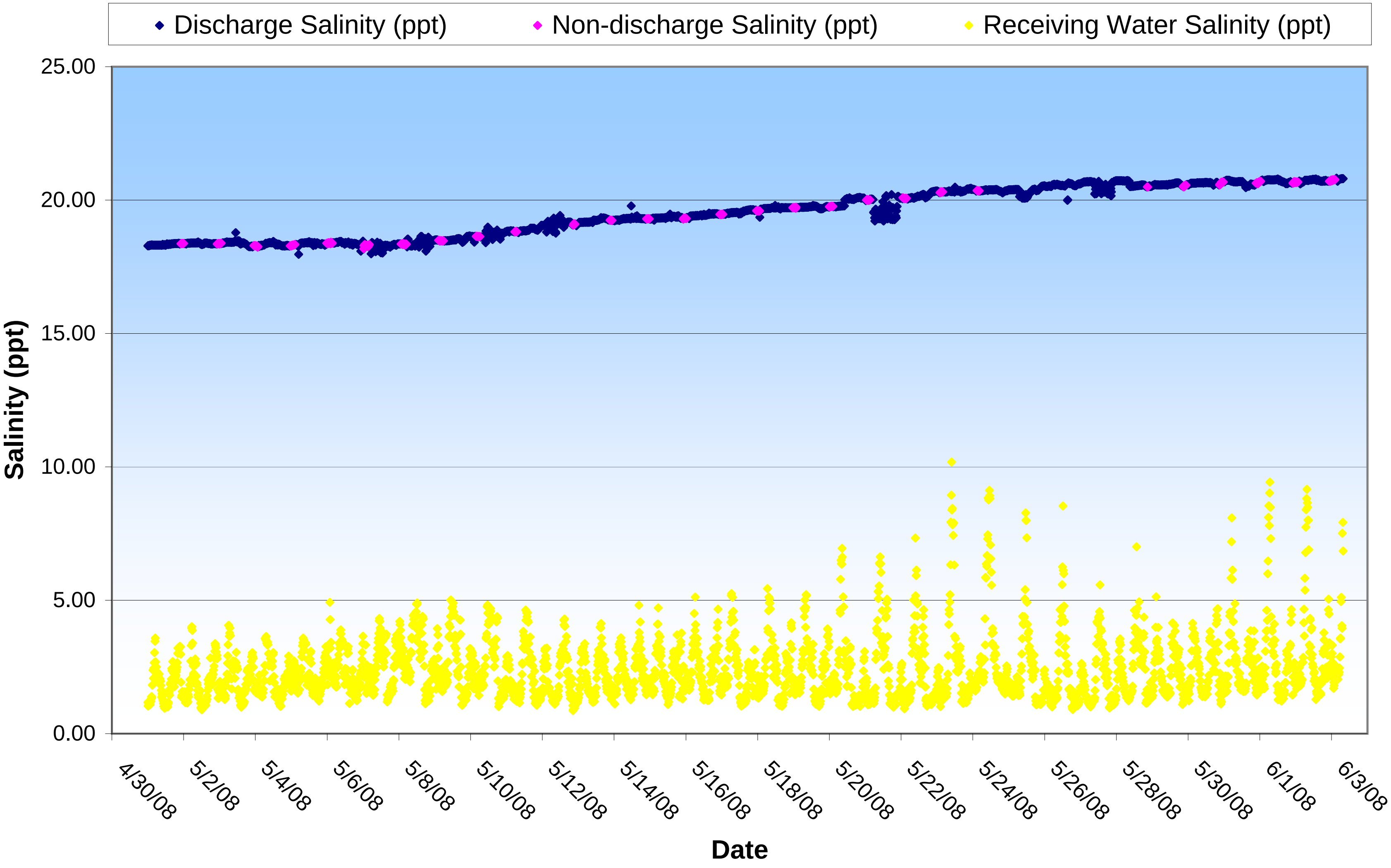
Pond A18 and Artesian Slough pH Comparisons
September 2008

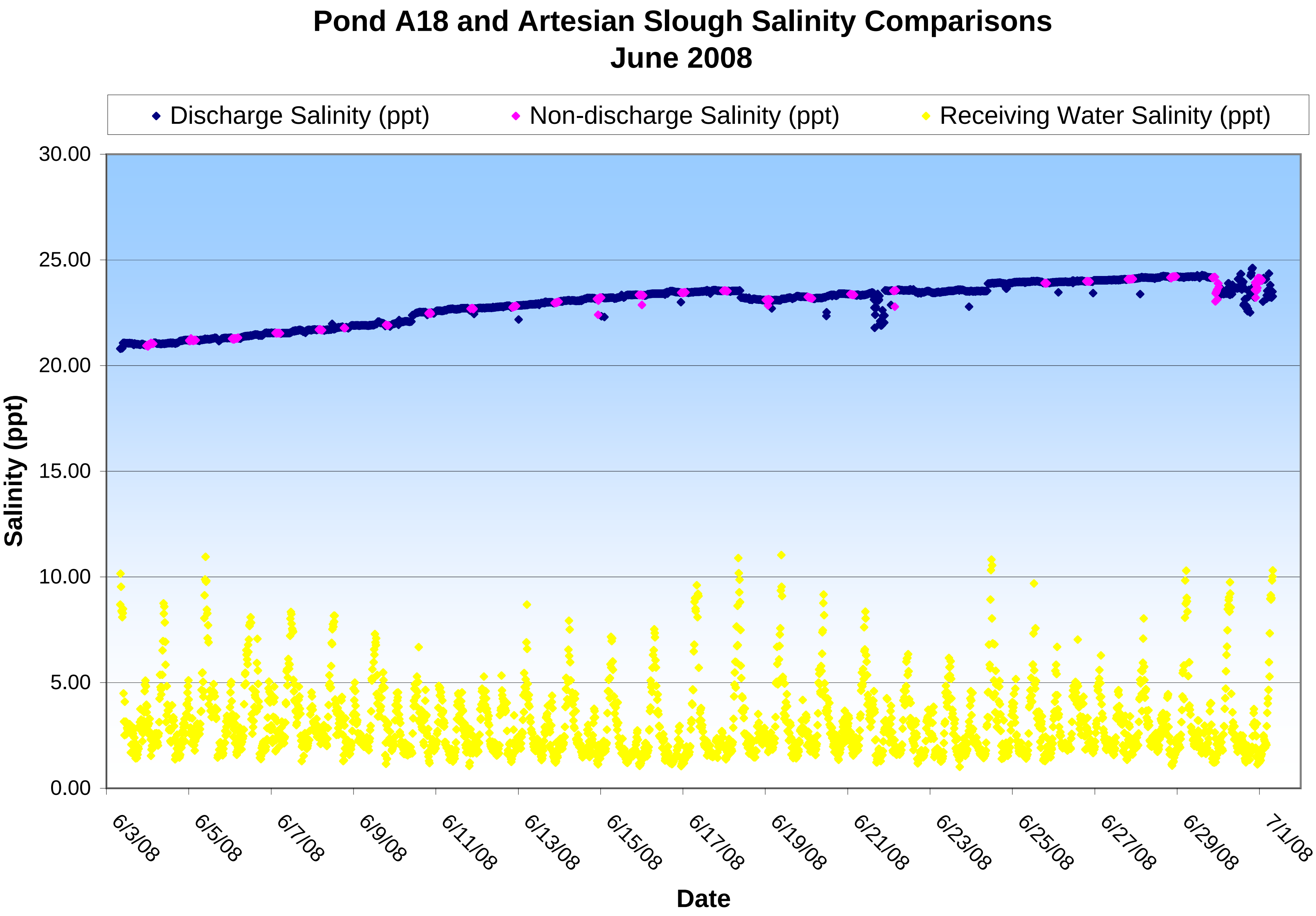


Pond A18 and Artesian Slough pH Comparisons
October 2008



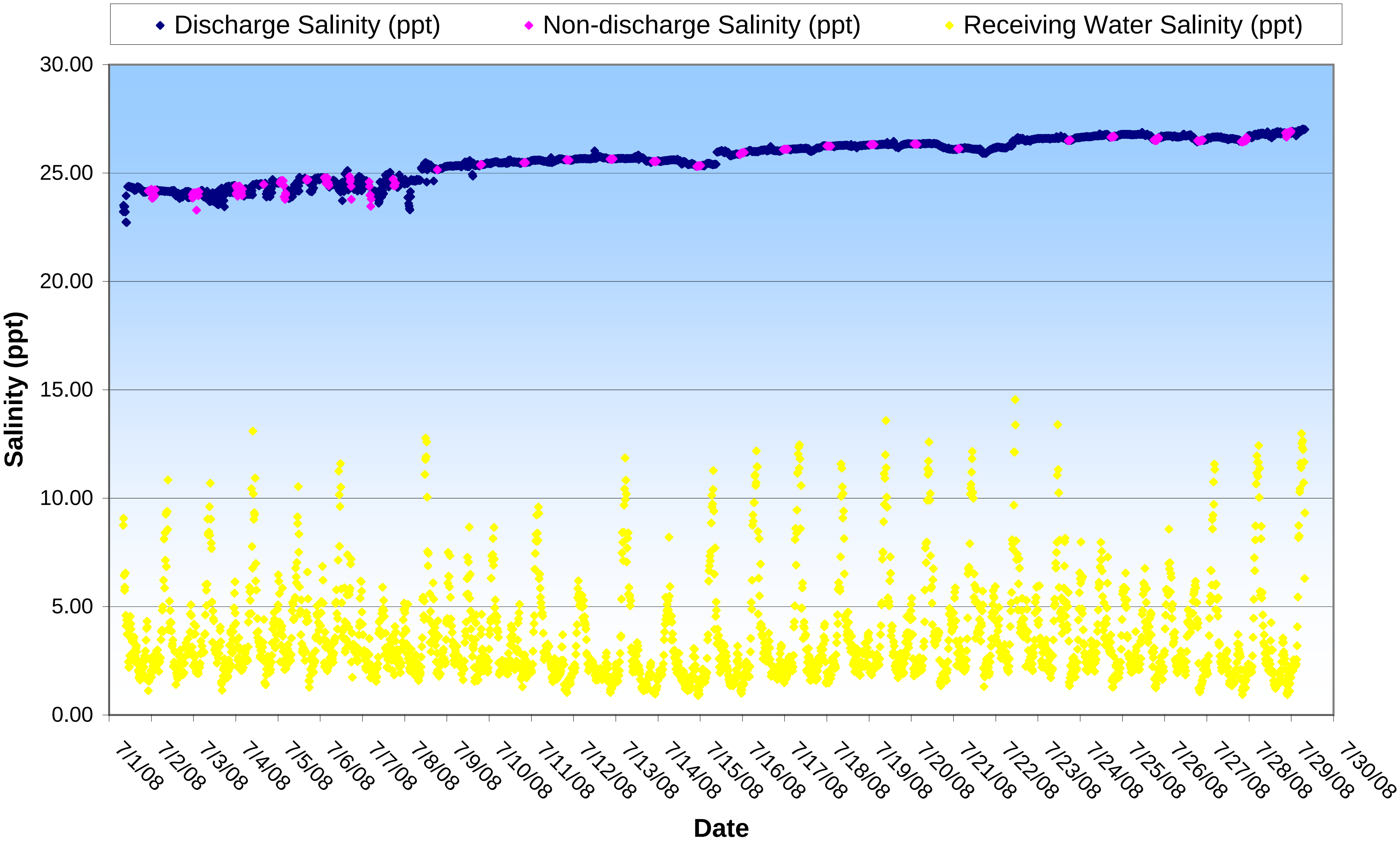
Pond A18 and Artesian Slough Salinity Comparisons
May 2008



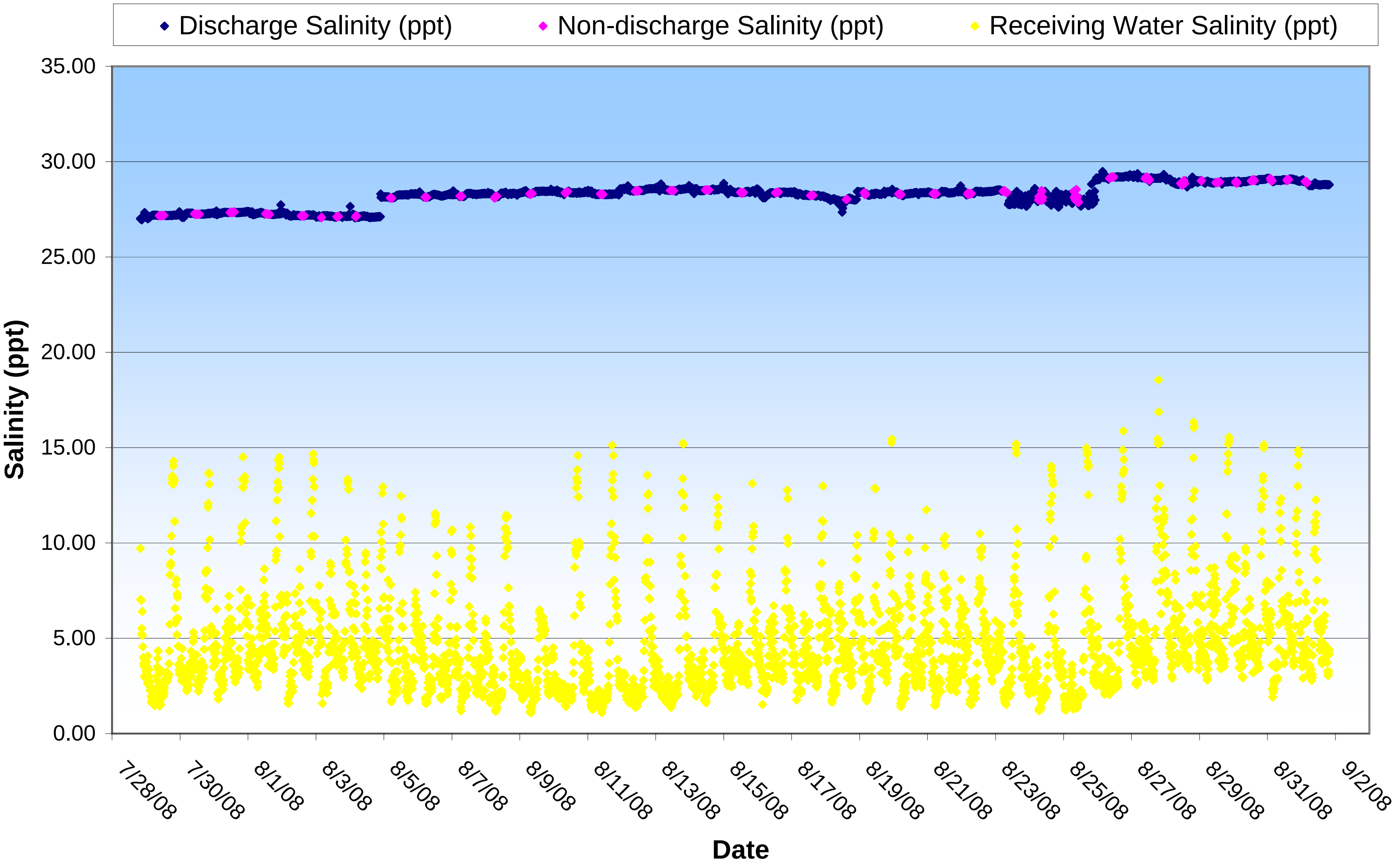


Pond A18 and Artesian Slough Salinity Comparisons
June 2008

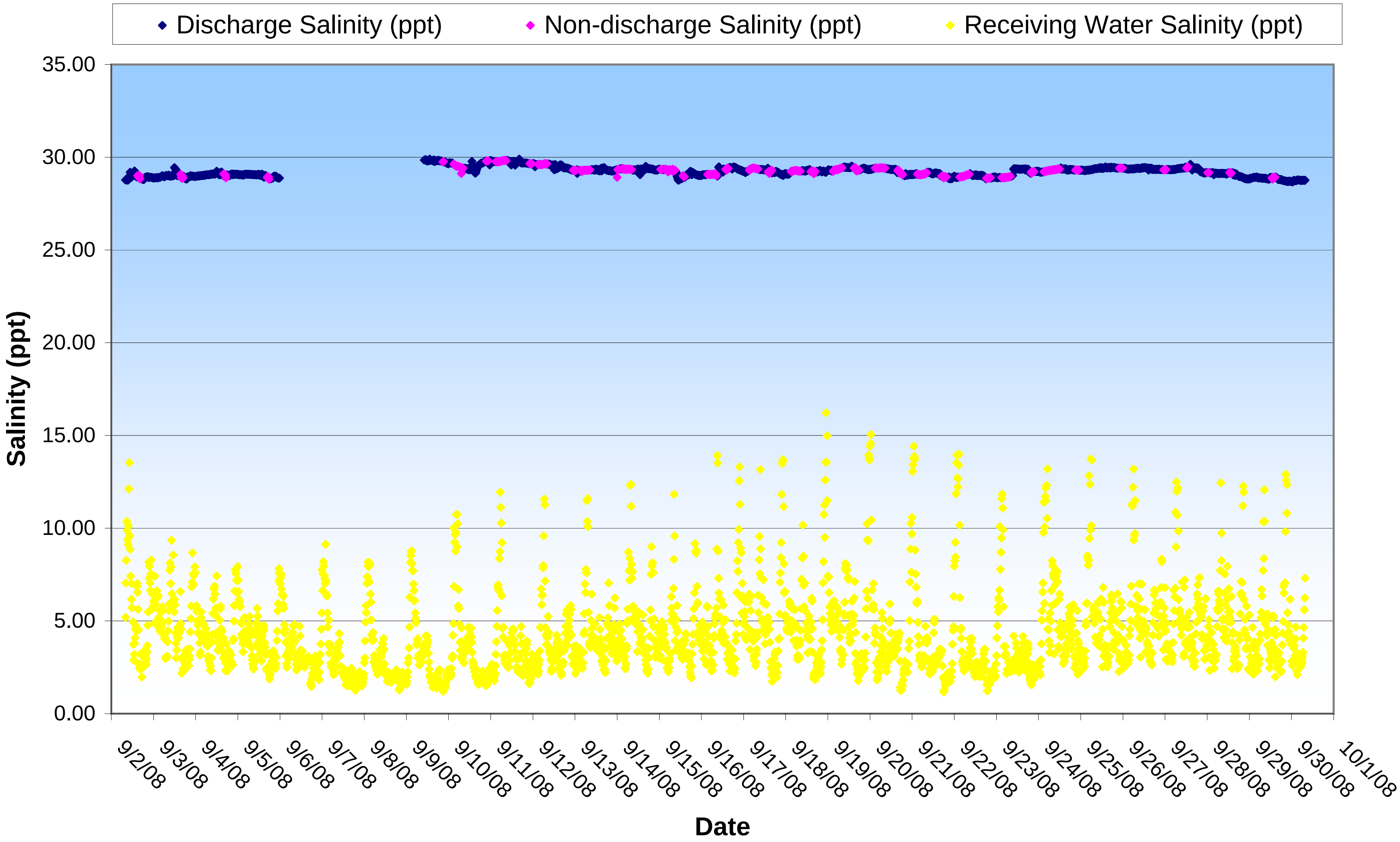
Pond A18 and Artesian Slough Salinity Comparisons
July 2008



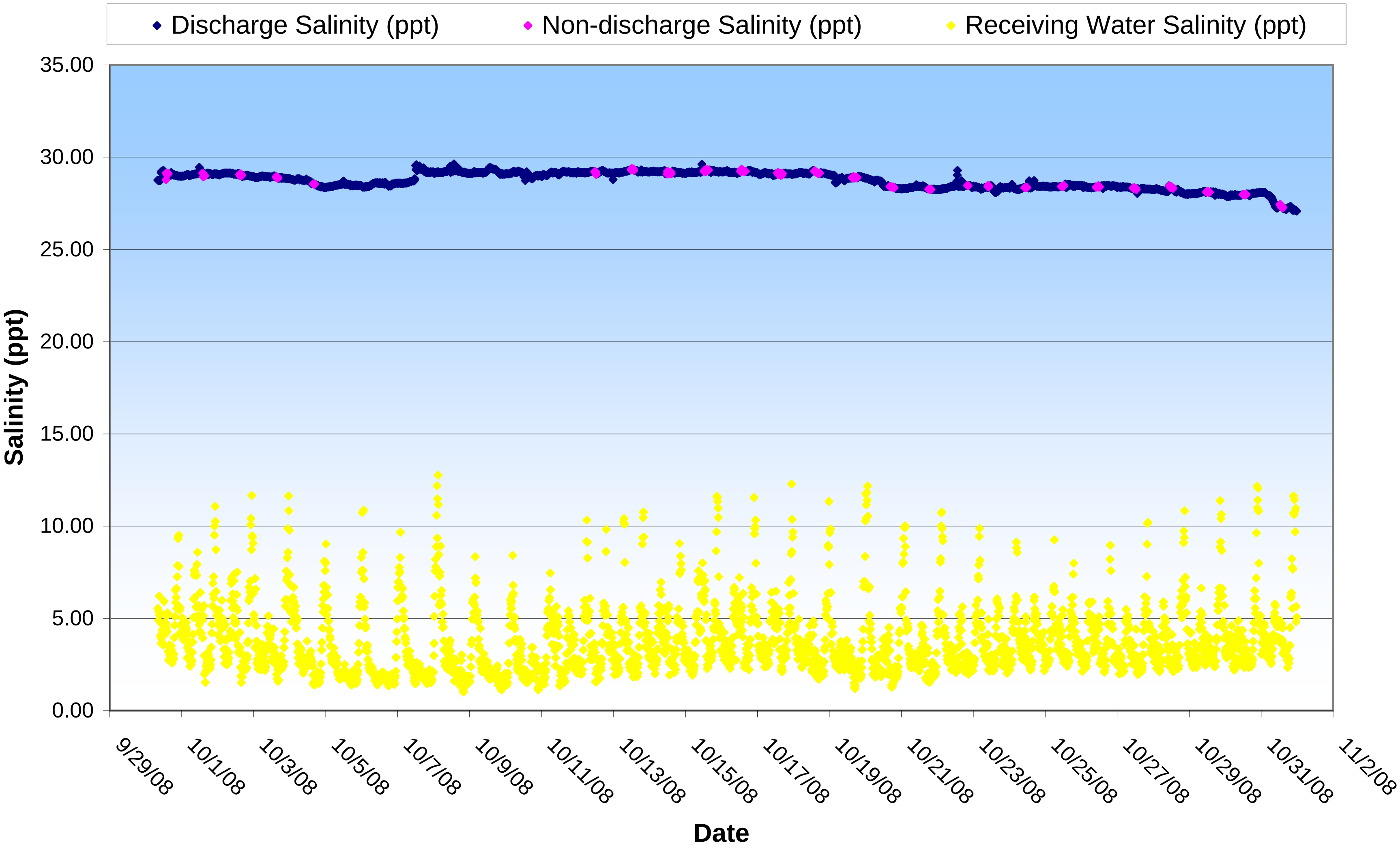
Pond A18 and Artesian Slough Salinity Comparisons
August 2008



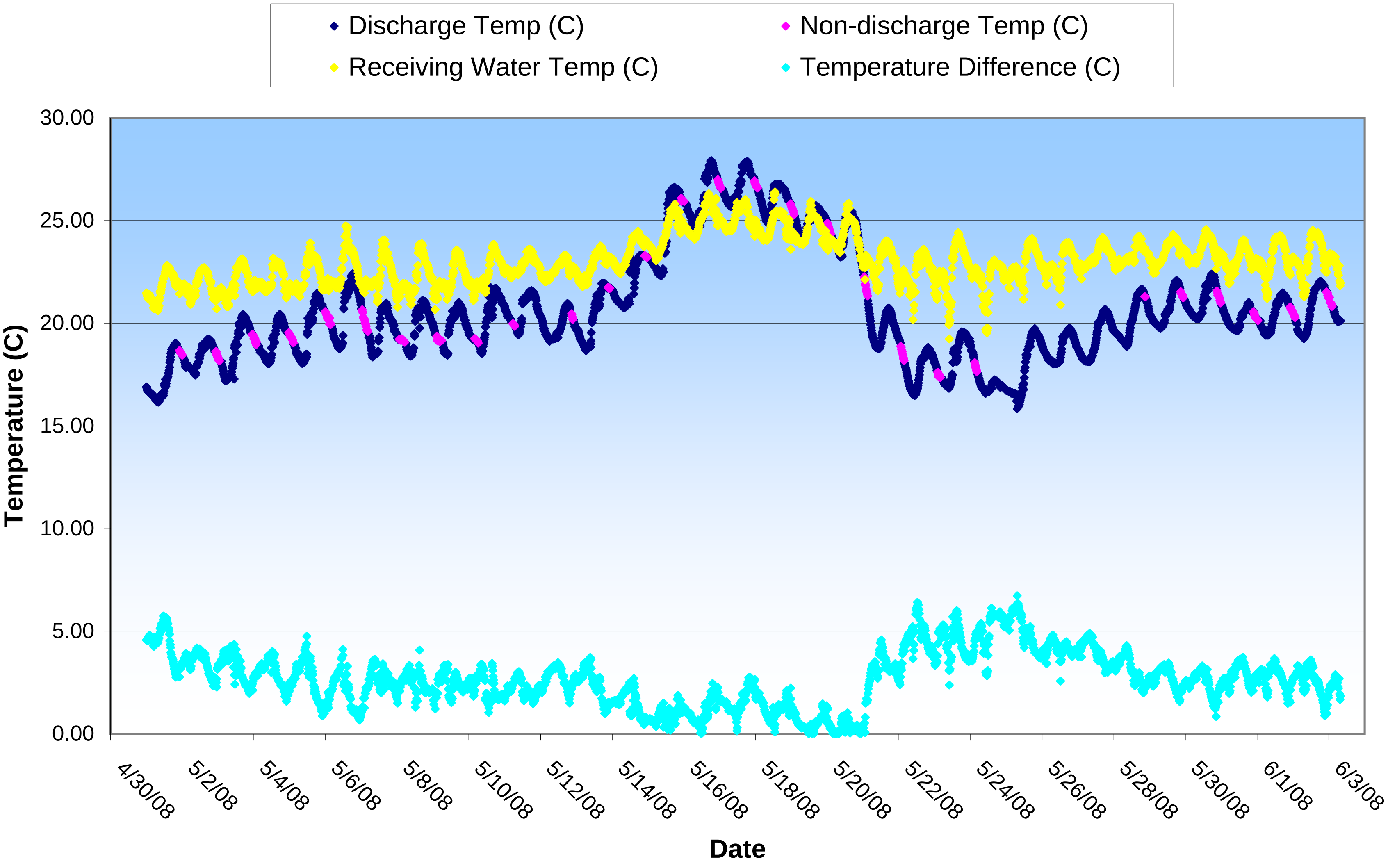
Pond A18 and Artesian Slough Salinity Comparisons
September 2008



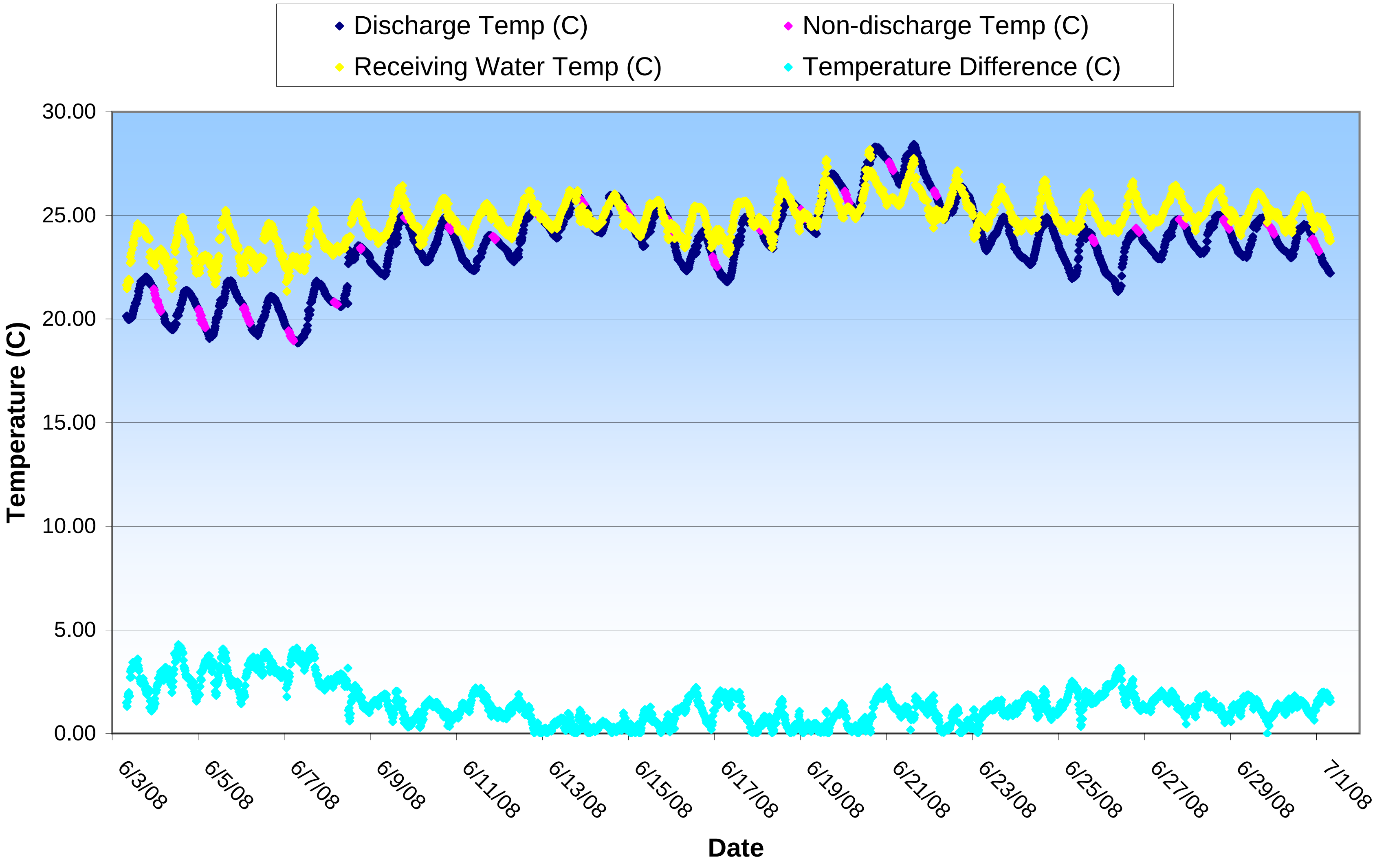
Pond A18 and Artesian Slough Salinity Comparisons
October 2008

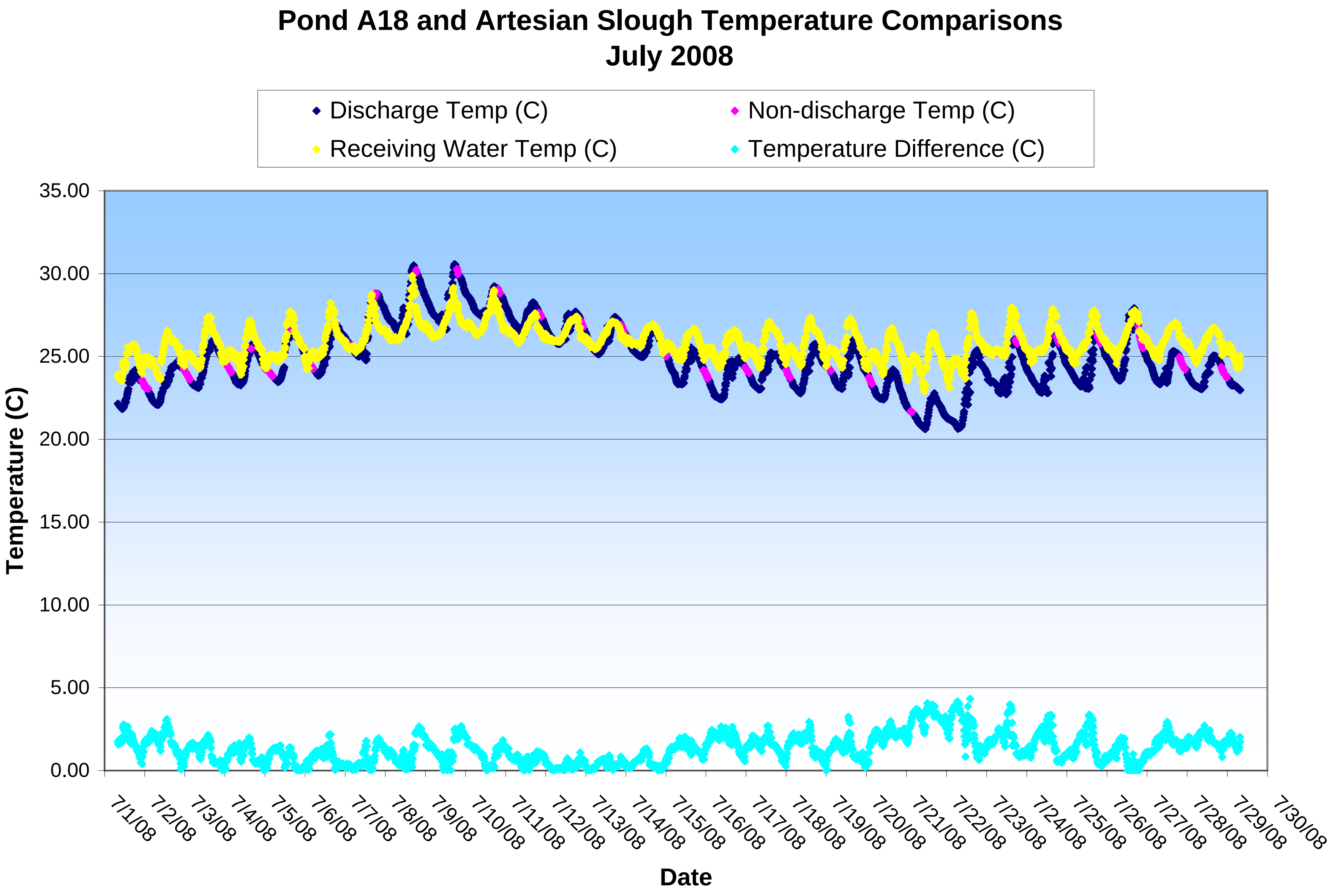


Pond A18 and Artesian Slough Temperature Comparisons
May 2008



Pond A18 and Artesian Slough Temperature Comparisons
June 2008




Pond A18 and Artesian Slough Temperature Comparisons
July 2008
◆ Discharge Temp (C)
◆ Non-discharge Temp (C)
◆ Receiving Water Temp (C)
◆ Temperature Difference (C)
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
Temperature (C)
7/1/08
7/2/08
7/3/08
7/4/08
7/5/08
7/6/08
7/7/08
7/8/08
7/9/08
7/10/08
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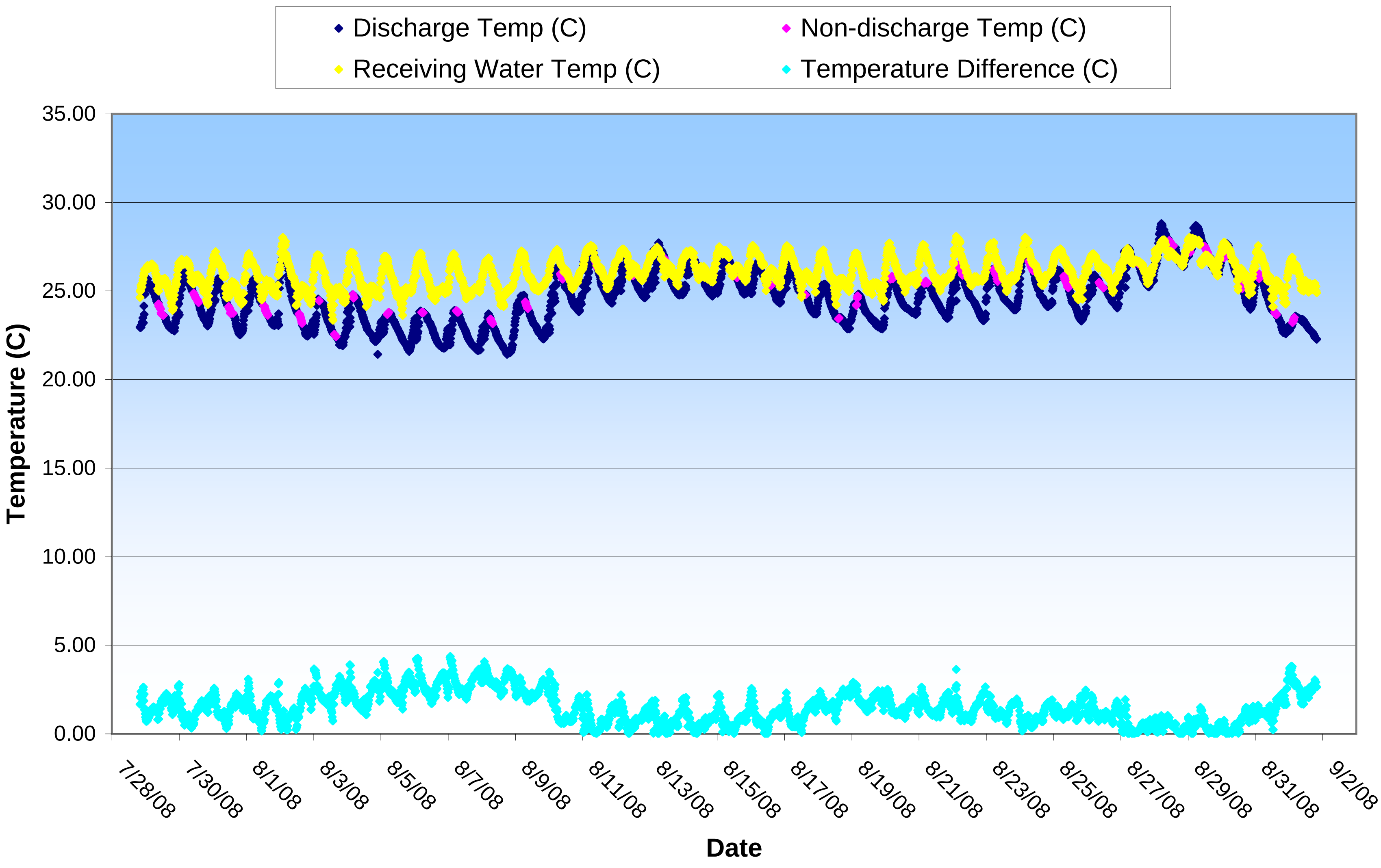
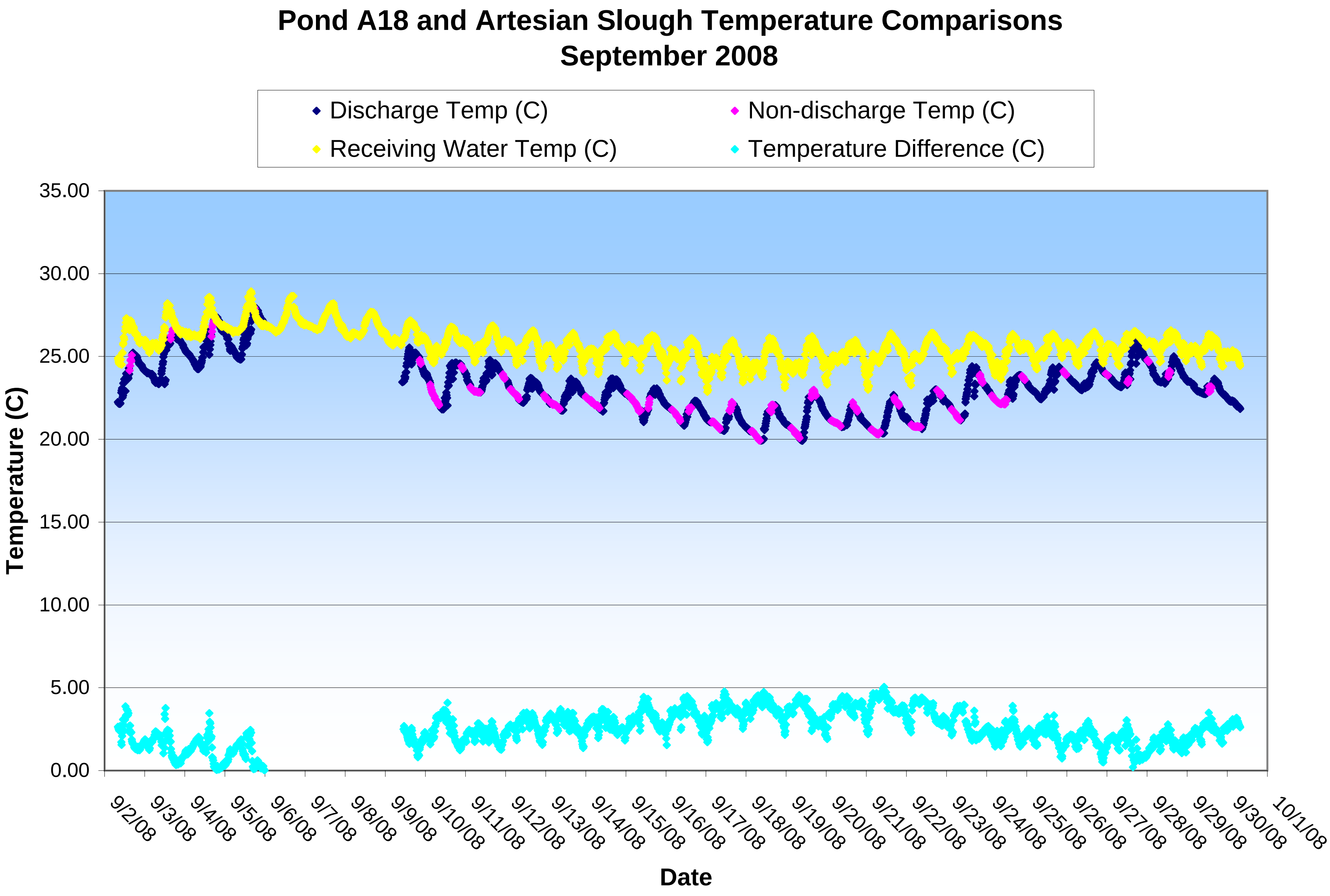
7/30/08
Date



Pond A18 and Artesian Slough Temperature Comparisons
August 2008


Pond A18 and Artesian Slough Temperature Comparisons
September 2008
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
9/2/08
9/3/08
9/4/08
9/5/08
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9/24/08
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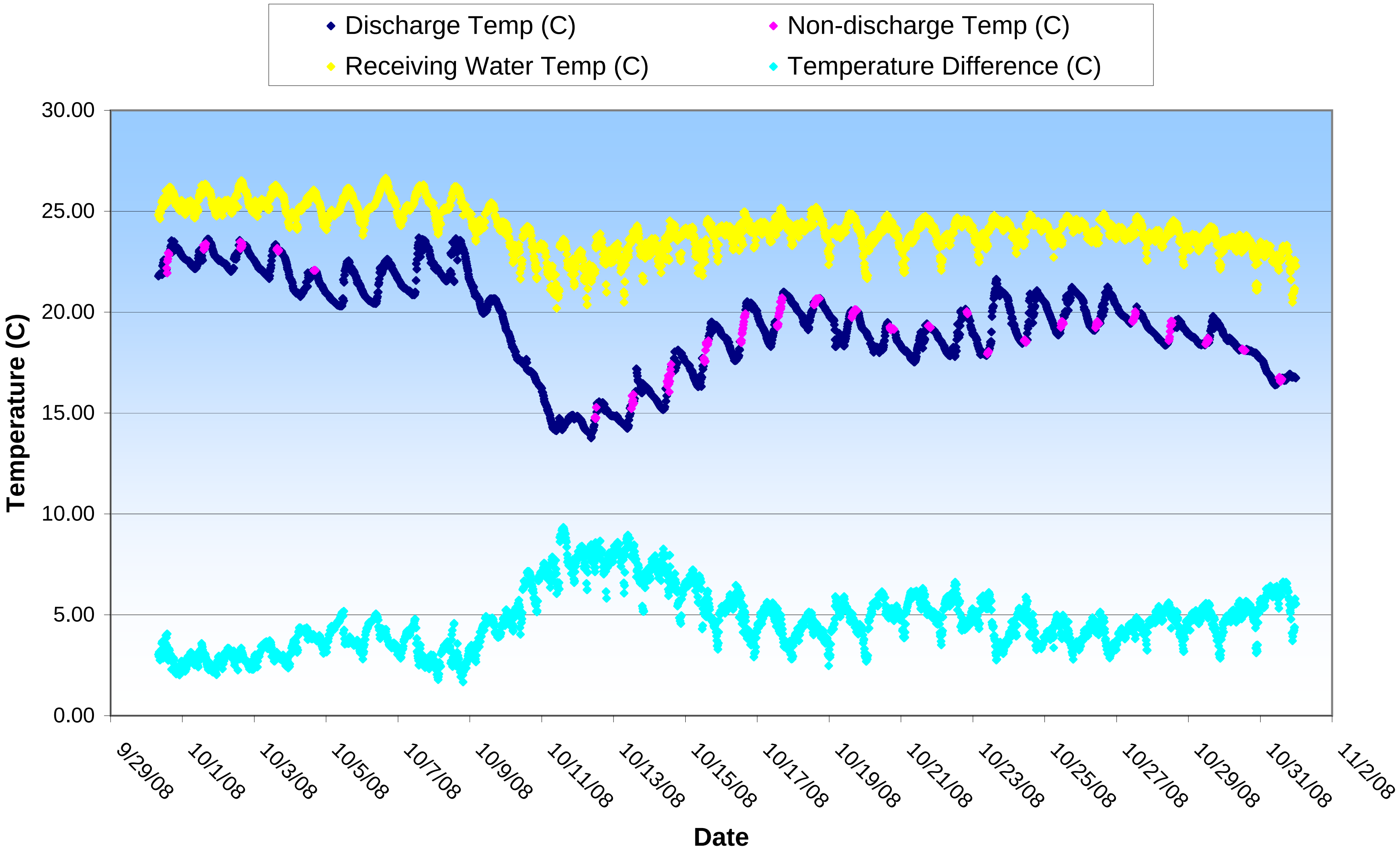
9/29/08
9/30/08
10/1/08
Date

Pond A18 and Artesian Slough Temperature Comparisons
October 2008



Appendix III. Pond A18 Sediment Mercury Report

POND A18 SEDIMENT MERCURY REPORT – 2008

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

21 November 2008

Pond A18 Sediment Mercury Report – 2008

Kinnetic Laboratories, Inc.
21 November 2008

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Pond A18 Sediment Mercury Report – 2008

Kinnetic Laboratories, Inc.
21 November 2008

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 27 August 2008. A 14-foot Jon Boat was used to access all sites. Sample locations were determined and recorded using a Garmin 76 handheld WASS 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, and particle size distribution. Each analytical laboratory provided sample containers for their appropriate analyses. An 8 oz. jar was provided for the total mercury, methyl mercury, and percent solids (for dry weight calculation) and a 16 oz. jar was provided for the pH, total organic carbon (TOC), total sulfides, 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 28 August 2008. All samples were received by the analytical laboratories by 10:30 AM on 29 August 2008.

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 YSI Model 63 handheld instrument was used to measure temperature (ºC), pH (units), and salinity (ppt). A YSI Model 58 portable D.O. meter was used to measure 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, 27 August 2008.

3.0 RESULTS

Stations were located and sampled on 27 August 2008 between 09:30 and 11:00 PDT (Table 1). Station water characteristics were recorded at each sampling site (Table 2). Water turbidity was moderate at all stations except A18-3 where turbidity was low. Water color was brown at three stations and light brown at one. No unusual odors (with the exception of the landfill odor drifting over station A18-1), trash, or any oil and grease sheen was observed.

Table 1. Station Locations and Sampling Times.

STATION	TIME (PDT)	LATITUDE	LONGITUDE
A18-1	09:30	37º 26' 43.0"	121º 57' 02.6"
A18-2	09:55	37º 26' 56.3"	121º 57' 19.3"
A18-3	10:30	37º 27' 14.4"	121º 57' 35.2"
A18-4	11:00	37º 27' 32.8"	121º 57' 38.7"

Table 2. Station Water Characteristics.

STATION	TURBIDITY	OIL & GREASE SHEEN	TRASH	COLOR	ODORS
A18-1	MODERATE	NONE	NONE	BROWN	LANDFILL ODOR
A18-2	MODERATE	NONE	NONE	BROWN	NONE
A18-3	LOW	NONE	NONE	BROWN	NONE
A18-4	MODERATE	NONE	NONE	LIGHT BROWN	NONE

3.1 Water Quality Parameter Field Measurements:

Overlying water quality field measurements are presented in Table 3. Depth ranged from 1.5 feet at station A18-4 to 2.5 feet at A18-1. pH ranged from 7.8 (A18-1) to 8.6 (A18-2 and A18-3). Temperature increased slightly going from south (A18-1 at 23.4 ºC) to north (A18-4 at 24.1 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 3.0 mg/L (36% saturation) at A18-1 to 7.9 mg/L (90% saturation) at A18-4. Changing oxygen levels may be a result of the time of sampling. Oxygen supersaturation from algal blooms was not visible during sampling, but was apparent with bubbles starting to come out of solution and increasing when motoring back to the launch site from station A18-4. ORP ranged from 87 mV (A18-3) to 98 mV (A18-4). Salinity increased from north to south ranging from 26.8 ppt (A18-4) to 27.9 ppt (A18-2 and A18-1).

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	2.5	7.8	23.4	3.0	36	84	27.9
A18-2	2.0	8.6	23.6	6.0	71	94	27.9
A18-3	2.0	8.6	23.5	7.2	83	87	27.6
A18-4	1.5	8.4	24.1	7.9	90	98	26.8

3.2 Sediment Quality Analytical Measurements:

Analytical results for sediment samples are presented in Table 4. Total mercury in sediment ranged from 0.417 mg/kg (dry wt.) at A18-3 to 0.573 mg/kg (dry wt.) at A18-2. Methyl mercury in sediment ranged from 0.000126 mg/kg (dry wt.) at A18-1 to 0.000386 mg/kg (dry wt.) at A18-4. Samples A18-2 and A18-4 contained a large amount of wood chips and organic material which due to buoyancy did not follow Stoke's Law for settling particles. This caused a high bias in the silt and clay fraction recoveries. Therefore the silt and clay fraction recovery was normalized by the analytical laboratory to create a 100 percent recovery.

Table 4. Analytical Results for Sediment Samples.

	SAMPLING STATIONS			
ANALYTE	**A18-1**	**A18-2**	**A18-3**	**A18-4**
Total Mercury				
mg/kg dry weight	0.558	0.573	0.417	0.446
ng/g dry weight	558	573	417	446
Methyl Mercury				
mg/kg dry weight	0.000126	0.000158	0.000132	0.000386
ng/g dry weight	0.126	0.158	0.132	0.386
% Solids (Brooks Rand – Mercury Samples)	39.6	30.5	27.3	31.6
% Solids (Columbia Analytical – Conventionals)	39.5	29.4	24.2	29.5
TOC (% dry wt.)	2.66	3.63	5.89	4.90
ORP (millivolts)	80.2	-126	-243	-109
pH (units)	7.74	7.79	7.69	7.72
Total Sulfide (mg/kg dry wt.)	1330	6880	1470	1520

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

	SAMPLING STATIONS			
ANALYTE	**A18-1**	**A18-2**	**A18-3**	**A18-4**
Particle Size Distribution (%)				
Gravel, Medium	18.12	31.6	11.3	32.1
Gravel, Fine	9.95	25.6	11.0	20.7
Sand, Very Coarse	4.67	12.6	10.4	11.0
Sand, Coarse	2.04	6.58	6.88	6.29
Sand, Medium	1.07	4.28	4.11	3.79
Sand, Fine	1.06	4.37	3.90	4.12
Sand, Very Fine	0.31	1.34	0.86	0.76
Silt	54.3	10.7	36.7	20.9
Clay	7.50	2.95	17.0	0.29

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 were performed within holding times.

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	0.02	0.003	-0.05
MB2	0.03	0.005	-0.02
MB3	0.02	0.002	-
MB4	-0.00002	0.002	-
Average	0.02	0.003	-0.06
Standard Deviation	0.01	0.001	-
Method Detection Limit	0.05	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	2.1	0.05

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

4.3 Laboratory Replicates

Laboratory replicates were performed on field sediment samples (Table 7). Relative Percent Difference (RPD) of all analyses, with the exception of particle size distribution, met QA/QC objectives. Normally, a laboratory replicate is not performed on a particle size distribution sample but some of these samples were problematic where they contained, as stated earlier, a large amount of wood chips and 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. Medium gravel and silt/clay fell out of this guideline for the duplicate analysis performed on the sample collected from A18-2. In addition, though fine sand was measured in the original sample but not in the duplicate, it is improper to calculate a RPD when one value is below reporting levels. These duplicate results, with the difference in the largest fraction size (medium gravel) and the likely effects of the normalization of silt and clay, shows the difficulty of obtaining a homogenized sample of this material even in the laboratory.

Table 7. Laboratory Replicate Results.

ANALYTE	SAMPLE VALUE	DUPLICATE VALUE	AVERAGE VALUE	DUPLICATE RPD	CONTROL LIMITS
Mercury (ng/g – wet weight)	12500	12800	12650	2%	≤ 30%
Methyl Mercury (ng/g – wet weight)	0.126	0.126	0.126	0%	≤ 35%
Percent Solids (%)	12.79	12.72	12.76	< 1%	≤ 15%
pH (units)	7.74	7.71	7.73	< 1%	≤ 20%
ORP (mV)	187	180	184	4%	≤ 20%
Total Sulfide (mg/kg)	109	89	99	20%	≤ 20%
Total Organic Carbon (%)	1.94	2.05	2.00	5%	≤ 20%
Particle Size Distribution (%)					
Gravel, Medium	31.6	13.5	22.6	**80**	≤ 50%
Gravel, Fine	25.6	20.3	23.0	23	≤ 50%
Sand, Very Coarse	12.6	18.3	15.5	37	≤ 50%
Sand, Coarse	6.58	5.80	6.19	13	≤ 50%
Sand, Medium	4.28	5.17	4.73	19	≤ 50%
Sand, Fine	4.37	0.00	2.19	NA[1]	≤ 50%
Sand, Very Fine	1.34	1.20	1.27	11	≤ 50%
Silt	10.7	28.6	19.7	**91**	≤ 50%
Clay	2.95	7.60	5.28	**88**	≤ 50%

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

4.4 Laboratory Control Samples

Laboratory Control Samples (LCSs) were run by Columbia Analytical Services, Inc. for pH, 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
pH (units)	6.58	6.56	100%	85-115%
Total Sulfide (mg/kg)	7.2	5.5	76%	60-130%
Total Organic Carbon (%)	0.42	0.39	93%	74-123%

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. 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.)	12500	3106	14400	NR	2973	15300	NR[1]	6%	70-130%	≤ 30%
Mercury (ng/g-wet wt.)[2]	12500	58100	75400	108%					77-123%	
Methyl Mercury (ng/g-wet wt.)	0.126	4.879	5.50	110%	4.979	5.76	113%	5%	65-135%	≤ 35%
Methyl Mercury (ng/g-wet wt.)[3]		0.02500	0.024	96%					65-135%	
Total Sulfide (mg/kg)	109	1000	1010	90%					60-130%	
Total Organic Carbon (%)	1.94	4.46	6.47	102%					75-114%	

[1] – NR = non-reportable
[2] – Post Spike (PS) Sample
[3] – Laboratory Fortified Blank

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	102.2	112%	75-125%
Methyl Mercury (ng/g – wet weight)	CC580	74.99	70.65	94%	65-135%
Methyl Mercury (ng/g – wet weight)	CC580	75.01	69.91	93%	65-135%

4.7 Mercury Analyses Instrument Calibration

Method requirements for satisfactory instrument calibration are established to ensure that the instrument is capable of producing acceptable quantitative data for mercury. Initial Calibration Verification (ICV) demonstrates that the instrument is capable of acceptable performance at the beginning of the analytical run. Continuing Calibration Verification (CCV) demonstrates that the initial calibration is still valid by checking the performance of the instrument on a continuing basis.

All ICV and CCV percent recoveries for this project were well within QC limits indicating that the instrument produced acceptable quantitative data (Table 11).

Table 11. Initial Calibration and Continuing Calibration Verification Results for Mercury Analyses.

QUALITY CONTROL SAMPLE ID	CERTIFIED VALUE	MEASURED VALUE	% RECOVERY	CONTROL LIMITS
Mercury (ng/L)				
ICV[1]	16.01	16.11	101%	85-115%
CCV1	5.00	4.96	99%	77-123%
CCV2	5.00	5.06	101%	77-123%
CCV3	5.00	5.13	103%	77-123%
Methyl Mercury (ng/L)				
ICV[2]	7.33	7.03	96%	80-120%
CCV1	0.625	0.551	88%	67-133%
CCV2	0.625	0.652	104%	67-133%
CCV3	0.625	0.679	109%	67-133%

1 = Preparation of the CRM NIST 1641d.
2 = ICV standard is prepared from an aliquot of the CRM DORM-2.

4.8 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. Communications Summary during 2008 A18 Monitoring

A18 2008 Communications with Regional Water Board and Others

Date	Person(s) Contacted	Type of Communication	Reason for Notification and Action
4/15	Robert Schlipf and San Jose staff	Teleconference	Discussed the Water Board's response to the 2007 A18 Report with Water Board staff. Clarified what additional information the Water Board needed from the City in a supplemental report to the 2007 Report.
5/6	Robert Schlipf	e-mail	Transmitted 1st week of monitoring data.
5/13	Robert Schlipf	e-mail	Sent draft version of the City's supplement to the 2007 Report for Water board review and comment
5/13	Robert Schlipf	e-mail	Transmitted 2nd week of monitoring data.
5/16	Robert Schlipf	U.S. Postal Mail	Sent the supplement to the 2007 A18 Report to Water Board staff.
5/20	Robert Schlipf	e-mail	Transmitted 3rd week of monitoring data.
5/28	Robert Schlipf	e-mail	Transmitted 4th week of monitoring data.
6/3	Robert Schlipf	e-mail	Transmitted 5th week of monitoring data.
6/10	Robert Schlipf	e-mail	Transmitted 6th week of monitoring data.
6/10	Robert Schlipf	e-mail	Transmitted an electronic version of the supplement to the 2007 A18 Report to Water Board staff.
6/19	Robert Schlipf	e-mail	Transmitted 7th week of monitoring data.
6/24	Robert Schlipf	e-mail	Transmitted 8th week of monitoring data.
7/2	Robert Schlipf	e-mail	Transmitted 9th week of monitoring data.
7/8	Robert Schlipf	e-mail	Transmitted 10th week of monitoring data – Pond data not available due to sonde damage.
7/15	Robert Schlipf	e-mail	Transmitted 11th week of monitoring data – Pond DO trigger met. Initiated discrete trigger monitoring
7/22	Robert Schlipf	e-mail	Transmitted 12th week of monitoring data – DO trigger still met. Continued trigger monitoring.
7/29	Robert Schlipf	e-mail	Transmitted 13th week of monitoring data – DO trigger still met. Continued trigger monitoring.

Date	Person(s) Contacted	Type of Communication	Reason for Notification and Action
8/5	Robert Schlipf	e-mail	Transmitted 14th week of monitoring data – DO trigger still met. Continued trigger monitoring.
8/12	Robert Schlipf	e-mail	Transmitted 15th week of monitoring data – DO trigger still met. Continued trigger monitoring.
8/20	Robert Schlipf	e-mail	Transmitted 16th week of monitoring data – DO trigger still met. Continued trigger monitoring.
8/29	Robert Schlipf	e-mail	Transmitted 17th week of monitoring data – DO trigger still met. Continued trigger monitoring. Bottom slough DO < 3.3 mg/L.
9/1	Scientific community	Journal publication	Article entitled Primary Production and Carrying Capacity of Former Sat Ponds after Reconnection to San Francisco Bay in the journal *Wetlands*.
9/3	Robert Schlipf	e-mail	Transmitted 18th week of monitoring data – DO trigger still met and low DO measured in receiving water. Continued trigger monitoring. Initiated timed valve closures of 5 hrs per day (discharge stopped from 3 am to 8 am).
9/9	Robert Schlipf	e-mail	Transmitted 19th week of monitoring data – No pond data due to damaged sonde. Continued trigger monitoring and 5 hr per day valve closures.
9/17	Robert Schlipf	e-mail	Transmitted 20th week of monitoring data – DO trigger still met. Continued trigger monitoring and 5 hr per day valve closures.
9/24	Robert Schlipf	e-mail	Transmitted 21st week of monitoring data – DO trigger still met. Continued trigger monitoring. Ceased valve closures due to consecutive weeks showing improved DO in receiving water and pond.
9/25	Numerous Salt Pond Restoration stakeholders	Poster presentation	Presented a poster on Pond A18 primary productivity at the South Bay Salt Pond Science Symposium held at the MLK Library in San Jose. A copy of this poster is in Appendix 6.

Date	Person(s) Contacted	Type of Communication	Reason for Notification and Action
10/1	Robert Schlipf	e-mail	Transmitted 22nd week of monitoring data – DO trigger still met. Continued trigger monitoring.
10/14	Robert Schlipf	e-mail	Transmitted 23rd and 24th week of monitoring data – DO trigger still met. Continued trigger monitoring.
10/21	Robert Schlipf	e-mail	Transmitted 25th week of monitoring data – DO above 3.3 mg/L trigger. Continued trigger monitoring to be protective.
10/28	Robert Schlipf	e-mail	Transmitted 26th week of monitoring data – final transmittal for dry season monitoring.
11/20	South Bay Salt Pond Stakeholder Forum	Powerpoint Presentation	Update and inform the Stakeholder Forum of the Salt Pond Restoration Project about the Plant Master Planning process and possible future uses of Pond A18.

Appendix V. 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, has undergone the first year of visioning, data analysis, and stakeholder engagement. Carollo Engineers and Brown & Caldwell are the consultant team assisting the City. In May 2008, environmental thought leaders presented to 30 City staff the world of possibilities for the Plant and 2,600 acres of Plant lands. Topics included energy generation, green building and sustainable planning, sea level rise, green technologies, and ecological restoration. 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 May 2008, about 4,000 people toured the Plant every Saturday through November. Four Stakeholder tours and workshops and a speaker's bureau have informed key stakeholders about the status of the Master Plan. A baseline survey of tributary area residents was performed. A 17-member Community Advisory Group (CAG), a stakeholder forum for the entire tributary area, was formed in the summer of 2008. City staff also met with Regional Board staff on November 18 to discuss the Master Plan, including the planning effort for A18. City staff also presented to the salt pond restoration stakeholder forum on November 20, 2008, to update that group on the Master Planning effort.

For 2009, the first community workshop is scheduled for April. Additional tours and stakeholder engagement are also planned for 2009, including specific outreach to regulatory and resource agencies.

Land Use Analysis

A land use workshop is scheduled for City staff on January 30, 2009 to gather pertinent land use information. Skidmore, Owings, and Merrill is the land use planning consultant developing concepts for potential plant land uses, including A18, the biosolids area, and the buffer lands along Highway 237. Following the land use workshop, land use alternatives will begin to be developed.

Technical Analysis

The City and consultant team reviewed over 10,000 data points from the last 10 years of Plant operation to develop technical Project Memoranda that describe flow and load projections. A technical workshop with wastewater industry experts was held on November 13 and 14, 2008, to review the merits of the consultant team’s 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. The TAG discussed the potential to use A18 for polishing of effluent as well as habitat restoration. Technical alternatives will be developed in 2009.

Appendix VI. Pond A18 Primary Productivity Publication in September 2008 volume of *Wetlands* and Poster Presentation displayed at 2008 Salt Pond Science Symposium.

WETLANDS, Vol. 28, No. 3, September 2008, pp. 841–851

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

Julien Thébault[1,2], Tara S. Schraga[1], James E. Cloern[1], and Eric G. Dunlavey[3]
[1]*United States Geological Survey*
345 Middlefield Rd., MS 496
Menlo Park, California, USA 94025

[2]*IUEM-UBO, UMR CNRS 6539*
Place Nicolas Copernic
29280 Plouzané, France

[3]*City of San Jose, Environmental Services Department*
700 Los Esteros Rd.
San Jose, California, USA 95134
E-mail: tschraga@usgs.gov

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

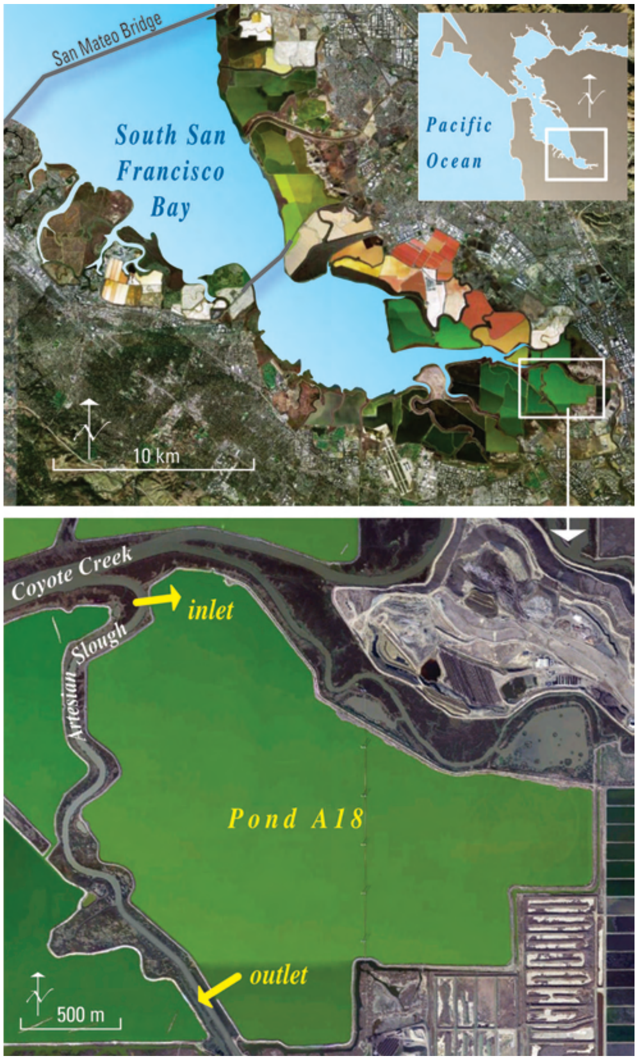

Figure 1. Upper panel: map of South San Francisco Bay ringed with ponds, note color variations in ponds due to bacteria and phytoplankton species, San Francisco Bay inset. Lower panel: map of Pond A18 including inlet and outlet water control structures. Satellite images courtesy of NASA (images altered 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 $\mu S\ cm^{-1}$ and 50,000 $\mu S\ cm^{-1}$. 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).

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):

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

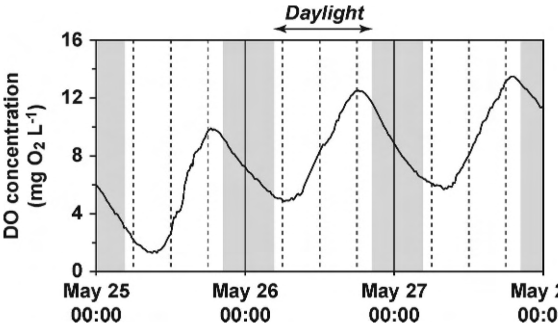

Figure 2. Diel cycles of DO concentration in Pond A18 from May 25 to May 28, 2006.

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}:

$$\begin{aligned} C_s(\mathrm{mg\ O_2\ L^{-1}}) = & \ C_s(\mu\mathrm{mol\ O_2\ kg^{-1}}) \\ & \times \rho_w \times 31.9988 \times 10^{-6} \end{aligned} \tag{4}$$

where ρ_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 ($\mathrm{d}C/\mathrm{d}t - D$) 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 $24 \times R$, 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:

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

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):

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

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

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

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:

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

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

$$R_{hetero} = ER - R_{auto}. \tag{10}$$

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

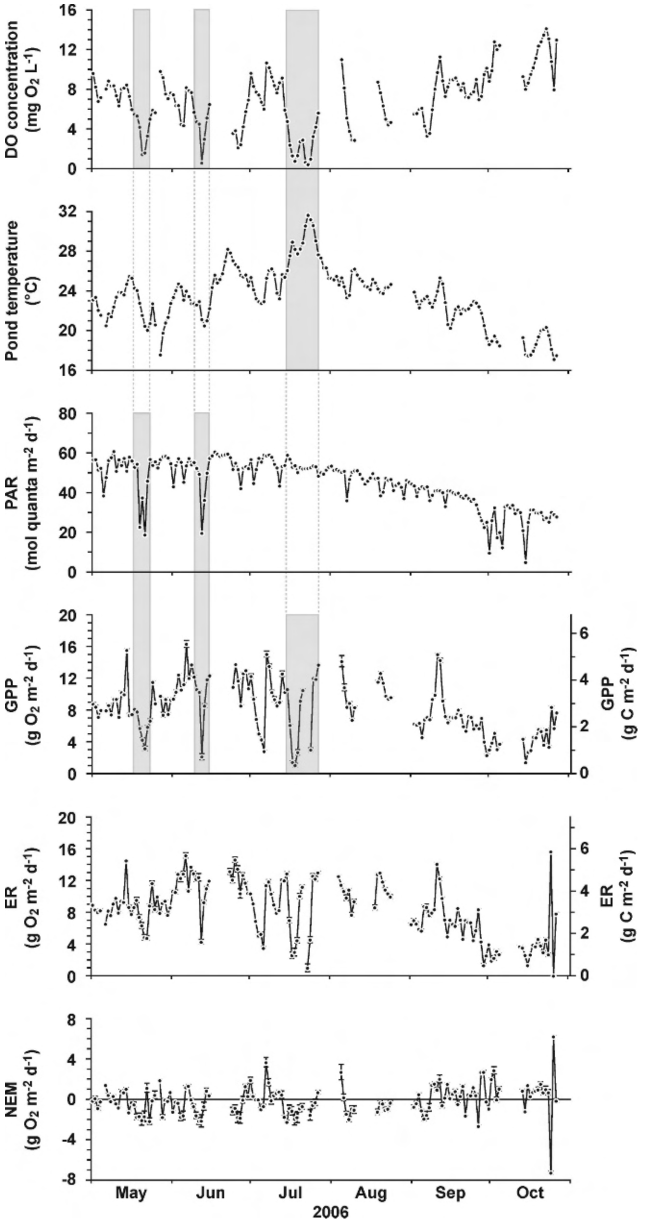

Figure 3. Pond A18 May–October 2006 daily mean DO concentration, pond temperature, photosynthetically active radiation, gross primary production (± 1 s.d.), ecosystem respiration (± 1 s.d.), and net ecosystem metabolism (± 1 s.d.). Shaded areas highlight periods of low DO and GPP coincident with extreme 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.

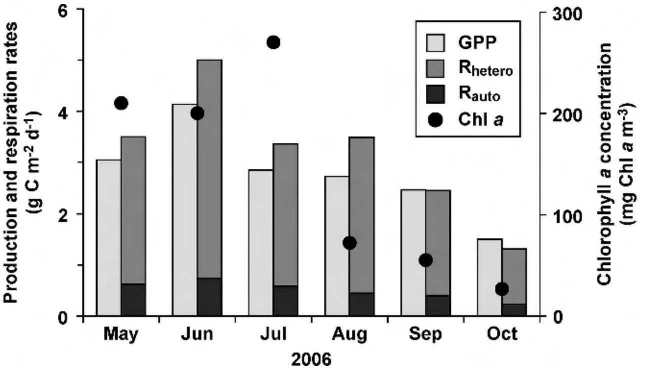

Figure 4. Monthly measurements (May–October 2006) of chlorophyll *a* concentration, estimates of autotrophic respiration (R_{auto}), heterotrophic respiration (R_{hetero}) and gross primary production (GPP; 7-d mean values centered on Chl *a* sampling dates) in Pond A18.

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 g O_2 m^{-2} d^{-1} (≡ −3.01 to 1.95 g C m^{-2} d^{-1}) with a May–October average of −0.09 g O_2 m^{-2} d^{-1} (≡ −0.31 g C m^{-2} 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 g C m^{-2} (≡ 1521 g O_2 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 g O_2 m^{-2} d^{-1}) roughly double the magnitude of the world's most productive estuaries, such as Chesapeake Bay (4.8 g O_2 m^{-2} 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 (g O_2 m^{-3} 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 g O_2 m^{-2} 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 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.

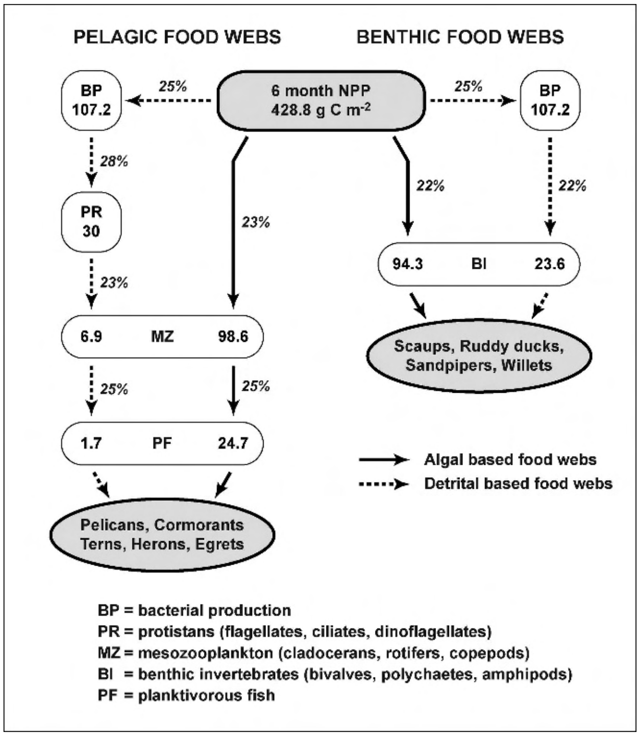

Figure 5. Idealized food webs and potential forage production (g C m^{-2}) in Pond A18 based on net primary production of 428.8 g C m^{-2} over the 6 month sampling period. Carbon is transferred to pelagic or benthic consumers through algal-based (plain arrows) and bacterial-based (dashed arrows) food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

ACKNOWLEDGMENTS

We thank A. Keith Miles for sharing nutrient data, Sarah E. Spring for nutrient data management and analyses, and technicians of the U.S. Geological Survey Davis Field Station for nutrient sample collection. Richard Dufford counted and identified phytoplankton, and Jeanne DiLeo designed Figure 1. We are grateful to Kris May and Gregory G. Shellenbarger for helpful comments on an earlier version of this manuscript. We also acknowledge two anonymous reviewers for providing constructive criticism and suggestions that substantially improved this manuscript, and Darold P. Batzer for editorial assistance. Julien Thébault expresses deep appreciation to the U.S. Geological Survey and UMR CNRS 6539 for support of his research stay within the Water Resources Division of the U.S. Geological Survey in Menlo Park, CA. Contribution N°1079 of the IUEM, European Institute for Marine Studies (Brest, France).

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Manuscript received 19 October 2007; accepted 12 May 2008.

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:

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

where K_L is the liquid-phase oxygen mass transfer coefficient (m d^{-1}), ν_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}), ρ_a is the density of air calculated from Eq. A6 (kg m^{-3}), ρ_w is the density of water calculated according to IES-80 (kg m^{-3}, UNESCO 1981), κ is the dimensionless Von Karman constant (= 0.4), Γ_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 (μ_w, in kg m^{-1} s^{-1}) and the density of water and was calculated hourly:

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

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

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

where μ_{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):

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

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

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

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 (= 1.72×10^{-10} m; Cussler 1984).

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

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

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:

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

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):

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

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:

$$\begin{aligned} K_L = 34.6 \times R_{visc} \times \big(D_{w,20^\circ C} \times 10^4\big)^{1/2} \\ \times U_{10}^{3/2} \end{aligned} \qquad \text{(A9)}$$

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:

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

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

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

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

USGS
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]

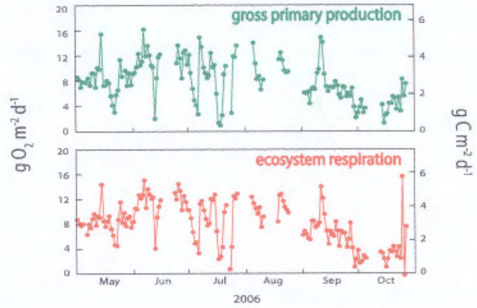
Mysterious new habitats

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

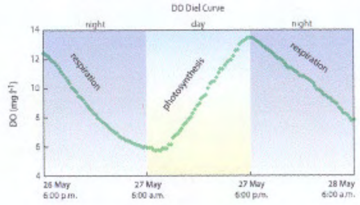
Remarkably high gross primary production (GPP mean = 8.2 g O_2 m^{-2} d^{-1}), DOUBLE the rate of the world's most productive estuaries!



- 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
$dO_2/dt = GPP - ER + D$

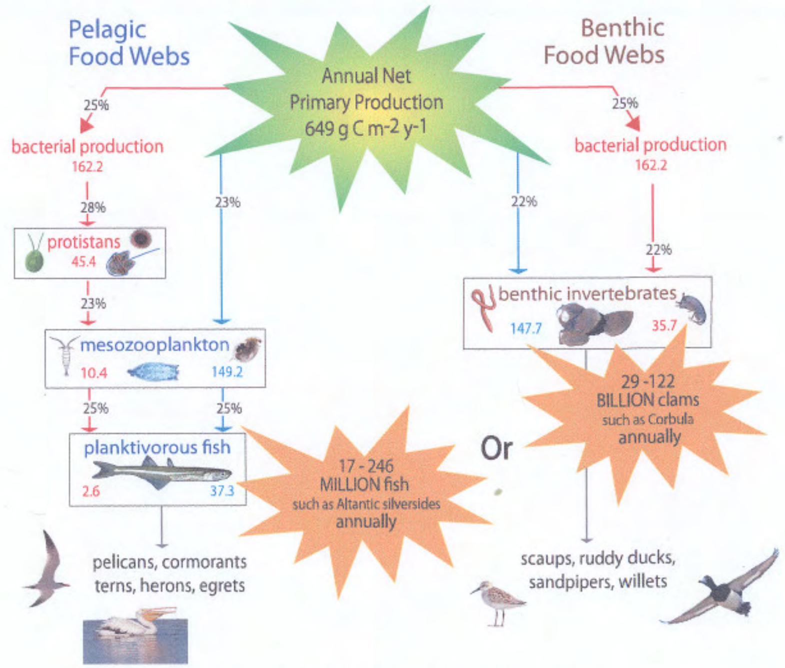
where D = atmospheric O_2 exchange. We assumed accrual from other water sources to be negligible due to the pond's long residence time (15-50 days).

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.

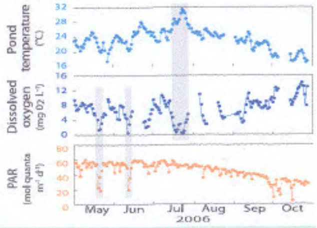
These ponds are for the birds

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}.



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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[1] U.S. Geological Survey, 345 Middlefield Rd., MS 496, Menlo Park, California 94025
[2] IUEM-UBO, UMR CNRS 6539, Place Nicolas Copernic, 29280 Plouzané, France
[3] City of San Jose, Environmental Services Department, 700 Los Esteros Rd., San Jose, California 95134

For further information, please contact Tara Schraga, email: tschraga@usgs.gov, tel: 650-329-4381