Stockton Channel Water Quality Improvements

Nutrient Data and Discussion

Revised DRAFT

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I. Overview

Introduction

This work was performed to partially complete Subtask 103.2- Nutrient Testing. The concentrations of nitrogen and phosphorus species were quantified in the Stockton Channel on two separate days. This work was scheduled on days in which HDR personnel were collecting nutrient data from storm drains entering the Stockton Channel, specifically at McLeod Lake. This work was also performed to take advantage of the nutrient data obtained for the San Joaquin River Dissolved Oxygen Total Mass Daily Load (TMDL) study, a concurrent but independent study investigating the cause of low dissolved oxygen concentrations in the San Joaquin River.

Scope of work

The following elements are included in this study:

- Concurrent measurements of nitrogen and phosphorus species and chlorophyll *a* in McLeod Lake, the Stockton Channel, and at storm drain discharge outfalls.
- Estimations of sediment nutrient fluxes using nitrogen and phosphorus concentration profiles near the sediment-water interface in McLeod Lake.
- Comparisons and analyses of nutrient and chlorophyll *a* concentrations in the Stockton Channel with TMDL study data for 2000.

In addition to these identified tasks, analyses were also performed with water quality data collected by the City of Stockton during 1996, 1997, and 1998. The data sets provide additional insight into parameters that may be useful in predicting objectionable blue-green blooms in the upper Stockton Channel.

II. Upper Stockton Channel Monitoring, 2000

Materials and Methods

Water quality measurements were performed *in situ* or by analyzing grab samples. *In situ* measurements were performed from a boat with a YSI-600D multi-parameter sonde. Sensors of the sonde simultaneously measure pressure (depth), temperature, electrical conductivity, pH, and dissolved oxygen. All grab samples were collected with a peristaltic pump and 0.25-inch dia tubing attached to the sonde. The flow rate was approximately 1L/min. The sonde accurately measures pressure from which water depth is internally calculated. Grab samples were collected from the surface at a depth of 2 feet, mid-depth, and 2 feet above the sediment-water interface. Before samples were collected in plastic or glass bottles, the peristaltic tubing was first flushed with approximately 2 volumes of water at each location and depth. Bottles were rinsed 3 times prior to collection for those samples analyzed by University of the Pacific (UOP) personnel. Sequoia Analytical, Inc., provided clean bottles (some with appropriate chemical preservatives) for the laboratory analyzed water and sediment samples. Table II-1 contains a list of the constituents that were monitored. All bottles were plastic except for the amber glass bottles used to collect samples for the chlorophyll *a* analyses. Field instruments were first calibrated in the laboratory at controlled temperatures. Calibration was periodically checked in the field and the electrodes were recalibrated at ambient water temperatures when necessary. Sediment samples were also collected using an Ekman dredge and were analyzed for total ammonia, nitrate, nitrite, total kjeldahl nitrogen (ammonia and organic nitrogen), and total phosphorus.

Total ammonia, nitrate, nitrite, total kjeldahl nitrogen, dissolved orthophosphate (dissolved reactive phosphorus), and total phosphorus were determined by Sequoia Analytical, Inc., by the analytical methods listed below in Table II-2. Sequoia Analytical is certified in California to perform these analyses. Copies of the laboratory reports from the contract laboratories are presented in Appendix B. Chlorophyll *a* concentrations were determined at the UOP laboratory using acetone for the pigment extraction and the spectrophotometric quantification method (Standard Methods, 10200 H).

Table II-1: Measured Water and Sediment Quality Constituents.

Constituent	**Matrix**	**Collection and Measurement Methods**
Temperature (°C)	Water	Field measurement with sonde.
Electrical conductivity (μmho/cm)	Water	Sonde measurement performed in the field.
Dissolved oxygen (mg/L)	Water	Two electrode measurements were performed in the field. *In situ* measurement was conducted with the sonde. The second record was performed with water collected with the peristaltic pump and measured with YSI-55 dissolved oxygen meter.
PH	Water	Sonde electrode measurement performed in the field.
Turbidity (NTU)	Water	Grab sample[1] measured in the field immediately after collection.
Depth (ft)	Water	Calculated from pressure measured by the sonde.
Secchi depth	Water	Measured in the field with a Secchi disk.
Total ammonia, nitrate, nitrite, total phosphorus, dissolved orthophosphate	Water	Grab sample immediately placed on ice, delivered to Sequoia Analytical laboratory within 6 hours.
Total ammonia, nitrate, nitrite, total phosphorus	Sediment[2]	Grab sample immediately placed on ice, delivered to Sequoia Analytical laboratory within 12 hours.
Chlorophyll *a*	Water	Grab sample immediately placed on ice, pigment extraction was completed within 8 hours after the samples were collected.

[1] All grab water samples were collected with a peristaltic pump.

[2] The upper 2 cm of sediment collected with an Ekman dredge were analyzed.

Table II-2: Nitrogen and phosphorus species quantified by Sequoia Analytical, Inc., reporting limit, and analytical method.

Constituent	Reported form[1]	Reporting Limit[2]	Analytical method
Total ammonia	mg/L of NH_3	0.10 / 5.0	US EPA 350.3
Nitrite	mg/L of NO_2	0.01 / 10.0	US EPA 300.0
Nitrate	mg/L of NO_3	0.01 / 10.0	US EPA 300.0
Total kjeldahl nitrogen	mg/L as N	0.5 / 40.0	US EPA 351.2
Dissolved orthophosphate	mg/L as P	0.01 / 40.0	US EPA 365.3
Total phosphorus	mg/L as P	0.01 / 2.5	US EPA 365.3

[1] Water matrix, mg/L; sediment analyses reported as mg/kg of wet sediment.

[2] Practical detection limit (water / sediment).

Sampling Locations and Descriptions

Table II-3 presents details of the three monitoring runs performed on September 28, October 12, and Oct 19, 2000. Sampling duration, purpose and approximate low and high tidal stages are provided. Sampling locations are shown in Figure 1 and described in Table II-4. Figure 2 shows the location of the Stockton Channel relative to the Turning Basin and the San Joaquin River.

Table II-3: Monitoring Runs and Sampling Duration.

Date	Task and Purpose	Sampling Times and Tidal Conditions	Tidal Stages at Stockton[1]
9/28/00	Characterize nutrient profiles in the water column of the upper Stockton Channel. Results compared with nutrient concentrations measured in storm drain discharges and San Joaquin River.	12:15 – 1:45 PM. Ebb tide	7:00 AM 3.79 ft 1:45 PM 0.51 ft 7:30 PM 3.68 ft
9/28/00	Quantify sediment concentrations in the Upper Stockton Channel.	8:00-9:30 AM, Ebb tide	
10/12/00	Measure nutrient concentrations near the sediment-water interface. Data used to attempt an estimate of the nutrient flux of phosphorus and nitrogen from the sediments	10:25 AM –1:00 PM Ebb tide/Low Slack tide	5:59 AM 3.26 ft 12:30 PM 0.1 ft
10/19/00	Same as 9/28 water column monitoring.	1:45 – 3:25 PM Ebb tide	6:30 AM -0.06 ft 12:40 PM 2.88 ft 17:00 PM 1.25 ft

[1] Department of Water Resources stage gage station at Rough and Ready Island (RRI), San Joaquin River, California Data Exchange Center (http://cdec.water.ca.gov).

Table II-4: Monitoring sites and descriptions for primary monitoring stations shown in Figure 1.

Sample Site	Description of Location
SW-1 / SD-1	Center of McLeod Lake
SW-2 / SD-2	Stockton Channel approximately 200 feet west of Weber Point
SW-3 / SD-3	Stockton Channel, center of channel off Marina
SS-1	Storm sewer outfall (42” dia.), north side of McLeod Lake.
SS-2	Storm sewer outfall (30” dia.), north side of McLeod Lake.
SS-3	Storm sewer outfall (72” dia.), southeast corner of McLeod Lake

Water Quality Data

Water column profiles

The water quality data obtained from samples collected in the upper Stockton Channel by UOP personnel on September 28, October 12, and October 19 are tabulated in Appendix A. Temperature profiles are shown in Figure 3. These data were collected at mid-day or afternoon hours. The September 28 and October 19 data indicate that the water column was stratified. Temperatures near the surface were typically 1 to 1.5° C greater than near sediment temperatures. The October 12 data exhibit little evidence of stratification. As discussed later, the storms of October 10 and October 11 were apparently sufficient to mix the water column of McLeod Lake.

The effects of stratification are also evident in the pH and dissolved oxygen (DO) profiles presented in Figures 4 and 5, respectively. On September 28 and October 19 pH values in the range of 7.5 to 7.8 were recorded 2 feet above the sediment surface. Near-surface pH values ranged from 8.4 to 9.1. The increase in pH at the surface is associated with algal photosynthesis. The DO profiles also show evidence of photosynthesis. Dissolved oxygen concentrations are depressed below 3 mg/L near the sediment, but are supersaturated near the surface. The DO concentrations 2 feet below the water surface in the upper Stockton Channel were approximately 12 and 15 mg/L on September 28 and October 19, respectively. Based on water temperatures, the saturated DO concentrations were 9.1 and 8.4 mg/L for September 28 and October 19, respectively. The DO was near zero on October 1 in McLeod Lake. Anaerobic water overlying the sediments enhance the release of phosphorus to the water column. The low concentrations at other locations and dates also suggest anoxic conditions may be common for the Stockton channel. The implications of phosphorus releases from the sediments are discussed in detail later.

Chlorophyll a profiles are presented in Figure 6 for measurements performed on September 28, 2000. Samples for chlorophyll *a* analyses were also collected on October 19; however, a mishap in the laboratory prevented quantification. These samples were collected during early afternoon and thus alga populations were greatest near the water surface. These surface measurements are consistent with the pH and DO levels discussed earlier. The highest chlorophyll *a* concentration was measured in McLeod Lake at 118 μg/L. Concentrations decreased with depth. Near the sediment-water interface the chlorophyll *a* concentrations were less than 20 μg/L. The species of algae present were not determined; however, enumeration data may become available in the future for the Turning Basin as part of the investigation performed by the Department of Water Resources for the TMDL study. Many algae, including blue-green algae, are capable of regulating their position in the water column. Blue-green algae contain gas vacuoles that permit buoyancy regulation in such a way as to optimize growth with respect to light intensity, temperature, nutrient concentrations, and oxygen concentration. Artificial circulation has been effective in reducing growth by disrupting the ability of blue-green algae to maintain a favorable position in the water column. However, potential benefits of circulation must be weighed against the detrimental effects of mixing nutrient rich waters often found deeper in the water column during periods of active photosynthesis.

Algae require nutrients in available forms. The nitrogen available for growth is the sum of the ammonia, nitrite, and nitrate concentrations. For phosphorus only the dissolved orthophosphate (dissolved reactive phosphorus) is generally available to algae (some blue-green species are capable of utilizing organic forms). Figures 7 and 8 present the profiles of these available nutrient measured on September 28 and October 19. As shown in Figure 7, the available nitrogen concentration was lower near the surface on September 28. This suggests that phytoplankton productivity had reduced surface concentrations of available nutrients. Similar measurements where available nitrogen was reduced near the surface were also reported for October 19 at locations SW-2 and SW-3, but not SW-1. The higher concentrations of nitrogen at SW-1 could be associated with storm water inputs from the outfalls that discharge to McLeod Lake.

Dissolved orthophosphate concentrations also increased with depth as shown in Figure 8 on September 28. However, on October 19 the lowest concentrations were observed at mid-depth. It is uncertain why relatively high dissolved orthophosphate concentrations were measured near the surface. The high dissolved oxygen (13-17 mg/L) and pH (8.4-8.9 levels) measured during the afternoon of October 19 suggest that algal photosynthesis was very active. Chlorophyll *a* concentrations estimated from organic phosphorus concentrations (see Figure 9) indicate that surface chlorophyll *a* levels were in the range of 45-70 μg/L. Thus, it appears that algae populations were sufficient to reduce dissolved orthophosphate concentrations and other sources of phosphorus may be the cause of high phosphorus levels measured near the surface in the upper Stockton Channel.

Figure 10 presents total phosphorus profiles measured in the upper Stockton Channel. Total phosphorus concentrations are typically lowest at mid-depth. This appears to be caused by the relatively high fraction of dissolved orthophosphate in the water column near the sediment, the relatively high concentration of algae near the surface that concentrate the phosphorus, and the unexplained high dissolved orthophosphate concentrations near the surface. The high orthophosphate concentrations near the sediment could be caused by the release of phosphorus from the sediment or from higher concentrations entering from the San Joaquin River. The dye study performed by U.C. Davis shows that water from the Turning Basin enters the upper Stockton Channel along the bottom and returns from the top. Longitudinal nitrogen and phosphorus concentration gradients from the San Joaquin River to the upper Stockton Channel are also consistent with this circulation pattern (see TMDL Water Quality Data).

The higher total phosphorus concentrations near the sediment-water interface could also be caused by resuspension of sediments. Plots of turbidity shown in Figure 11 indicate that suspended particulate matter is often highest near the sediment-water interface. These observations are also consistent with the occasional turbidity plumes observed by U.C. Davis during the dye investigation near the channel bottom at grade transitions. The highest turbidities were measured on October 12, a day after 0.53 inches of precipitation fell in Stockton on October 10 and 11. The impacts of this storm are discussed later. On September 28 and October 19, the lowest turbidity measurements were recorded at mid-depth. The increase of turbidity near the water surface appears to be associated with higher concentrations of algae.

Storm drain inputs

As shown in the sampling location map (Figure 1), the storm drain data presented here was obtained from samples collected from pipelines that empty into McLeod Lake. The storm drains discharge near the water surface of McLeod Lake. Nutrient concentrations measured in water samples collected by HDR and UOP personnel on September 28 and October 19 are compared with water column data in Figures 12-14. Samples collected by UOP were taken at the outfall to McLeod Lake; HDR samples were collected farther up the storm drains at locations shown in the HDR report. All the storm drain sampling locations are influenced by tidal waters. However, samples were often collected during ebb tides to minimize (put probably not eliminate) the effects of water from McLeod Lake entering the storm drain system during flood tides.

Temperature data for McLeod Lake at the time of the monitoring indicate that the lake is often well stratified (see Figures 3-5) and storm drain water temperatures were greater than near surface water temperatures. Thus, storm drain inflow to McLeod Lake would be expected to remain near the surface during the afternoons that these measurements were made.

Available nitrogen (nitrate, nitrite, and ammonia) concentrations measured in the storm drains are compared with the water column measurements from the upper Stockton Channel in Figure 12. Concentrations of available nitrogen in the storm drains and McLeod Lake were generally higher on October 19. These higher concentrations appear correlated to the near surface concentrations of McLeod Lake. Thus, the storm drain samples appear to be influenced, in part, by the tide entering the pipelines from McLeod Lake.

Unlike available nitrogen, dissolved orthophosphate concentrations were typically greater in the storm drains on September 28 as shown in Figure 13. The storm drain concentrations of dissolved orthophosphate exceeded the water column concentrations near the surface of McLeod Lake on September 28. Contrary to the September 28 data, most of the storm drain October 19 data were lower than McLeod Lake concentrations. These data suggest that the high dissolved orthophosphate concentrations measured near the water surface in the upper Stockton Channel on October 19 originated from sources other than the McLeod Lake storm drains.

Nutrient profiles were measured in McLeod Lake on October 12, one day after the first significant rainfall event for water year 2000-2001. Precipitation at Stockton Metropolitan Airport was measured at 0.02, 0.18, and 0.34 inches for October 9, 10, and 11, respectively. Water quality measurements were made during late morning to early afternoon. The color of the water in McLeod Lake was light brown from sediment washed in from storm drains or matter resuspended from the bottom. As shown previously in Figure 11, the turbidity of McLeod Lake was approximately twice the levels measured on September 28 or October 19. Temperature profiles show little evidence of stratification on September 12 (Figure 3). The dissolved oxygen throughout the water column was only approximately 1.5 mg/L as shown in Figure 5.

Average nutrient concentrations in McLeod Lake on September 28, October 12 and October 19 are presented in Table II-5. These data show significant increases in nitrogen species but not phosphorus from September 28 to October 19. Both available nitrogen and total nitrogen concentrations were elevated by the storm event of October 10-11. Total nitrogen increased from 1.2 to 2.1 mg/L in McLeod Lake and available nitrogen increased from 1.2 to 1.6 mg/L.

Of the 0.4 mg/L increase in available nitrogen, 0.2 mg/L was associated with increases in ammonia (this could be artificially high due to the fact that most samples measured on September 28 were below the detection limit). On September 28 and October 19, ammonia was below detectable levels (0.08 mg/L-N) in McLeod Lake. On October 12, the average concentration in the water column was 0.20 mg/L-N. The increase in ammonia could be due to storm water inputs or the resuspension of sediments caused by high storm drain inflows or waves.

Table II-5: Average nutrient concentrations in McLeod Lake on September 28, October 12, and October 19, 2000.

Constituent	September 28	October 12	October 19
Available Nitrogen[1] (mg/L-N)	1.2	1.6 (36)[2]	1.5
Total Nitrogen (mg/L-N)	1.2	2.1 (81)	1.7
Dissolved Orthophosphate (mg/L-P)	0.048	0.056 (17)	0.046
Total Phosphorus (mg/L-P)	0.12	0.11 (-08)	0.090

[1] Total ammonia, nitrate, and nitrite.

[2] Percent increase above 9/28 measurement.

These data suggest that wet weather inputs to the upper Stockton Channel may increase available and total nutrient concentrations. Available nitrogen and phosphorus concentrations increased 36 percent and 17 percent, respectively. For the total nitrogen and phosphorus concentrations, nitrogen increased 80 percent, but phosphorus remained unchanged. These data indicate that available nutrient concentrations in the water carried to McLeod Lake by the first precipitation event are relatively modest compared with concentrations in the channel. Degradable organic matter loads appear to be more significant as shown by the DO deficit observed in McLeod Lake on October 12. Severe DO deficits are common for many Stockton tributaries immediately after precipitation events (Litton, 1995; DeltaKeeper, 2000). As will be discussed later when reviewing the TMDL data, the San Joaquin River water appears to be the dominant source of nutrients for the Stockton Channel. However, active photosynthesis may still deplete near-surface nutrient concentrations to levels that limit algal productivity. Significant nutrient inputs from storm drains during at these times could set off or enhance an objectionable algae bloom by either introducing nutrients or circulating nutrient rich waters or sediments to the surface. However, the precipitation events also appear to yield high turbidities that reduce light penetration and inhibit algae growth. In addition, precipitation events during summer months are uncommon. Estimates of dry weather nutrient loads from storm drains are shown by HDR to be much lower than estimated loads entering from the San Joaquin River.

Limiting nutrient ratios

Nitrogen to phosphorus (N/P) ratios were calculated from water quality data collected in the upper Stockton channel. Algae growth is potentially limited by phosphorus when N/P ratios exceed 20 and potentially nitrogen limited when N/P ratios are less than 5. A common chemical representation for algae,

$$106\ CO_2 + 16\ NO_3^- + HPO_4^{2-} + 122\ H_2O + 18\ H^+ \Leftrightarrow \underset{\text{(algae)}}{C_{106}H_{263}O_{110}N_{16}P} + 138\ O_2\ ,$$

when nitrate is the dominant nitrogen species assimilated by the algae (Stumm and Morgan, 1996). The stoichiometry of this equation indicates that algae require 16 nitrogen atoms to 1 phosphorus atom. On a mass basis this ratio is equivalent to 7. This ratio can vary with the alga species and their growth phase, however, the data presented here suggests that algae N/P ratios are approximately 4-8. Therefore, if total nutrient concentrations are predominantly associated with algal biomass, total N/P ratios will be more representative of plant stoichiometry.

Available N/P and total N/P ratios for the upper Stockton Channel are presented in Table II-6. Based on available nutrient concentrations, the upper Stockton Channel appear to be potentially phosphorus limited throughout the 2000 monitoring season. Ratios calculated with total N and P concentrations also suggest that the water was potentially phosphorus limited, but total N/P ratios are often lower than the N/P ratios calculated with available nutrient concentrations. This appears to be due in part to the effect of algae that concentrate the nutrients in organic forms.

On August 3 and 4 algae growth appeared to be limited by low dissolved orthophosphate concentrations near the water surface. The highest chlorophyll *a* concentrations in the Stockton Channel during the 2000 monitoring were measured on this date. The environmental conditions leading up to August 3 provide evidence of some of the factors important to this nutrient limiting condition. Figure 15 presents the chlorophyll *a*, phosphorus concentrations, and air and water temperatures measured from September 27 to August 4. As shown in Figure 15, the average chlorophyll *a* concentrations near the water surface increased from 59 to 94 μg/L. This growth of algae appears to be correlated to increases in air temperature and water temperature. The maximum air temperature for each day increased from 88°F on September 27 to 104°F on August 3. Surface water temperatures also increased during this period from 83.2°F to 86.9°F (28.4-30.5°C). The highest surface water temperature was 88.9°F (31.6°C), measured on August 2. Available phosphorus concentrations near the surface decreased from 40 to 13 μg/L and available nitrogen (nitrate) decreased from 600 to 390 μg/L during this period. The decrease in available nitrogen is approximately 7 times greater than the decrease in available phosphorus, a result consistent with the algal chemical stoichiometry presented earlier. Therefore, it appears that the decreases in available nutrients were associated with algal productivity during this week.

Table II-6: Nitrogen to phosphorus ratios in the upper Stockton Channel near Weber Point.

Date	Available N/P[1]	Total N/P
	Near surface / near sediment[2]	Near surface / near sediment[2]
July 27-28[3]	15 / 12	11 / 12
August 3-4[3]	30 / 10	7 / 8
September 28	17 /36	15 / 15
October 12[4]	29	20
October 19	33 / 35	19 / 24

[1] Available N/P is the ratio of ammonia + nitrate + nitrite / dissolved orthophosphate

[2] Near surface ratio was determined with samples collected 2-3 feet from surface. Near sediment ratio was determined with samples collected 2-3 above water-sediment interface.

[3] Data obtained by HDR personnel. Total kjeldahl nitrogen concentrations were often reported below the 0.5 mg/L detection limit for July 27-28 samples. Total N averages used this detection limit for total N/P ratios. Thus the total N/P ratios for July 27-28 may be high.

[4] Average water column concentrations were used.

Near surface algal productivity increased 60 percent during this 7 day period. However algal growth rates can not be estimated from these observations. On August 3, phytoplankton growth in the Stockton Channel appears to be limited by low available phosphorus concentrations near the surface. Figure 16 contains a plot of the near surface chlorophyll *a* and available phosphorus concentrations for August 3-4. As shown in this figure, the chlorophyll *a* concentrations fluctuated around 100 µg/L from 8:30 AM to 9:00 PM on August 3. Total phosphorus concentrations are also consistent with the chlorophyll *a* concentrations (1:1 ratio), suggesting that most of the total phosphorus measured near the surface is associated with the algae.

Michaelis-Menton approaches are commonly used to model algal growth and indicate that growth is relatively independent of nutrient concentrations until available concentrations are reduced below threshold levels. Typical thresholds for phosphorus limited growth range from 5-20 µg/L while nitrogen limited growth levels ranges from 25 to 100 µg/L (Chapra, 1997). Based on these guidelines, the near-surface available phosphorus concentrations measured on August 3-4 were at or below these threshold concentrations. The trends in the chlorophyll *a* concentrations and total phosphorus shown in Figure 16 provide further evidence that algal growth was phosphorus limited on August 3.

Although near-surface concentrations of available phosphorus were near growth limiting levels, relatively high concentrations were measured within 2 feet of the sediment-water interface. Shown in Figure 17 are the concentrations of available nitrogen and phosphorus near Weber Point measured on August 3-4. Near-surface and near-bottom measurements indicate that near-bottom nutrients were approximately 10 and 3 times greater for available N and P, respectively. The relatively constant chlorophyll *a* shown in Figure 16 or the decreasing total phosphorus concentrations shown in Figure 17 suggest that stratification of the water column inhibited the transfer of the available phosphorus near the bottom to the water surface during the day. However, near-surface concentrations of both nitrogen and phosphorus are greatest in the early morning of August 3 and evening of August 4. However, the nutrient data presented in Figure 17 indicate that mixing of the water column was very limited during the night of August 2 and 3 because early morning concentrations on August 3 were significantly lower near the surface when compared with near sediment concentrations. Temperature profiles for August 3 and 4 also indicate the water column is well stratified, effectively isolating the nutrient rich lower waters. Thus stratification appears to have inhibited algal growth on August 3 by limiting nutrient transport to the water surface. Since algae consist of approximately 1 percent phosphorus and chlorophyll *a*, mixing of the lower waters could substantially increase algal productivity. For example, if 100 µg/L of available phosphorus were added to the upper water column, chlorophyll *a* levels could potentially increase by 100 µg/L. If the initial chlorophyll *a* concentrations were 100µg/L, the algal biomass would double. Of course this assumes that the algae remain in the euphotic zone during the introduction of nutrients. A sufficiently energetic redistribution of the nutrients in the water column would also disrupt the distribution of algae near the surface and potentially lower their growth rate.

The previous analysis suggests that mixing of the water in the Stockton Channel on August 3 would have increased the concentration of dissolved orthophosphate in the upper water column, possibly simulating more algae growth. Under these conditions mixing may have other adverse effects. Measurements of pH shown in Figure 4 indicates that near surface pH values can exceed 9 while values near the sediment-water interface remain near 7.6. The high pH near the surface is caused by algal photosynthesis. Mixing the water column on August 3 would have raised the pH near the sediment-water interface. At pH 7 dissolved orthophosphate is adsorbed by iron oxides and hydroxides as well as other sediment surfaces. Raising the pH of the water contacting these surfaces above 8 is known to result in the release of phosphate (Breeuwsma and Lyklema, 1973; Chen *et. al.*, 1973). Phosphorus releases from sediments induced by high pH in the overlying waters under aerobic conditions have been suspected of triggering massive blue-green blooms in the Potomac Estuary (Di Toro and Fitzpatrick, 1984.)

Nutrient sediment flux estimates at McLeod Lake

The field measurements and nutrient concentrations measured in McLeod Lake on October 12, 2000 are presented in Table 2 of Appendix A. These data were used to estimate the flux of nitrogen and phosphorus leaving the bottom sediments and entering the water column. Figure 18 presents a hypothetical illustration of how phosphorus can increase in the water column during a slack tide period when released from the sediments.

The release of dissolved phosphate is calculated from the following equation.

$$\text{Phosphorus flux}\,(\mathrm{g}\cdot\mathrm{m}^{-2}\mathrm{d}^{-1}) = \frac{\text{area between profiles}\,(\mathrm{g}\cdot\mathrm{m}^{-3}\cdot\mathrm{m})}{\text{time between measurements}\,(\mathrm{d})}$$

The nitrogen flux was calculated using the same approach. Figures 19 and 20 display the phosphorus and nitrogen profiles measured in McLeod Lake on October 12, 2000. The phosphorus profiles indicate an increase in the dissolved phosphate flux. Based on the differences in the measured profiles, the flux of dissolved orthophosphate is 0.065 mg/ft^2/d. This value is significantly higher than modeling parameters currently used for the Stockton TMDL modeling of the San Joaquin River. The flux of phosphorus in this model is calibrated with a value of 0.0043 mg/ft^2/d. The flux of phosphorus subject to aerobic conditions have been reported to range from approximately 0.05 to 1 mg/ft^2/d (Thomann and Mueller, 1987). The 0.065 mg/ft^2/d estimate is consistent with these reported values, however, spatial variability in phosphorus moving out of McLeod Lake could also explain the field estimate, instead of sediment releases.

If complete nitrification and denitrification occurs within the sediment, then the release of nitrogen from the sediment is zero. When these processes are incomplete quantifiable releases of nitrogen in forms available for phytoplankton growth are possible. Nitrate concentrations were similar over the slack tide, while ammonia levels decreased as shown in Figure 20. This suggests a net gain of ammonia within the sediment (negative flux to the water column). The decrease in ammonia concentrations near the sediment water interface shown in Figure 20 can probably best be explained by spatial variability in the water column passing the fixed monitoring station. This estimate for the dissolved orthophosphate release will be used later to compare sediment loads to San Joaquin River inputs. Literature values for ammonia-nitrogen release from sediments often range from 2 to 4 $mg/ft^2/d$, with some reported values as high as approximately 30 $mg/ft^2/d$ (Thomann and Mueller, 1987).

III. TMDL 2000 and City of Stockton (1996-1998) Monitoring

Nutrient inputs from the San Joaquin River

TMDL 2000 data

Data collected by the City of Stockton for the San Joaquin River Dissolved Oxygen Total Daily Maximum Load (TMDL) Investigation was used to evaluate nutrient inputs from the San Joaquin River. Complete data sets generated by the Department of Water Resources for the TMDL study remain unavailable and thus are not included here. City of Stockton personnel collected water samples from the San Joaquin River and the Turning Basin on a weekly basis from June 20 to October 31, 2000. Results for the Turning Basin, Channel Point (Station R-3) and upstream of Stockton’s Wastewater Treatment Plant outfall (Station R-2) are presented here. These locations are shown in Figure 2.

A conceptual model for purposes of analyzing the data is shown in Figure 21. The dye study conducted by U.C. Davis indicates that circulation from Weber Pt to the I-5 bridge, just east of the Turning Basin is significant. The general circulation pattern for water exchange was shown to flow into the upper Stockton Channel near the bottom and return to the Turning Basin near the surface. These water exchanges are shown with arrows in Figure 21. Mixing of the water column was observed during the night in the absence of temperature stratification. As discussed earlier, nutrient concentrations measured on August 3 and 4 suggested that limited mixing was observed on August 3 and 4, apparently due to the hot weather conditions or a calm evening.

The water quality samples obtained by the City of Stockton personnel were collected at mid-depth and near the sediment-water interface, near-surface samples were not collected. The Weber Point monitoring and the City of Stockton monitoring was not performed on the same day. City samples were collected on Tuesday morning of each week, while the Weber Point samples were collected on Thursday, with some continued monitoring on Friday, July 28 and Friday, August 4. Department of Water Resources collected water samples near the surface in the Turning Basin and at R-3 on some of these Thursdays, but the data provided to date is too incomplete to present at this time.

Figure 22 exhibits the dissolved orthophosphate concentrations at R-2, R-3, the Turning Basin, and average surface concentrations near Weber Point for July 27, August 3, September 28, and October 19. These dates correspond to days that HDR or UOP personnel collected water samples at or near Weber Point. As shown in Figure 22, the mid-depth concentrations in the San Joaquin River were often similar at Stations R-2 and R-3. For the summer months the dissolved orthophosphate concentrations were somewhat lower in the Turning Basin, but were similar for the late September and October monitoring. Between the Turning Basin and Weber Point the dissolved orthophosphate concentrations decreased significantly apparently due to algal uptake in the upper Stockton Channel. The lower concentrations observed in the Turning Basin during late August and early September also appear to be reduced by algal uptake.

As shown in Figure 23, the reduction in dissolved orthophosphate between the Turning Basin and Weber Point was not as dramatic when Turning Basin data was compared with near-sediment samples collected at Weber Point. As shown and discussed earlier, near sediment nutrient levels were often significantly higher than near surface levels. A reduction was observed for each day except for August 3. The August 3 monitoring was conducted after several days of hot weather and relatively warm, calm evenings. These conditions apparently restricted mixing during the night and stratification of the water column persisted. As such the near bottom concentrations of dissolved orthophosphate were similar for the Turning Basin and Weber Point.

Similar patterns were also observed for available nitrogen as shown in Figures 24 and 25. Near-surface concentrations at Weber Point shown in Figure 24 were approximately half the Turning Basin or San Joaquin River concentrations. Uptake by algae appears to be the dominant cause for the decrease in nitrate measured in the upper Stockton Channel near the surface when compared with Turning Basin concentrations. Available nitrogen concentrations were about 1.2 mg/L for all four sampling shown in Figure 24. Near surface concentrations were approximately 0.6 mg/L on July 27 and September 28. The lowest nitrate concentrations near the surface of the upper Stockton Channel were measure on August 3 and 4, a date in which phosphorus was previously shown to limit algae growth. Only a 0.10 mg/L decrease in nitrate was observed when compared with Turning Basin concentrations.

Figure 25 compares near-bottom concentrations of available nitrogen in the upper Stockton Channel with levels measured in the San Joaquin River and Turning Basin. A decrease in available nitrogen from the Turning Basin to Weber Point was observed only on July 27. This decrease in near sediment nutrient concentrations suggests that water column stratification was insufficient to inhibit water column mixing at night or by wind. August 3 and September 28 near bottom concentration at Weber Pt were similar to the Turning Basin concentration. This could be caused if stratification of the water column was not disturbed with the cooling of air temperatures or wind at night. The data collected on October 19 shows an increase in the available nitrogen near the bottom when compared with the Turning Basin. This suggests that the source of nitrogen nutrients came from a source other than the Turning Basin. As shown earlier, the October 10 and 11 storm increased the available N concentration in McLeod Lake to 1.60 mg/L, the near bottom concentrations remained at this level for a week after the precipitation event.

Estimated Nutrient Loads from the San Joaquin River

The longitudinal profiles for available nutrients shown earlier suggest that the inputs from the San Joaquin River are significant. Figures 26 through 29 exhibit the mid-depth and near-bottom concentrations of available and total phosphorus and nitrogen in the Turning Basin from June 20 to October 31, 2000. As shown in Figure 24, the available phosphorus concentration range from approximately 0.17 to 0.11 mg/L. Trend lines suggest that bottom and mid-depth concentrations are similar. These concentrations are about 5 to 20 times the concentration necessary to inhibit phytoplankton growth. Available nitrogen ranges from 1 to 2 mg/L in the Turning Basin as shown in Figure 28. These concentrations are also well above levels necessary to inhibit algal productivity. Mass loads to the upper Stockton Channel in early August were estimated with available phosphorus, total phosphorus, available nitrogen, and total nitrogen concentrations of 0.13, 0.15, 1.2 and 1.3 mg/L, respectively.

The tidal exchange rate is estimated from the volume of water that enters the Stockton Channel during two flood tides per day. Exchange rates were calcuated for two sections of the Stockton Channel: 1) within 1100 feet of Weber point (including McLeod Lake) and 2) east of the Interstate-5 bridge. The surface areas and volumes for these channel sections are shown in Table III-1 . For an average tidal stage fluctuation of 3 feet, tidal flows entering and leaving these two channel sections are estimated to be 12 and 58 million gallons per day (MGD), respectively.

The estimated available and total nutrient loads entering the Stockton Channel in August 2000 from the Turning Basin are presented in Table III-2. The available nutrient loads are only slightly less than the total loads because the nutrient concentrations in the San Joaquin River (passing through the Turning Basin) are mostly in chemical forms available for algae growth. The nitrogen loads are approximately 10 times the phosphorus loads, suggesting the incoming San Joaquin River was potentially neutral or slightly phosphorus limiting at this time.

Table III-1 : Estimated Surface area, volume, and tidal exchange flow of two sections of the Stockton Channel.

Channel Section	Surface area[1]	Volume[1]	Tidal Exchange[2]
	(acres)	(acre-ft)	(MGD)
Eastern 1100 ft of Stockton Channel + McLeod Lake	12.2	133	12
Stockton Channel east of I-5 bridge + McLeod Lake	59.1	767	58

[1] Estimated by HDR personnel.

[2] Assuming two flood stages per day with an average 3 feet of variation in stage.

Table III-2: Estimated nutrient loads from the San Joaquin River[1].

Channel Section	Available Nitrogen and Phosphorus Inputs from the Turning Basin (lb/d)		Total N Nitrogen and Phosphorus Inputs from the Turning Basin (lb/d)	
	N (1.2 mg/L)	P (0.13 mg/L)	N (1.3 mg/L)	P (0.14 mg/L)
Eastern 1100 ft of Stockton Channel + McLeod Lake	120	13	130	14
Stockton Channel east of I-5 bridge + McLeod Lake	580	63	630	68

[1] Turning Basin concentration used to calculate the available nutrients entering from the San Joaquin River and passing through the Turning Basin.

Tables III-3 and III-4 compare the nutrient loads entering the Stockton Channel from the San Joaquin River with potential sediment inputs. The dissolved orthophosphate estimates suggest that nutrient input from the Turning Basin is at least an order of magnitude greater than the highest anticipated sediment release of phosphorus for aerobic conditions. Anaerobic rates reported in the literature range from 2.4 to 9.0 mg/ft^2/d, with averages reported at approximately 2.8 mg/ft^2/d, a flux approximately 3 times the maximum aerobic rate used here (Thomann and Mueller, 1987). The flux from aerobic sediments at elevated pH levels are expected to be on the same order as those reported for anaerobic conditions. The dissolved orthophosphate release from sediments in the Potomac Estuary was estimated to be approximately 3.9 mg/ft^2/d.

Modeling the upper Stockton Channel as a well-mixed reactor and assuming no losses of phosphorus associated with settling or algae uptake, an aerobic sediment input of 0.93 mg/ft^2/d will yield an average phosphorus concentration of approximately 0.01 mg/L. If phosphorus and chlorophyll *a* concentrations in algae are about 1 percent on a dry mass basis, then sediment releases generating 0.01 mg/L of dissolved orthophosphate could potentially generate chlorophyll *a* concentrations of 10 mg/L. These calculations suggest that under aerobic conditions, at a neutral pH, the potential release of phosphorus from the sediments is quite small. However, sediment releases of available phosphorus may be significant at elevated pH levels or anaerobic conditions, especially if phosphorus is at limiting concentrations in the Stockton Channel.

Table III-3: Comparisons of available phosphorus (dissolved orthophosphate) sources entering the Stockton Channel

Channel Section	Aerobic Phosphorus sediment release[1]	Anaerobic Phosphorus sediment release[2]	Inputs from San Joaquin River

	(lb/d)	(lb/d)	(lb/d)
Eastern 1100 ft of Stockton Channel + McLeod Lake	0.08-1.1	3.3	13
Stockton Channel east of I-5 bridge + McLeod Lake	0.37-5.3	15.6	63

[1] Range= 0.06 to .93 mg/ft^2/d (typical range for aerobic conditions overlying water column). The 0.06 mg/ft^2/d was determined by the phosphorus release study.
[2] Based on 2.8 mg/ft^2/d

Figure III-4 compares sediment loads with San Joaquin River inputs. Literature values for ammonia release are typically reported to range from 2 to 4 mg/ft^2/d, however, values as high as 30 mg/ft^2/d appear in the literature (Thomann and Mueller, 1987). As with phosphorus, the inputs from the San Joaquin River are typically more than an order of magnitude higher than estimated loads from the sediments within the Stockton Channel. If an extreme flux of 30 mg/ft^2/d is used, the loads entering from the San Joaquin River are still about 3 times the sediment load. Therefore, only at extreme ammonia fluxes, which have not been observed in the Stockton Channel, may the inputs of nitrogen from the sediments be significant.

Table III-4: Comparisons of available nitrogen (nitrate, nitrite, and ammonia) sources entering the Stockton Channel

Channel Section	Aerobic or anaerobic ammonia sediment release[1]	Inputs from San Joaquin River
	(lb/d)	(lb/d)
Eastern 1100 ft of Stockton Channel + McLeod Lake	0- 3.5	120
Stockton Channel east of I-5 bridge + McLeod Lake	0 - 17	580

[1] Range for available nitrogen flux 0 to 3 mg/ft^2/d. Values as high as 30 mg/ft^2/d appear in the literature. No release from the sediments is associated with complete denitrification.

City of Stockton 1996-1998 data

The City of Stockton collected near-surface water samples during 1996 and 1997 that were analyzed for ammonia, nitrate and nitrite, dissolved orthophosphate. Some of the most significant data were measured in 1997, the last year that objectionable blue-green algal mats were reported. No chlorophyll *a* measurements were performed. As a follow-up to these data, additional monitoring was performed during 1998. These data were used by Chen and Tsai (1999) to model the upper Stockton Channel and evaluate potential measures to inhibit blue-green algae growth.

Figures 30-33 present the longitudinal distributions of available nutrients measured in 1996 and 1997 from the San Joaquin River to Weber Point. These concentrations determined from samples collected near the water surface. As shown in these figures, concentrations decrease with distance from the San Joaquin River. As previously discussed this trend was also observed in 2000. However, the 1996 and 1997 data show a greater reduction in the concentrations from the San Joaquin River to the Turning Basin because the samples were collected near the surface where utilization by algae was active. Turning Basin data for 2000 were collected at mid-depth and near the bottom and were generally similar to those concentrations in the San Joaquin River.

Average summer concentrations of available phosphorus and nitrogen in the San Joaquin River for 1996 and 1997 were only 10 to 20 percent higher than levels measured in 2000. Thus, estimates of source inputs to the upper Stockton Channel from the San Joaquin River will be similar to those presented earlier in Table III-2. As shown in Figure 30, available phosphorus concentrations for the summer months at Weber Point typically ranged from 0.05 to 0.1 mg/L, well above concentrations considered to be growth inhibiting. Available phosphorus levels for April, 1996 are near growth inhibiting concentrations. As shown in Figure 31, the concentrations of available nitrogen declined dramatically during April, June, and July and approached nutrient limiting concentrations at Weber Point during 1996. Although chlorophyll *a* was not measured, elevated pH levels suggest that the reduction in available nutrient concentrations were caused by algal photosynthesis.

The available nutrient concentrations along the upper Stockton Channel for 1997 are presented in Figures 32 and 33. Available phosphorus concentrations during June and July decline sharply from the San Joaquin River to the Turning Basin. Available phosphorus concentrations from the Turning Basin to Weber Point also decreased, but may have remained above the growth threshold (approximately 0.01 mg/L). The maintenance of available phosphorus above growth limiting conditions suggests the presence of a source in addition to the San Joaquin River. Inputs of phosphorus from storm drain or sediments are probable sources. However, June concentrations of dissolved orthophosphate in the Stockton Channel were below a relatively high detection limit of 0.05 mg/L. This detection limit for dissolved orthophosphate was significantly higher than the 0.01 mg/L detection limit reported for the 1996 data. Since analytical accuracy is lost near detection limits, some of the phosphorus concentrations near the reporting limit of 0.05 mg/L that were reported for the upper Stockton Channel in the 1997 could be a laboratory artifact and thus falsely indicate that an unknown source of phosphorus exists.

As shown in Figure 33, available nitrogen concentrations fell below detection limits of 0.11 mg/L during June and July of 1997. These concentrations are at levels where algal productivity is limited by the lack of available nitrogen, a condition that favors blue-green algae species capable of fixing atmospheric nitrogen. Objectionable mats of blue-green algae were reported during the summer of 1997. Severe blue-green algae blooms in the upper Stockton Channel appear correlated to conditions where nitrogen concentrations limit growth and available phosphorus may have remained at levels sufficient to support growth. Since the June measurements of available phosphorus east of I-5 in the upper Stockton Channel were below the

0.05 mg/L detection limit, it is not known whether phosphorus concentrations also became limiting. Blue-green algae are capable of maintaining their position within the water column at light intensities and other factors to optimize growth. Populations can remain viable as long as nutrients are sufficient and other conditions favorable (e.g., pH). Extensive surface mats can develop once growth is no longer sustainable and the population dies off rapidly. Therefore, phosphorus depletion may have triggered a rapid population decline, generating the mats observed during the summer of 1997. Inhibitory pH levels could also be responsible. Monthly near surface pH measurements indicate that the pH was as high as 9.6 and 9.7 during July of 1997. However, monthly measurements performed during this time were too infrequent to adequately assess mechanisms impacting the algae during the growth cycle.

Trends in Nitrogen-Phosphorus Ratios

The review of available N/P ratios in the upper Stockton Channel for 1996, 1997 and 2000 indicate that different inputs or mechanisms were operational in 2000. Ratios of available nitrogen to phosphorus suggest that waters near Weber Point were phosphorus limited in 2000, while nitrogen limited conditions appeared to be prevalent during 1996 and 1997. The available N/P ratios for 1996 and 1997 are presented in Figures 34 and 35.

Nutrient data are also available for 1998, however, dissolved orthophosphate was not analyzed, only total phosphorus. In addition, only ammonia, nitrate, and nitrite concentrations were determined, but not total N. Therefore meaningful comparisons of N/P ratios based on either a total or available nutrient basis are not possible with the 1998 data.

Temporal trends for 1996 and 1997

As shown in Figure 34 available N/P ratios during 1996 increase from the San Joaquin River to Weber Point in April and May, but decreased during June and July, and then returned to a neutral or increasing mode in September and October. Similar trends were also observed in 1997 as shown in Figure 35.

This shift from high available N/P ratios in the spring to low ratios during the summer for 1996 and 1997 is unknown. This shift could be associated with changes in algae species (different stoichiometry) and growth phases, or additional inputs of phosphorus in the upper Stockton Channel. Alga stoichiometry could be estimated if total phosphorus and total kjeldahl nitrogen concentrations were measured during 1996 and 1997. Unfortunately this data is not available. For example, measurements performed in 2000 indicate that the mass ratio of N to P for the algae species was approximately 5. This alga composition ratio would result in an increase in the available N/P ratio from the San Joaquin River to Weber Point. However, mass N/P ratios in algae typically range from 5 to 20. An alga N/P composition ratio of 20 would lower the available N/P ratio in the water column. If the alga composition N/P ratio were low during June and July of 1996 or 1997, then additional inputs of phosphorous must have occurred in the upper Stockton Channel. Possible sources are discussed later.

Comparisons with TMDL 2000 data

Table III-5 presents the N/P ratios for available N and P measured during 1996, 1997, and 2000. Nutrient ratios were very different for 1996 and 1997 when compared with the data collected during 2000. As discussed earlier, nitrogen limiting conditions were measured at Weber Point during June and July of 1996 and 1997. An extensive blue-green bloom was observed during 1997, but no records of observations exist for 1996. These data suggest that blue-green algae blooms are associated with conditions in which available nitrogen limits growth. Nitrogen limiting conditions also existed during the summer of 1996, however, chlorophyll *a* or algae specie identification were not performed, so it is difficult to determine whether the blue-green species were present, but extensive mats did not form and no complaints were reported.

As shown in Table III-5, the available N/P ratios for the San Joaquin River range from 4.4 to 13. However, most of these ratios are between 7 and 10. Turning Basin ratios were generally higher than San Joaquin River ratios. One notable exception was the N/P ratio of 3.1 that was measured in the Turning Basin during the blue-green algae bloom of July 1997. The available N/P ratios for 2000 measured in the Stockton Channel were typically quite different than values observed during 1996 and 1997. During 2000, Weber Point available N/P ratios were often 2 to 3 times the San Joaquin River ratios suggesting that the upper Stockton Channel was potentially phosphorus limited. On August 3 and 4, dissolved orthophosphate concentrations were at growth limiting levels.

Table III-5: Available N/P ratios for 1996 and 1997, 2000 water quality data collected by the City of Stockton.

	Sampling Location			
Date	San Joaquin River (R-3)	Turning Basin	East of I-5	Weber Point
Apr 96	8.9	9.6	16.5	17
May 96	5.1	6.0	8.4	8.2
Jun 96	9.2	7.5	5.8	2.3
Jul 96	7.0	13.0	6.6	2.0
Aug 96	4.8	12.5	23.8	11.8
Sep 96	7.1	5.9	9.9	10.0
Oct 96	4.4	6.1	7.2	5.8
Apr 97	9.1	13.0	14.0	17.5
May 97	10.0	10.4	9.3	(0.57 mg/L N, <0.05 mg/L P)
Jun 97	9.2	13.2	(0.18 mg/L N, < 0.05 mg /L P)	(0.07 mg/L N, <0.05 mg/L P)
Jul 97	7.3	3.1	2.0	1.4
Jul 25, 00[2]	8	13	-	14[1]
Aug 1, 00[2]	8	9	-	22[1]
Sep 26, 00[2]	13	11	-	27
Oct 17, 00[2]	12	11	-	30

Note: 1996 and 1997 ratios were calculated from samples collected near the surface. 2000 ratios appearing in this table are determined from mid-depth samples.

[1] Average of top and bottom sample results.

[2] Samples were collected during this week, but not all on the same day.

As shown in Table III-5, the available N/P ratios in the Stockton Channel are considerably lower than the San Joaquin River during June and July of 1996 and 1997. This could be caused by different algae species populating the Stockton Channel. An alternative explanation is that a source of phosphorus (other than from the San Joaquin River) exists that drives the shift in nutrient ratios from phosphorus to nitrogen limiting conditions. Potential sources of phosphorus are from sediment release, storm drain inputs (usually dry weather inflow during summer months), or the release of nutrients from the marina (e.g., illegal discharges from boat wastewater holding tanks or cleaning agents washed into the surface waters). Little evidence exists in support of phosphorus inputs associated with marina discharges based on 2000 data. Bacteriological monitoring by DeltaKeeper during 2000 have shown no contamination around the marina (Jennings, 2000). The potential for dry weather storm drain loads are addressed in the HDR report. Phosphorus releases from the sediments during 1997 are difficult to evaluate because detection limits were too high to quantify whether phosphorus limited growth. It is likely that phosphorus did become limiting, the depletion of which could have triggered a large-scale die off and the formation of the extensive mats reported during the summer of 1997.

Dissolved orthophosphate sediment releases may have been generated under anaerobic conditions induced by low dissolved oxygen in the San Joaquin River. During July of 1997, the DO was measured at only 3.8 near the surface at Station R-3. If circulation from the San Joaquin River entered the Stockton Channel along the bottom (as was observed during 2000) then anaerobic conditions near Weber Point were more likely to occur than if the incoming water were closer to saturation. The measurements performed in 2000 indicate that the DO is often less than 3 mg/L near the sediment-water interface when incoming San Joaquin River water was near saturation. Phosphorus release from sediments increases significantly under anaerobic conditions. Therefore it may be possible that DO conditions in the Stockton Deep Water Ship Channel (DWSC) contribute to phosphorus releases, that in turn promote objectionable algae growth. The causes of the DO deficits in the (DWSC) are currently under investigation as part of the San Joaquin River DO TMDL study. However, extreme DO deficits in the DWSC appear to be associated with low net flow in the San Joaquin River at Stockton.

Temperature also appears to be an important factor influencing the formation of objectionable blue-green algae mats. Table III-6 exhibits near surface temperatures in the Stockton Channel during 1996 and 1997. Near surface temperatures were significantly higher in 1997, the last year in which objectionable algal mats formed. Higher temperatures generally favor blue-green algae populations. As shown in Table III-6, June temperatures were 2 to 3° C warmer in the 1997. It appears that the temperatures in the San Joaquin River influence Stockton Channel temperatures. Cooler temperatures in the San Joaquin River are influenced by upstream releases from reservoirs. Temperatures measured in 1998, a year of extremely high net flows in the San Joaquin River. Flow in the San Joaquin River during June and early July was approximately 7000 cfs compared with 1997 flows, in which the flow typically ranged from 500 to 1000 cfs (Chen, 1999).

Table III-6: Near surface temperatures in the Stockton Channel during 1996 and 1997.

Location	1996	1997
	June / July	June / July
San Joaquin R.	22.0 / 26.0	24.0 / 26.5

Turning Basin	22.5 / 26.0	24.0 / 26.5
East of I-5	23.5 / 26.5	25.5 / 27.0
Weber Point	24.0 / 27.0	27.1 / 27.0

Water temperatures for June, July, and August, 2000 are presented in Table III-7. San Joaquin River and Turning Basin temperatures for 2000 were often as high or higher than 1997 temperatures for June and July. However, during early July, San Joaquin River temperatures cooled down about 2° C, followed by high temperatures in late July and early August. Late July and early August temperatures at Weber Point were similar or exceeded measurements recorded in 1997. Objectionable blue-green algal mats were not observed in 2000 as they were in 1997, even though water temperatures were similar. As discussed earlier, it appears that phosphorus limited conditions inhibited phytoplankton productivity during 2000. In 1997, the Stockton Channel waters appears to first be nitrogen limited.

Table III-7: Near surface San Joaquin River, Turning Basin, and Stockton Channel water temperatures (° C), June and July, 2000.

Location	6/20	6/27	7/11	7/18	7/25	8/1	8/8
San Joaquin River	25.0	26.0	23.5	24.5	25.0	27.0	26.0
Turning Basin	25.0	26.5	24.0	24.5	25.0	26.5	25.5
Weber Point[1]					27.1[2]	28.9	

[1] Temperature averaged over 24-hr.

[2] Measured on 7/27.

During the summer of 1998 nitrate concentrations were measured below a detection limit of 0.2 mg/L suggesting that nitrogen limiting conditions may have existing in 1998. However, dissolved orthophosphate was not measured, so available N/P ratios are unknown. Blue-green blooms were not reported for 1998. The water quality data for 2000 indicate that the upper Stockton Channel would be phosphorus limited. Samples collected on August 3-4 suggest that algal growth was inhibited by available phosphorus concentrations of approximately 0.10 mg/L. Thus, the water quality data for 1996 to 1998 indicate the upper Stockton Channel was nitrogen limited during the summer. Of these three years, blue-green blooms were only reported for 1997. This was the only year in which available data indicated that nitrogen levels were apparently low enough to inhibit algal grow, except for blue-green algae capable of nitrogen fixation. The high available N/P ratios measured during 2000 contradict prior observations.

IV. Conclusions and Recommendations

Summary of observations

Circulation of water within the Stockton Channel facilitates the transport of water from the San Joaquin River containing high concentrations of phosphorus and nitrogen in forms available for algal growth. The San Joaquin River appears to be the dominant source of nutrients entering the upper Stockton Channel. However, algal uptake can deplete near-surface nutrient concentrations to growth inhibiting levels in the Stockton Channel east of Interstate 5. This condition was observed in 1997 and 2000. It may also have occurred when nitrate-nitrogen was measured near grow-limiting concentrations during 1996 and 1998. Once nutrient concentrations begin to limit growth, then other sources (e.g., sediment or storm drain inputs) may become significant enough to support the development of objectionable blue-green algae blooms. The last observed blue-green algae bloom occurred in the summer of 1997. Available nitrogen concentrations became limiting for algae species incapable of fixing nitrogen generating favorable conditions for blue-green algae.

Based on existing data, objectionable blue-green blooms appear to be correlated to the available nitrogen-phosphorus ratio. Low N/P ratios indicate that the water is nitrogen limited, a condition that favors blue-green algae capable of fixing nitrogen. Monitoring this ratio in the upper Stockton Channel may serve as indicator of future objectionable blue-green blooms. During 1996 and 1997, available N/P ratios measured at Weber Point were generally observed to be higher than San Joaquin River N/P ratios early in the season. By June and July the available N/P ratios were well below San Joaquin River ratios. During September and October higher available N/P ratios were observed again. Thus decreasing N/P ratios in the Stockton Channel may serve as an early indication that objectionable blue-green blooms may develop.

However, low available N/P ratios can not alone predict future objectionable blue-green blooms and mat formation. For example low available N/P ratios were measured in 1996 and probably also in 1998, but nutrient concentrations appeared to remain above limiting conditions and algal mats were not observed during those years. High water temperature and solar radiation also seem to play a role (Chen, 1999) as these conditions are necessary to simulate growth to levels sufficient to deplete available nitrogen and phosphorus in the upper water column. Blue-green algal scums or mats consist of cells that are rarely viable suggesting that objectionable mat formation occurs when highly concentrated populations rapidly die off. The algal mats that were observed in 1997 appear to have been caused by the depletion of available phosphorus in the upper water column. During June and July of 1997 available phosphorus concentrations were measured below a detection limit of 0.05 mg/L. However, this detection limit is too high to be confident that phosphorus concentrations did in fact become limiting. Other factors such as extreme pH or dissolved oxygen concentrations can also inhibit blue-green growth.

The available N/P ratio in the San Joaquin River at channel point is often between 7 and 10. During the summers of 1996, 1997 and 1998 available N/P ratios in the upper Stockton Channel decreased to approximately 2. This low ratio indicates the waters were potentially nitrogen limiting. Available nitrogen concentrations did reach limiting concentrations during June and July of 1997. Monitoring performed during the summer of 2000 yielded N/P ratios of 14 to 22, suggesting that the upper Stockton Channel was potentially phosphorus limited. On August 3, 2000 dissolved orthophosphate concentrations were measured near the surface at or below 0.01 mg/L, a concentration low enough to limit algal growth. The monitoring performed during these years is insufficient to determine the cause of this shift.

The factors that influence the available N/P ratio in the upper Stockton Channel include alga stoichiometry and nutrient inputs. Mass ratios of nitrogen to phosphorus measured in algae vary from approximately 5 to 20. Therefore, if the upper channel is populated with an alga species with a N/P ratio of 5, the algae will use 5 times more nitrogen than phosphorus for growth. If the source water (i.e., San Joaquin River) has an available N/P ratio of 10, this species will increase the available N/P ratio in the water column yielding water that is potentially phosphorus limited. The alga N/P ratio was estimated to be approximately 5 using data collected in 2000. This ratio is consistent with the phosphorus-limited condition measured in 2000. Unfortunately, the data for 1996-1998 is insufficient to estimate the N/P ratio of the algae populating the channel during those years. If a different algae species populated the channel with a N/P ratio of 20 to 1 during 1996-1998, this could explain the nitrogen limited condition observed at those times. Algae populations follow a succession throughout the year that is determined by environmental conditions including temperature, light, and nutrient availability. A review of the available N/P ratio in the upper Stockton Channel for 1996 from April to October indicates the waters were initially potentially phosphorus limited in April, then shifting to nitrogen limiting in June and July, and then back to phosphorus limiting in September and October. These transitions suggest a succession of different algae species exhibiting seasonal dominance.

An alternative explanation for the low N/P ratios observed in 1996-1998 could be associated with high phosphorus inputs. This would decrease the available N/P ratio in the upper Stockton Channel. Probable sources include releases from sediments, discharges from storm drains, and illegal dumping of domestic wastes from boats. Water column measurements for 2000 indicate that dissolved orthophosphate can be significantly higher near the sediment-water interface. This is caused by the release of phosphorus from sediments, resuspension of sediment due to tidal flows, waves, or benthic organisms, and the inflow of nutrient rich water from the San Joaquin River that was observed to enter along the bottom of the channel.

The release of phosphorus from the sediments can be accelerated if the water overlying the sediment becomes anaerobic or if the pH becomes elevated under aerobic conditions. Estimates of the phosphorus flux from the sediments suggests that the input is typically small compared to the input from the San Joaquin River. However, under anaerobic or high pH conditions, the releases from the sediment could be important. The data for 1996-1998 are insufficient to evaluate whether phosphorus releases contributed to the nitrogen limiting conditions observed for those years. The relatively high concentrations of dissolved orthophosphate in the upper water column (mid or near-bottom samples were not collected), measured during 1996 suggests that additional inputs of phosphorus could have contributed substantially to the nutrient budget. During July, 1997 low DO concentrations were observed in the Stockton Deep Water Ship Channel at the confluence of the Stockton Channel and the San Joaquin River (site R-3). Since this water serves as the source of circulation within the Stockton Channel, and the water enters the Stockton channel near the sediment-water interface, low DO in the DWSC could lead to anoxic conditions near Weber Point and high releases of dissolved orthophosphate. The causes of low DO in the DWSC are currently under investigation, but data and modeling simulations suggest that DO deficits are associated with low flows. The flow in the San Joaquin River is largely controlled by reservoir releases. San Joaquin River temperatures are influenced by the flow regime, which in turn affect Stockton Channel temperatures.

Discharges from the storm drains are also a potential source, however, non-point sources are often high in nitrogen relative to phosphorus. This was substantiated with the 2000 monitoring, but no storm water measurements were performed from 1996 to 1998. Illegal releases of domestic sewage from boats are difficult to quantify, but these inputs are expected to be small relative to other sources. Monitoring performed in 2000 failed to provide evidence of illegal discharges near the marina and bacteriological measurements performed by DeltaKeeper in this area also exhibited little indication of contamination.

The high dissolved orthophosphate concentrations near the bottom of the Stockton Channel could adversely impact the effectiveness of some control measures that have been used historically to control blue-green algae blooms. Methods that disrupt stratification would increase circulation and the transport of nutrient rich bottom water to potentially nutrient limited surface waters. On August 3, 2000, phosphorus concentrations in the upper water column were approximately 0.01 mg/L while near- bottom concentrations were 10 times as high. Providing nutrients to the surface could have promoted more algal growth. Circulation could also increase the release of phosphorus from the sediments by raising the pH of overlying water. Vigorous photosynthesis in the upper Stockton Channel has been shown to yield pH values as high as 9.8 near the water surface. A massive blue-green bloom is thought to have been triggered in the Potomac Estuary by phosphorus released from sediments when the pH of overlying aerobic water increased (Di Toro and Fitzpatrick, 1984).

Based on extant data, it is not possible to predict with certainty all the factors influencing euthrophication processes in the upper Stockton Channel. Additional measurements are necessary to develop the knowledge necessary to predict and effectively manage blue-green algal productivity. Although objectionable blue-green blooms appear to be associated with declines in the available N/P ratio at Weber Point, the mechanisms that control the extent of a bloom is uncertain. It is recommended that additional monitoring be included with the implementation of a selected control measure.

Future water quality monitoring

Future water quality monitoring is necessary to better understand the mechanisms that control blue-green algal bloom and mat formation in the Stockton Channel. The following suggested program is based on the insight of past observations and the need to fill critical gaps in the data. This plan represents the minimum monitoring that should be conducted. However, it is expensive and it may be necessary to perform this monitoring over several years. It is also recommended that a limnologist be retained to review this monitoring plan and participate in future studies. Once a better understanding of the euthrophication processes are known it may be possible to reduce the monitoring to a few critical locations and times. The plan contains a regular monitoring schedule and provisions special monitoring when nutrient levels approach limiting conditions or algae concentrations become objectionable.

Installation of a continuous monitoring station near Weber Point that measures chlorophyll *a*, pH, dissolved oxygen and electrical conductivity at the surface should be seriously considered. In addition to these parameters, water temperature should be measured at a minimum of three depths as well as air temperature and wind speed. Data obtained from this station would be used to schedule the nutrient monitoring. However, it would still be important to conduct monitoring prior to the development of limited nutrient conditions or the formation of objectionable algae mats in order to develop predictive capabilities. With a continuous station, it may be possible to reduce the monitoring frequency outlined below.

Regular monitoring schedule

I. Water column monitoring.

A. Frequency and time of day:

Water quality data should be collected at least once every two weeks starting on May 1 and continuing until the end of September. It may be possible to reduce this frequency to monthly sampling later in the season. Ideally samples should be collected during the afternoon, however, laboratory delivery schedules and sampling hold times may necessitate late morning monitoring.

With the onset of hot weather, discrete water samples should also be collected prior to and throughout day light hours for two days. This data would be used to estimate algal growth rates before nutrients become limited. Near-surface and near-sediment samples should be collected.

B. Constituents

1. Field measurements
    a. Water column profiles
        i. Temperature
        ii. pH
        iii. Dissolved oxygen
        iv. Specific conductance
        v. Turbidity

    b. Miscellaneous
        i. Secchi depth

2. Nutrients
    a. Nitrogen series: ammonia, nitrate+nitrite, total kjeldahl nitrogen. (maximum allowable detection limit: 0.1 mg/L as N)

    b. Phosphorus series: dissolved orthophosphate, total phosphorus (maximum allowable detection limit: 0.01 mg/L as P)

    Due to long processing times required of commercial laboratories, the surface samples collected at Weber Point and East of I-5 stations should be analyzed in house by City of Stockton personnel (or on a rush basis with a contract laboratory) to evaluate whether nutrient limiting conditions exist and Special Monitoring (see below) is required.

  3. Phytoplankton
    a. Chlorophyll *a* and pheophytin *a*
    b. Species identification and estimate of mass fraction

B. Locations
  1. Weber Point
  2. East of I-5 Bridge
  3. Turning Basin
  4. San Joaquin River (R-3)

C. Depths

  1. Water column profiles: continuous or 0.5 m interval depending on available equipment. The near surface measurement should be collected below the surface, but within 10 cm of the surface.

  2. Nutrients
    a. 2 feet below surface
    b. Mid-depth
    c. 2- feet above sediment

  3. Chlorophyll *a*
    a. 2 feet below surface
    b. Mid-depth

  4. Species identification (perform monthly)
    a. 2 feet below surface at all locations
    b. Mid-depth at 2 locations

II. Sediment nutrient release monitoring

A. Water column profiling near sediment-water interface (attempt 2 more times under typical summer conditions.

B. Sediment chamber or core measurements

    1. Monitor dissolved orthophosphate, ammonia and nitrogen vs. time in an enclosed chamber or core apparatus.
    2. Conduct tests at 3 locations, once each month, unless variability warrants adding locations and increasing the frequency.

  C. Perform the regular water column monitoring on days with extreme winds to evaluate the potential for sediment and nutrient resuspension and water column mixing.

III. Storm water impacts

Estimating storm water loads is problematic due to limited access to storm drains, tidal influence, and inherent variability of non-point sources.

  A. Perform the regular water column monitoring immediately after significant storms between May and September.

  B. Additional sampling should be considered for the three storm drains entering the McLeod Lake.

<u>Special monitoring</u>

Additional monitoring should be conducted when nutrient concentrations approach limiting levels or objectionable algae conditions appear. The actual plan should be tailored to existing data. However, the following activities are envisioned:

1. Increase regular water column monitoring to a weekly frequency. Samples of the algae mats should be sampled for identification since some blue-green species can not fix nitrogen.

2. Perform sediment nutrient release experiments (near surface nutrient profiles or chamber/core methods).

3. When limited nutrient conditions exist, at least one 24-hr monitoring should be conducted near Weber Point to evaluate whether algal growth is in fact limited or whether nutrient transport to the euphotic zone is sufficient to sustain high growth rates. Automatic samplers collecting discrete water samples at a 2-hr interval during the day (less frequent during the night) would be sufficient. Near surface and near sediment samples should be collected.

V. References

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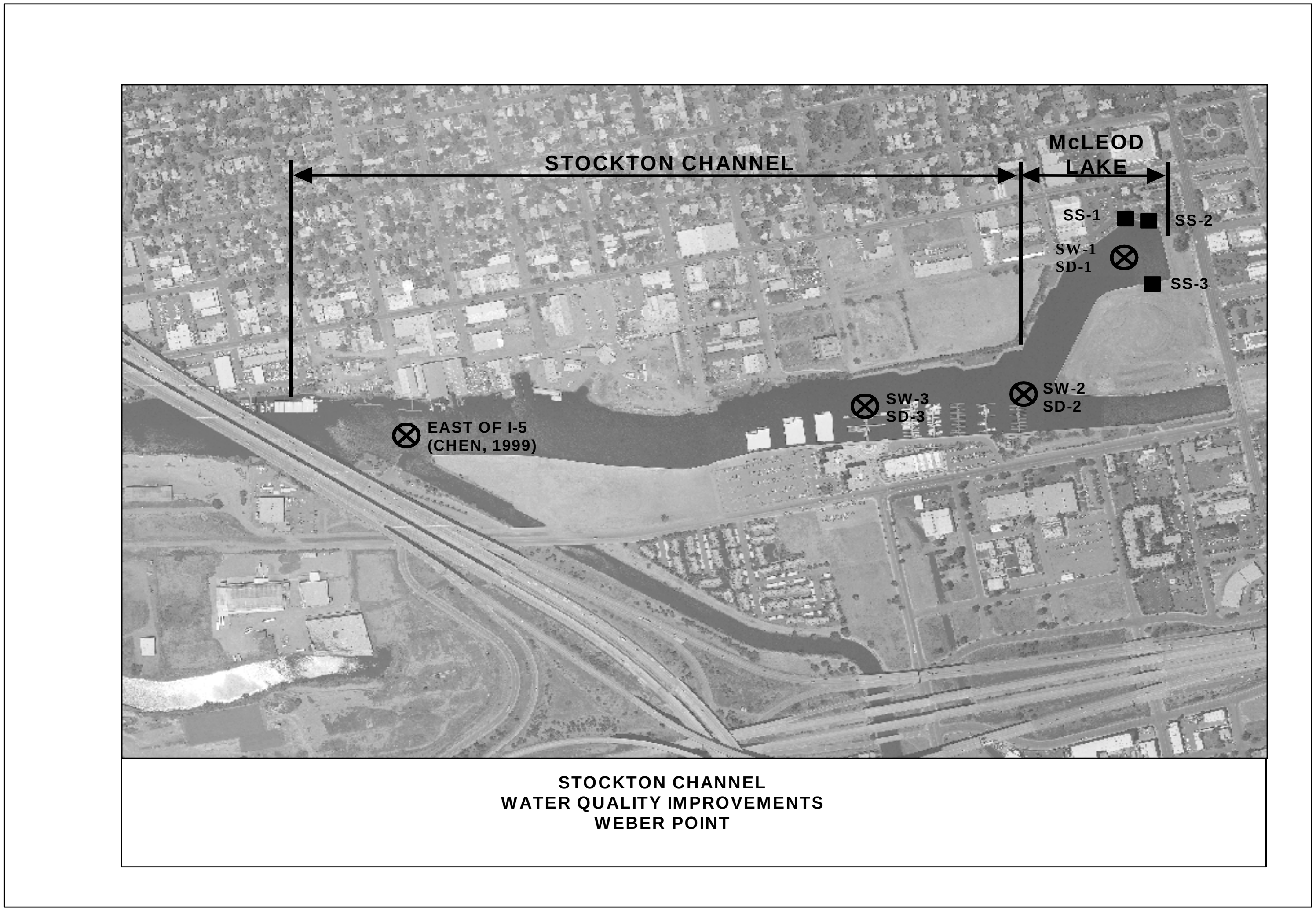

Figure 1: Sampling locations in the upper Stockton Channel.

Figure 2

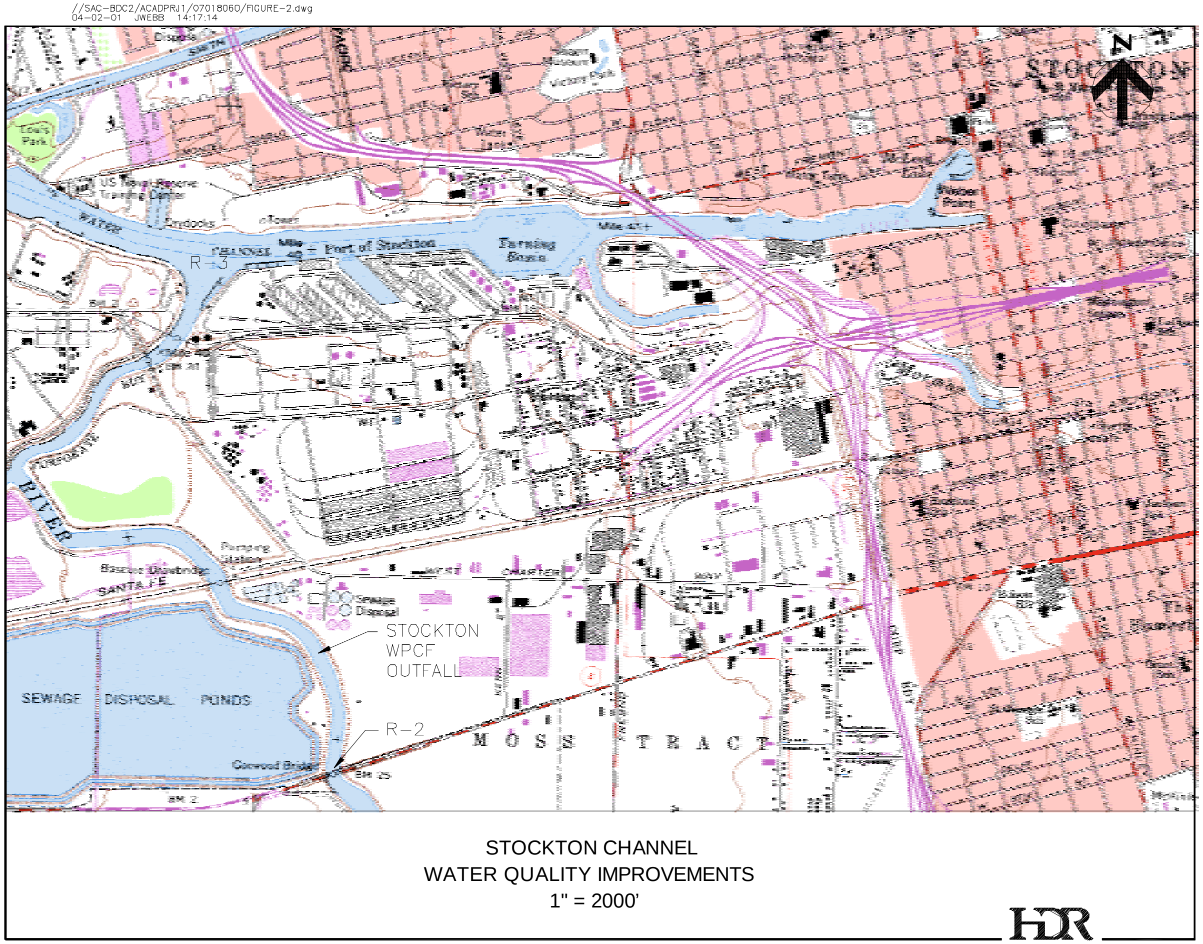

Figure 2: Sampling locations for the TMDL 2000 monitoring and the 1996-1998 City of Stockton monitoring.

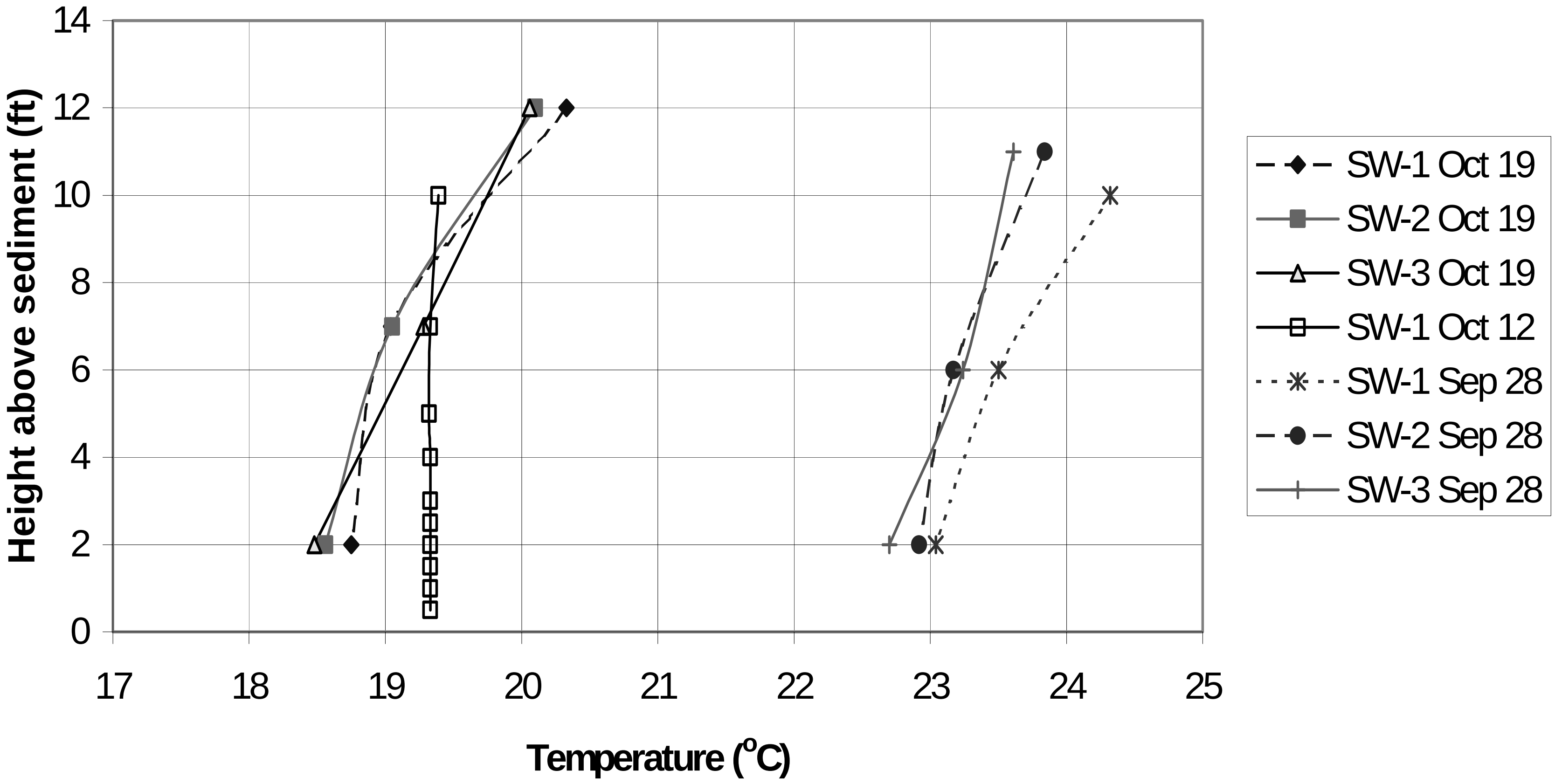

Figure 3: Temperature profiles in the upper Stockton Channel.

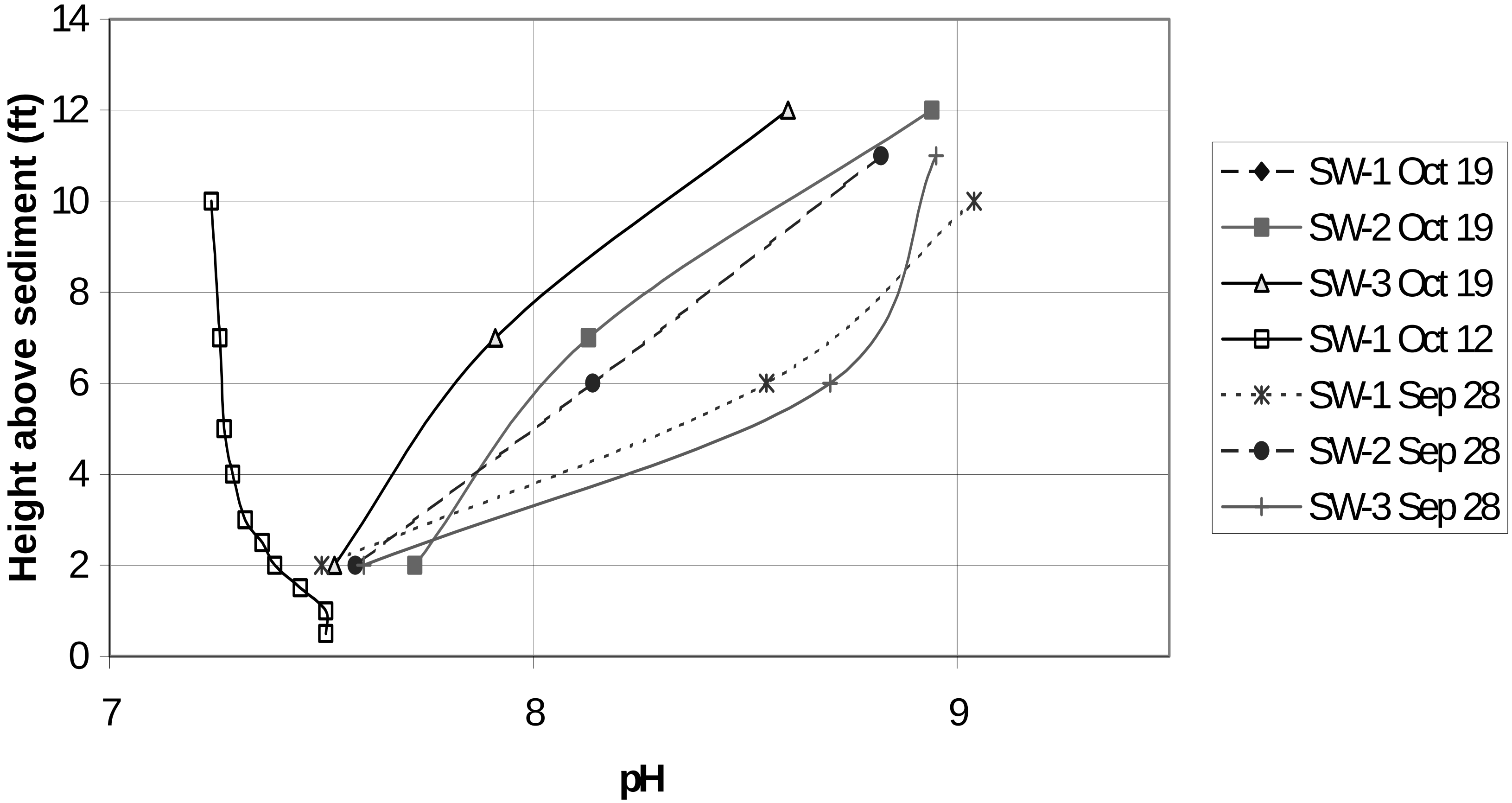

Figure 4: Upper Stockton Channel pH profiles.

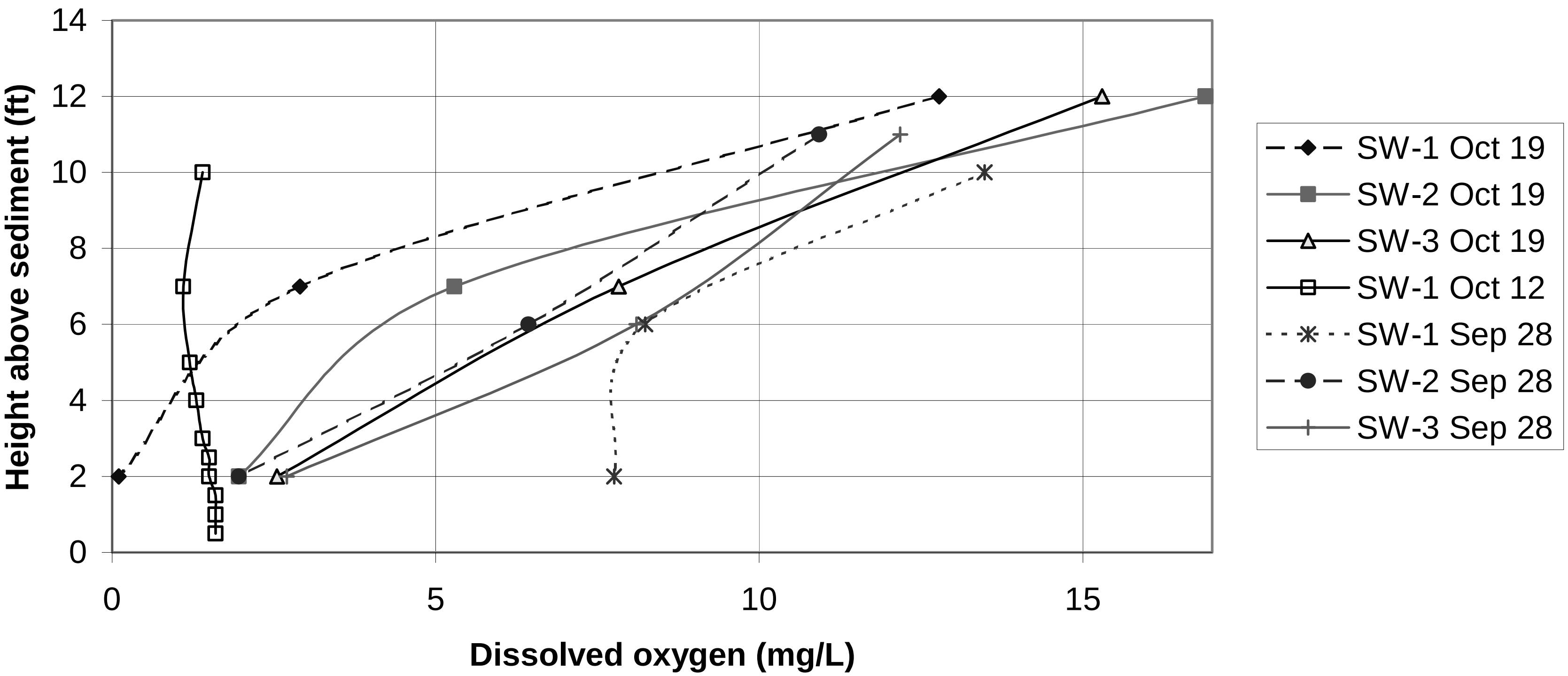

Figure 5: Dissolved oxygen profiles in the upper Stockton Channel.

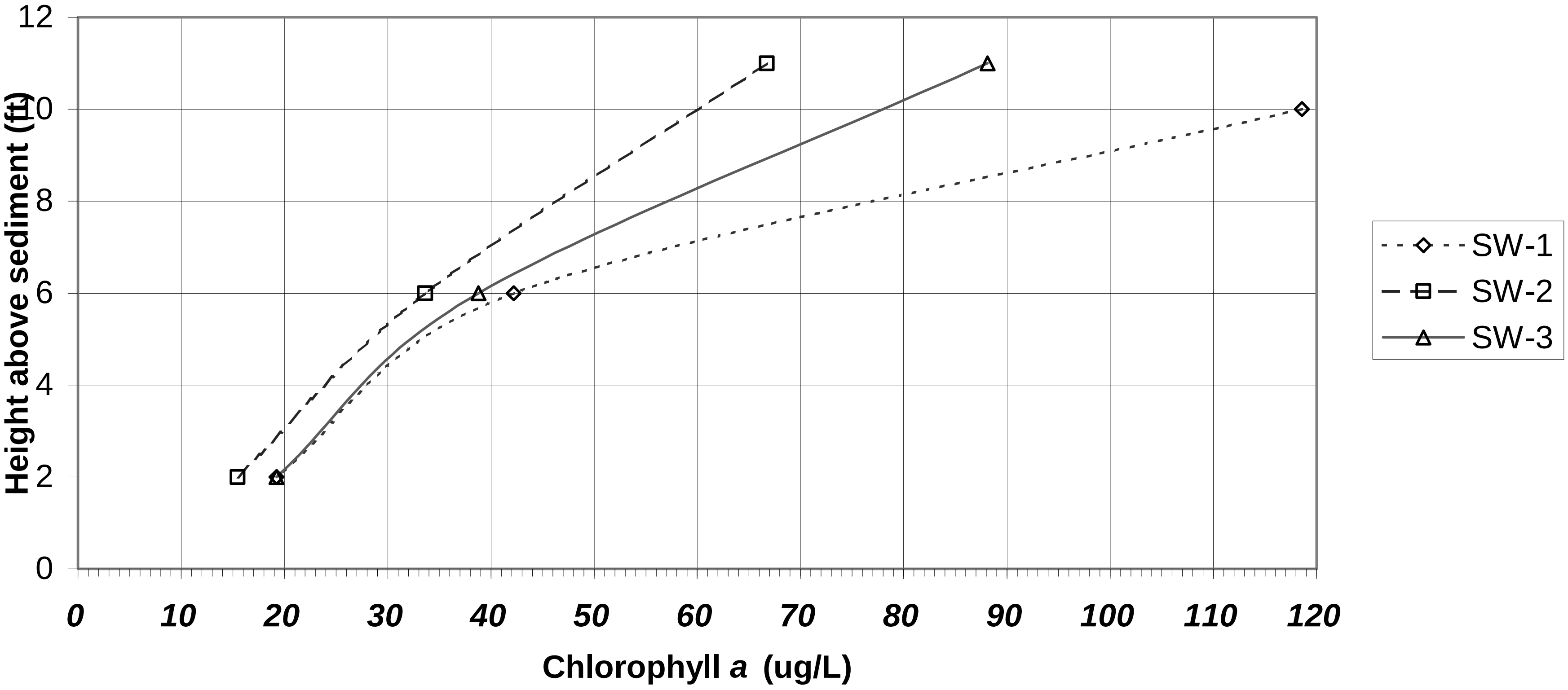

Figure 6: Chlorophyll *a* concentration profiles in the upper Stockton Channel.

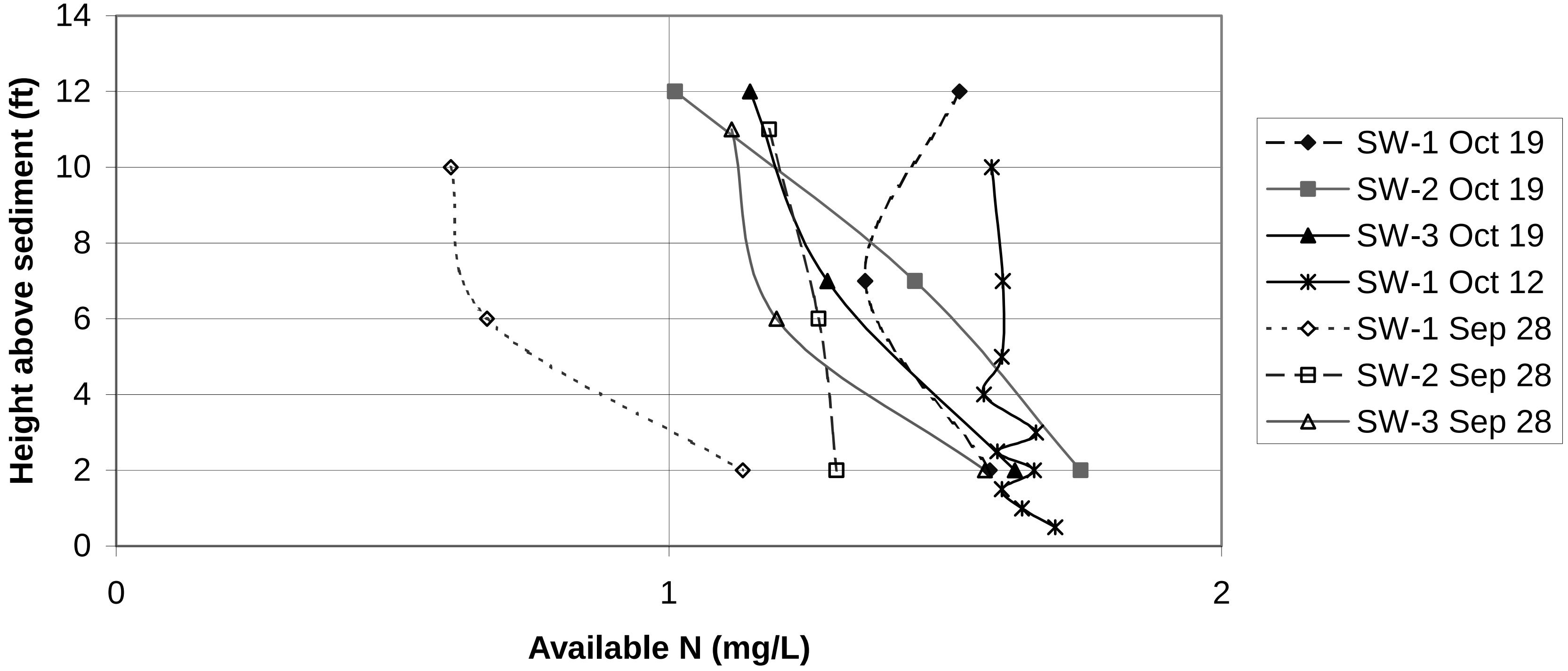

Figure 7: Available nitrogen profiles in the upper Stockton Channel.

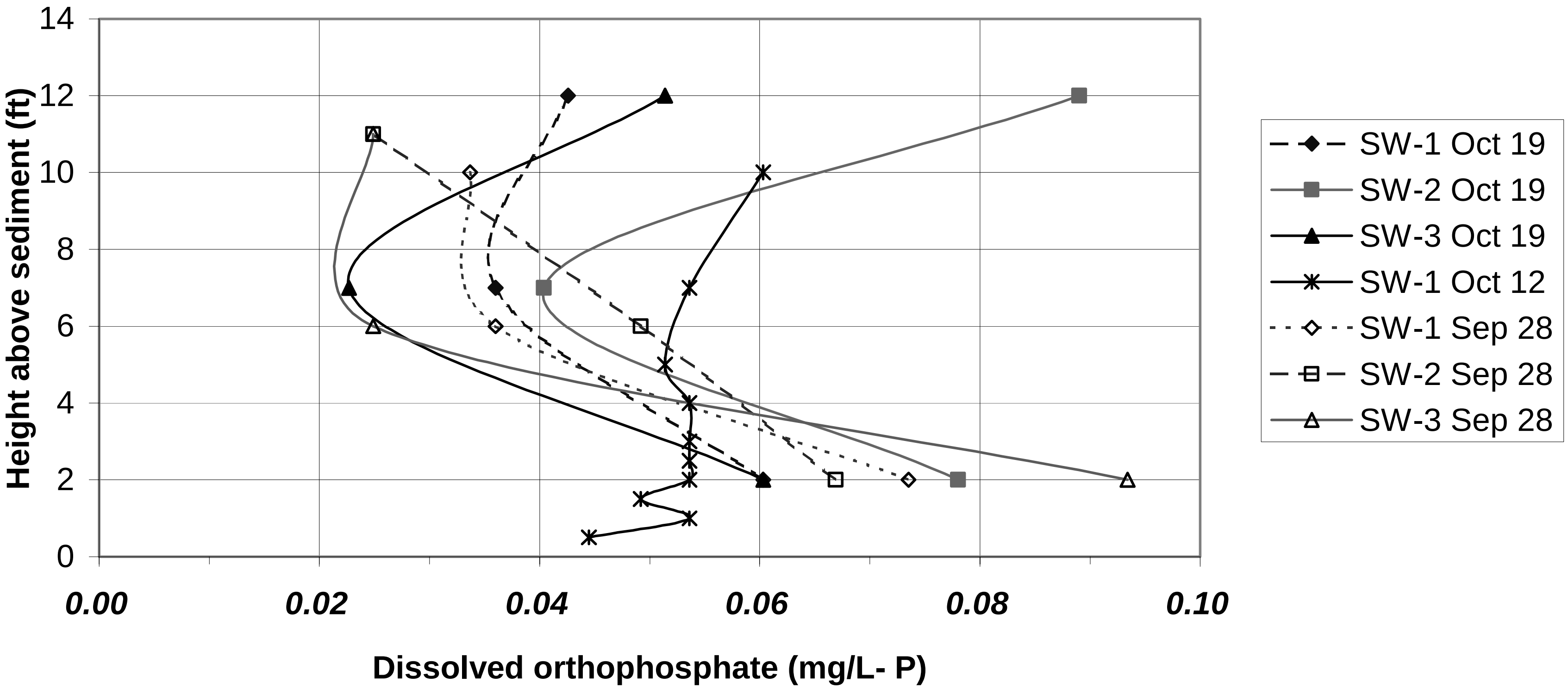

Figure 8: Dissolved orthophosphate profiles in the upper Stockton Channel.

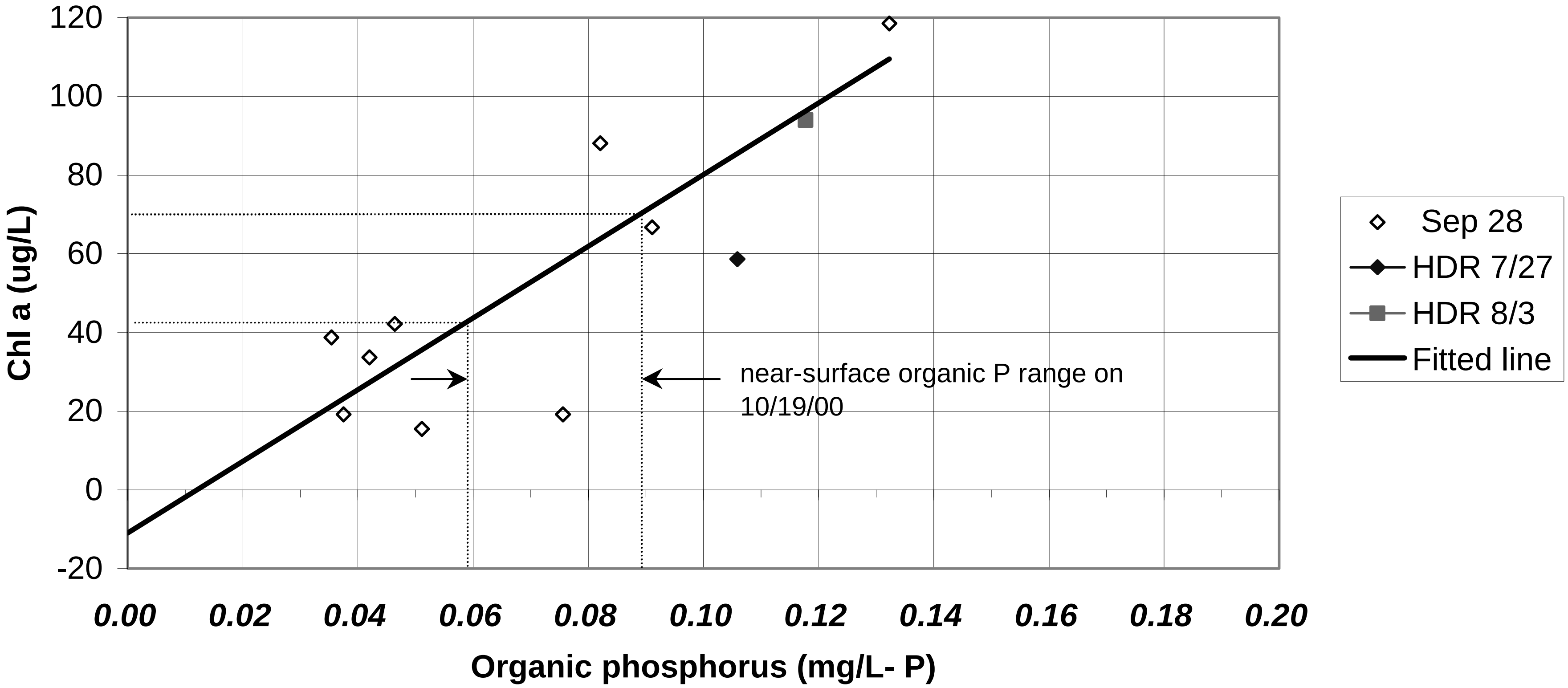

Figure 9: Correlation of Chlorophyll *a* with organic phosphorus in the upper Stockton Channel.

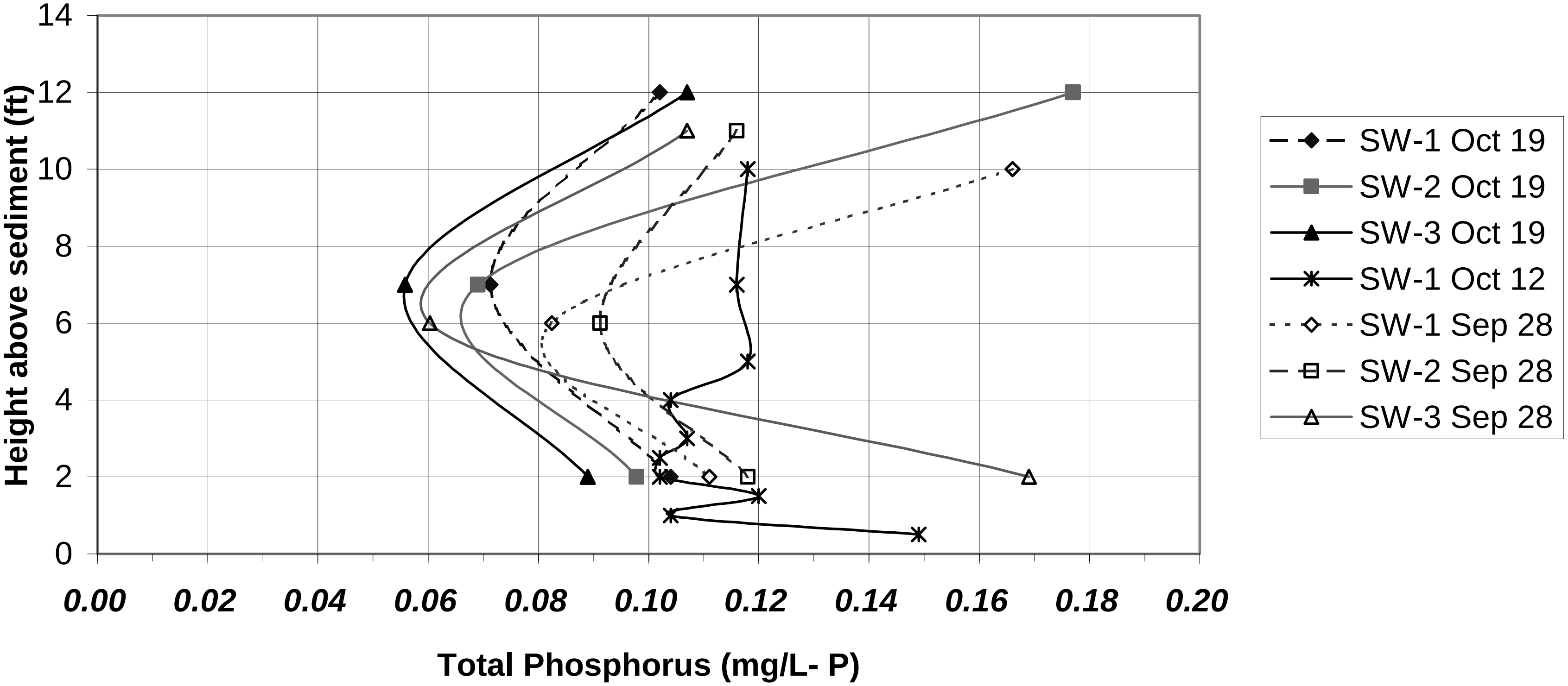

Figure 10: Total phosphorus profiles in the upper Stockton Channel.

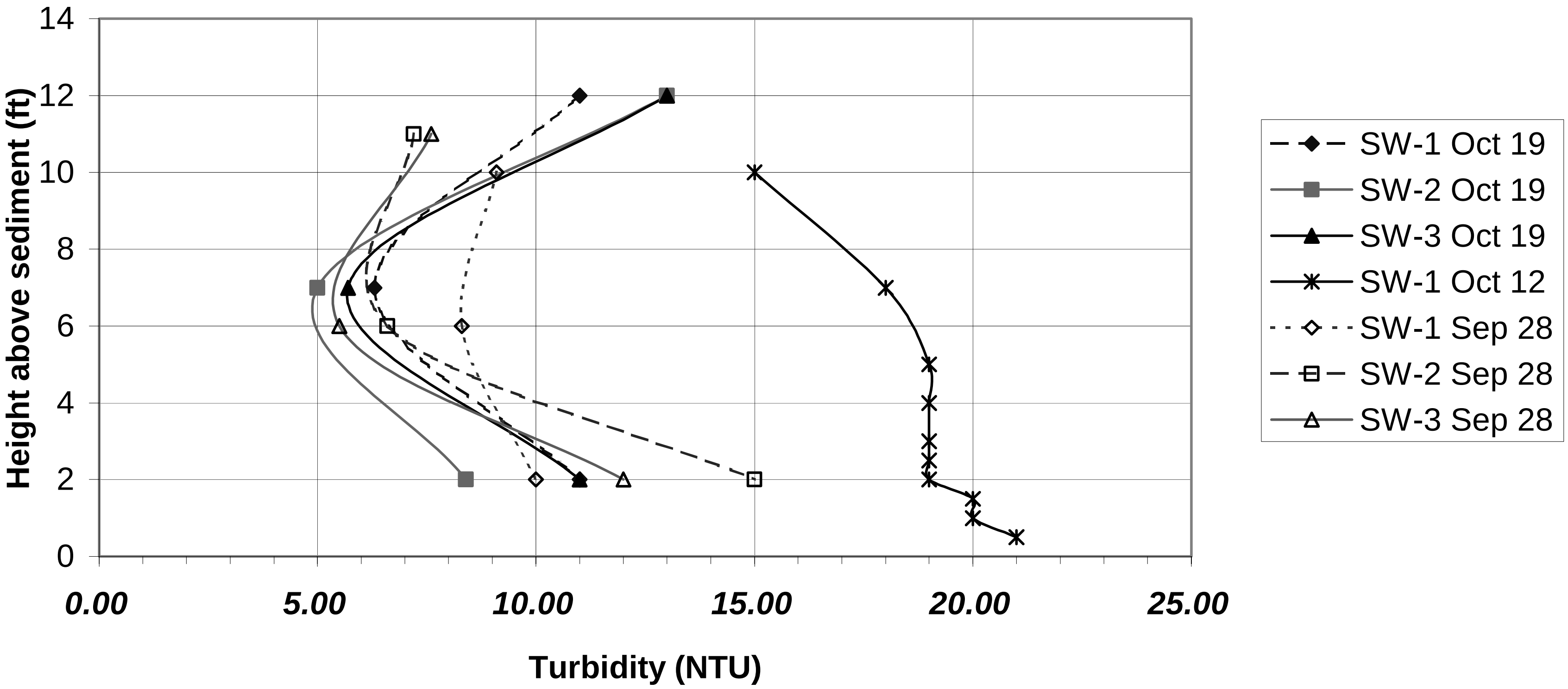

Figure 11: Turbidity profiles in the upper Stockton Channel.

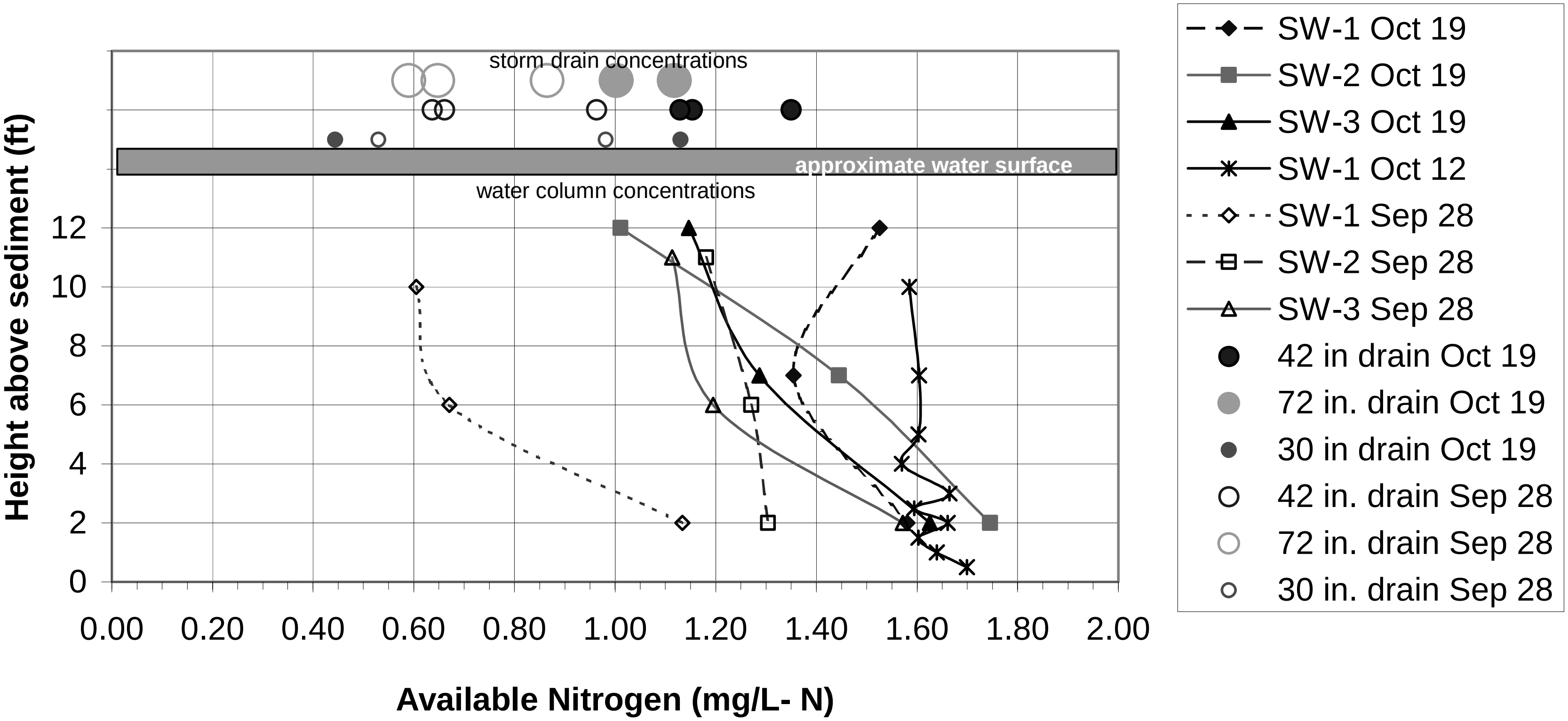

Figure 12: Comparison of storm drain and water column available nitrogen concentrations.

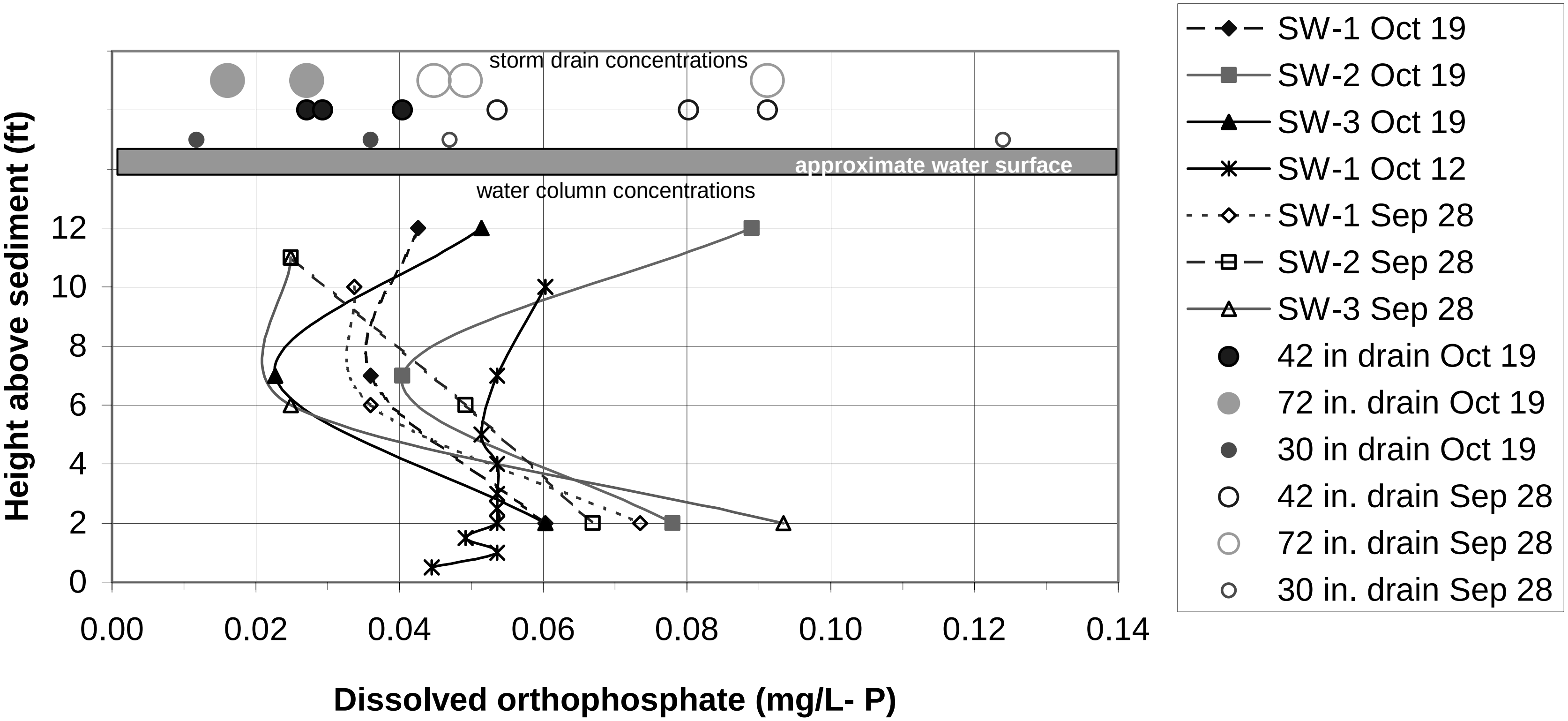

Figure 13: Comparison of storm drain and water column dissolved orthophosphate concentrations.

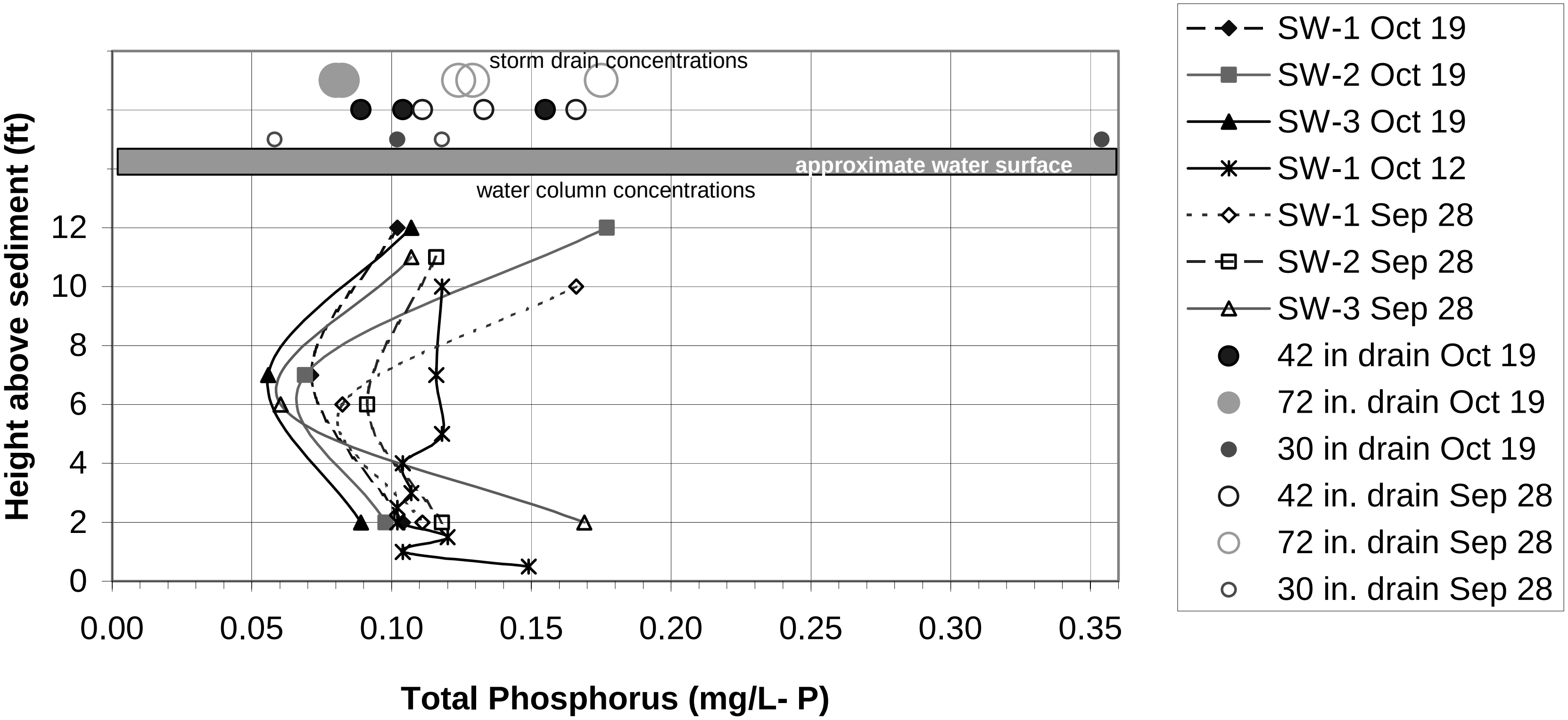

Figure 14: Comparisons of storm drain and water column total phosphorus concentrations.

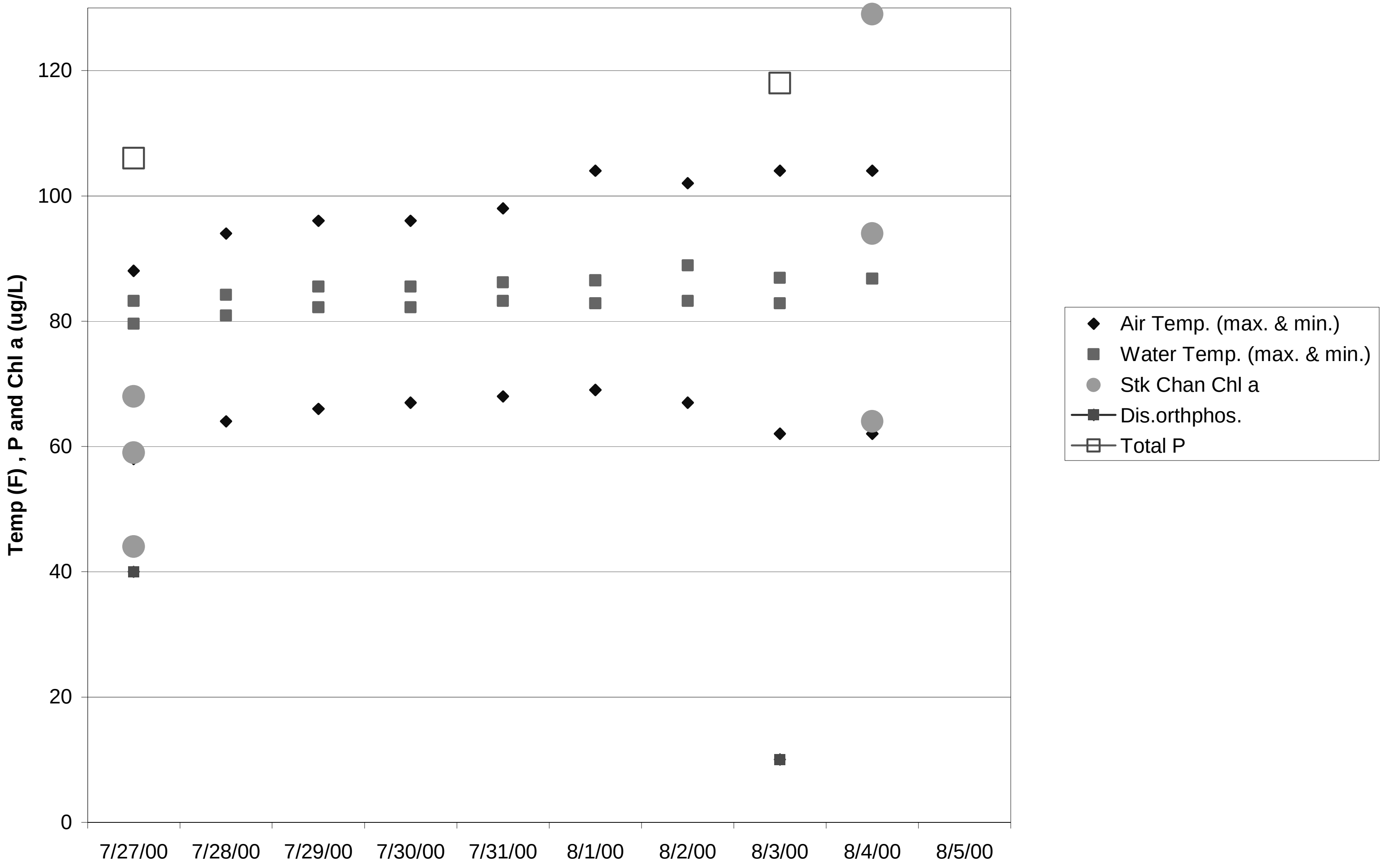

Figure 15: **Changes in chlorophyll *a*, nutrient concentrations, and air and water temperatures from September 27 to August 4, 2000.**

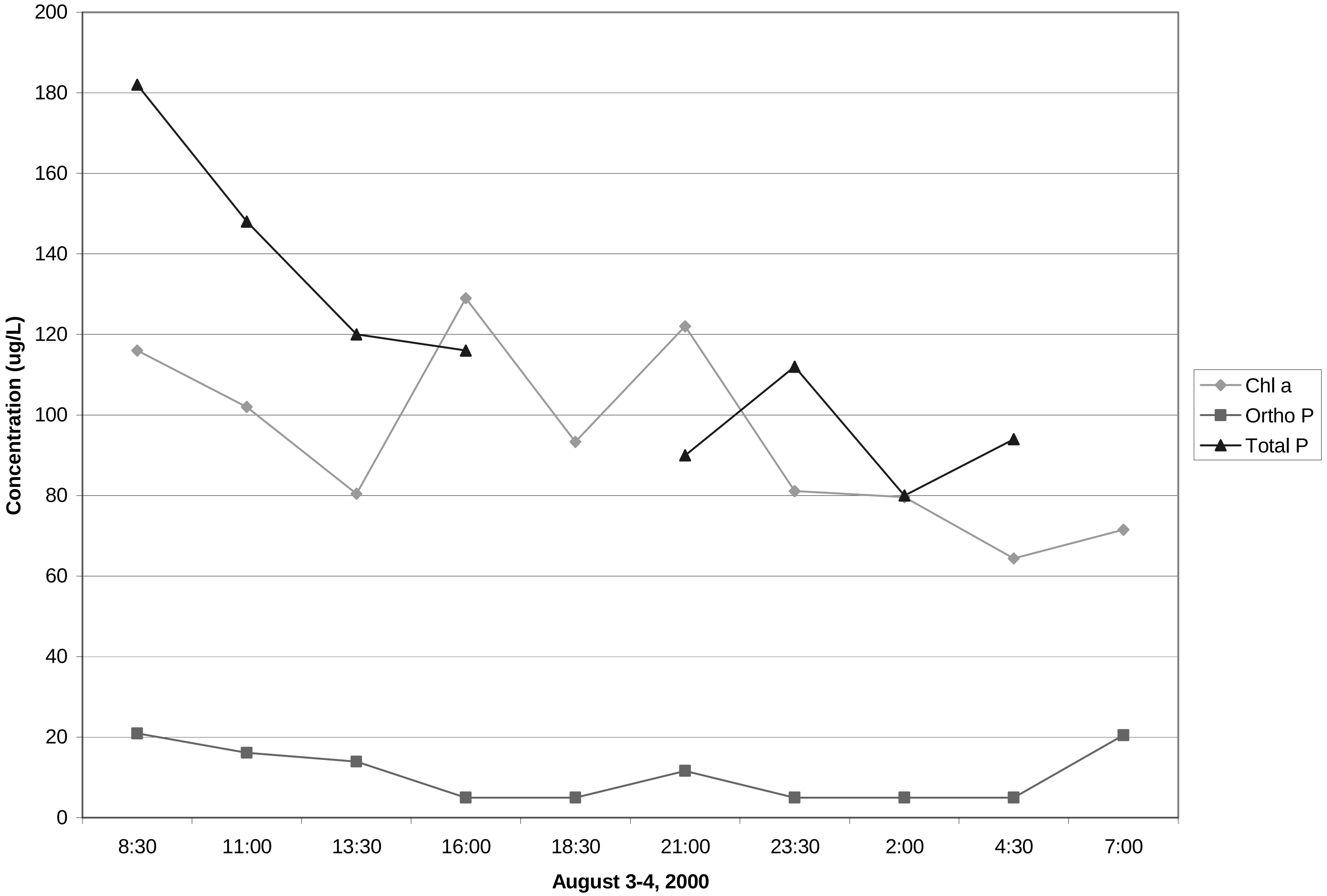

Figure 16: Near-surface chlorophyll *a* and phosphorus concentrations on August 3 and 4, 2000 at Weber Point.

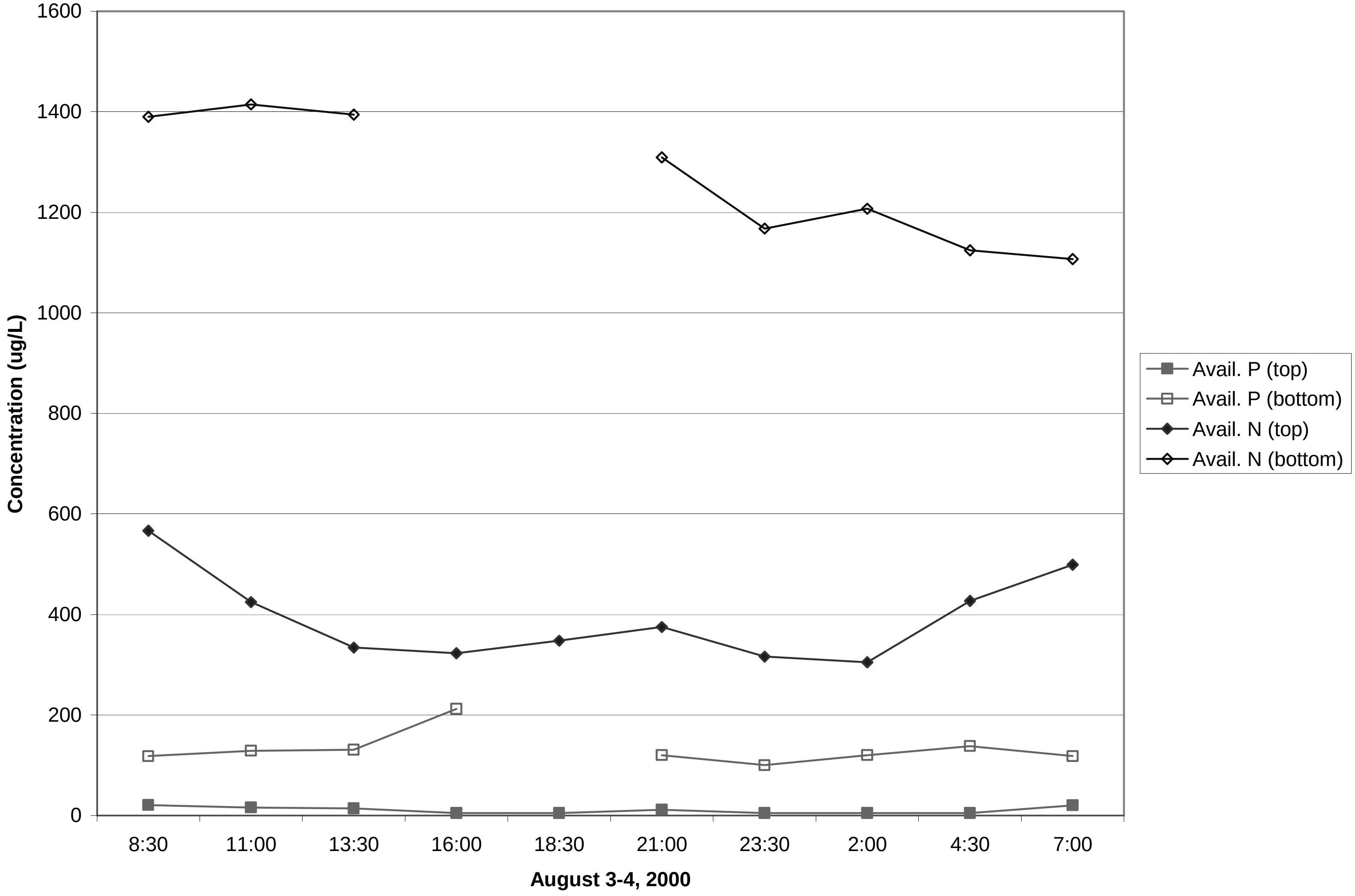

Figure 17: Near-surface and near-bottom available nutrient concentrations on August 3-4, 2000 at Weber Point.

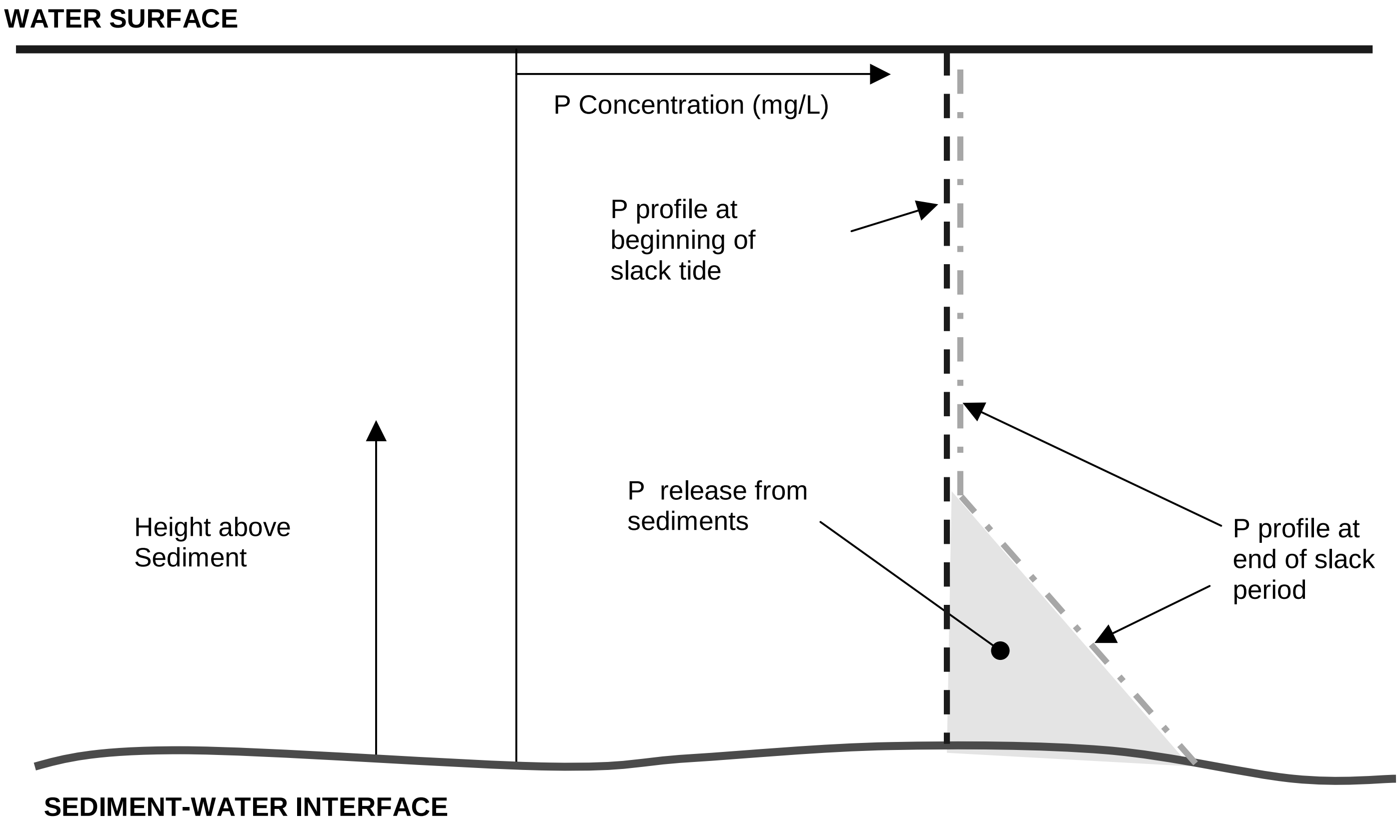

Figure 18: Hypothetical dissolved phosphate profiles at the beginning and end of a slack tide period.

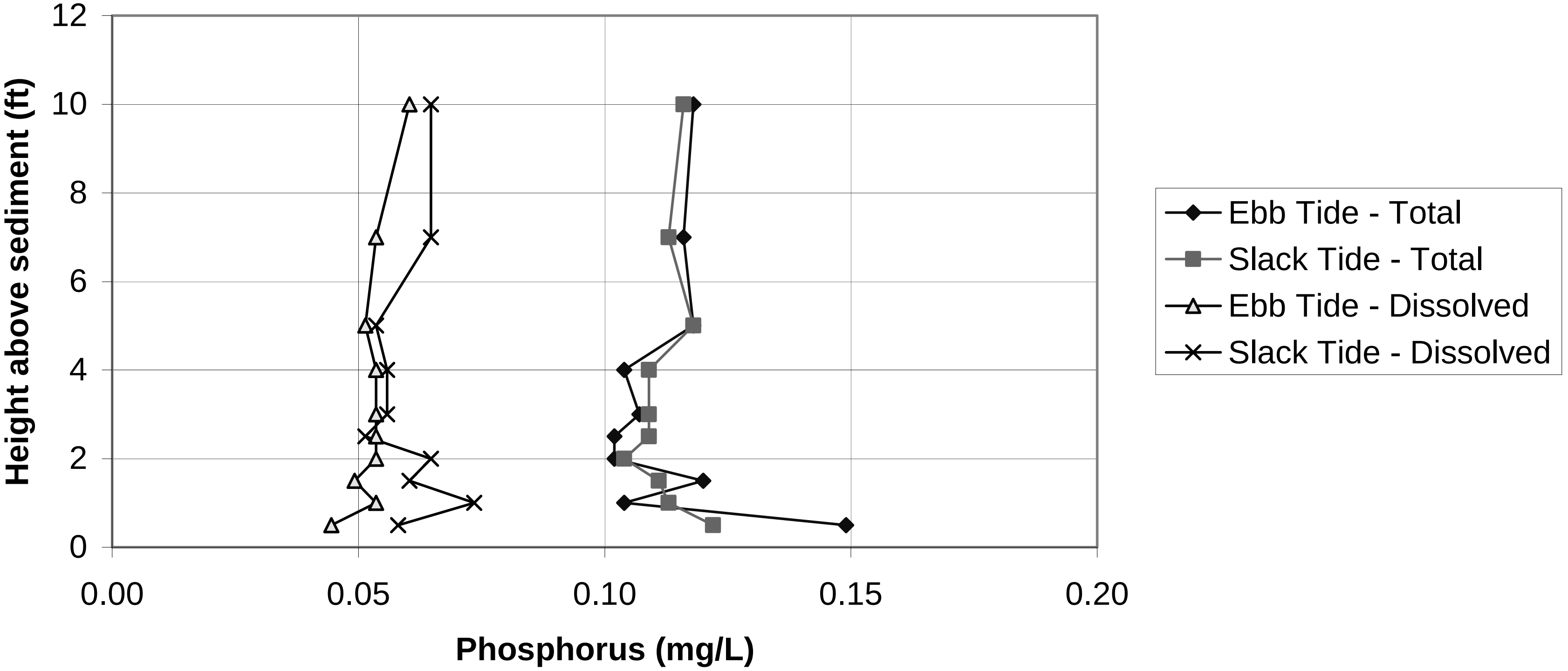

Figure 19: Dissolved orthophosphate and total phosphorus profiles in McLeod Lake on October 12, 2001.

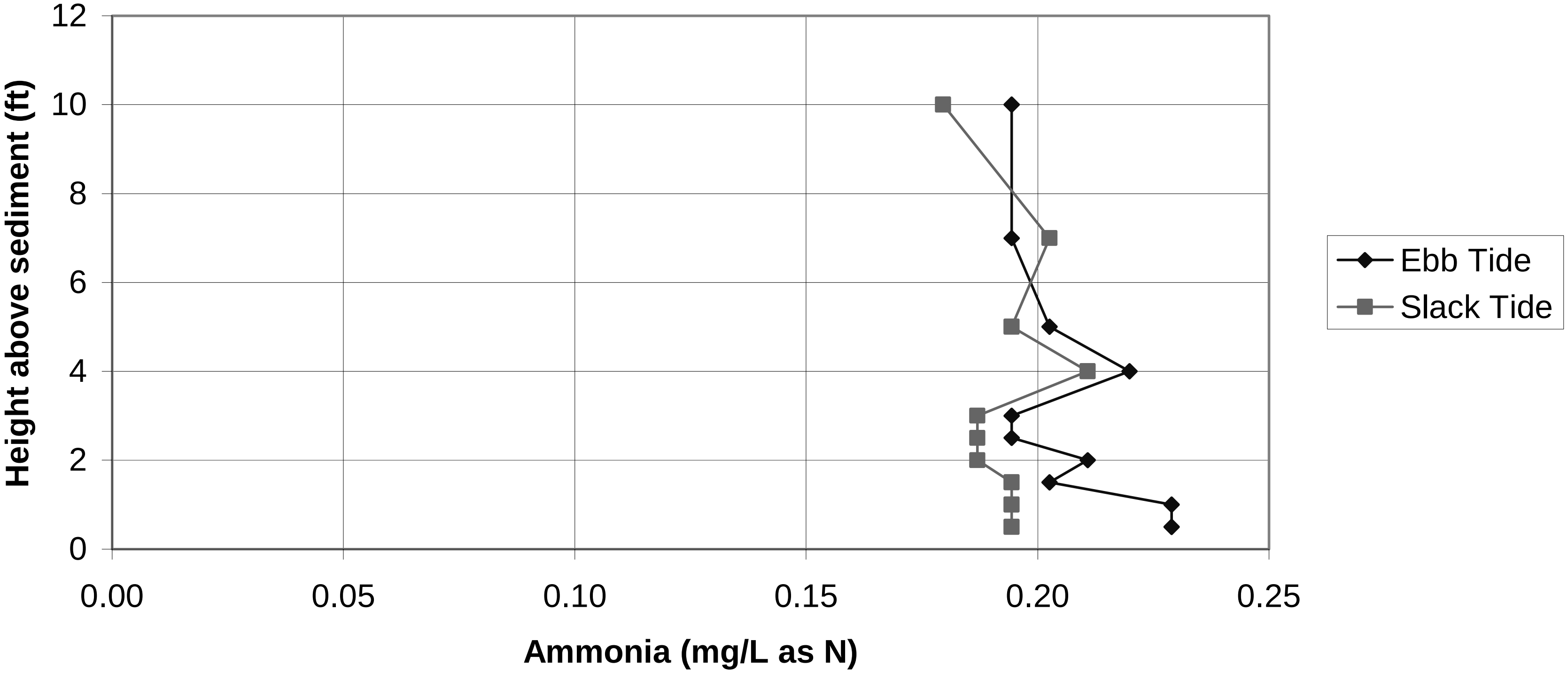

Figure 20: Ammonia profiles in McLeod Lake on October 12, 2001.

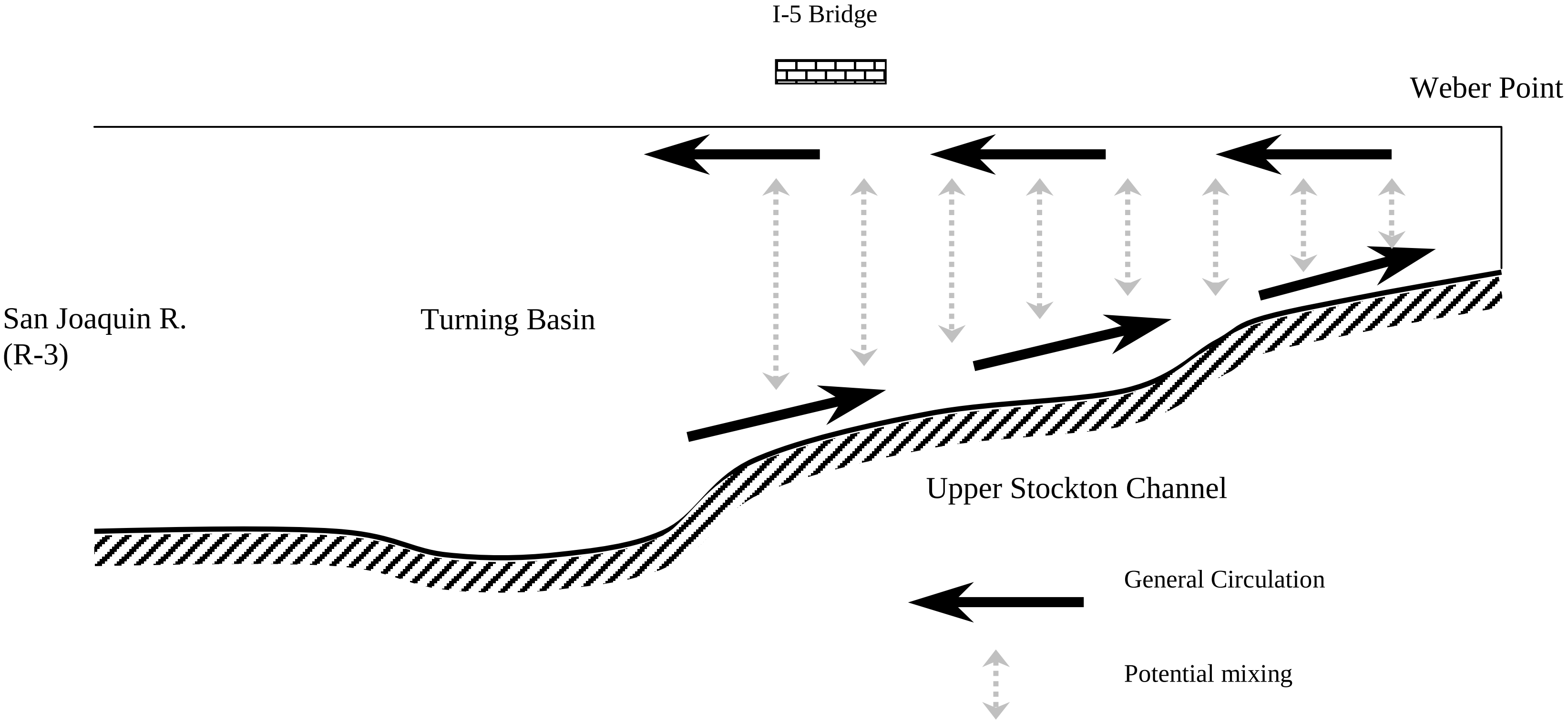

Figure 21: Conceptual model of water circulation in the Stockton Channel.

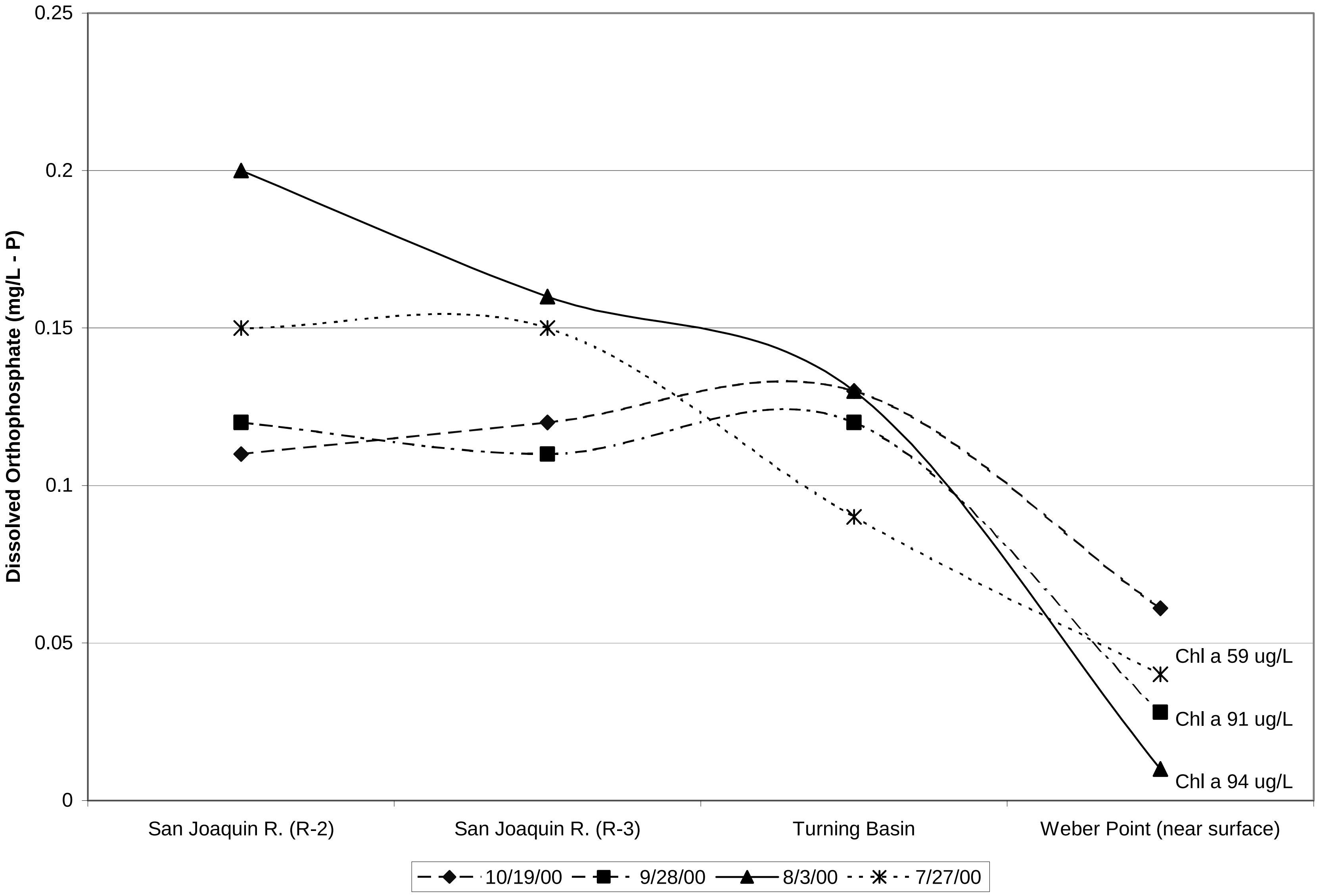

Figure 22: Dissolved orthophosphate concentrations along the Stockton Channel, August-October, 2000. Near-surface concentrations are plotted at Weber Point.

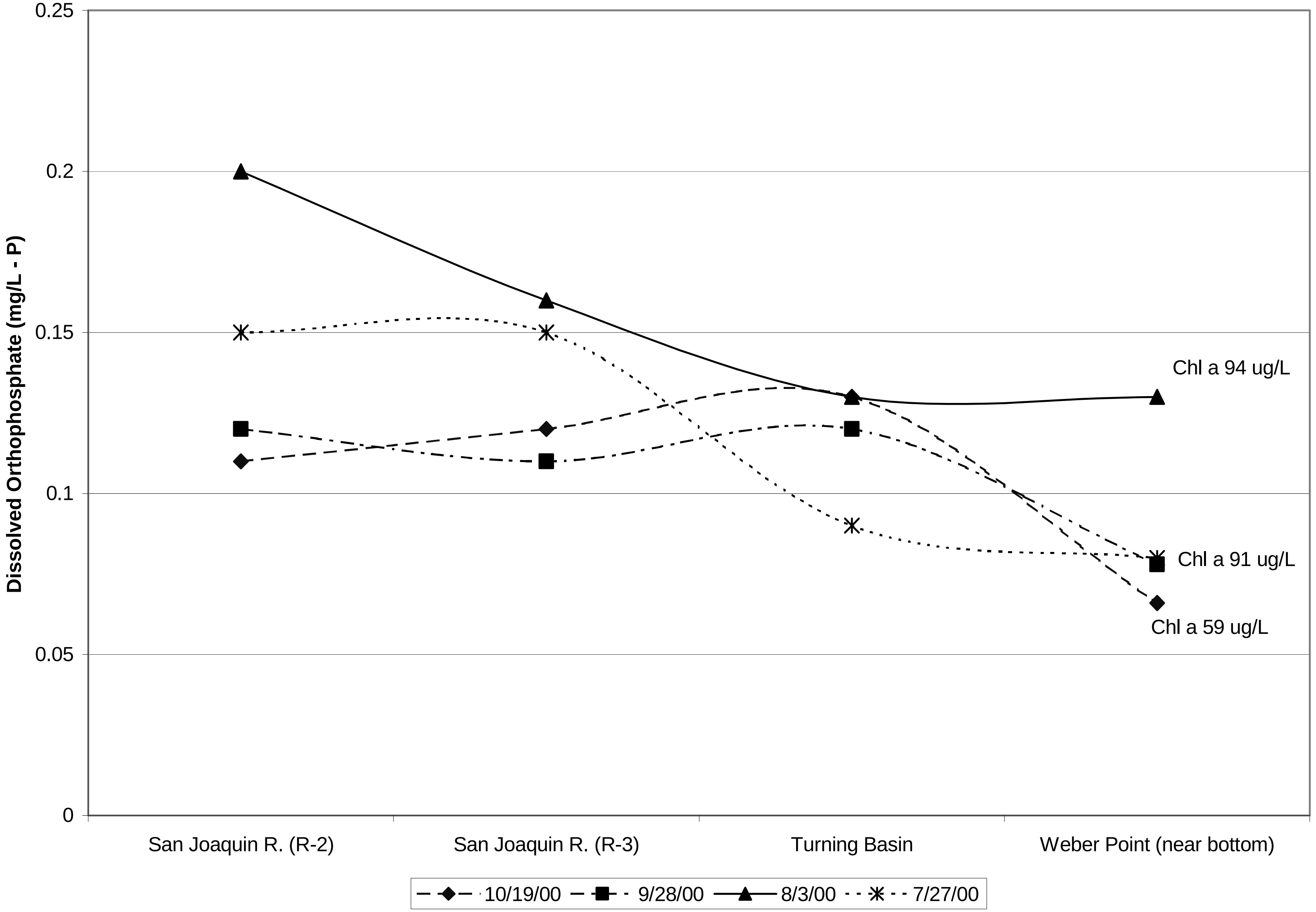

Figure 23: Dissolved orthophosphate concentrations along the Stockton Channel, August-October, 2000. Near-sediment concentrations are plotted at Weber Point.

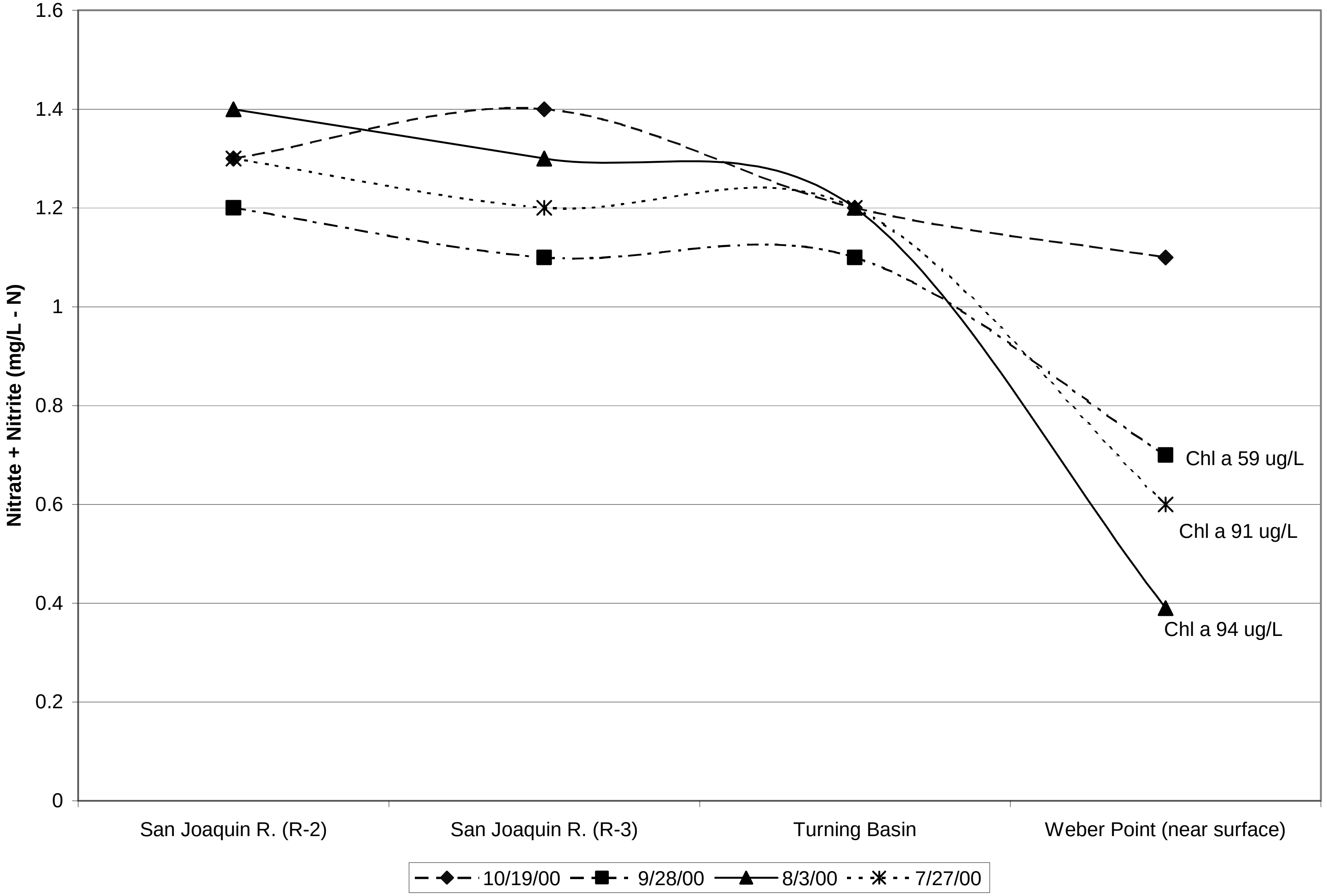

Figure 24: Available nitrate concentrations along the Stockton Channel, August-October, 2000. Near-surface concentrations are plotted at Weber Point.

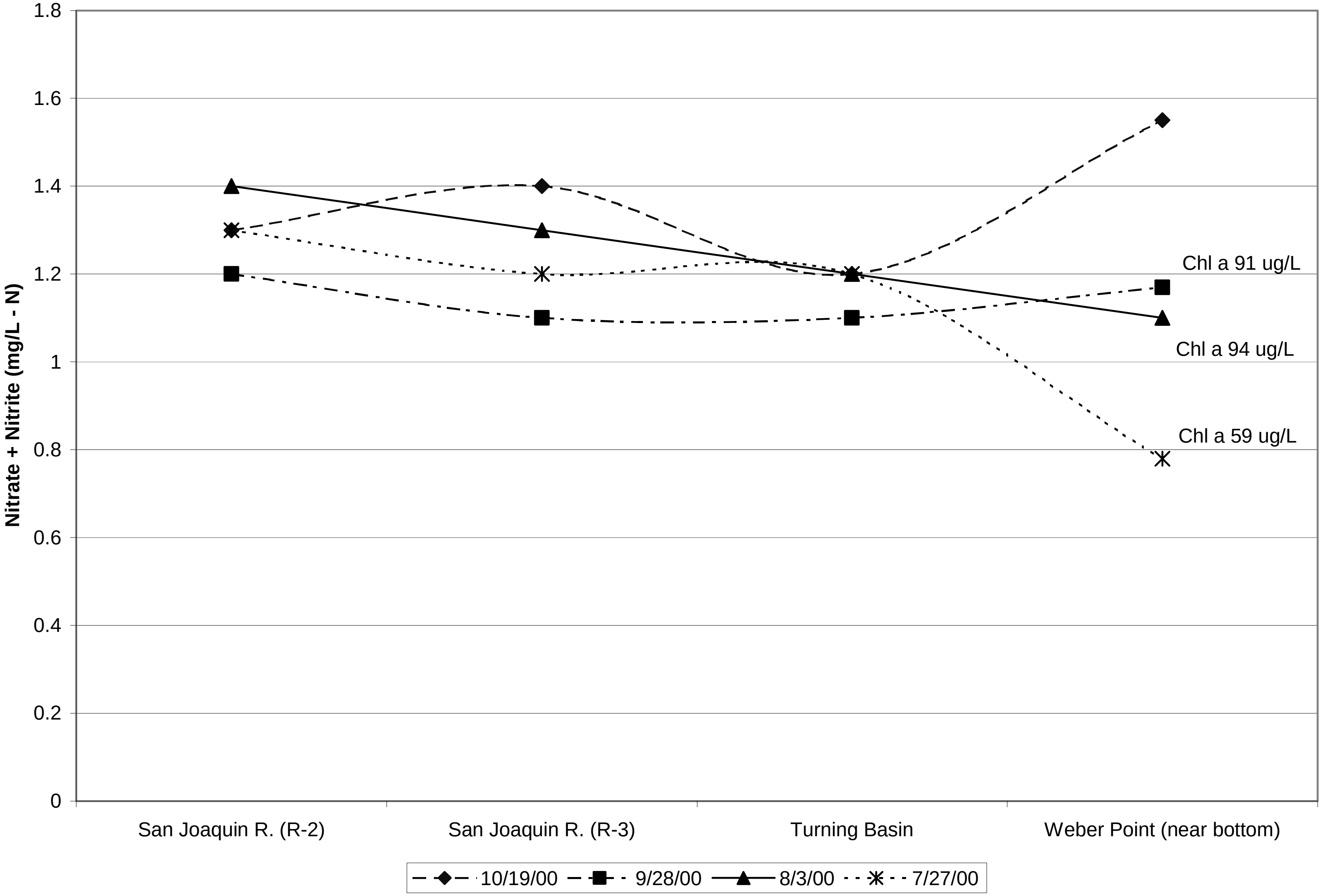

Figure 25: Available nitrate concentrations along the Stockton Channel, August-October, 2000. Near-sediment concentrations are plotted at Weber Point.

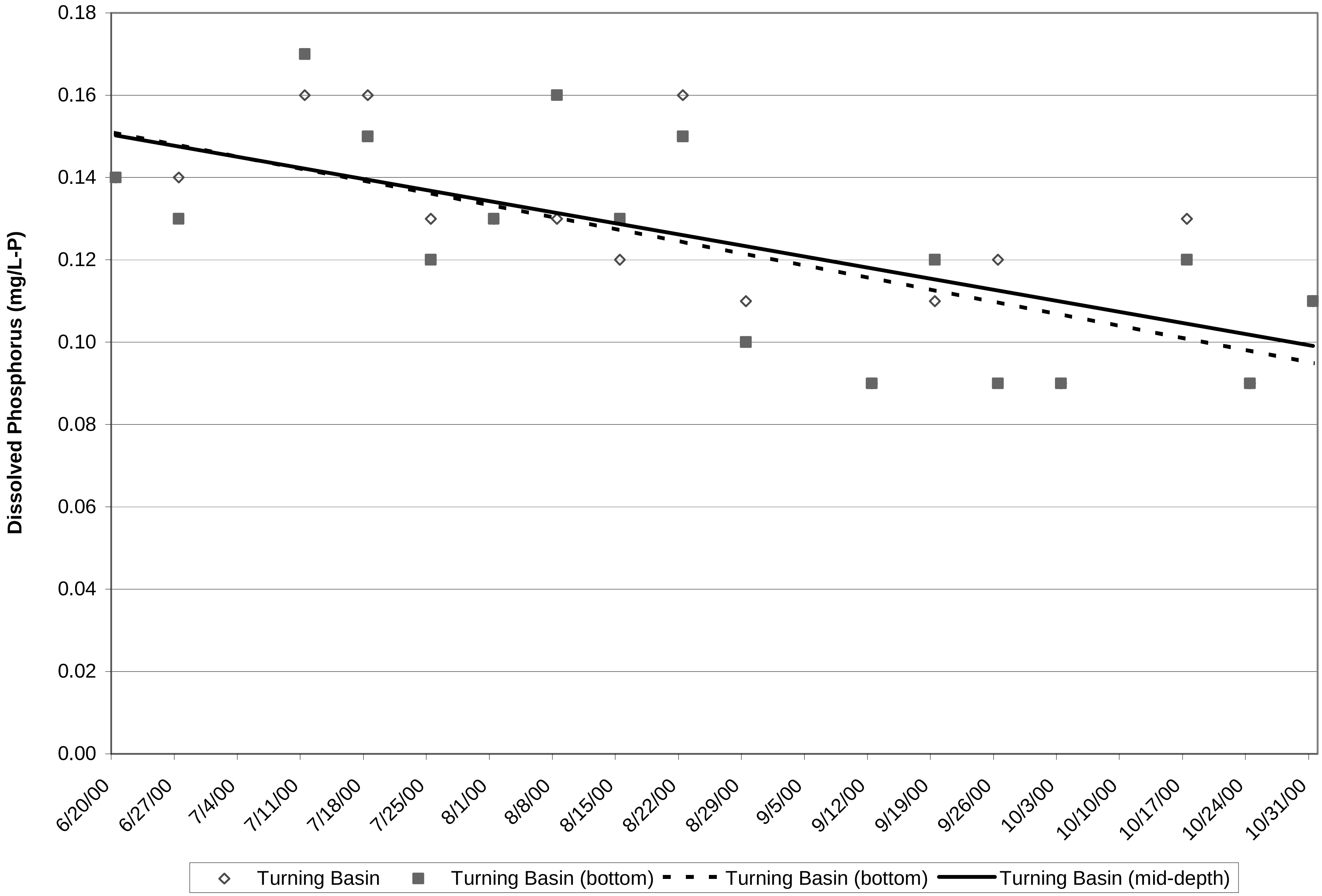

Figure 26: Dissolved orthophosphate concentrations in the Turning Basin at mid-depth and near the sediment-water interface.

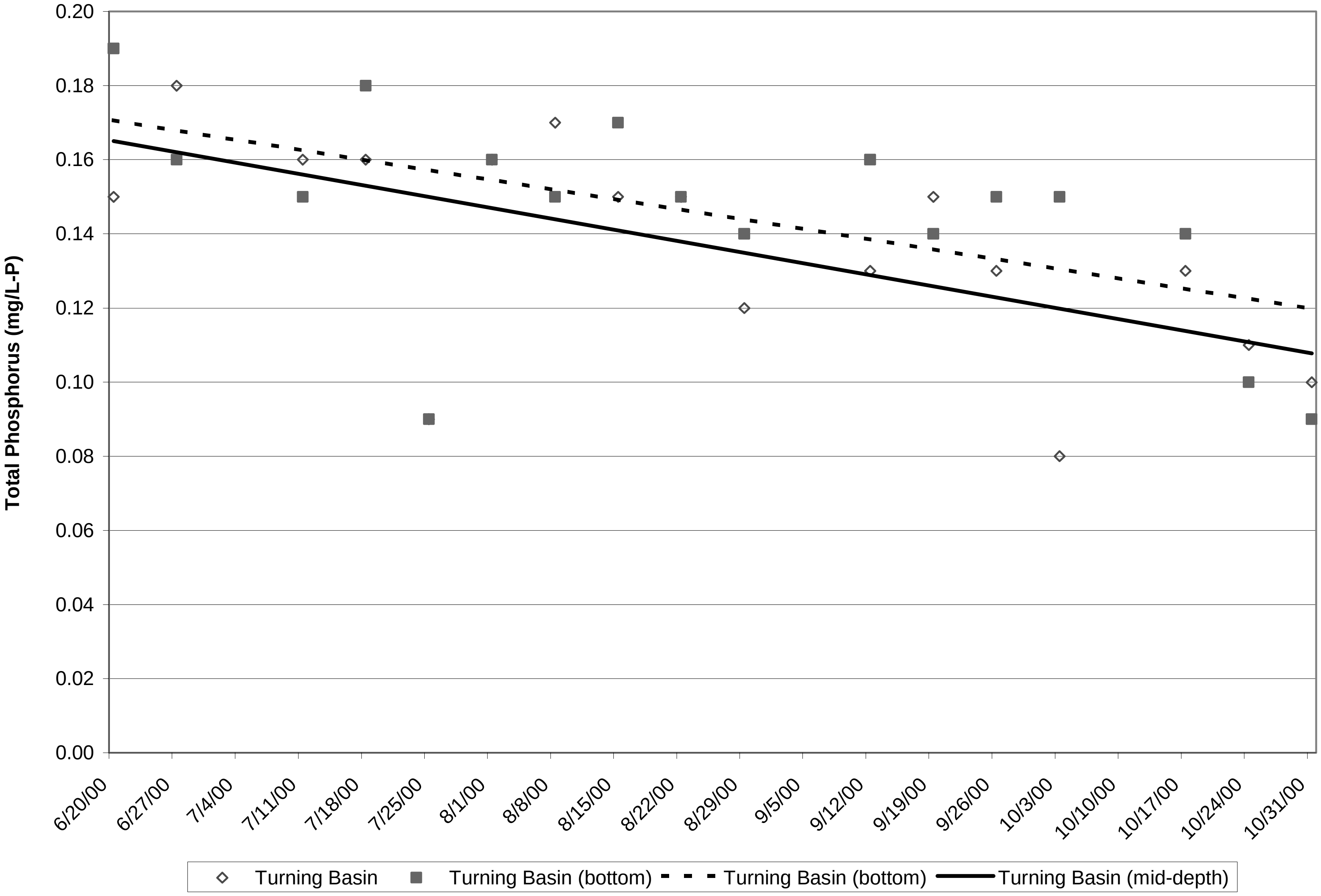

Figure 27: Total phosphorus concentrations in the Turning Basin at mid-depth and near the sediment-water interface.

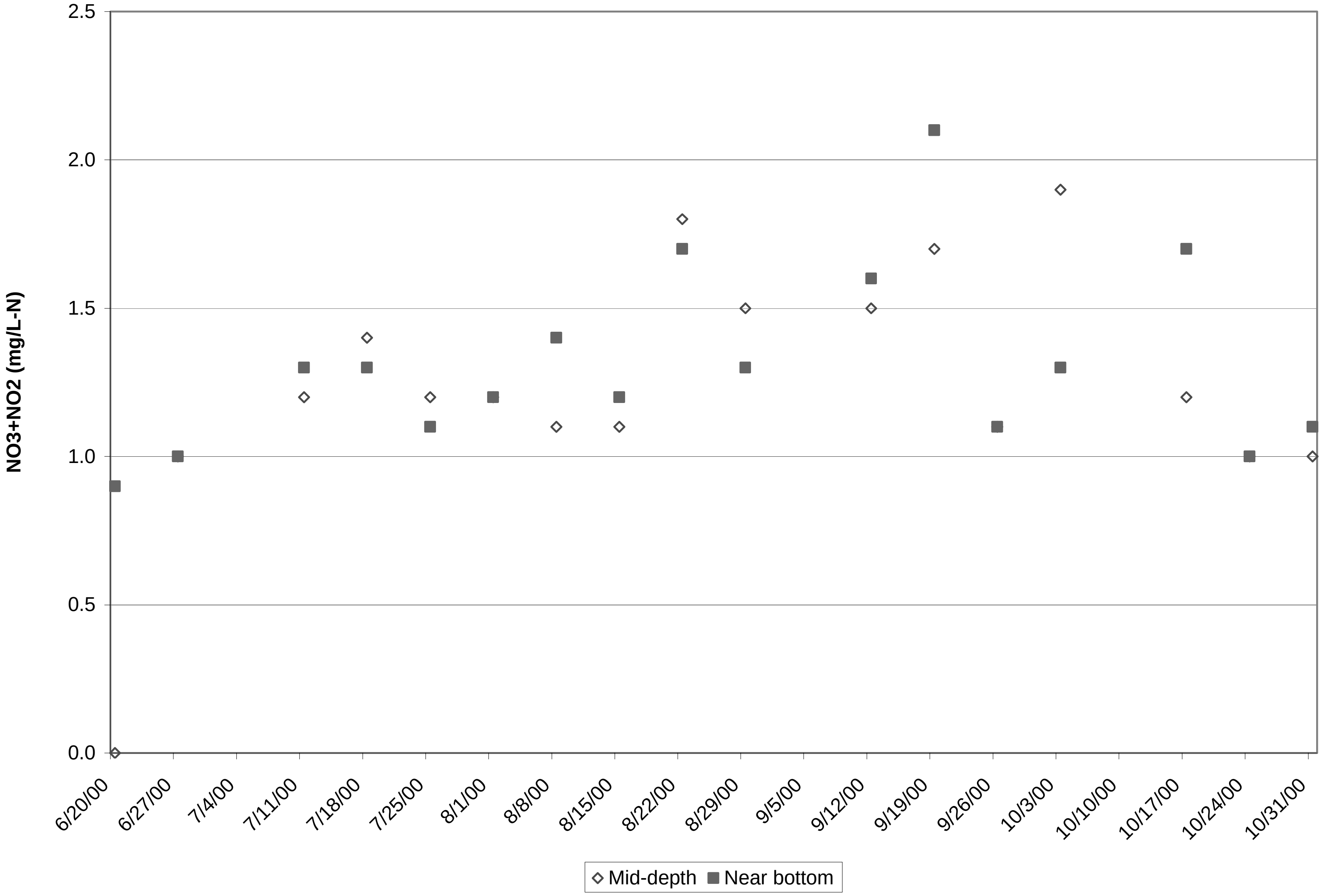

Figure 28: Available nitrogen concentrations in the Turning Basin at mid-depth and near the sediment-water interface.

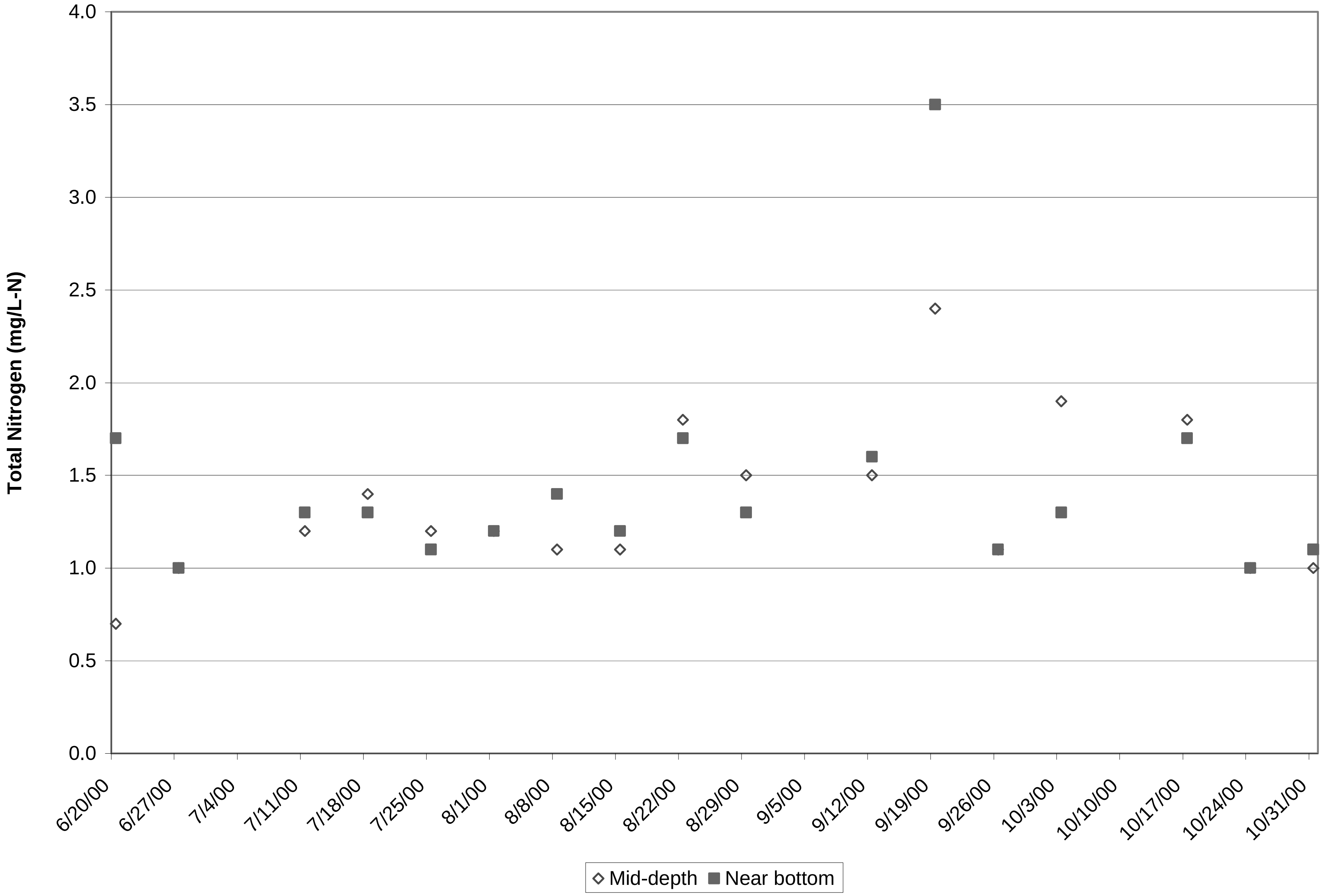

Figure 29: Total nitrogen concentrations in the Turning Basin at mid-depth and near the sediment-water interface.

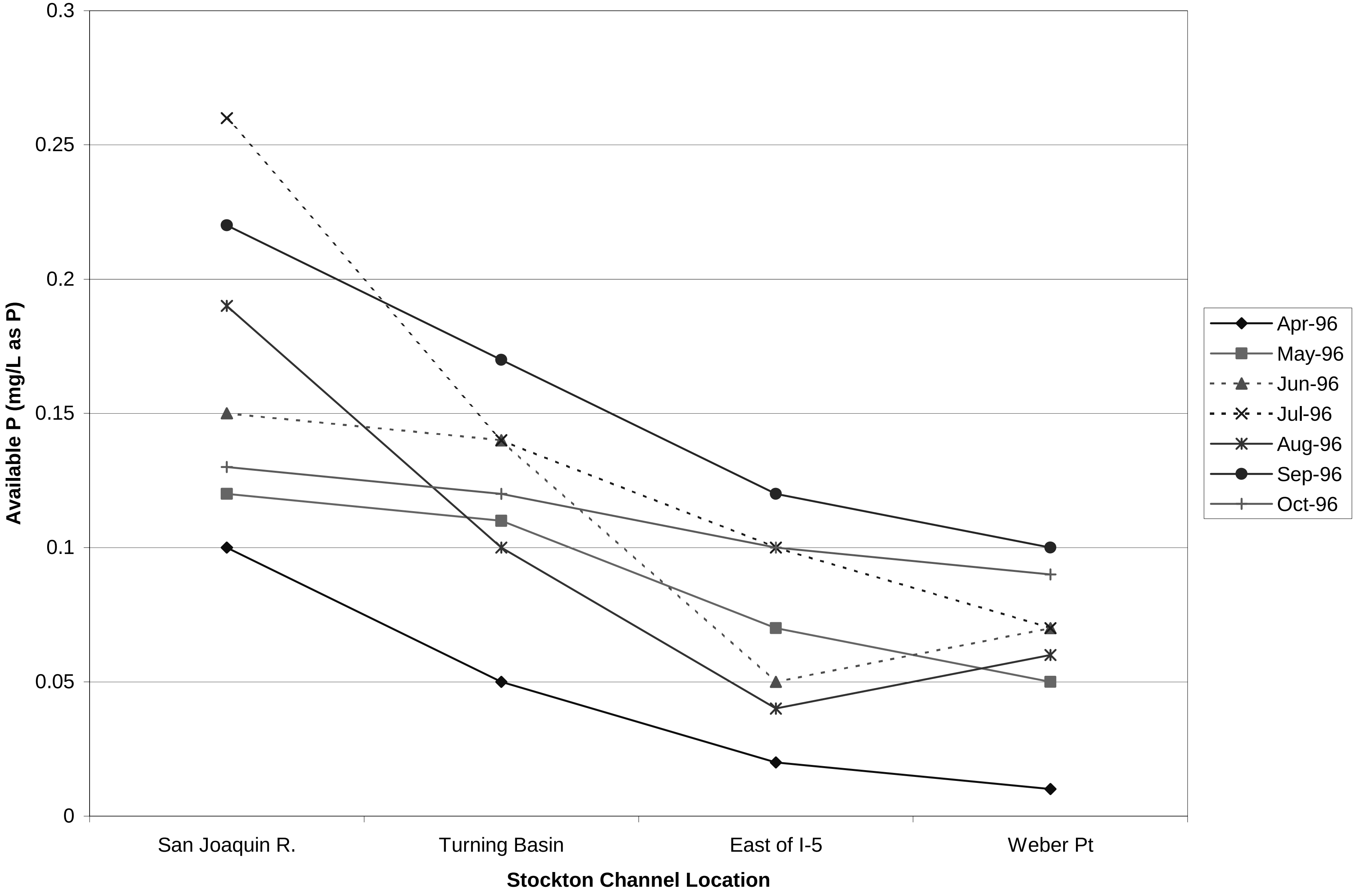

Figure 30: Available phosphorus concentrations (dissolved orthophosphate) in the Stockton Channel, 1996.

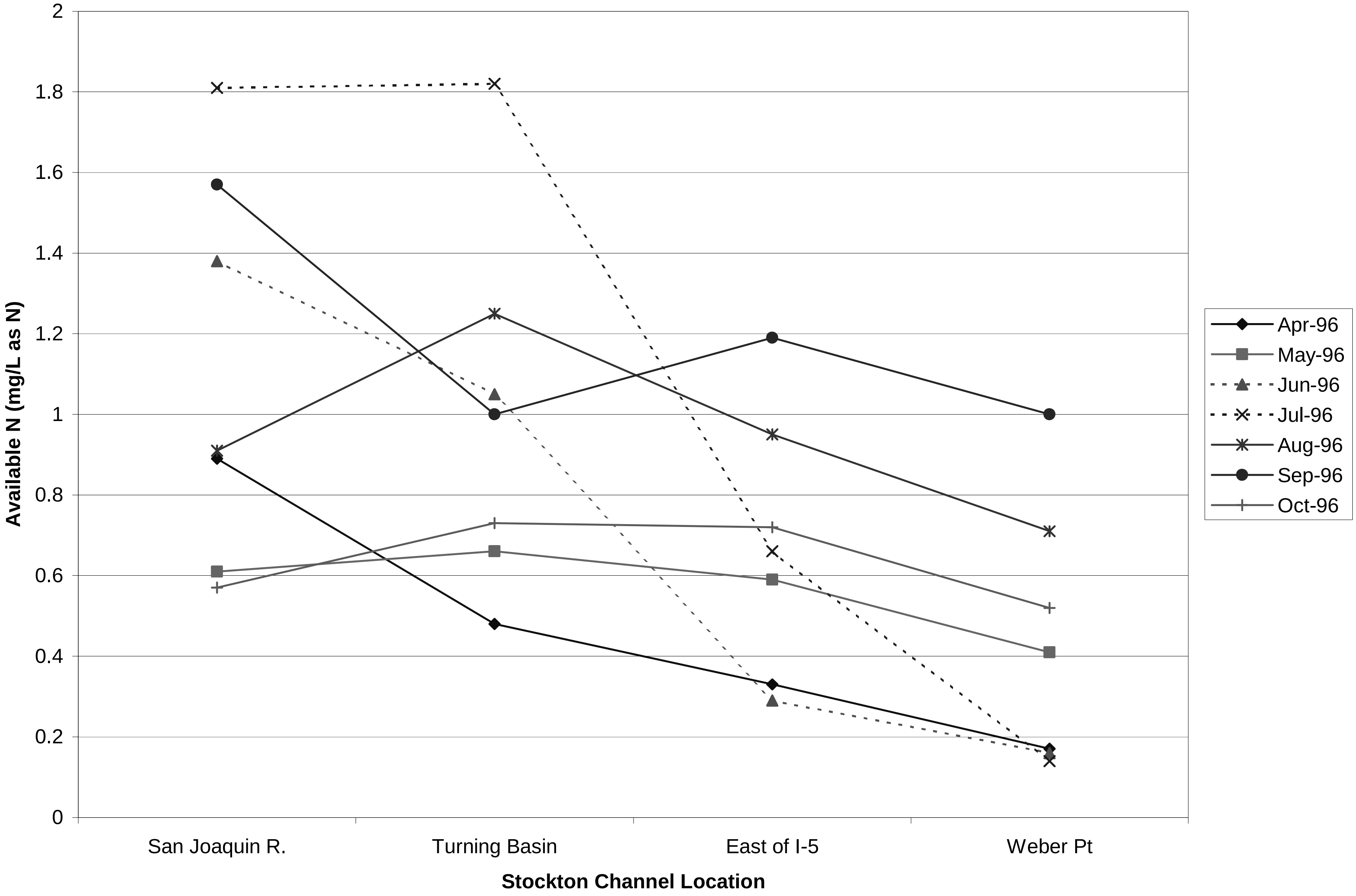

Figure 31: Available nitrogen concentrations (nitrate, nitrite and ammonia) in the Stockton Channel, 1996.

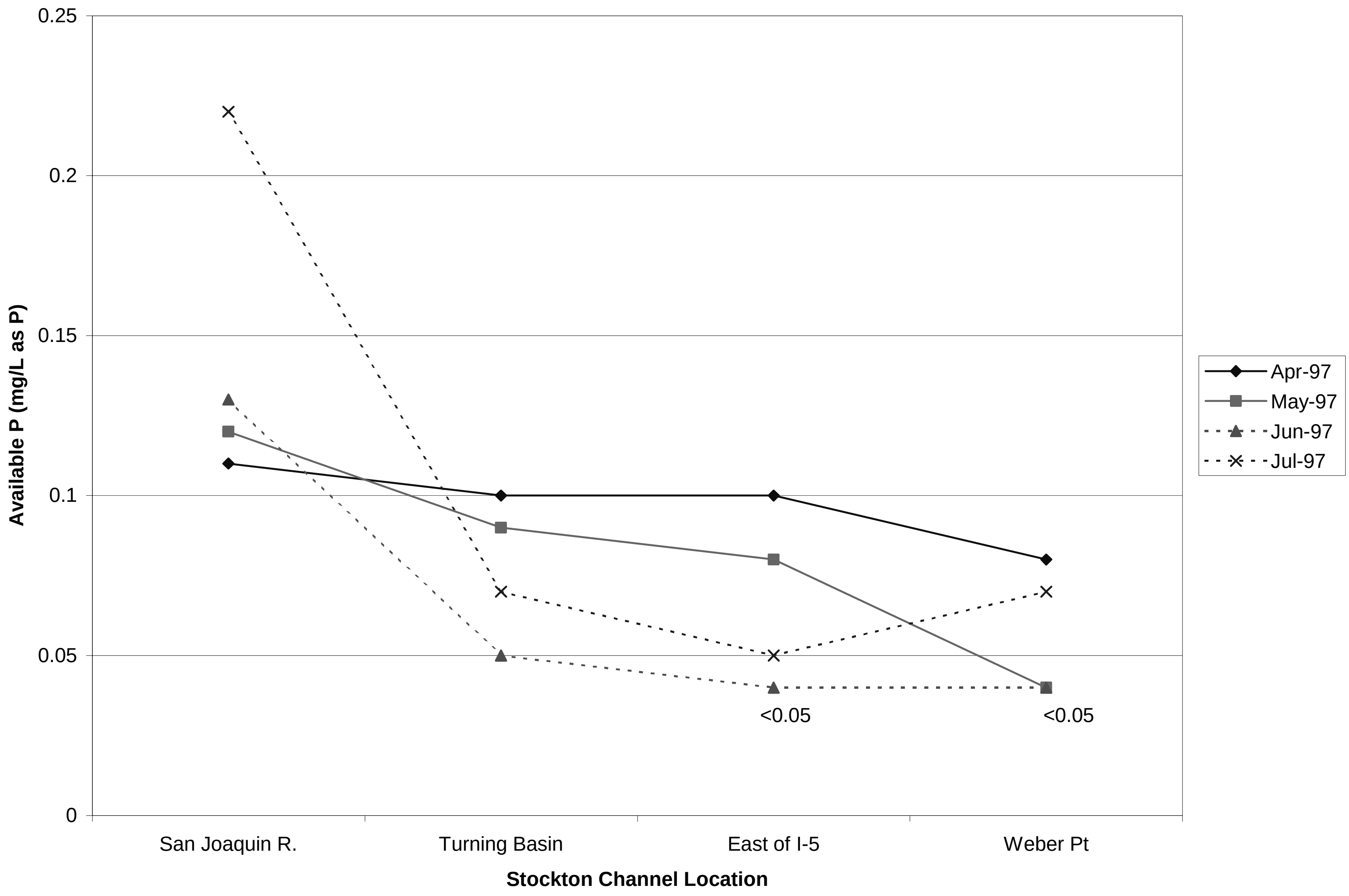

Figure 32: Available phosphorus concentrations (dissolved orthophosphate) in the Stockton Channel, 1997.

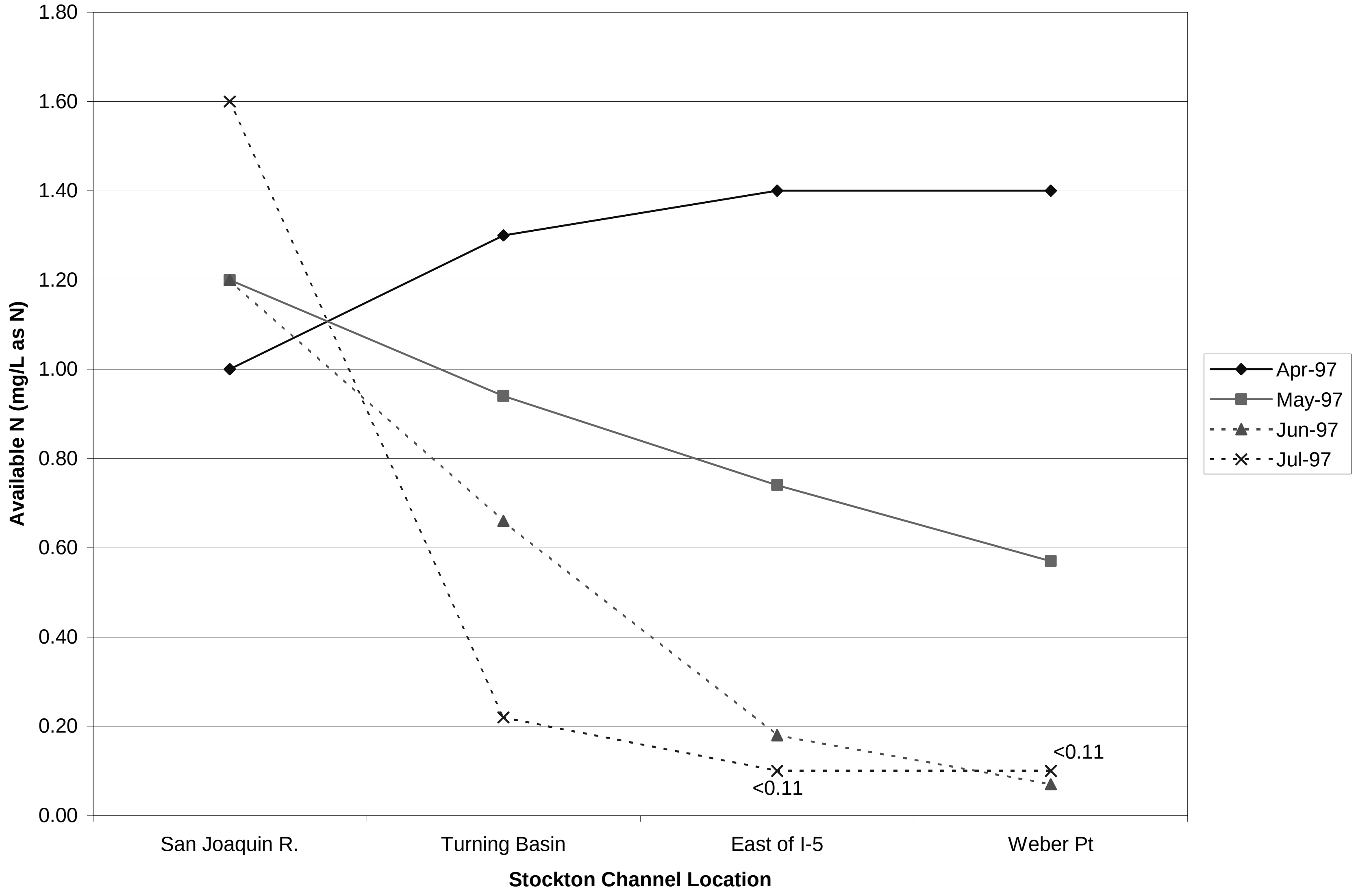

Figure 33: Available nitrogen concentrations (nitrate, nitrite and ammonia) in the Stockton Channel, 1997.

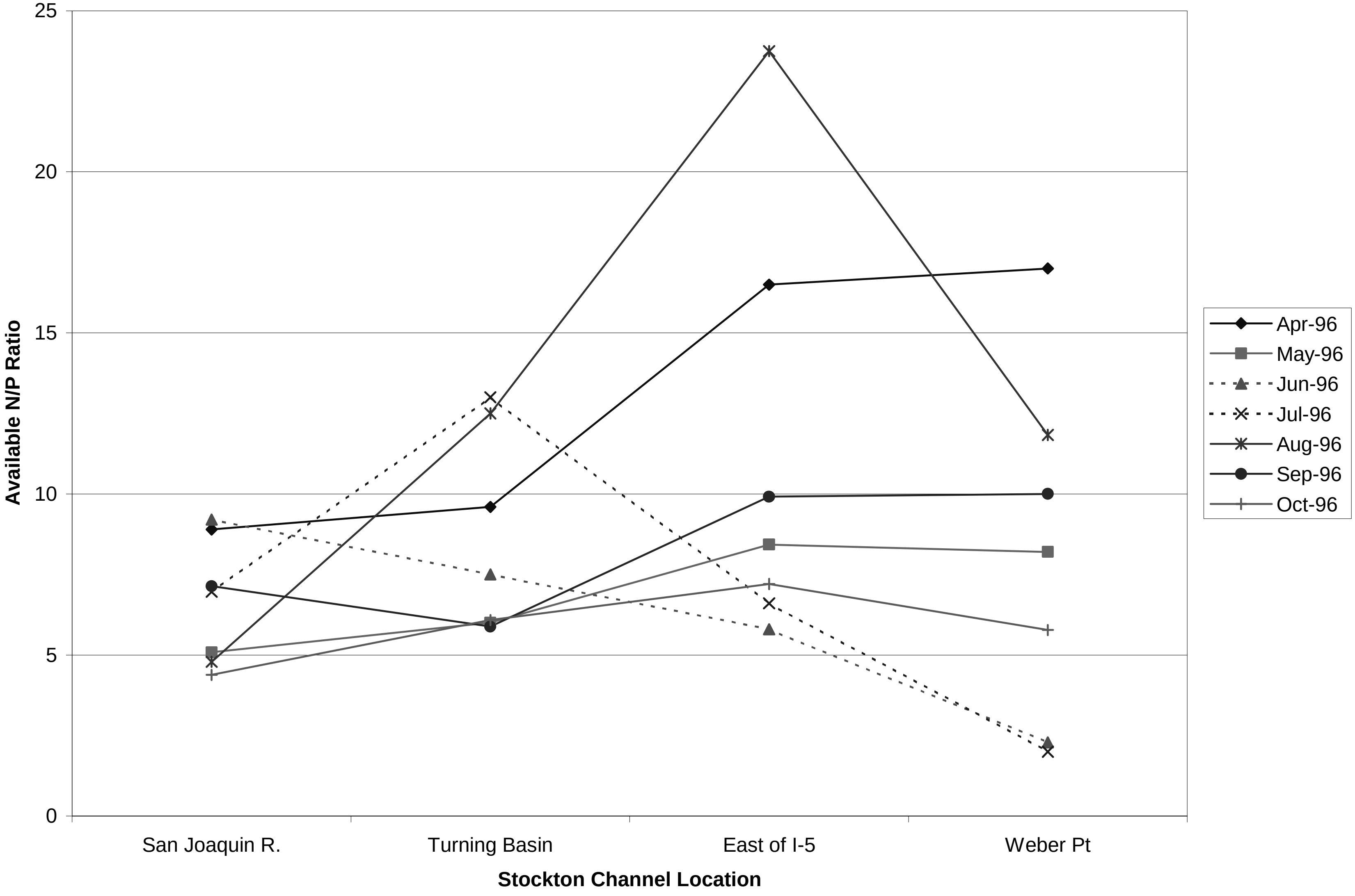

Figure 34: Available N/P ratios for the Stockton Channel, 1996.

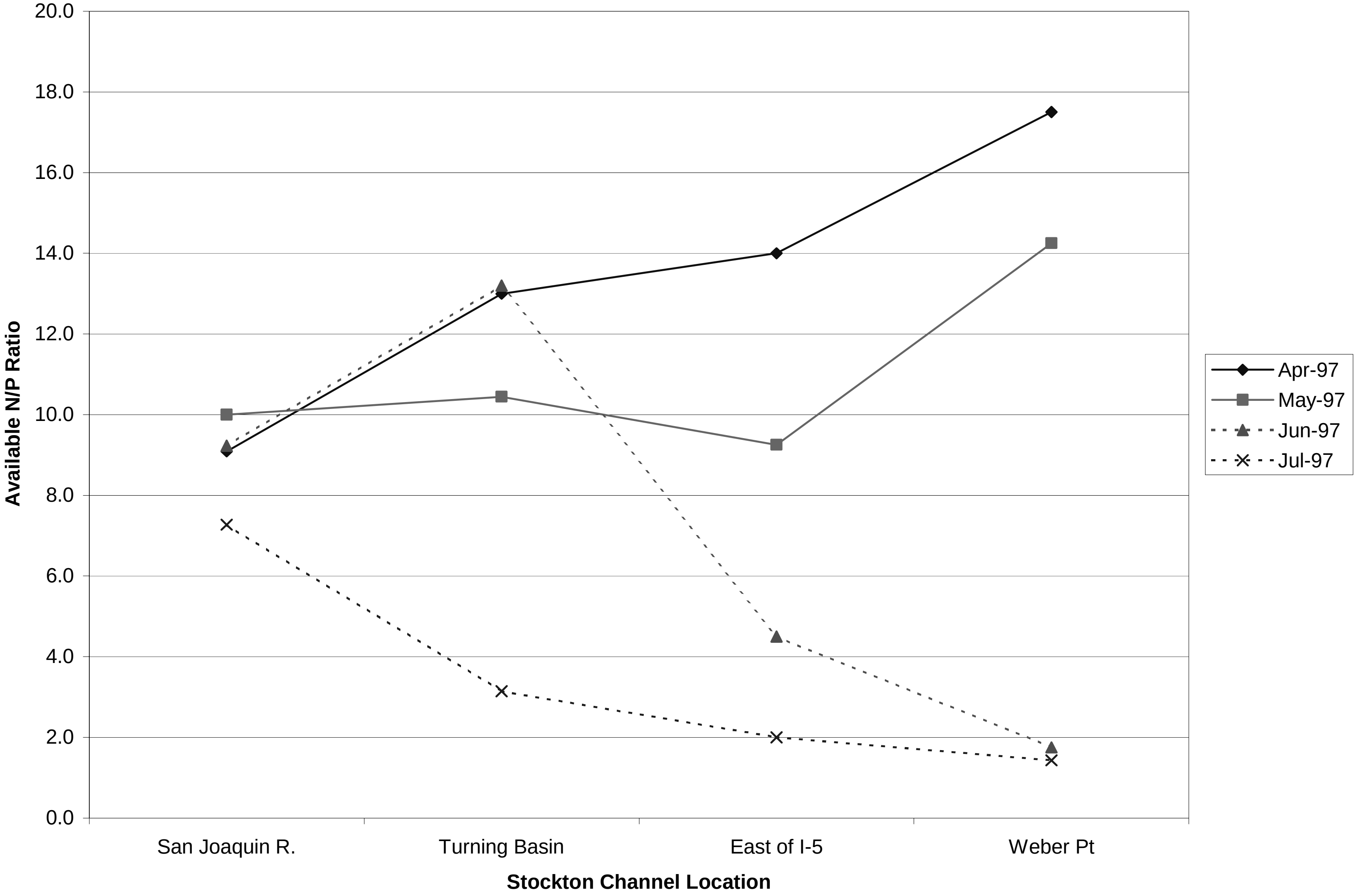

Figure 35: Available N/P ratios for the Stockton Channel, 1997.

Table A-2: Field water quality data measured in the Stockton Channel on September 28, 2000.

Sample Location	Time	Height above sediment (ft)	Temperature (°C)	Electrical Conductivity (µmho/cm)	pH	Dissolved Oxygen (mg/L)	Turbidity (NTU)	Secchi Disk Depth (ft)
SW-1	13:05	10	24.32	486	9.04	13.48	9.1	2.5
		6	23.50	481	8.55	8.24	8.3	
		2	23.04	461	8.50	7.76	10.0	
SW-2	12:40	11	23.84	478	8.82	10.93	7.2	2.9
		6	23.17	468	8.14	6.43	6.6	
		2	22.92	457	7.58	1.96	15.0	
SW-3	12:15	11	23.61	475	8.95	12.18	7.6	2.8
		6	23.24	472	8.70	8.10	5.5	
		2	22.70	453	7.60	2.70	12.0	
SS-1	13:15	Surface[1]	24.90	586-620	7.83	8.49	---	---
SS-2	13:30	Surface	24.89	509	8.82	14.0	---	---
SS-3	13:45	Surface	24.85	486	9.0	13.5	---	---

[1] Sample collected approximately 1 foot below the water surface.

Table A-3: Nitrogen, phosphorus, and chlorophyll concentrations in the water column and sediments of the Stockton Channel on September 28, 2000.

Sample Location	Height above sediment	Total Ammonia	Nitrate	Nitrite	Total Kjeldahl Nitrogen	Total Nitrogen	Total Phosphorus	Dissolved Ortho-phosphorus	Chlorophyll *a*
	ft	(mg/L -N)	(mg/L - N)	(mg/L - N)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(µg/L)
SW-1	10	< 0.083	0.61	< 0.30	< 0.500	0.61	0.166	0.0337	118.55
	6	< 0.083	0.67	< 0.30	0.596	1.27	0.0824	0.0360	42.19
	2	< 0.083	1.13	< 0.30	0.536	1.67	0.111	0.0735	19.22
SW-2	11	< 0.083	0.78	0.40	0.748	1.93	0.116	0.0249	66.75
	6	< 0.083	0.88	0.39	< 0.500	1.27	0.0912	0.0492	33.64
	2	0.098	1.20	< 0.30	< 0.500	1.30	0.118	0.0669	15.49
SW-3	11	< 0.083	0.71	0.40	0.706	1.82	0.107	0.0249	88.11
	6	< 0.083	0.79	0.40	< 0.500	1.19	0.0603	0.0249	38.79
	2	< 0.083	1.17	0.40	< 0.500	1.57	0.169	0.0934	19.22
SS-1	Surface[1]	< 0.083	0.64	< 0.30	0.685	1.32	0.133	0.0802	
SS-2	Surface	< 0.083	0.53	< 0.30	0.549	1.08	0.118	0.0470	
SS-3	Surface	< 0.083	0.59	< 0.30	0.705	1.29	0.124	0.0448	
		mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg		
SD-1	na	28.8	53.8	<10	651	705	35.5		
SD-2	na	38.8	62.2	<10	771	833	48.3		
SD-3	na	28.8	111.0	<10	741	852	46.0		

< 0.10: less than the detection limit (in this example 0.10), na: not applicable

[1] Sample collected approximately 1 foot below the water surface.

Table A-4: Field water quality data measured in the Stockton Channel on October 19, 2000.

Sample Location	Time	Height above sediment (ft)	Temperature (^oC)	Electrical Conductivity (µmho/cm)	pH	Dissolved Oxygen (mg/L)	Turbidity (NTU)	Secchi Disk Depth (ft)
SW-1	14:30	12	20.33	533	8.43	12.78	11.0	1.9
	14:35	7	19.04	464	8.03	2.90	6.3	
	14:40	2	18.75	466	7.54	0.10	11.0	
SW-2	14:05	12	20.10	452	8.94	16.90	13.0	1.8
	14:10	7	19.05	452	8.13	5.29	5.0	
	14:15	2	18.56	452	7.72	1.96	8.4	
SW-3	13:45	12	20.06	451	8.60	15.30	13.0	2.0
	13:50	7	19.28	454	7.91	7.83	5.7	
	13:55	2	18.48	453	7.53	2.55	11.0	
SS-1	15:10	Surface[1]	20.60	606	7.82	6.70		
SS-2	15:20	Surface	20.60	589	7.71	4.40		
SS-3	15:30	Surface	20.30	800-2400	7.55	6.00		

[1] Sample collected approximately 1 foot below the water surface.

Table A-5: Nitrogen, phosphorus, and chlorophyll concentrations in the water column and sediments of the Stockton Channel on October 19, 2000.

Sample Location	Height above sediment ft	Total Ammonia (mg/L - N)	Nitrate (mg/L - N)	Nitrite (mg/L - N)	Total Kjeldahl Nitrogen (mg/L)	Total Nitrogen (mg/L)	Total Phosphorus (mg/L)	Dissolved Ortho-phosphorus (mg/L)	Chlorophyll *a* (μg/L)
SW-1	12	<0.082	0.93	0.60	0.747	2.27	0.0426	0.102	
	7	<0.082	1.35	< 0.030	< 0.500	1.35	0.0360	0.0713	
	2	<0.082	1.58	< 0.030	< 0.500	1.58	0.0603	0.104	
SW-2	12	<0.082	0.97	0.04	< 0.500	1.01	0.0890	0.177	
	7	<0.082	1.45	< 0.030	0.617	2.06	0.0404	0.0690	
	2	<0.082	1.45	0.30	0.578	2.32	0.0780	0.0978	
SW-3	12	<0.082	1.11	0.04	1.04	2.19	0.0514	0.107	
	7	<0.082	1.29	< 0.030	0.509	1.80	0.0227	0.0558	
	2	<0.082	1.63	< 0.030	< 0.500	1.63	0.0603	0.0890	
SS-1	Surface[1]	< 0.0820	1.13	< 0.030	0.637	1.77	0.0293	0.104	
SS-2	Surface	0.096	1.02	< 0.030	0.505	1.52	0.0360	0.102	
SS-3	Surface	Sample collected by HDR					---	---	

< 0.10: less than the detection limit (in this example 0.10)

[1] Sample collected approximately 1 foot below the water surface.

Table A-6: Nitrogen and phosphorus concentrations in the water column at McLeod Lake on October 12, 2000.

Sample Description	Tidal Condition	Height above sediment (ft)	Ammonia (mg/L-N)	Nitrate (mg/L-N)	Nitrite (mg/L-N)	Total Kjeldahl Nitrogen (mg/L)	Organic N (mg/L -N)	Phosphorus (Ortho)-Dissolved (mg/L)	Total Phosphorus (mg/L)
E 0.5	Ebb	0.25	0.229	1.47	< 1.00	0.660	0.431	0.0445	0.149
E 1.0	Ebb	0.75	0.229	1.41	< 1.00	0.702	0.473	0.0536	0.104
E 1.5	Ebb	1.25	0.203	1.40	< 1.00	0.608	0.405	0.0492	0.120
E 2.0	Ebb	1.75	0.211	1.45	< 1.00	0.688	0.477	0.0536	0.102
E 2.5	Ebb	2.25	0.194	1.40	< 1.00	0.678	0.484	0.0536	0.102
E 3.0	Ebb	2.75	0.194	1.47	< 1.00	0.573	0.379	0.0536	0.107
E 4	Ebb	3.75	0.220	1.35	< 1.00	0.507	0.287	0.0536	0.104
E 5	Ebb	4.75	0.203	1.40	< 1.00	0.693	0.490	0.0514	0.118
E 7	Ebb	6.75	0.194	1.41	< 1.00	0.648	0.454	0.0536	0.116
E 10	Ebb	9.95	0.194	1.39	< 1.00	0.709	0.515	0.0603	0.118
S 0.5	Low Slack	0.25	0.194	1.38	< 1.00	0.676	0.482	0.0581	0.122
S 1.0	Low Slack	0.75	0.194	1.37	< 1.00	0.668	0.474	0.0735	0.113
S 1.5	Low Slack	1.25	0.194	1.46	< 1.00	0.752	0.558	0.0603	0.111
S 2.0	Low Slack	1.75	0.187	1.39	< 1.00	1.070	0.883	0.0647	0.104
S 2.5	Low Slack	2.25	0.187	1.47	< 1.00	0.560	0.373	0.0514	0.109
S 3.0	Low Slack	2.75	0.187	1.34	< 1.00	0.607	0.420	0.0558	0.109
S 4	Low Slack	3.75	0.211	1.37	< 1.00	0.859	0.648	0.0558	0.109
S 5	Low Slack	4.75	0.194	1.34	< 1.00	0.551	0.357	0.0536	0.118
S 7	Low Slack	6.75	0.203	1.42	< 1.00	0.703	0.500	0.0647	0.113
S 10	Low Slack	9.95	0.180	1.41	< 1.00	0.550	0.370	0.0647	0.116

<1.0: less than detection limit (in this example 1.0)

Table A-6: Comparisons of Nutrient Concentrations in the Stockton Ship Channel and San Joaquin River, 7/27/2000.

Location	$NO_3^- + NO_2^-$ (mg/L -N)	Total Ammonia (mg/L -N)	Dissolved PO_4 (mg/L -P)	Total Phosphorus (mg/L -P)	Chlorophyll *a* (ug/L)
San Joaquin R. (R-2)	1.3	<0.20	0.15	0.14	55
San Joaquin R. (R-3)	1.2	<0.20	0.15	0.11	18
Turning Basin	1.2	<0.20	0.09	0.15	11
Weber Point at bottom	0.78	0.18	0.08	0.13	29

Notes:

1 Sample collected by HDR personnel near water surface on 7/27/2000.

2 Sample collected by P. Lehman, Dept. of Water Resources on 7/25/2000

3 Sample collected by City of Stockton Personnel on 7/25/2000 (samples collected during early morning)

Table A-7: Comparisons of Nutrient Concentrations in the Stockton Ship Channel and San Joaquin River, 8/3/2000

Location	$NO_3^- + NO_2^-$ (mg/L -N)	Total Ammonia (mg/L -N)	Dissolved PO_4 (mg/L -P)	Total Phosphorus (mg/L -P)	Chlorophyll *a* (ug/L)
San Joaquin R. (R-2)	1.4	<0.2	0.2	0.16	38
San Joaquin R. (R-3)	1.3	<0.2	0.16	0.2	34
Turning Basin	1.2	<0.2	0.13	0.16	26
Weber Point Bottom	1.10	0.17	0.13	0.19	57

Notes:

1 Sample collected by HDR personnel near water surface on 8/3/2000. (2 dissolved P lab values were 10X other samples, average assumes these were incorrectly reports and should be 10X lower)

2 Sample collected by P. Lehman, Dept. of Water Resources on 8/7/2000

3 Sample collected by City of Stockton Personnel on 8/1/2000 (Samples collected during early morning)

Table A-8: Comparisons of Nutrient Concentrations in the Stockton Ship Channel and San Joaquin River, 9/28/2000

Location	NO_3^- + NO_2^- (mg/L -N)	Total Ammonia (mg/L -N)	Dissolved PO_4 (mg/L -P)	Total Phosphorus (mg/L -P)	Chlorophyll *a* (ug/L)
San Joaquin R. (R-2)	1.2	0.7	0.12	0.19	30
San Joaquin R. (R-3)	1.1	0.3	0.11	0.14	30
Turning Basin	1.1	0.2	0.12	0.13	31
Weber Point	1.17		0.078	0.13	18

Notes:
1 Samples collected by UOP on 9/28/2000. (Averages for shallow samples collected from Stations SW-1, SW-2, and SW-3 in the upper Stockton Channel).
2 Samples collected by P. Lehman, Dept. of Water Resources on 9/28/2000
3 Samples collected by City of Stockton Personnel on 9/26/2000

Table A-9: Comparisons of Nutrient Concentrations in the Stockton Ship Channel and San Joaquin River, 10/12/2000.

Location	NO_3^- + NO_2^- (mg/L -N)	Total Ammonia (mg/L -N)	Dissolved PO_4 (mg/L -P)	Total Phosphorus (mg/L -P)	Chlorophyll *a* (ug/L)
Weber Pt[1]	1.41	0.2	0.056	0.11	
Turning Basin[2]		0.13	0.05	0.13	9.6
Turning Basin[3]					
San Joaquin R.[2]		0.32	0.11	0.2	10.2
San Joaquin R. (R-3)[3]					
Upper San Joaquin R.[2]					
Upper San Joaquin R.(R-2)[3]					

Notes:
1 Samples collected by UOP on 10/12/2000. (Samples collected from Stations SW-1as part of the nutrient profiling).
2 Samples collected by P. Lehman, Dept. of Water Resources on 10/12/2000
3 No samples were collected by City of Stockton personnel this week.

Table A-10: Comparisons of Nutrient Concentrations in the Stockton Ship Channel and San Joaquin River, 10/19/2000

Location	$NO_3^- + NO_2^-$ (mg/L -N)	Total Ammonia (mg/L -N)	Dissolved PO_4 (mg/L -P)	Total Phosphorus (mg/L -P)	Chlorophyll *a* (ug/L)
San Joaquin R. (R-2)	1.3	<0.2	0.11	0.12	9
San Joaquin R. (R-3)	1.4	<0.2	0.12	0.18	4
Turning Basin	1.2	0.2	0.13	0.13	1
Weber Point (near bottom)	1.55	<0.1	0.066	0.097	<10

Notes:
1 Samples collected by UOP on 10/19/2000. (Averages for shallow samples collected from Stations SW-1, SW-2, and SW-3 in the upper Stockton Channel).
2 Samples collected by P. Lehman, Dept. of Water Resources on 9/16/2000 (Turning Basin) and 9/25/2000 (San Joaquin River).
3 Samples collected by City of Stockton Personnel on 10/17/2000.