# Narragansett Bay Fixed-Site Monitoring Network: Final Report on Activities during 2005-2008


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# Narragansett Bay Fixed-Site Monitoring Network (NBFSMN):
# Final Report on Activities during 2005-2008

This report constitutes the final report for activities conducted by Rhode Island Department of Environmental Management (RIDEM) in association with the Bay Window program with support from grant NA05NMF4721129 awarded by the National Oceanic and Atmospheric Administration (NOAA)

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Narragansett Bay Commission (NBC)
Narragansett Bay National Estuarine Research Reserve (NBNERR)
Narragansett Bay Estuary Program (NBEP)
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## Narragansett Bay Fixed-Site Monitoring Network (NBFSMN): Final Report for Activities from 2005-2008

### Introduction

The following report summarizes the activities for the period October 2005- September 2008 of the Narragansett Bay Fixed-Site Monitoring Network (NBFSMN) supported by a grant to the Rhode Island Department of Environmental Management from the National Oceanic and Atmospheric Administration (NOAA) - NA05NMF4721129. In addition to describing the monitoring program, the report includes summaries of analyses of the data generated via the NBFSMN that relate to hypoxia in Narragansett Bay. The activities described were undertaken as part of a larger collaborative research and monitoring program known as the Bay Window Program.

### Background

*Hypoxia Issue Definition*

While hypoxia in estuaries can occur naturally, periodically both hypoxia, and the more extreme condition of anoxia (a total loss of dissolved oxygen), may indicate a stressed environment resulting from a systemic problem of an overabundance of nutrients (i.e., eutrophication). Eutrophication is defined as an increase in the rate of supply of organic matter to an ecosystem (Nixon, 1995). An increase in the rate of supply of organic matter is either from external sources or from production within the system through biological processes stimulated by increased nutrients. Increased organic matter and, more specifically, nutrient inputs can lead to a variety of deleterious effects, including overgrowth of aquatic plants such as dense nuisance algal blooms. Aquatic plants rapidly increase in abundance by uptaking these excess nutrients, and through photosynthesis, converting this matter into energy. When these plants die, their organic material sinks to bottom waters and is decomposed by microbes (e.g., bacteria), consuming oxygen in the process, which may lead to hypoxia (**figure 1**), and in extreme cases, anoxia (NSTC, 1993).

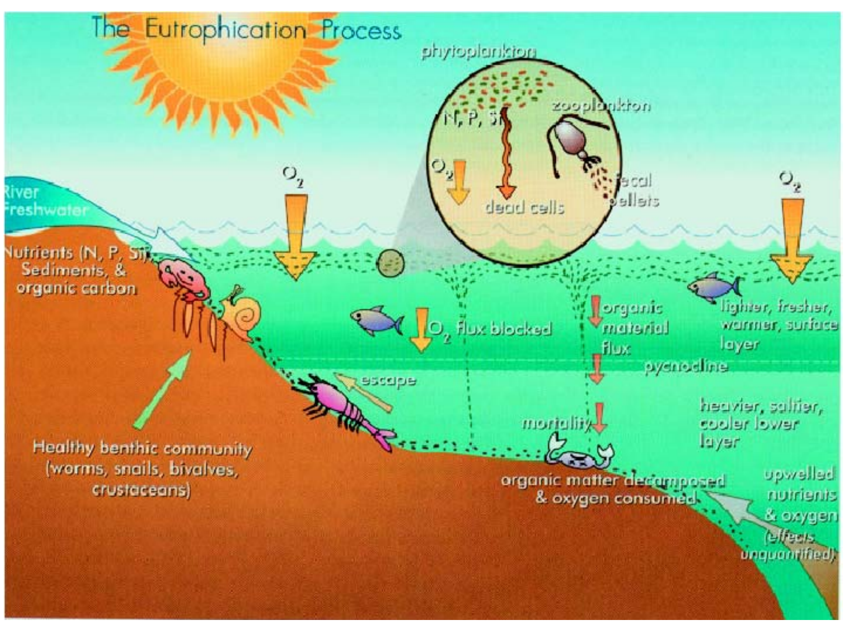


**Figure 1**. The Eutrophication Process in an estuary (NSTC, 1993).

*Narragansett Bay Watershed*

The Narragansett Bay watershed covers a land area of 1,657 square miles. Forty percent of the Bay's watershed is in Rhode Island; the remaining 60% is in Massachusetts. **Figure 2** is a map of the Narragansett Bay watershed. Narragansett Bay covers approximately 147 square miles with an undulating shoreline that creates a string of sheltered coves where water circulation may be restricted. These characteristics, and other factors such as the location of urban areas on the Bay's shoreline and within its watershed, make it difficult to use existing data to characterize the water quality of all the small coves and harbors. In general, there is a clear north to south gradient of pollution in the main channels of the Bay. There is a prominent nutrient and chlorophyll gradient (Oviatt et al., 2002; Melrose et al., 2007) with highest concentrations near the head of the bay in the north. In general, the highest pollutant levels are documented in the urbanized Providence/Seekonk tidal rivers and the Fall River/Taunton River area, and slightly lower levels in the urbanizing areas such as Greenwich Bay and the upper Bay (between Conimicut Point and Prudence Island). Levels of pollutants in the open Bay channels continue to decrease south towards the mouth of the Bay, with lowest levels at the openings to Block Island Sound. Small harbors and coves, such as Wickford Harbor and Newport Harbor can experience significant pollutant impacts due to poor flushing, which exacerbates the level and impact of local pollutant sources.

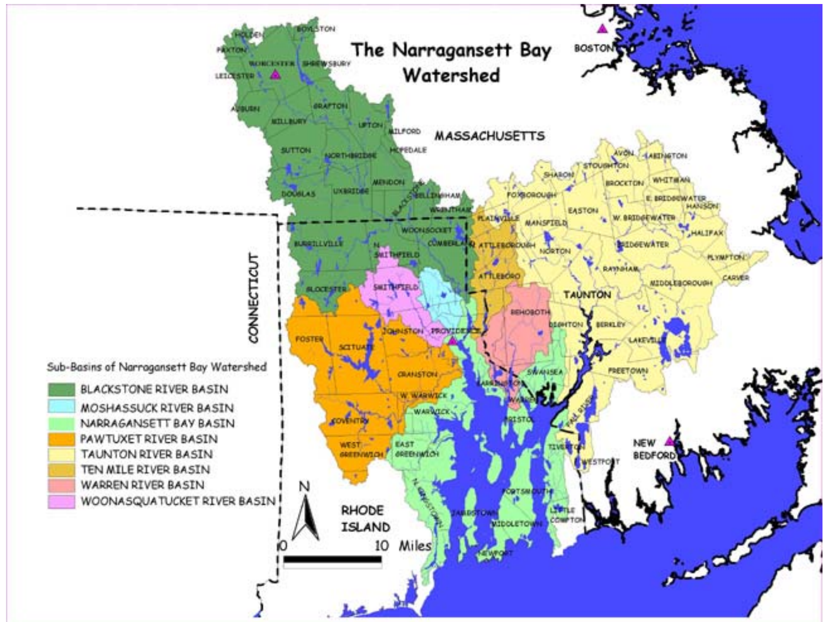


**Figure 2**. Narragansett Bay Watershed.

*History of the Narragansett Bay Fixed-Site Monitoring Network*

Hypoxia in upper Narragansett Bay has been an acknowledged state management concern for over twenty years. Effectively abating the negative impacts of eutrophication on aquatic life involves understanding how the ecosystem responds to nutrient loading and what natural processes control the magnitude of the impacts, in particular the impacts on dissolved oxygen. Shifts in physical and/or chemical properties of the water column cause hydrographic changes in estuarine waters that affect their ability to sustain life. Temperature, salinity, pH, dissolved oxygen (DO), chlorophyll levels, and turbidity are among the most important parameters affecting the distribution of aquatic life throughout the water column.

Programs to measure water quality bay-wide on a continuous basis in Narragansett Bay have developed only in the last decade. The Narragansett Bay Project outlined a recommended bay –wide monitoring plan in 1992 (Taylor, et al., 1992). The plan was partially implemented when URI-GSO deployed three continuous water quality monitoring stations as part of a research effort led by Dr. Dana Kester. The Narragansett Bay National Estuarine Research

Reserve also added two stations in the early 1990s. Additional progress was made when an interagency collaborative research and monitoring effort was established in 1998 among NOAA, DEM, the University of Rhode Island and other partners. Known as the Bay Window Program, it provided support to expand continuous monitoring of water quality as part of a larger effort to improve the understanding of the Narragansett Bay ecosystem. In 2001, the Narragansett Bay Commission, a quasi-state regional wastewater management authority, deployed two stations in the Providence and Seekonk Rivers with EPA funding from its EMPACT program. By 2004, eight locations were continuously monitored by four organizations: URI-GSO, NBNERR, NBC, and RIDEM. These sites constituted the basis for officially establishing the fixed-site network in 2004. Since that time, this collaborative monitoring program has been maintained and expanded to 13 stations in part with federal grant funds provided by the NOAA Bay Window Program, EPA Clean Water Act (sections 319 & 106) and NOAA National Estuarine Research Reserve System's System Wide Monitoring Program (NERRS-SWMP). Rhode Island Department of Environmental Management's Office of Water (RIDEM-OWR) serves as the lead agency for the NBFSMN. The participating agencies are listed at the beginning of this document. Those that maintain monitoring stations are noted in **Table 1**. The network is a key component of Rhode Island's strategy for monitoring Narragansett Bay. Working with partners, RIDEM-OWR coordinates the program to produce data to support management decision-making including the periodic assessment of the Bay's water quality conditions in relation to Rhode Island's water quality criteria.

- <u>Expansion of the NBFSMN: 2005-2008:</u>

Funding from NOAA was instrumental in allowing the NBFSMN to expand. Prior to the grant award, which is the subject of this report, a plan for expanding the network to provide bay wide data was developed establishing a need for 19 stations.

With the initial NOAA grant award, RIDEM procured new equipment to allow the deployment of three new stations in 2005 (**Figure 4**). These stations were Conimicut Point, Mt. Hope Bay, and Quonset Point. Conimicut Point was selected to restore monitoring at a previously established site in this area to gain higher resolution in the Upper Bay, especially, at a hydrodynamic restricted area. Mt Hope Bay was selected because limited data was available for this embayment. Quonset Point was established to have temporal data further down bay in the west passage to document the potential hypoxia risk indicated by past spatial surveys.

Funds available from increases in FY06 and FY07 to the NOAA grant award allowed stations to be upgraded. NOAA funding in combination with Rhode Island state funds were used to upgrade equipment at all established site to have better continuity between stations and improve quality assurance measures. Stations were equipped with data back-up measures to minimize data gaps and extended deployment instrumentation to reduce the potential for erroneous data.

Once the upgrades were complete, technical meetings were conducted to prioritize areas in need of higher temporal resolution to better determine the impact of hypoxia in the bay. Based on these meetings, Greenwich Bay was identified as the area with the greatest need for further research. In 2008, Sally Rock, a mid-bay station, was established on a seasonal basis in Greenwich Bay. This was done in recognition that the existing station located at Greenwich Bay Marina, a station on the western edge of the bay, was not representative of the conditions in Greenwich Bay as a whole and would not be expected to serve as the best location to capture any effects of the recently upgraded wastewater treatment facilities (WWTF). Sally Rock was chosen, based on scientific consensus, to provide the needed supplemental temporal information and support additional research activities.

- Operation and Maintenance of NBFSMN: 2005-2008

During 2005-2008, the network was reliably maintained by the primary collaborating agencies. RIDEM contracts with URI-GSO for technical services to operate and maintain nine stations in the network. A single quality assurance project plan (QAPP) was developed to document the protocols used by the agencies in operating the network. The plan is entitled Quality Assurance Project Plan: Narragansett Bay Fixed-Site Water Quality Monitoring Network Seasonal Monitoring and is available through the network website: www.dem.ri.gov/bart/stations.

The plan extensively covers the operations, maintenance, and quality assurance measures of the equipment used to run the NBFSMN stations. Parameters measured are temperature, salinity, and dissolved oxygen at near-surface and near-bottom depths, and near-surface chlorophyll fluorescence using *YSI* instrumentation (**figure 3a & 3b**). Conditions are monitored on a 15-minute basis for high-resolution temporal data. These parameters and station locations provide a water column view of physical water quality conditions that influence hypoxia in the bay.

**Figure 3a**. Surface and bottom sonde deployment at NP buoy.

**Figure 3b**. YSI 6600 EDS Sonde.

When equipment fails or data is missing it is documented in a metadata document that accompanies each stations dataset on an annual basis. Each station manager is responsible for maintaining and operating each station to the best of its ability. If problems should occur, the quality assurance officer is notified and the justification is noted in the metadata document. Problems range from sensor failure to station failures. A large upgrade to existing equipment was conducted during 2006 and 2007 by RIDEM to minimize data gaps, improve sensor quality, and reduce bad data caused by fouling. Using NOAA funding, all the critical stations were upgraded to allow for data back up by updating data transfer components as well as sonde logging capabilities. All stations are now equipped with back up systems and minimize fouling effects through the use of the extended deployment sondes. These upgrades have helped to improve the quality of data from 2005-2008.

*Data Distribution of NBFSMN*

Through electronic file sharing mechanisms, RIDEM-OWR has direct access to downloaded data from critical stations in the upper Bay and Greenwich Bay in order to systematically track water quality conditions. NBC provides real-time data access to the public via www.narrabay.com website. As part of the agreement, URI-GSO summarized the continuous data for a weekly RIDEM website updates and monthly graphic interpretations using daily averages and raw data. These graphs are accessible via the URI Coastal Institute's website (www.narrabay.org) and the RIDEM website (www.dem.ri.gov/bart). These websites coordinated with the other public outreach activities described in the Bay Window Project plans submitted by URI. RIDEM-OWR, through staff support at URI-GSO and NBNERR, compile the data into a single database to facilitate the review of the data from the fixed-station network. Datasets from all stations is now available through RIDEM-OWR, the lead agency for the Narragansett Bay Fixed-Site Monitoring Network (www.dem.ri.gov/bart/stations).

In addition to state managers, the data are relied upon or being used by researchers at several agencies and institutions. Operation of the network has also been noted by newly created regional associations developing coastal and ocean observing systems, including New England Regional Association of Coastal and Ocean Observing Systems and the Mid-Atlantic Coastal and Ocean Observing Regional Association. As appropriate and feasible, the NBFSMN will coordinate data distribution activities with these organizations to support the mutual goal of fostering an integrated and comprehensive monitoring program in coastal waters.

In addition, through collaboration between the NBFSMN manager and principle investigators of the Narragansett Bay Coastal Hypoxia Research Program (CHRP), managers and scientists meet annually to present findings and discuss preliminary results. This dialogue is aimed at informing decision-making by managers and focusing research to assist management needs. These proceedings from the meetings are available to the public through URI-GSO Marine Ecosystem Laboratory's website (http://www.gso.uri.edu/merl/merl.html).

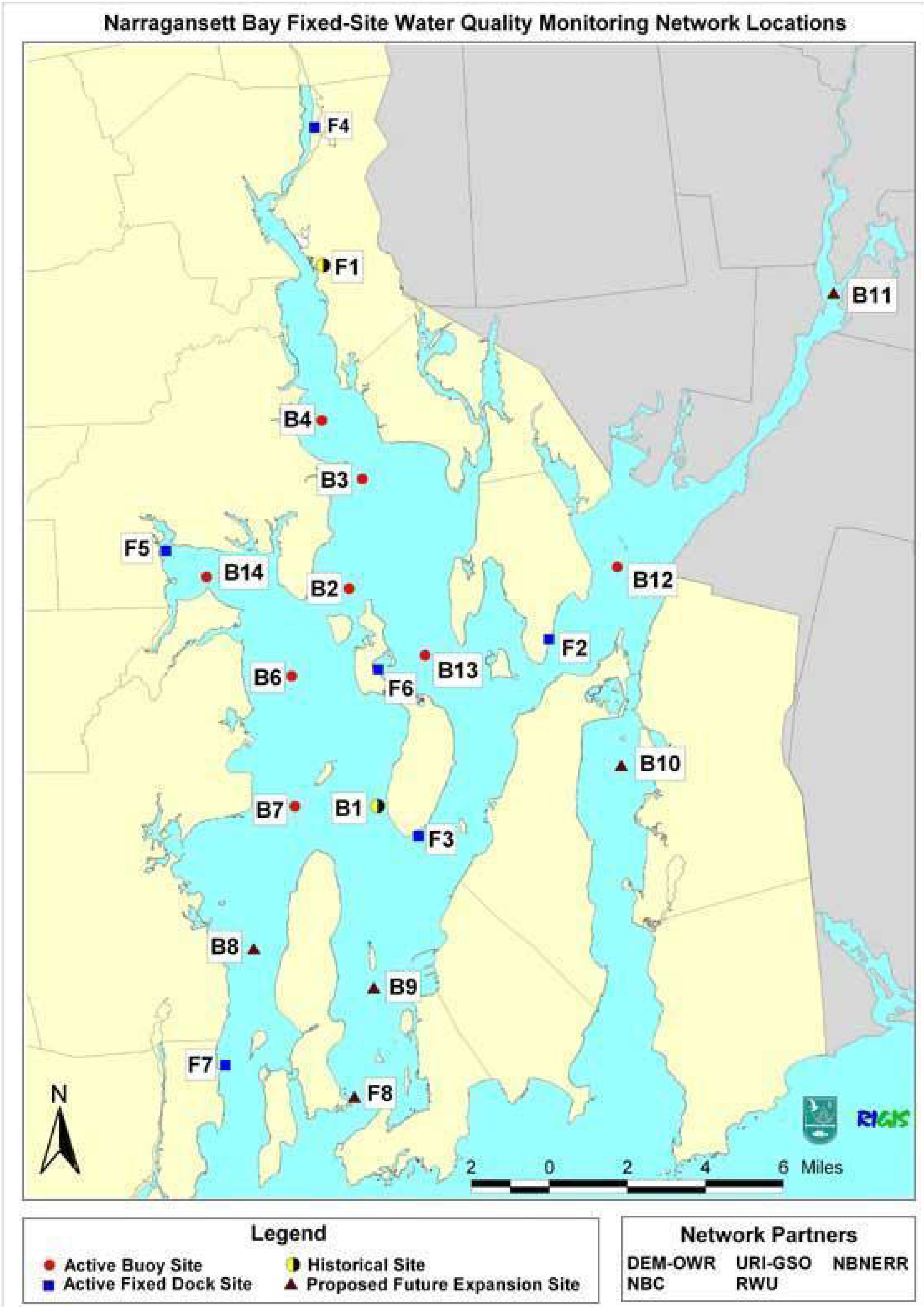


**Figure 4**. NBFSMN Station Locations- 2008

**Table 1.** Station and Sampling Characteristics of Fixed-Site Network[a].

| Group | Station | Latitude N | Longitude W | Water Depth[b] (m) | Agency | Years Sites Operational |
|---|---|---|---|---|---|---|
| Upper bay | Phillipsdale (PD-F4) | 41 50.505 | 71 22.332' | | NBC | 2001-present |
| | Bullock Reach (BR-B4) | 41 44.434' | 71 22.480' | 6 | NBC | 2001-present |
| | Conimicut Point (CP-B3) | 41 42.828' | 71 20.628' | 7 | GSO/DEM | 2003, 2005-present |
| | North Prudence (NP-B2) | 41 40.224' | 71 21.283' | 11 | GSO/DEM | 1999-present |
| West passage | Mt. View (MV-B6) | 41 38.304' | 71 23.621' | 7 | GSO/DEM | 2004-present |
| | Quonset Point (QP-B7) | 41 35.288' | 71 22.839' | 7 | GSO/DEM | 2005-present |
| | GSO Dock (GD-F7) | 41 29.535 | 71 25.137 | 2 | GSO/DEM | 1995-present |
| East passage | Popposquash Point (PP-B13) | 41 38.907' | 71 19.207' | 8 | GSO/DEM | 2004-present |
| | Potter's Cove (PC-F6) | 41 38.435 | 71 20.467 | 1 | NBNERR | 1995-present |
| | T-Wharf (TW-F3) | 41 34.731' | 71 19.287' | 6 | NBNERR | 2003-present |
| Embay-ments | Greenwich Bay Marina (GB-F5) | 41 41.090' | 71 26.762' | 3 | GSO/DEM | 2003-present |
| | Sally Rock (SR-B14) | 41 40.518 | 71 25.437 | 4 | GSO/DEM | 2008-present |
| | Mt. Hope Bay (MH-B12) | 41 40.808' | 71 12.913' | 5 | GSO/DEM | 2005-present |

*Station F2 was operated by Roger Williams University in 2006. In 2006, a power surge destroyed the dock-based station. It has not been returned to operation.*

*a. All data from 2003-present available at http://www.dem.ri.gov/bart/stations.htm.*
*b. Depths relative to Mean Lower Low Water.*
*c. Each station has a shallow and a deep sensor; except for Potter's Cove and GSO Dock.*
*d. Year-round dock stations: Phillipsdale, GSO Dock, T-wharf, Greenwich Bay Marina*
*e. T-Wharf has data available from a nearby station from 1996-2002.*

**Data Synthesis and Results**

The fixed-station network continues to provide a time-series data set important to state managers and researchers striving to improve the understanding of water quality conditions and ecological functioning in the upper Bay and other areas sampled. Prior monitoring efforts have documented that the upper Bay including the estuarine Providence River experience hypoxia (Deacutis, et al, 2006; Bergondo et al, 2005, RIDEM, 1997). In recent years, data reveals that summer low oxygen events in bottom waters of the Bay are episodic and can be widely distributed. In 2003, fixed-station monitoring revealed that hypoxic waters were found all the way down Bay to Dutch Island in the lower West Passage (B. Sullivan personal communication with C. Oviatt). That same year, a massive fish kill in Greenwich Bay dramatically focused public attention on the problem of low dissolved oxygen. (RIDEM, 2003) With additional monitoring targeting this pollution problem, researchers and resource managers have been able to better characterize the frequency and duration of hypoxia. A sustained and expanded monitoring program remains needed to both further define existing water quality conditions and track changes over time.

One data objective for the network is to produce information to support analysis of the spatial and temporal distribution of hypoxia in Narragansett Bay during the summer. The network is the primary source of detailed temporal data that helps define events. Network data is used in conjunction with information from other monitoring programs that have greater spatial coverage of Narragansett Bay to understand water quality conditions. These programs, partially funded through the Bay Window Program, include: (1) monthly year-round monthly ecological monitoring surveys conducted by NOAA National Marine Fisheries Service (NMFS) with support from RIDEM Marine Fisheries Section focused on the spatial distribution of primary productivity throughout the deeper sections of the bay, including the lower bay; (2) the seasonal spatial water quality surveys , known as the “Day Trippers” (consisting of Brown University, NBEP/DEM, and Save the Bay) which profile water quality at over 70 locations in the Providence River, Greenwich Bay, and the Upper East and West Passages of Narragansett Bay on a bi-monthly basis. These spatial surveys are snapshots of the water quality conditions throughout the bay for a given day. Continuous monitoring provides information needed to define the temporal variability of water quality. This level of observation will capture events that occur on short time scales (hours to days) or during times when it is impractical to deploy field crews.

Continuous monitoring captures the daily variability in water quality to provide managers and scientists with the information necessary to fully assess criteria attainment throughout the bay. It also provides early warning of potential harmful algae blooms and low-dissolved oxygen related fish kills, allowing managers to coordinate appropriate supplemental sampling (e.g., plankton sampling) or prepare for responses to environmental events; e.g. fish kills.

The data results from the NBFSMN are analyzed in conjunction with the spatial surveys by RIDEM-OWR to fully assess water quality conditions within Narragansett Bay. To help understand the ecological implications to Narragansett Bay, hypoxia trends are characterized in several ways including measuring intermittency of hypoxic events through inter-annual variability, geographic patterns, and state assessment trends.

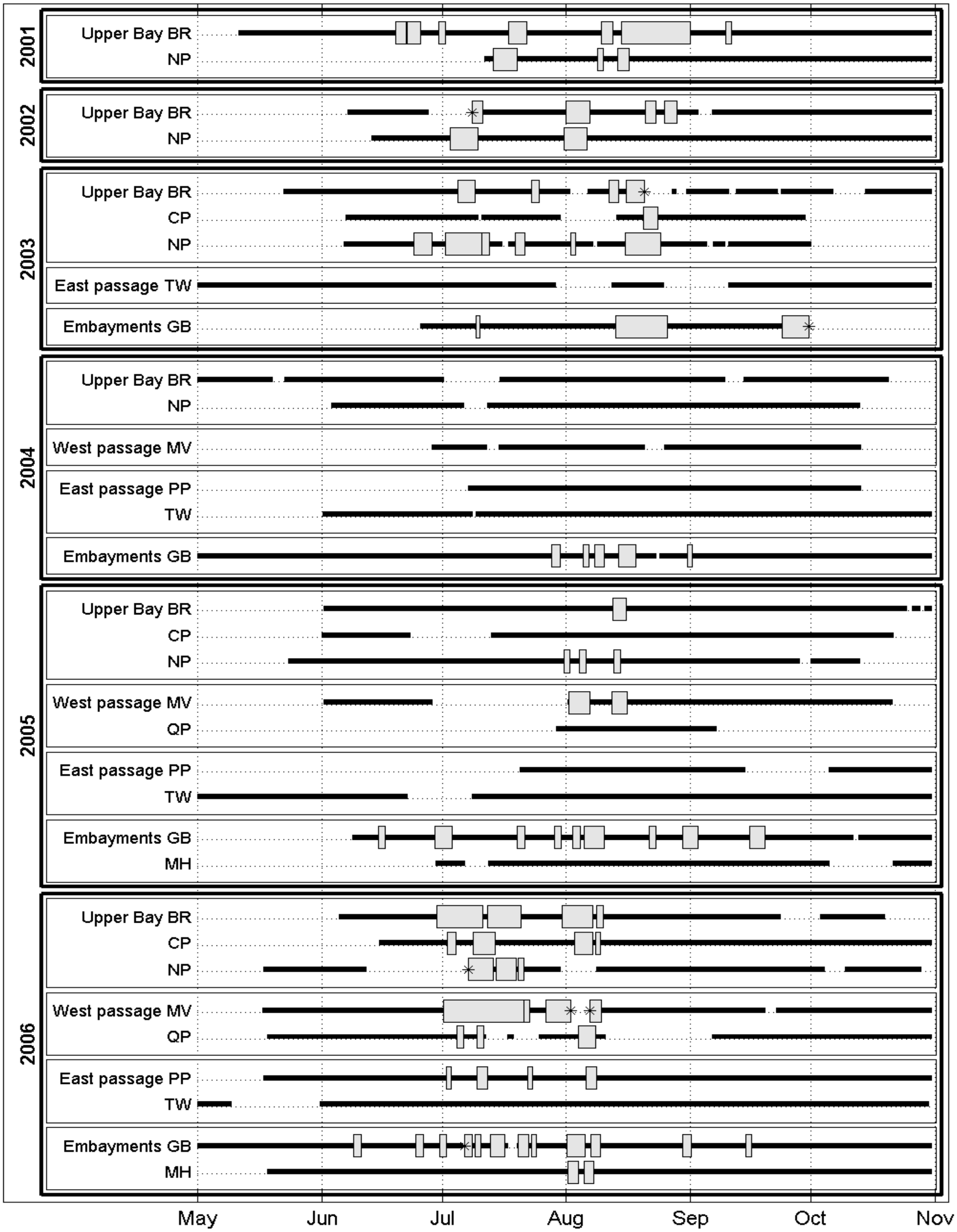


**Figure 5**. Hypoxic events at all station locations from 2001-2006 (Codiga, D., et.al, submitted). *Black lines indicate sampling period coverage and gaps are shown for each year, from May to October. Boxes indicate hypoxic events. * Indicates data gaps during an event. Refer to Table 1 for station identifications.*

**Status and Trends**

The NBFSMN is providing data used by both managers and researchers to better characterize hypoxia in Narragansett Bay. The results from analyses of multi-year datasets are highlighted below. The analyses draw upon information available (2001-2008) in time-series records from the monitoring network in the northern portion of the bay (**figure 4**), where nutrient loadings and hypoxia are known to be severe.

*Hypoxia Definitions*

Hypoxia refers to conditions where the dissolved oxygen concentration decreases to the point where organisms are adversely affected. The State of Rhode Island has adopted dissolved oxygen criteria that reflect the following thresholds for estuarine surface waters: 4.8 mg/L instantaneous values, 2.9-mg/L/24- hour average value, and 1.4 mg/L/one- hour average for below the pycnocline of stratified waters. Description of the full criteria is contained in the RI Water Quality Regulations (RIDEM, 2006). These criteria are based on the lethality of low oxygen to various marine organisms at various life stages in Narragansett Bay. Adapted from the federal Environmental Protection Agency guidance, the Rhode Island DO criteria for saltwater is designed to provide protection to all life stages from larval through adult.

*Intermittent Hypoxic Event Trends*

The datasets for 2001-2006 were analyzed to identify hypoxic events (**figure 5**) as defined by thresholds consistent with state water quality criteria using an algorithm developed through collaboration with members of the Narragansett Bay Coastal Hypoxia Research Program (NBCHRP). These events were then analyzed to determine trends.

When the dissolved oxygen data is looked at on a bay wide scale, there are substantial temporal and spatial variations. Temporal differences in dissolved oxygen concentrations occur diurnally, seasonally, and annually.

The deeper upper bay bottom water conditions show little diurnal changes in oxygen concentrations compared to the shallower embayments. Greenwich Bay shows the largest diurnal variation compared to any other site (see appendix B). The Greenwich Bay station is strongly influenced by photosynthetically produced oxygen. High chlorophyll levels dominate the diurnal cycle of surface and bottom oxygen concentrations in the water column of the western portion of Greenwich Bay during the summer season.

Hypoxia typically occurs intermittently seasonally from late June through early September, at most northern stations. These northern stations, excluding the Phillipsdale site which was not part of the NBCHRP analysis, generally document 1-11 events with nominal durations of 2-7 days, totaling 5-35 days seasonally depending upon the station location and year (**Table 2**) (Codiga, D., et al, submitted). Seasonally, hypoxia affects the areas from the Seekonk River to Mt. View in the west passage and Poppasquash Point in the east passage. Each season is variable on the temporal and spatial extent of the hypoxic conditions documented at these stations.

Inter-annual variability of hypoxia is prominent in the Upper Bay and is linked to freshwater inflow. In general, the higher the seasonal freshwater inflow, the more severe the cumulative hypoxia is on an annual basis (**Figure 7**). The hypoxia also follows the north-south pollution gradient, with the exception of Greenwich Bay. Therefore, the years with the highest cumulative hypoxia also have the largest spatial extent down bay. The number and duration of hypoxic events down bay are higher in the west passage compared to the east passage. This is expected since the west passage has a predominant outflow pattern while the east passage has a predominant in-flow of waters from Rhode Island Sound (Pilson, 1985).

The higher the intensity and/or duration of a hypoxic event the more detrimental it is to organisms exposed to these conditions. The forcing factors such as river runoff, a source of nutrients and enhanced stratification, significantly attribute to the intensity and duration of the hypoxic events documented in the Upper Bay. The relationships among these forcing factors and water quality are being further explored by researchers, including within the Bay Window Program.

**Table 2.** Statistics of hypoxic events for data available from June 1 through September 30.

| Year | Stn | Cum. sam-pling [dy] | Num. evts.[a] | Indiv. event duration[a] [dy] | | | Indiv. Event min. conc.[a] [mg $L^{-1}$] | | | Seasonal duration (cum. events)[b] | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Min. | Mean | Max. | Min. | Mean | Max | Abs.[c] [dy] | Sampl. norm'd[c] |
| 2001 | BR | 121.0 | 7 | 1.6 | 4.8 | 17.1 | 0.6 | 1.4 | 2.3 | 33.8 | 0.279 |
| | NP | 81.0 | 3 | 1.3 | 3.4 | 5.8 | 1.2 | 1.4 | 1.6 | 10.2 | 0.126 |
| 2002 | BR | 100.0 | 3 | 2.5 | 3.9 | 6.0 | 0.3 | 1.4 | 2.0 | 14.2 | 0.142 |
| | NP | 108.0 | 2 | 5.6 | 6.2 | 6.9 | 0.7 | 0.7 | 0.7 | 12.5 | 0.115 |
| 2003 | BR | 104.0 | 3 | 1.9 | 2.9 | 4.2 | 1.1 | 1.5 | 1.8 | 13.0 | 0.125 |
| | CP | 100.0 | 1 | 3.4 | 3.4 | 3.4 | 1.0 | 1.0 | 1.0 | 3.4 | 0.034 |
| | NP | 110.0 | 6 | 1.3 | 4.6 | 9.1 | 0.0 | 1.0 | 1.8 | 27.9 | 0.253 |
| | GB | 96.0 | 2 | 1.1 | 6.9 | 12.7 | 0.0 | 0.0 | 0.0 | 20.5 | 0.213 |
| | TW: no events | | | | | | | | | | |
| 2004 | GB | 120.0 | 5 | 1.2 | 2.3 | 4.2 | 0.1 | 0.4 | 0.7 | 11.4 | 0.095 |
| | BR, NP, MV, PP, TW: no events | | | | | | | | | | |
| 2005 | BR | 121.0 | 1 | 3.3 | 3.3 | 3.3 | 1.9 | 1.9 | 1.9 | 3.3 | 0.027 |
| | NP | 119.0 | 3 | 1.3 | 1.6 | 1.8 | 1.0 | 1.3 | 1.7 | 4.8 | 0.041 |
| | MV | 86.0 | 2 | 3.9 | 4.5 | 5.1 | 1.3 | 1.6 | 1.9 | 9.1 | 0.105 |
| | GB | 113.0 | 9 | 1.6 | 2.8 | 5.1 | 0.0 | 0.5 | 1.1 | 25.5 | 0.226 |
| | CP, QP, PP, TW, MH: no events | | | | | | | | | | |
| 2006 | BR | 110.0 | 4 | 1.5 | 7.2 | 11.3 | 0.7 | 1.0 | 1.3 | 28.7 | 0.261 |
| | CP | 107.0 | 4 | 1.1 | 3.3 | 5.4 | 1.1 | 1.3 | 1.5 | 13.2 | 0.123 |
| | NP | 86.0 | 2 | 1.4 | 3.2 | 5.0 | 1.4 | 1.7 | 2.0 | 12.7 | 0.148 |
| | MV | 113.0 | 2 | 1.4 | 10.7 | 20.0 | 0.1 | 1.0 | 1.8 | 30.3 | 0.268 |
| | QP | 82.0 | 3 | 1.6 | 2.5 | 4.1 | 1.0 | 1.4 | 1.6 | 7.4 | 0.091 |
| | PP | 121.0 | 4 | 1.1 | 2.0 | 2.8 | 0.4 | 0.9 | 1.7 | 7.8 | 0.065 |
| | GB | 118.0 | 11 | 1.2 | 2.2 | 4.6 | 0.0 | 0.2 | 0.7 | 26.7 | 0.226 |
| | MH | 121.0 | 2 | 2.3 | 2.5 | 2.7 | 1.4 | 1.5 | 1.5 | 5.0 | 0.041 |
| | TW: no events | | | | | | | | | | |

a. As appropriate for calculation of individual event statistics, the 7 events that start/end adjacent to missing data (*, Fig. 5) are excluded from the "number of events" and the "individual event" columns.
b. As appropriate for calculation of summer-season sums, the 7 events that start/end adjacent to missing data (*, Fig. 5) are included in the "seasonal duration". (Codiga, D., et.al, submitted)

*DEM Assessment of DO Criteria in Narragansett Bay*

In 2006, RIDEM conducted a comprehensive assessment of Narragansett Bay water quality conditions including assessing compliance with the state dissolved oxygen criteria. During this characterization, RIDEM applied newly revised water quality criteria for dissolved oxygen applicable to Narragansett Bay. The revisions of water quality standards and criteria are required under Section 303(d) of the Clean Water Act and USEPA's Water Quality Planning and Management Regulations (40 CFR Part 130). The water quality standards and criteria are aimed at protecting the designated uses of the Bay including its suitability to support aquatic life. This can be viewed as protecting living resources (water quality to support crabs, oysters, and fish) and vital habitats (water quality to support submerged aquatic vegetation - SAV).

The 2006 assessment was made on a seasonal basis that involves examining all data for the period May – October. RIDEM utilizes a customized application of the EPA software program, known as DOCS, to calculate a measure (DOCRI unit) that reflects the cumulative number of exceedences of the applicable DO water quality criteria. A number less than one DOCRI unit meets the criteria; any number one or above is considered a potential impairment. The 2006 assessment resulted in RIDEM designating an additional 7.62 square miles of Narragansett Bay as impaired due to low dissolved oxygen. (Figure 6) This new recognition of this portion of the Bay as impaired is the result of the availability of data. RIDEM does not attribute the conditions to a recent worsening of water quality, but rather believes that hypoxia has likely been occurring in this area for some time.

The RIDEM assessment produced results similar and consistent with the trends described above. The upper bay stations consistently exceed the DO criteria, although the degree of impairment is inter-annually variable. On a season-cumulative basis, there was 1.7 -67 cumulative days, as measured by RIDOCS that exceeded water quality criteria for dissolved oxygen in stratified waters throughout the Upper Bay (**Table 3**). The most severe hypoxia is exhibited at the Phillipsdale station in the estuarine Seekonk River and the Greenwich Bay station. Among years with complete data records, these stations consistently exceed water quality criteria by 51-67 DOCRI units. These areas are also noted to be prone to fish kills caused by anoxic events. Spatially, Bullock Reach, Conimicut Point, and North Prudence show a down bay gradient by the decrease in the number of exceedences. Conditions in Mt. Hope Bay, which are monitored near the state line, also indicate less risk of hypoxia. In addition, GSO Dock, T-Wharf, and Quonset Point are assessed at low risk for hypoxia, showing little to no evidence of hypoxic conditions. To date, the only station to remain consistently below one DOCRI unit is the GSO dock which is currently the southern most station in the network. With the exception of Greenwich Bay, these assessment patterns follow the north-south pollution gradient that is well documented in Narragansett Bay. The seasonal extent of impairments is variable on a temporal (the DOCRI number) and spatial scale (southward extent of impairments).

**Table 3. DOCSRI Results**. Results from the DOCSRI assessment for dissolved oxygen using time-series data. Data greater than 1 DOCSRI unit equals a water quality exceedence for Rhode Island's state water quality criteria for dissolved oxygen for saltwater in stratified waters.

| Station Name | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 |
|---|---|---|---|---|---|---|---|---|
| **Upper Bay:** | | | | | | | | |
| Phillipsdale | | | | **67.2** | **58.2** | 58.2 | **62.8** | |
| Bullock Reach | **49.1** | **29.6** | 28.6 | 6.0 | **12.4** | **39.9** | **7.5** | 46.9 |
| Conimicut Pt | | | 18.2 | | 12.8 | **23.4** | **11.1** | 35.4 |
| North Prudence | **19.4** | **14.8** | **39.1** | **1.7** | **12.3** | 16.8 | **5.3** | 15.7 |
| **West Passage:** | | | | | | | | |
| Greenwich Bay | | | 57.5 | 59.7 | **51.9** | 60.2 | 27.3 | 50.8 |
| Mt. View | | | | **0.3** | **13.5** | **39.6** | 6.8 | 13.3 |
| Quonset Pt | | | | | 0.0 | **15.1** | 0.0 | 1.7 |
| GSO Dock | **0.0** | **0.0** | | **0.0** | **0.0** | **0.0** | **0.0** | **0.0** |
| **East Passage:** | | | | | | | | |
| Popposquash Pt* | | | | **2.6** | 2.3 | **24.5** | **23.2** | 25.8 |
| Mt. Hope Bay | | | | | **0.0** | **9.2** | 0.0 | 4.9 |
| T-Wharf | | | | **0.0** | **0.0** | **1.9** | 0.0 | |

-Blanks indicate no data available for analysis
-Non-Bold indicates data missing during critical period. The less complete dataset likely results in an under-reporting of the seasonal cumulative exposures to low dissolved oxygen levels of concern.
*Popposquash Pt was located about one minute north from 2006-2008.

**Figure 6**. **303(d) Listed areas impaired for hypoxia in Narragansett Bay** (RIEMC, 2008).


*RI000727E-03J and RI007029E-010 added to the 303(d) list in 2008. Previously and remaining listed areas are shaded in yellow.*

*Forcing Factors*

In addition to pollutant loadings resulting from human activities in a watershed, the intensity and duration of seasonal primary production and hypoxic events in stratified water, such as Narragansett Bay, are influenced by several natural forcing factors: stratification, temperature, freshwater in-flow, tidal-mixing, and winds(Bergondo et. al, 2005).

Stratification refers to density differences between the surface and bottom waters being measured. These density differences occur in Narragansett Bay when there are temperature and salinity differences between the surface and bottom waters and vertical mixing from winds and/or tides tend to be reduced. The greater the density difference between the surface and bottom waters the harder it is for oxygen to reach the bottom waters. There is a strong link between stratification and the intensity and duration of a hypoxic event (Codiga, D., submitted). The worst years for hypoxia were 2001, 2003, 2006, and 2008; which correlates, with the years with the most intense stratification.

Warm waters hold less dissolved oxygen. However, data analyses show that temperature appears to less strongly related to seasonal hypoxia in the upper bay than stratification. Temperature varies little on an inter-annual scale compared to freshwater in-flows. 2004 was the coldest year on average in the past 10 years. The colder conditions in 2004 along with less than average flows contributed to decreased stratification and minimal hypoxia bay-wide. However, 2005, one of the warmest years in a 10-year span, also reported below average hypoxia throughout the bay. This year again had below average freshwater flows, limiting primary productivity and stratification. In the Upper Bay, stratification is driven more by lower salinities in the surface water, caused by freshwater in-flow from rivers, than by temperature differences.

Stratification is influenced by freshwater inflows. There are six major rivers dumping into the headwaters, the Providence River and the Upper Bay areas, of the Narragansett Bay estuary (**figure 1**). About eighty three percent of the total surface freshwater input to the bay comes from these major rivers: Taunton, Blackstone, Pawtuxet, Woonasquatucket, Ten Mile, and Moshassuck (Bergondo, et.al, 2005). The Taunton River empties into Mt. Hope Bay, while the others collectively empty into the Upper Bay area.

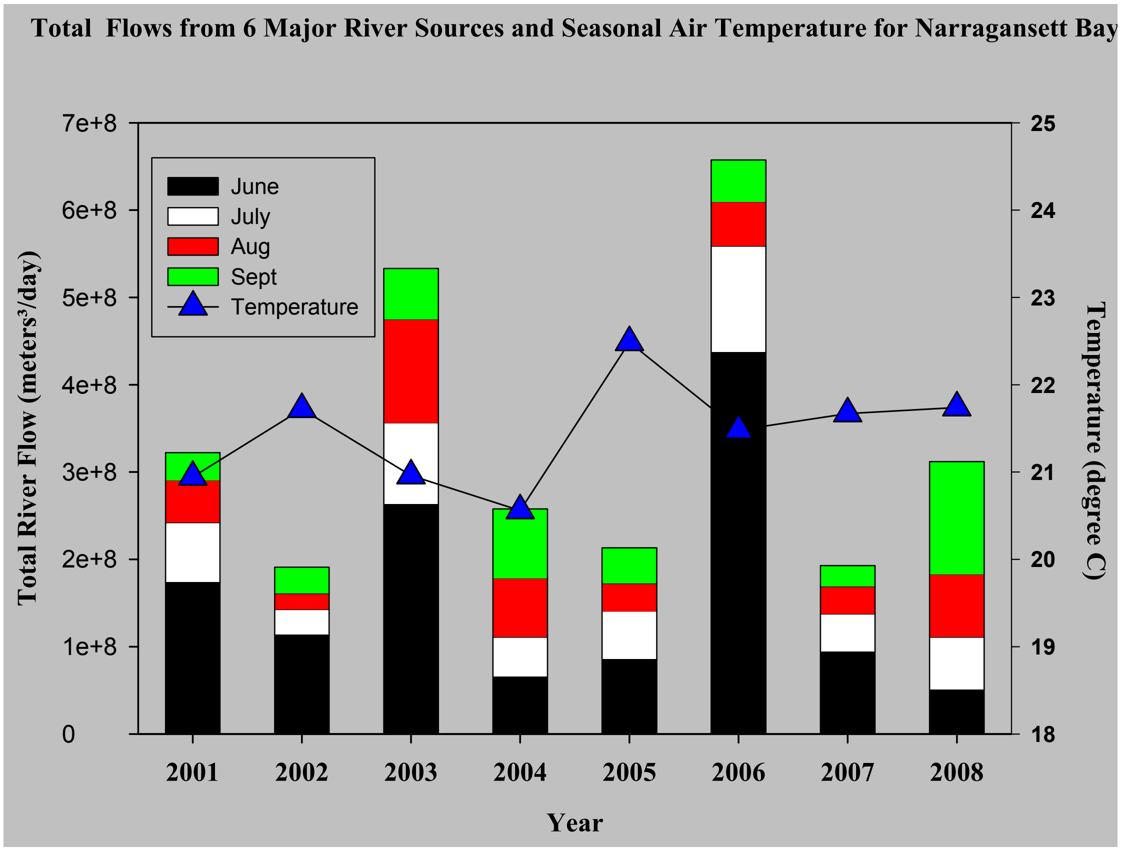


**Figure 7.** Major river flow and seasonal air temperature for Narragansett Bay (Total seasonal river flow from USGS monitored rivers represented by the left *y*-axis and seasonal air temperature from NOAA ports Quonset Pt. data represented by right *y*-axis.)

River flow tends to be greater in the spring (April-June) compared to the summer months (July-September). These spring river flows not only contribute nitrogen to the Bay for primary production, but also contribute to the setup of stratification. Years with the highest flows in June (2001, 2003, and 2006) reported the highest number of hypoxic days. In addition, with the exception of Greenwich Bay, the years with the highest flow of the summer season (2001, 2003, 2006, and 2008) are linked to the longest durations and highest intensities of documented stratification and hypoxic events in the Upper Bay (**figure 7**), (Codiga, D., submitted).

Greenwich Bay is located in a western embayment of Narragansett Bay. The continuous monitoring station along with spatial surveys has confirmed that this area does not follow the north to south pollution gradient. The Greenwich Bay station consistently has among the highest number of exceedences independent of seasonal river flow (**Table 3)**. In addition, Greenwich Bay experiences the highest variability in intensity and the largest cumulative days in duration of hypoxia during a season. The linkage between hypoxic events and stratification due to weak tidal mixing in this area is also variable. Prior research found that when stratification is present and tidal mixing has been reduced; such as during a neap tide, there is a high predictability that a hypoxic event will occur in the Upper Bay (Bergondo, 2005). However, in Greenwich Bay, a hypoxic event can occur independent of tidal mixing (**Figure 8**) (Codiga, D., presentation at NBCHRP meeting).

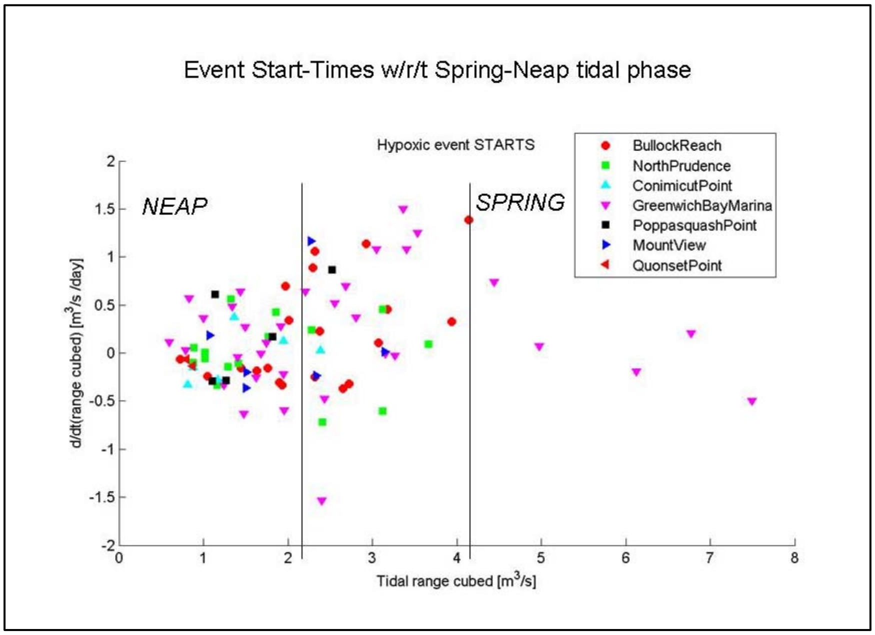


**Figure 8.** Event Start-Times w/r/t Spring-Neap tidal phase (Codiga, D., presentation at NBCHRP meeting).

The reasoning for the high cumulative season impacts and high variability caused by hypoxia in Greenwich Bay is not completely understood. Experts suggest poor flushing and excess nutrients from ground water intrusion among the possible factors influencing the impacts of hypoxia in Greenwich Bay (NBEP, 2008). Some scientists suggest that poor flushing is a result of wind patterns influences. Typical summer wind patterns cause poor water quality waters to potentially build up in the western position of Greenwich Bay (Kincard, C., presentation at NBCHRP meeting). This has been examined more closely by Justin Rogers, a graduate of URI/GSO. Waters in the western portion of the bay have been modeled in response to typical summer wind patterns. The preliminary results show that it is possible for the winds and topography to produce a double gyre circulation pattern in the embayment, resulting in poor flushing of the western portion of Greenwich Bay (**Figure 9**) (Kincard, C., presentation at NBCHRP meeting).

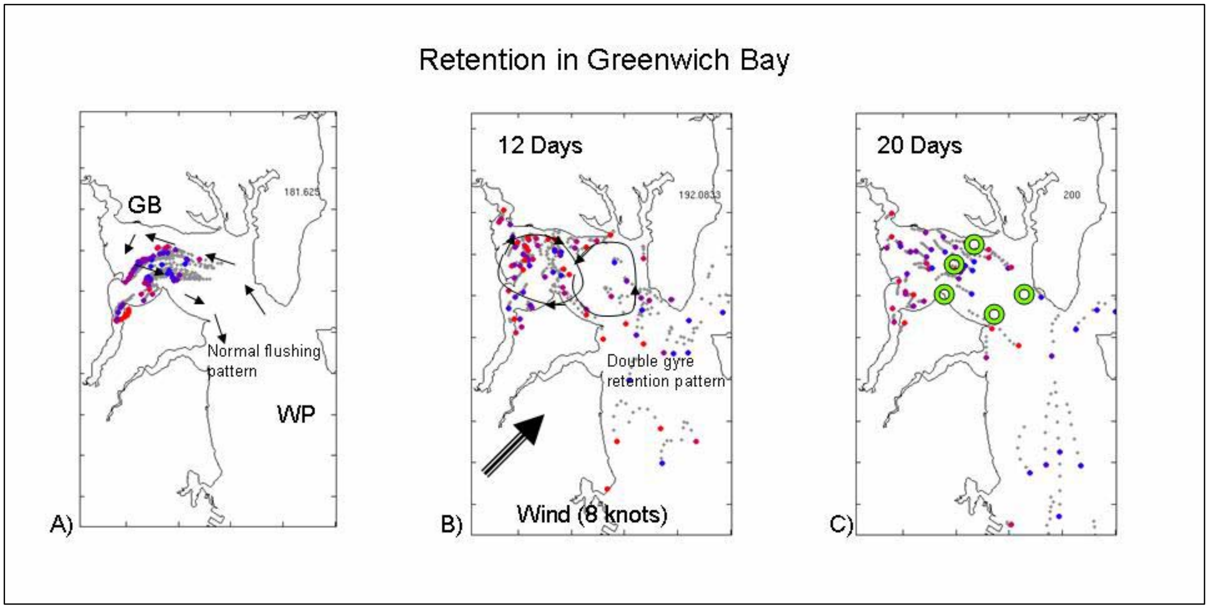


**Figure 9**. Frames from a ROMS model run for summer stratification, intermediate tidal amplitude and runoff and a prevailing (steady) 8 kt applied northeastward wind stress. Tracer floats are used to track water parcels and provide an estimate of advective flushing time for the Greenwich Bay (GB) system. A. Nearly initial tracer locations at day 180. B. After 12 days of simulation, only a small fraction of tracers have left. Prevailing winds set up a double gyre system (shown schematically with arrows) which limits exchange with the West Passage (WP). C. After 20 days only 40% of tracers have flushed from GB, as opposed to ~90% flushing after ~3 days for cases without this wind forcing (shown with arrows in A). The natural progression in the data-modeling cycle is a time series deployment to test this ***model prediction*** of multi-gyre residual flow patterns during specific wind conditions (locations shown in C).

Greenwich Bay water quality is also influenced by groundwater contributions of nitrogen from septic systems operating in the watershed (NBEP, 2008). More research to better characterize the groundwater contributions is needed. It is notable that chlorophyll levels in the Greenwich Bay are higher on average than the other stations in the bay. The levels in Greenwich Bay are comparable to the Providence River. High chlorophyll levels have the potential to influence the high variability in the diel cycle of oxygen in the surface and bottom water. Chlorophyll blooms are generally followed by hypoxic events (Bergondo, 2005). Since Greenwich Bay has some of the highest chlorophyll levels in Narragansett Bay, it is among the areas with the greatest risk for hypoxic and anoxic conditions.

*Application of Data to Management*

The data generated by the NBFSMN is used in various ways by state resource managers. One example involves the state's strategy for reducing nutrient pollutant loadings to Narragansett Bay. Rhode Island public sewer systems currently collect 140 million gallons of wastewater for treatment each day. Over 75% of the treated effluent is discharged directly into estuarine waters, mostly in Narragansett Bay. The remaining

25% is discharged into freshwater rivers; mostly into tributaries that empty into upper Narragansett Bay. In 2005, DEM, building on prior work, released a nutrient reduction plan that applied to 11 RI wastewater treatment facilities (WWTF) and addressed a mandate, prescribed in state law, to reduce seasonal summer nitrogen pollutant loadings into upper Narragansett Bay by 50%. This plan reflects an adaptive management approach that acknowledges another phase of reductions may be required to fully achieve water quality restoration goals. By July 2006, improvements at 8 of the 11 WWTFs had resulted in a 35% reduction. Further reductions at RI facilities are in various stages of planning, design or construction. Additionally, RI has advocated for appropriate reductions from WWTFs located within the Massachusetts portion of the Narragansett Bay watershed. As part of the overall nutrient control strategy, continued monitoring of Narragansett Bay is essential for the near term. The data is needed by managers to assess progress toward water quality restoration goals and provide information important to refining and adapting pollution control management strategies.

**Conclusions**

Deployment and operation of the NBFSMN has generated data that has improved the understanding of hypoxia in Narragansett Bay. The NBFSMN should be sustained in order to provide further accurate water quality information in pivotal areas of Narragansett Bay over time; especially in light of the changes anticipated from current and future implementation of nutrient pollution control measures in the watershed. The information generated from the NBFSMN is useful in many ways. Managers, researchers, and the community use the data. State managers use the information to assess water quality and to enhance management strategies that will help to achieve the ultimate goal of restoring water quality to acceptable conditions to support a healthy Bay ecosystem. Water quality information from NBFSMN is relied upon by researchers and is expected to support refinement, calibration and validation of the ecological and water quality models developed for the bay. For all parties involved, including the public, it is important to continue documenting the bay's water quality conditions and assessing the extent of damaging effects of eutrophication in Narragansett Bay. Long-term continuous monitoring provides information needed to define the temporal variability of hypoxia and track changes in water quality that will result from management strategies to alleviate eutrophication in Narragansett Bay. The data from the NBFSMN will continue to be used for analyzing water quality conditions; measuring trends overtime, identifying impaired waters, and assessing effectiveness of management decisions (i.e. waste water treatment facilities (WWTF) upgrades).

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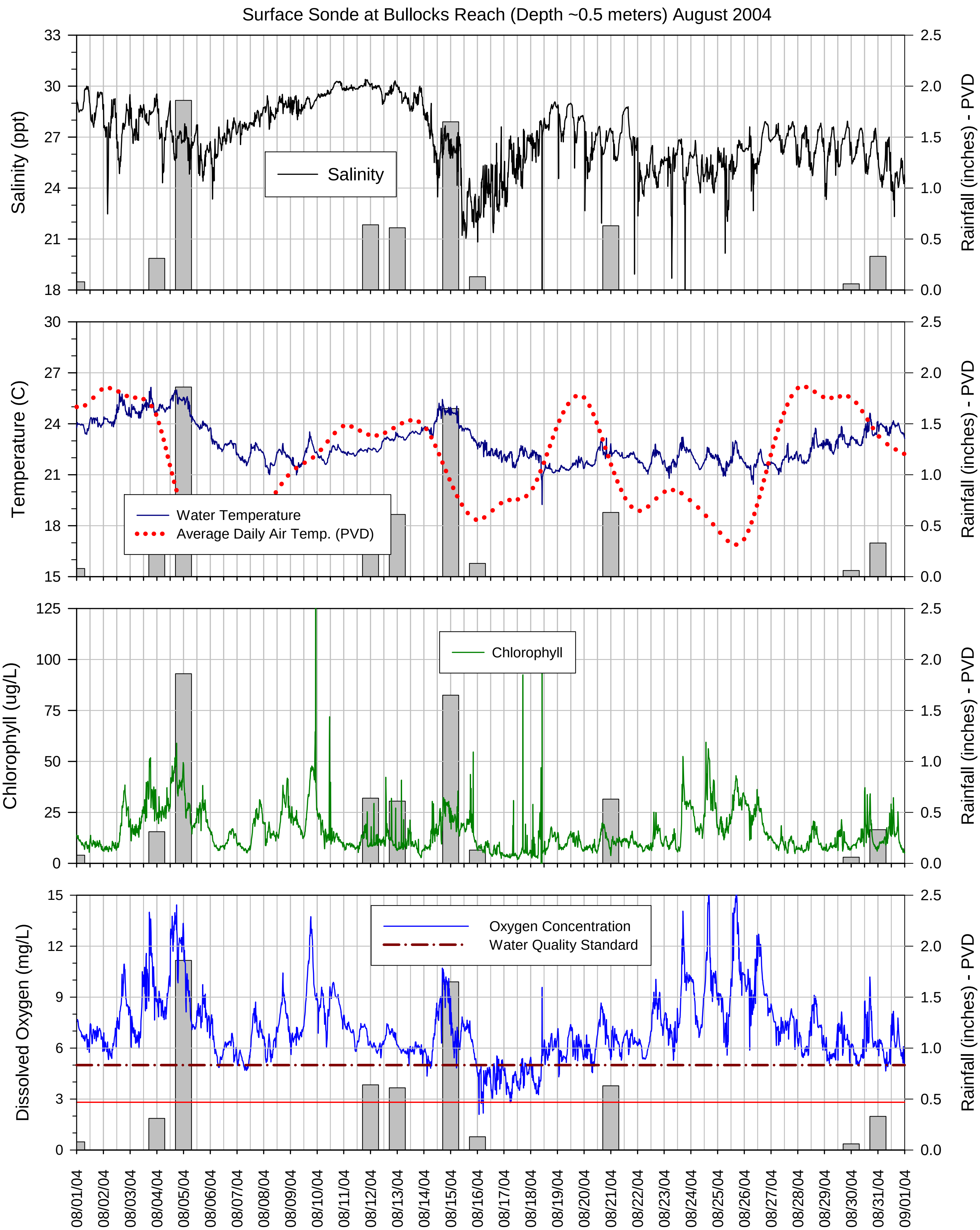
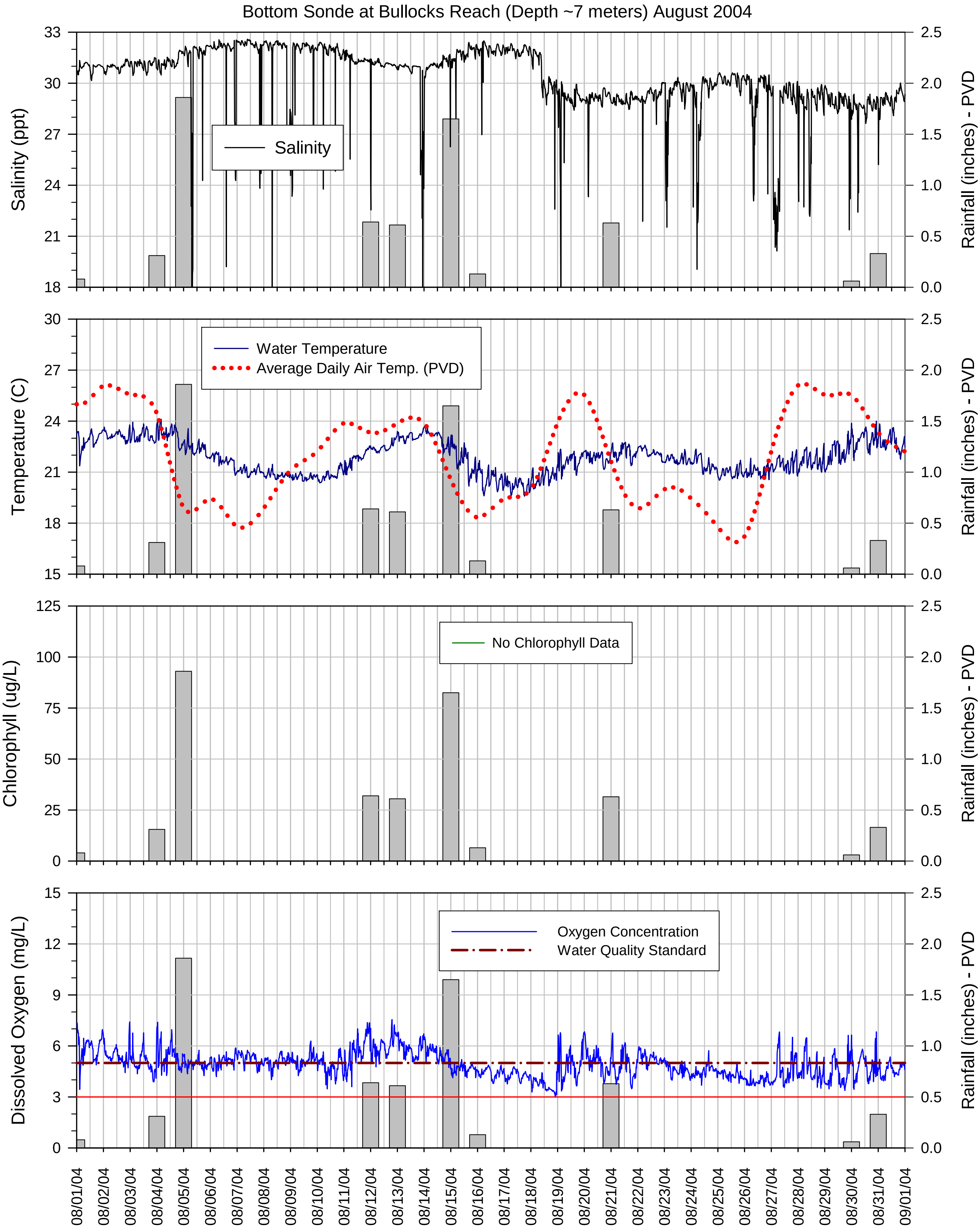
**Appendix A.** Seasonal Monthly Graphics of Critical Stations in Narragansett Bay

(Theses graphs can also be found through www.dem.ri.gov/bart)




The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by the Narragansett Bay Commission.

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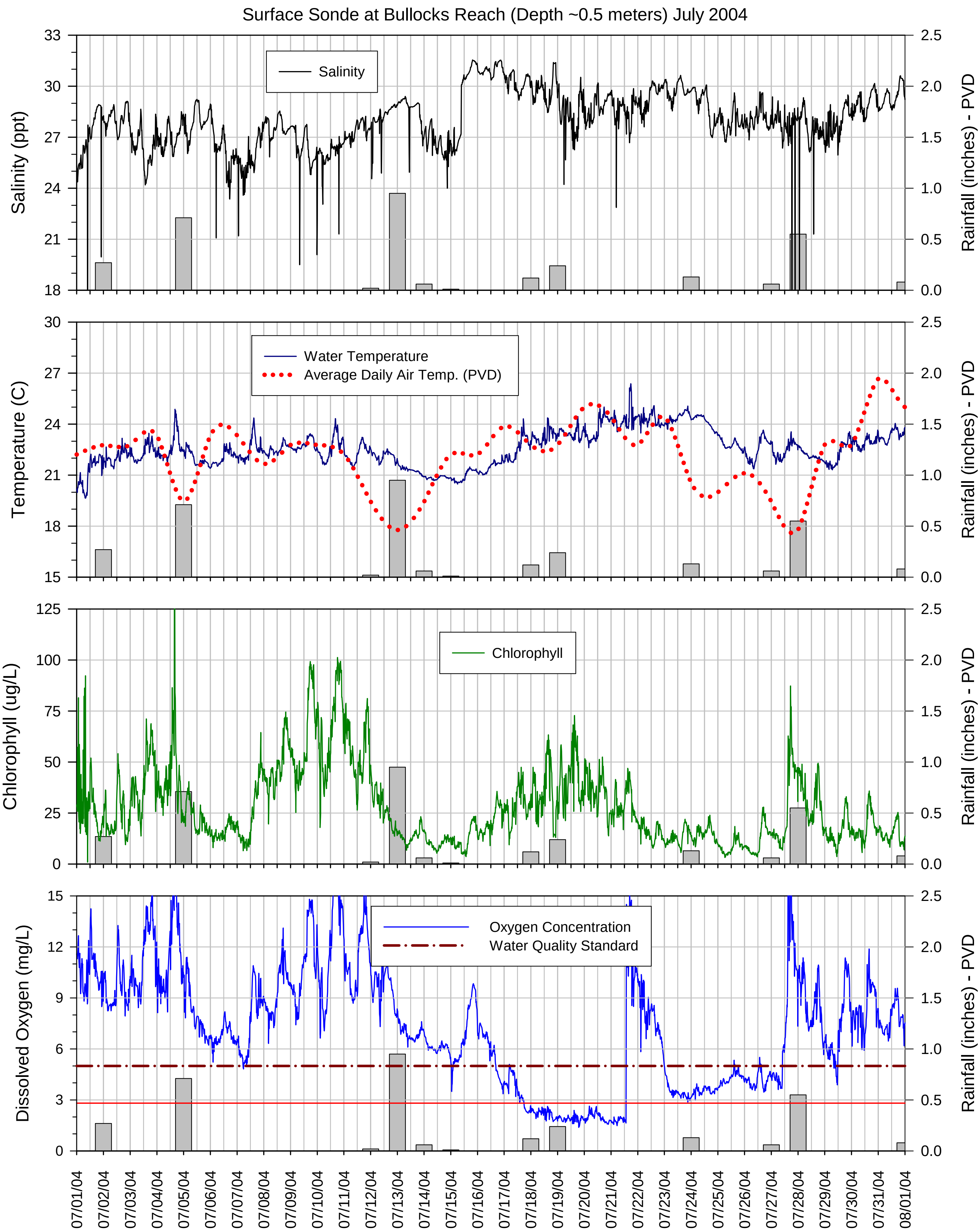


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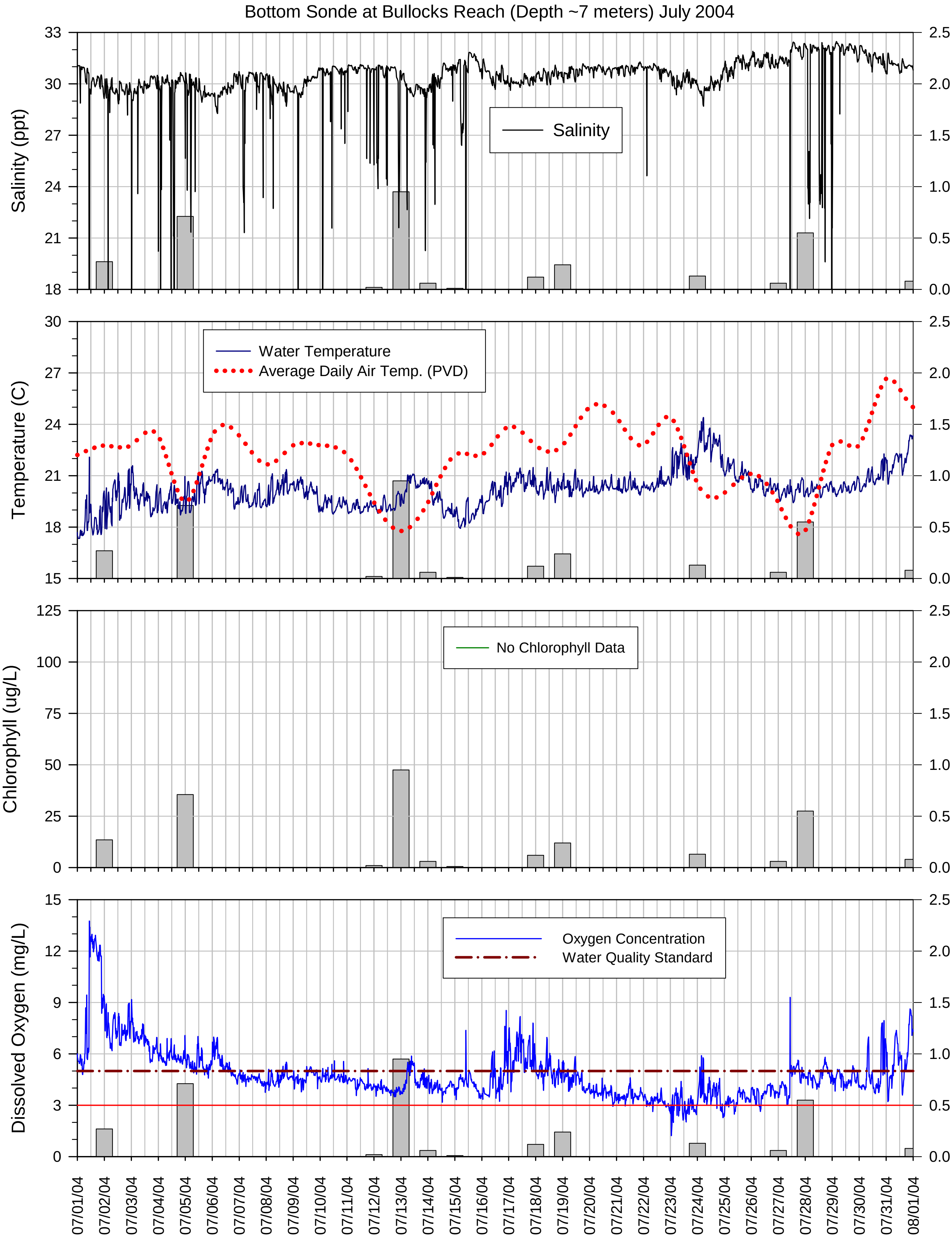


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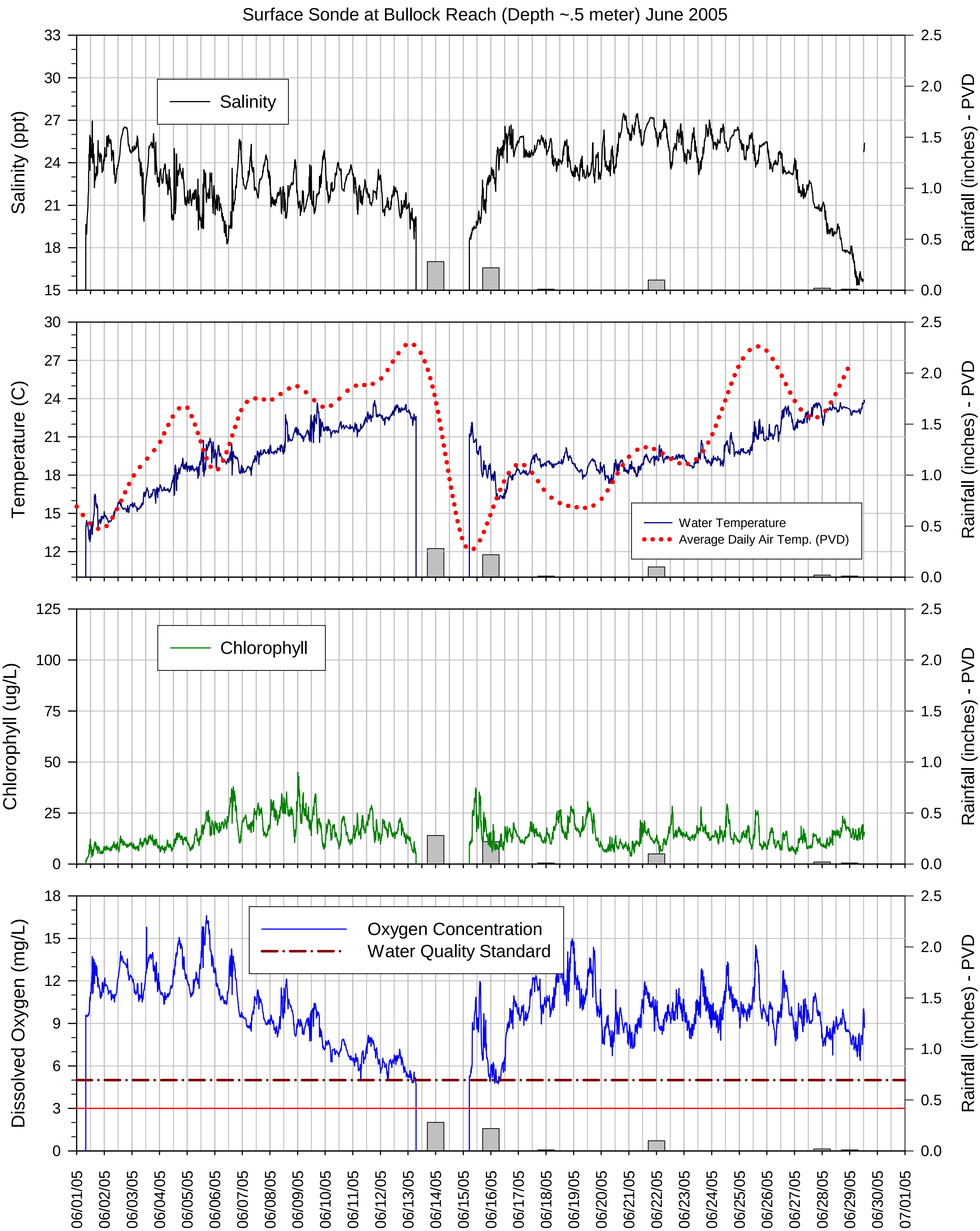


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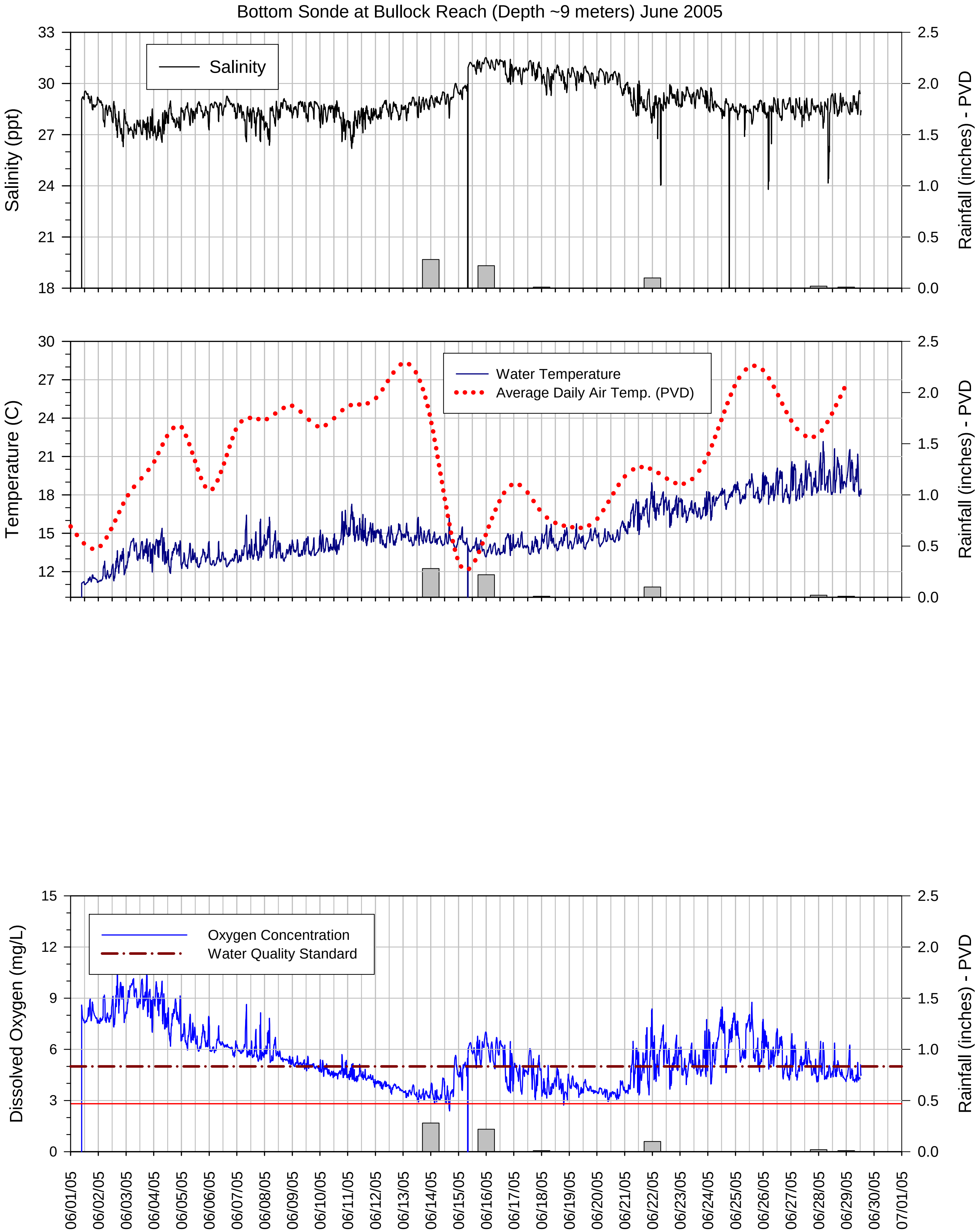


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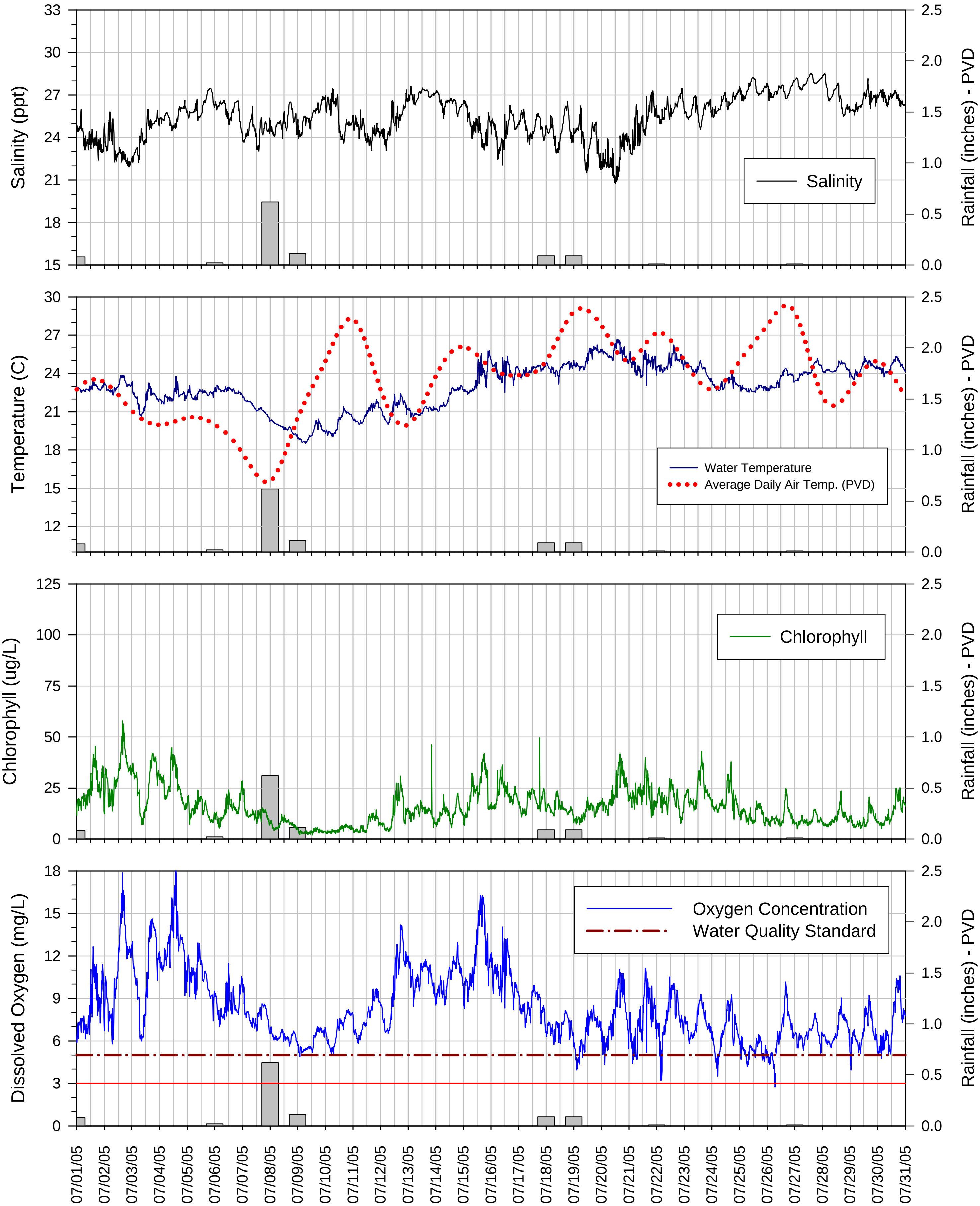
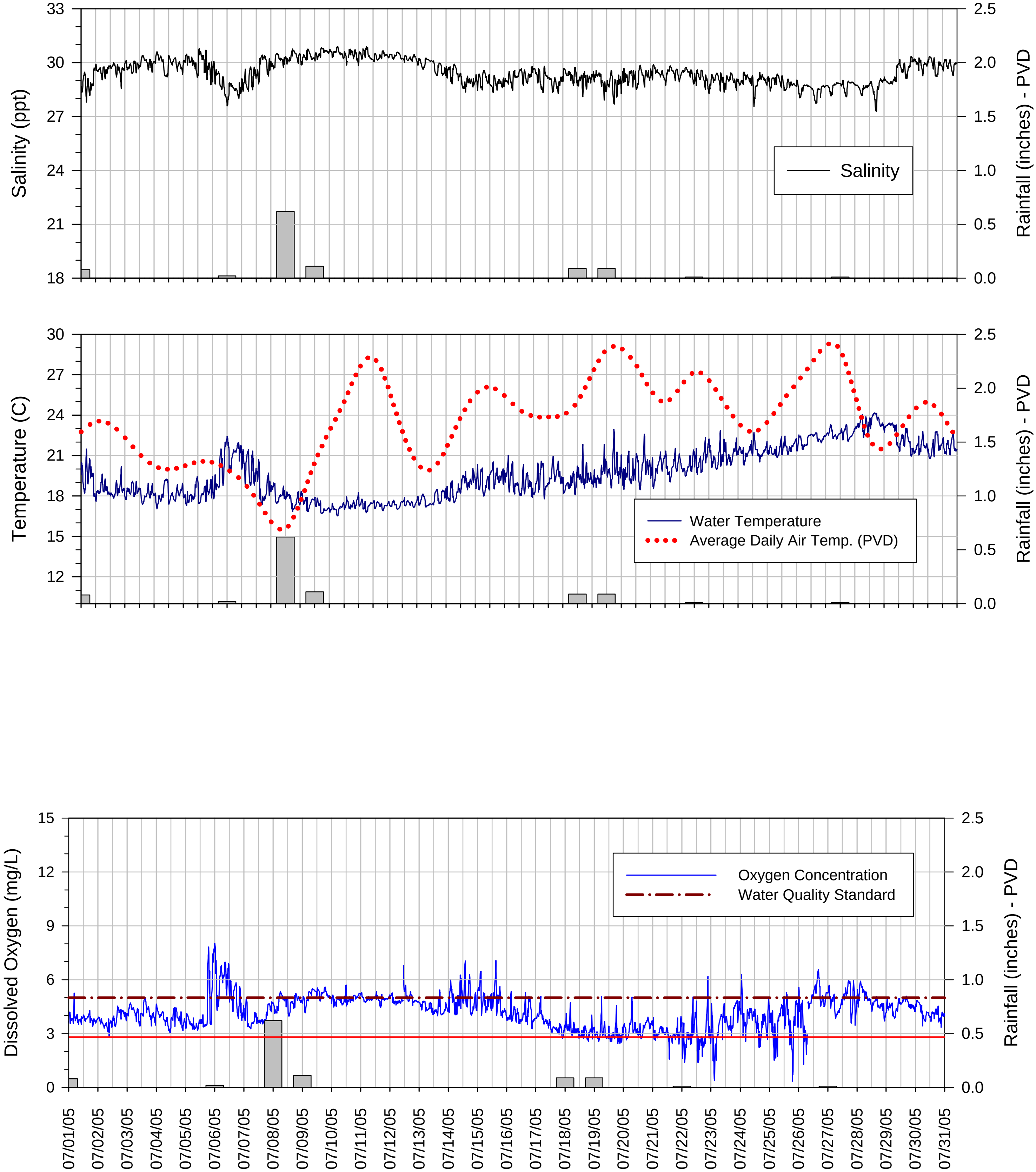
Surface Sonde at Bullock Reach (Depth ~.5 meter) July 2005




The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by NBC. Equipment supplied byRIDEM - Office of Water Resources.

Bottom Sonde at Bullock Reach (Depth ~9 meters) July 2005

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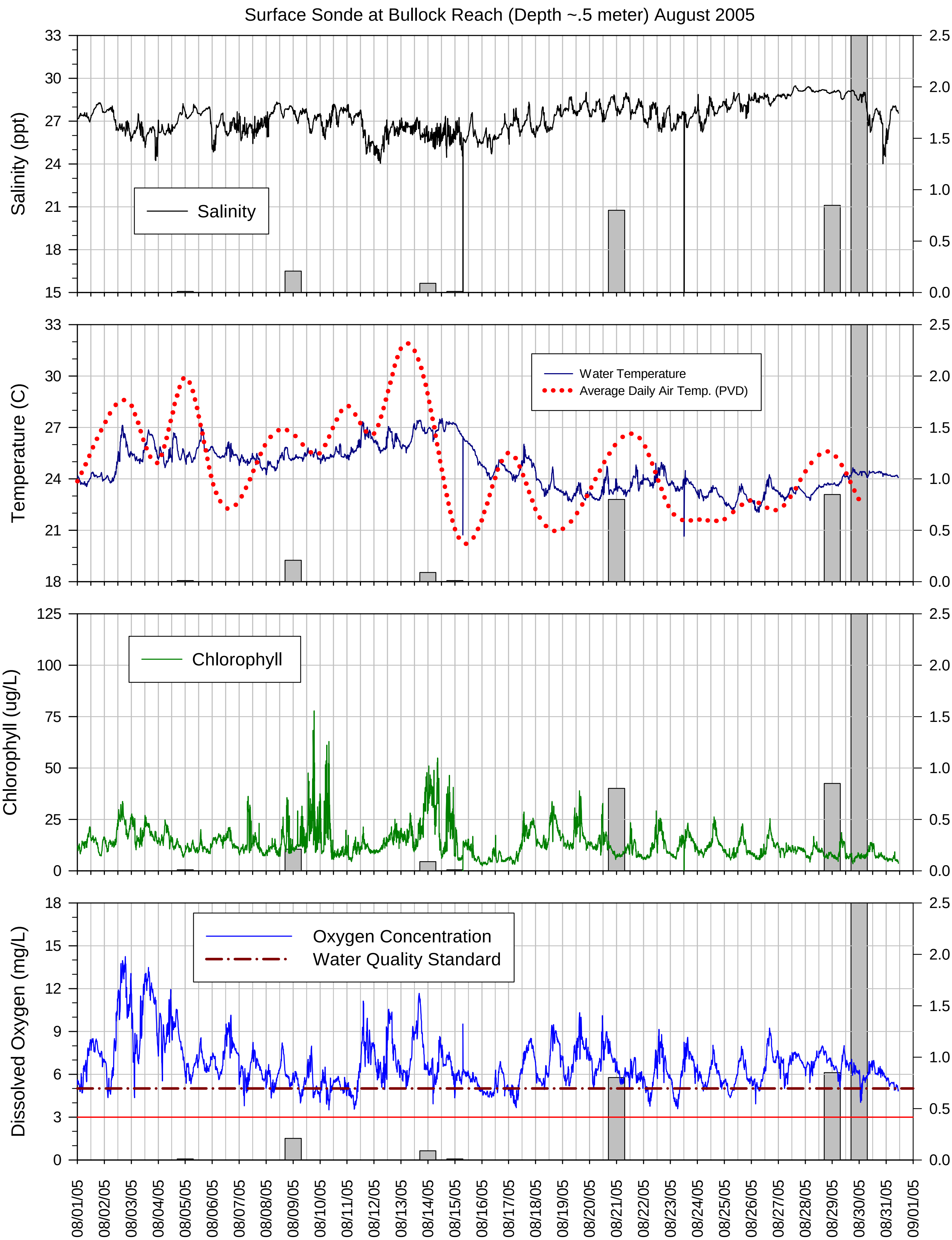


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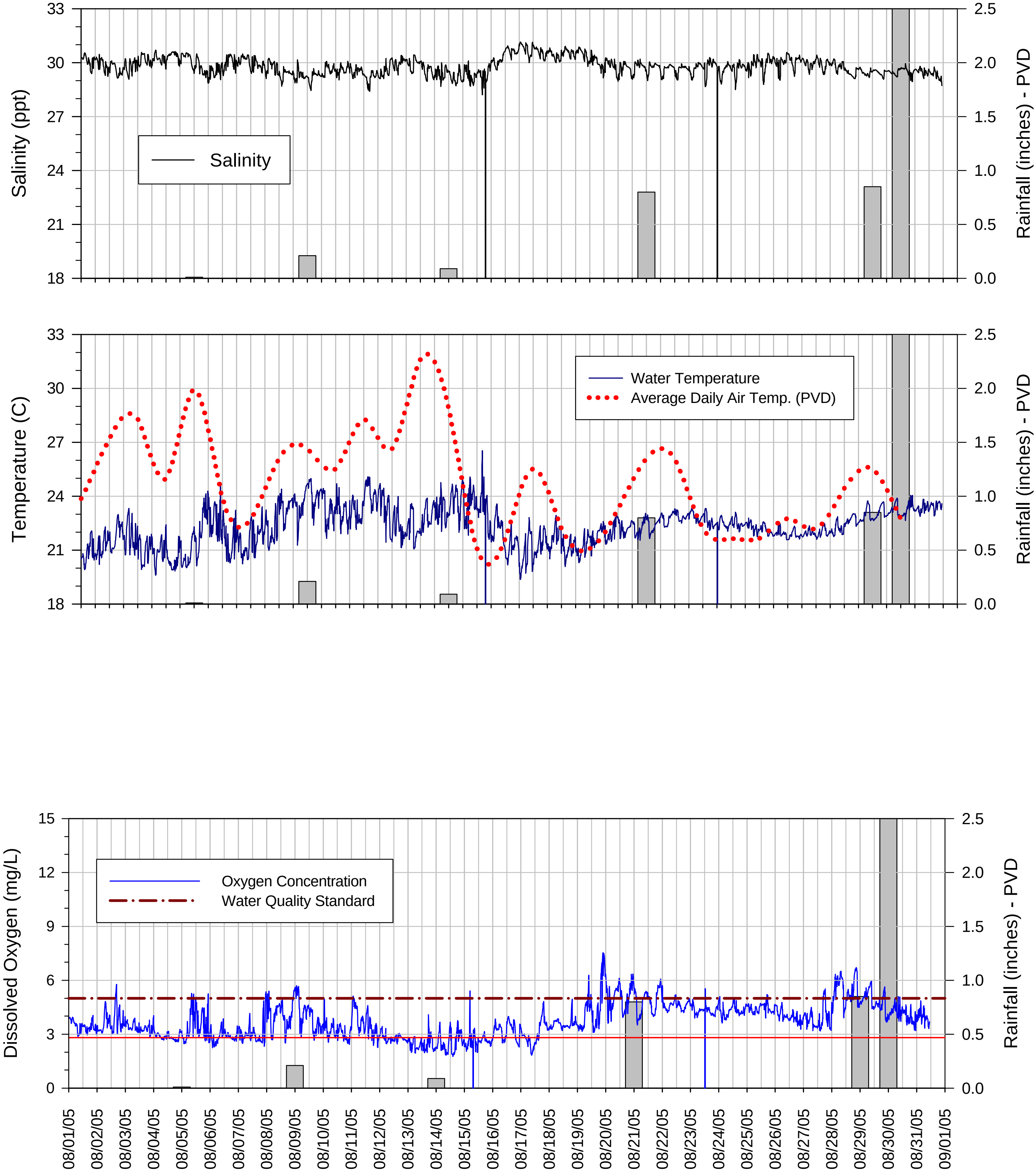
Bottom Sonde at Bullock Reach (Depth ~9 meters) August 2005

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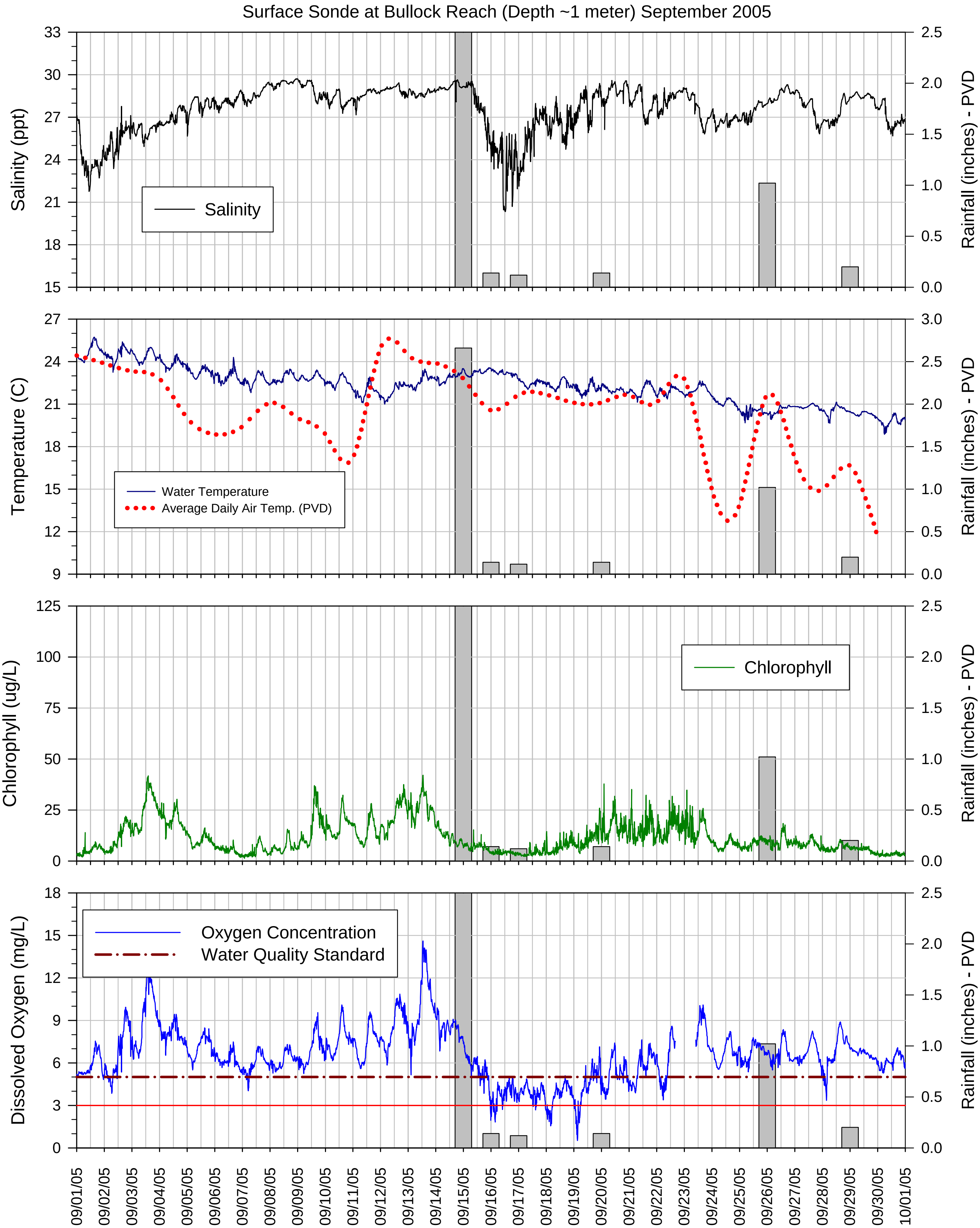


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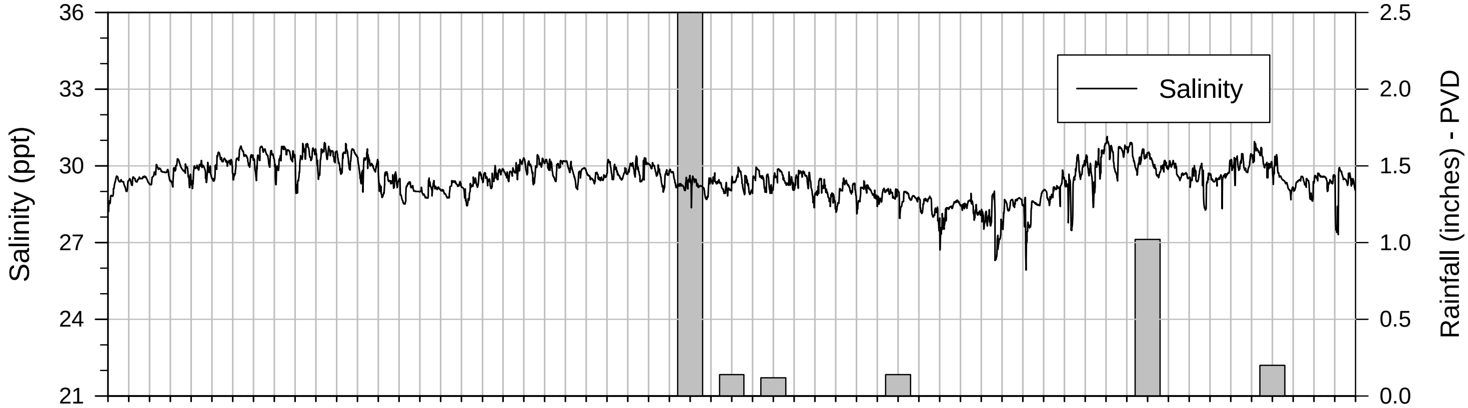
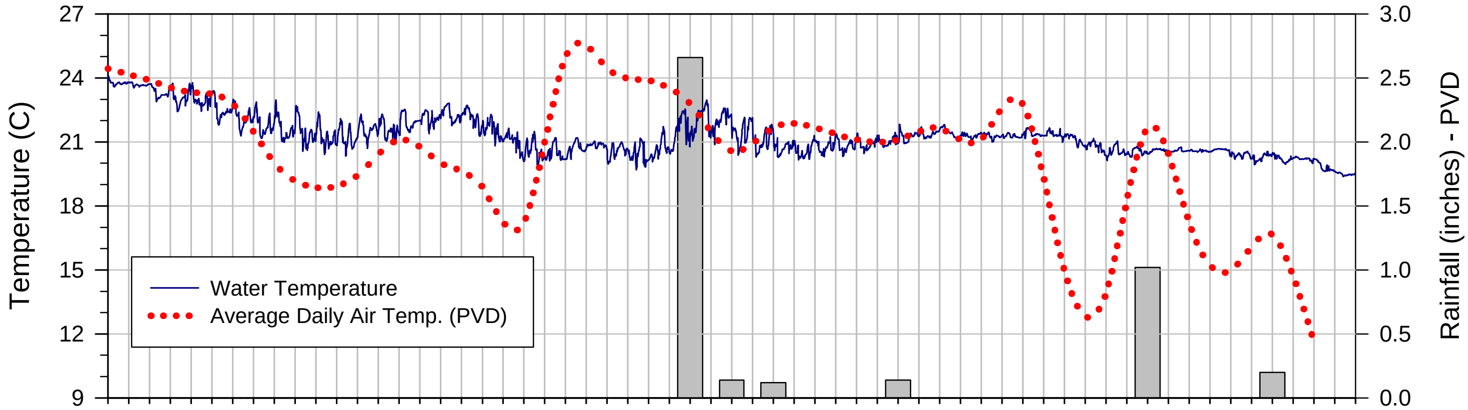
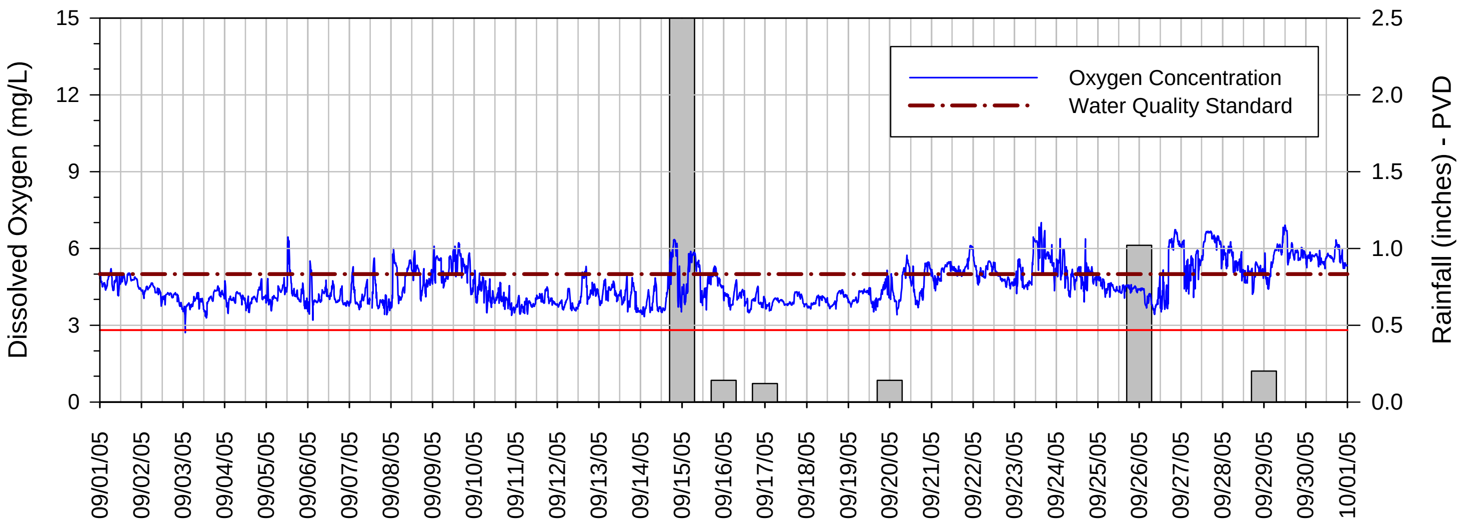
Bottom Sonde at Bullock Reach (Depth ~9 meters) September 2005

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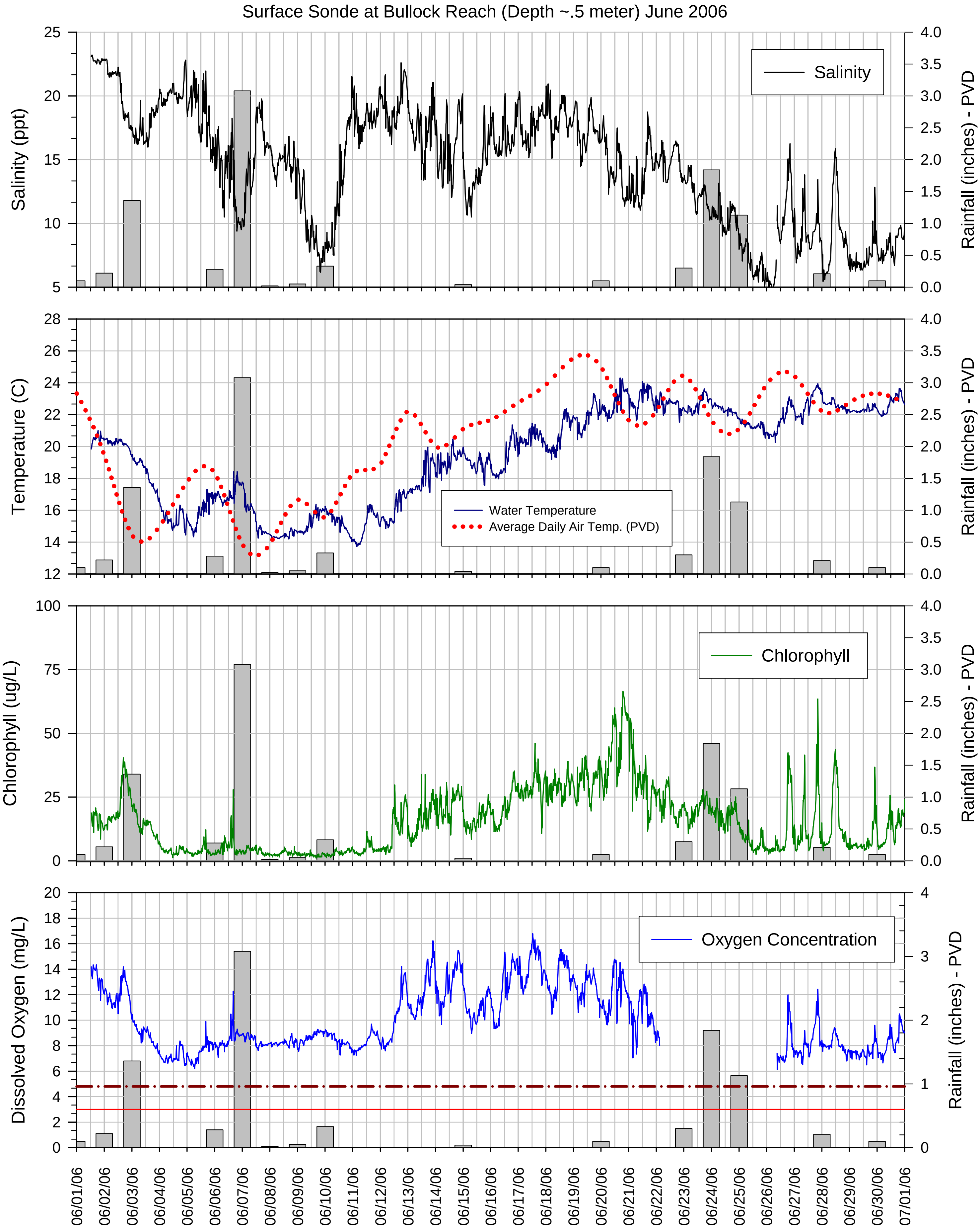


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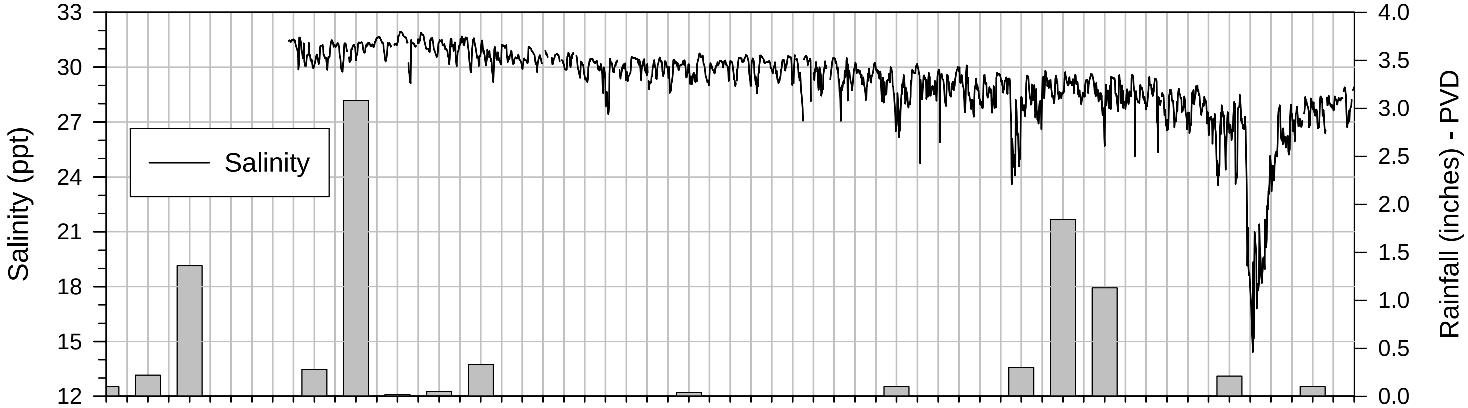
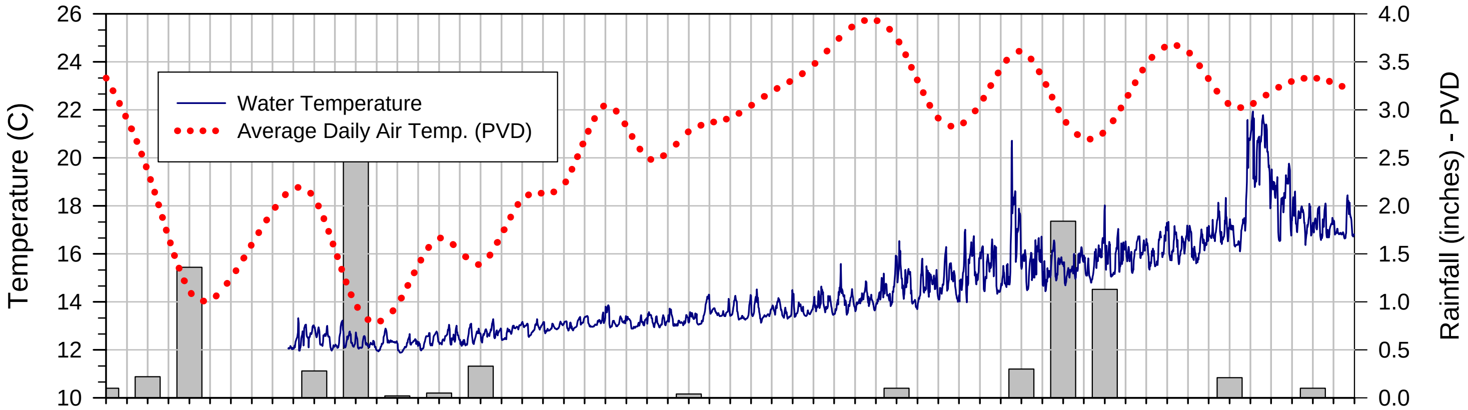
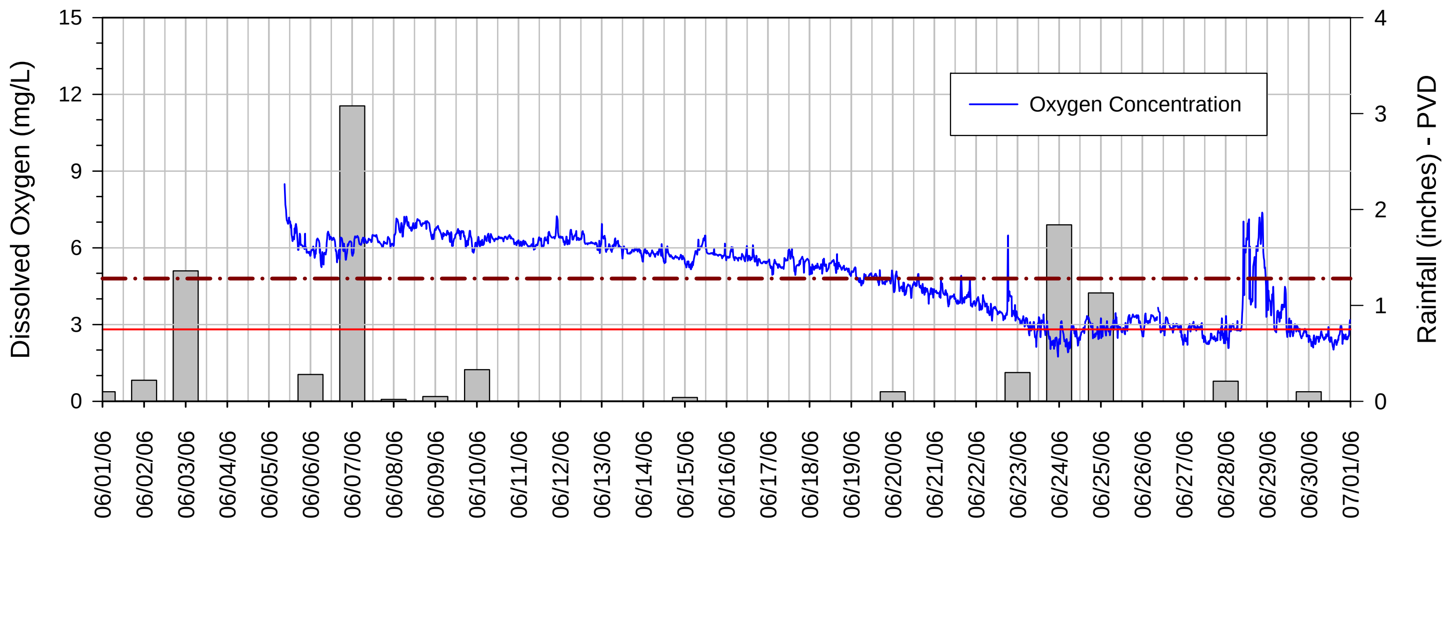
This station is maintained by NBC and RIDEM - Office of Water Resources.

Bottom Sonde at Bullock Reach (Depth ~9 meters) June 2006

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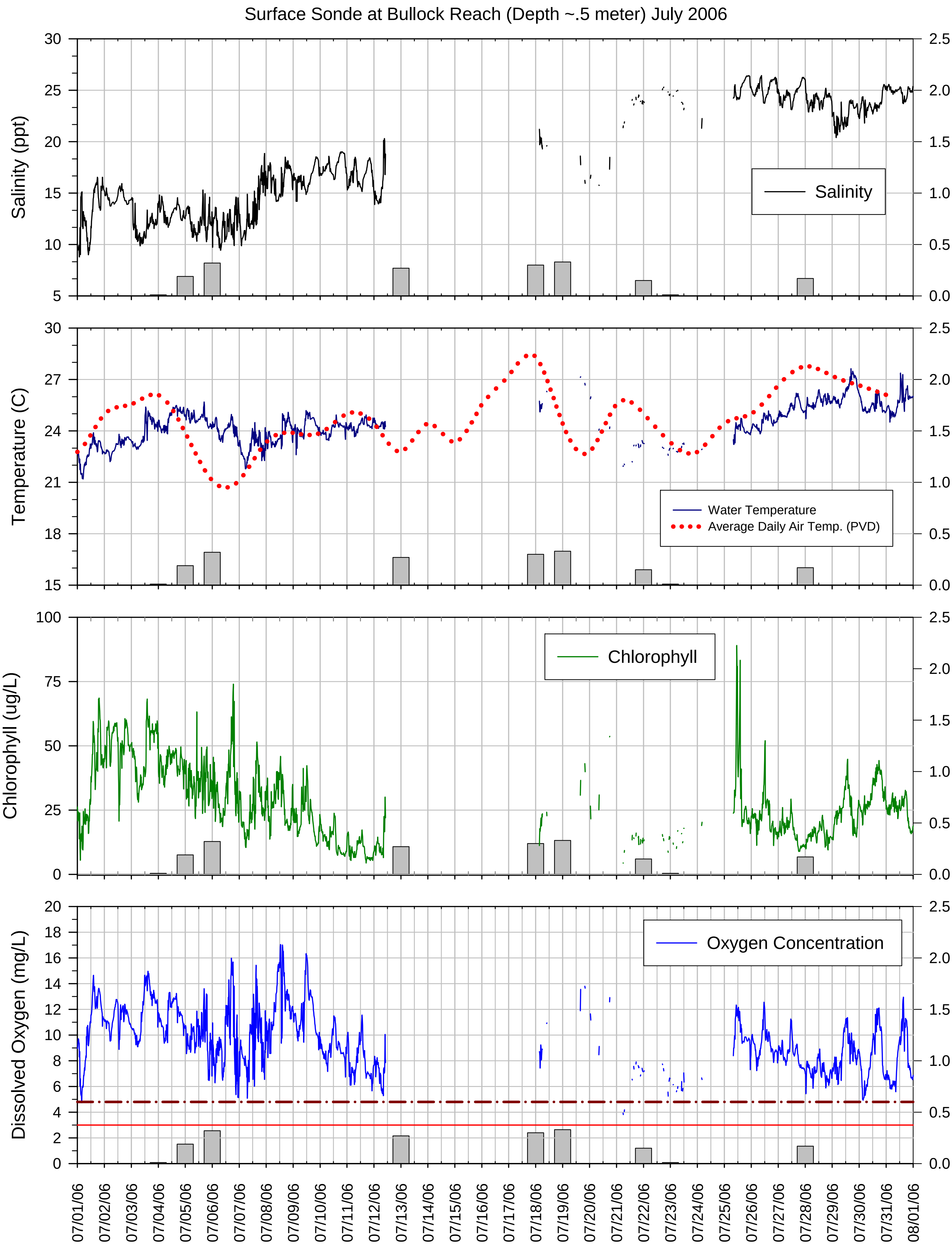


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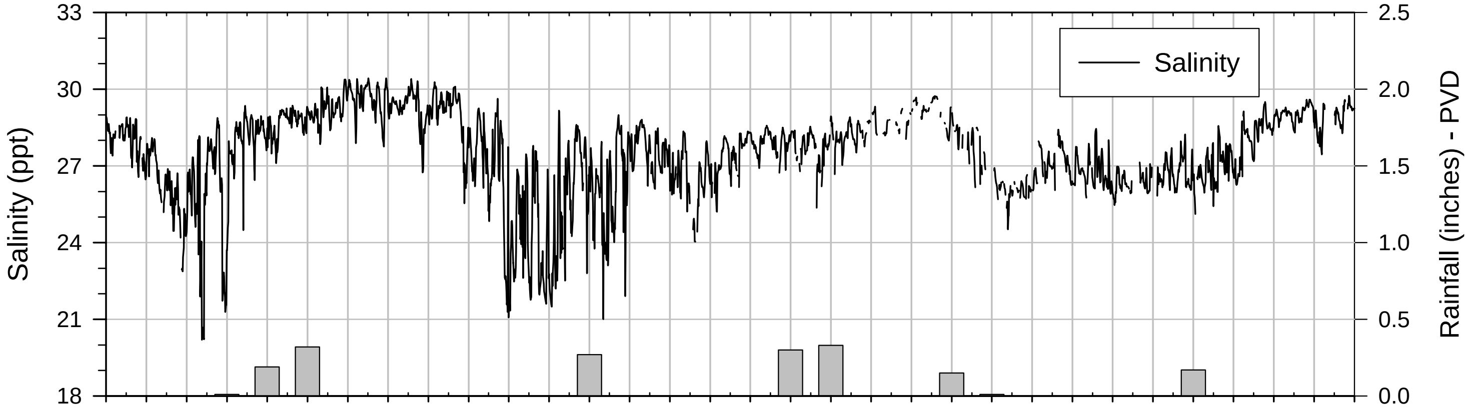
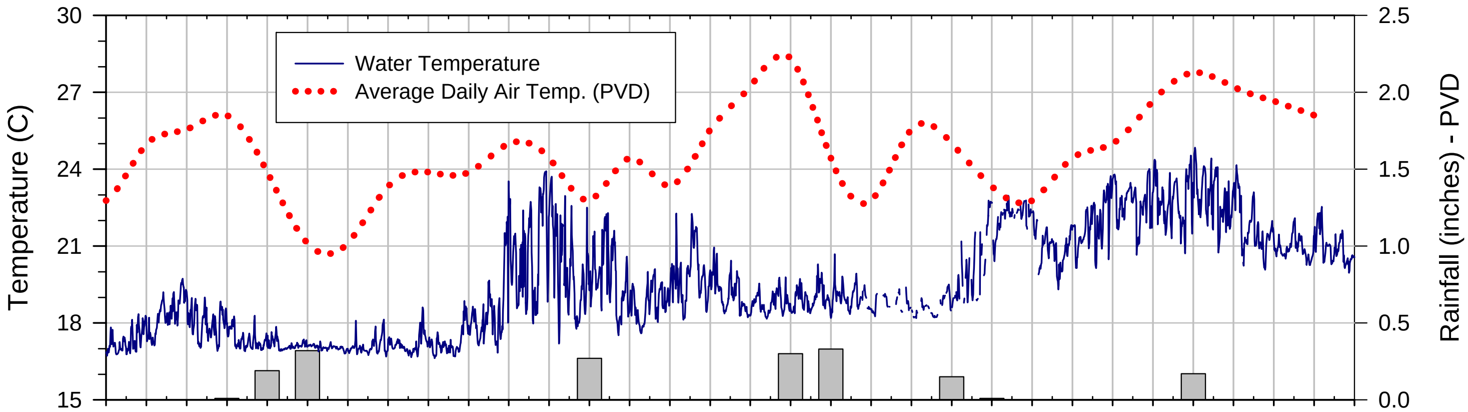
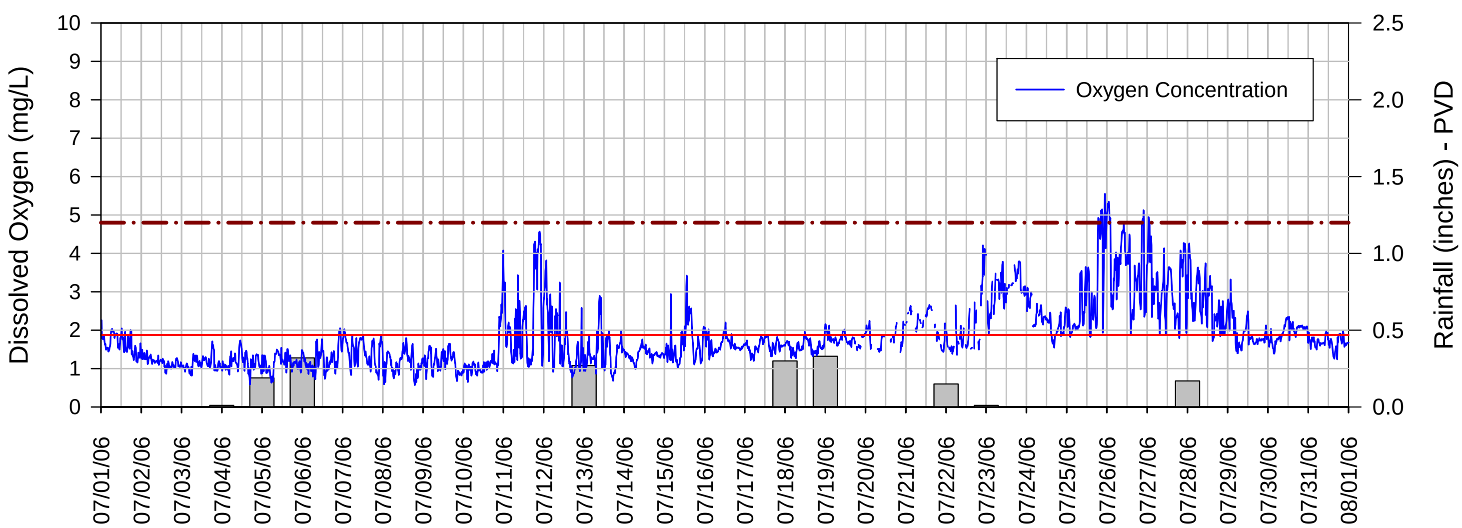
Bottom Sonde at Bullock Reach (Depth ~9 meters) July 2006

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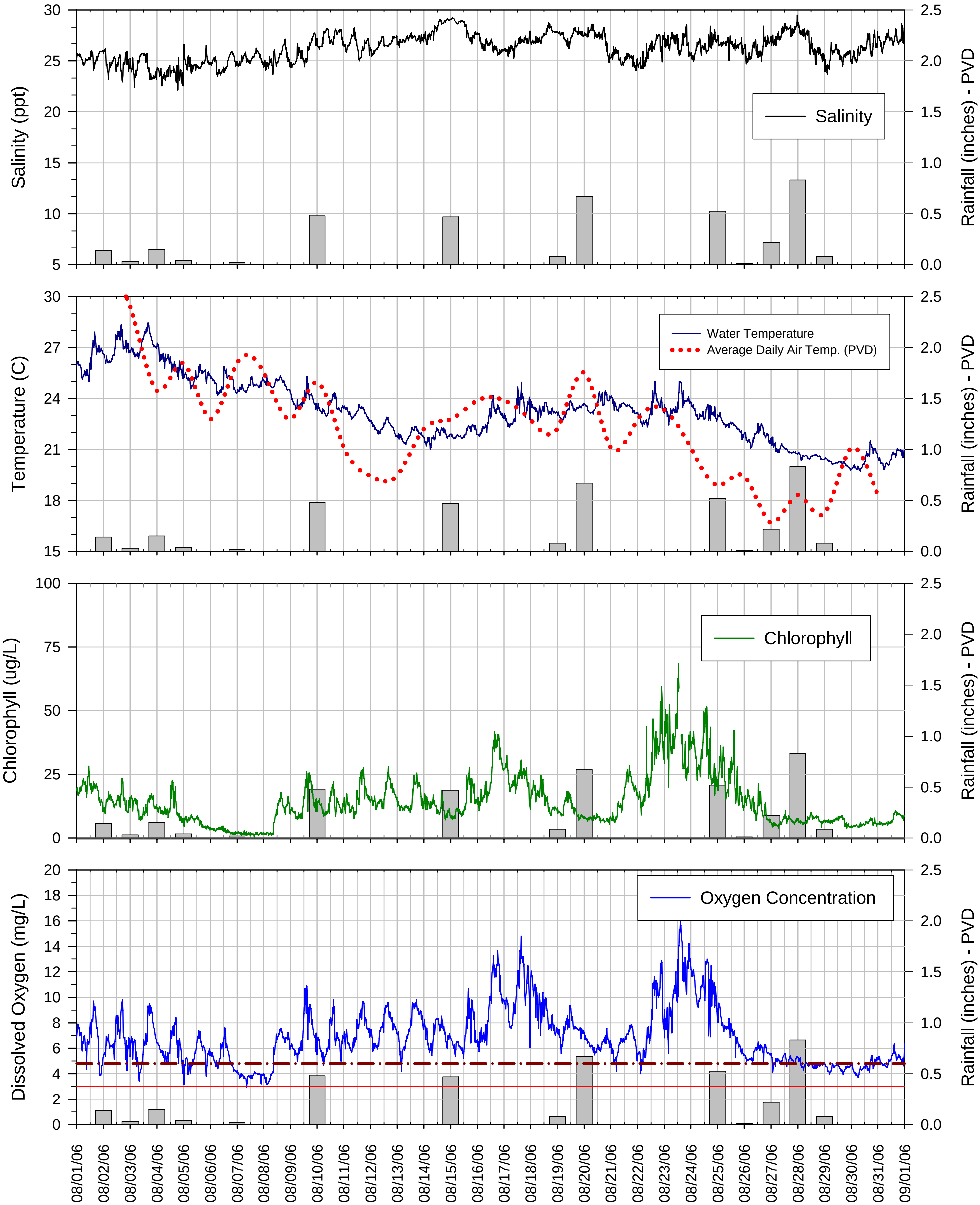
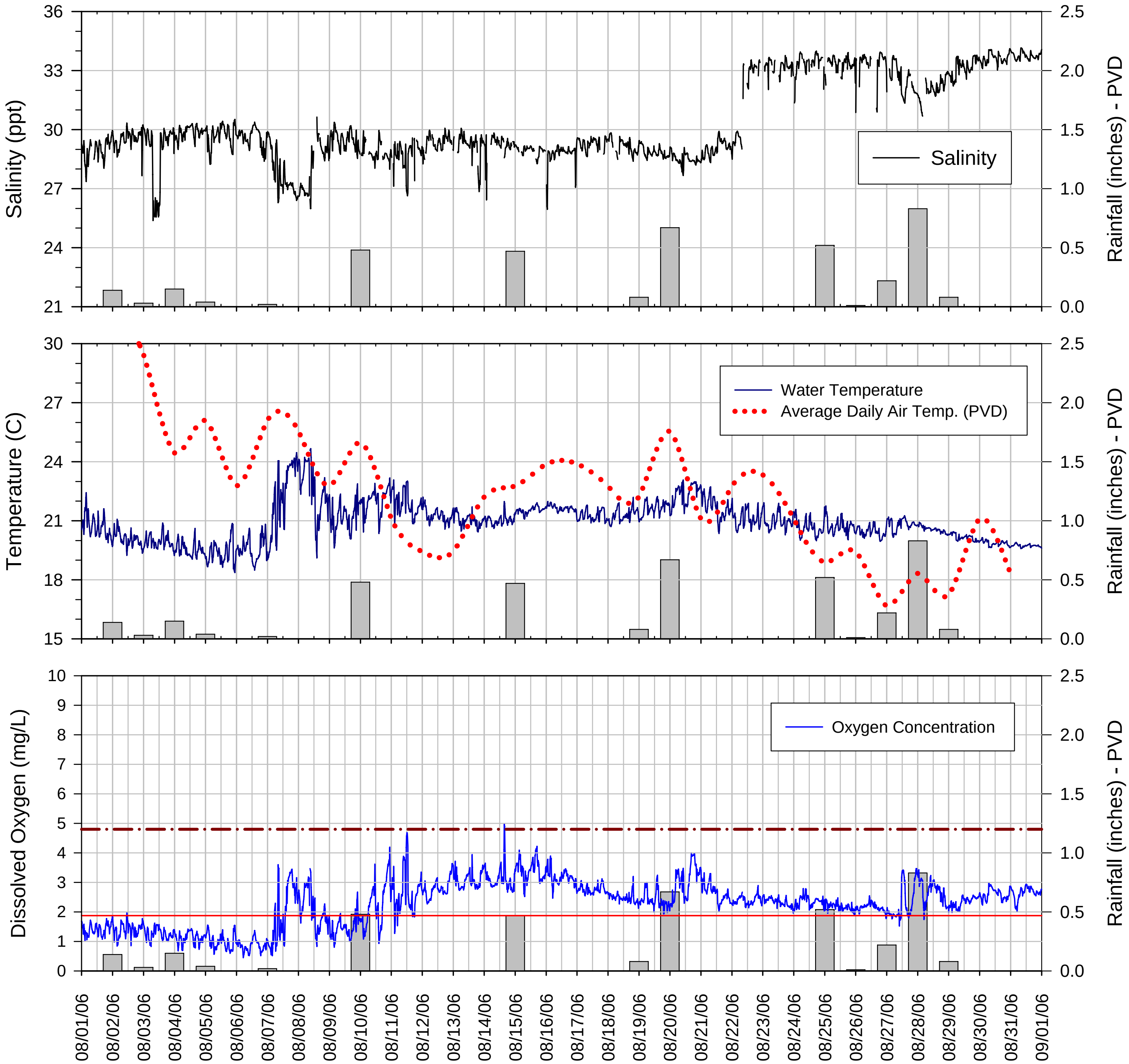
Surface Sonde at Bullock Reach (Depth ~.5 meter) August 2006

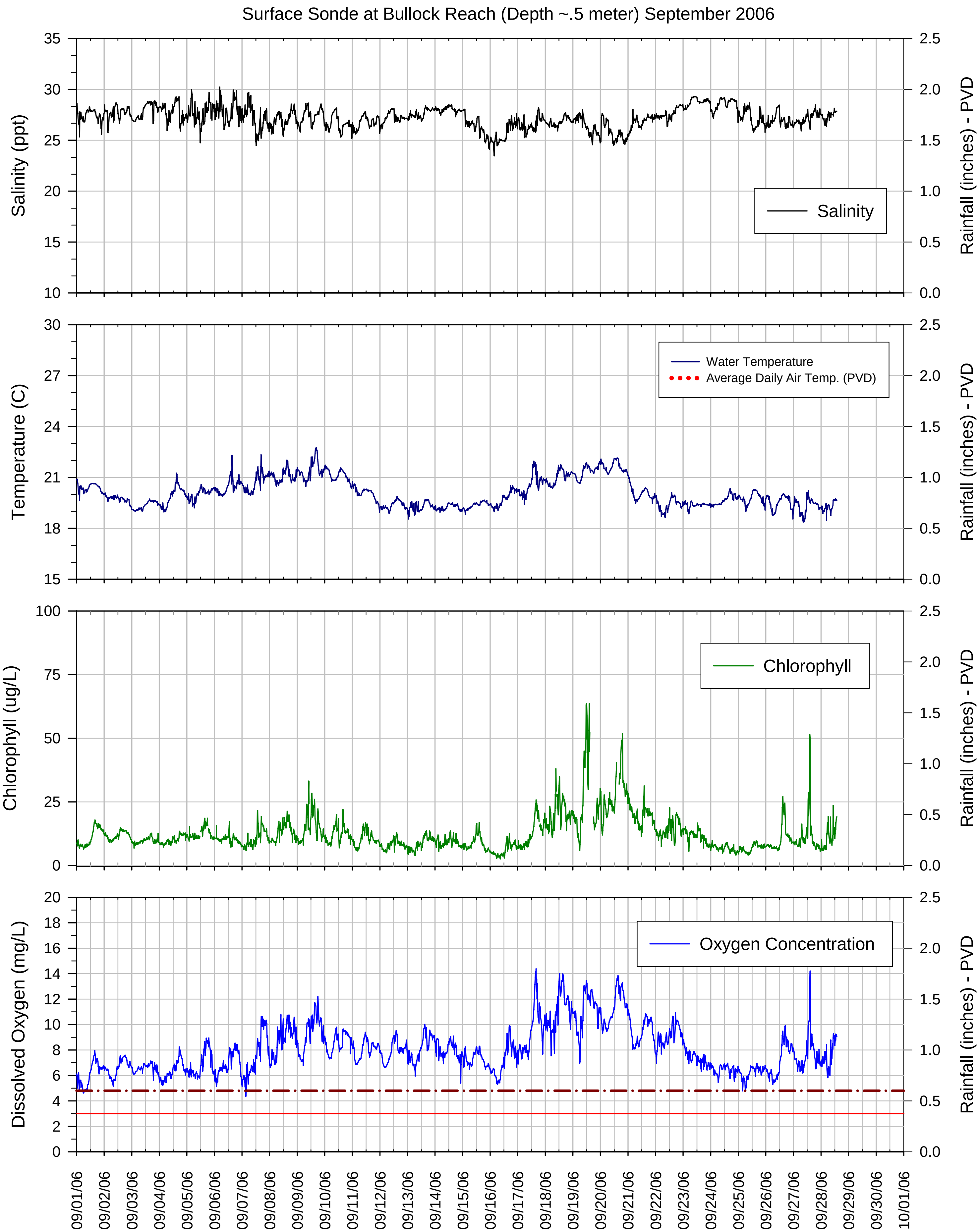



The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by NBC and RIDEM - Office of Water Resources.

Bottom Sonde at Bullock Reach (Depth ~9 meters) August 2006

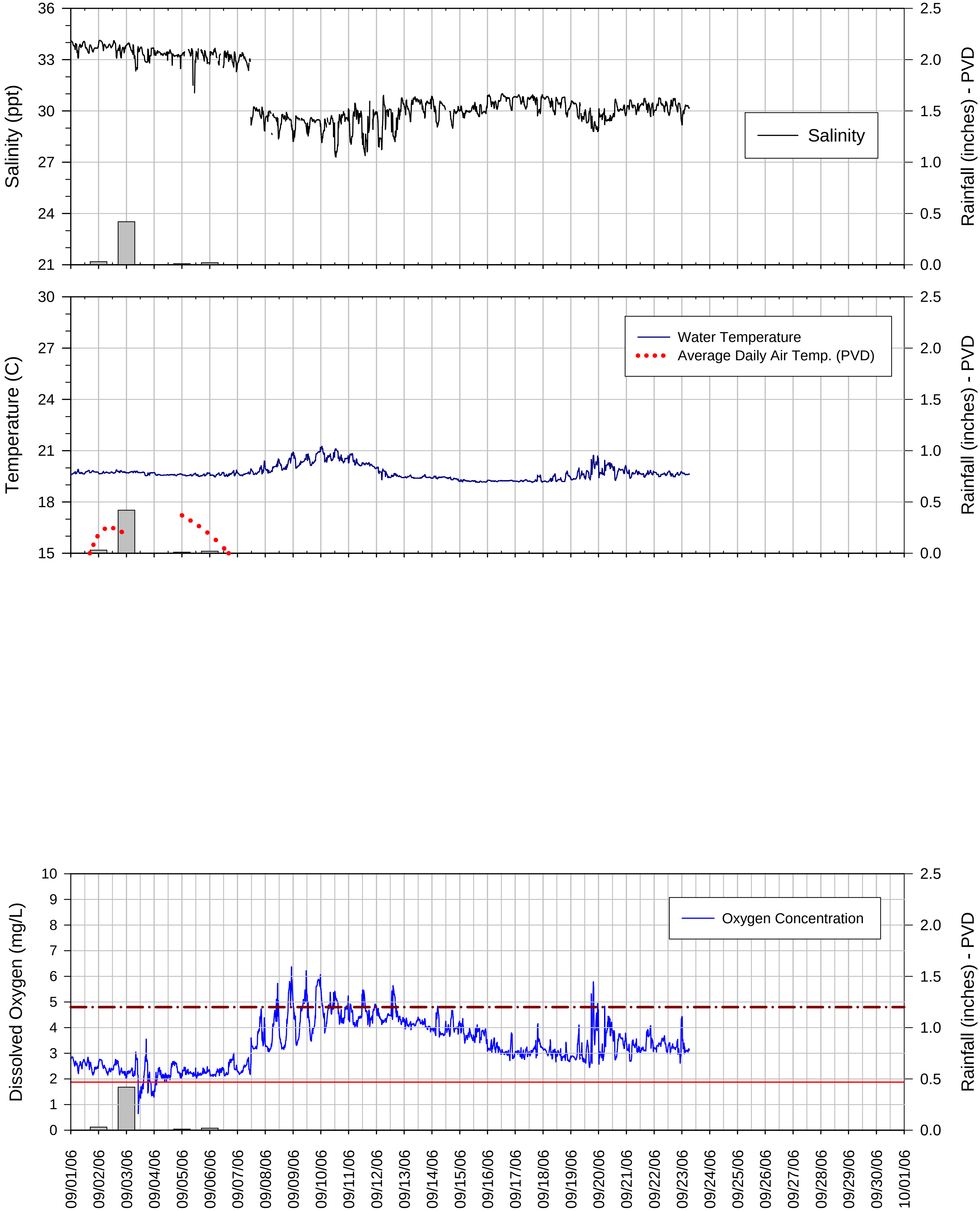



The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by NBC and RIDEM - Office of Water Resources .

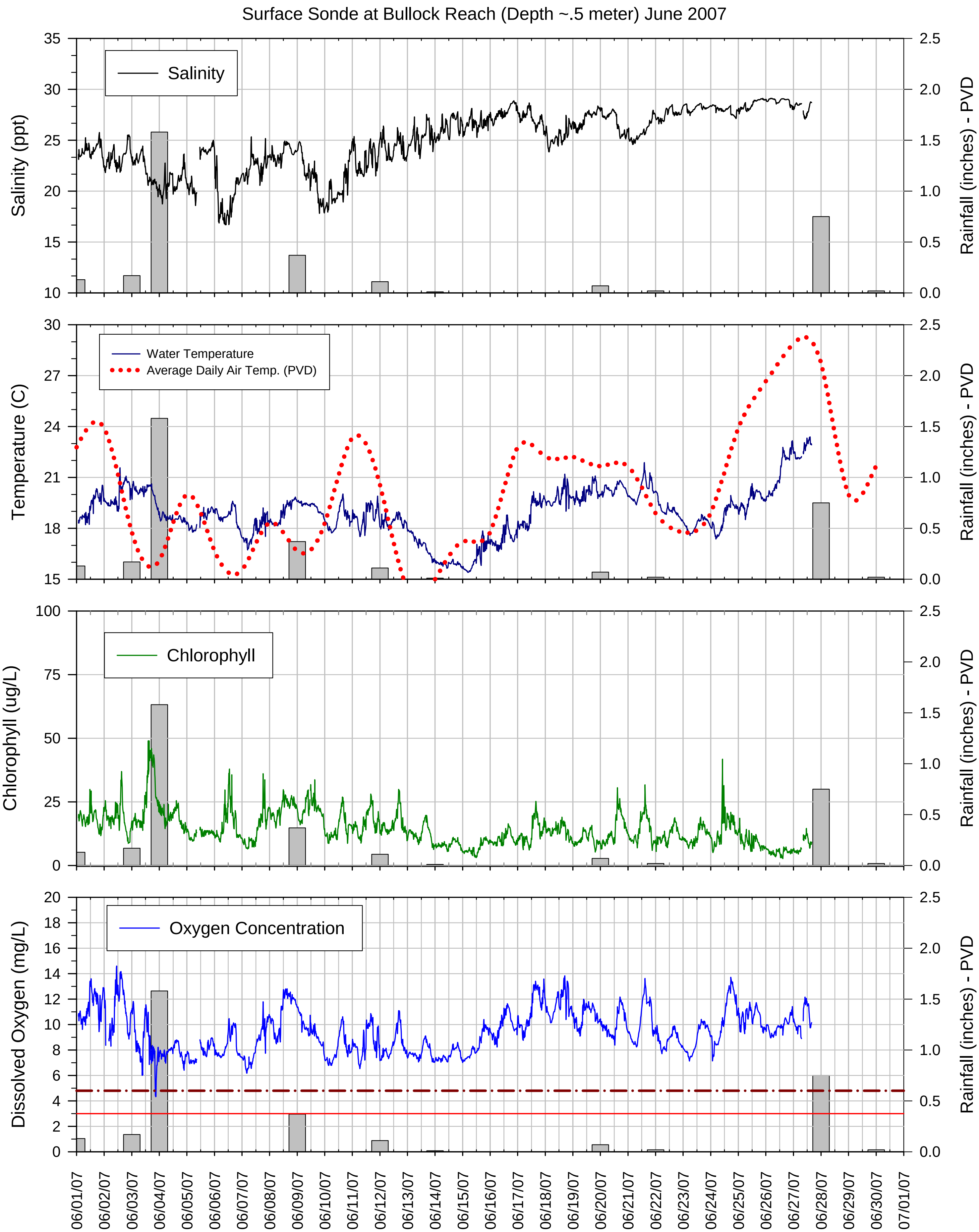



The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by NBC.

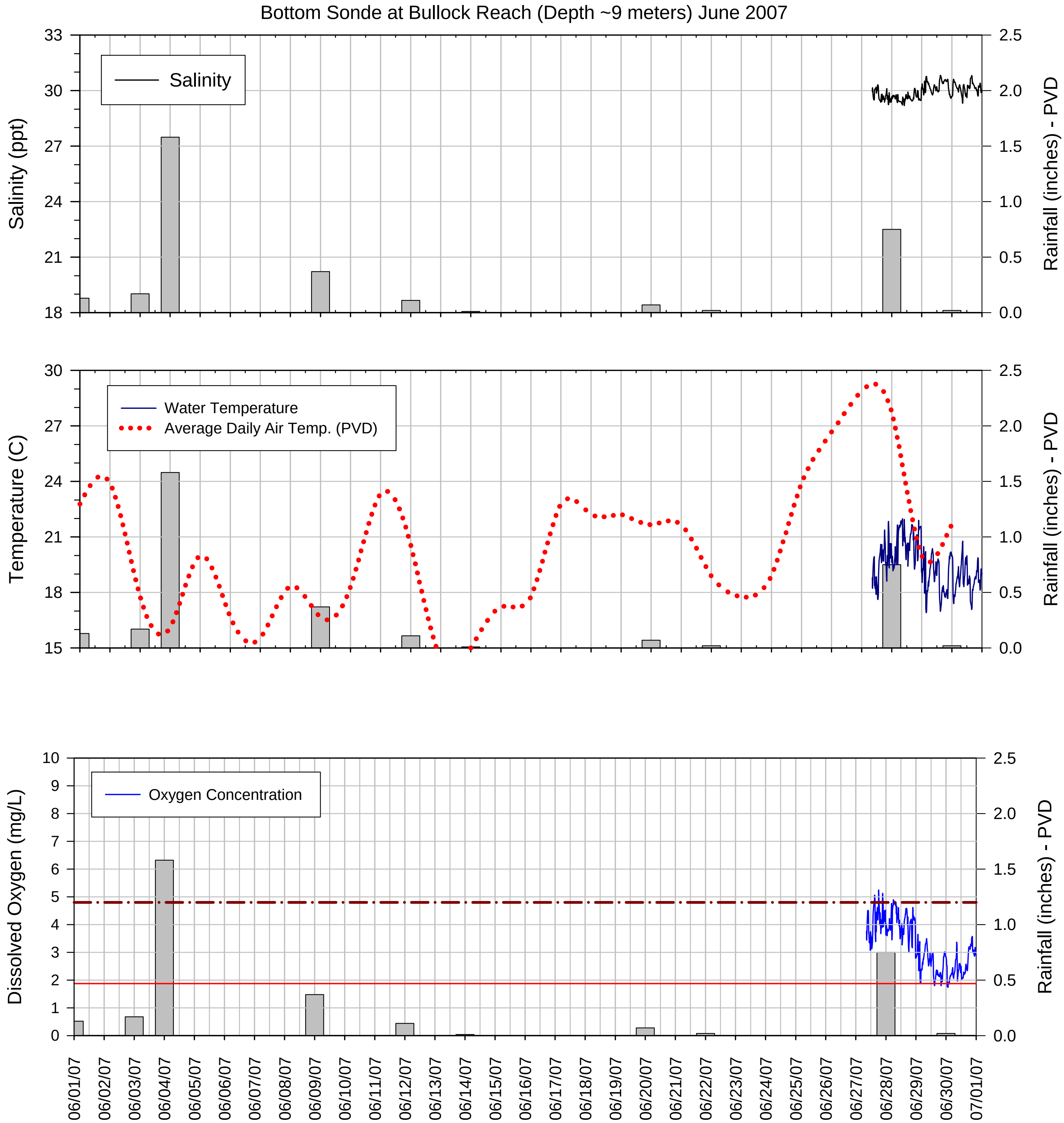
Bottom Sonde at Bullock Reach (Depth ~9 meters) September 2006




The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by NBC.

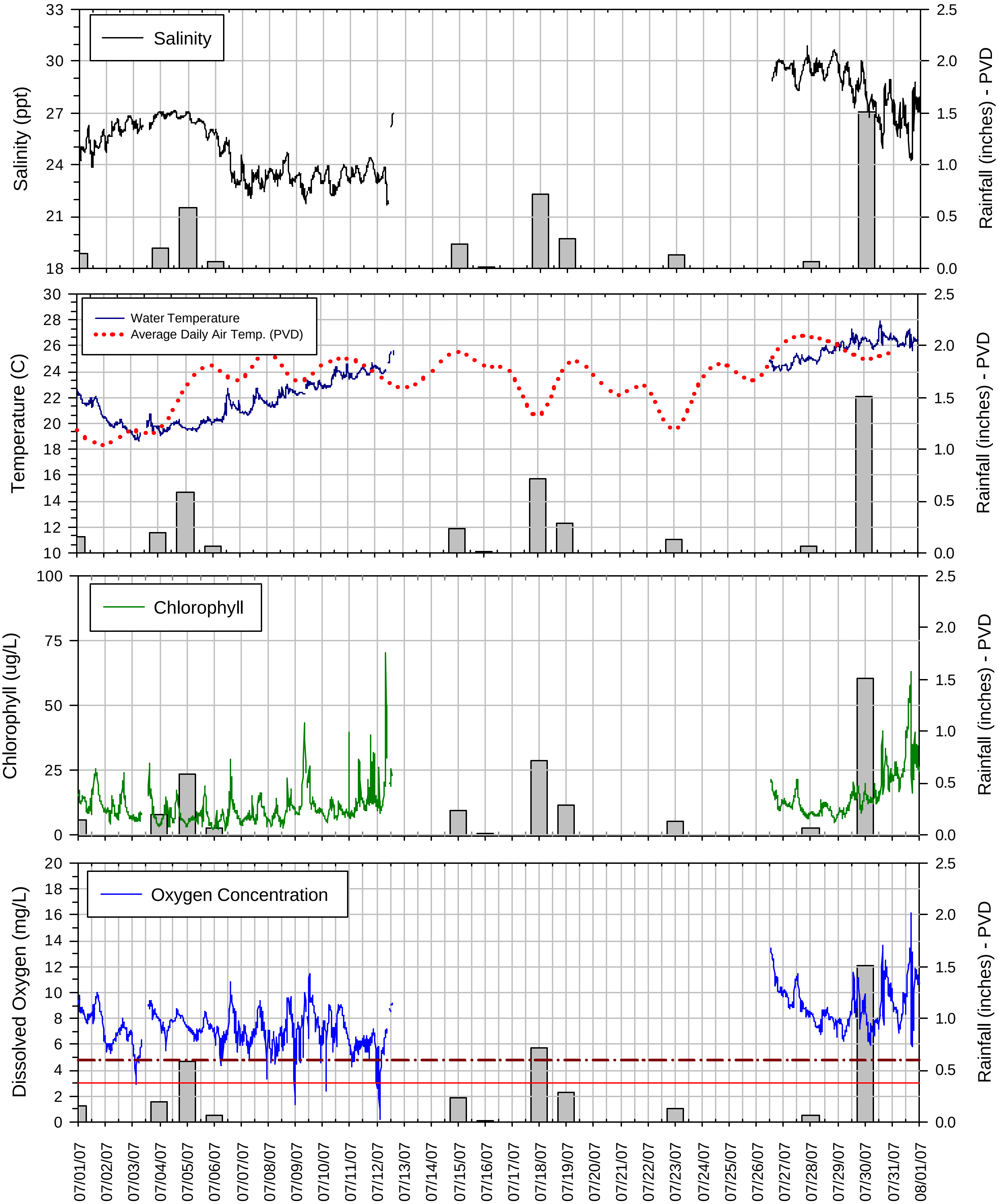



The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by NBC and RIDEM - Office of Water Resources.



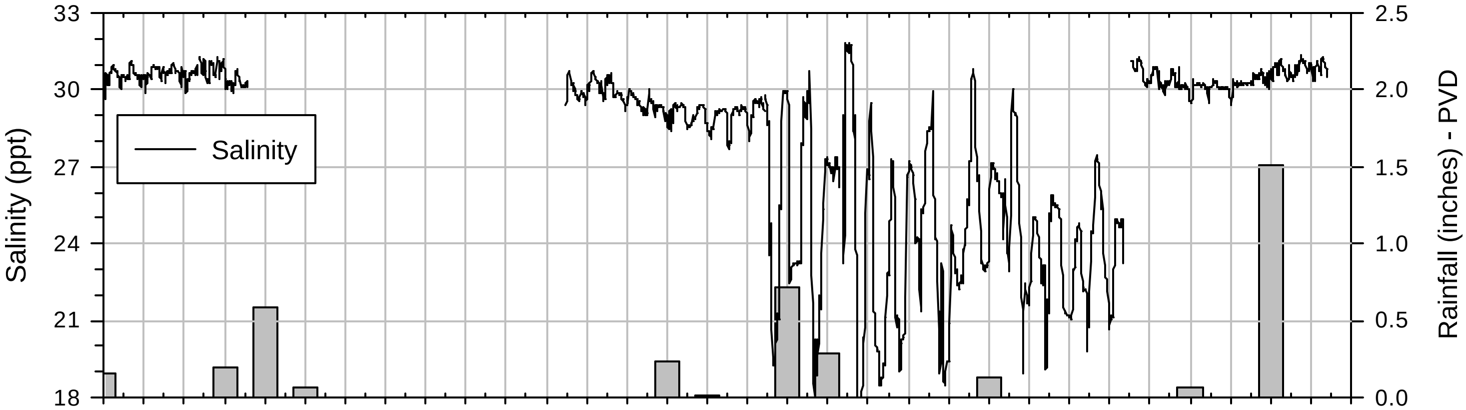

The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by NBC and RIDEM - Office of Water Resources .

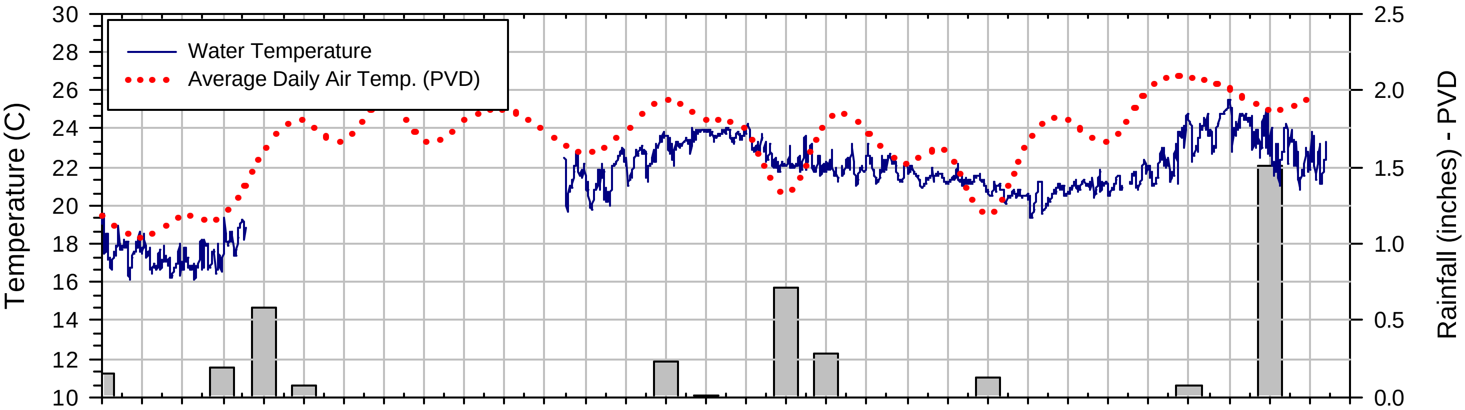
Surface Sonde at Bullock Reach (Depth ~.5 meter) July 2007

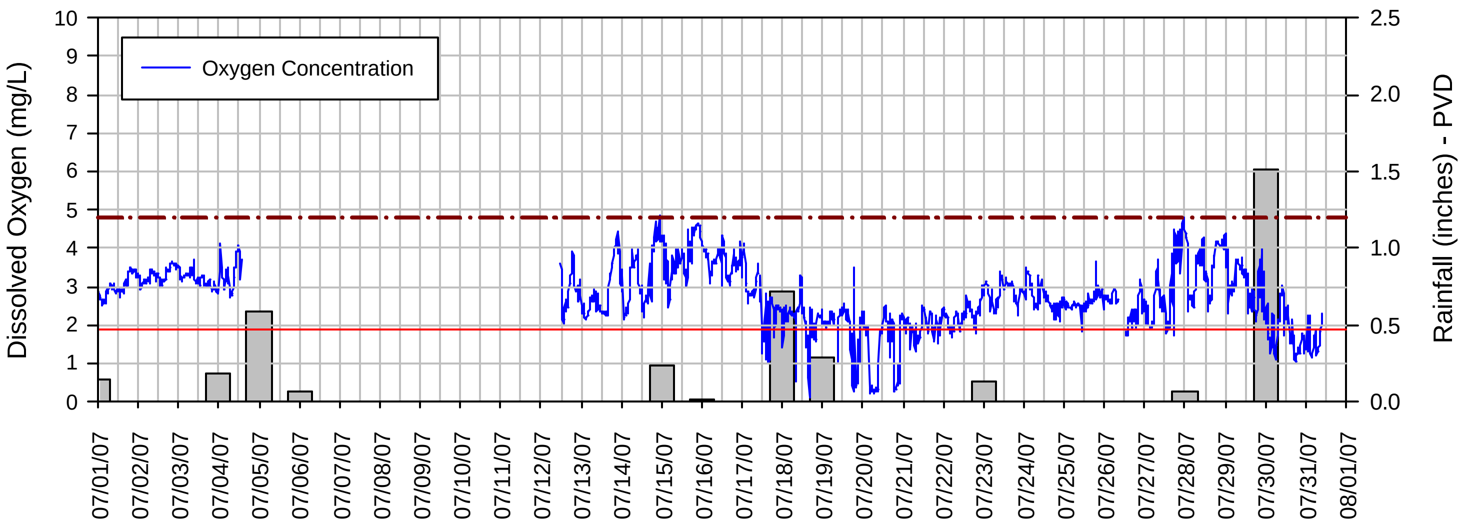



The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by NBC and RIDEM - Office of Water Resources.

Bottom Sonde at Bullock Reach (Depth ~6 meters) July 2007

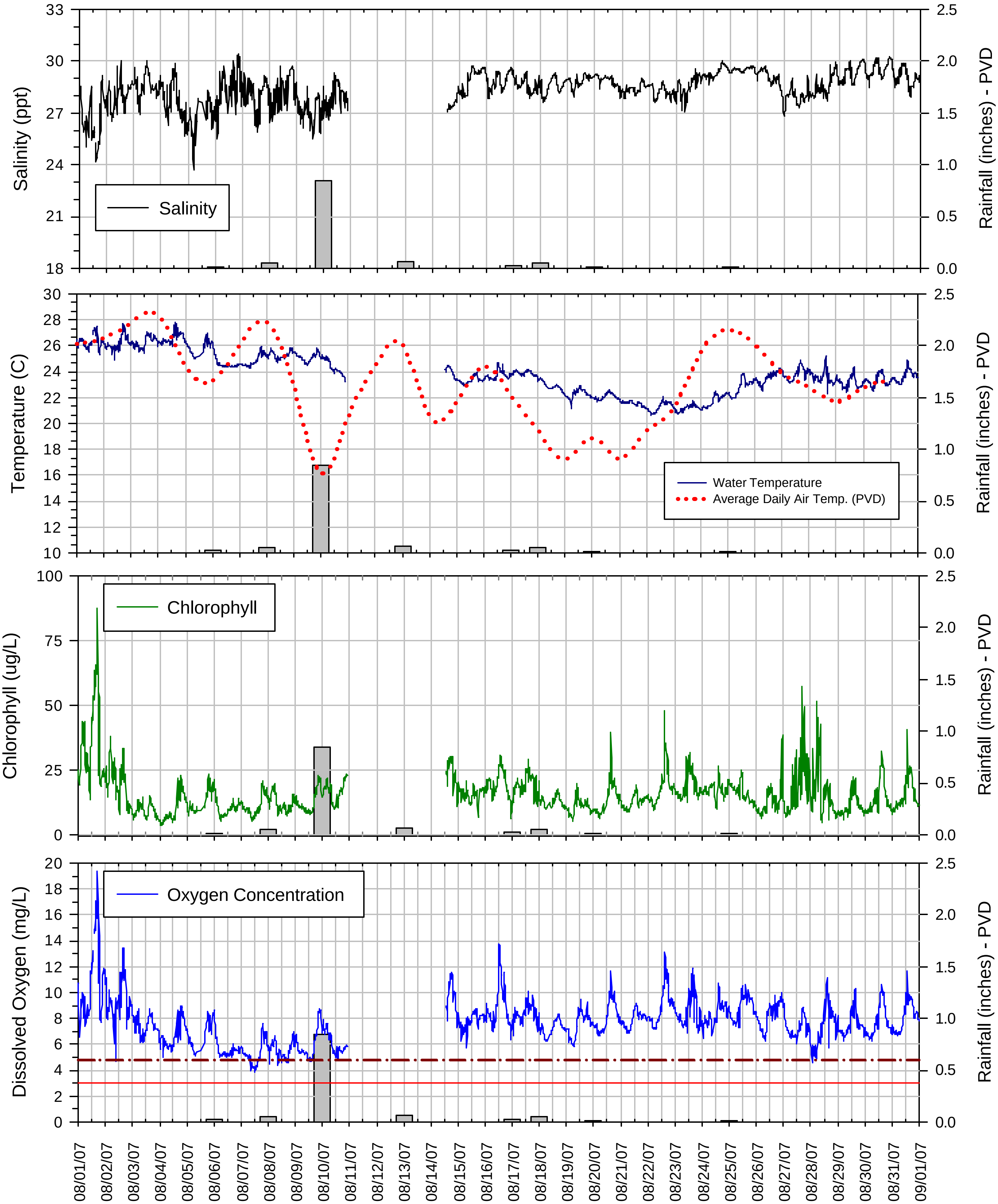


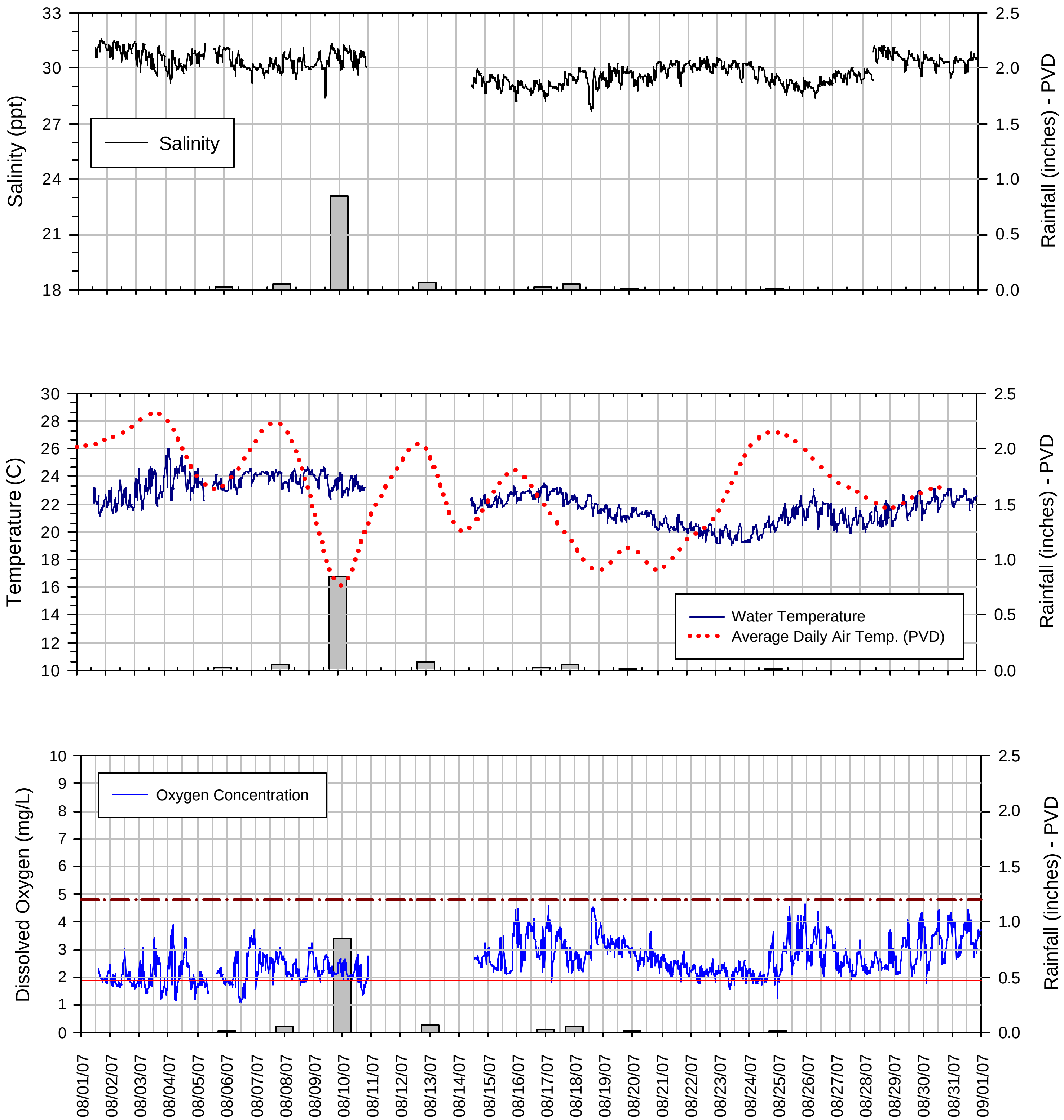

The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by NBC and RIDEM - Office of Water Resources .

Surface Sonde at Bullock Reach (Depth ~.5 meter) August 2007

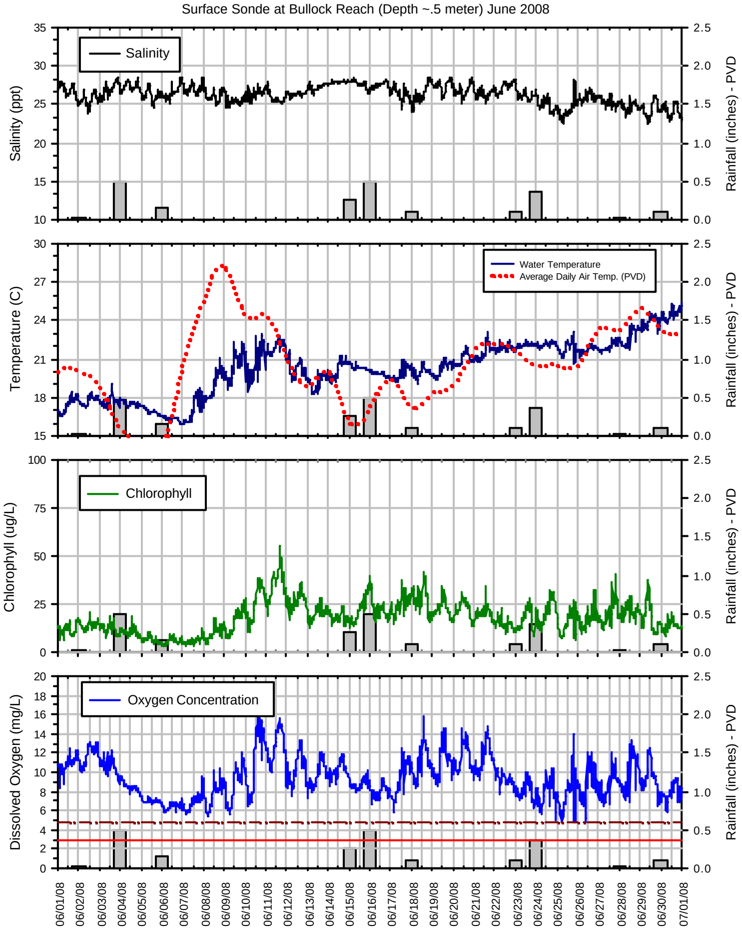



The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by NBC and RIDEM - Office of Water Resources.

Bottom Sonde at Bullock Reach (Depth ~6 meters) August 2007

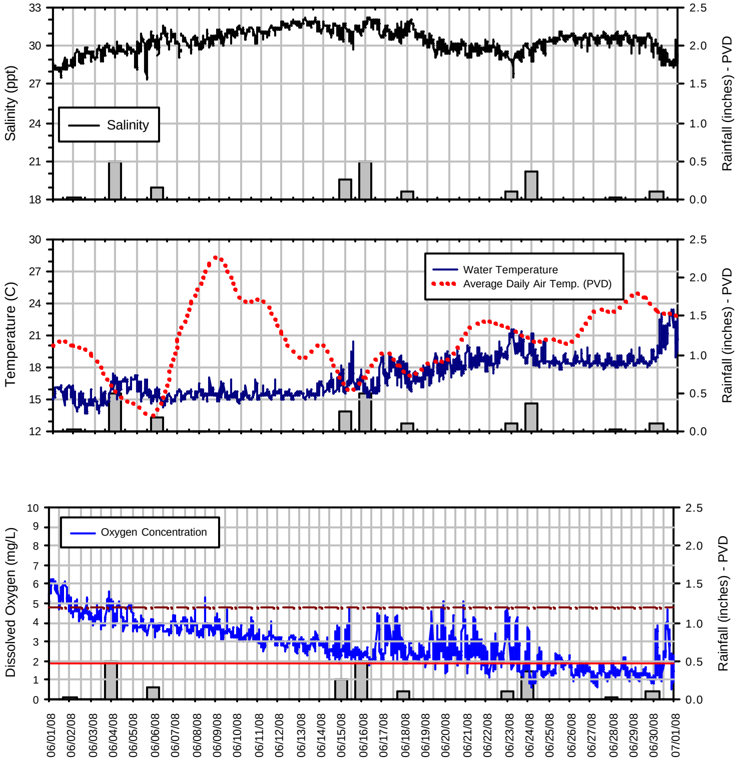



The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by NBC and RIDEM - Office of Water Resources .



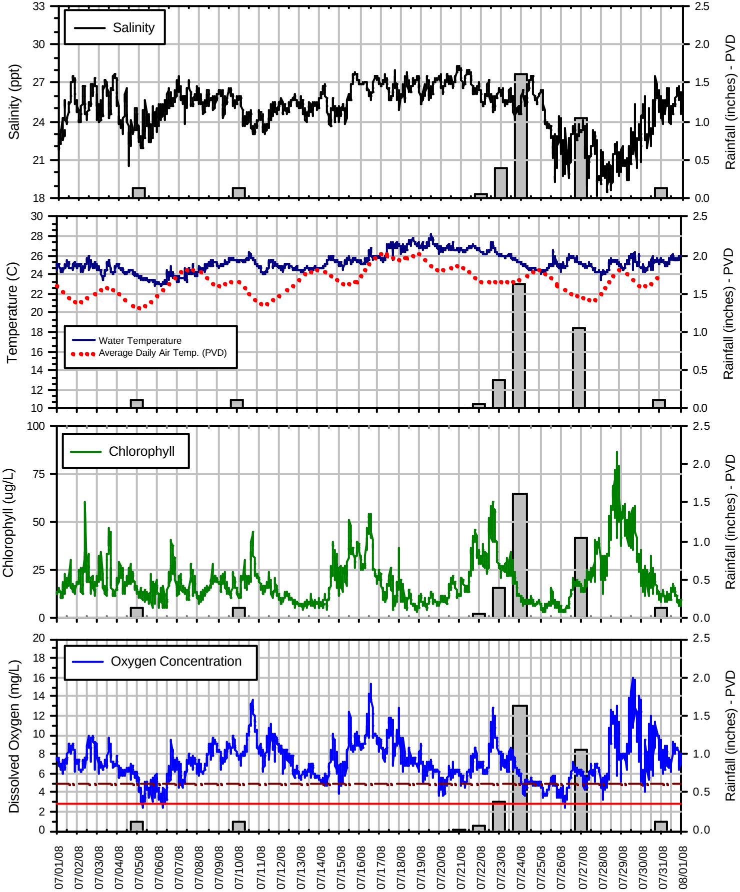

The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by NBC and RIDEM - Office of Water Resources.

Bottom Sonde at Bullock Reach (Depth ~9 meters) June 2008

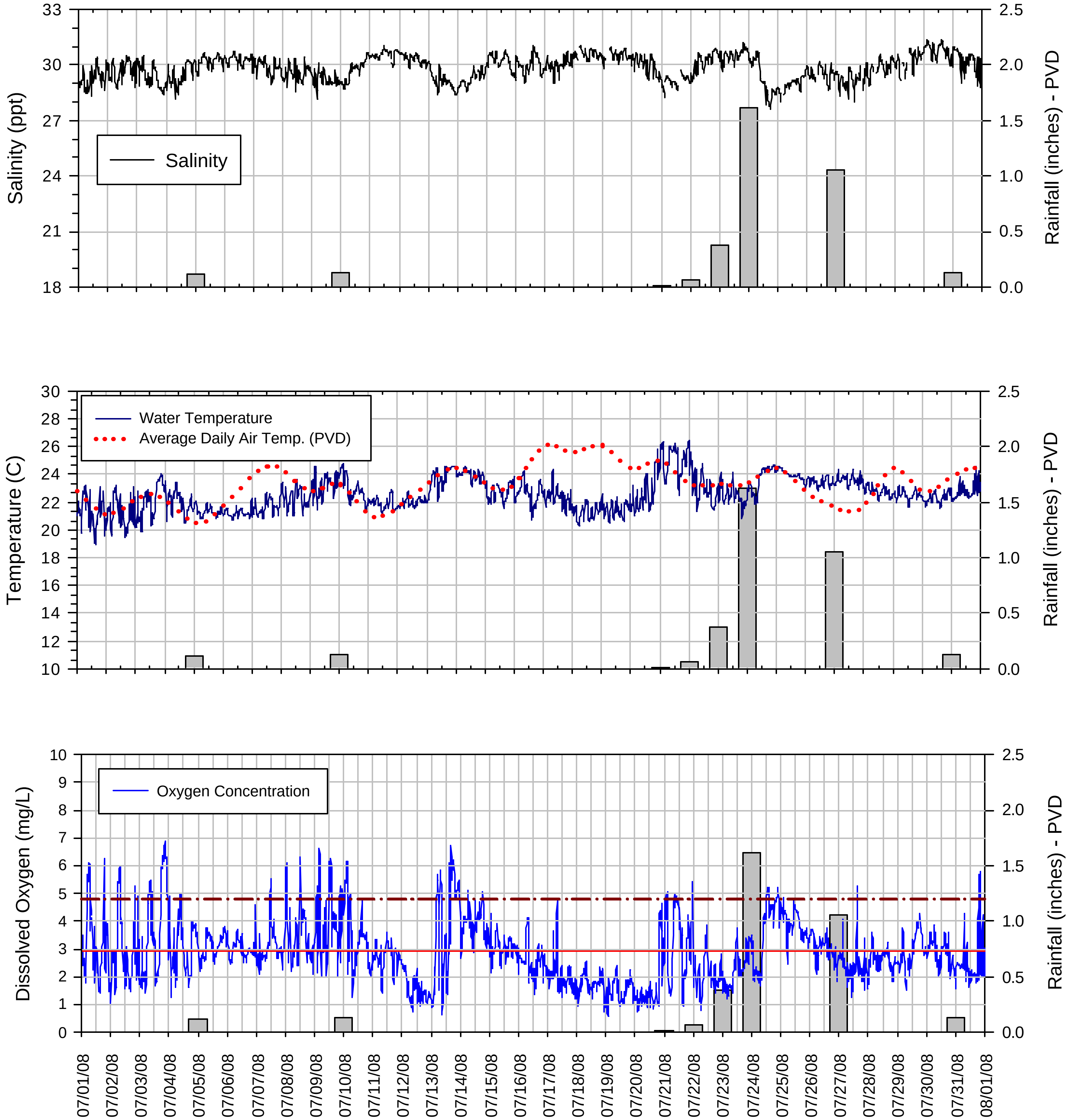



The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by NBC and RIDEM - Office of Water Resources .

Surface Sonde at Bullock Reach (Depth ~.5 meter) July 2008

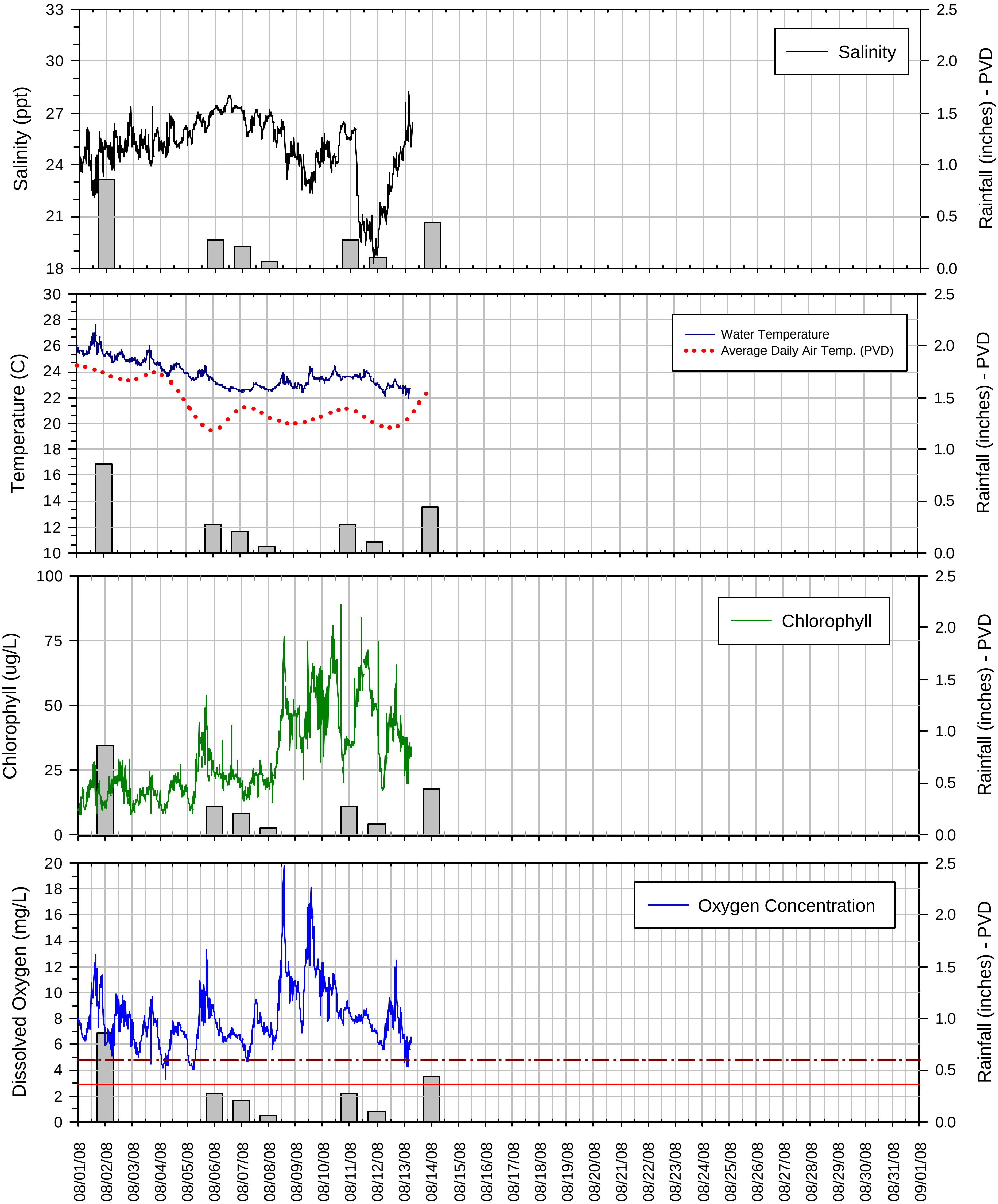


Bottom Sonde at Bullock Reach (Depth ~6 meters) July 2008



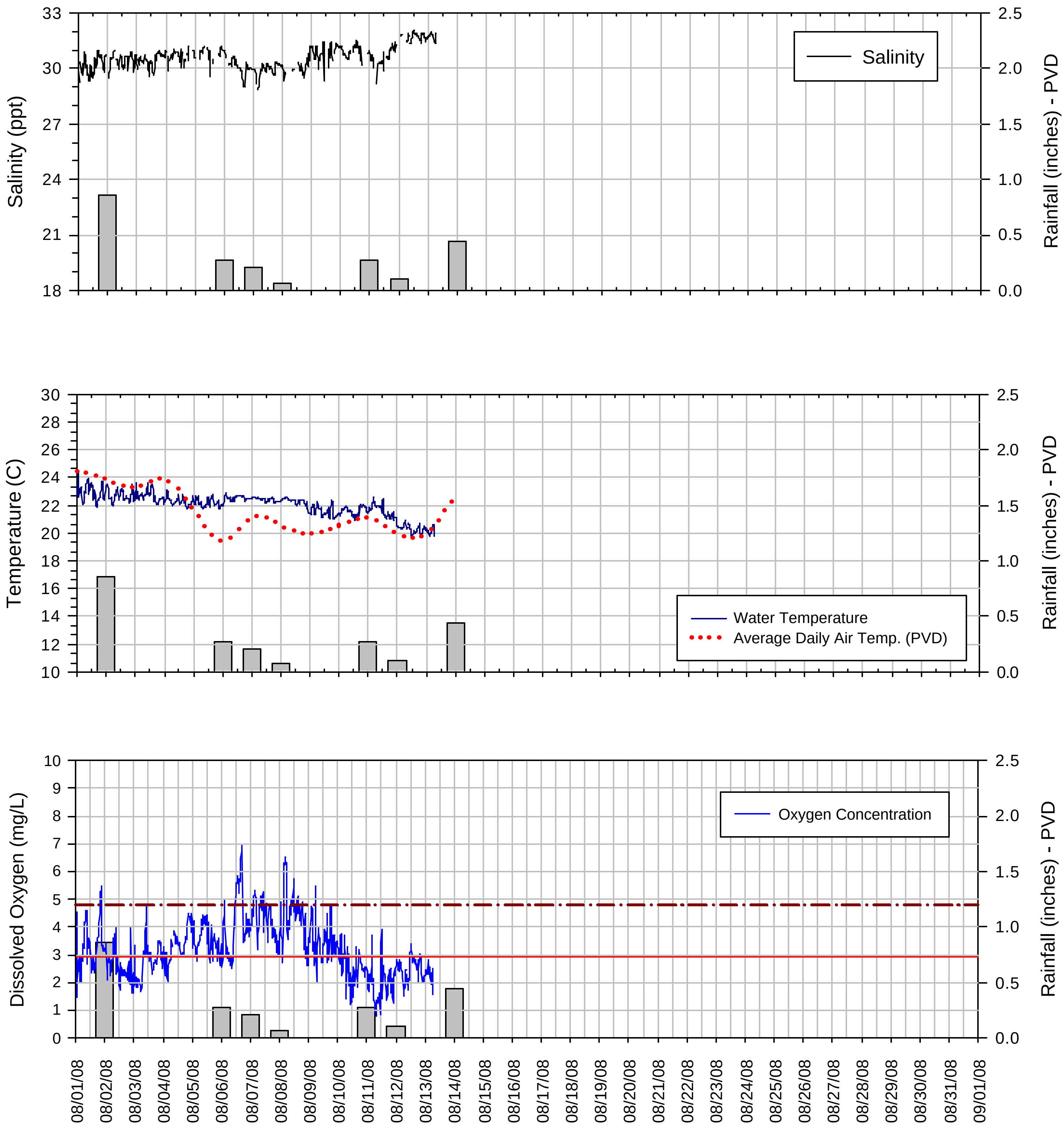

The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by NBC and RIDEM - Office of Water Resources .

Surface Sonde at Bullock Reach (Depth ~.5 meter) August 2008



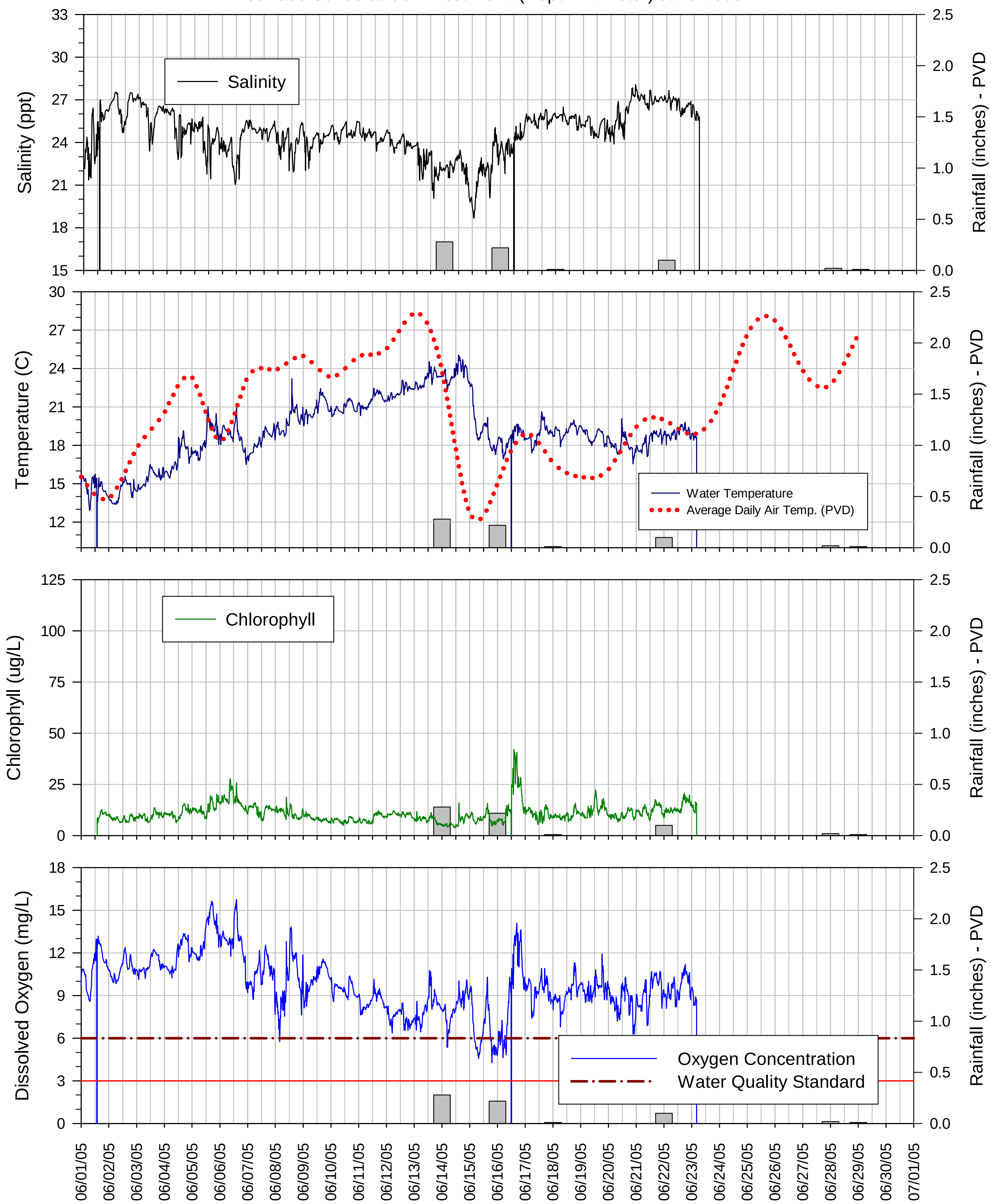

The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by NBC and RIDEM - Office of Water Resources.

# Bottom Sonde at Bullock Reach (Depth ~6 meters) August 2008



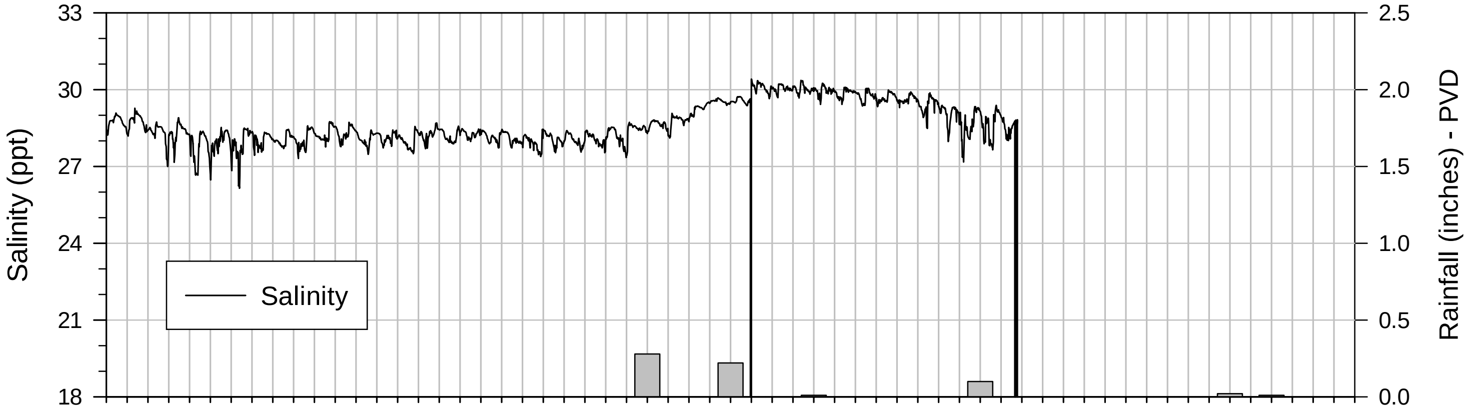

The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by NBC and RIDEM - Office of Water Resources .

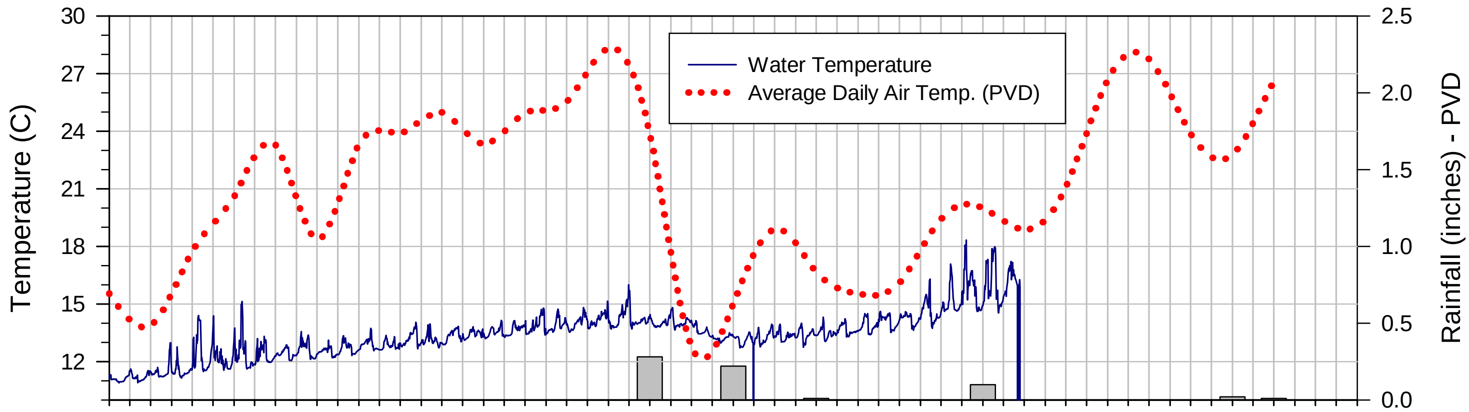
Surface Sonde at Conimicut Point (Depth ~1 meter) June 2005

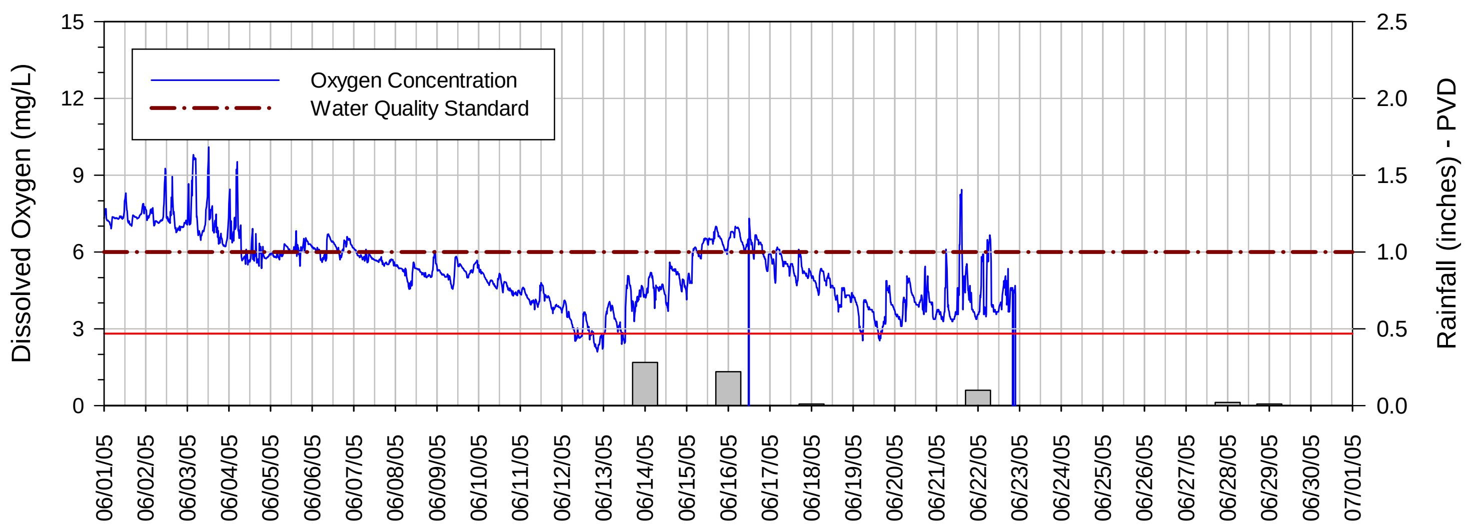



The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by RIDEM - Office of Water Resources and URI/GSO.

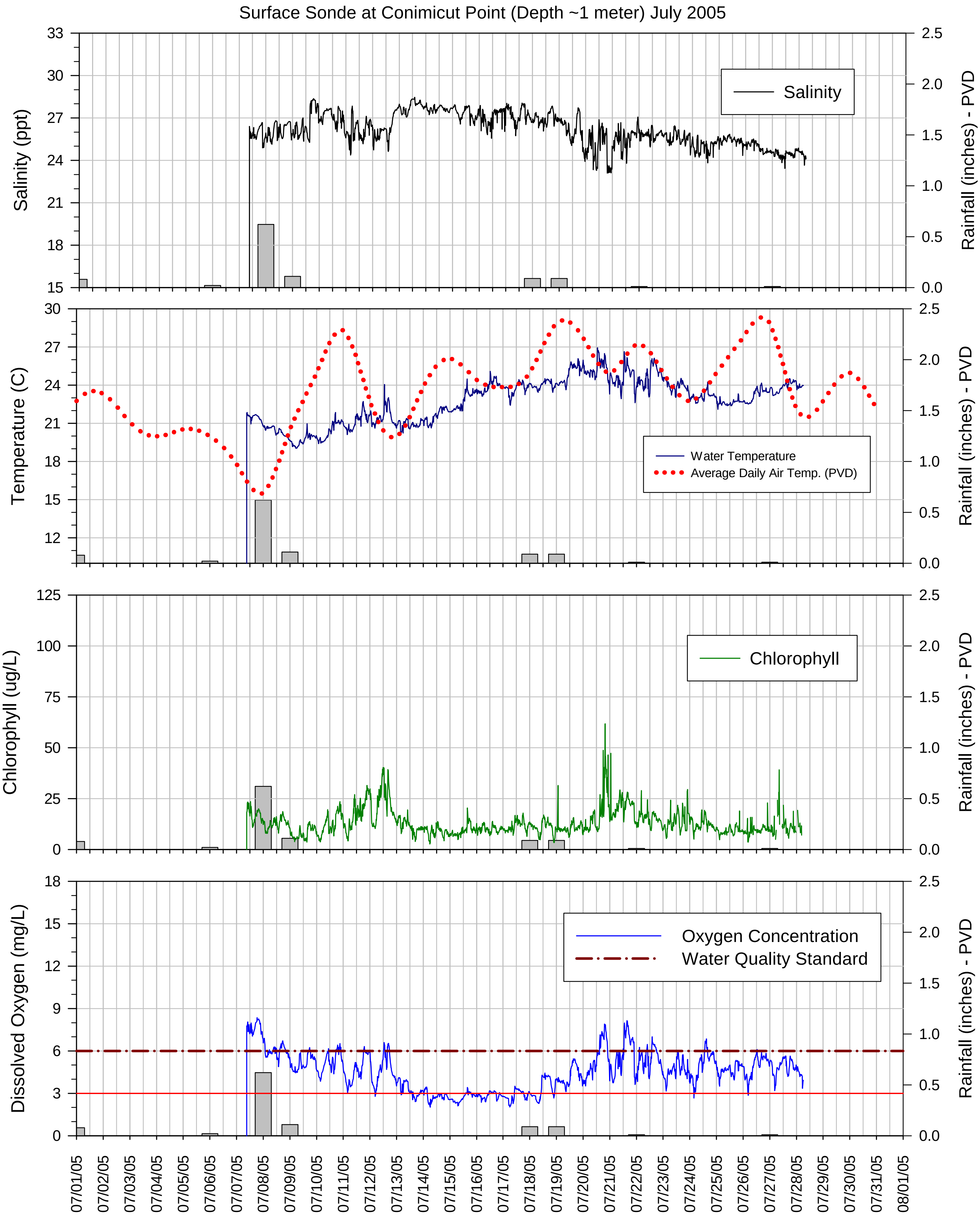
Bottom Sonde at Conimicut Point (Depth ~9 meters) June 2005



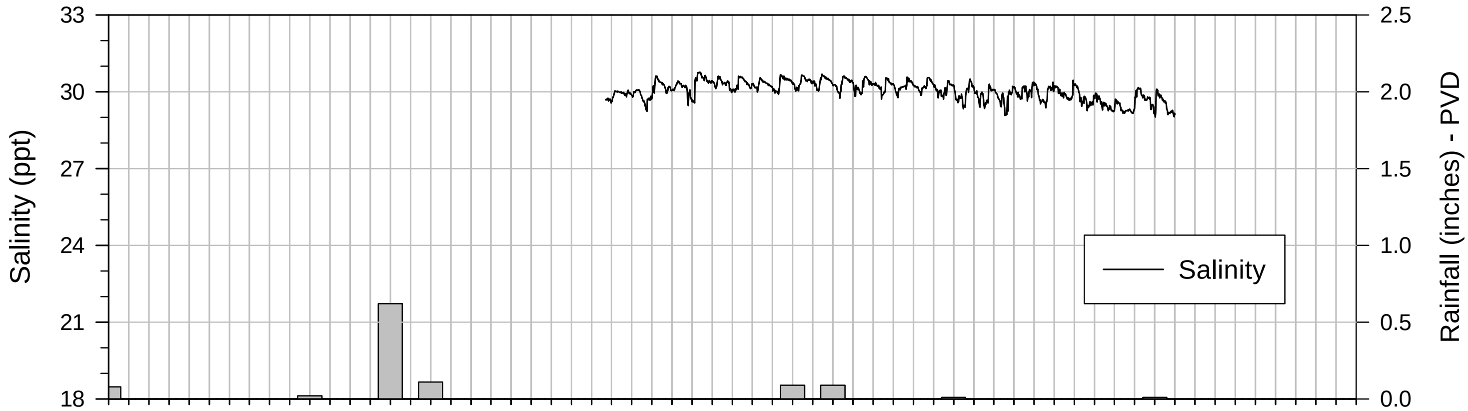



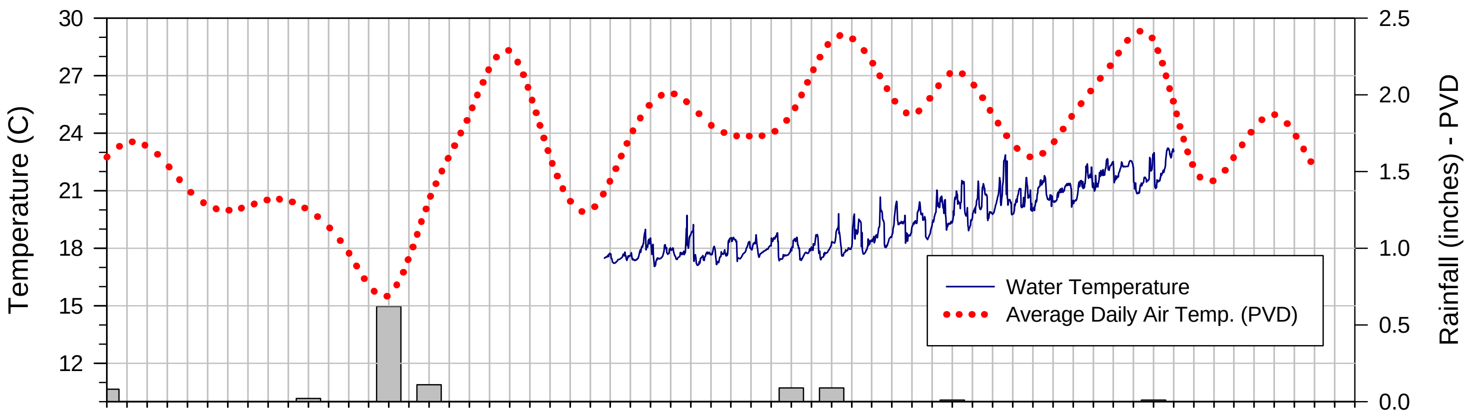

The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by RIDEM - Office of Water Resources and URI/GSO .

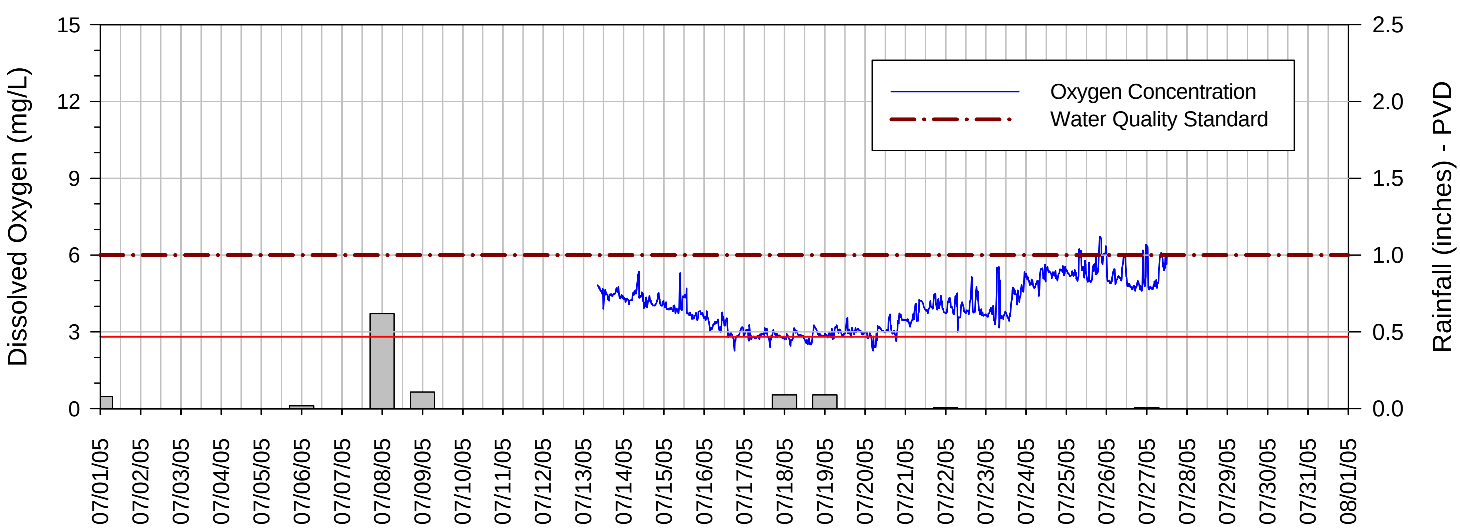



The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by RIDEM - Office of Water Resources and URI/GSO.

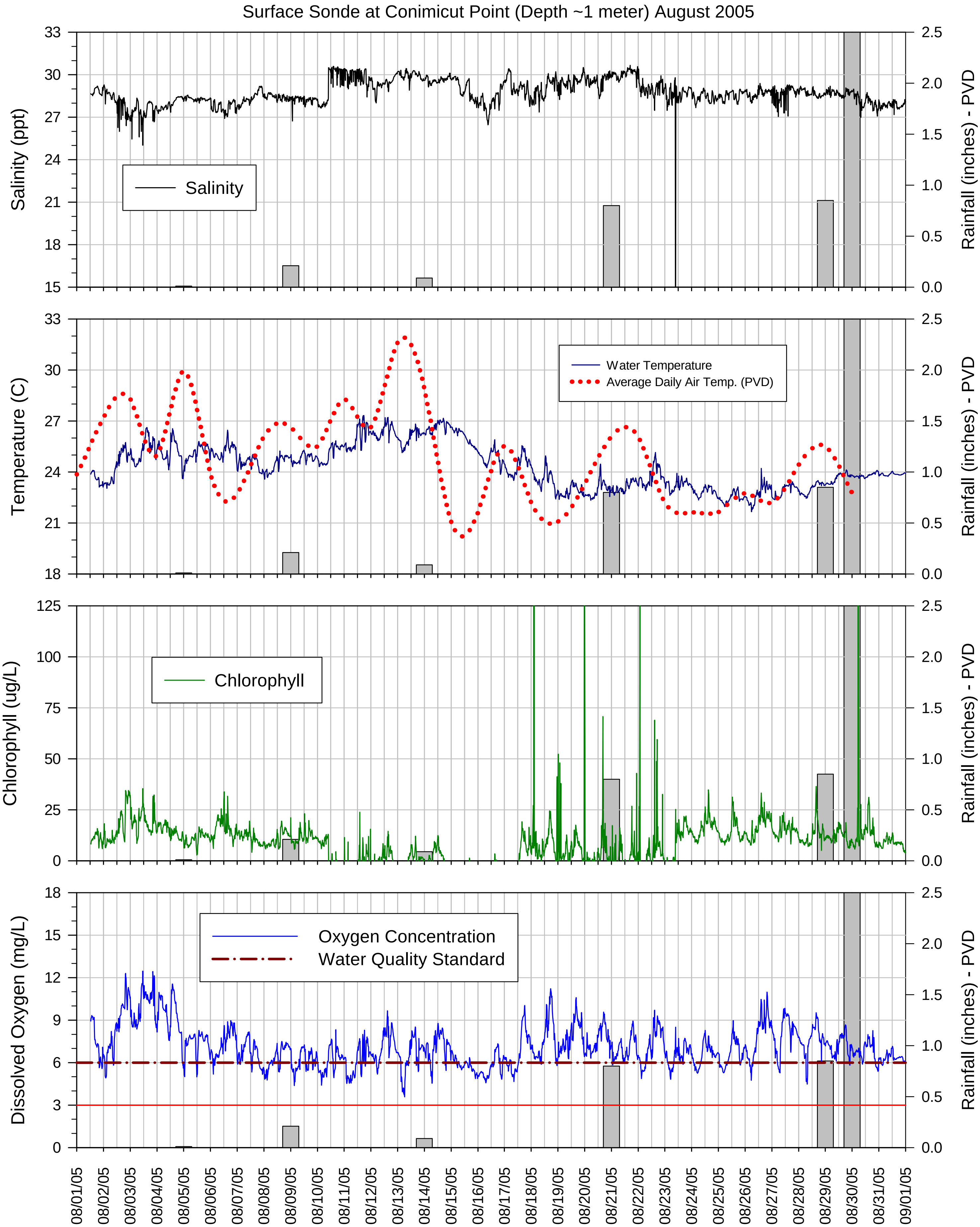
Bottom Sonde at Conimicut Point (Depth ~9 meters) July 2005



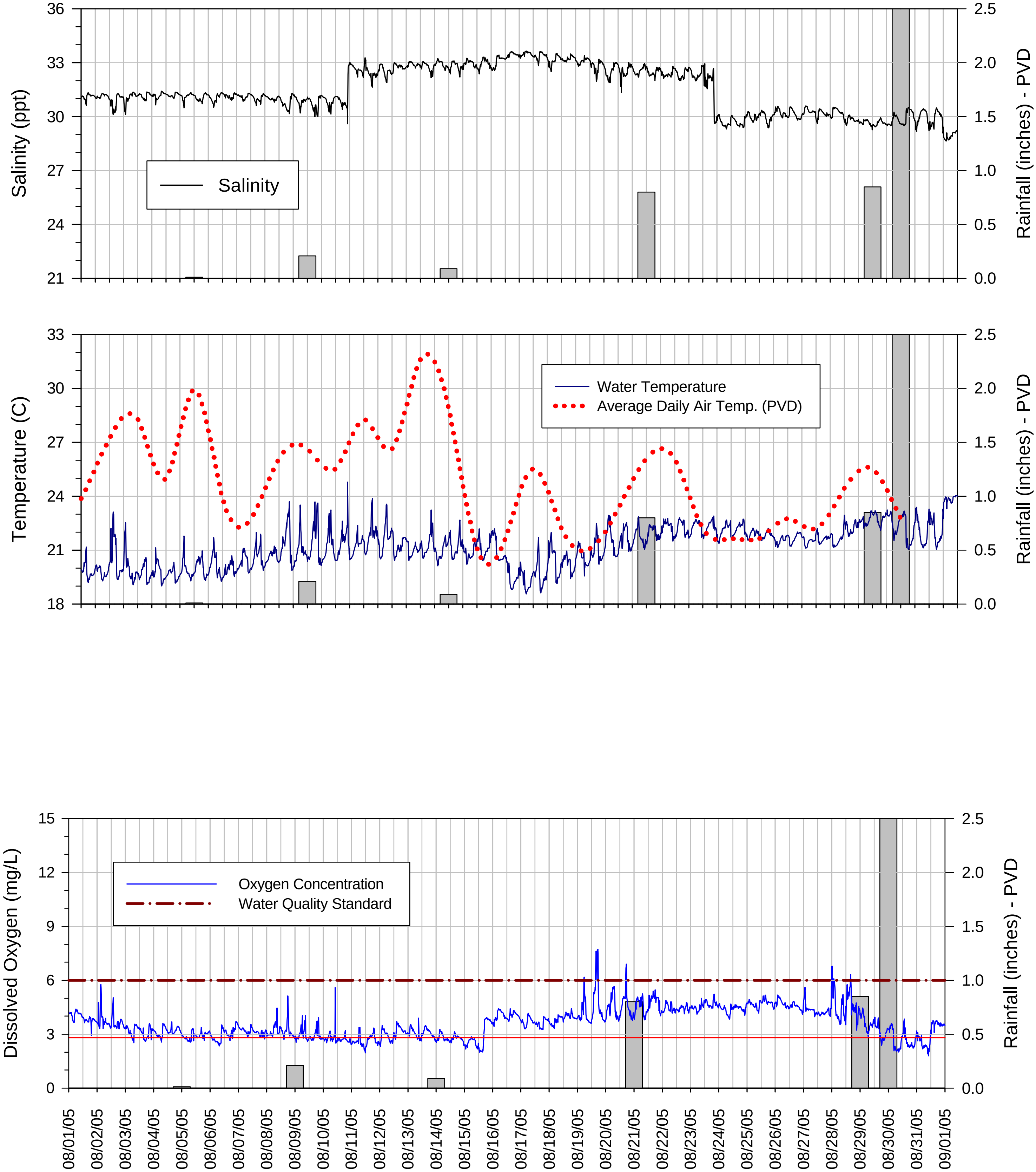




The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by RIDEM - Office of Water Resources and URI/GSO .



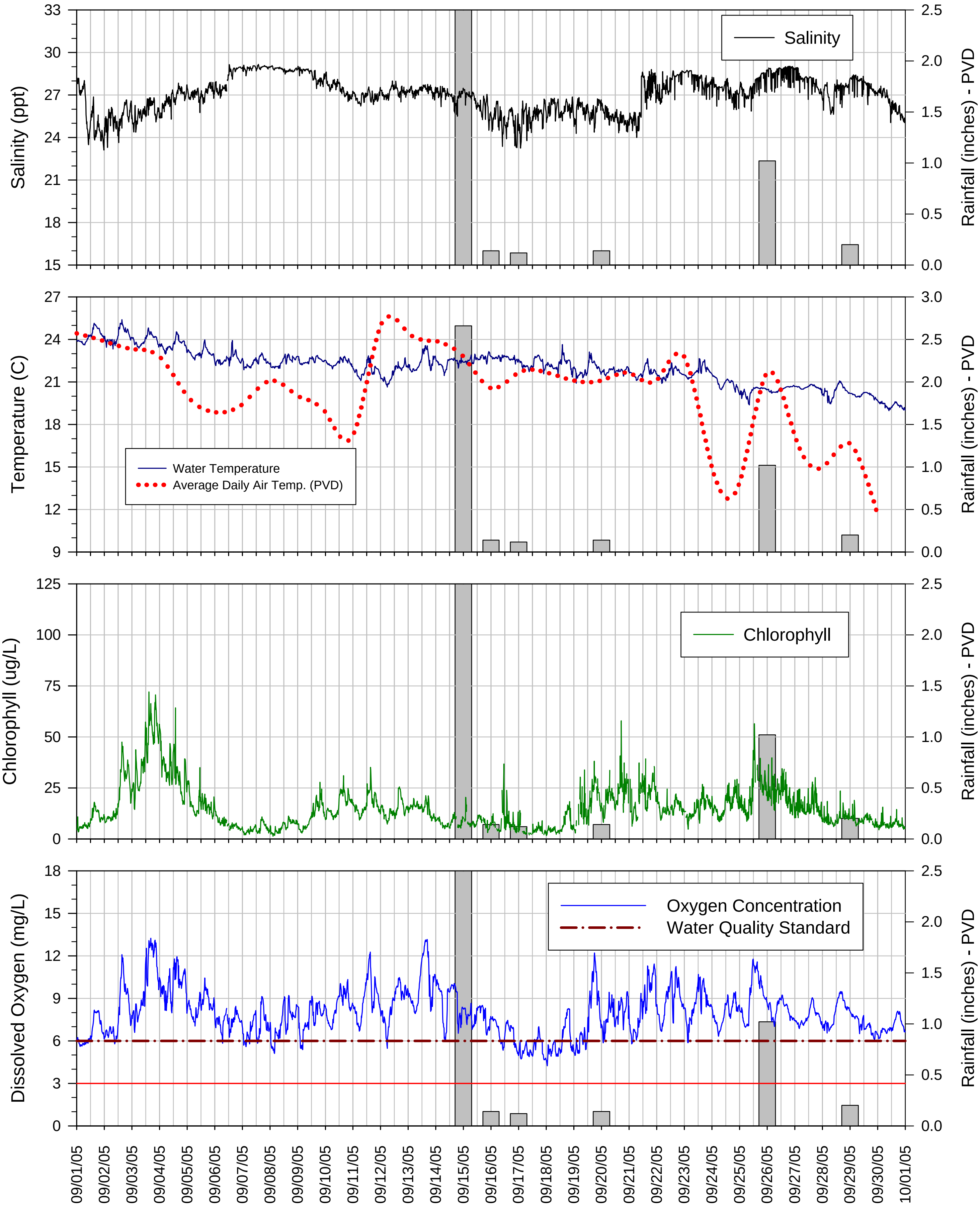

The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by RIDEM - Office of Water Resources and URI/GSO.

Bottom Sonde at Conimicut Point (Depth ~9 meters) August 2005



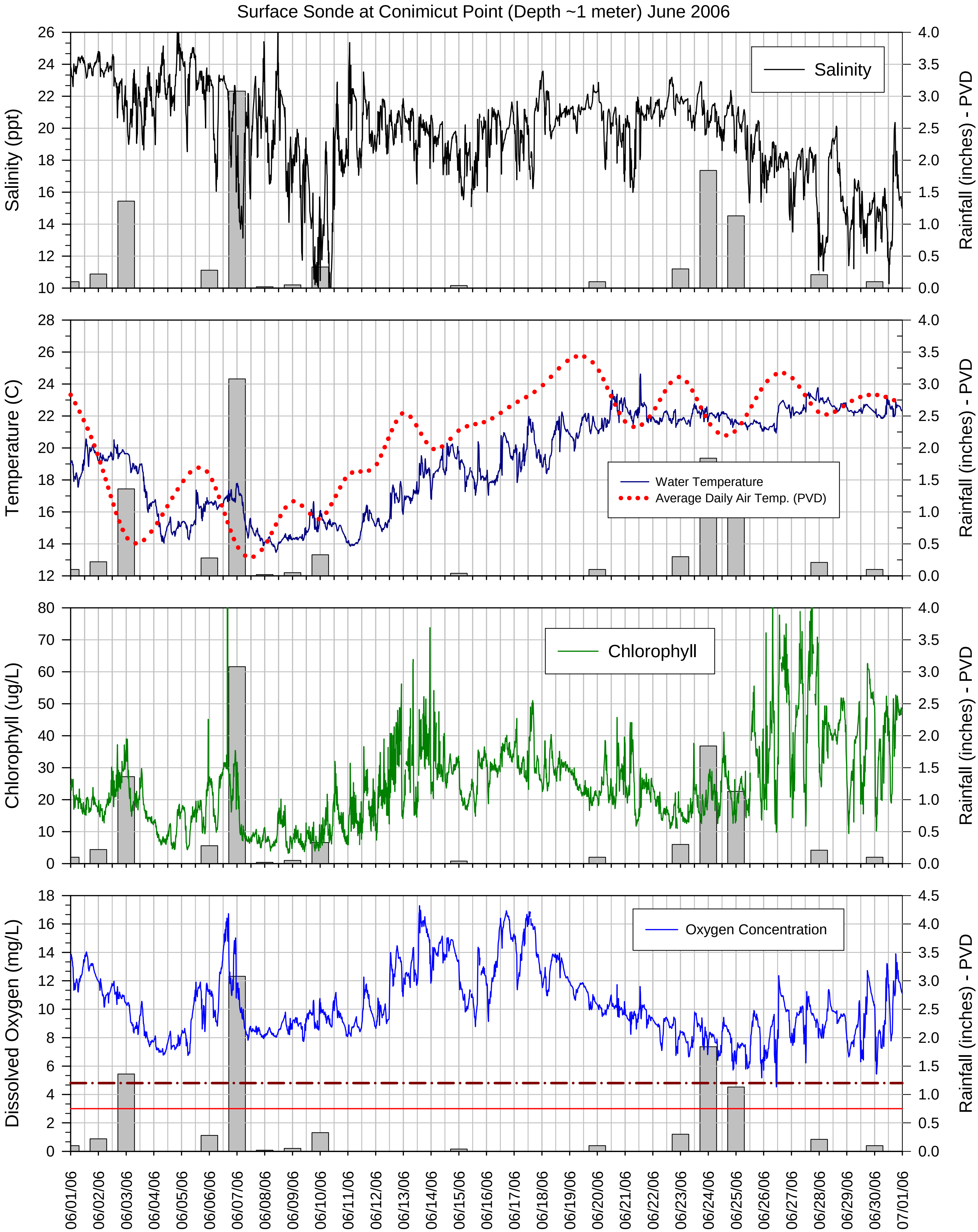

The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by RIDEM - Office of Water Resources and URI/GSO.

Surface Sonde at Conimicut Point (Depth ~1 meter) September 2005



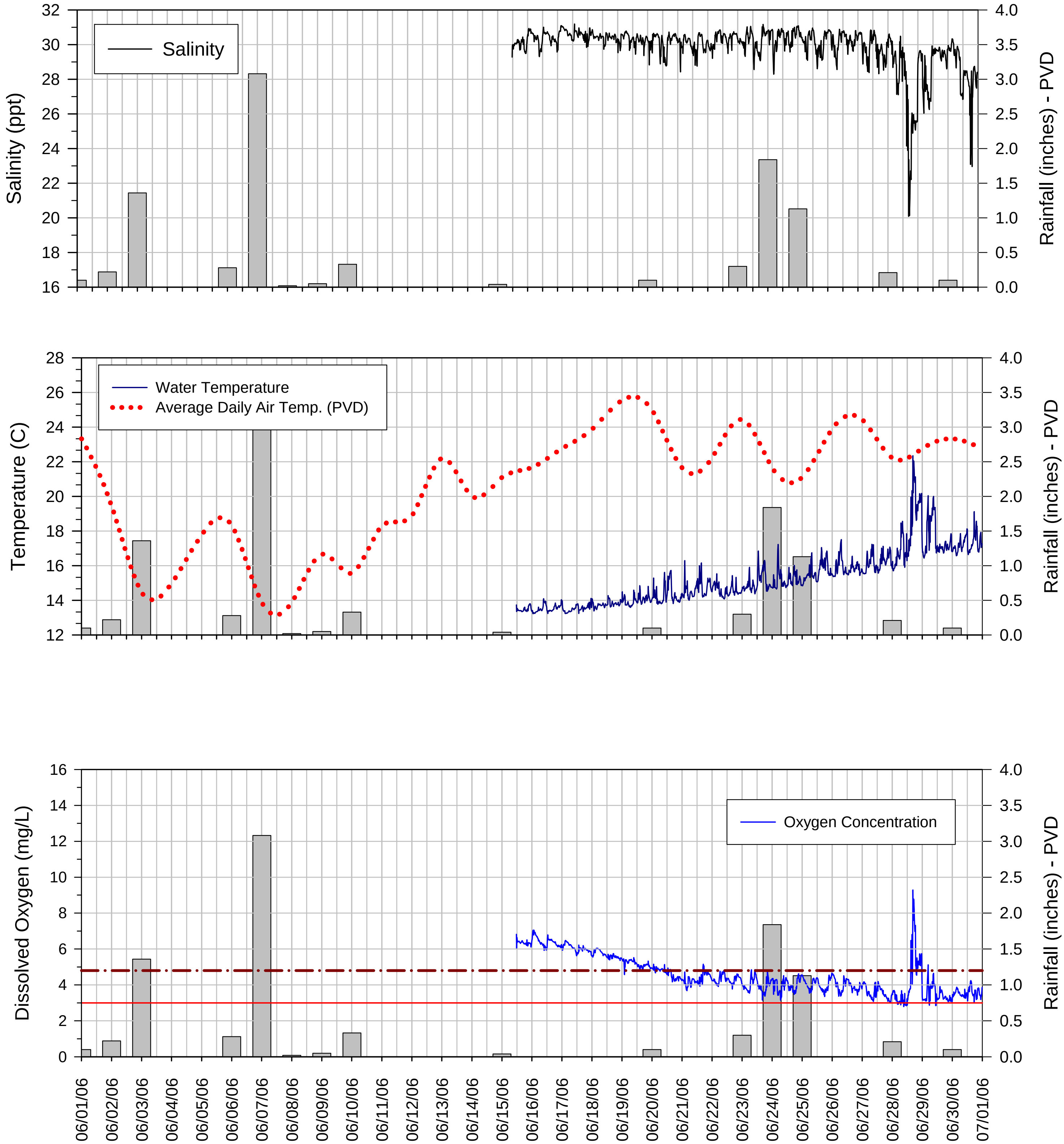

The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by RIDEM - Office of Water Resources and URI/GSO.


The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by RIDEM - Office of Water Resources and URI/GSO.

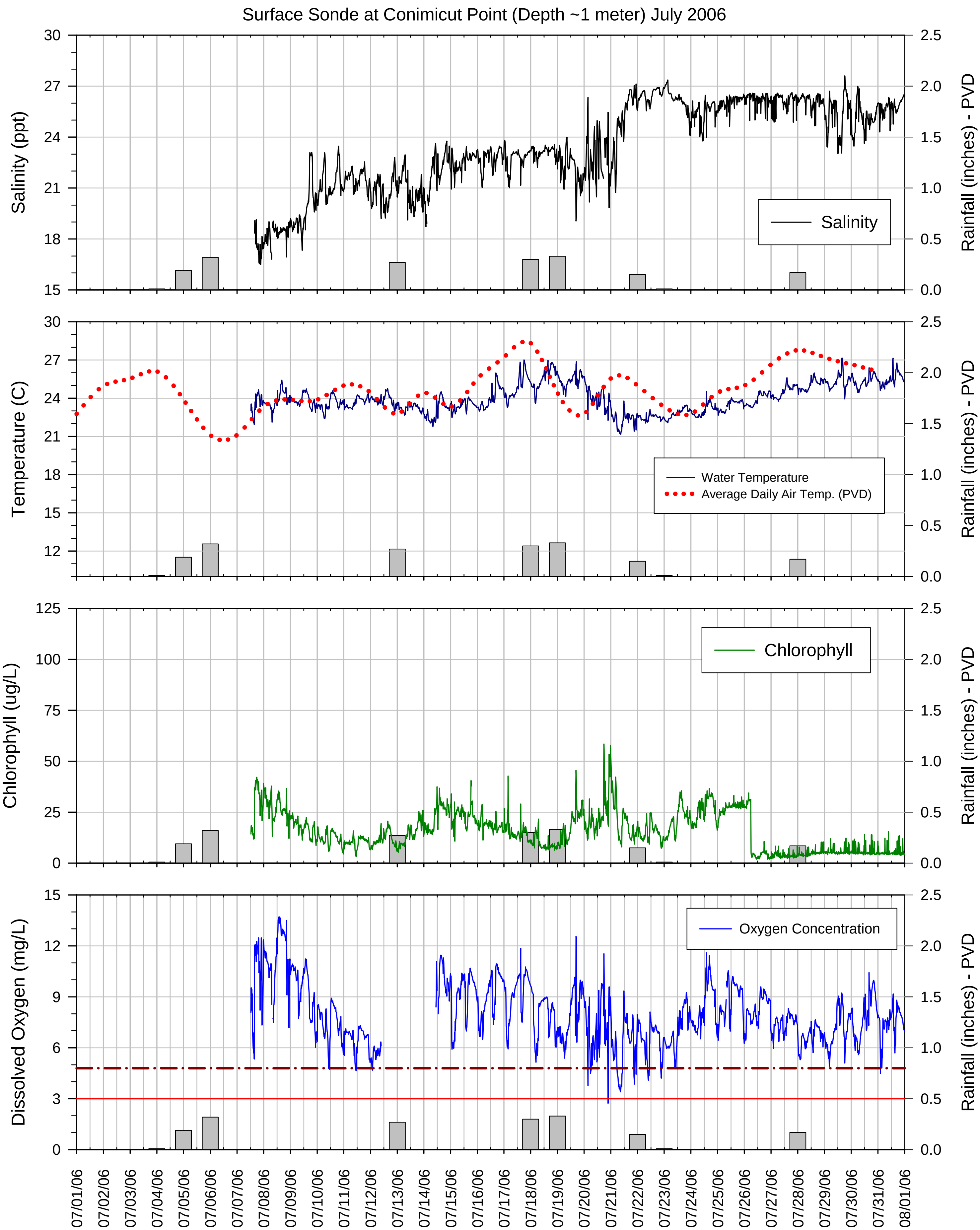



The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by RIDEM - Office of Water Resources and URI/GSO.

## Bottom Sonde at Conimicut Point (Depth ~7.5 meters) June 2006

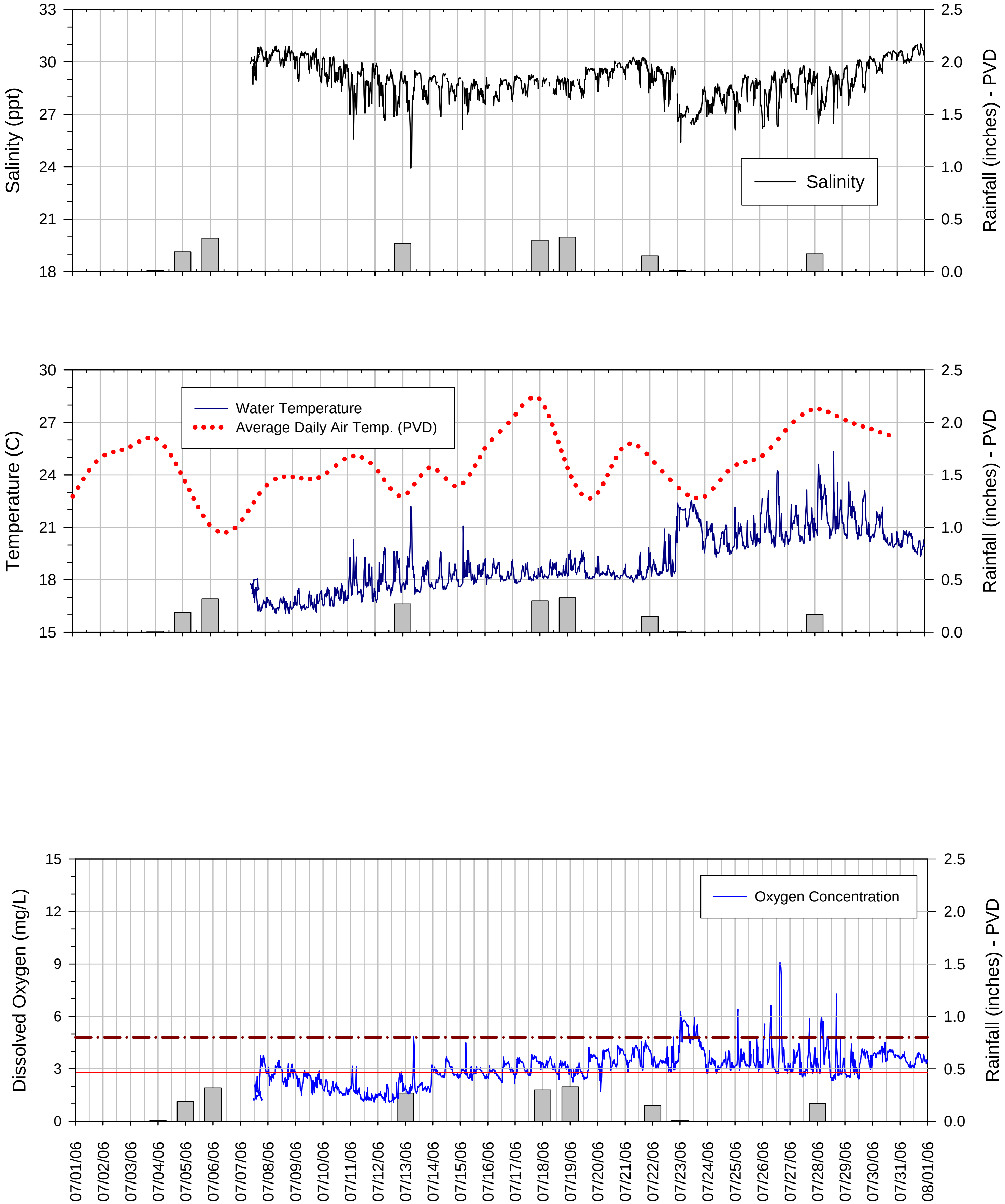



The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by RIDEM - Office of Water Resources and URI/GSO.

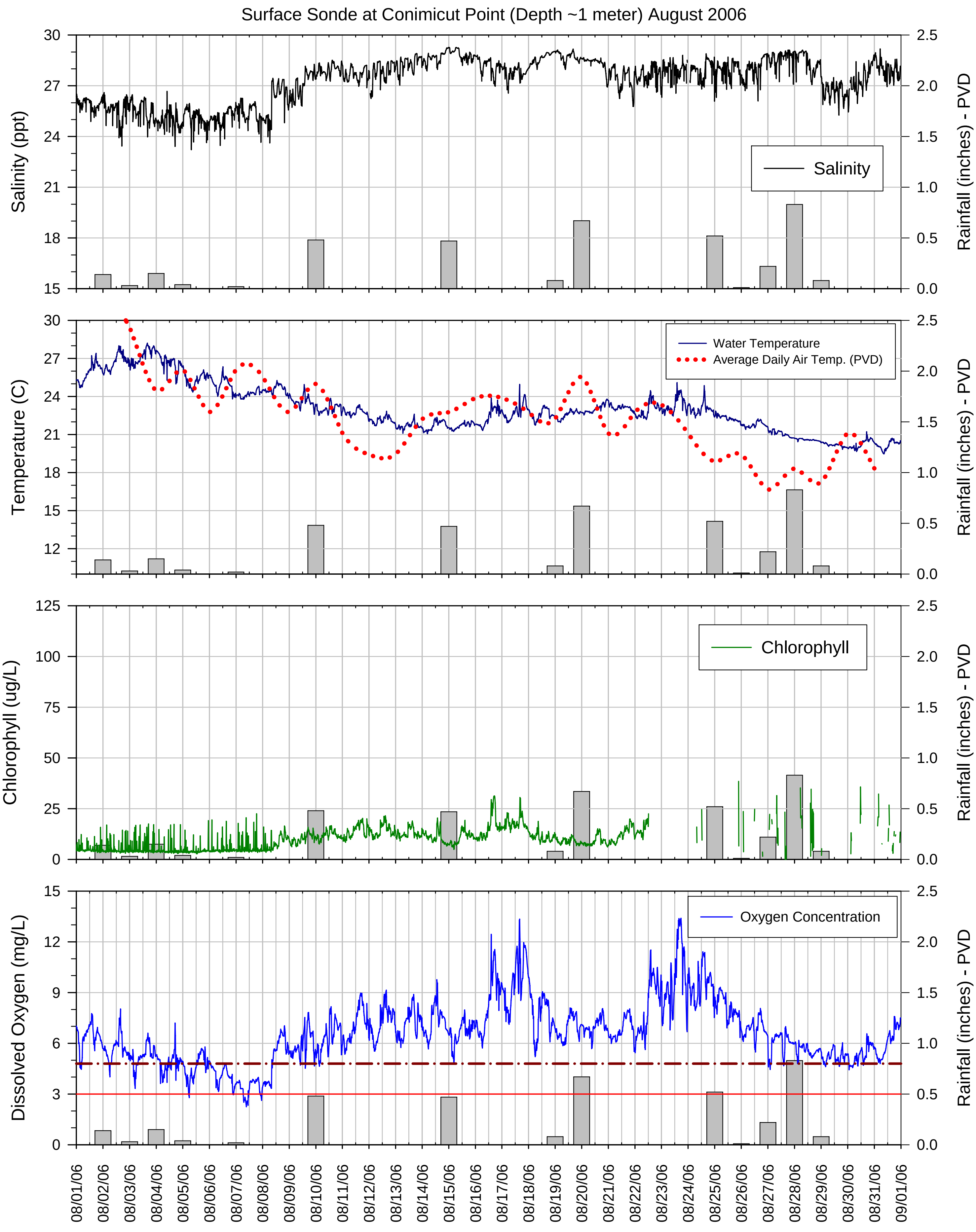



The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by RIDEM - Office of Water Resources and URI/GSO.

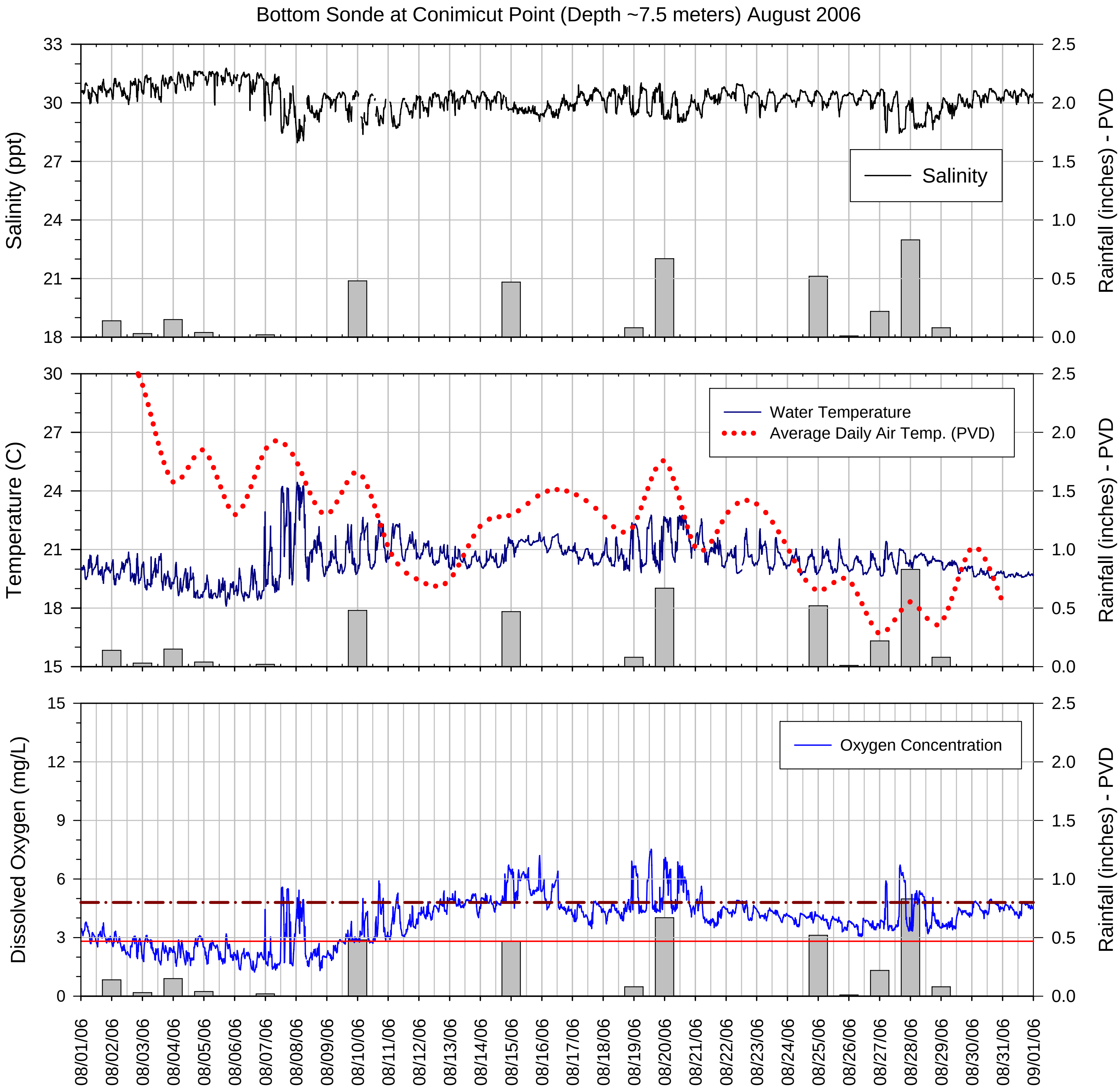
Bottom Sonde at Conimicut Point (Depth ~7.5 meters) July 2006



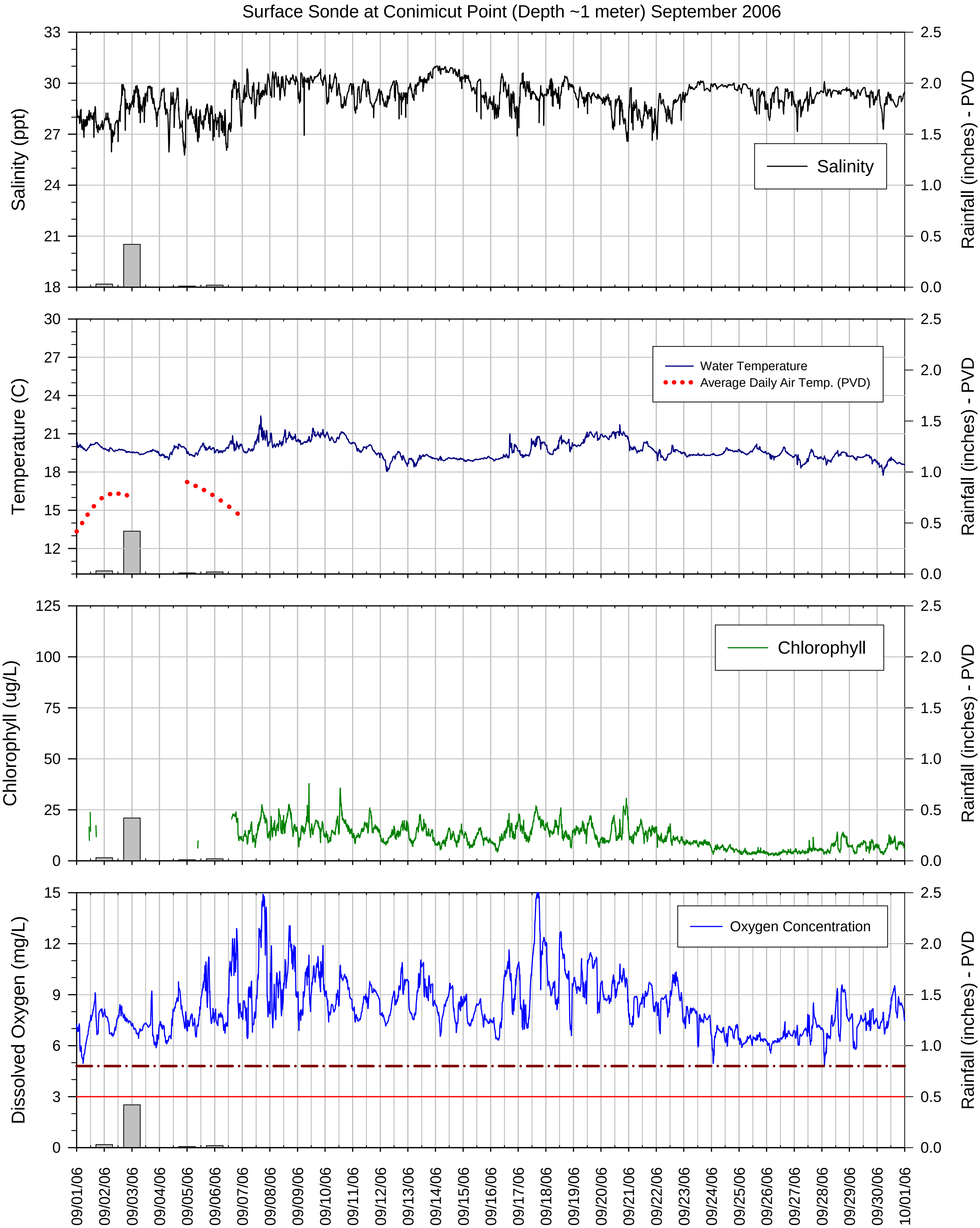

The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by RIDEM - Office of Water Resources and URI/GSO.




The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by RIDEM - Office of Water Resources and URI/GSO.

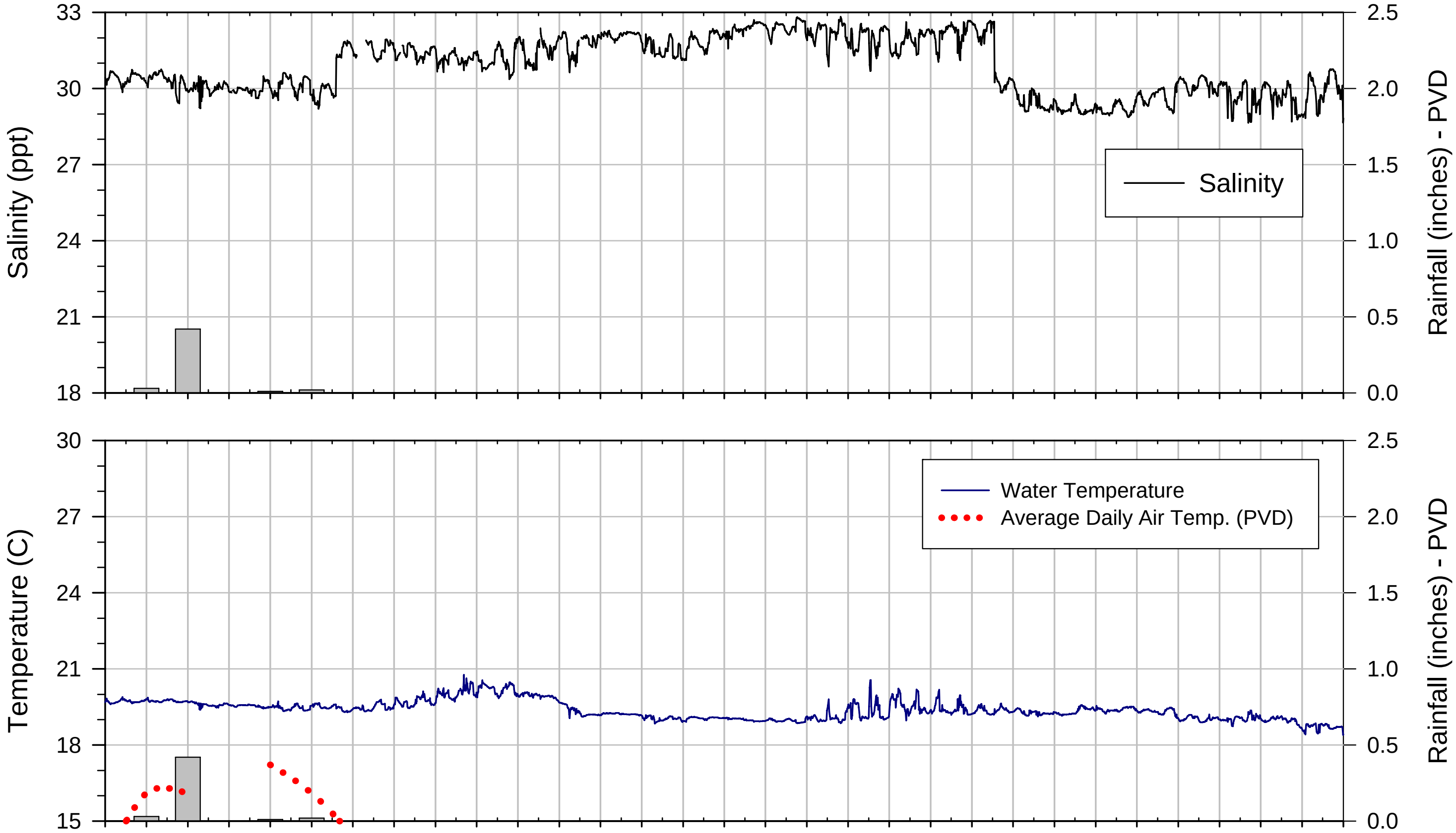


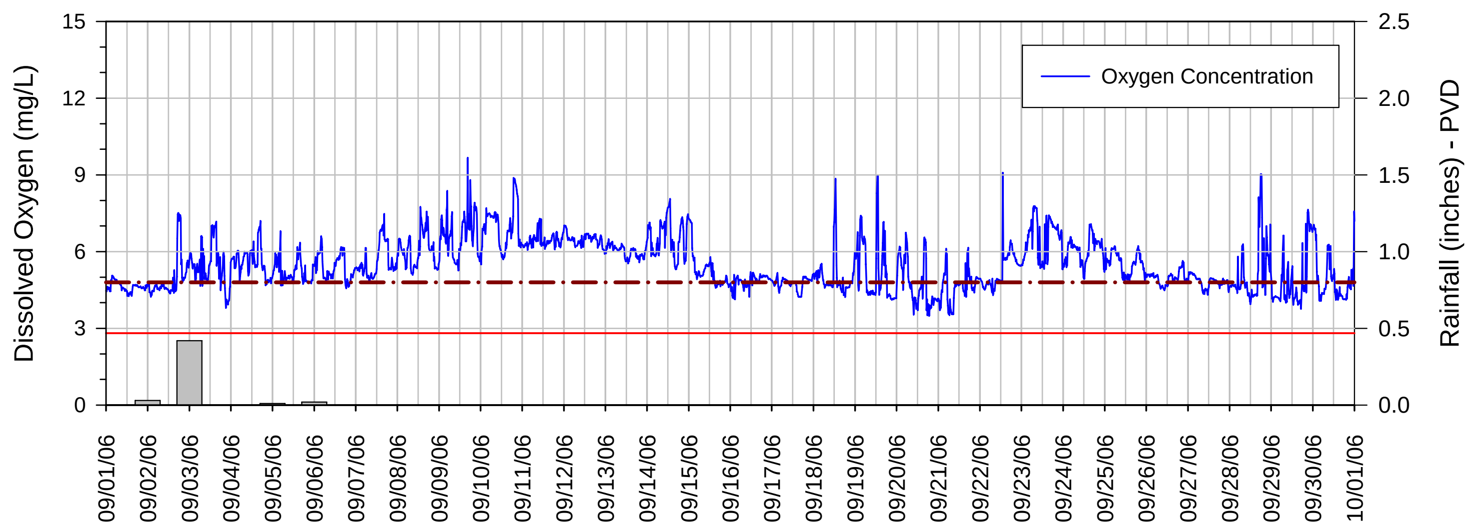

The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by RIDEM - Office of Water Resources and URI/GSO.




The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by RIDEM - Office of Water Resources and URI/GSO.

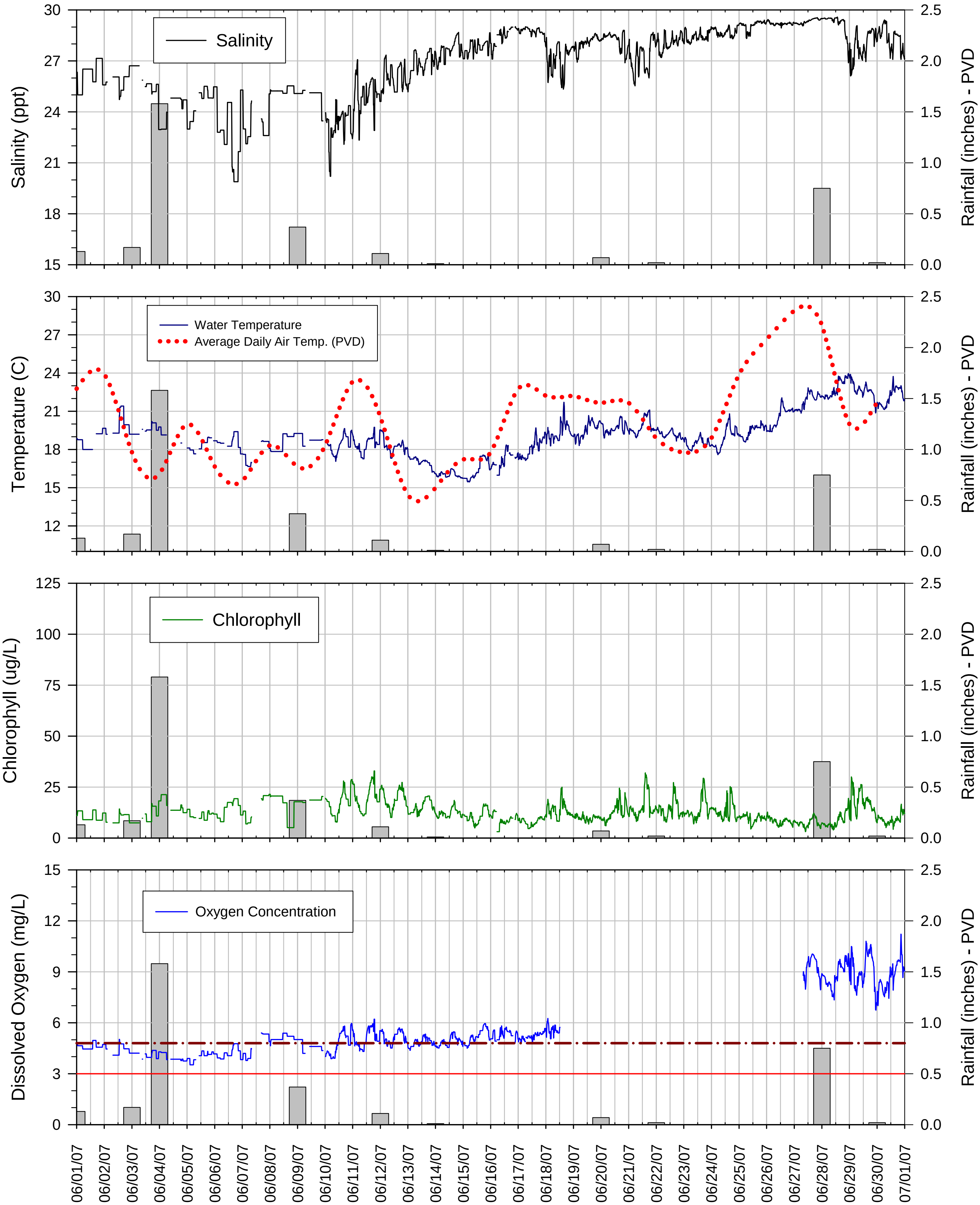
Bottom Sonde at Conimicut Point (Depth ~7.5 meters) September 2006



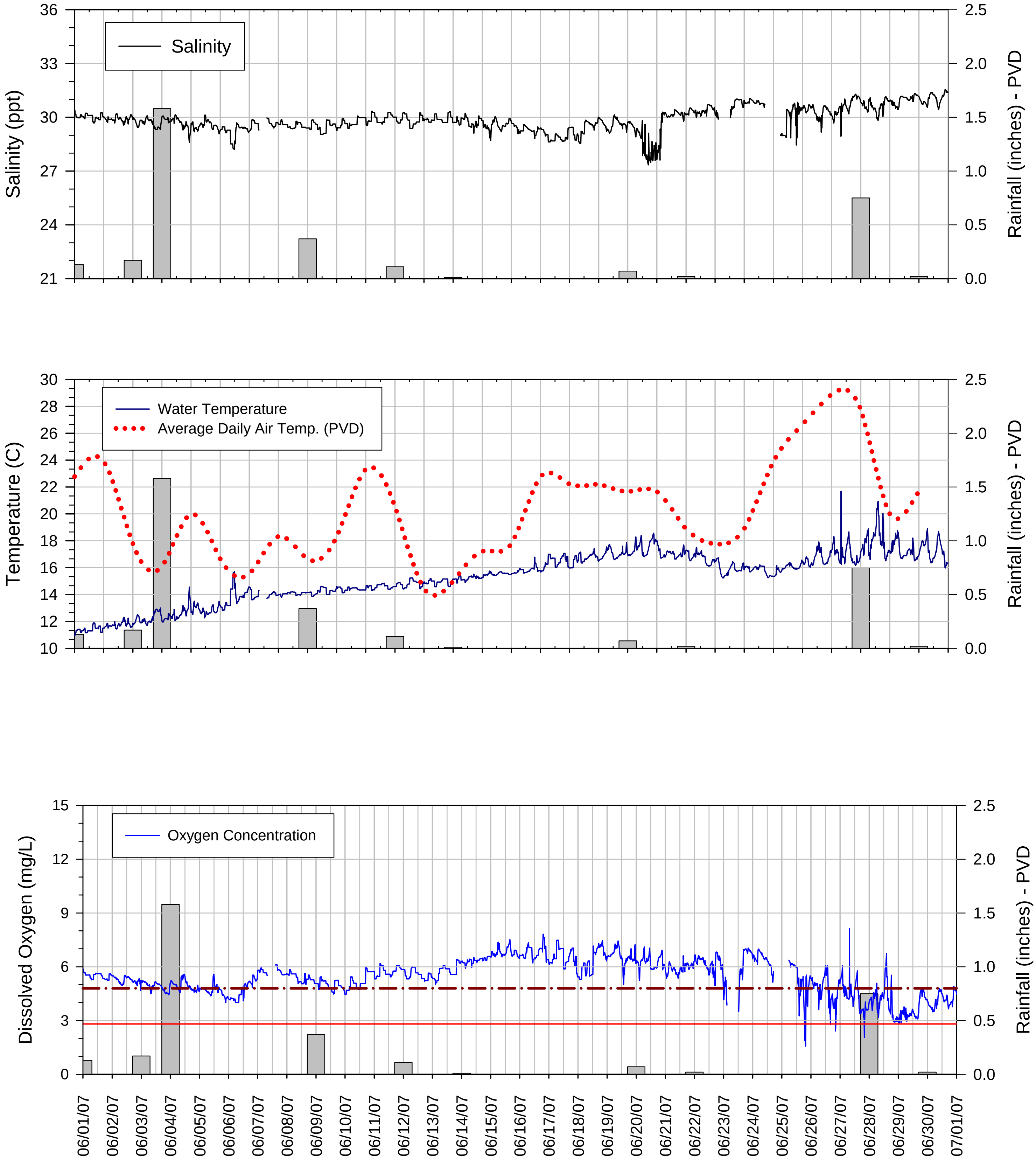

The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by RIDEM - Office of Water Resources and URI/GSO.

Surface Sonde at Conimicut Point (Depth ~1 meter) June 2007



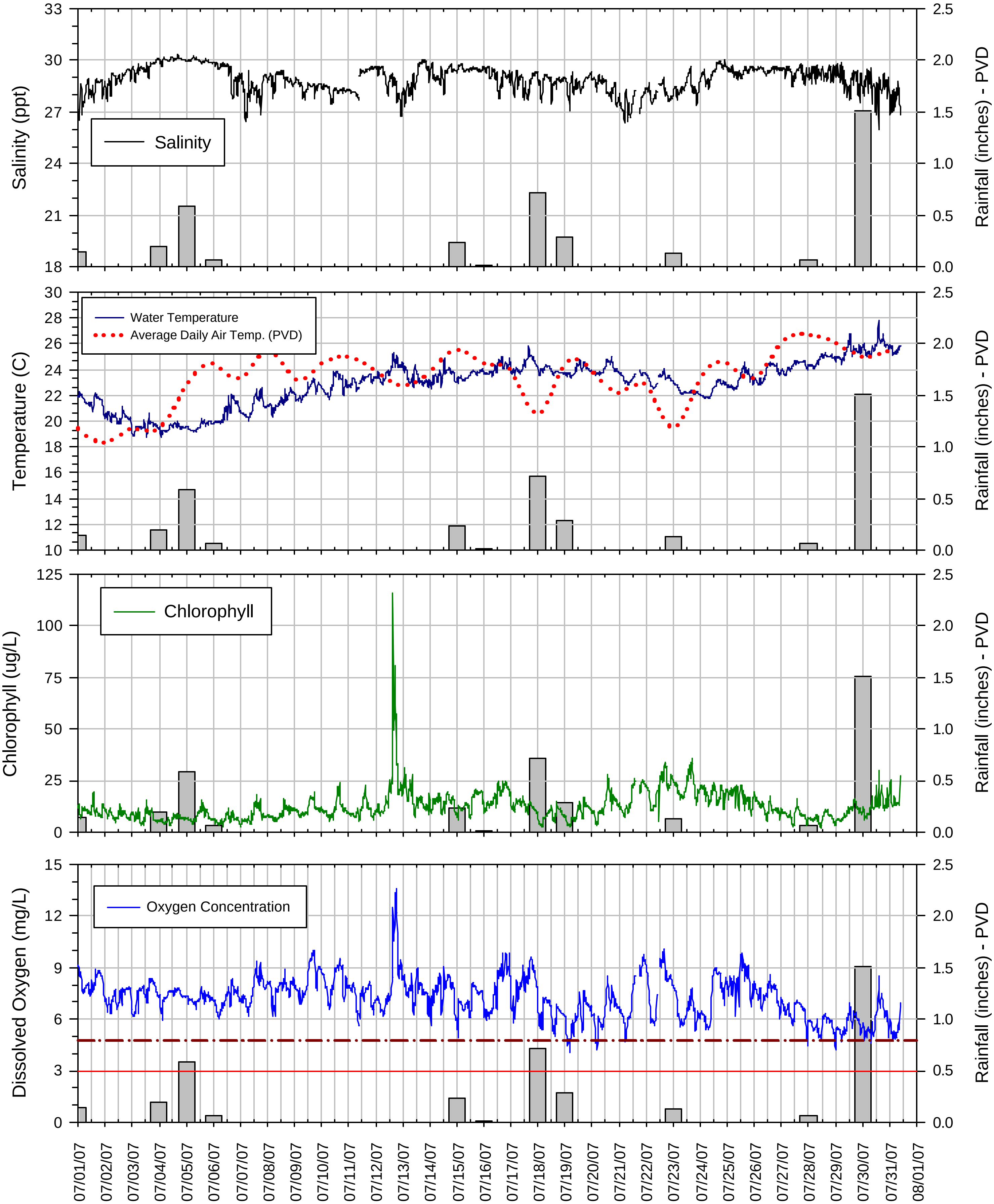

The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by RIDEM - Office of Water Resources and URI/GSO.

Bottom Sonde at Conimicut Point (Depth ~7.5 meters) June 2007



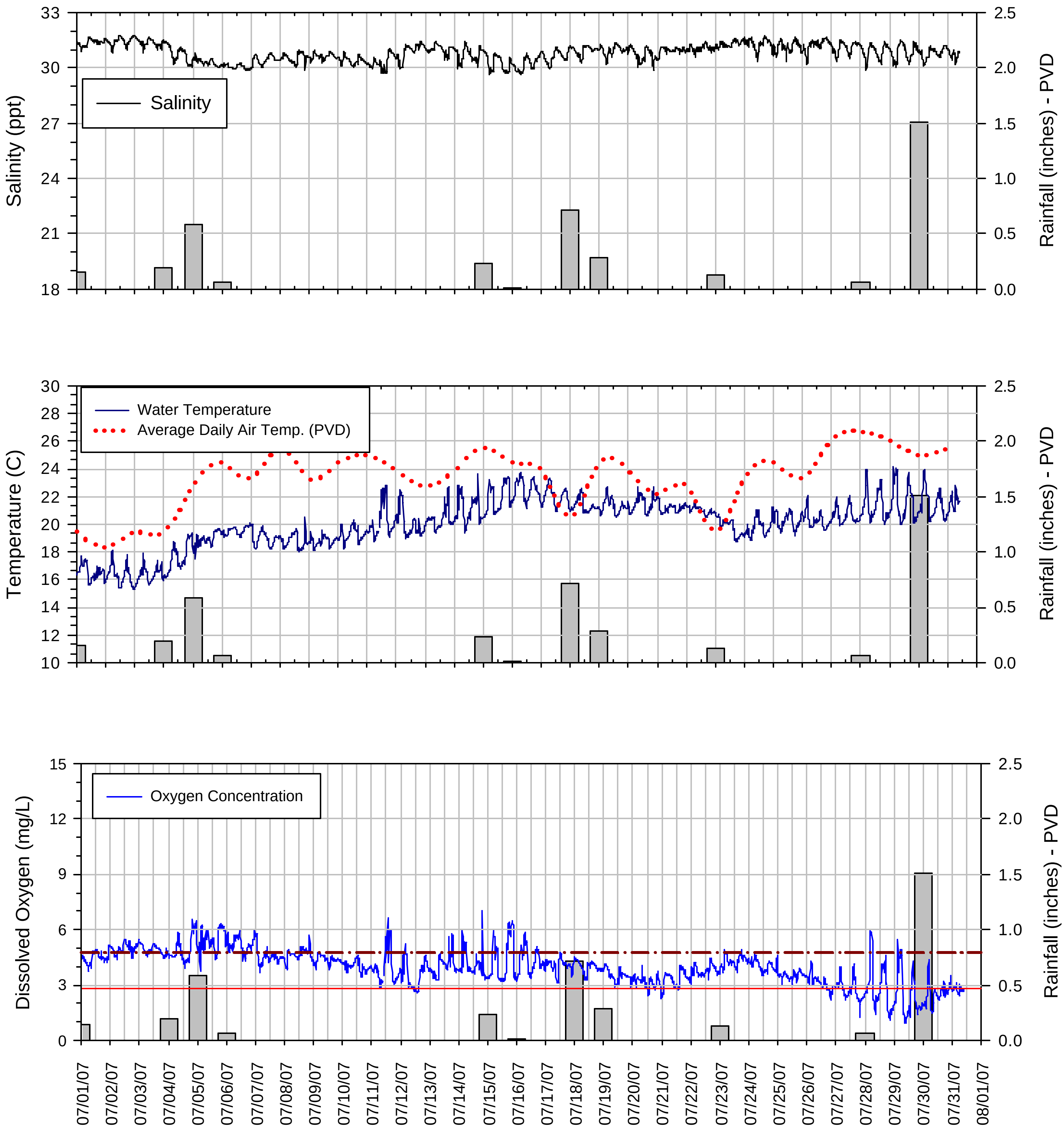

The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by RIDEM - Office of Water Resources and URI/GSO.

Surface Sonde at Conimicut Point (Depth ~1 meter) July 2007



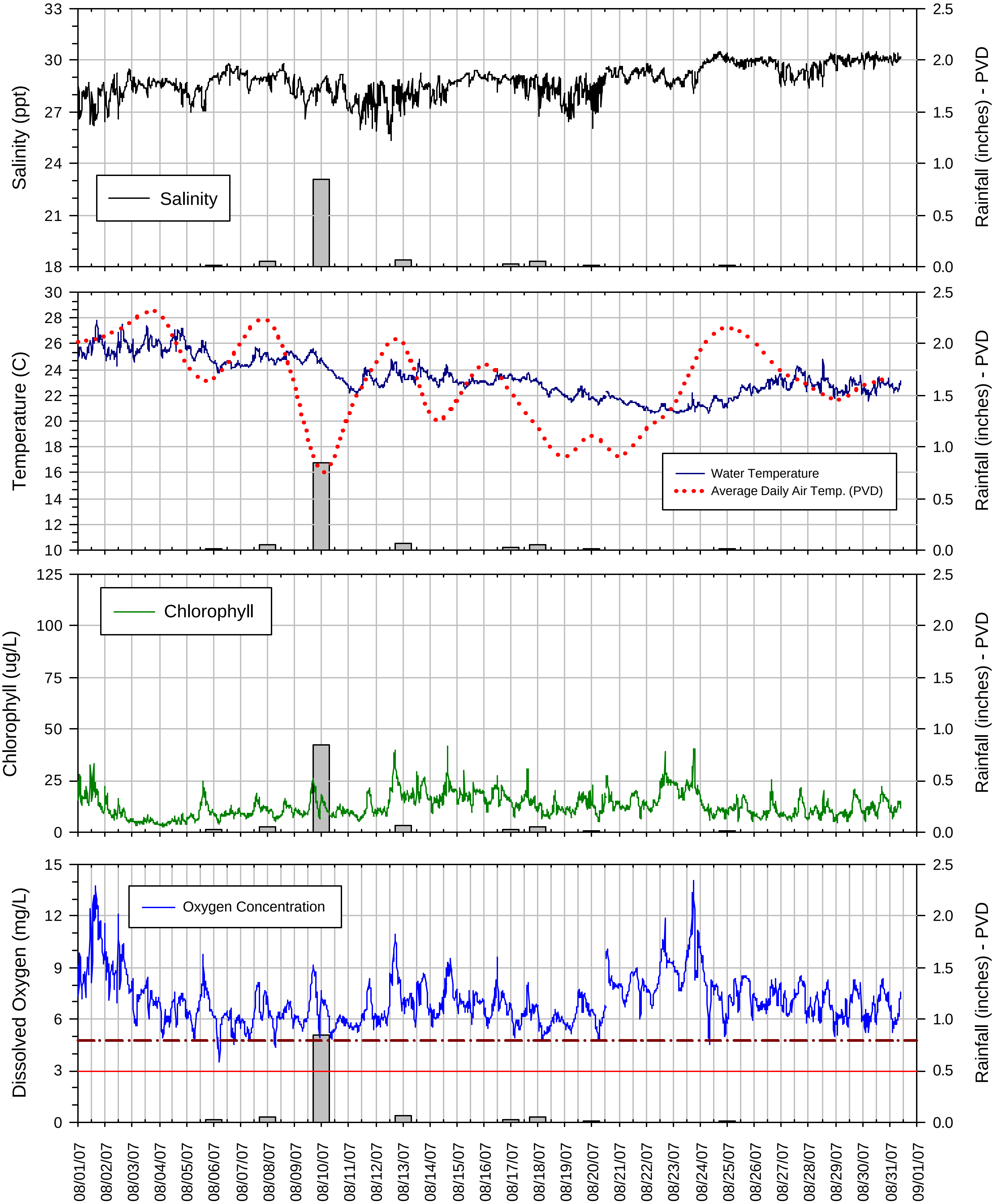

The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by RIDEM - Office of Water Resources and URI/GSO.

Bottom Sonde at Conimicut Point (Depth ~7.5 meters) July 2007



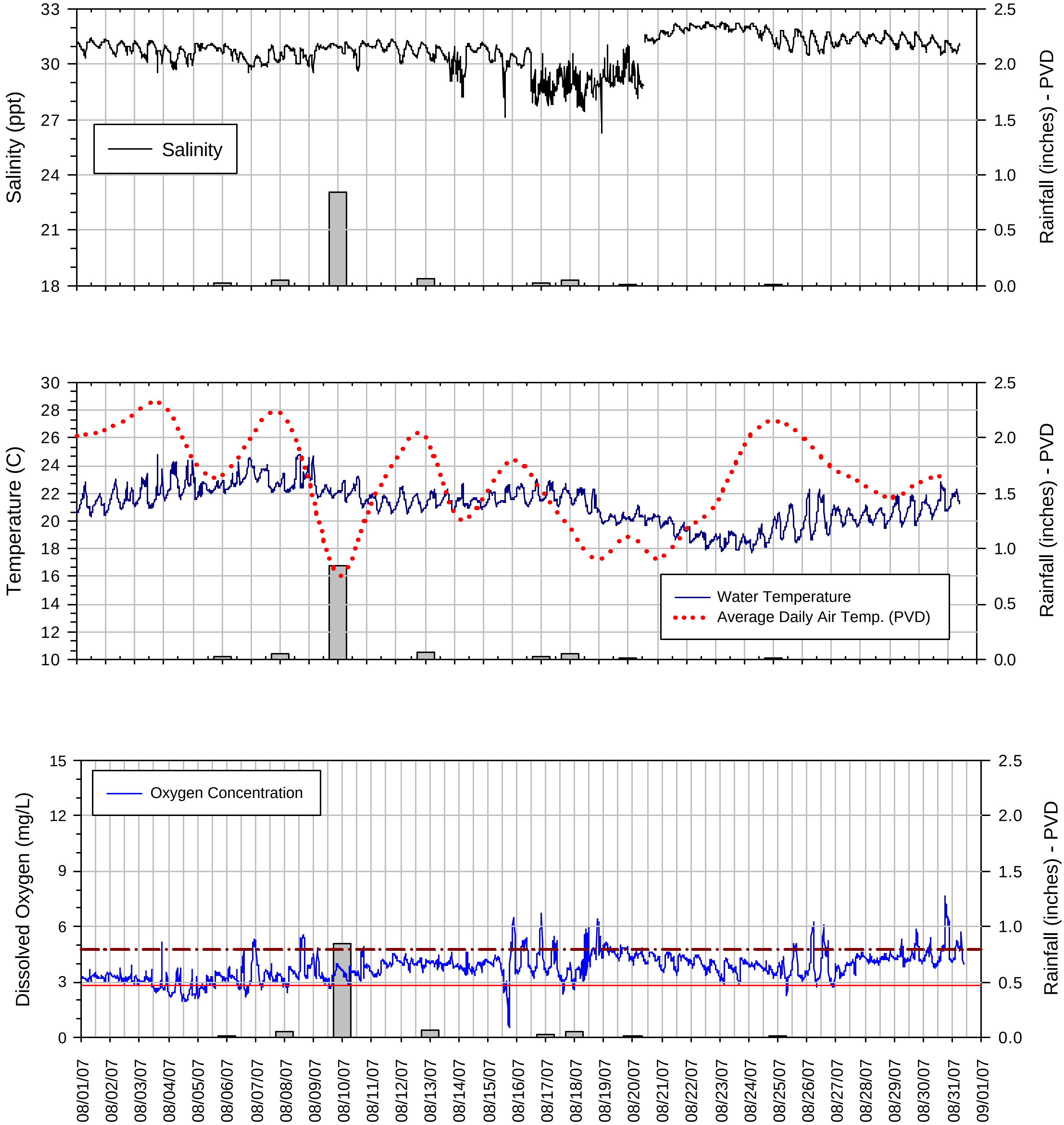

The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by RIDEM - Office of Water Resources and URI/GSO.

Surface Sonde at Conimicut Point (Depth ~1 meter) August 2007

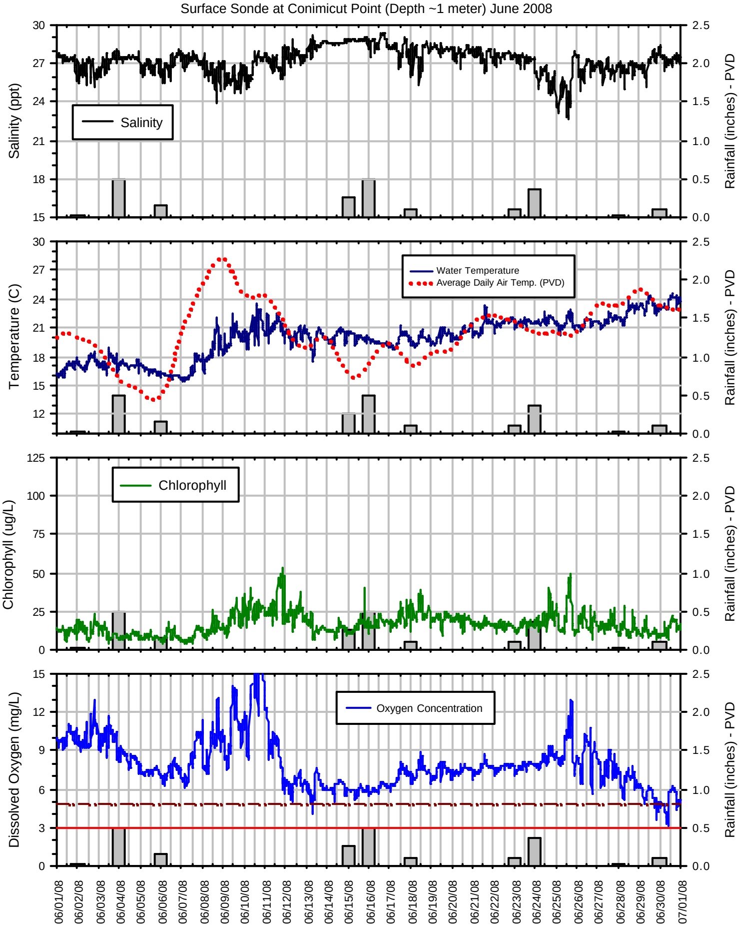



The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by RIDEM - Office of Water Resources and URI/GSO.

Bottom Sonde at Conimicut Point (Depth ~7.5 meters) August 2007

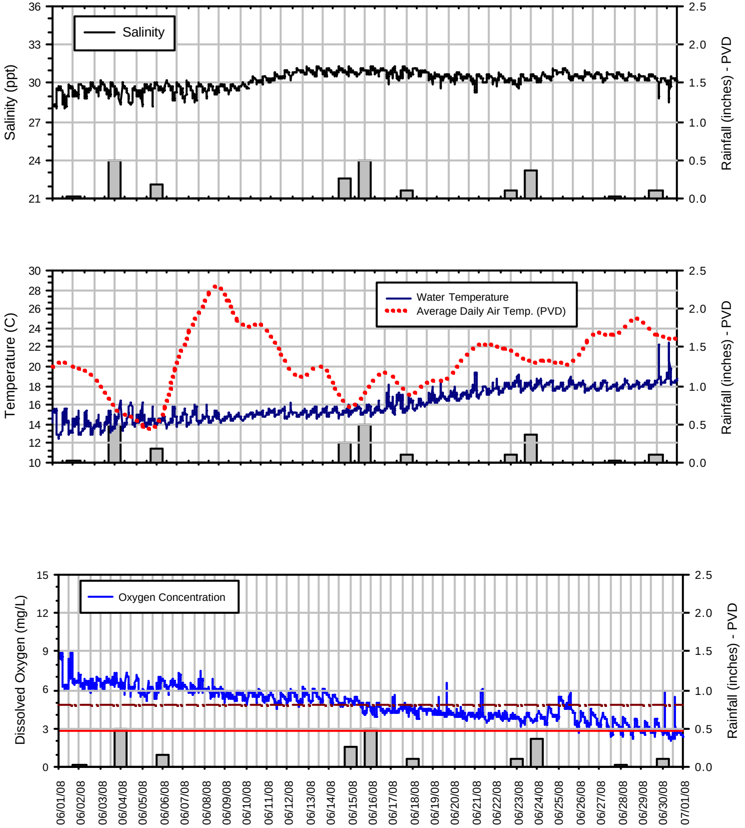



The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by RIDEM - Office of Water Resources and URI/GSO.

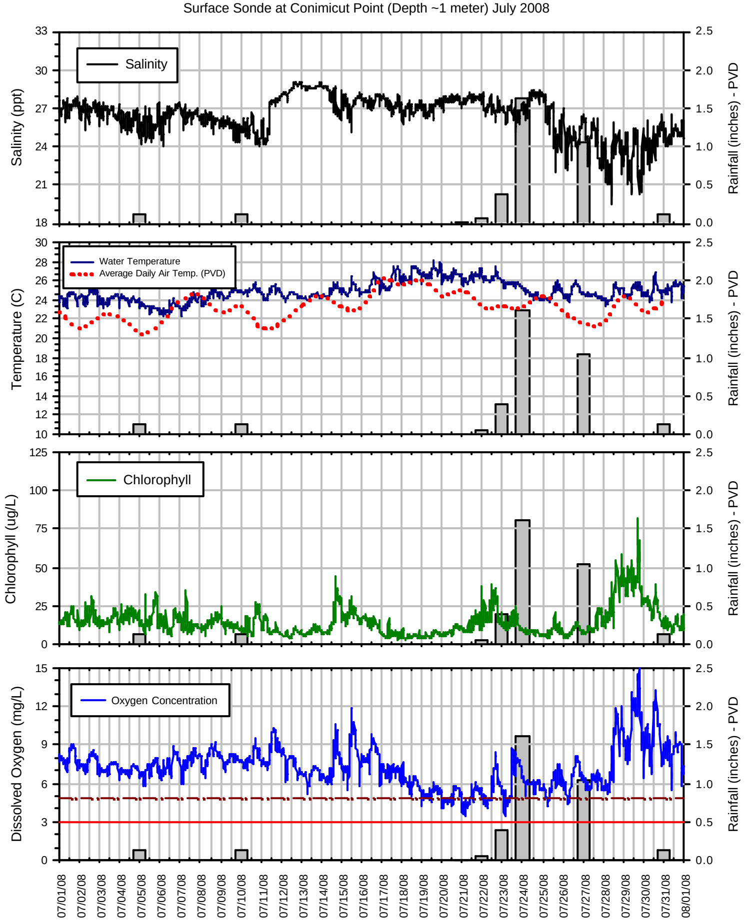



The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by RIDEM - Office of Water Resources and URI/GSO.

Bottom Sonde at Conimicut Point (Depth ~7.5 meters) June 2008

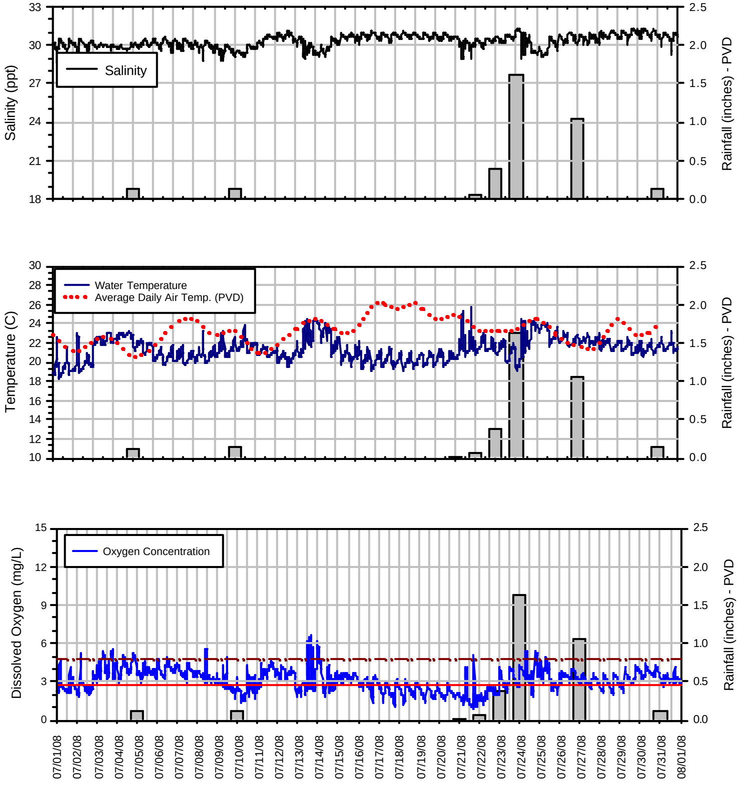



The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by RIDEM - Office of Water Resources and URI/GSO.



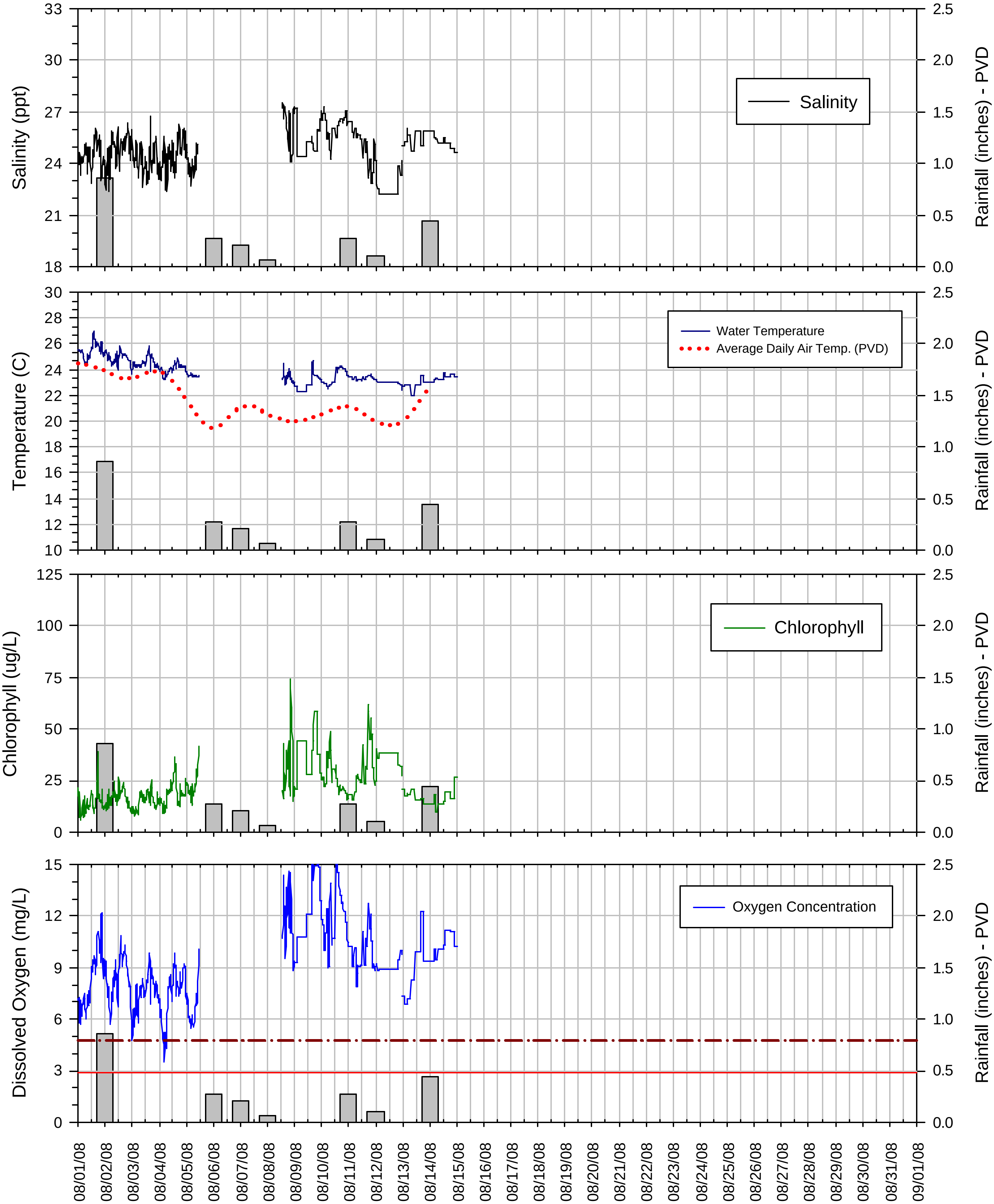

The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by RIDEM - Office of Water Resources and URI/GSO.

Bottom Sonde at Conimicut Point (Depth ~7.5 meters) July 2008



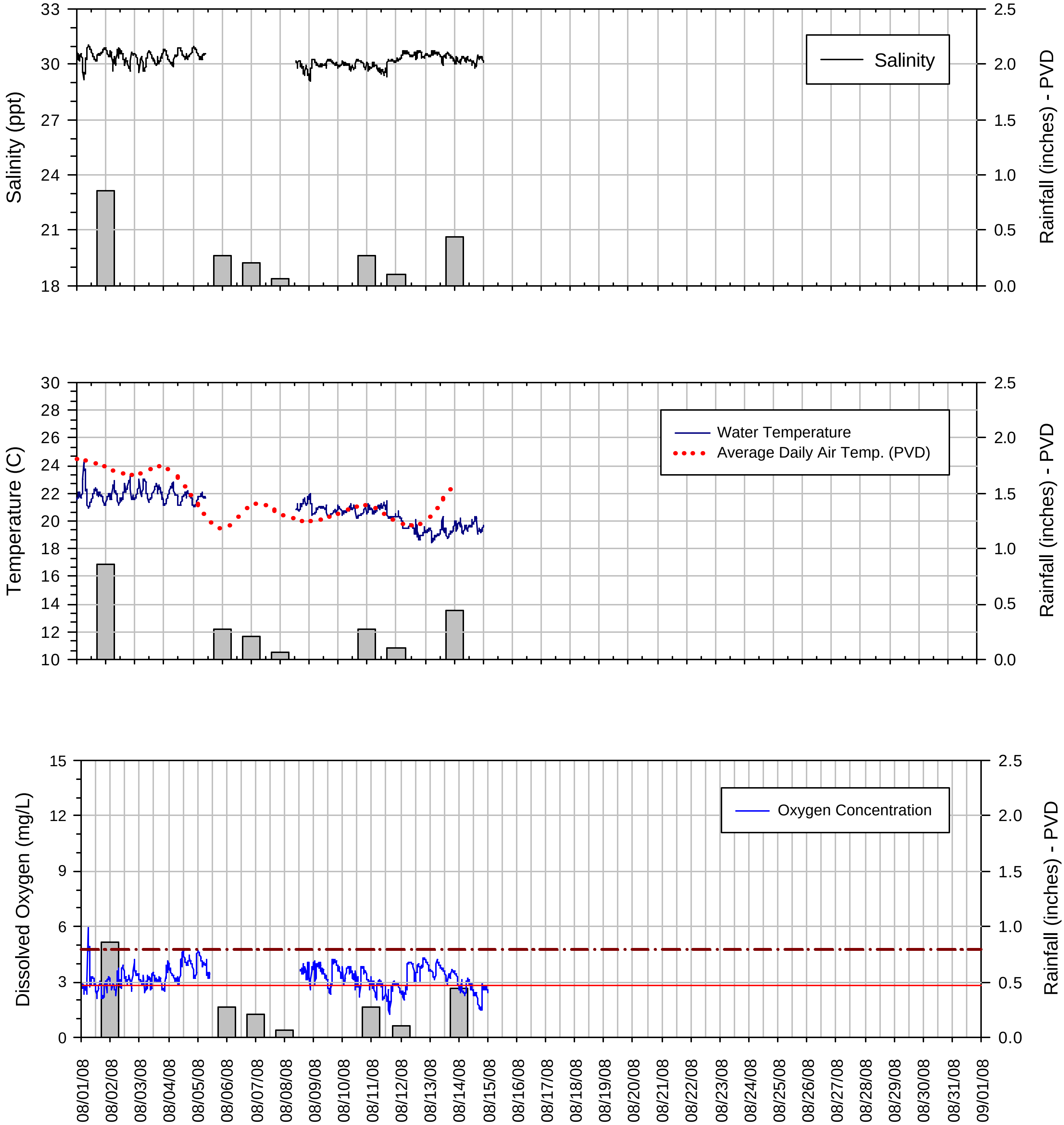

The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by RIDEM - Office of Water Resources and URI/GSO.

Surface Sonde at Conimicut Point (Depth ~1 meter) August 2008

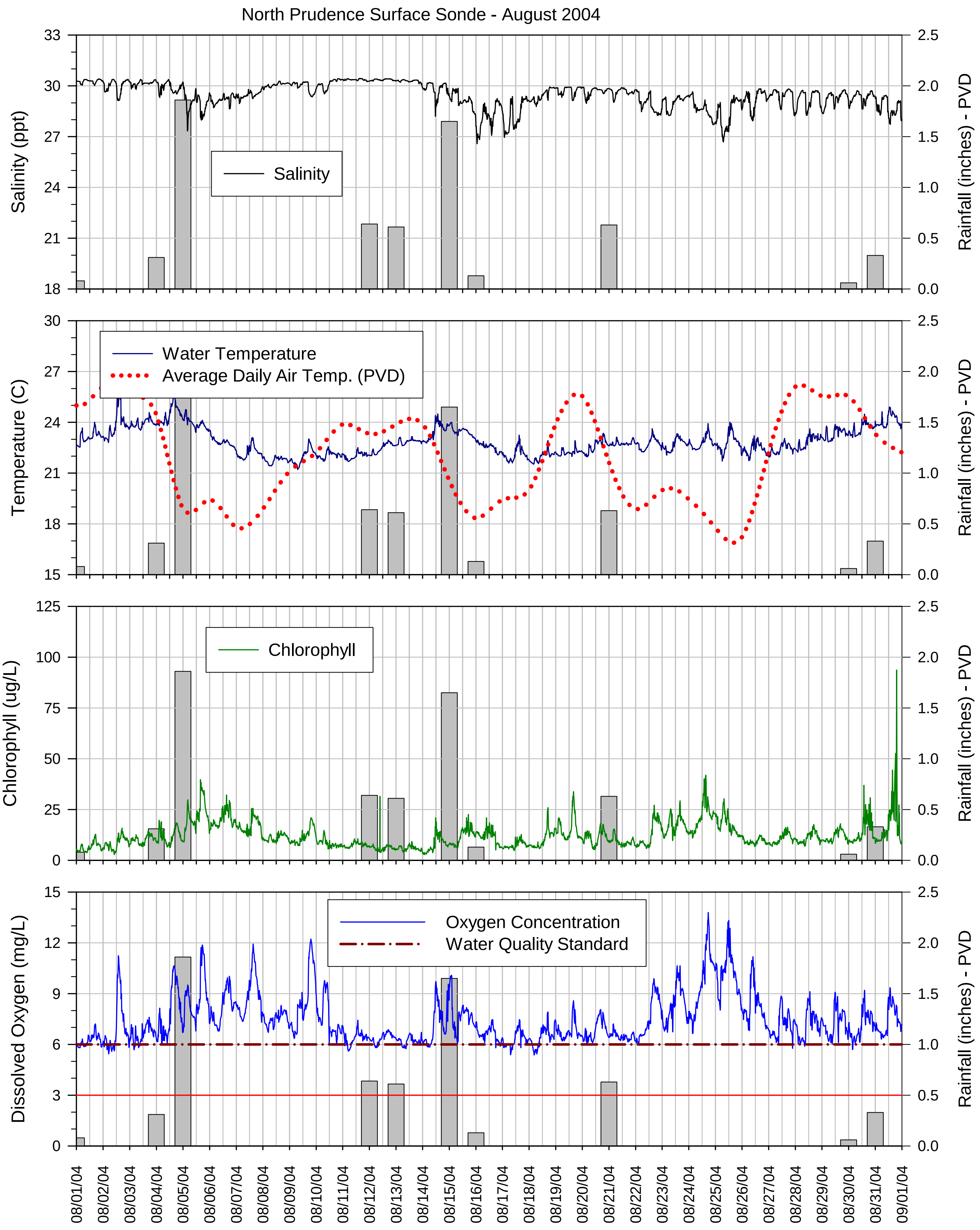



The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by RIDEM - Office of Water Resources and URI/GSO.

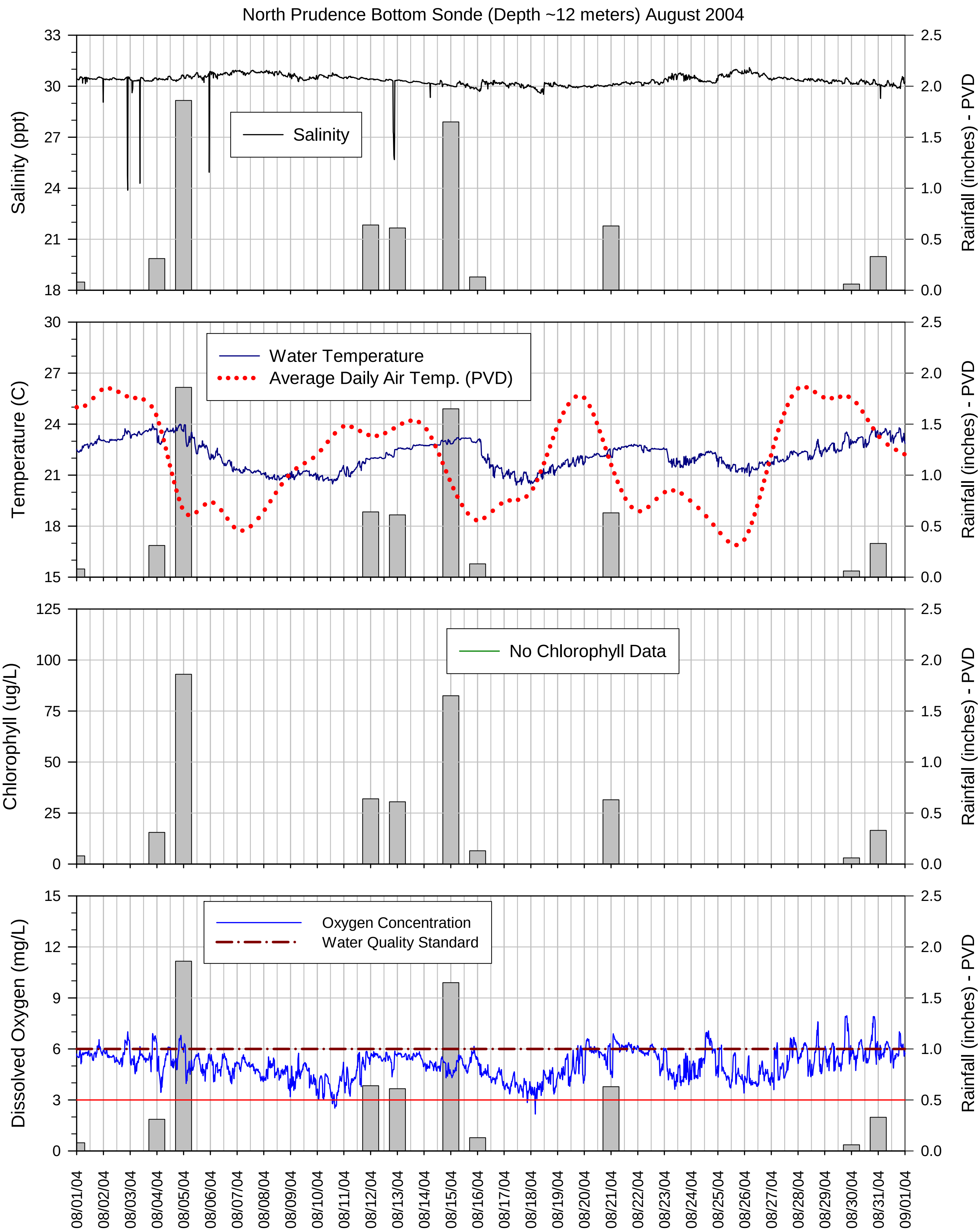
Bottom Sonde at Conimicut Point (Depth ~7.5 meters) August 2008



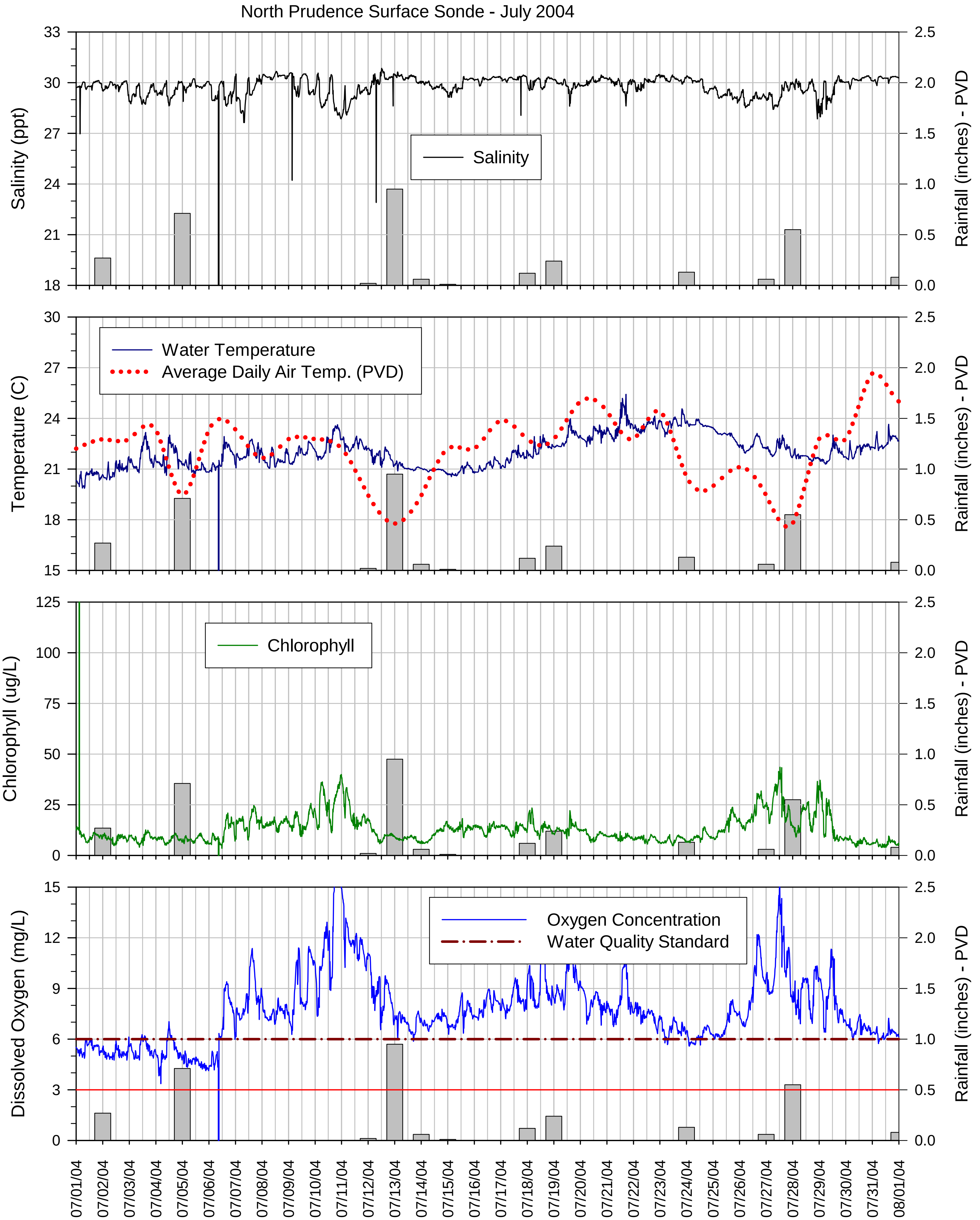

The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by RIDEM - Office of Water Resources and URI/GSO.



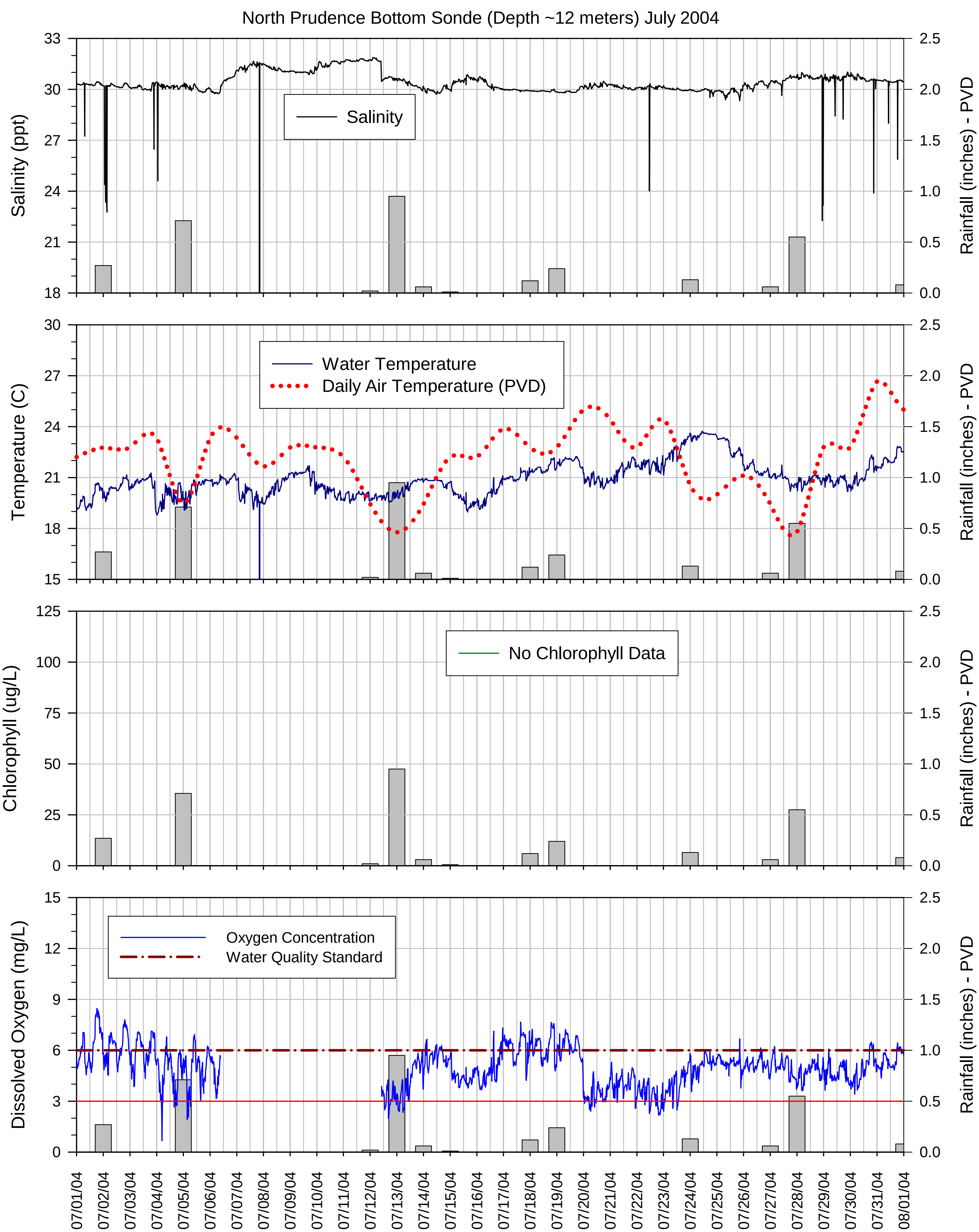

The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses. This station is maintained by URI/GSO.



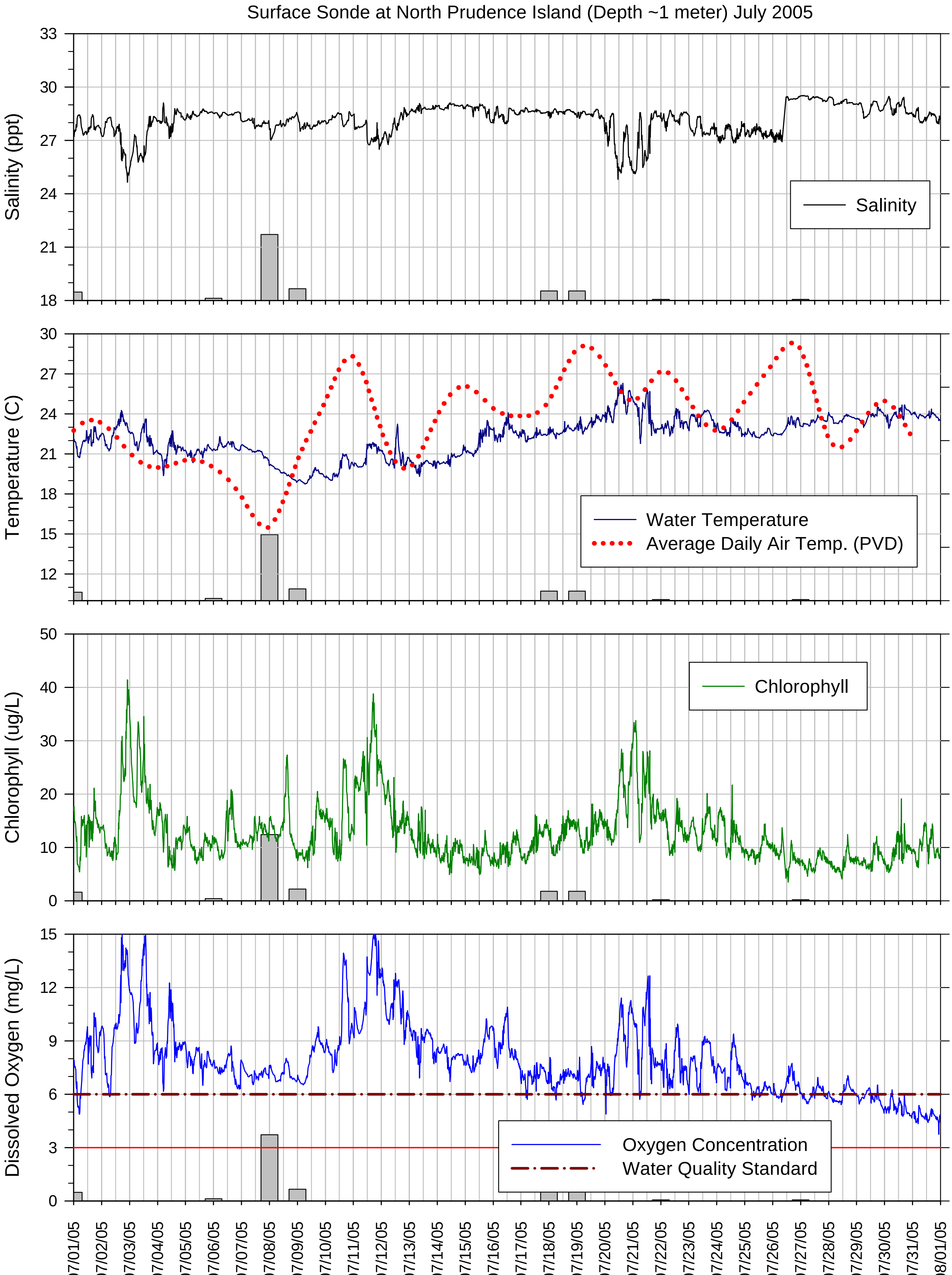

The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by URI/GSO.




The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by URI/GSO.

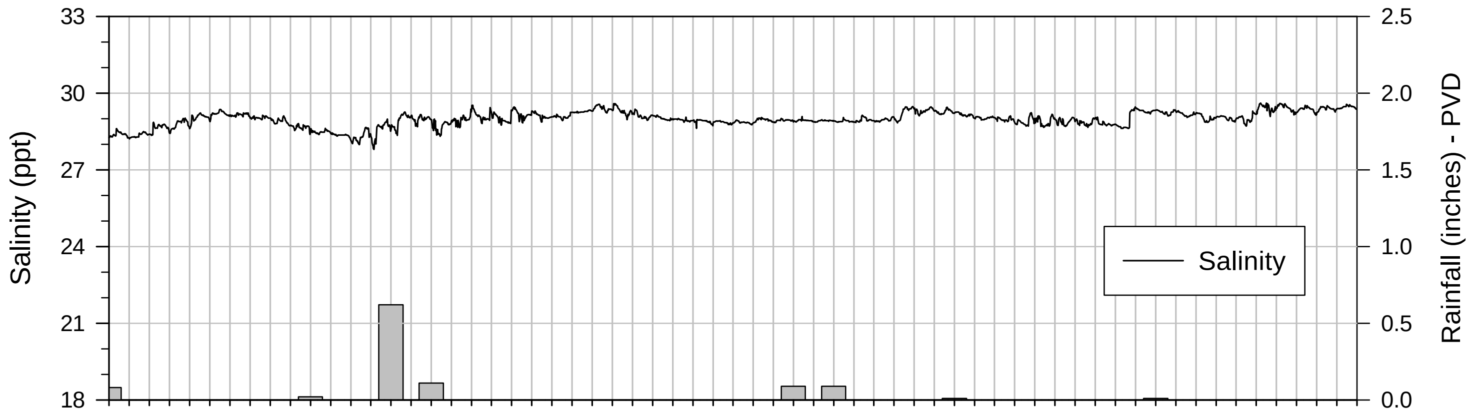


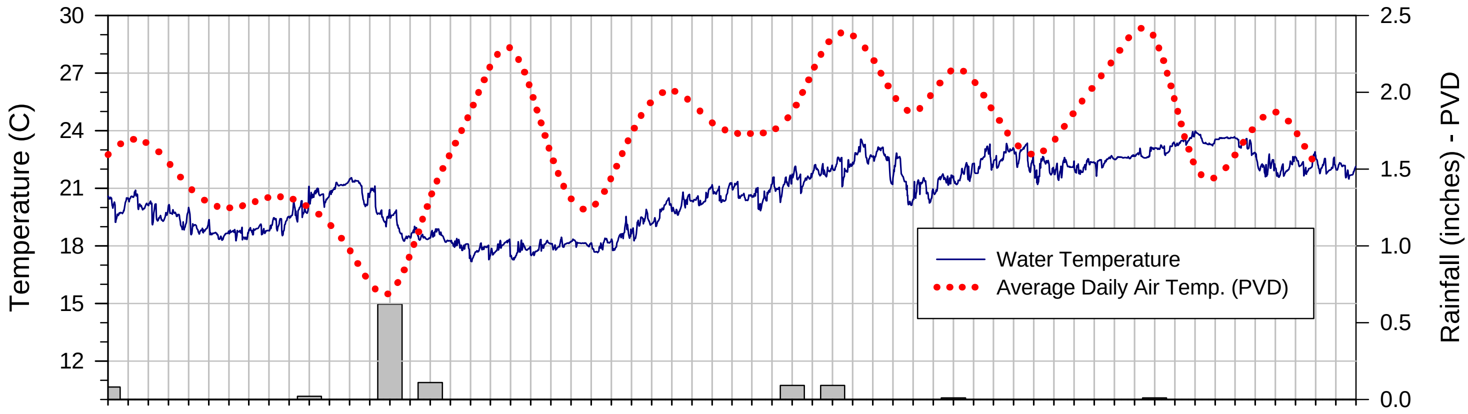

The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by URI/GSO.

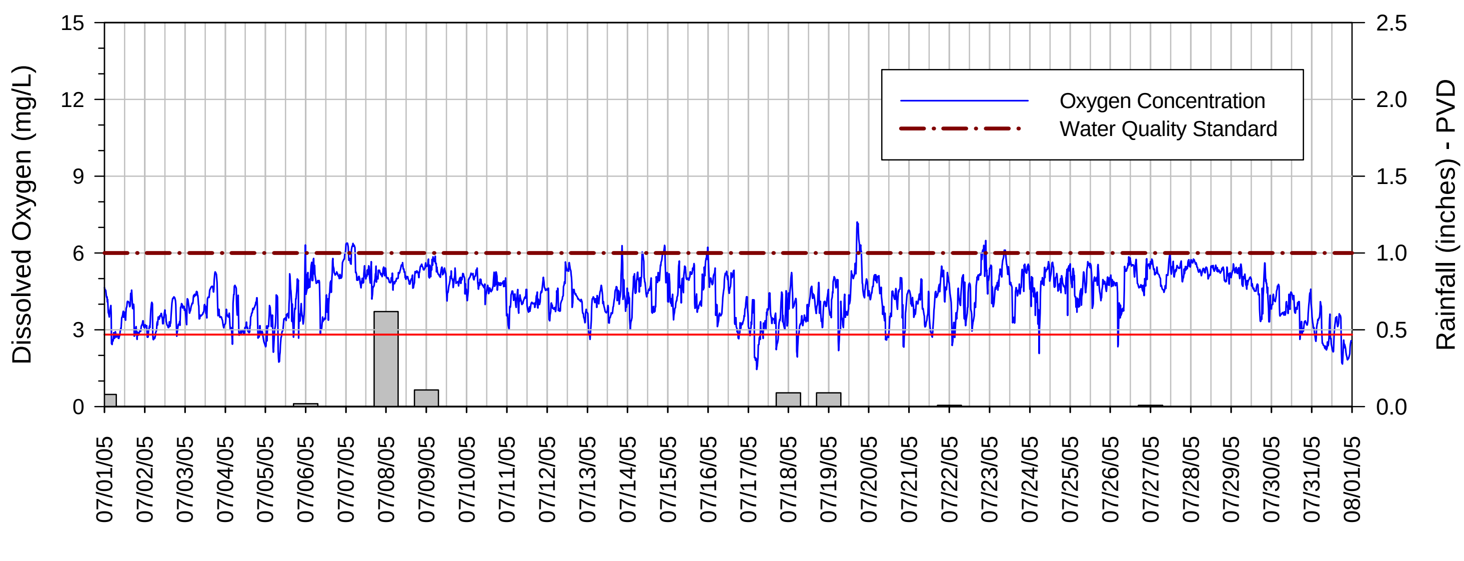



The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by RIDEM - Office of Water Resources and URI/GSO.

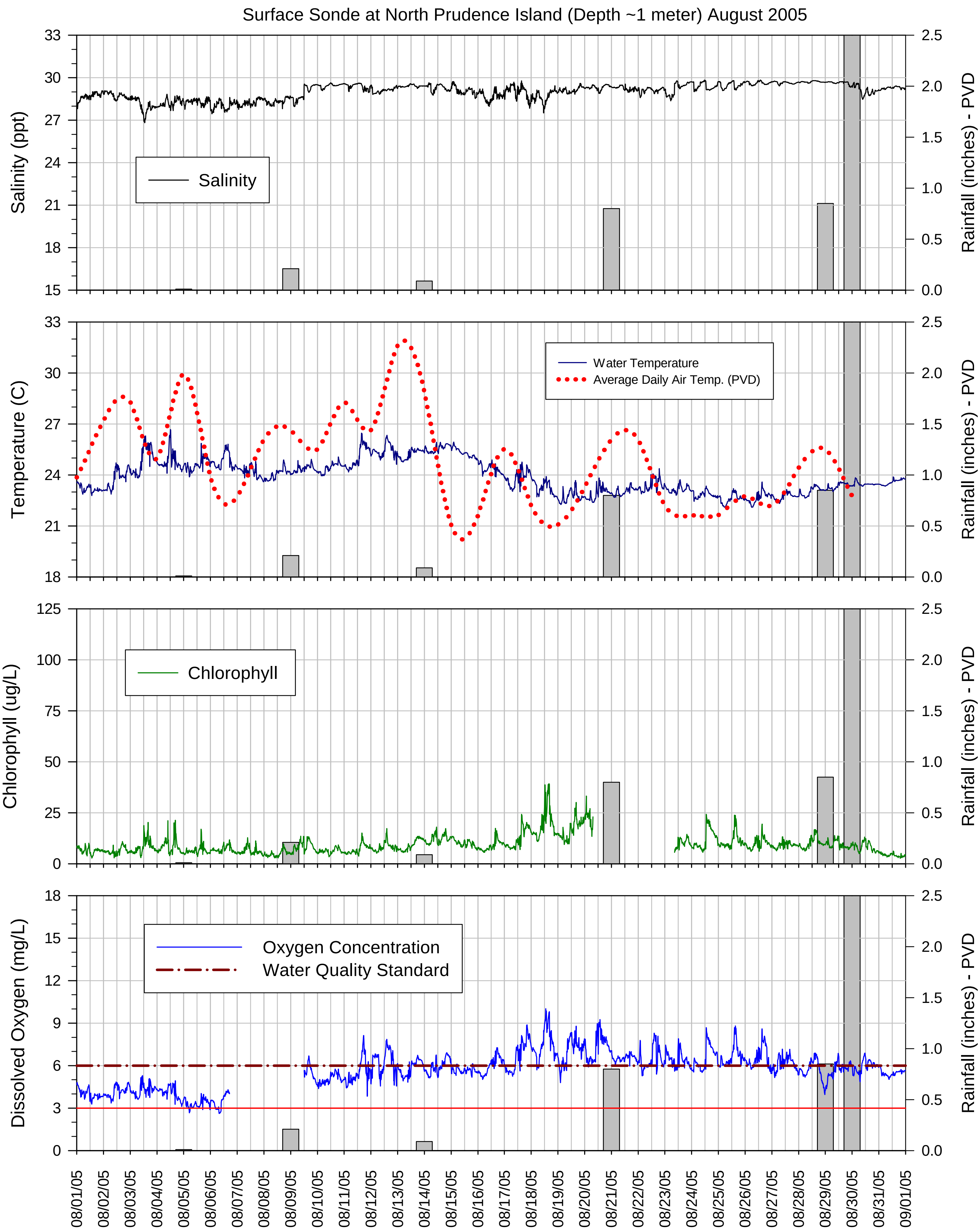
Bottom Sonde at North Prudence Island(Depth ~10 meters) July 2005



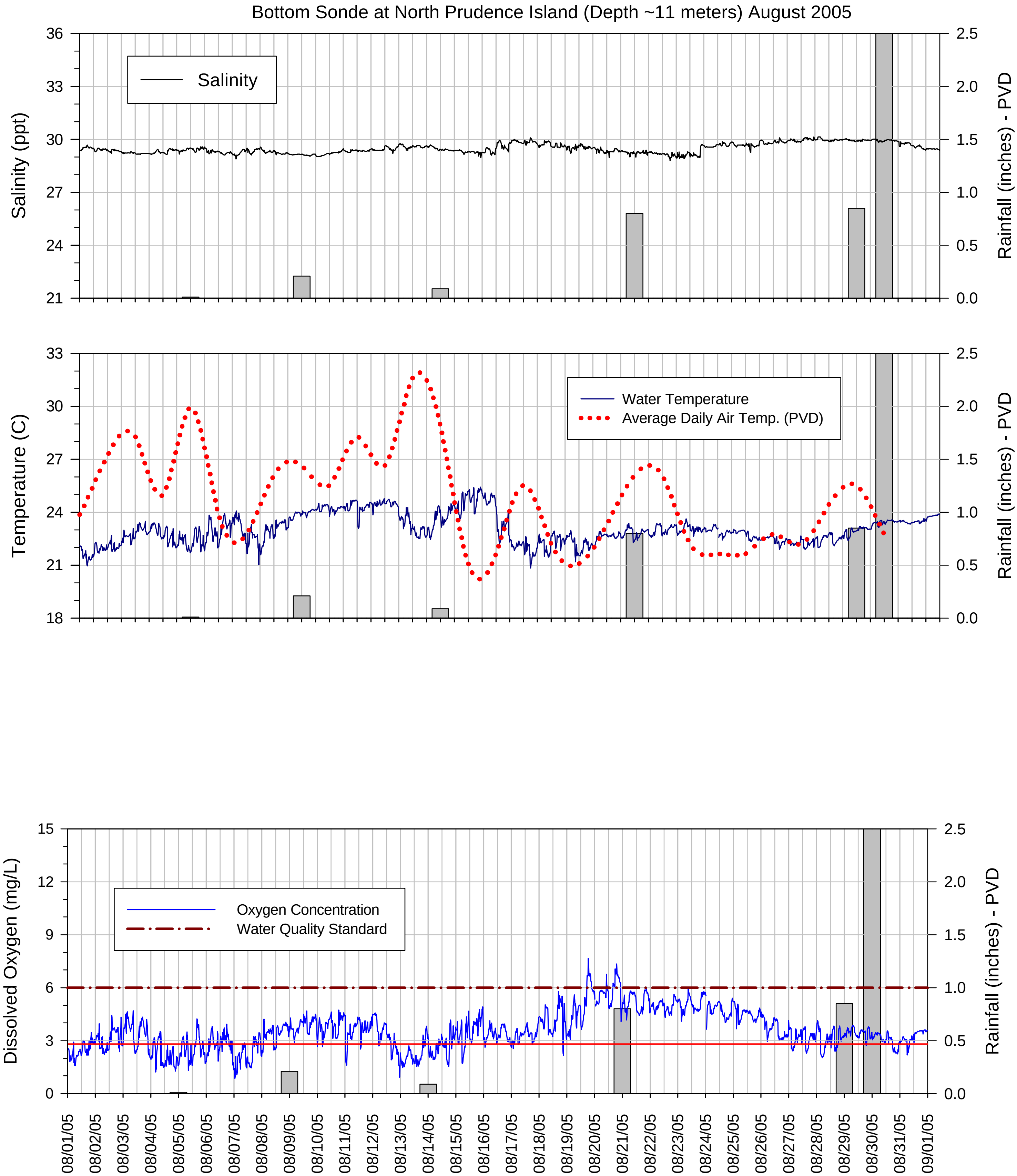



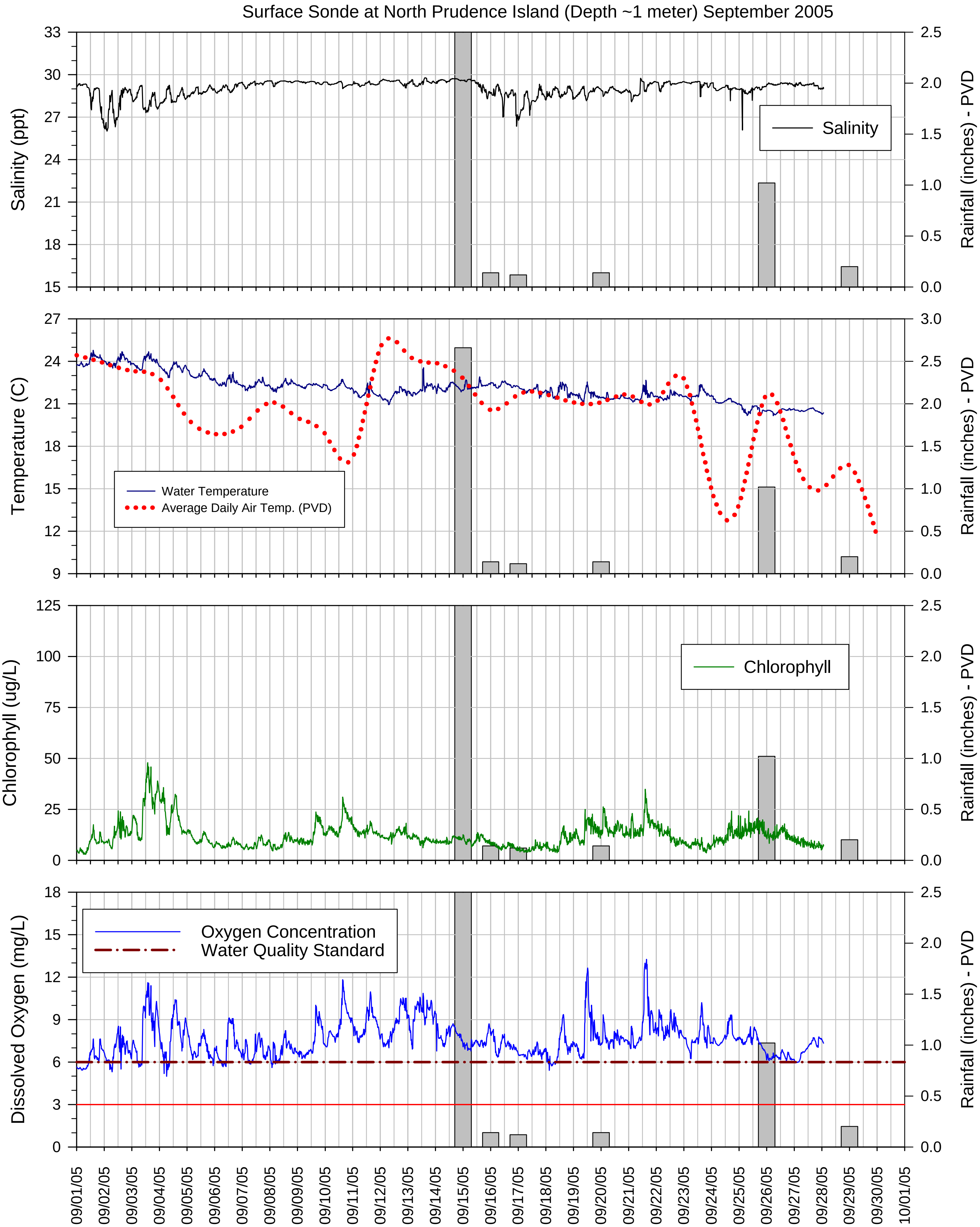

The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by RIDEM - Office of Water Resources and URI/GSO.




The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by RIDEM - Office of Water Resources and URI/GSO.

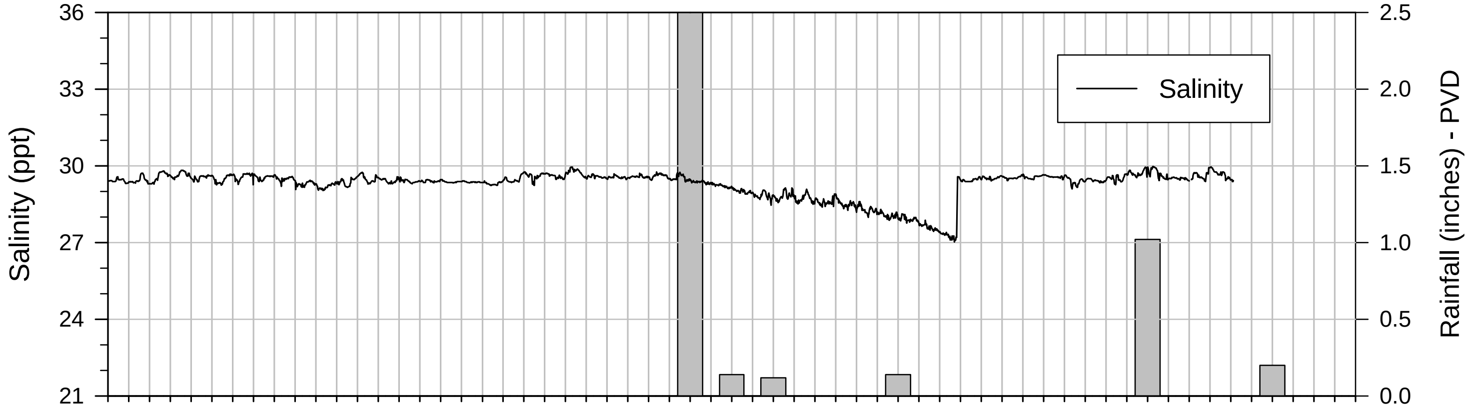


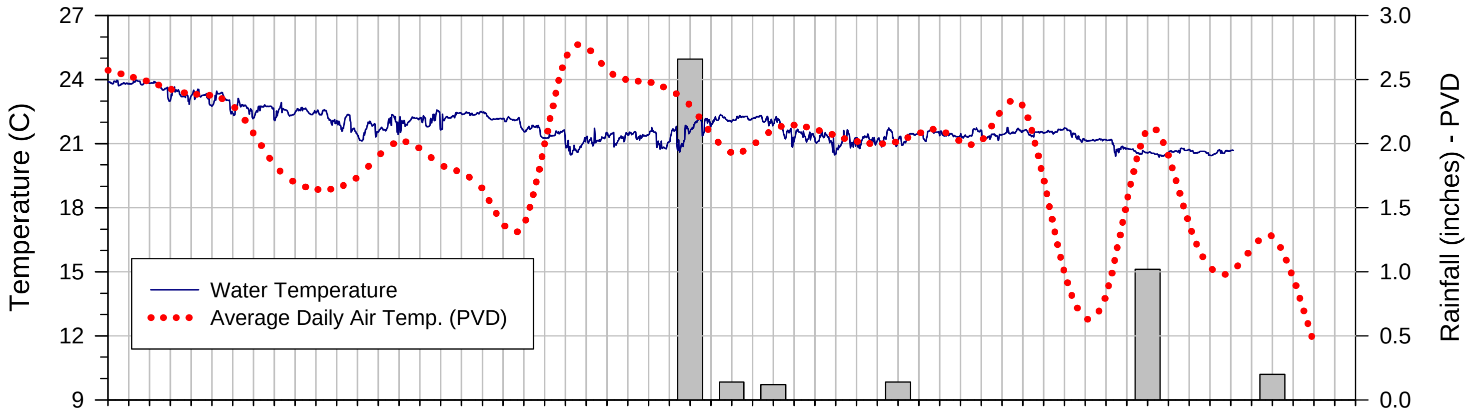

The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by RIDEM - Office of Water Resources and URI/GSO.

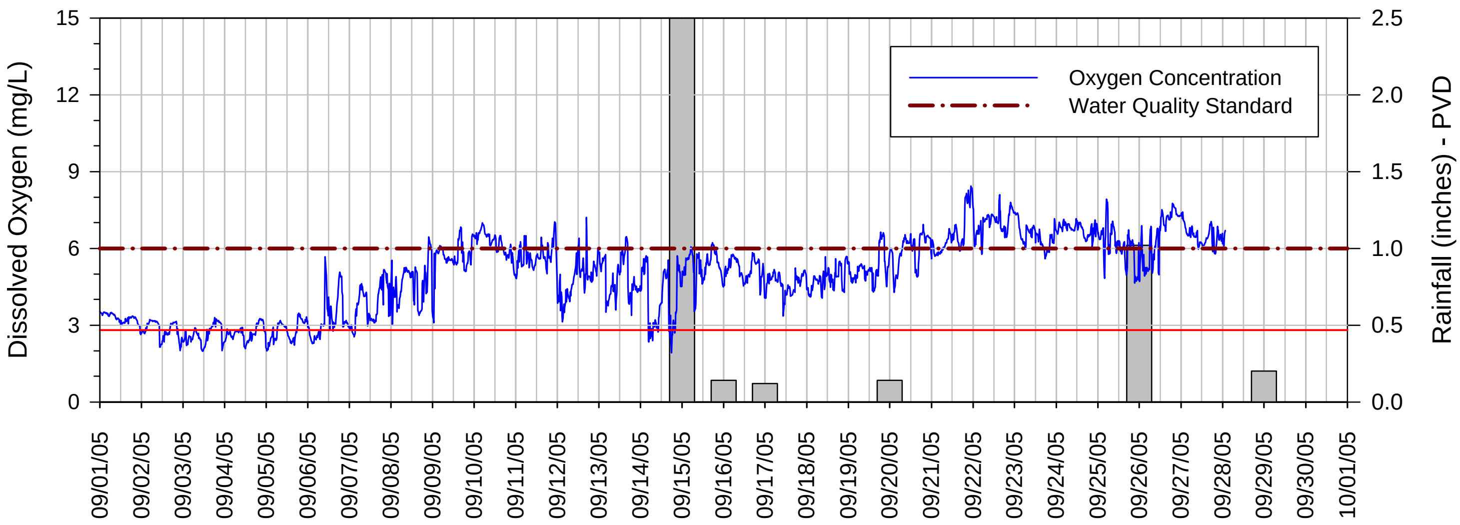



The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by RIDEM - Office of Water Resources and URI/GSO.

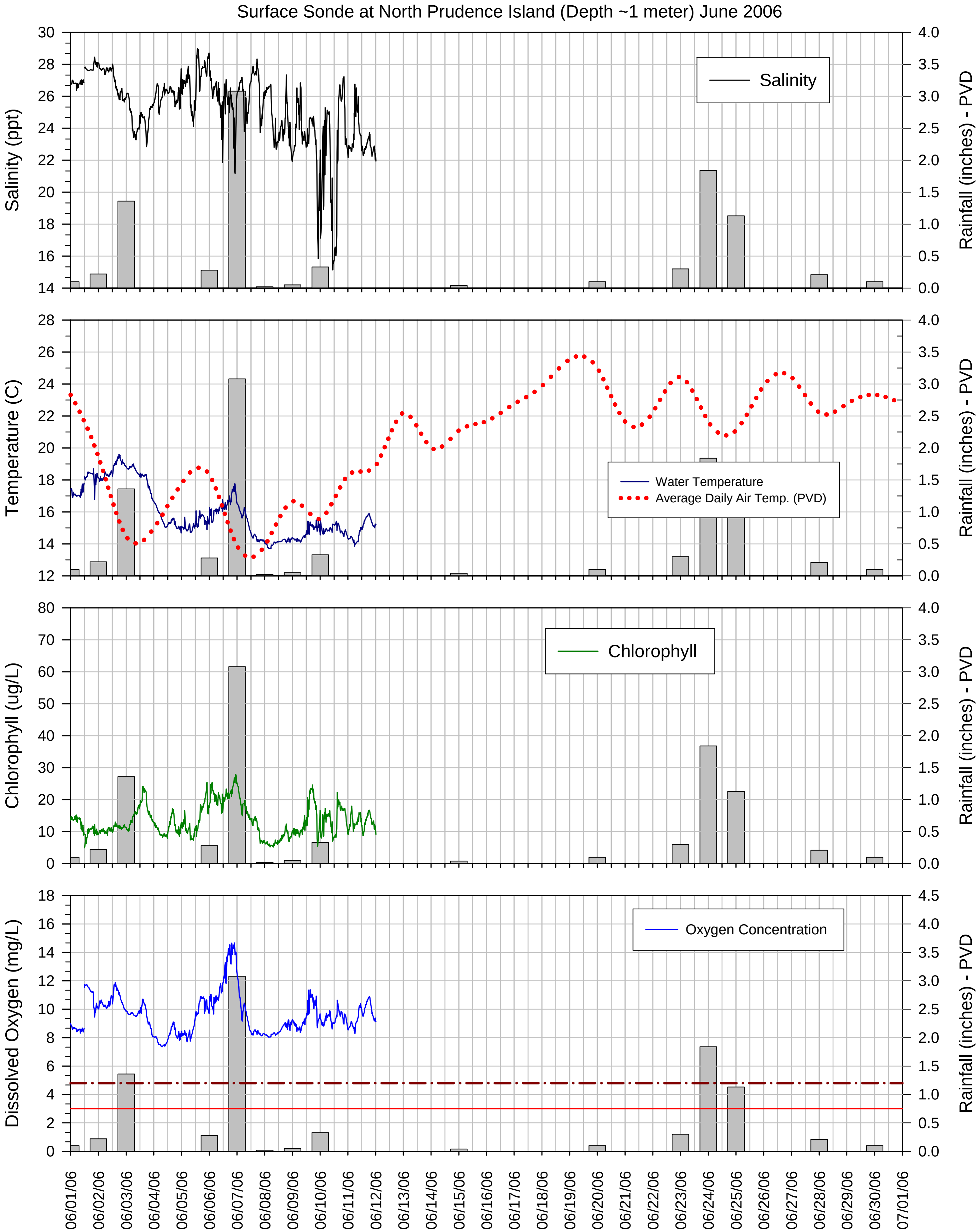
Bottom Sonde at North Prudence Island (Depth ~11 meters) September 2005



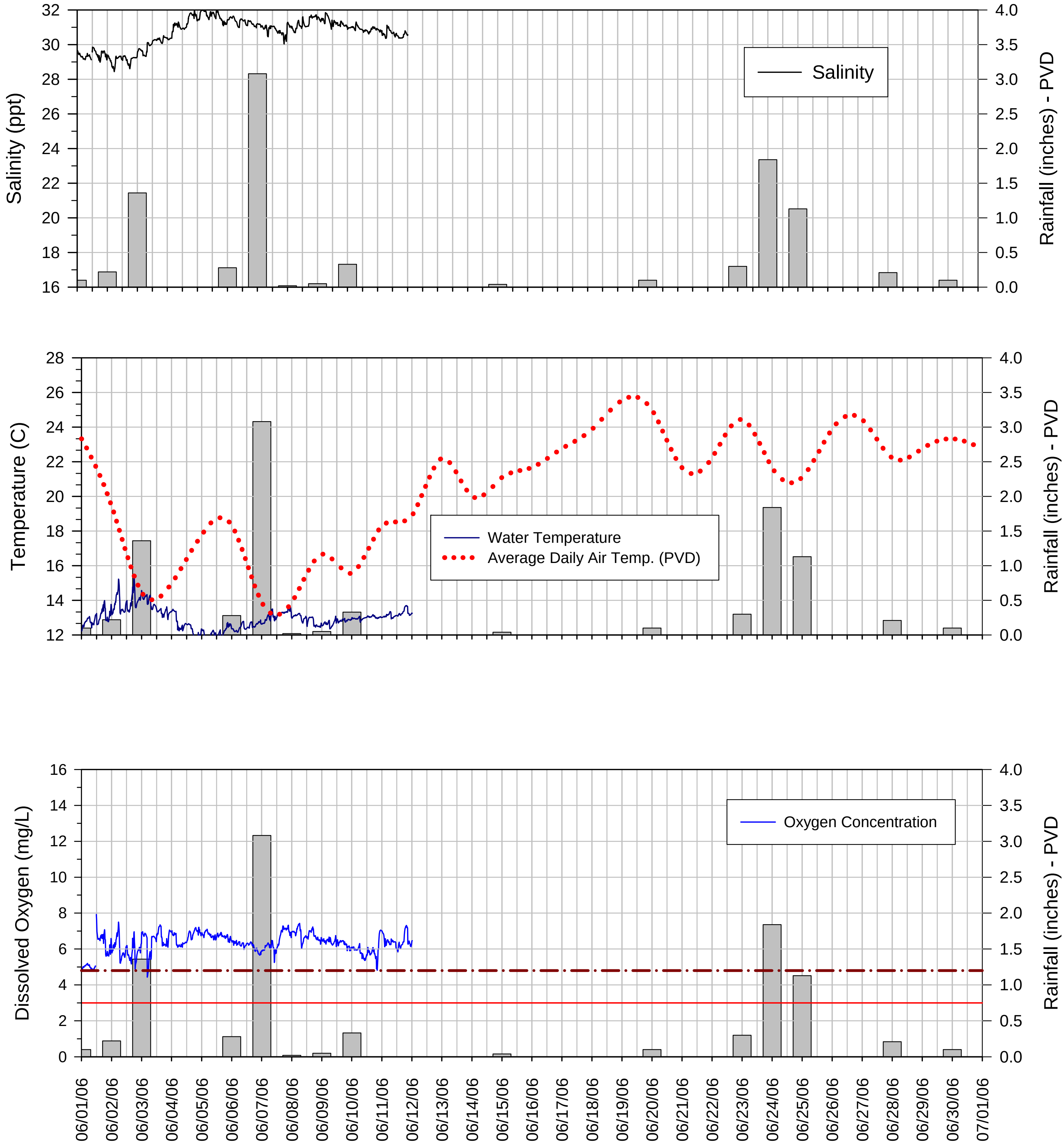




The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by RIDEM - Office of Water Resources and URI/GSO.

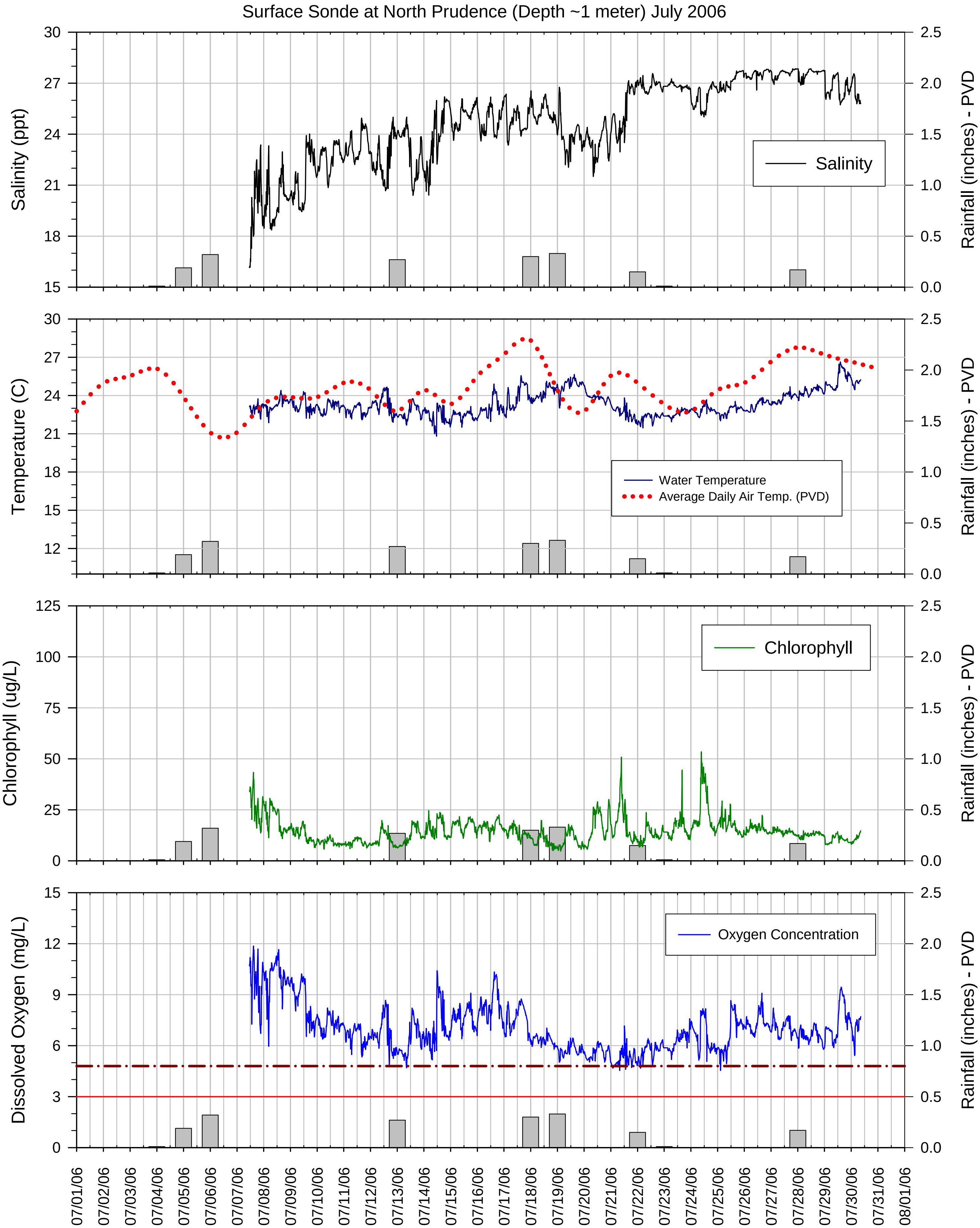



The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by RIDEM - Office of Water Resources and URI/GSO.

Bottom Sonde at North Prudence Island (Depth ~11 meters) June 2006

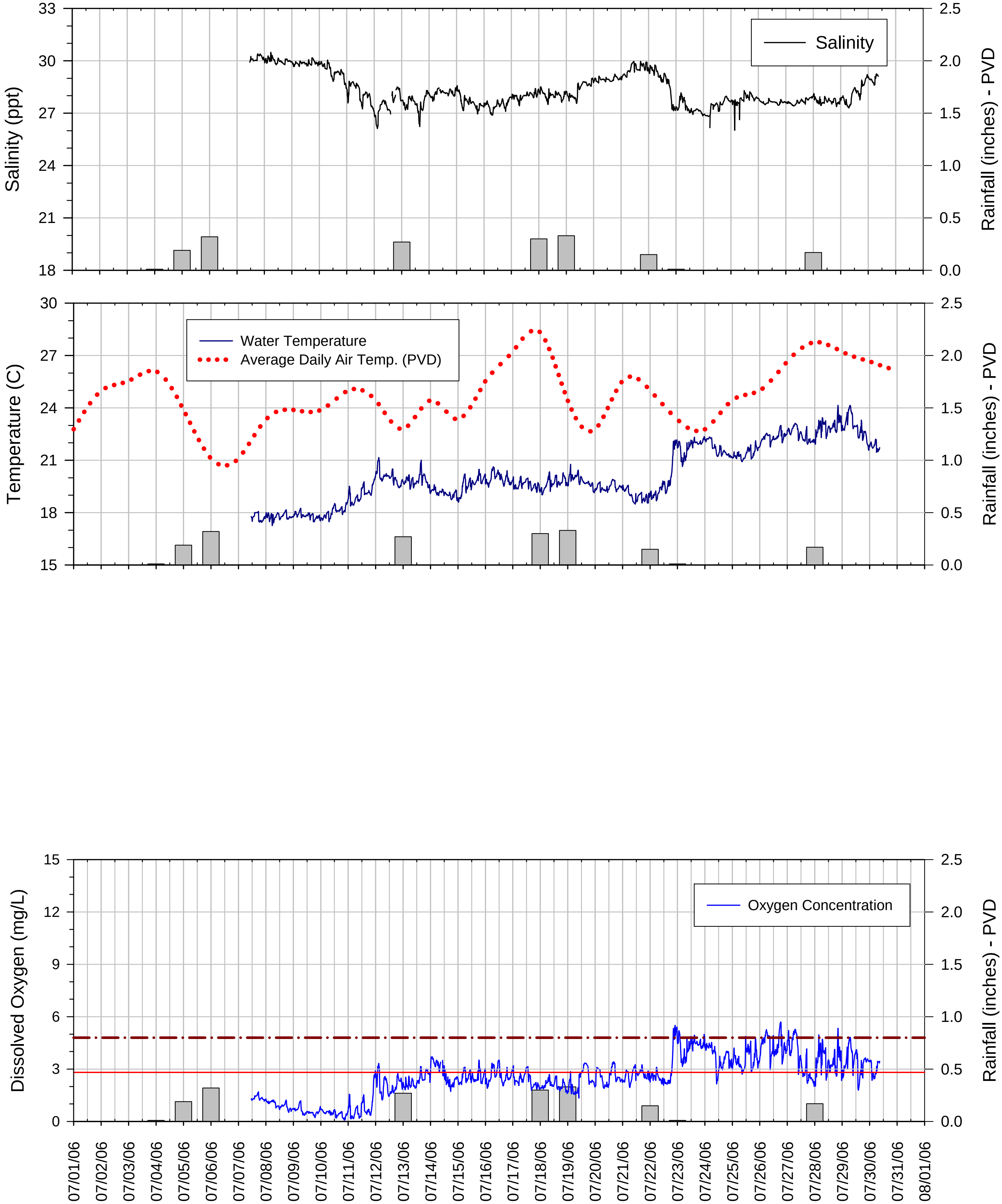



The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by RIDEM - Office of Water Resources and URI/GSO.

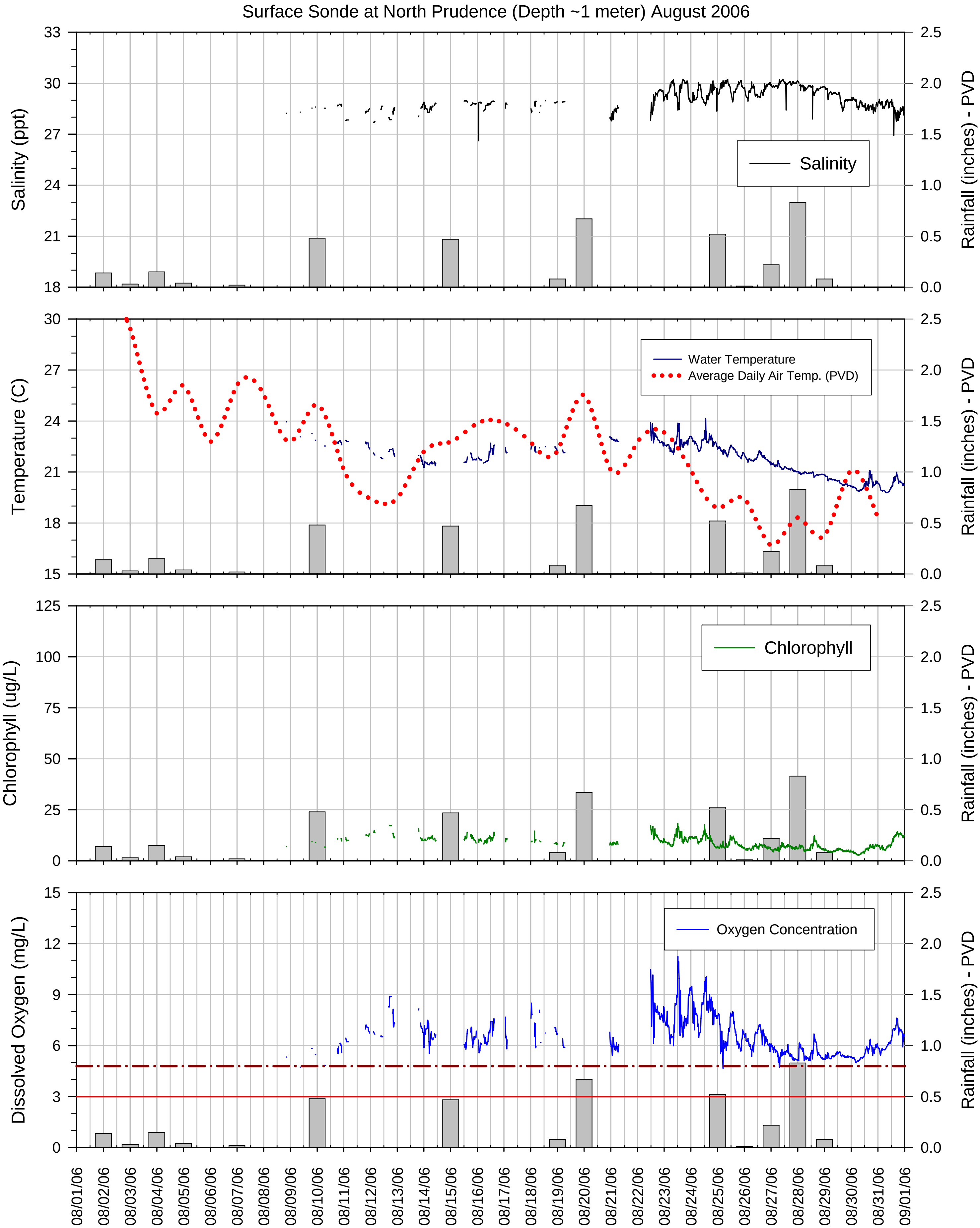



The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by RIDEM - Office of Water Resources and URI/GSO.

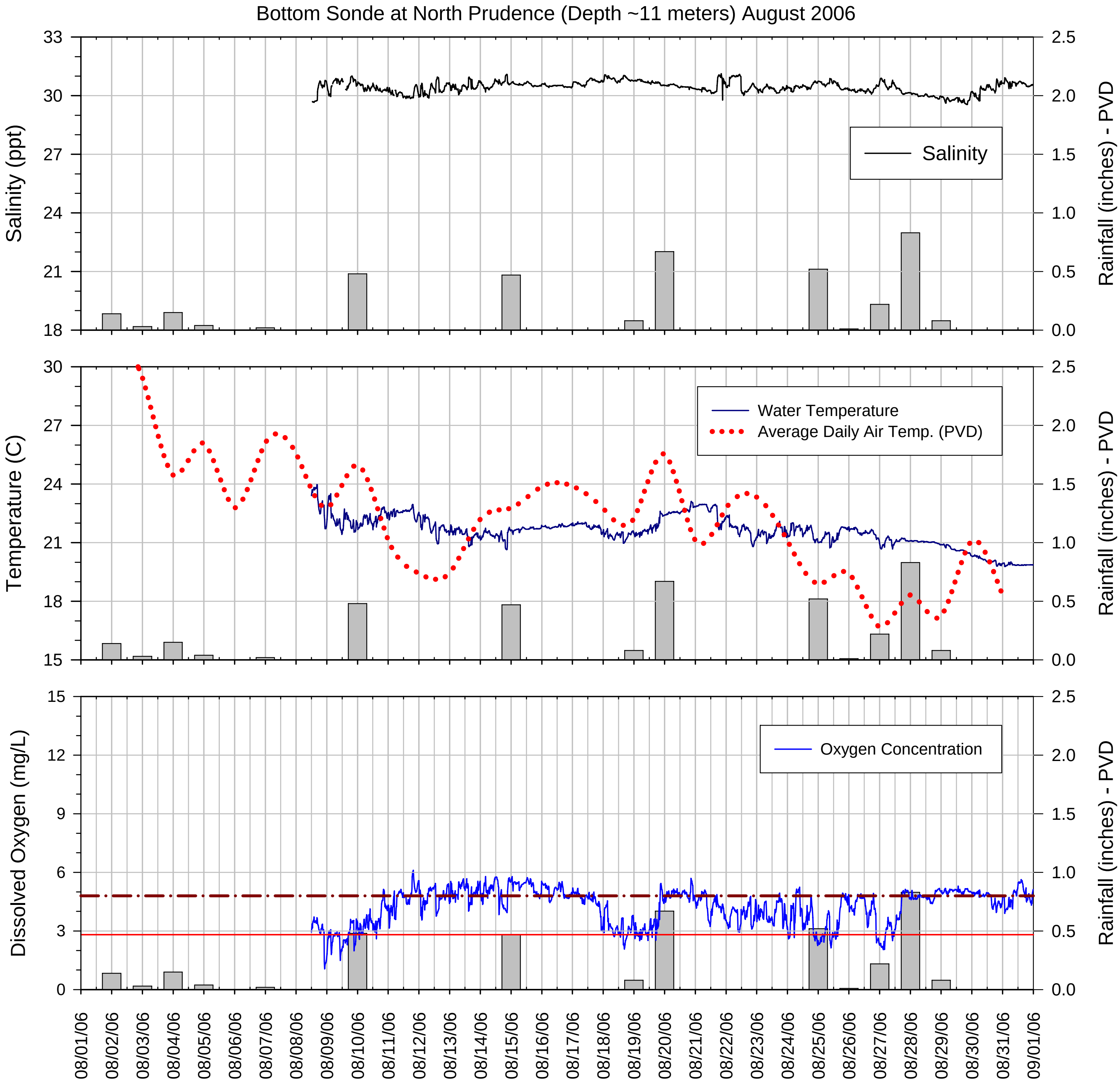
Bottom Sonde at North Prudence (Depth ~11 meters) July 2006



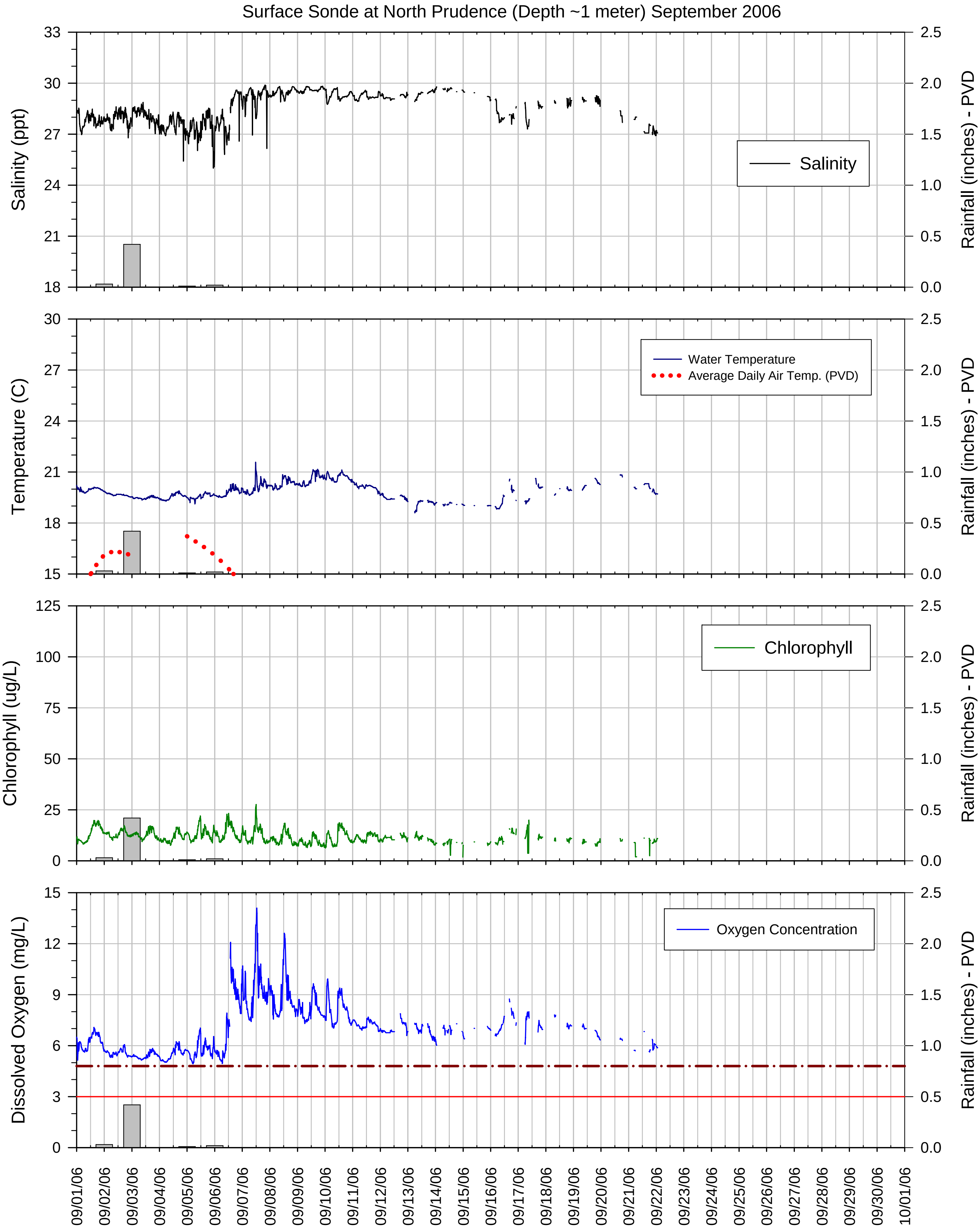

The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by RIDEM - Office of Water Resources and URI/GSO.




The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by RIDEM - Office of Water Resources and URI/GSO.

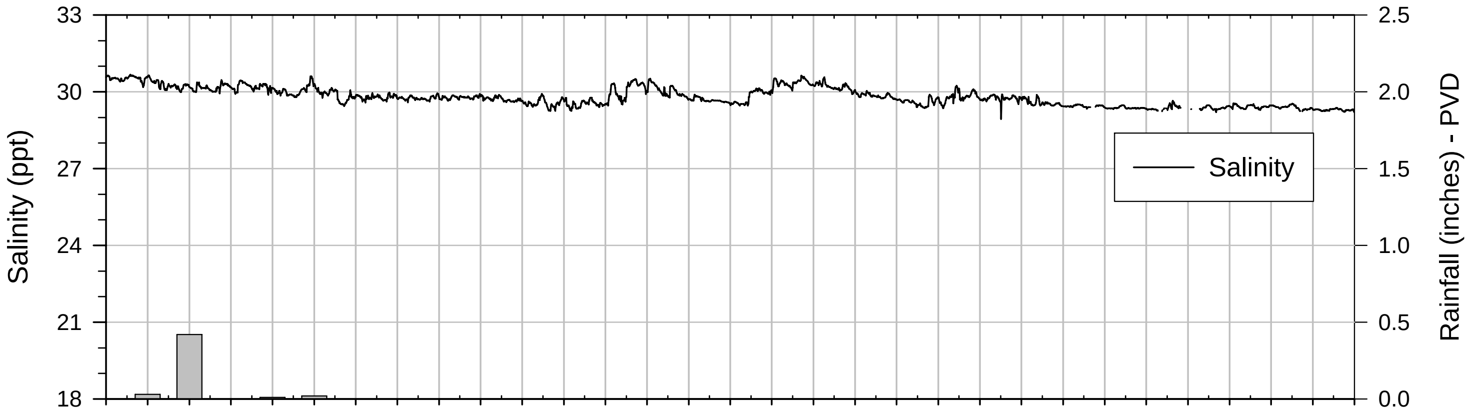


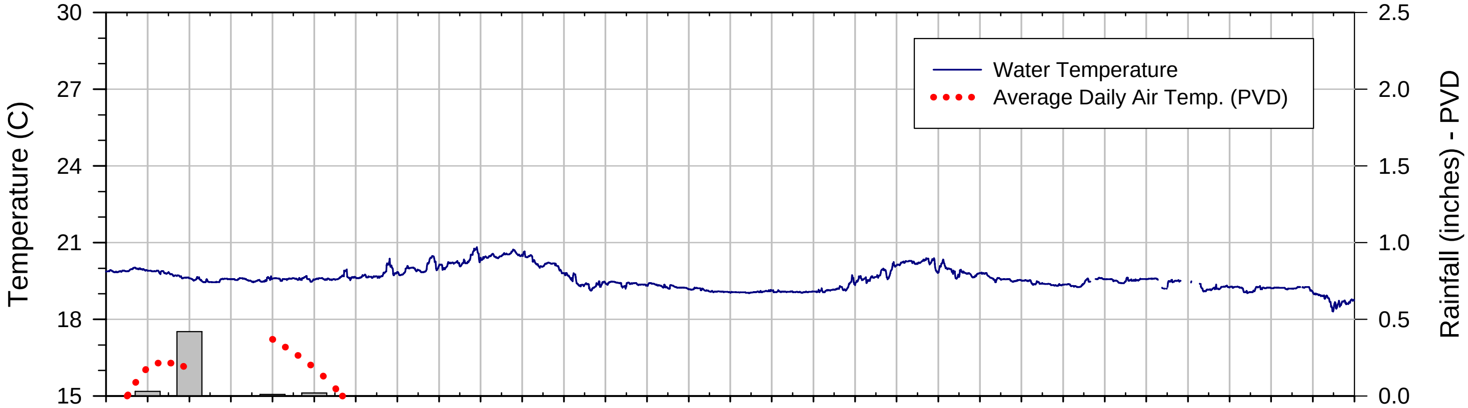

The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by RIDEM - Office of Water Resources and URI/GSO.

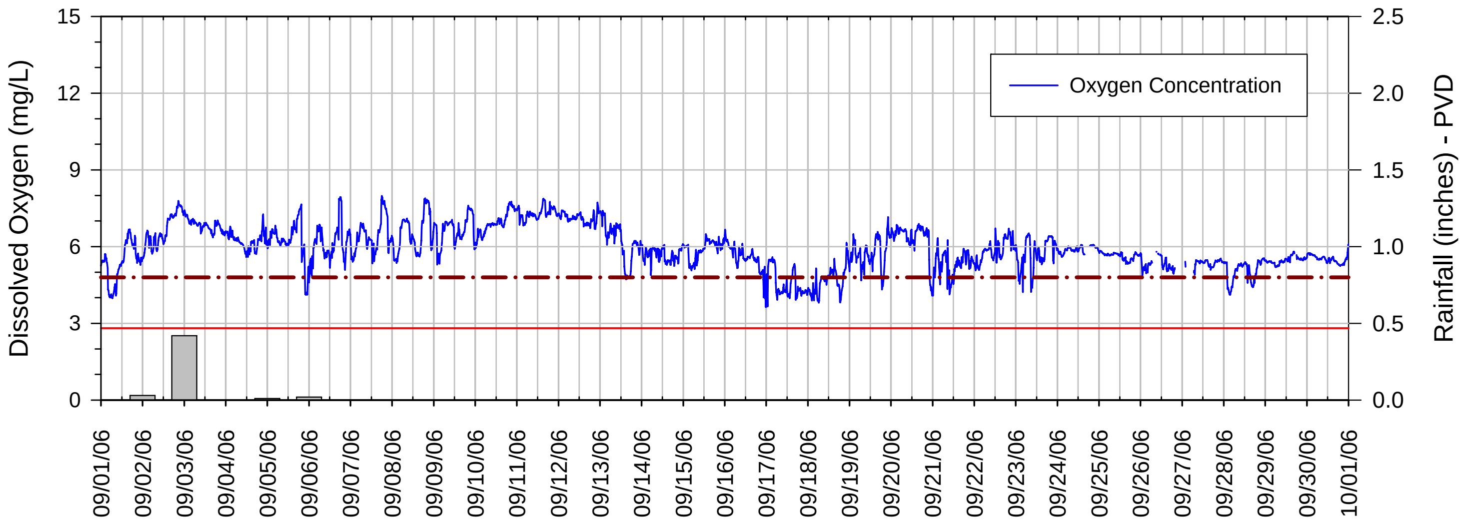



The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by RIDEM - Office of Water Resources and URI/GSO.

Bottom Sonde at North Prudence (Depth ~11 meters) September 2006

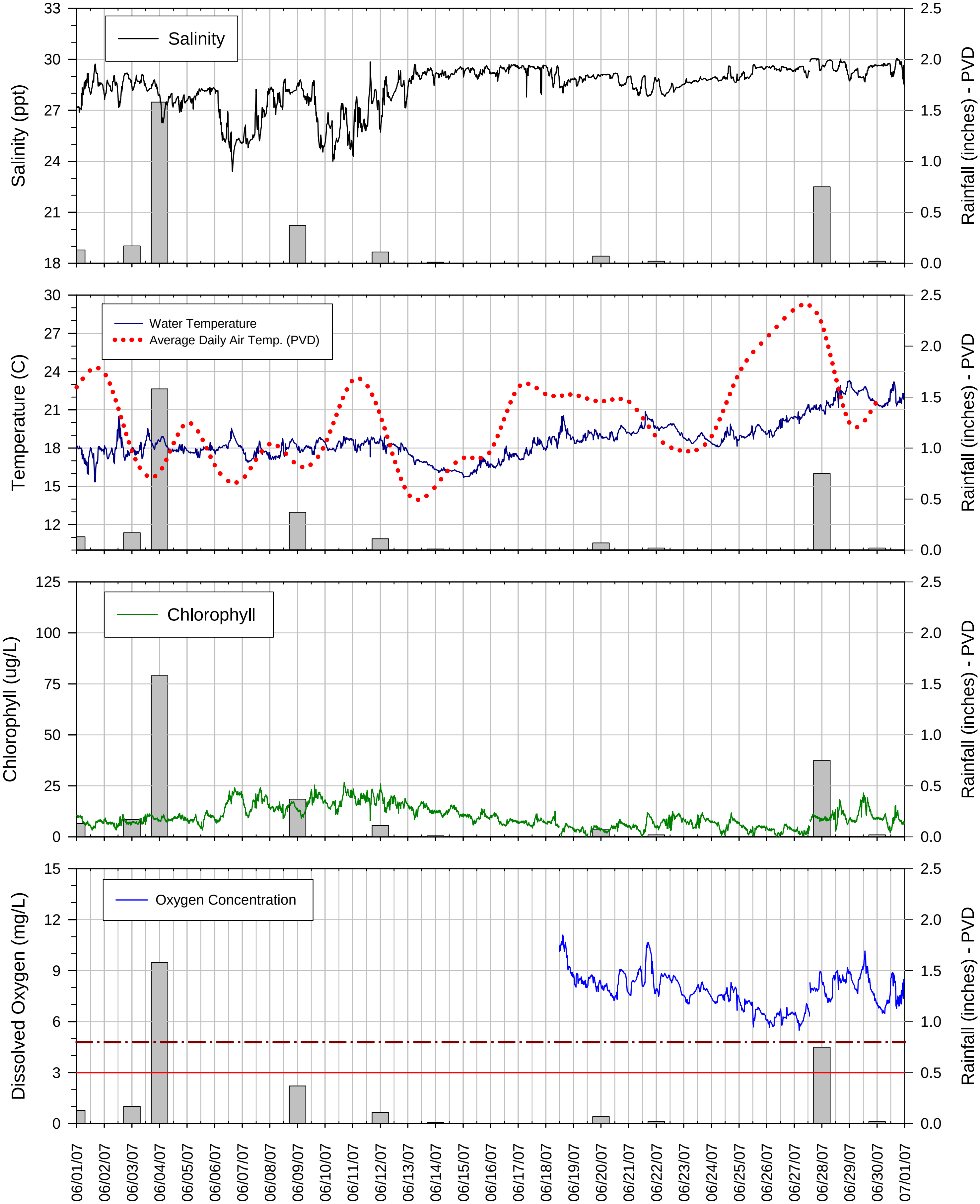


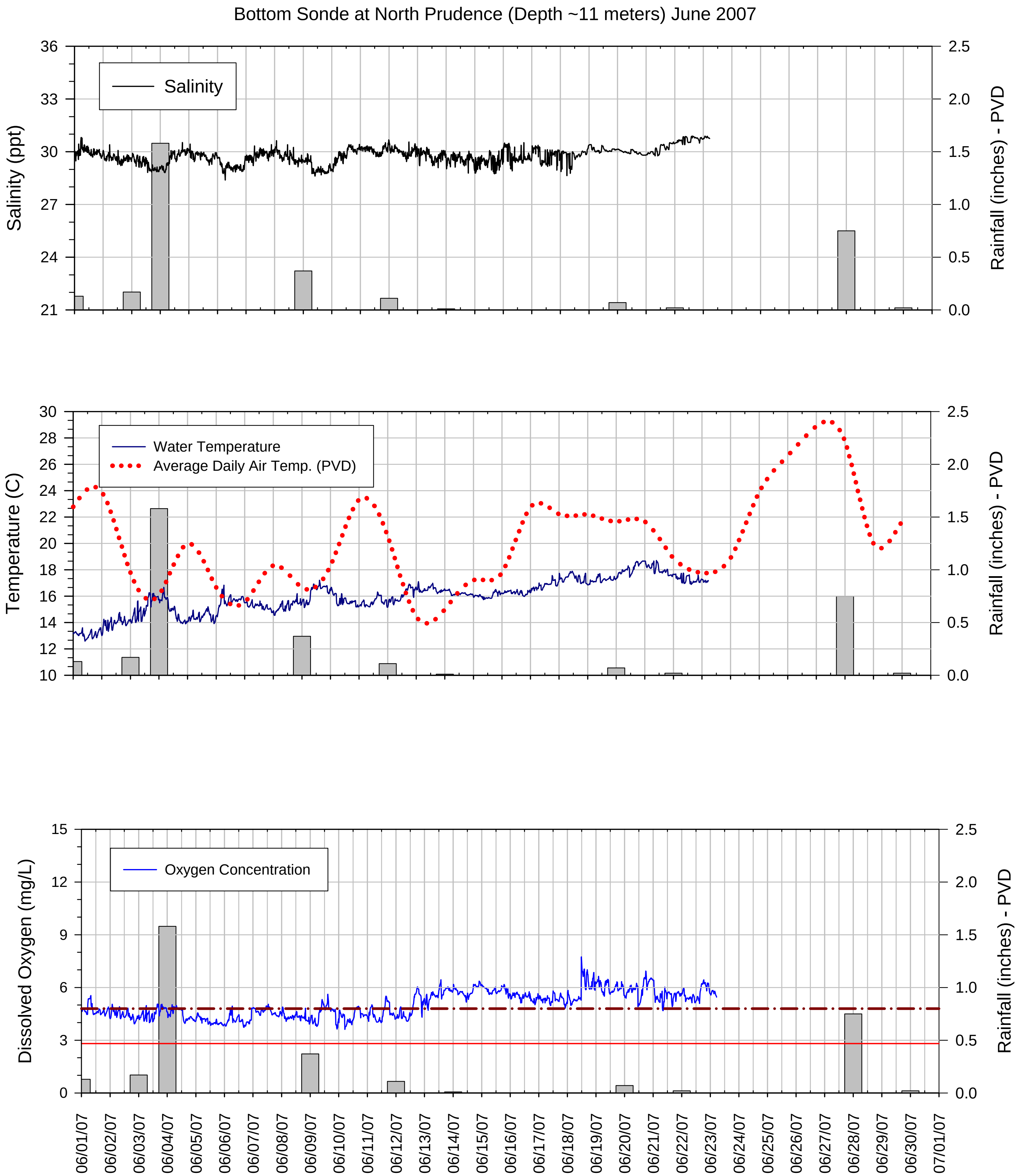




The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by RIDEM - Office of Water Resources and URI/GSO.

Surface Sonde at North Prudence (Depth ~1 meter) June 2007

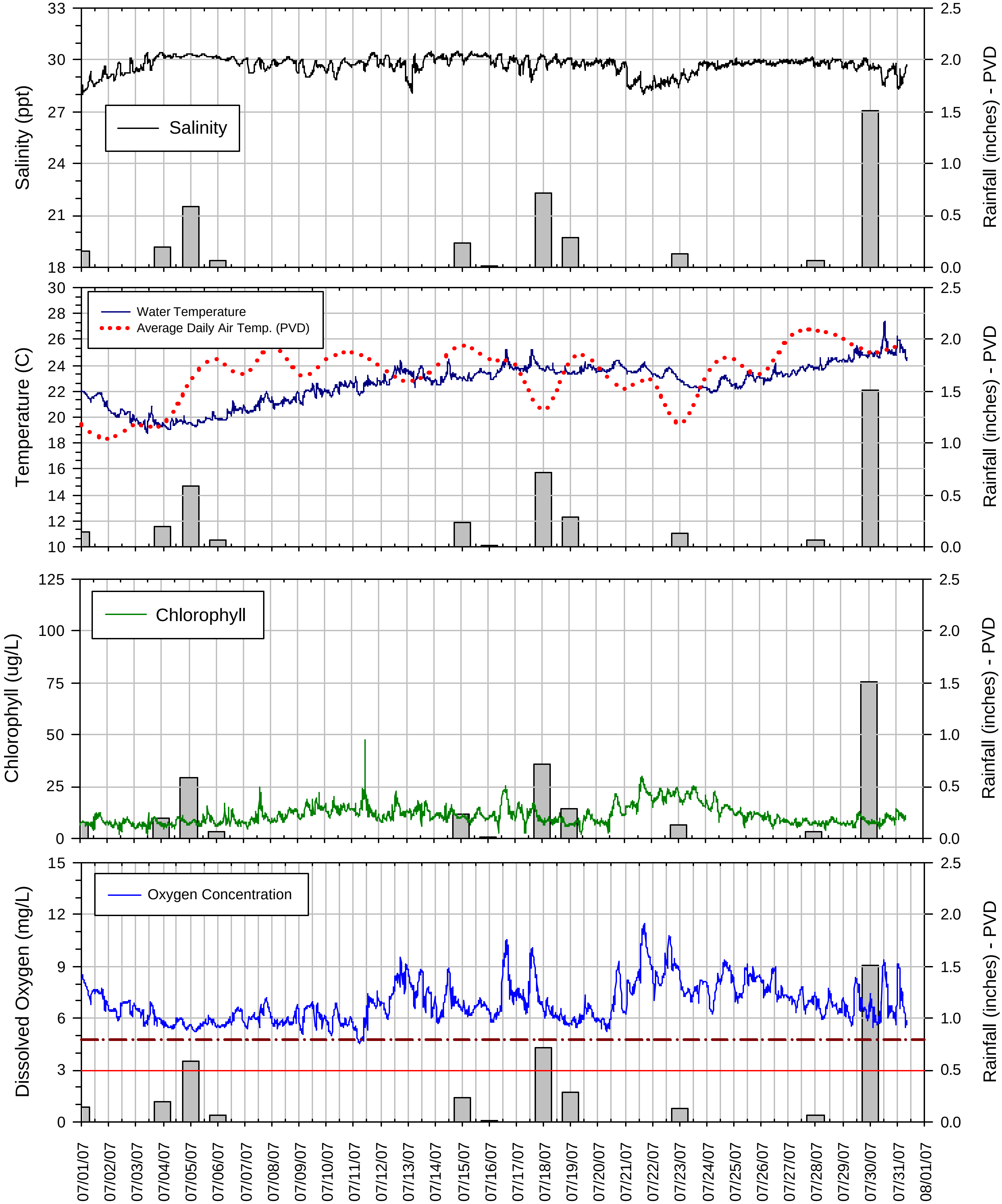



The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by RIDEM - Office of Water Resources and URI/GSO.



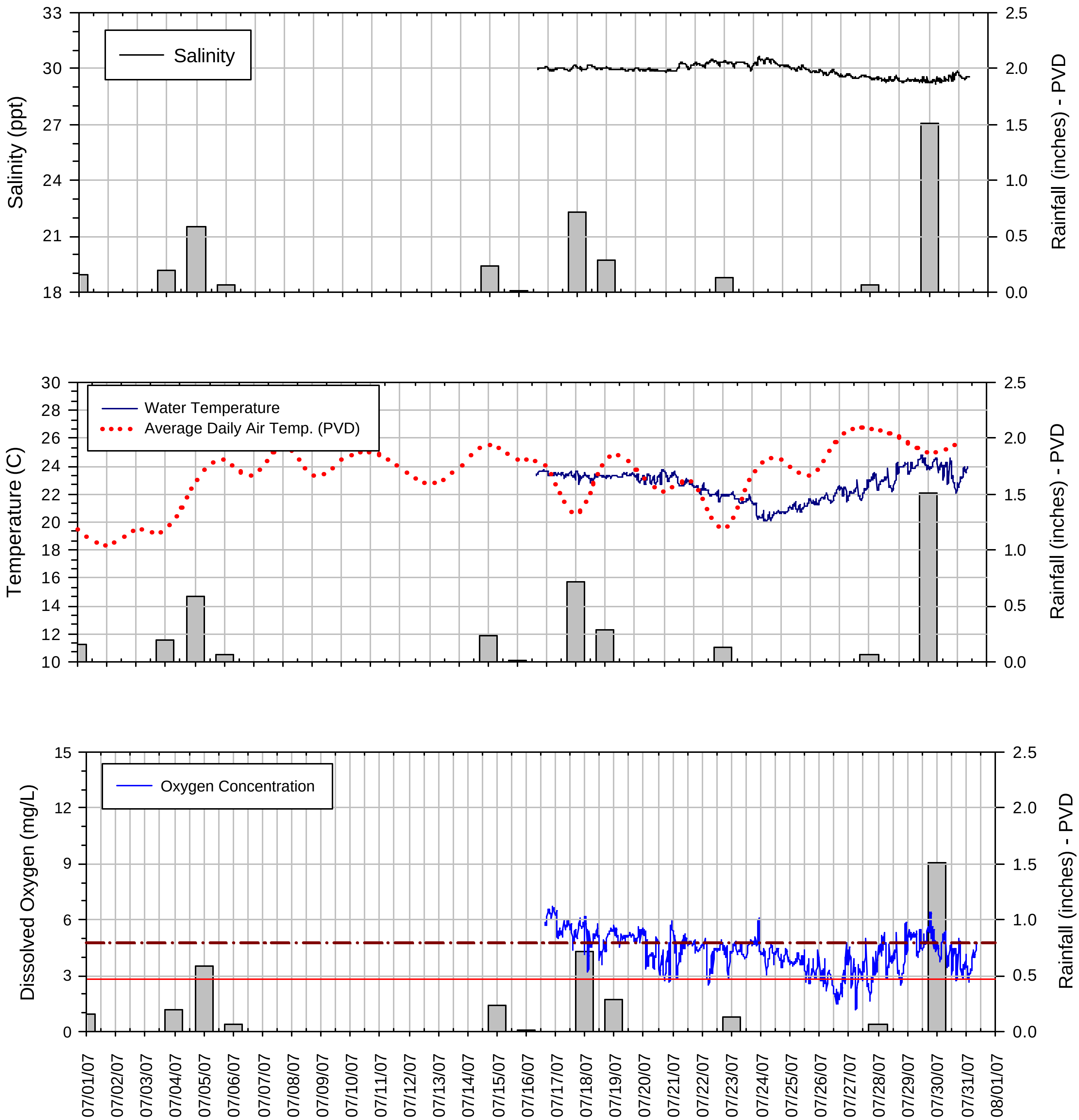

The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by RIDEM - Office of Water Resources and URI/GSO.

Surface Sonde at North Prudence (Depth ~1 meter) July 2007

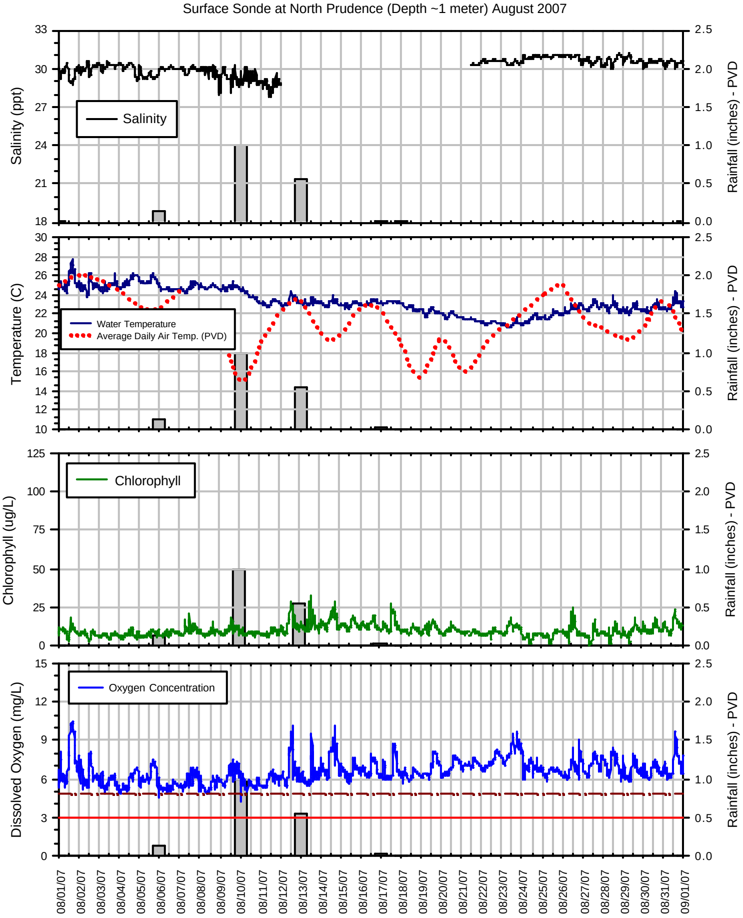



The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by RIDEM - Office of Water Resources and URI/GSO.

Bottom Sonde at North Prudence (Depth ~11 meters) July 2007

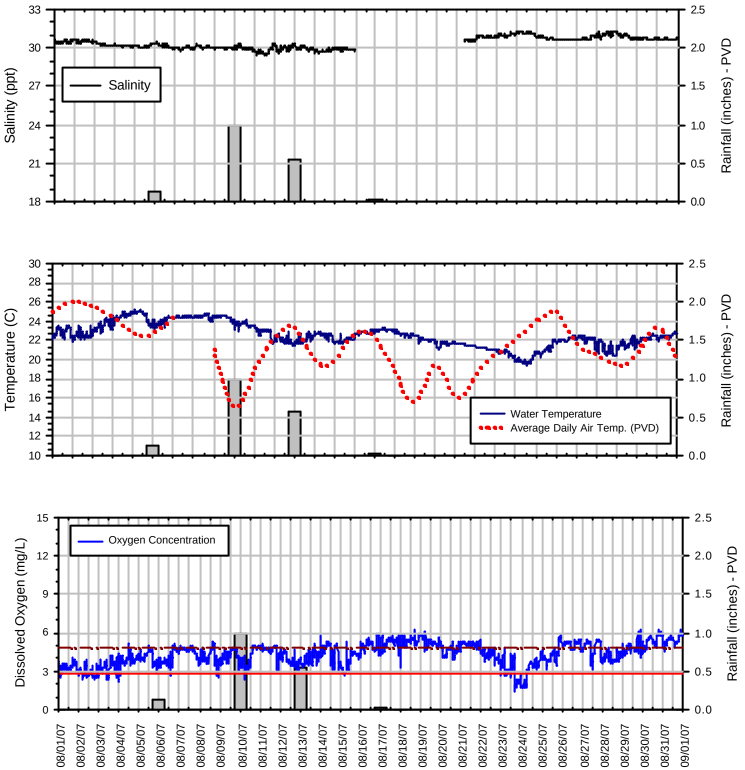



The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by RIDEM - Office of Water Resources and URI/GSO.

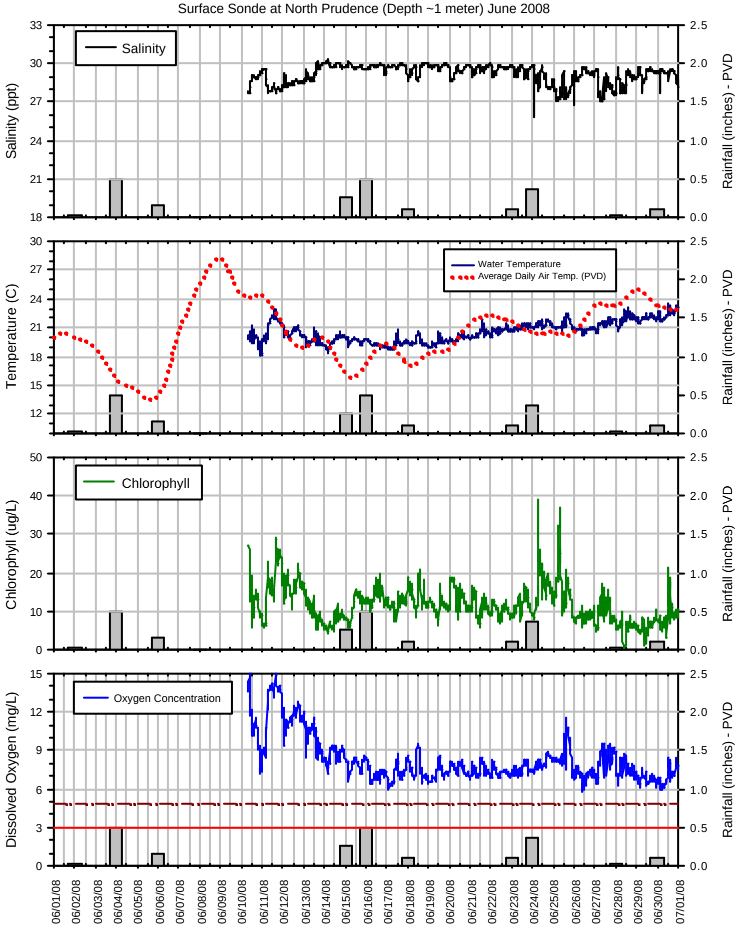



The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by RIDEM - Office of Water Resources and URI/GSO.

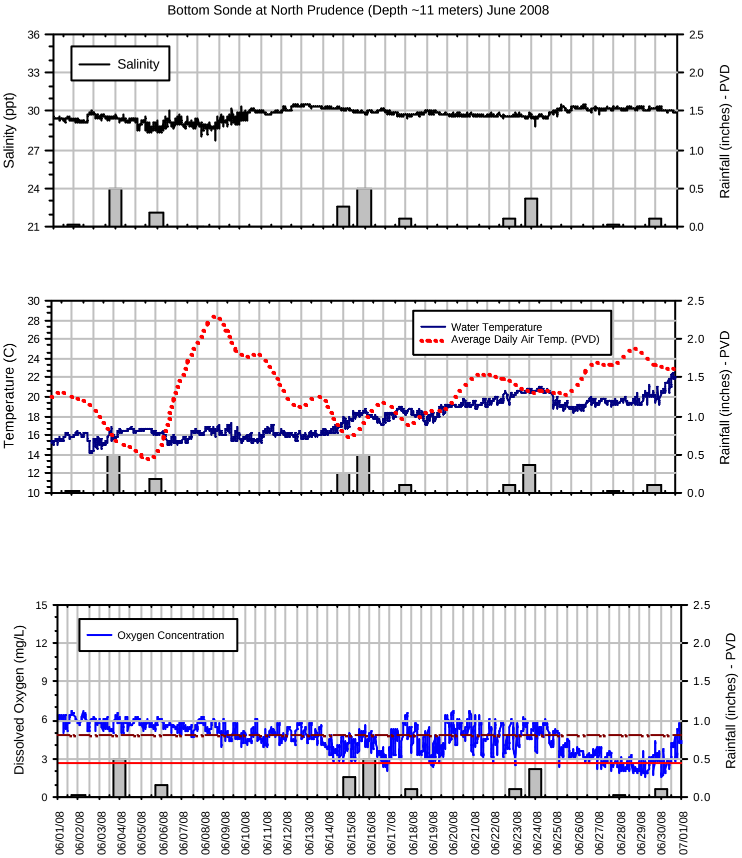
Bottom Sonde at North Prudence (Depth ~11 meters) August 2007



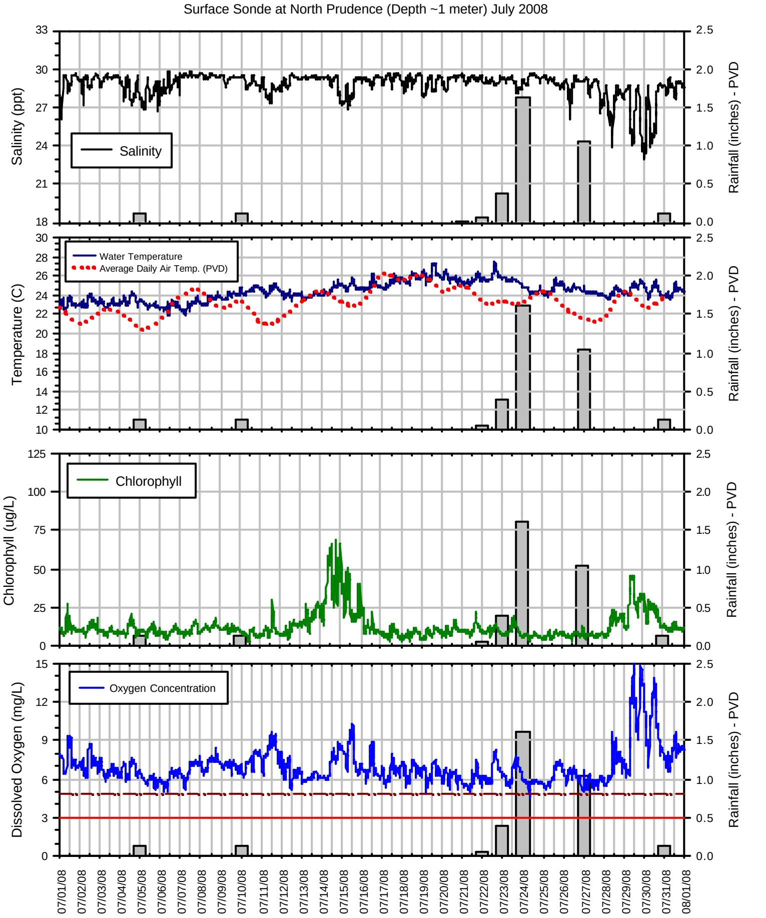

The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by RIDEM - Office of Water Resources and URI/GSO.




The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by RIDEM - Office of Water Resources and URI/GSO.

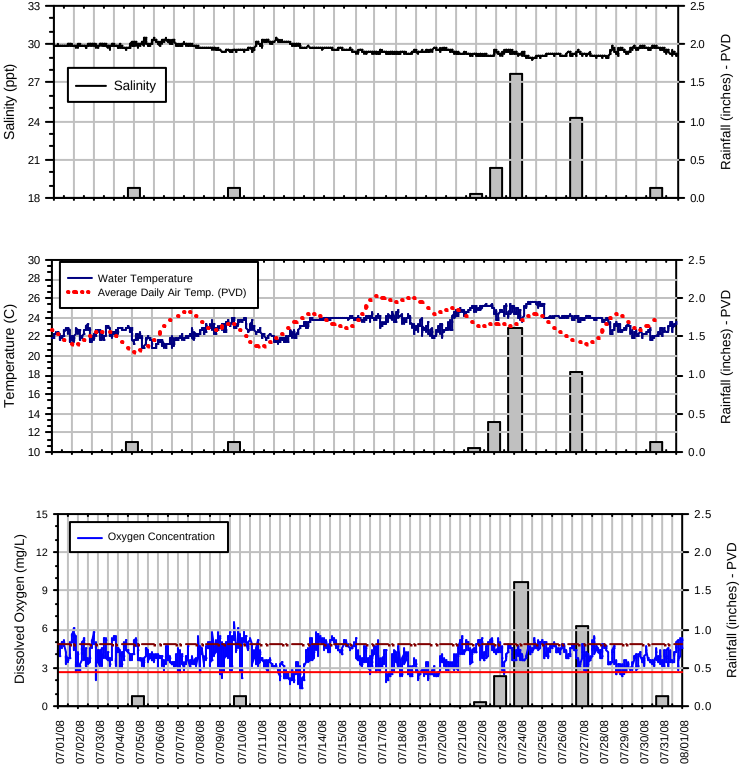



The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by RIDEM - Office of Water Resources and URI/GSO.



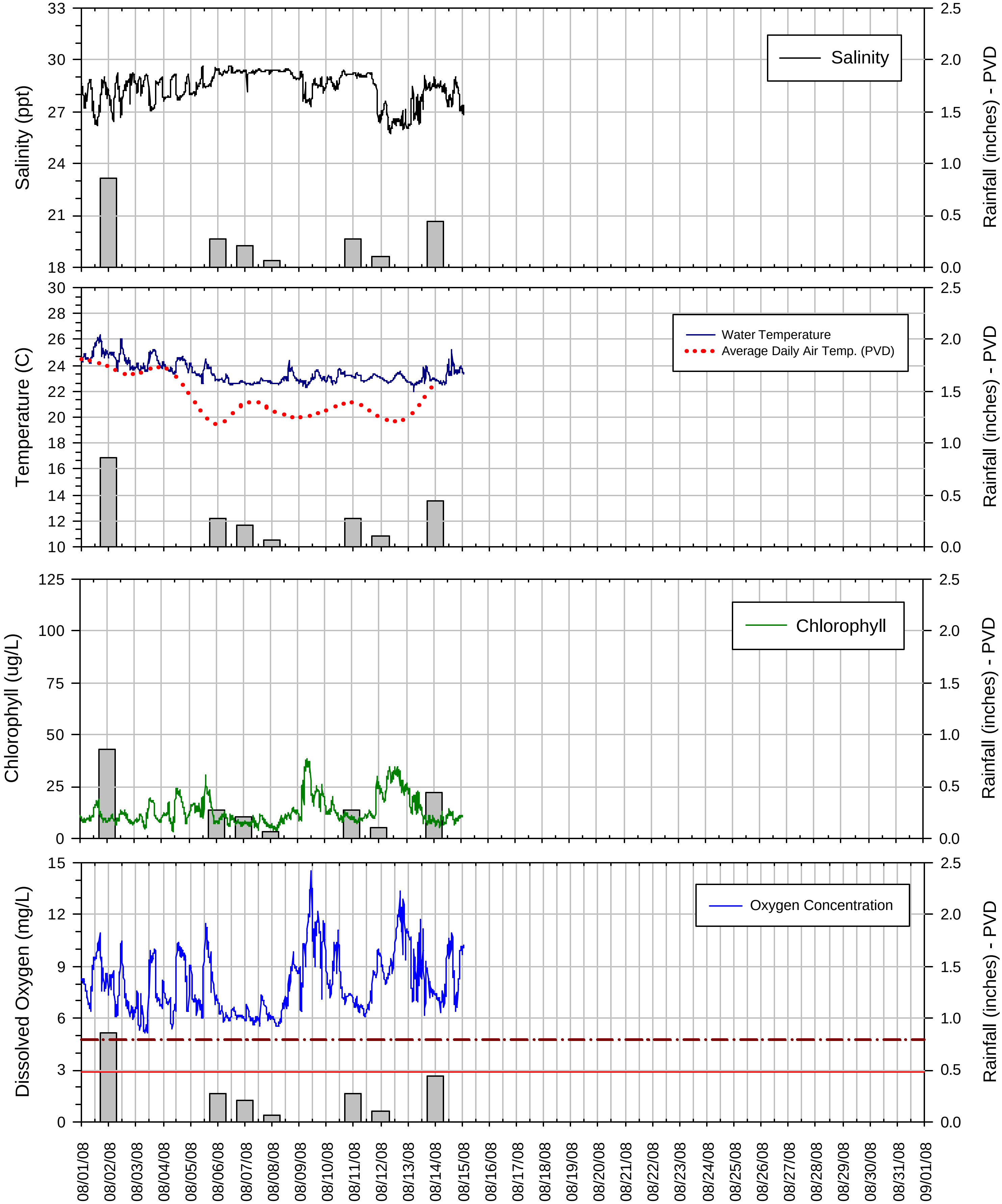

The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by RIDEM - Office of Water Resources and URI/GSO.

Bottom Sonde at North Prudence (Depth ~11 meters) July 2008



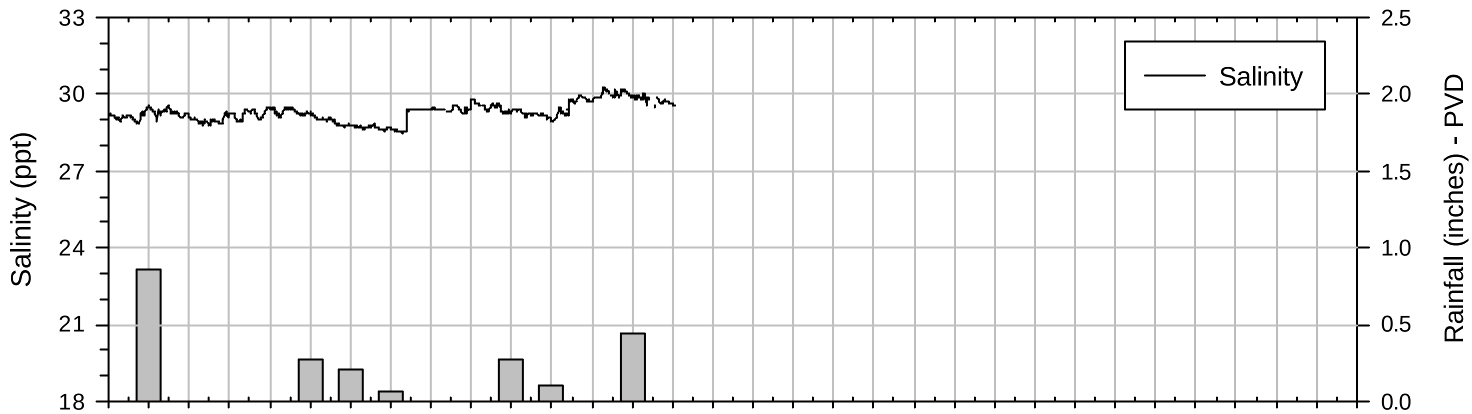

The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by RIDEM - Office of Water Resources and URI/GSO.

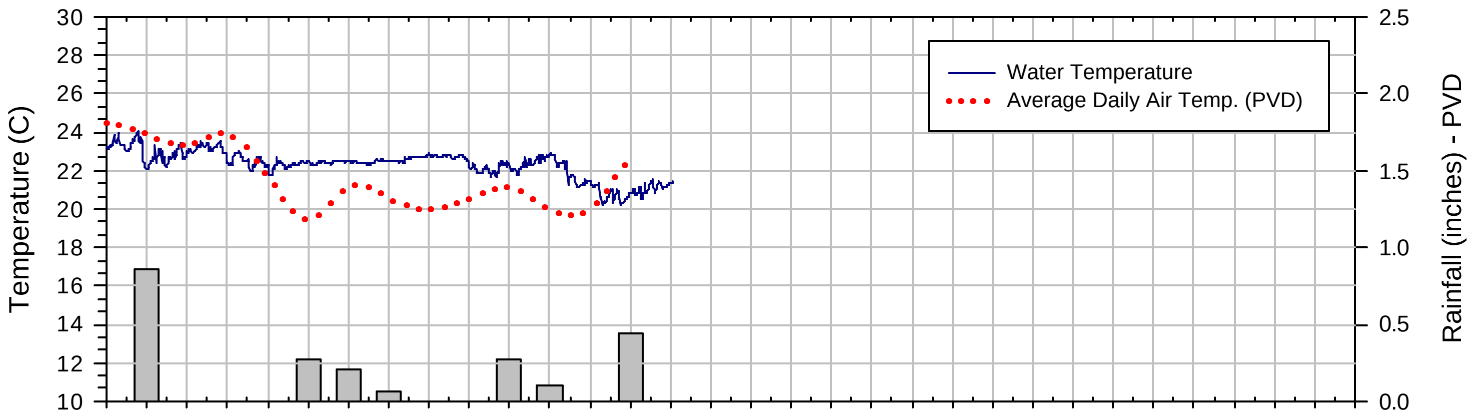
Surface Sonde at North Prudence (Depth ~1 meter) August 2008

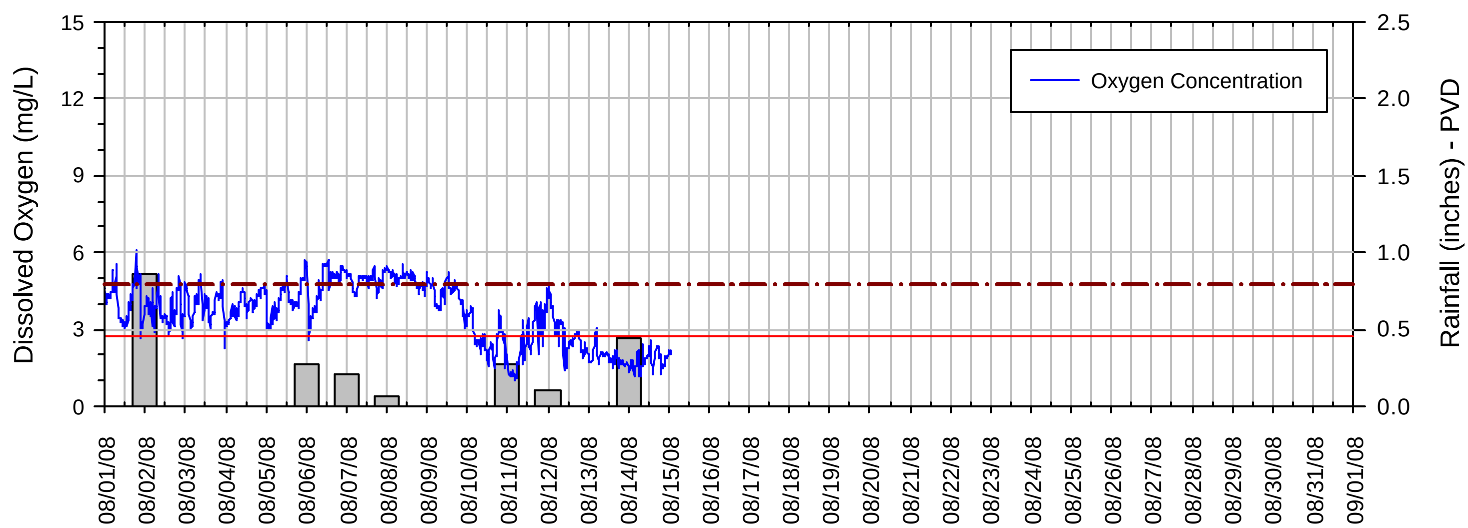



The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by RIDEM - Office of Water Resources and URI/GSO.

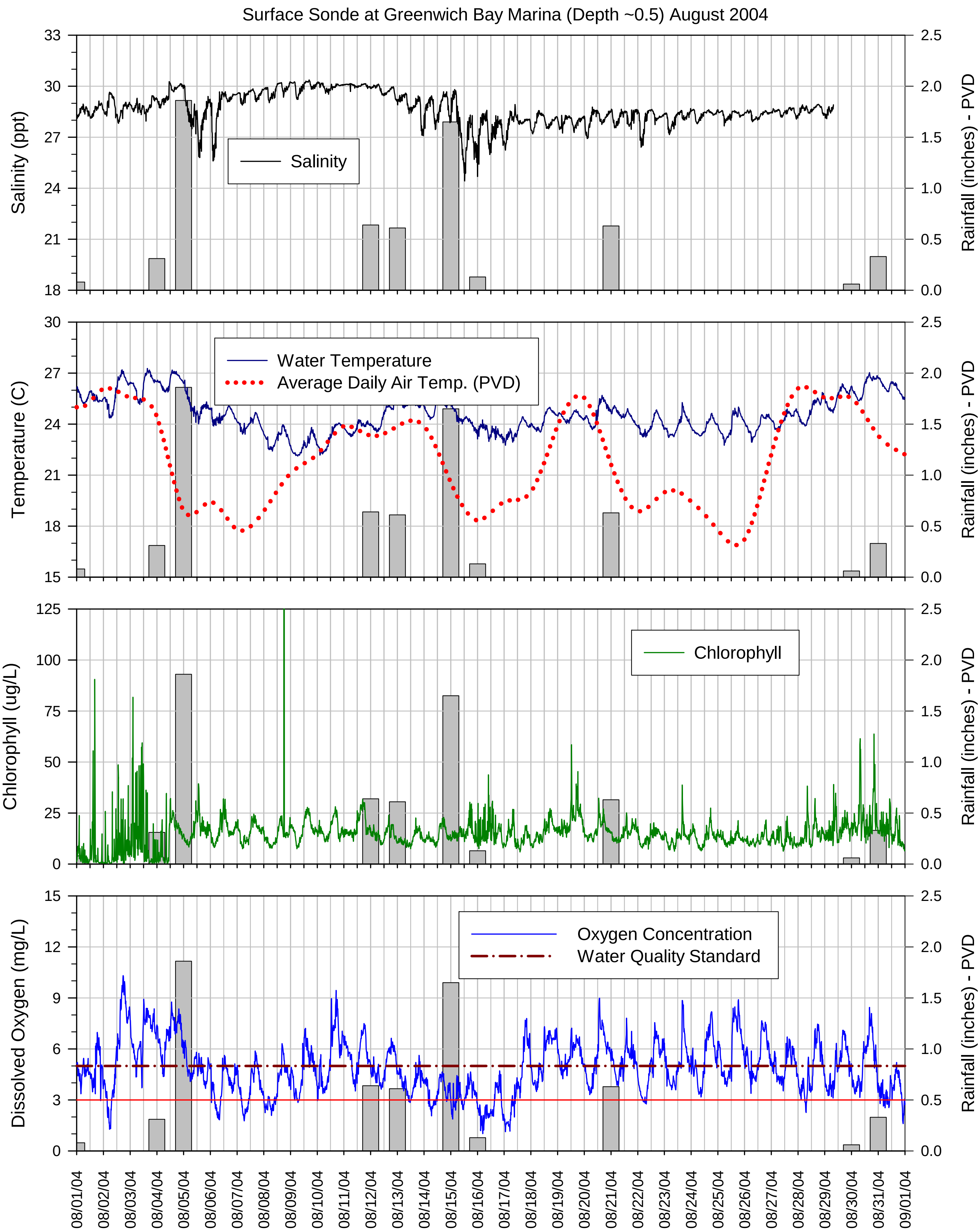
Bottom Sonde at North Prudence (Depth ~11 meters) August 2008



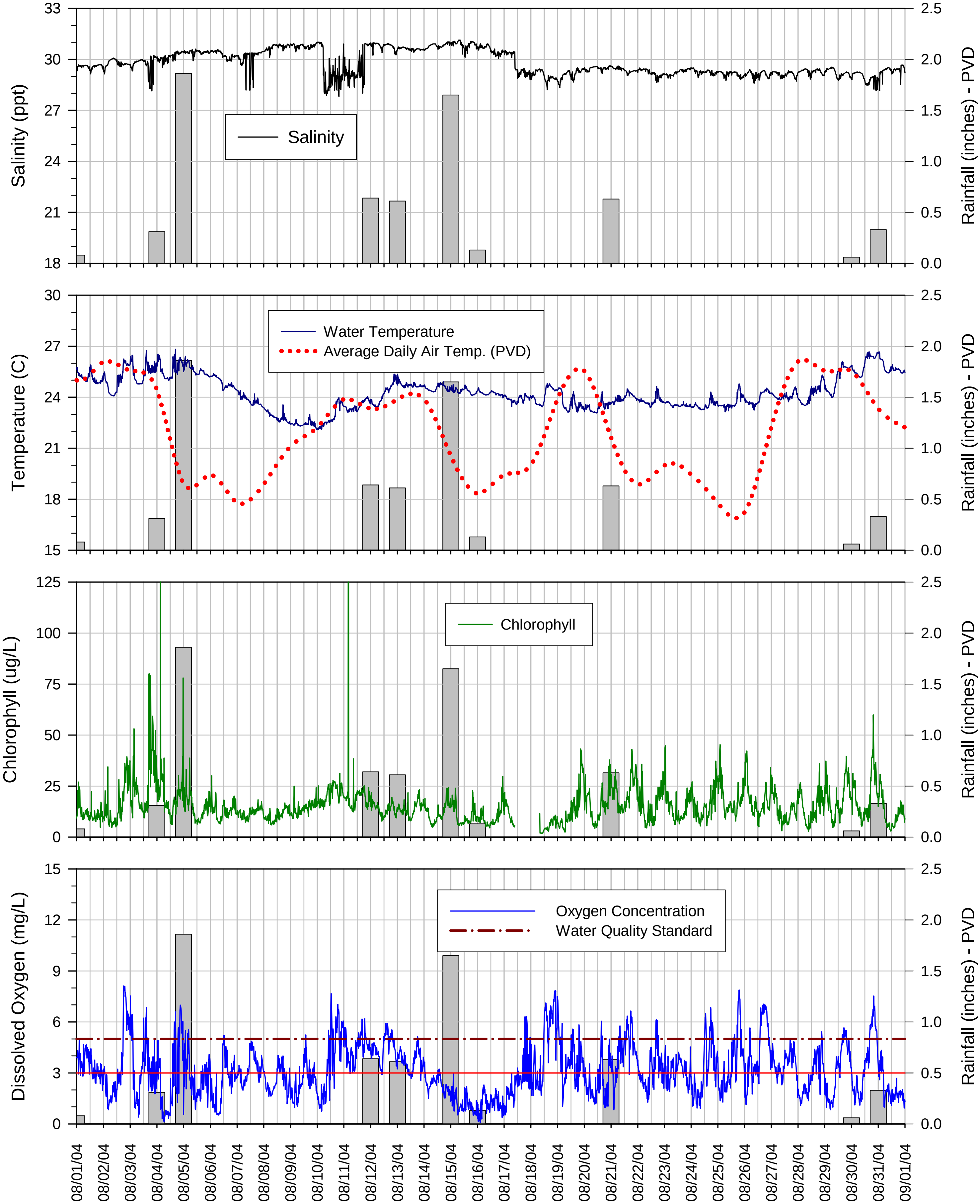




The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by RIDEM - Office of Water Resources and URI/GSO.

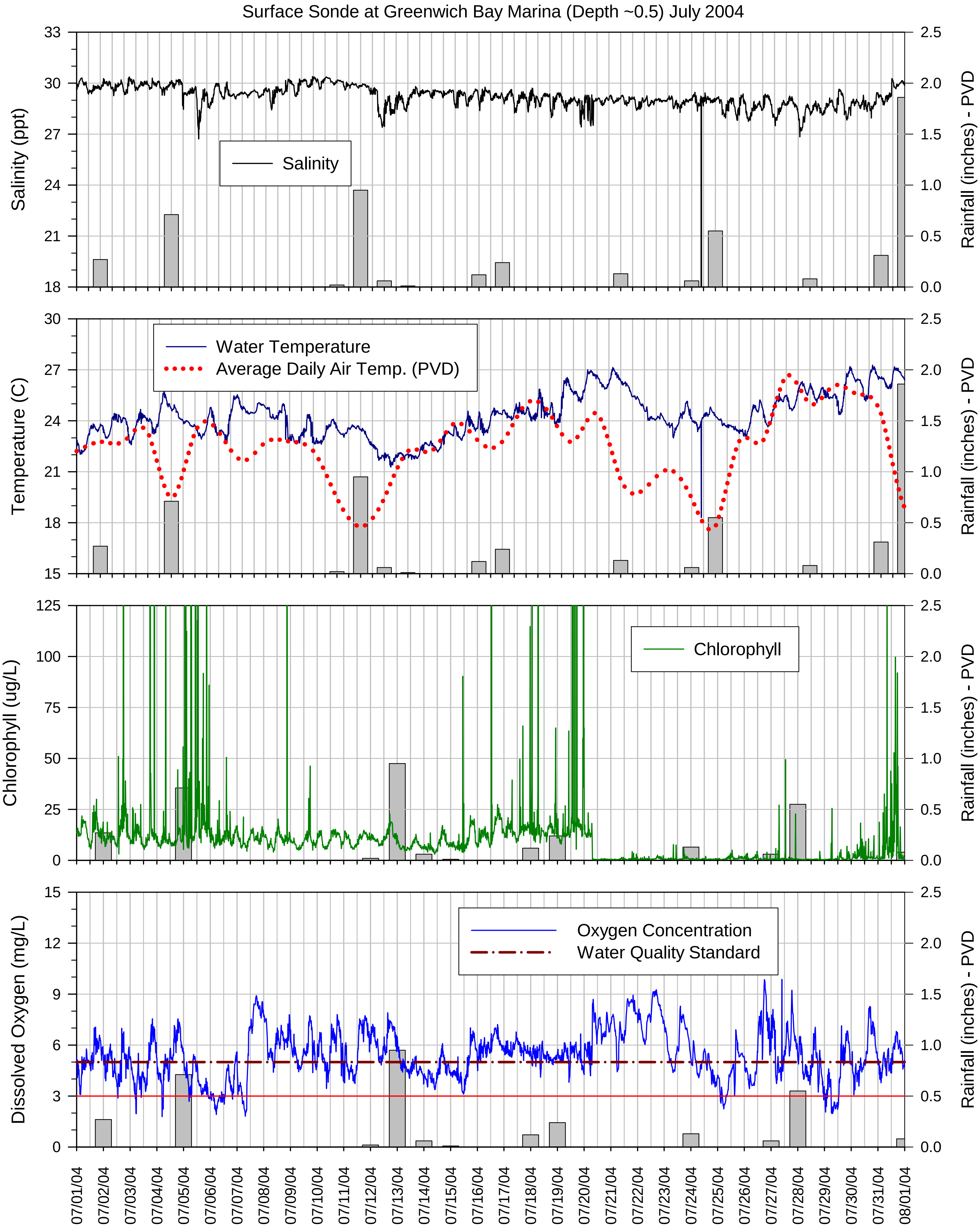



The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by the Narragansett Bay National Estuarine Research Reserve (NBNERR).

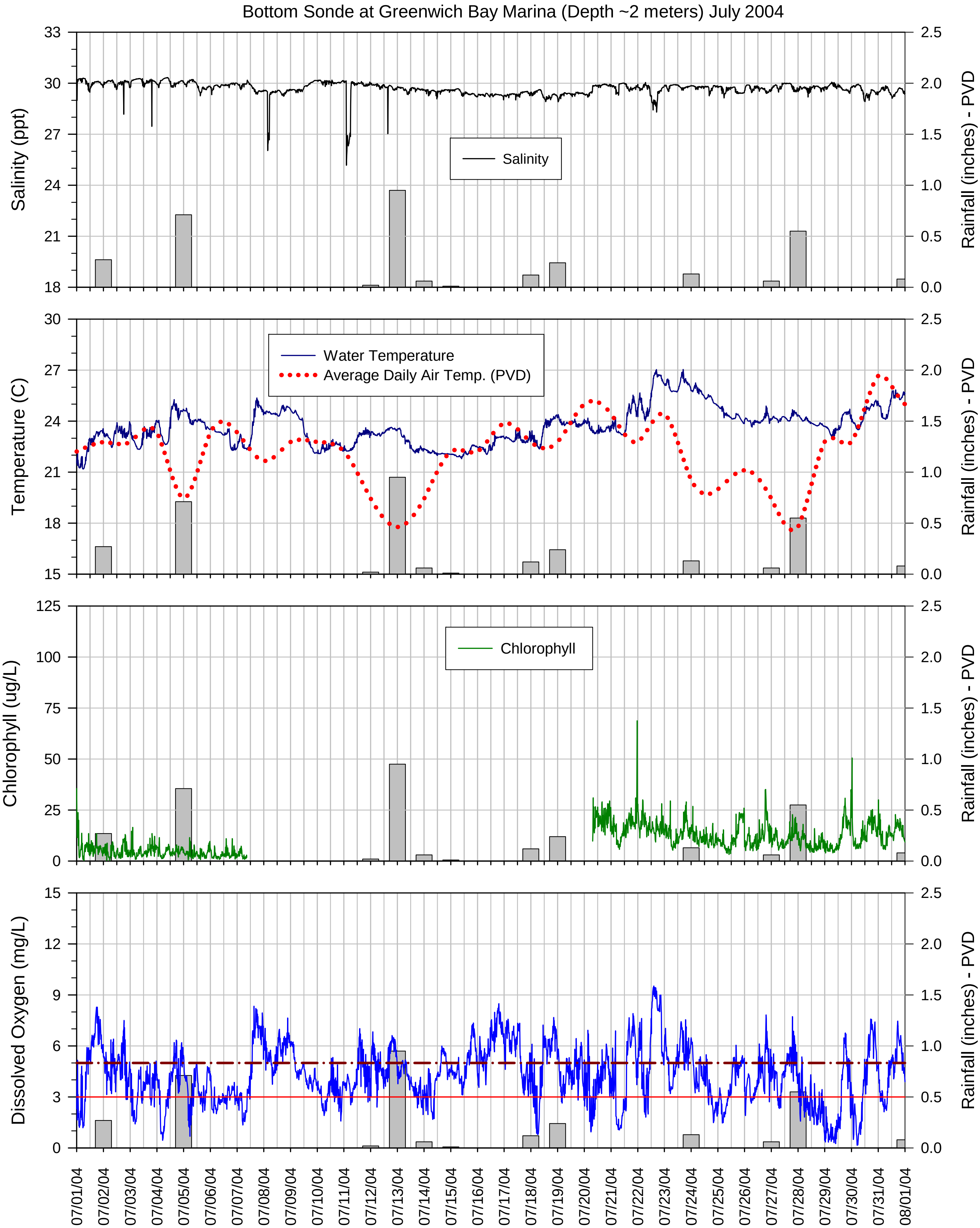
Bottom Sonde at Greenwich Bay Marina (Depth ~2 meters) August 2004




The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by the Narragansett Bay National Estuarine Research Reserve (NBNERR).

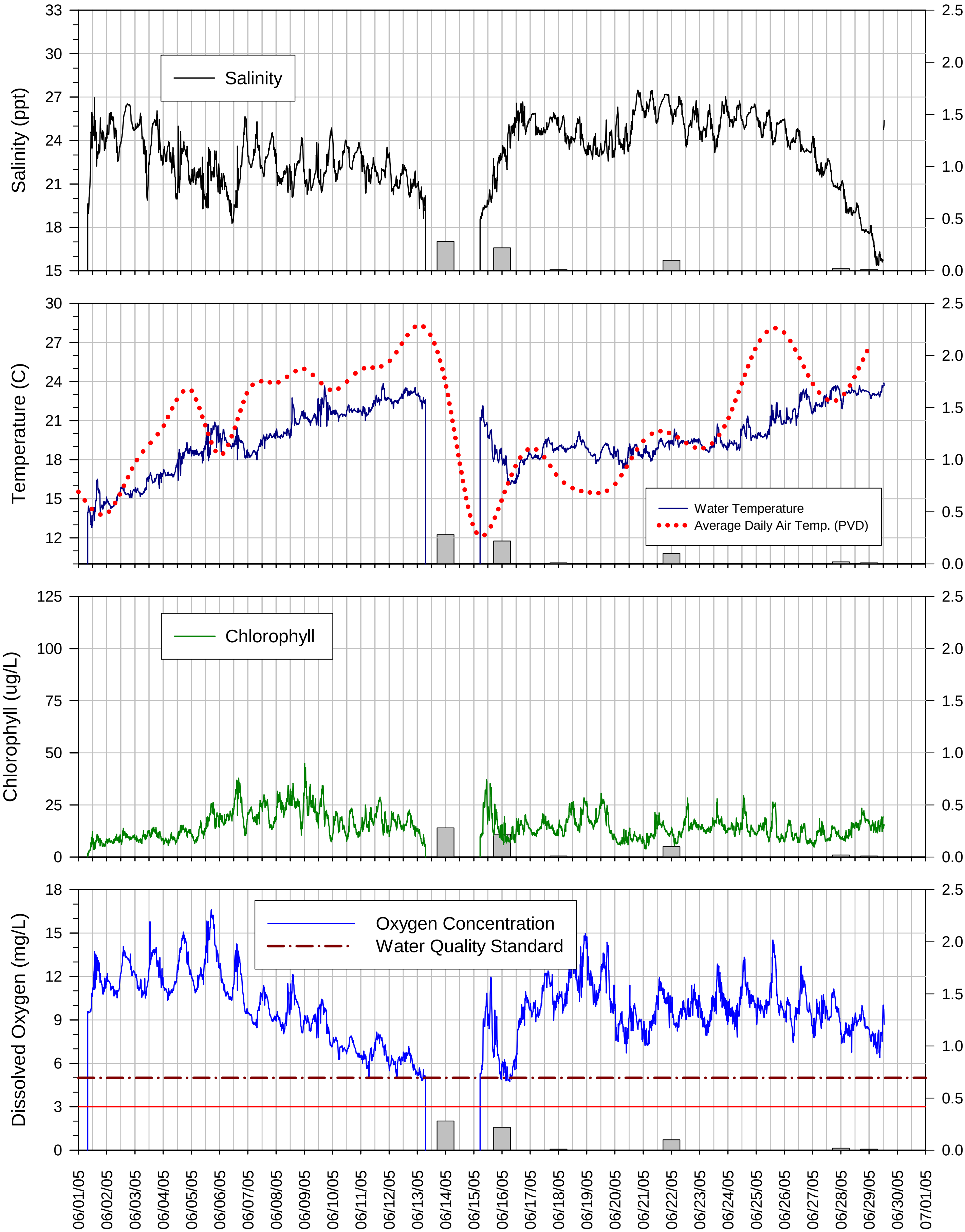



The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by the Narragansett Bay National Estuarine Research Reserve (NBNERR).



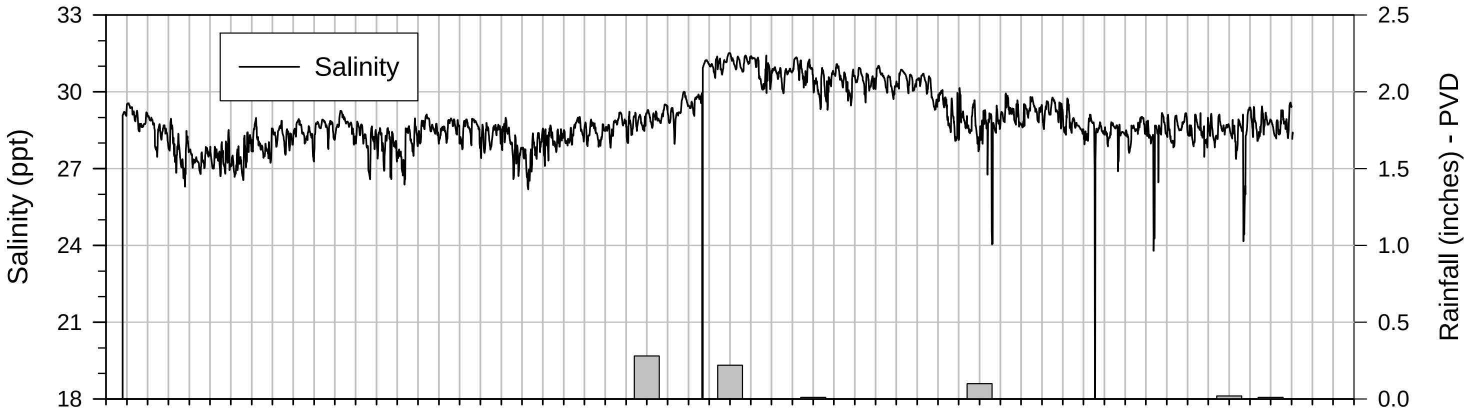

The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by the Narragansett Bay National Estuarine Research Reserve (NBNERR).

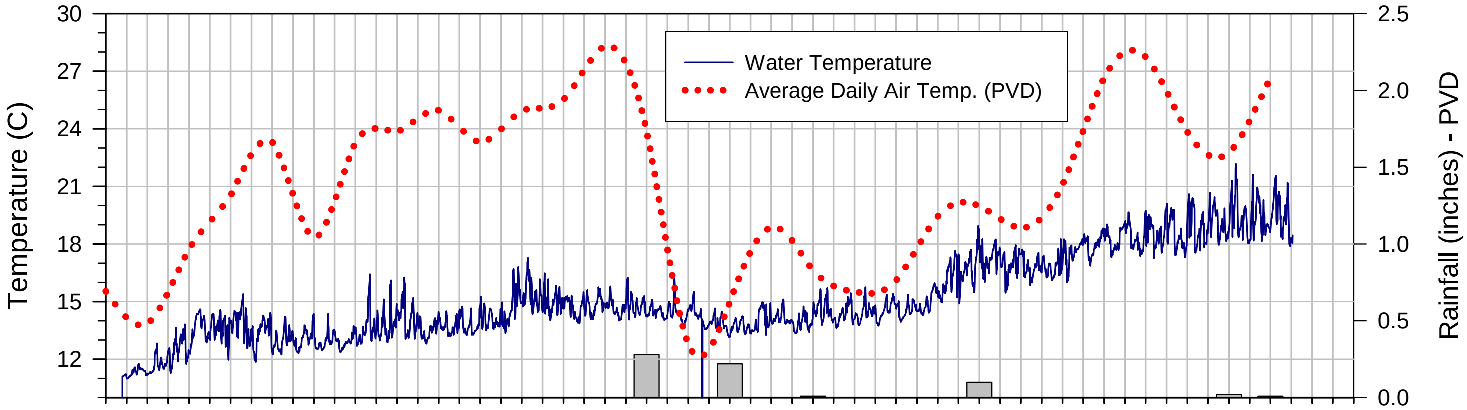
Surface Sonde at Bullock Reach (Depth ~.5 meter) June 2005

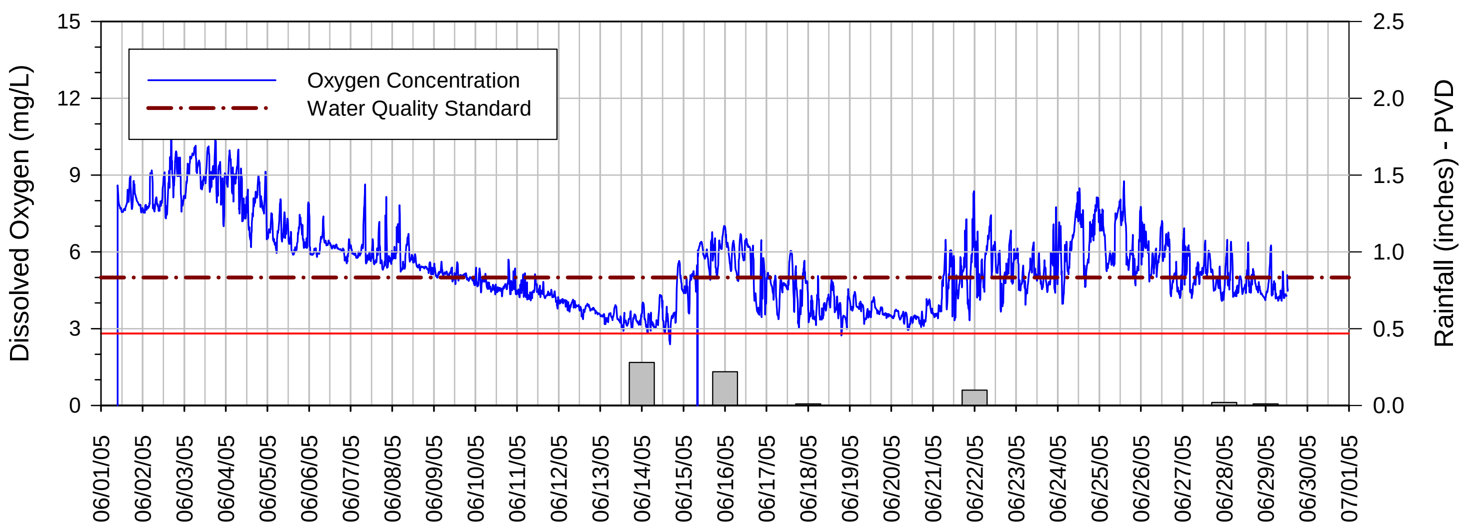



The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses. During 2005, this station is maintained by the Narragansett Bay Commission with equipment on loan from the RIDEM Office of Water Resources.

Bottom Sonde at Bullock Reach (Depth ~9 meters) June 2005

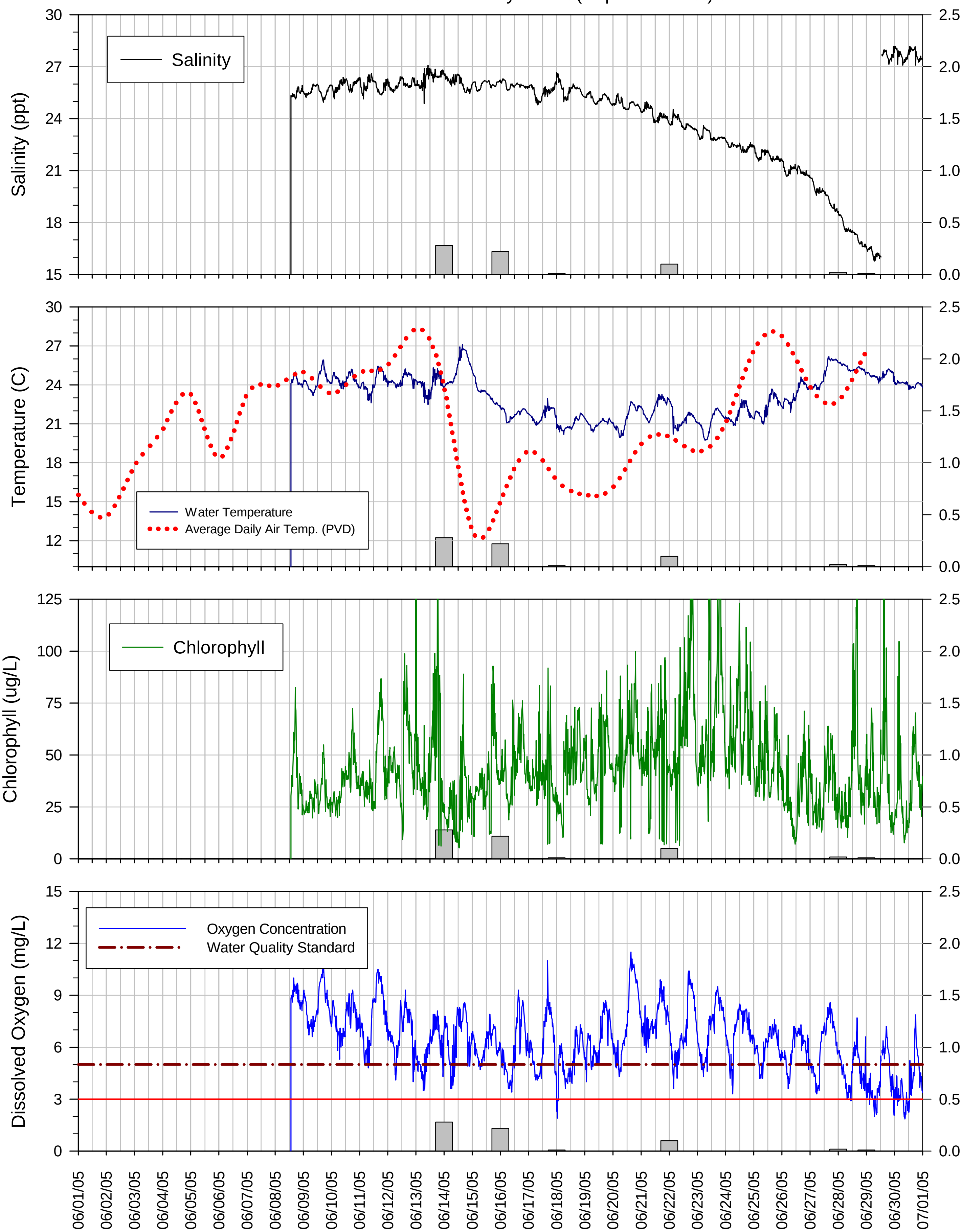


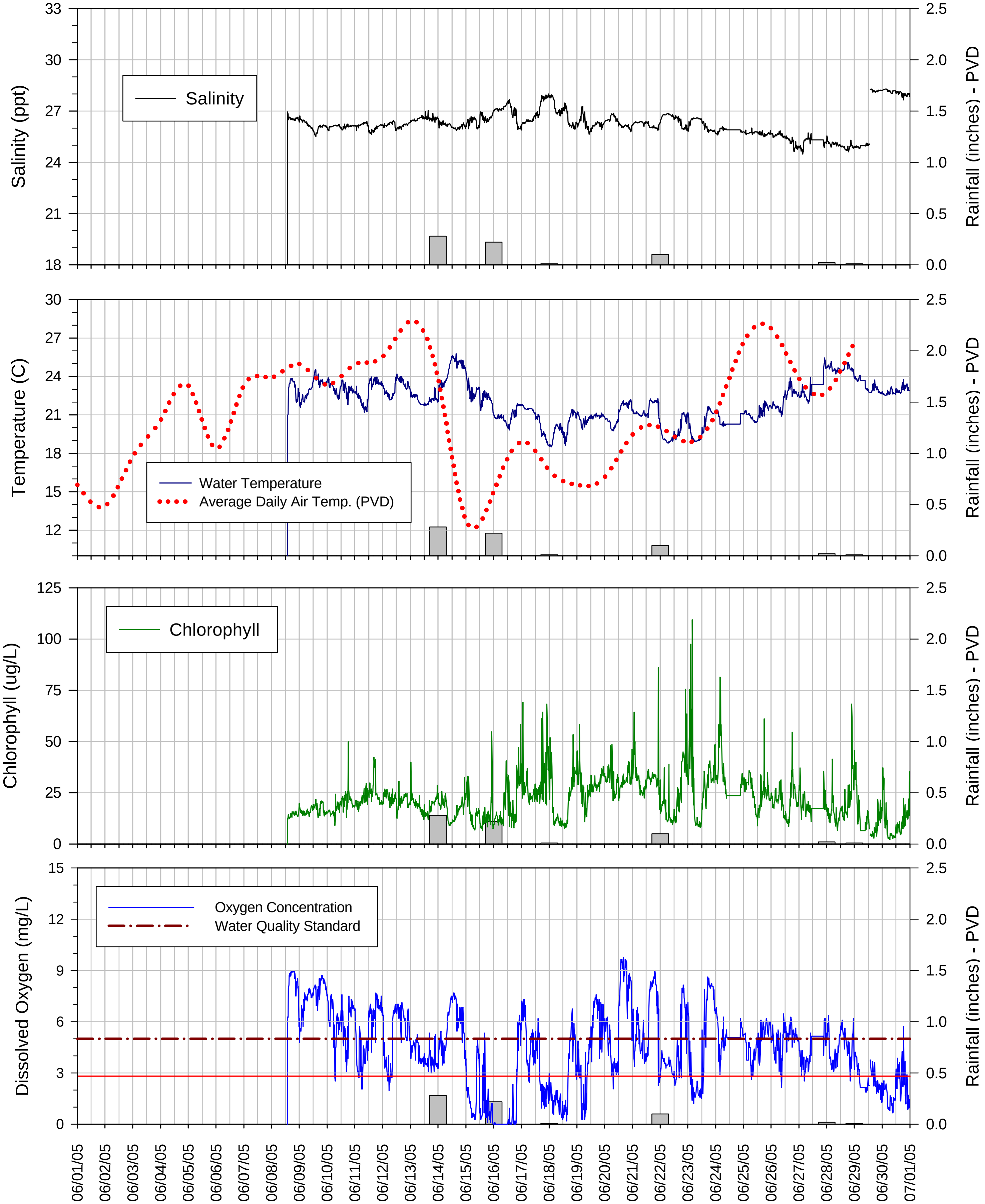

The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses. During 2005, this station is maintained by the Narragansett Bay Commission with equipment on loan from the RIDEM Office of Water Resources.

Surface Sonde at Greenwich Bay Marina(Depth ~1 meter) June 2005

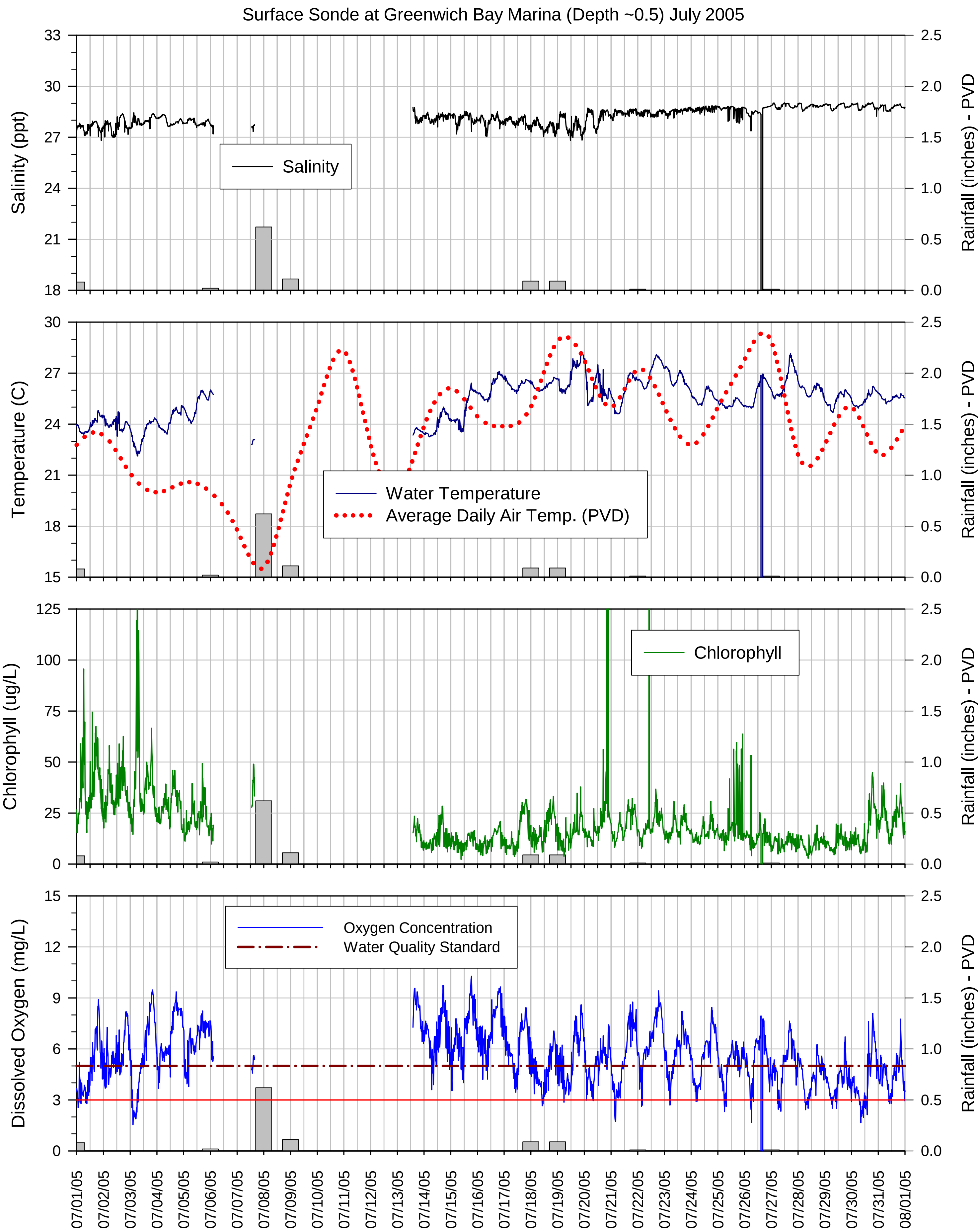



The data displayed on this chart is provisional and is subject to change based on post-season quality control analys
This station is maintained by RIDEM - Office of Water Resources and URI/GSO.

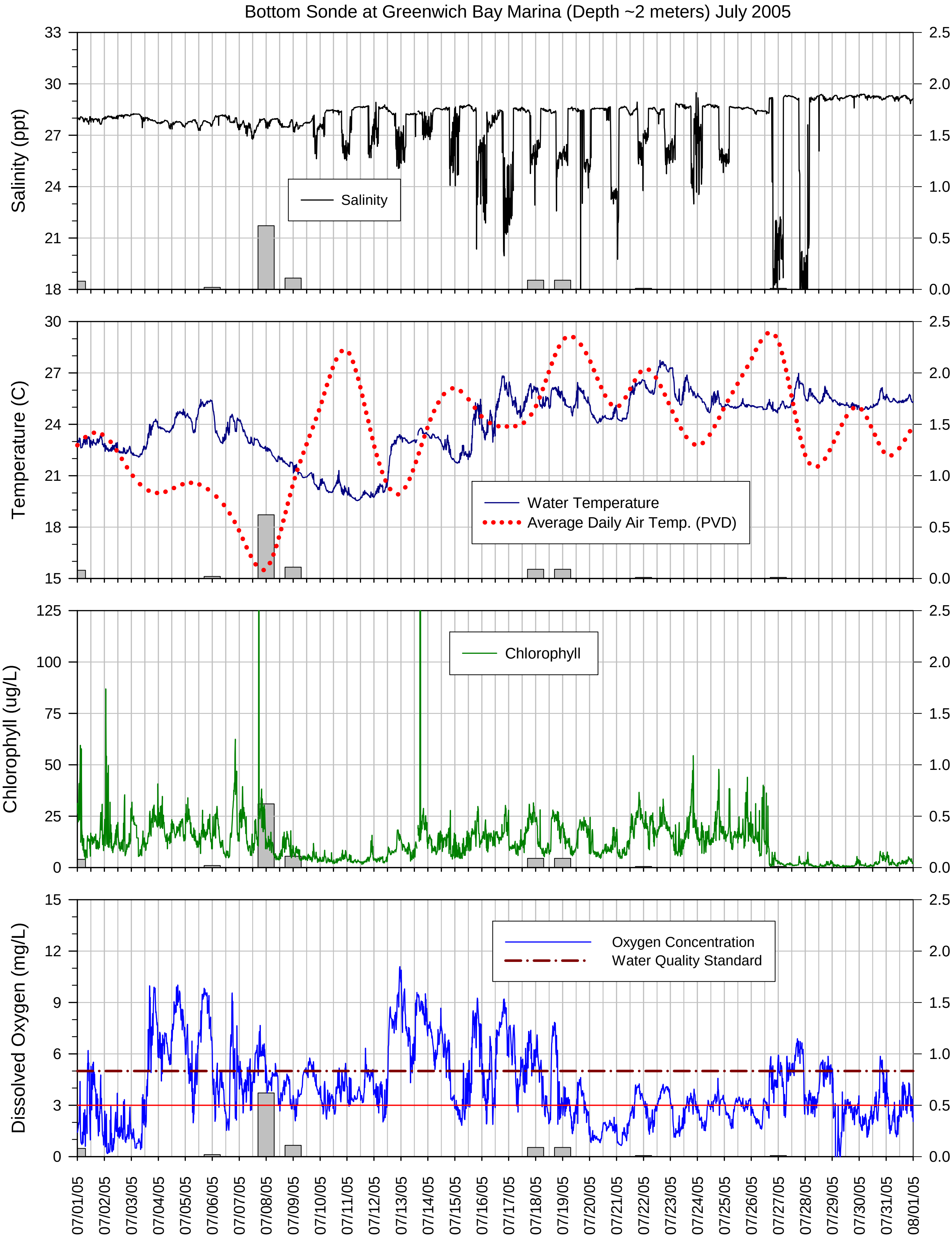
Bottom Sonde at Greenwich Bay Marina (Depth ~3 meters) June 2005



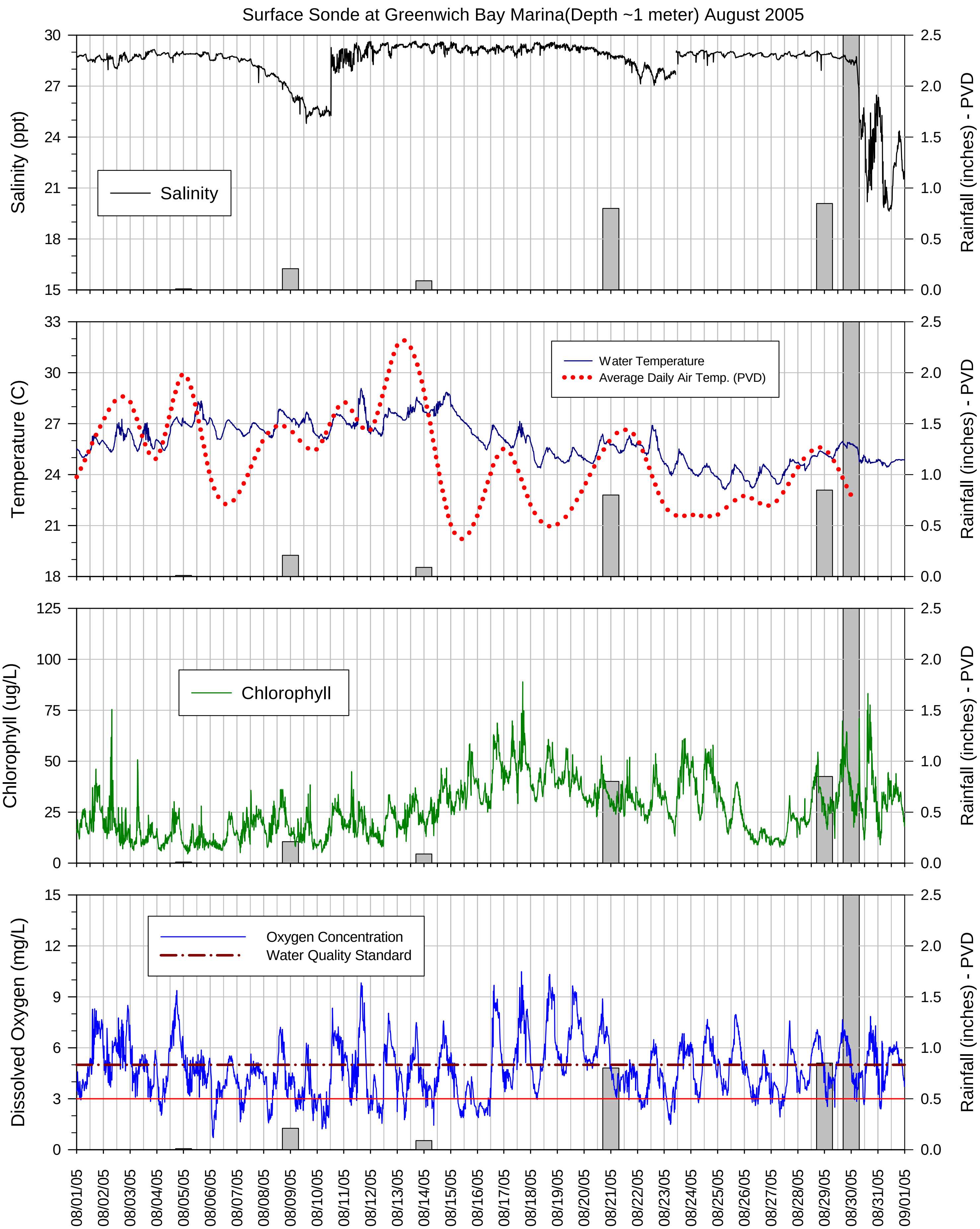

The data displayed on this chart is provisional and is subject to change based on post-season quality control analys
This station is maintained by RIDEM - Office of Water Resources and URI/GSO.




The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by RIDEM - Office of Water Resources and URI/GSO.

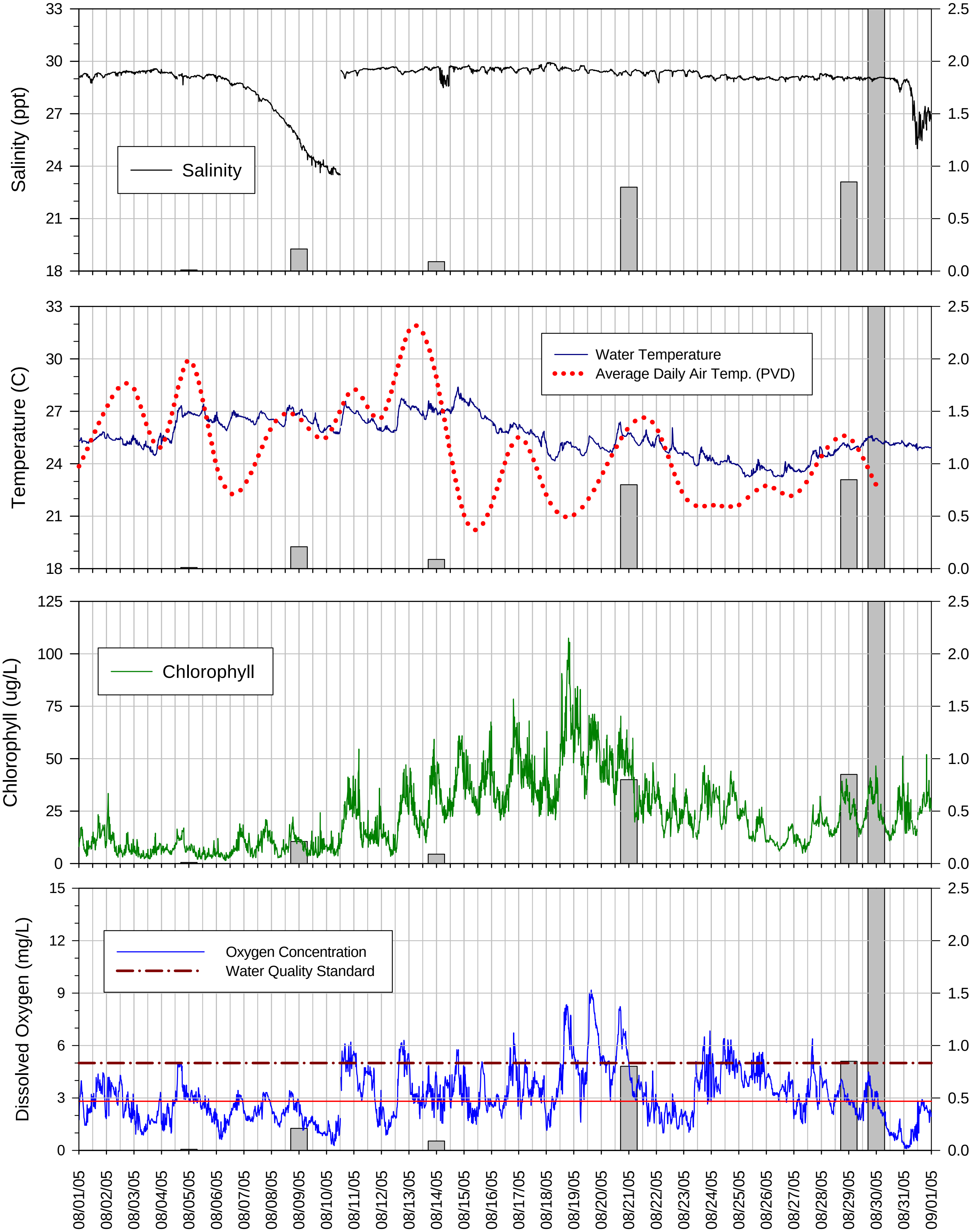



The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by RIDEM - Office of Water Resources and URI/GSO.

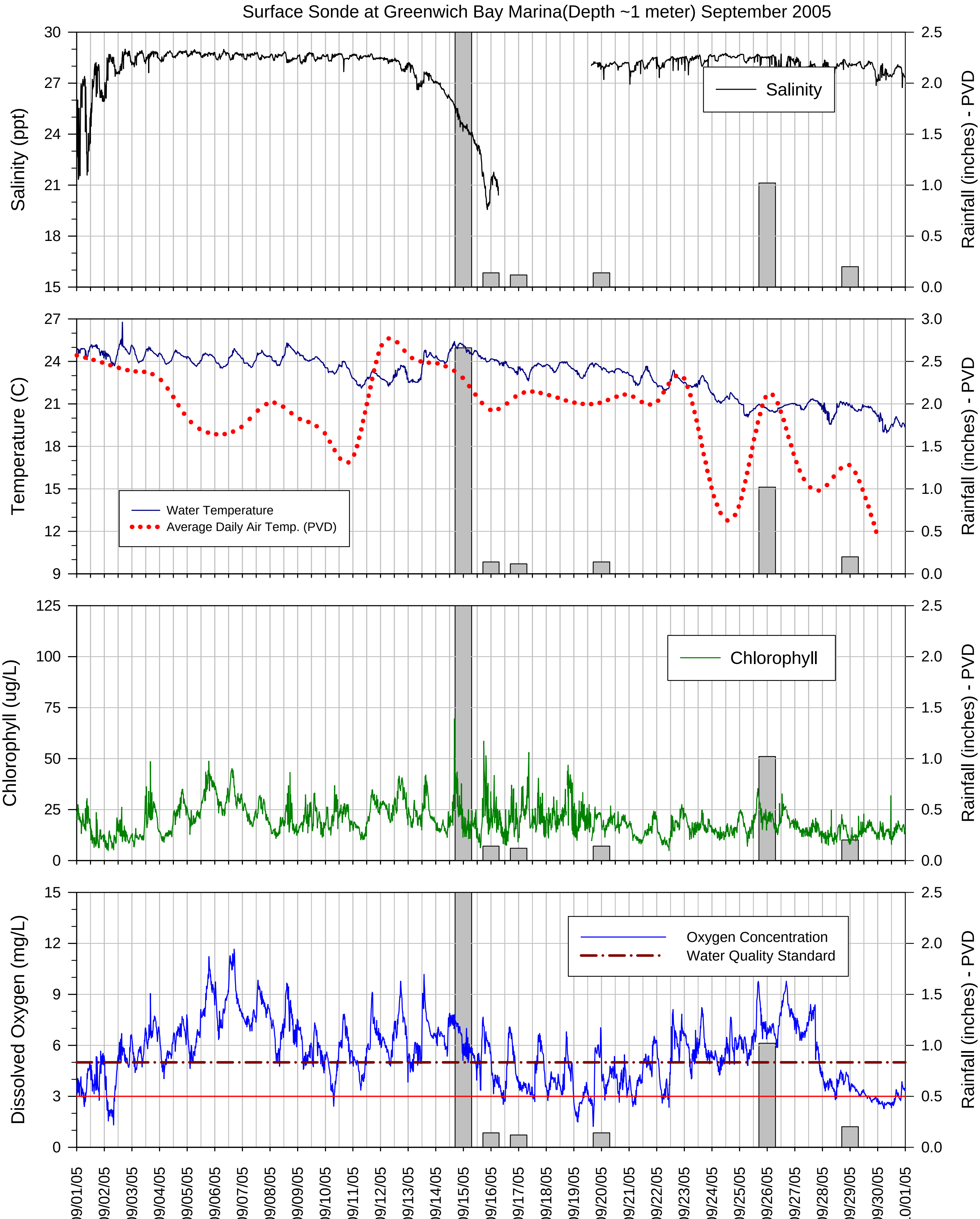



The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by RIDEM - Office of Water Resources and URI/GSO.

Bottom Sonde at Greenwich Bay Marina (Depth ~3 meters) August 2005

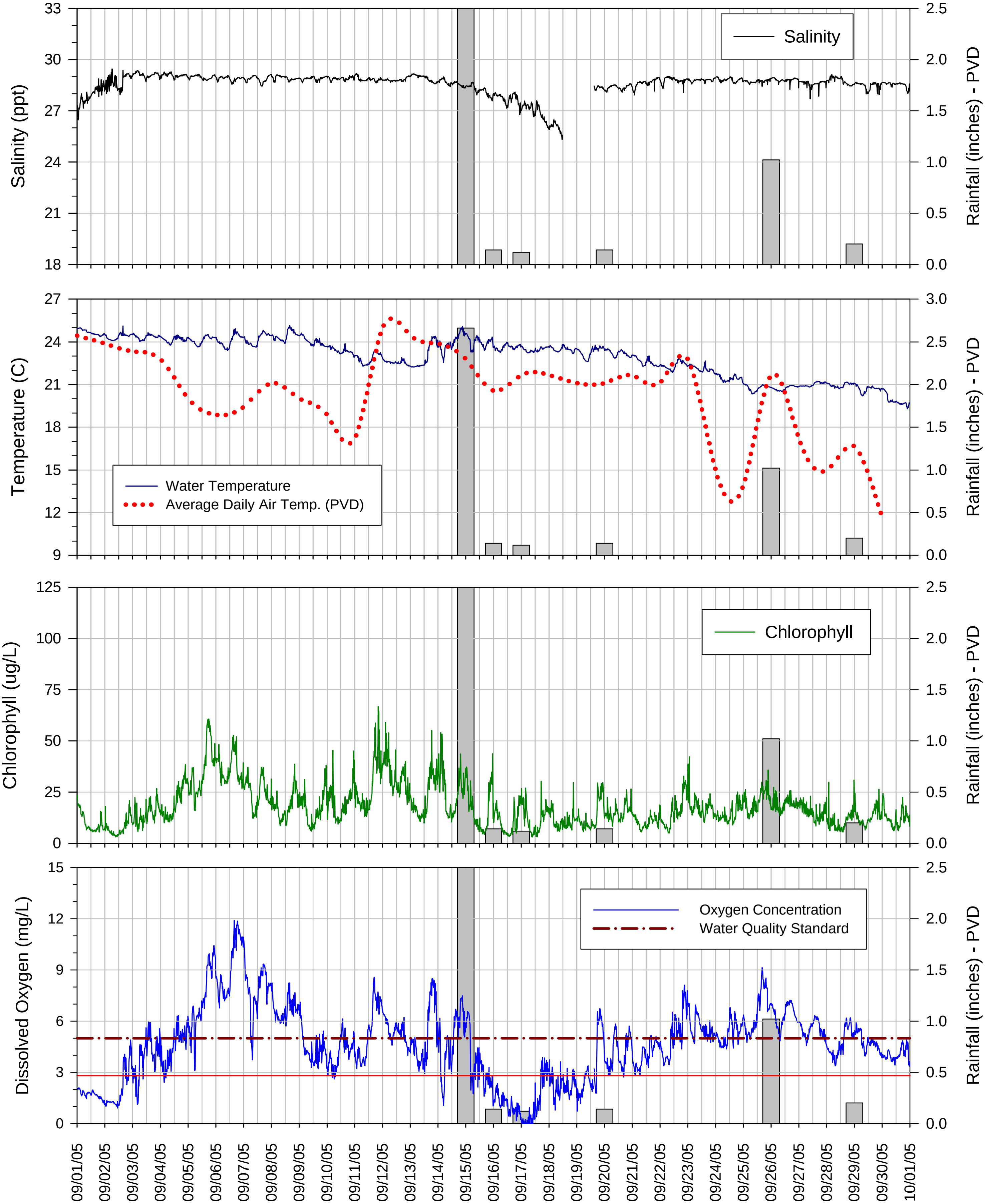



The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by RIDEM - Office of Water Resources and URI/GSO.



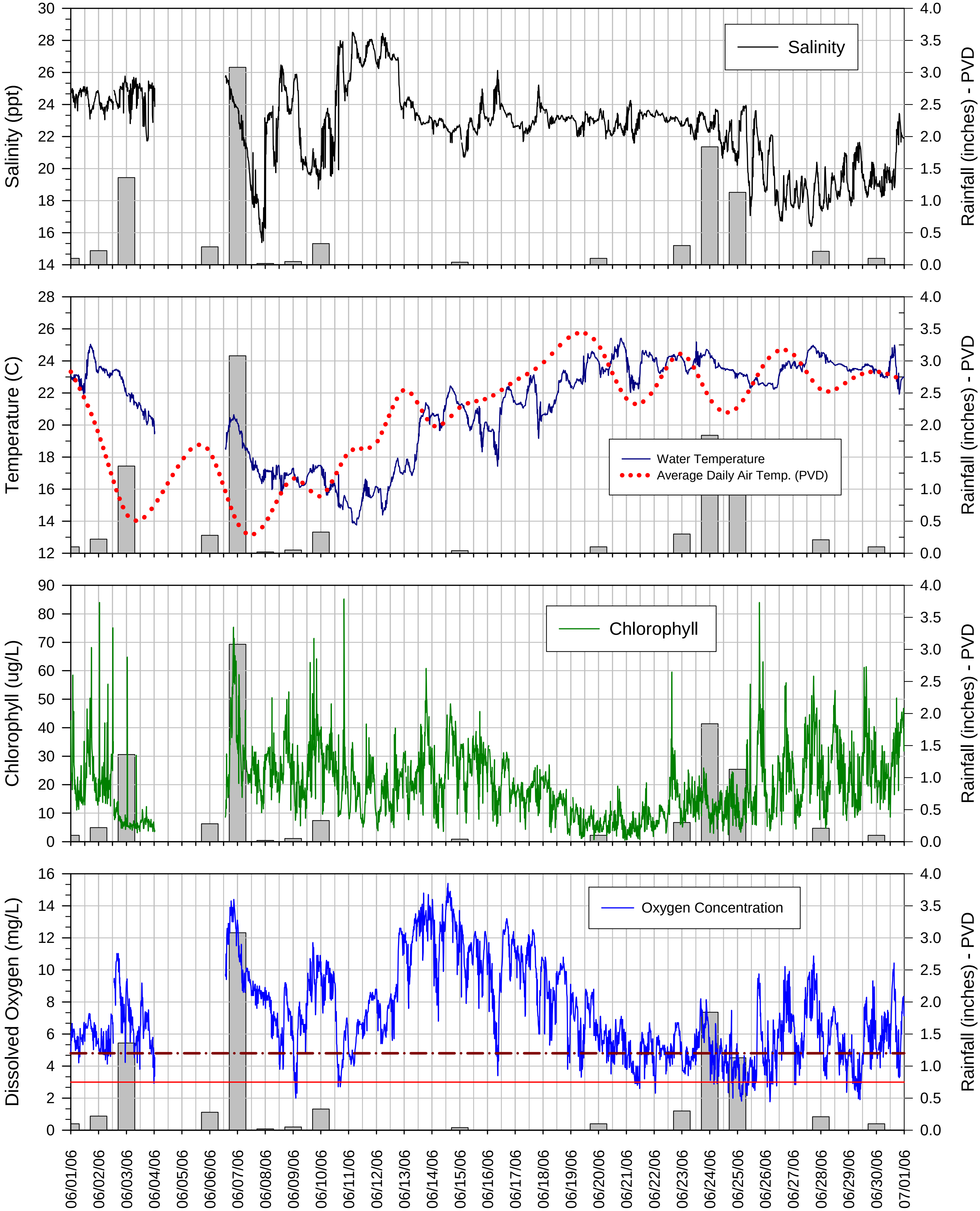

The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by RIDEM - Office of Water Resources and URI/GSO.

Bottom Sonde at Greenwich Bay Marina (Depth ~3 meters) September 2005



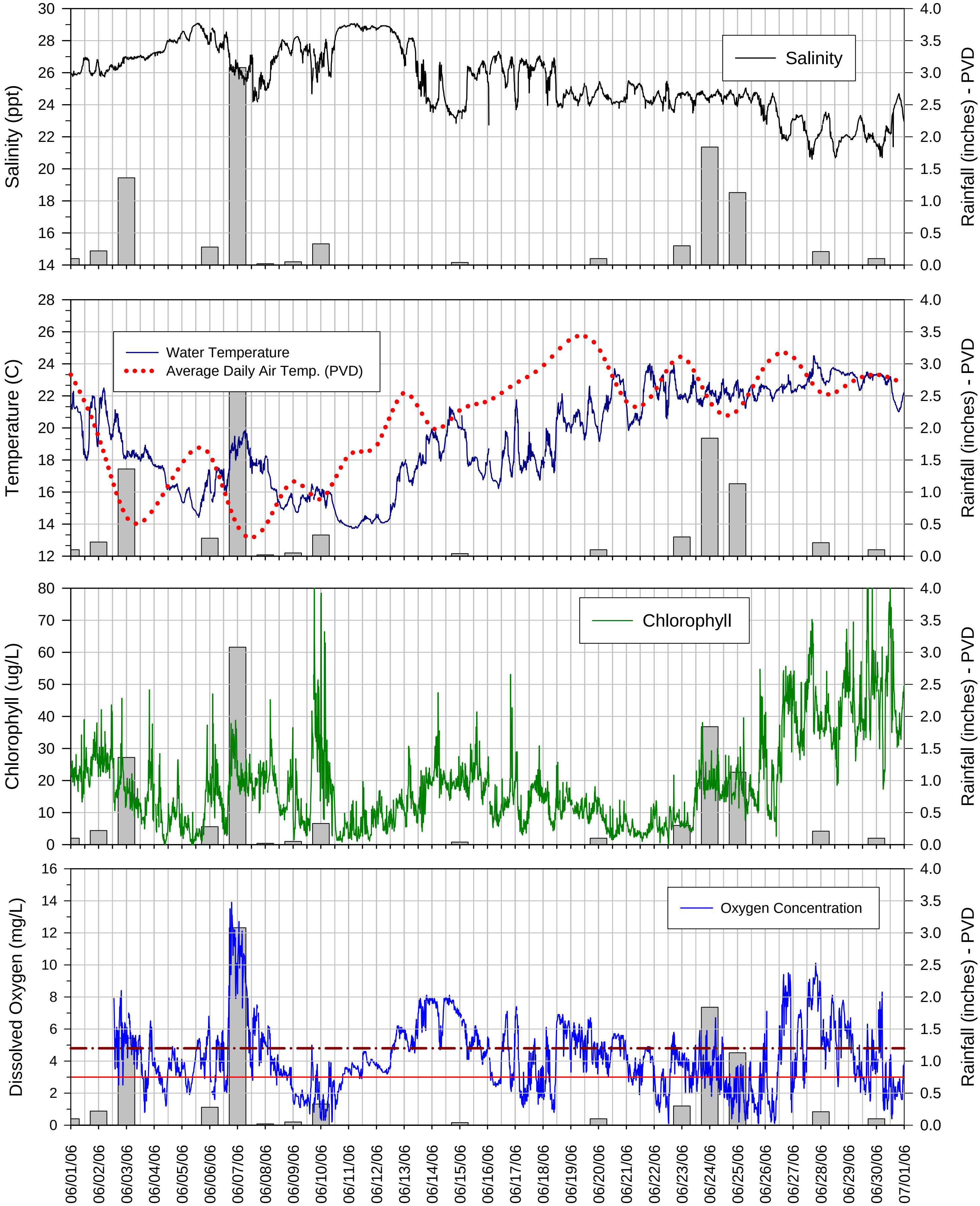

The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by RIDEM - Office of Water Resources and URI/GSO.

Surface Sonde at Greenwich Bay Marina (Depth ~1 meter) June 2006



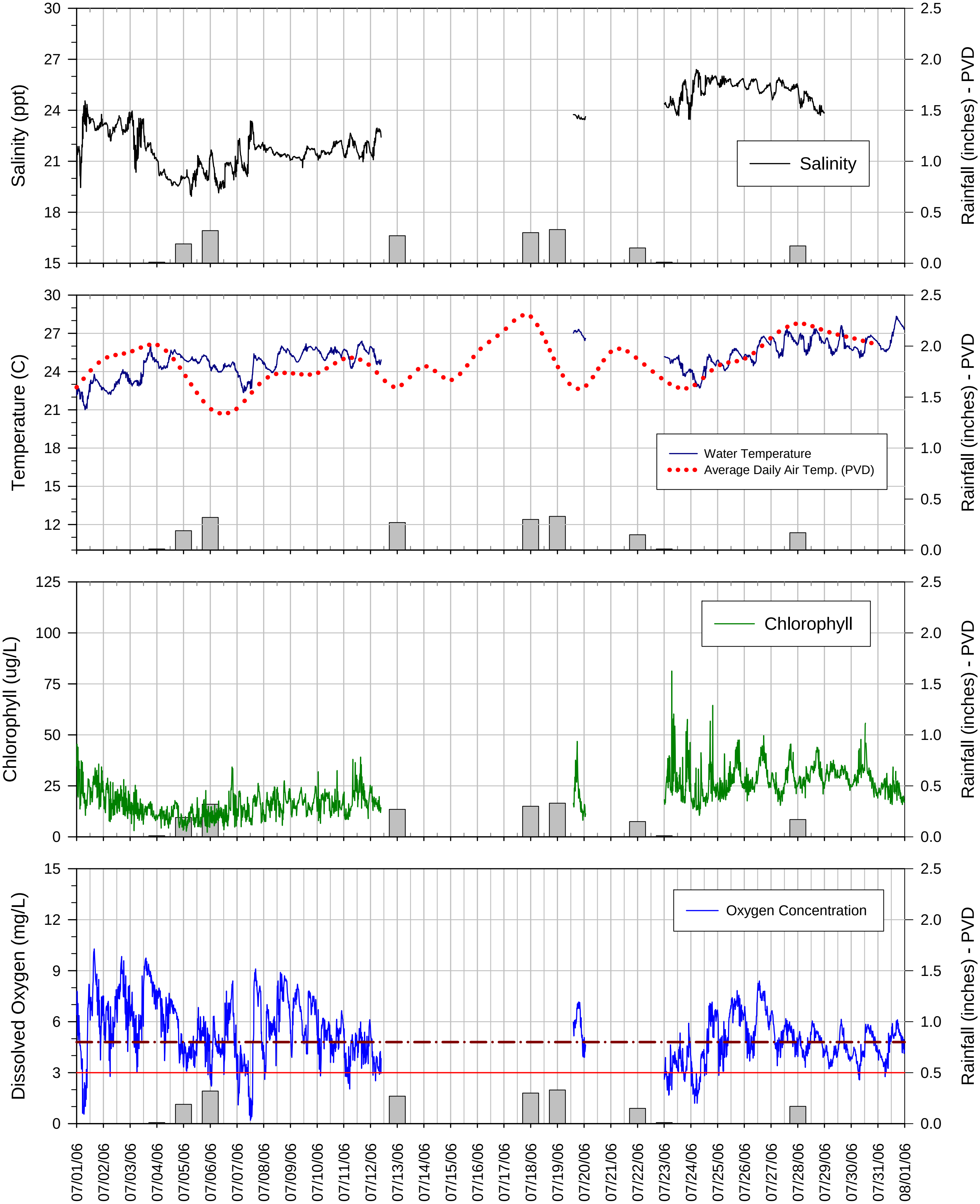

The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by RIDEM - Office of Water Resources and URI/GSO.

Bottom Sonde at Greenwich Bay Marina (Depth ~3 meters) June 2006



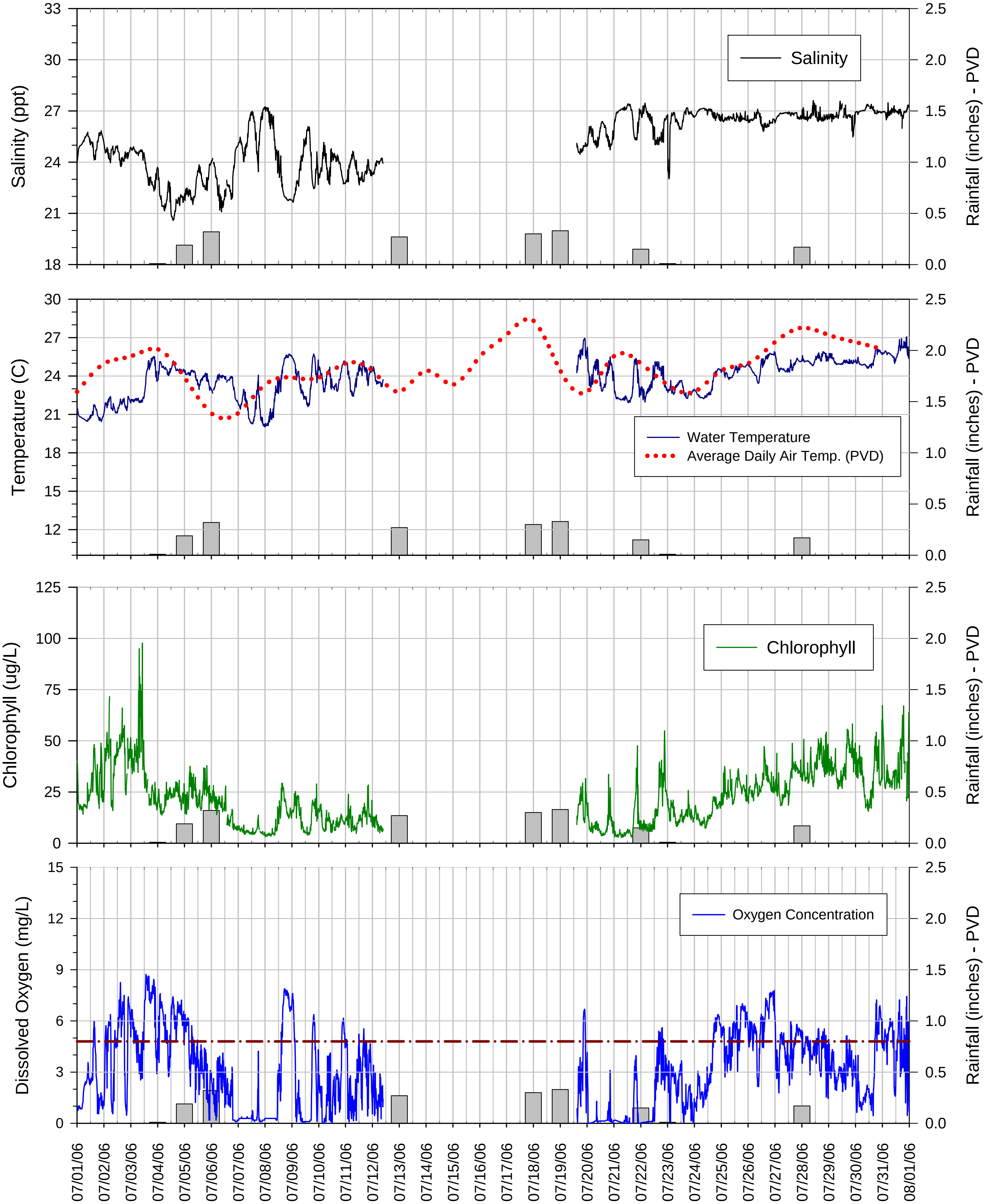

The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by RIDEM - Office of Water Resources and URI/GSO.

Surface Sonde at Greenwich Bay Marina(Depth ~1 meter) July 2006

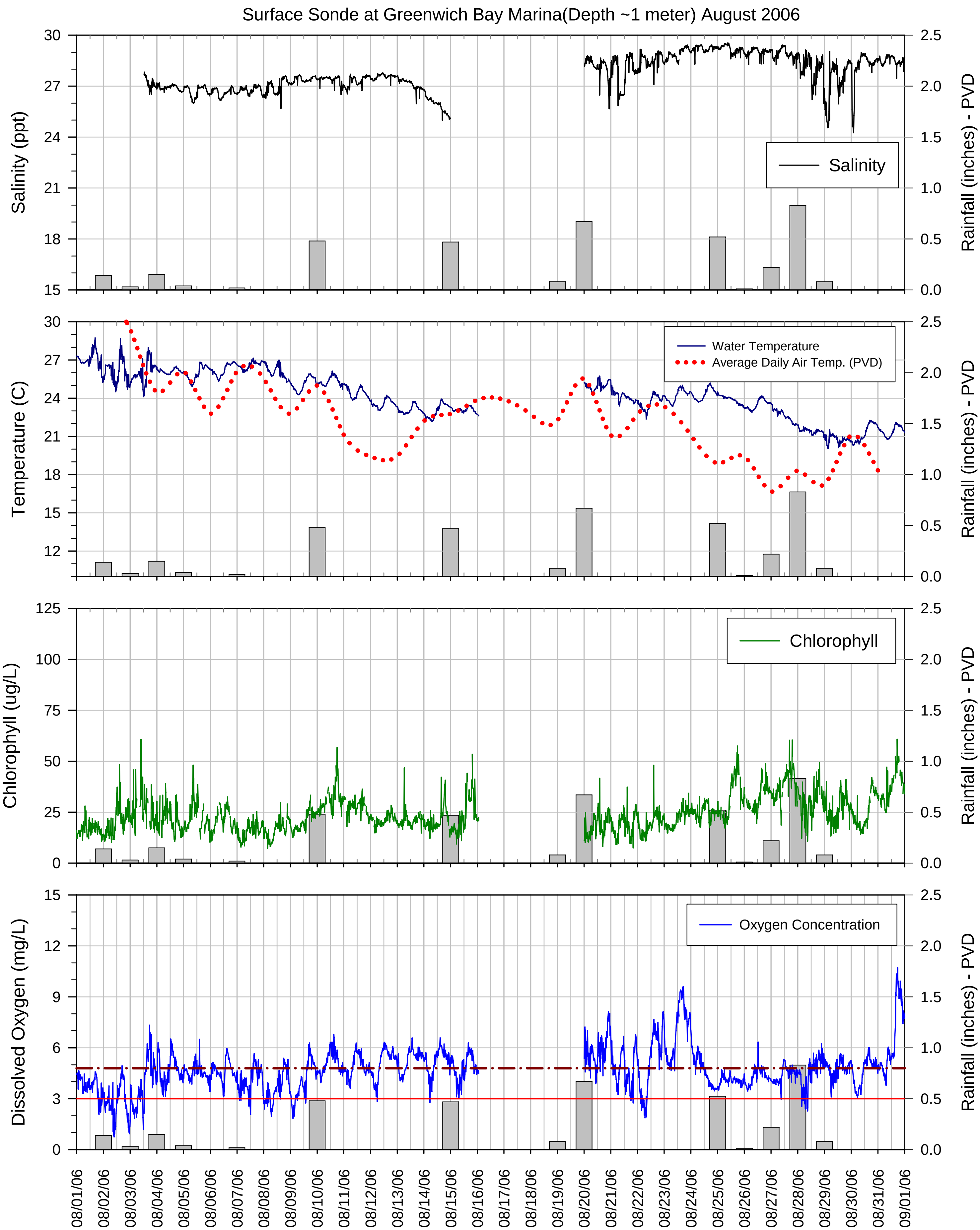



The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by RIDEM - Office of Water Resources and URI/GSO.

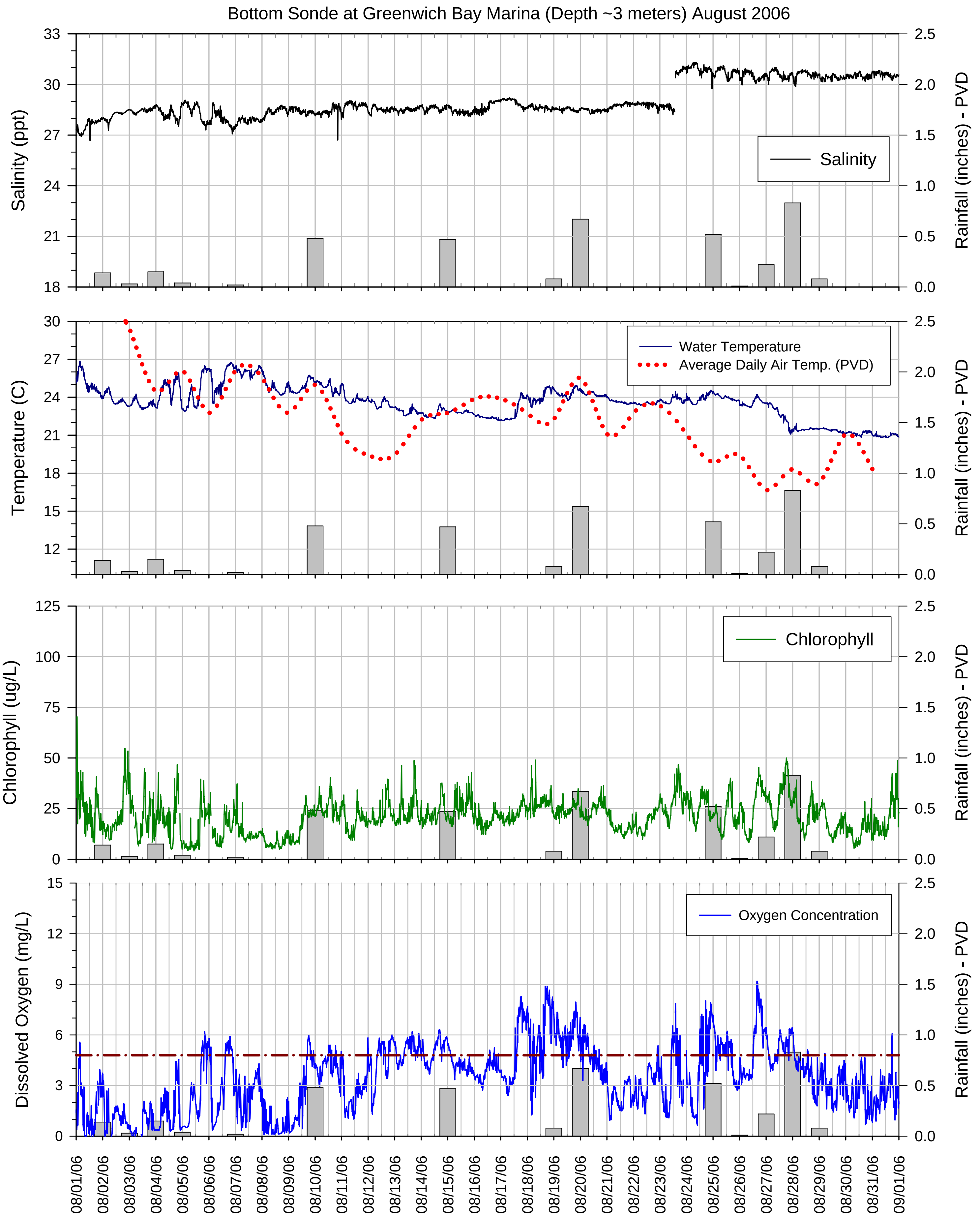
Bottom Sonde at Greenwich Bay Marina (Depth ~3 meters) July 2006




The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by RIDEM - Office of Water Resources and URI/GSO.

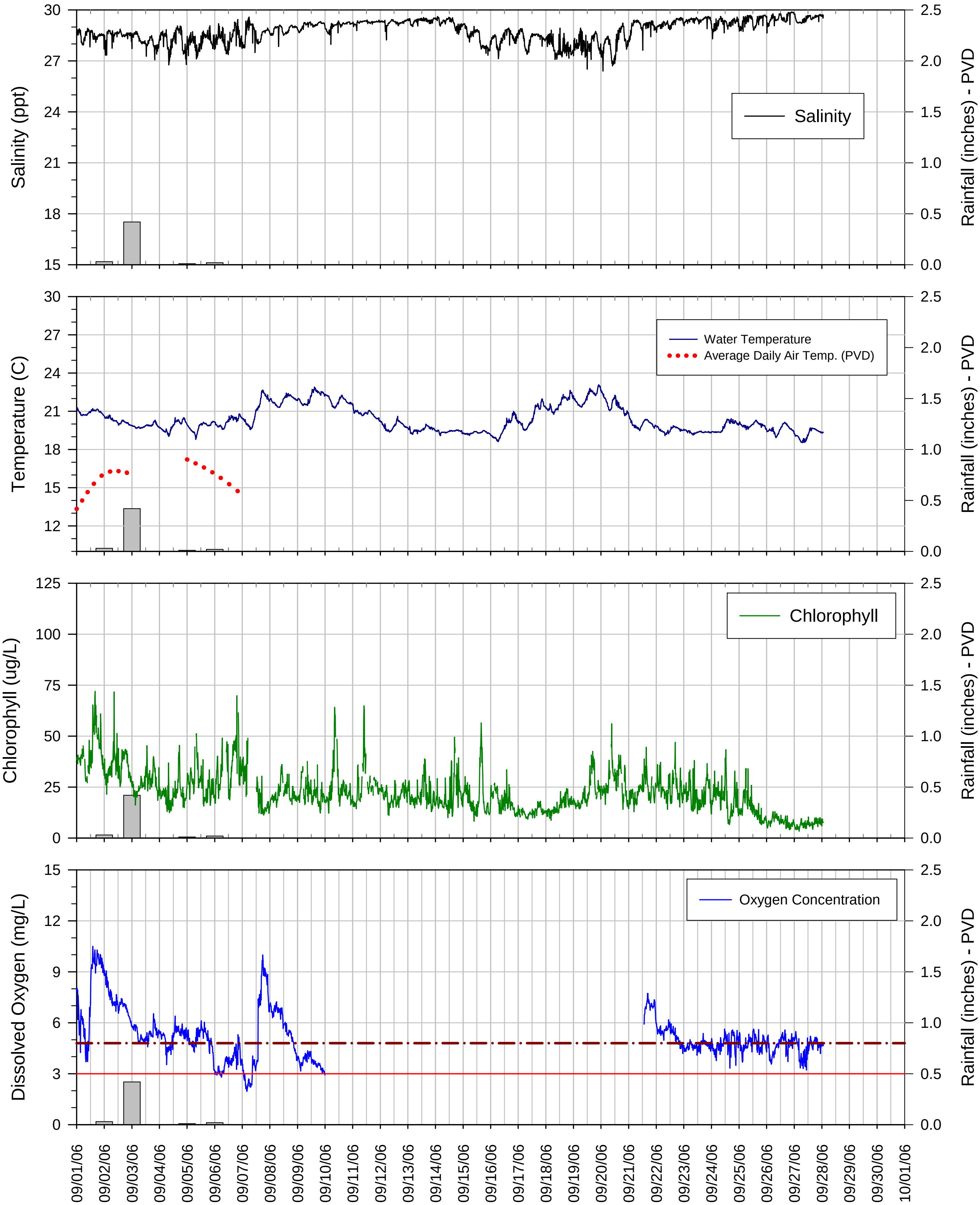



The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by RIDEM - Office of Water Resources and URI/GSO.

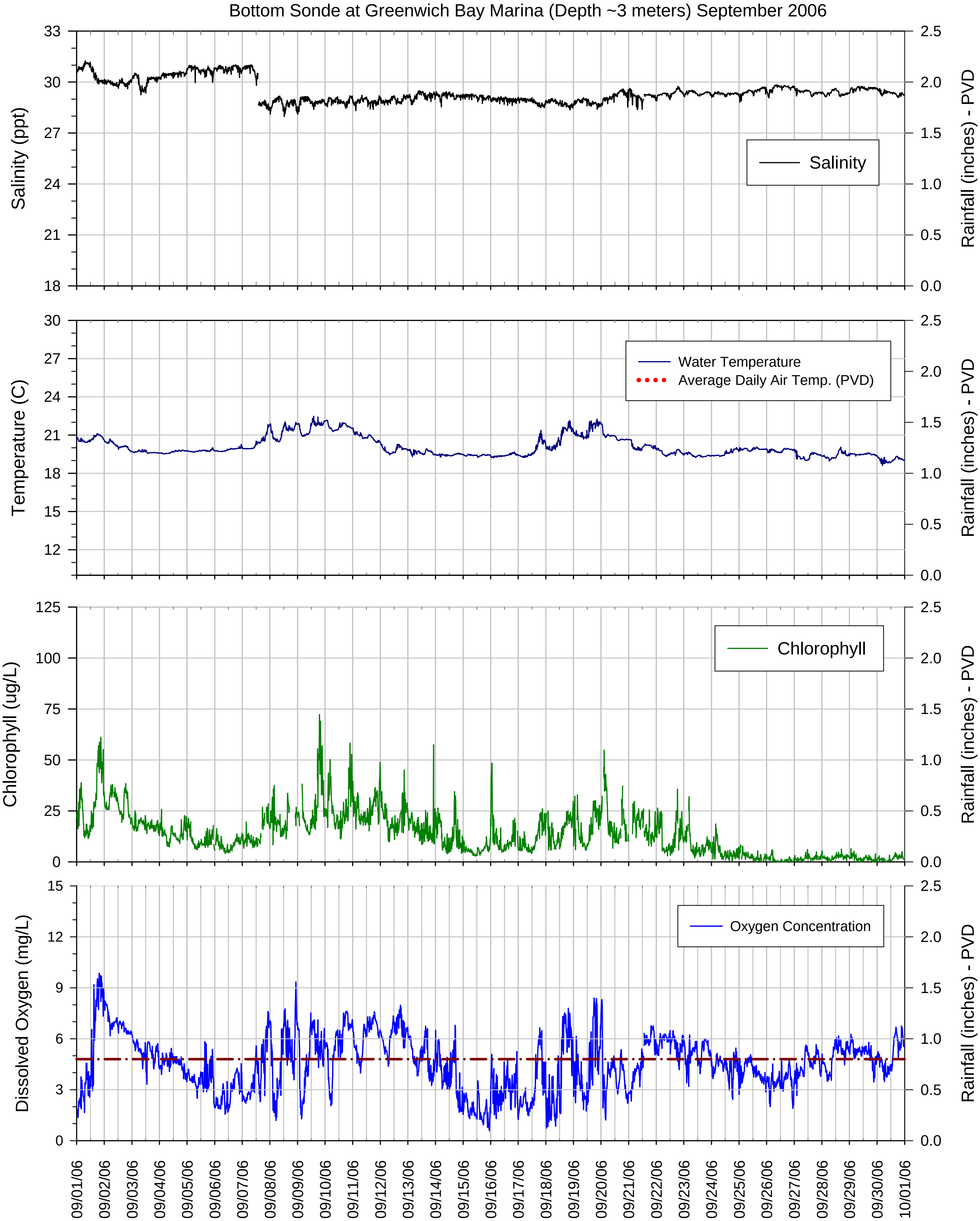



The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by RIDEM - Office of Water Resources and URI/GSO.

Surface Sonde at Greenwich Bay Marina(Depth ~1 meter) September 2006




The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by RIDEM - Office of Water Resources and URI/GSO.

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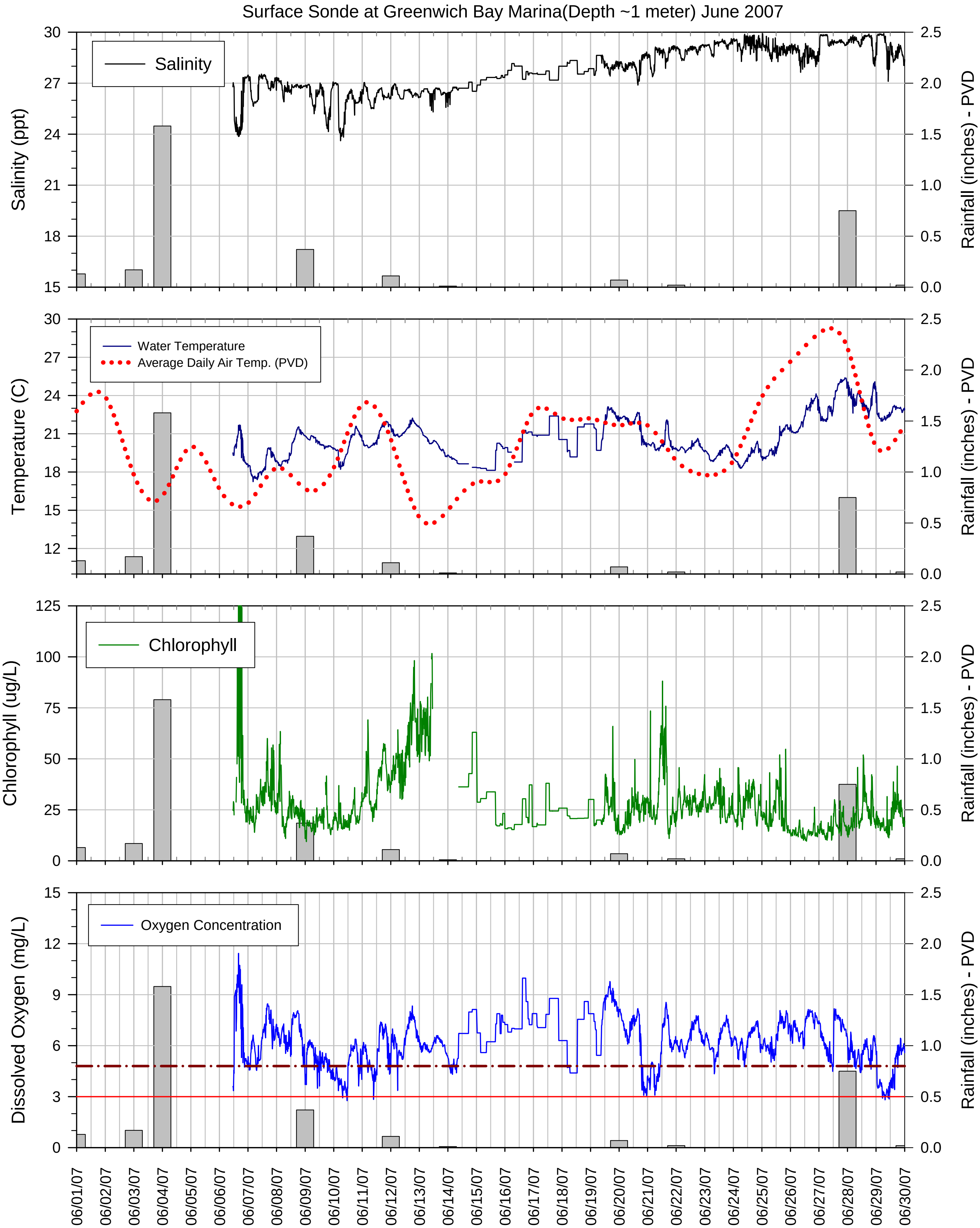
This station is maintained by RIDEM - Office of Water Resources and URI/GSO.

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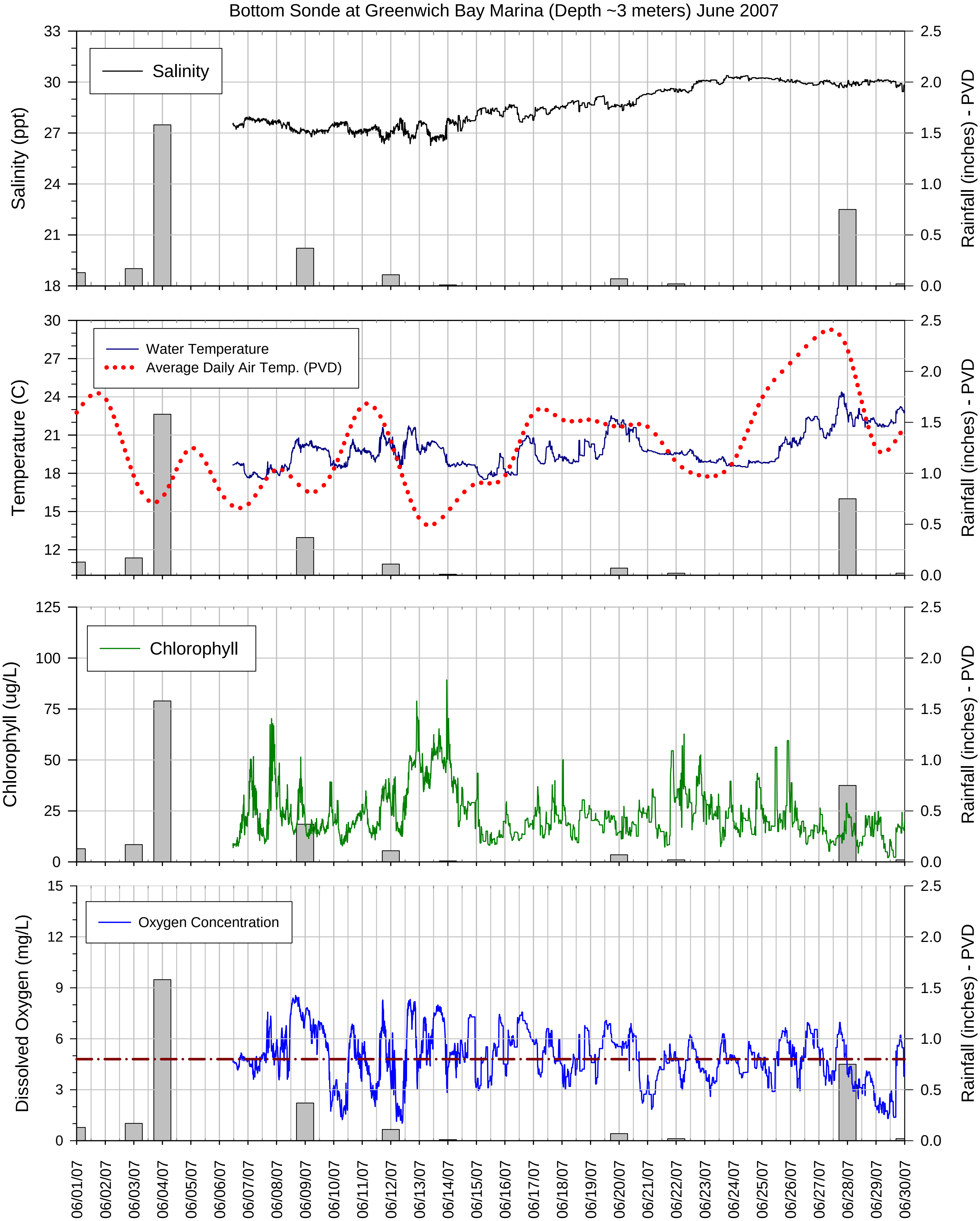


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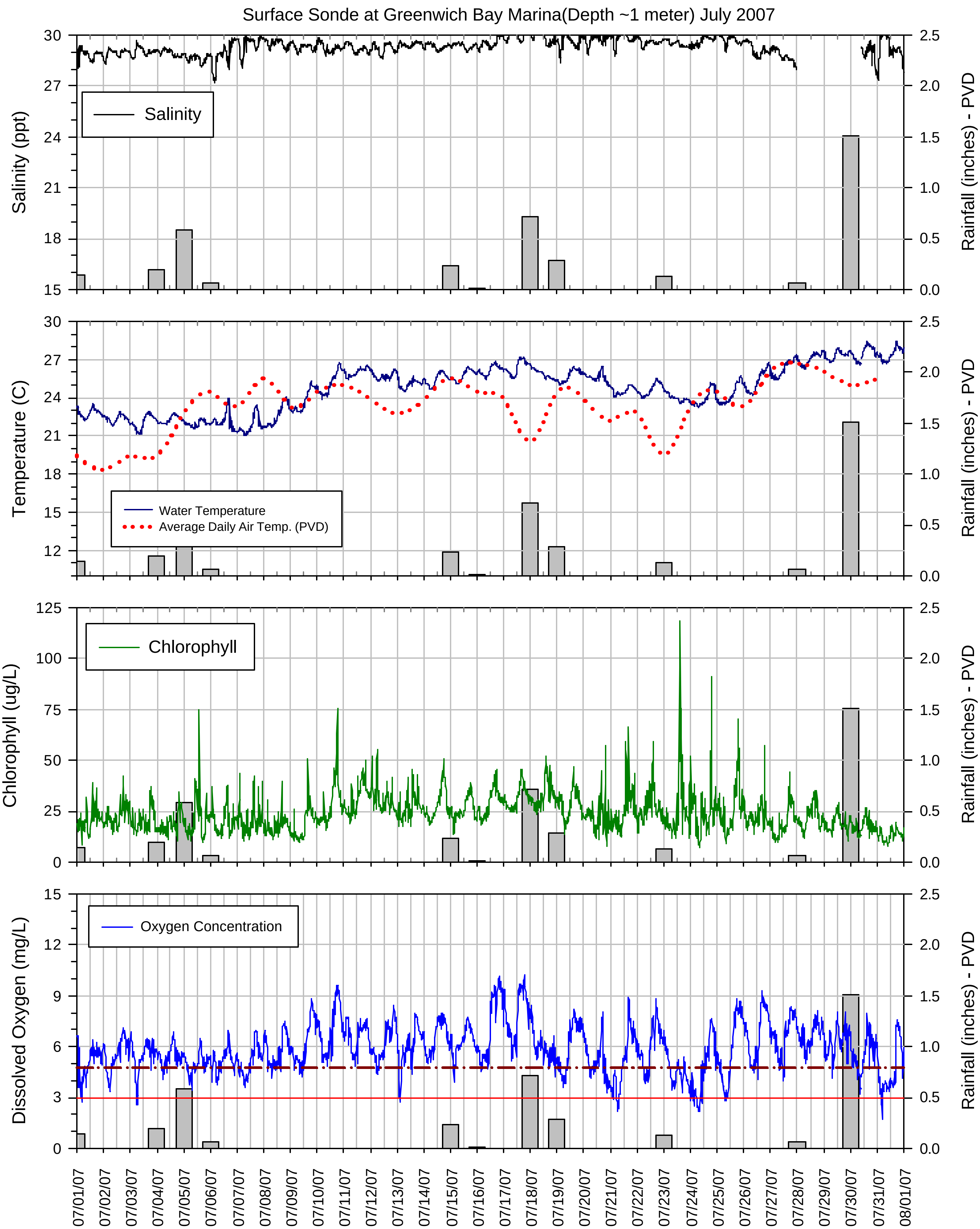
This station is maintained by RIDEM - Office of Water Resources and URI/GSO.

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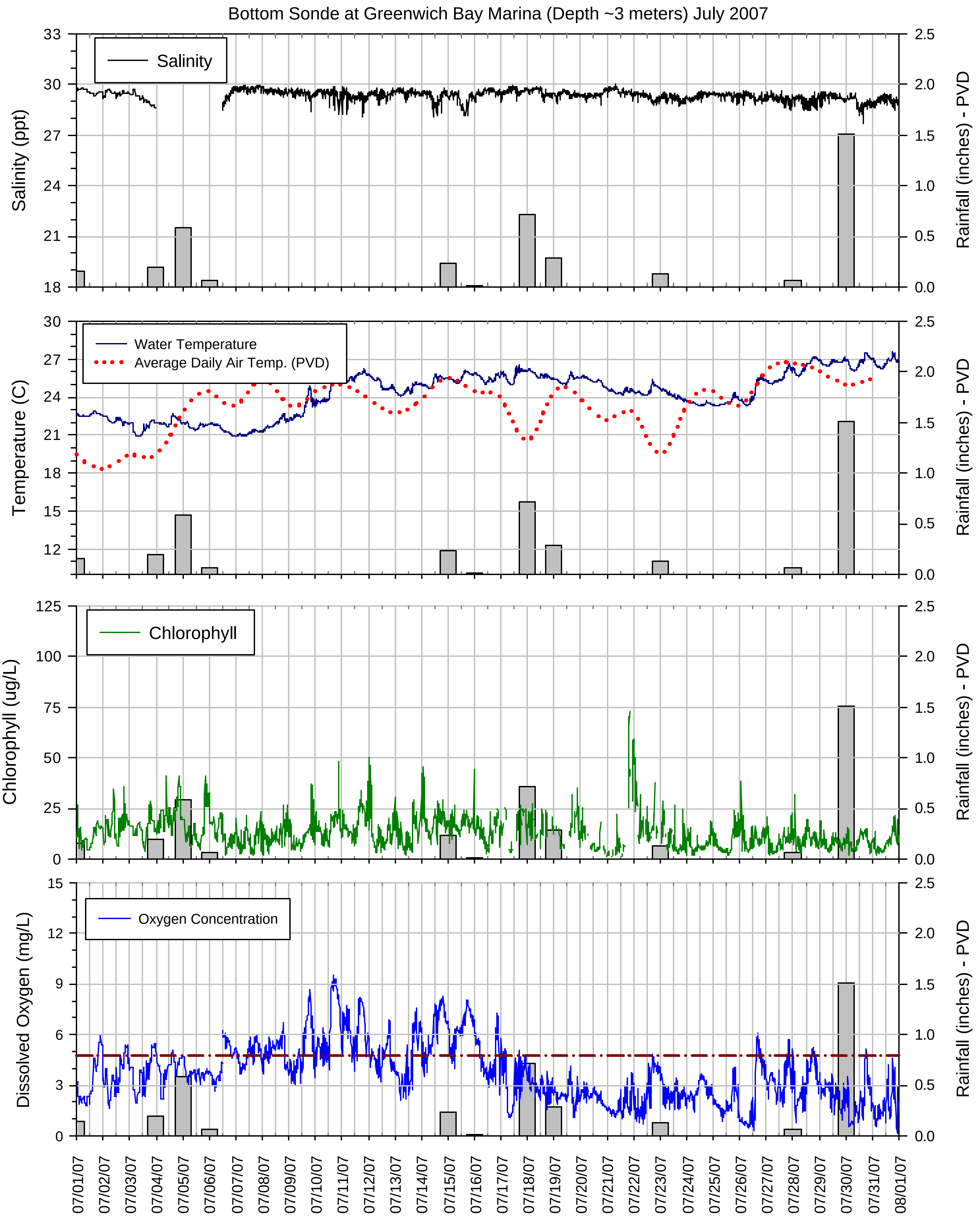


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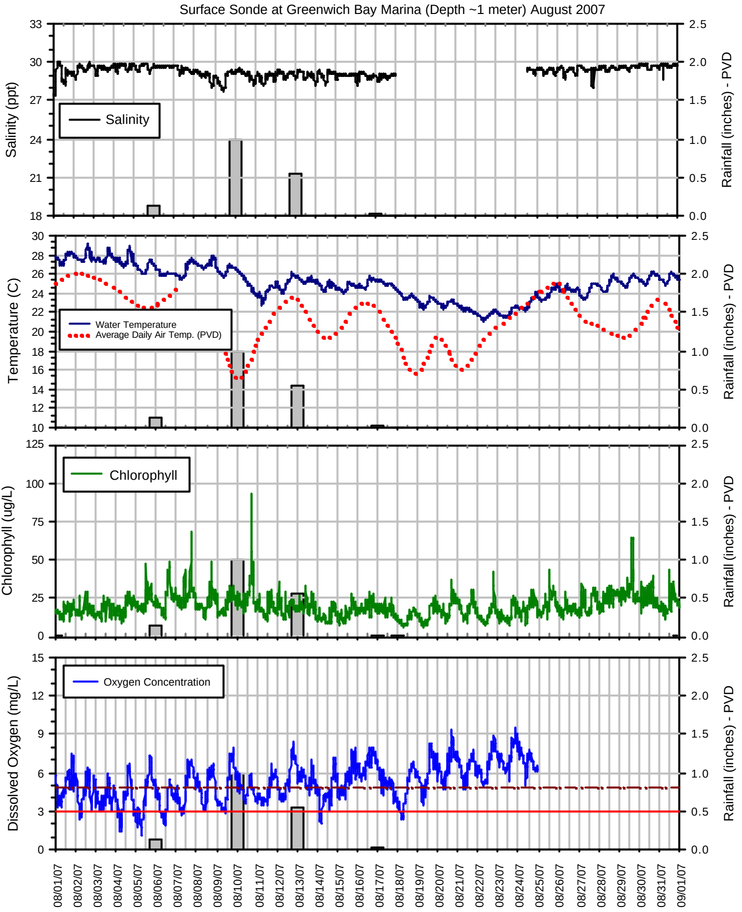
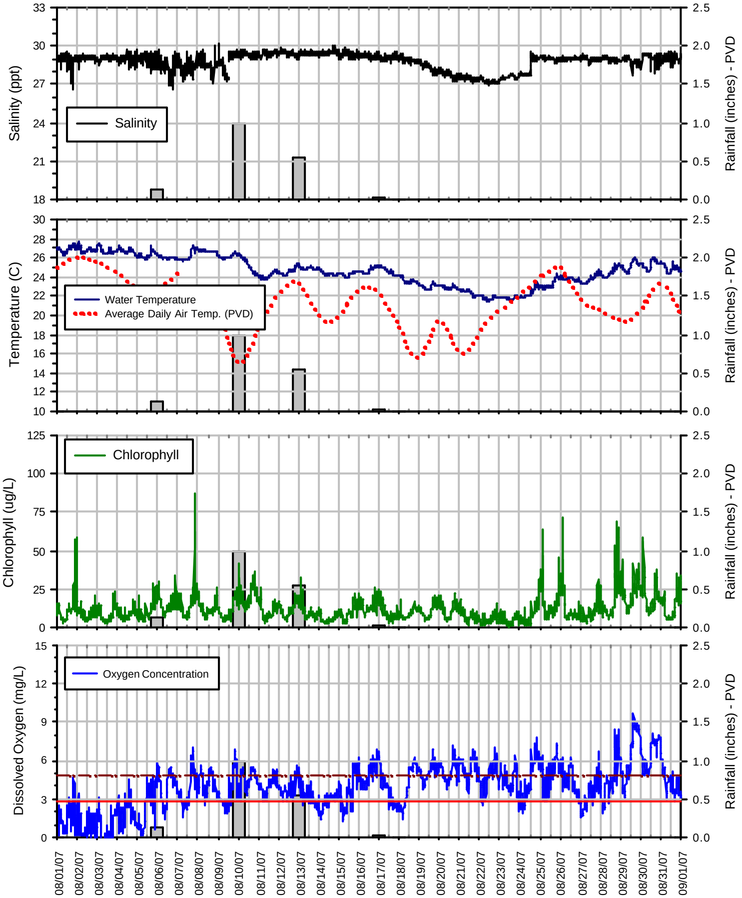
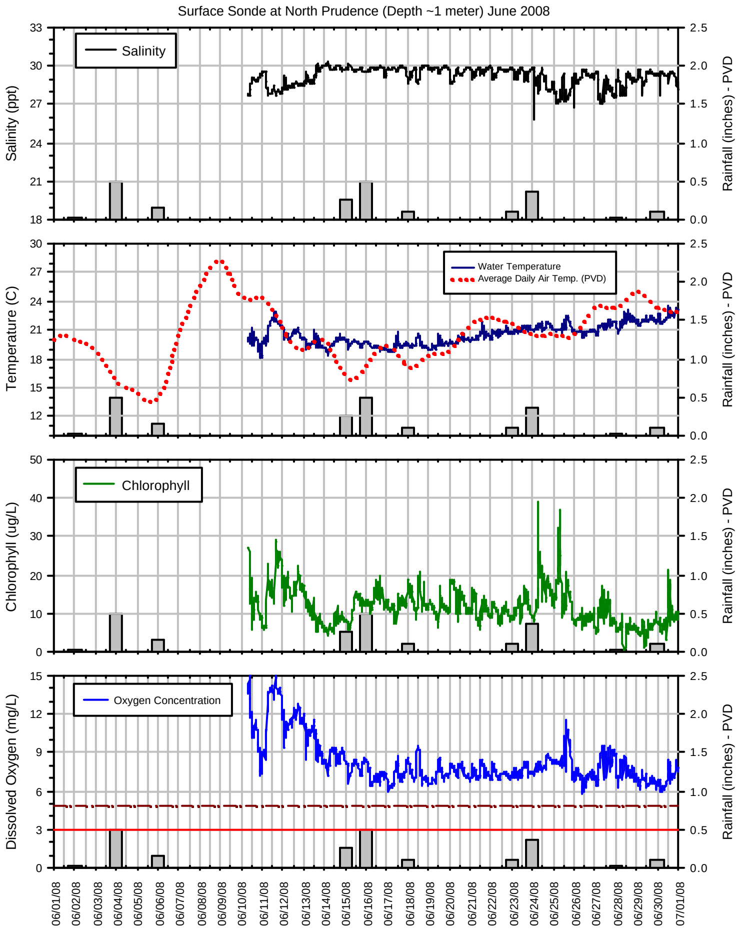



The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by RIDEM - Office of Water Resources and URI/GSO.

Bottom Sonde at Greenwich Bay Marina (Depth ~3 meters) August 2007

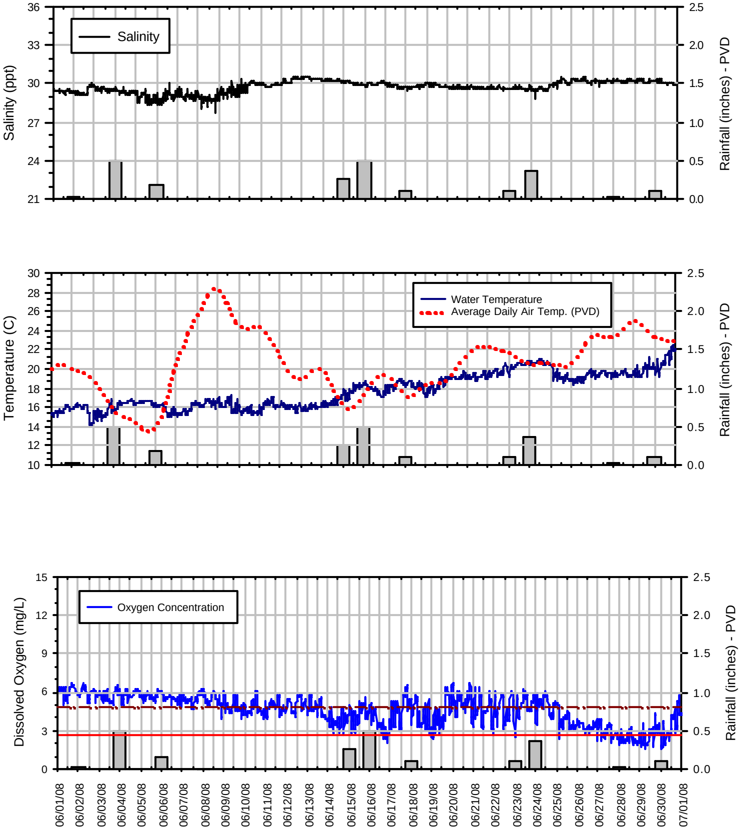



The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by RIDEM - Office of Water Resources and URI/GSO.

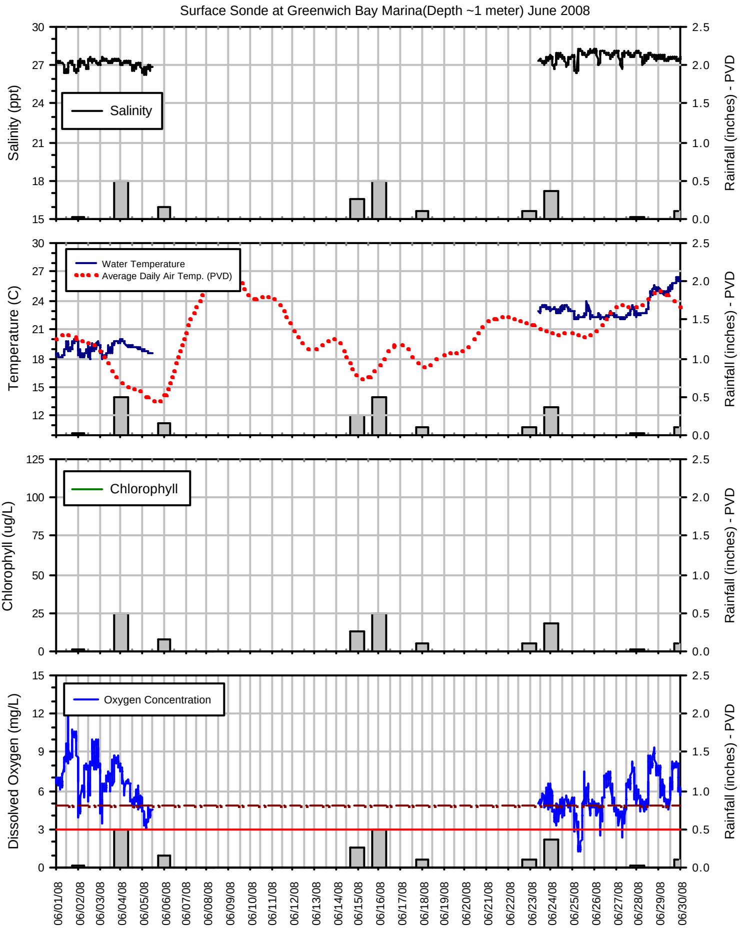



The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by RIDEM - Office of Water Resources and URI/GSO.

Bottom Sonde at North Prudence (Depth ~11 meters) June 2008

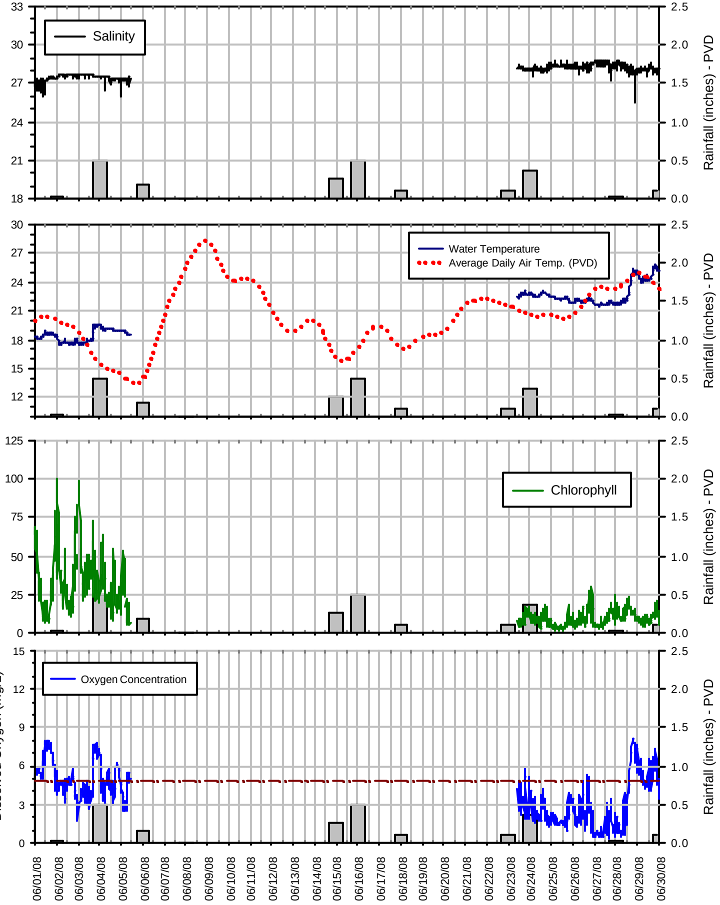



The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by RIDEM - Office of Water Resources and URI/GSO.



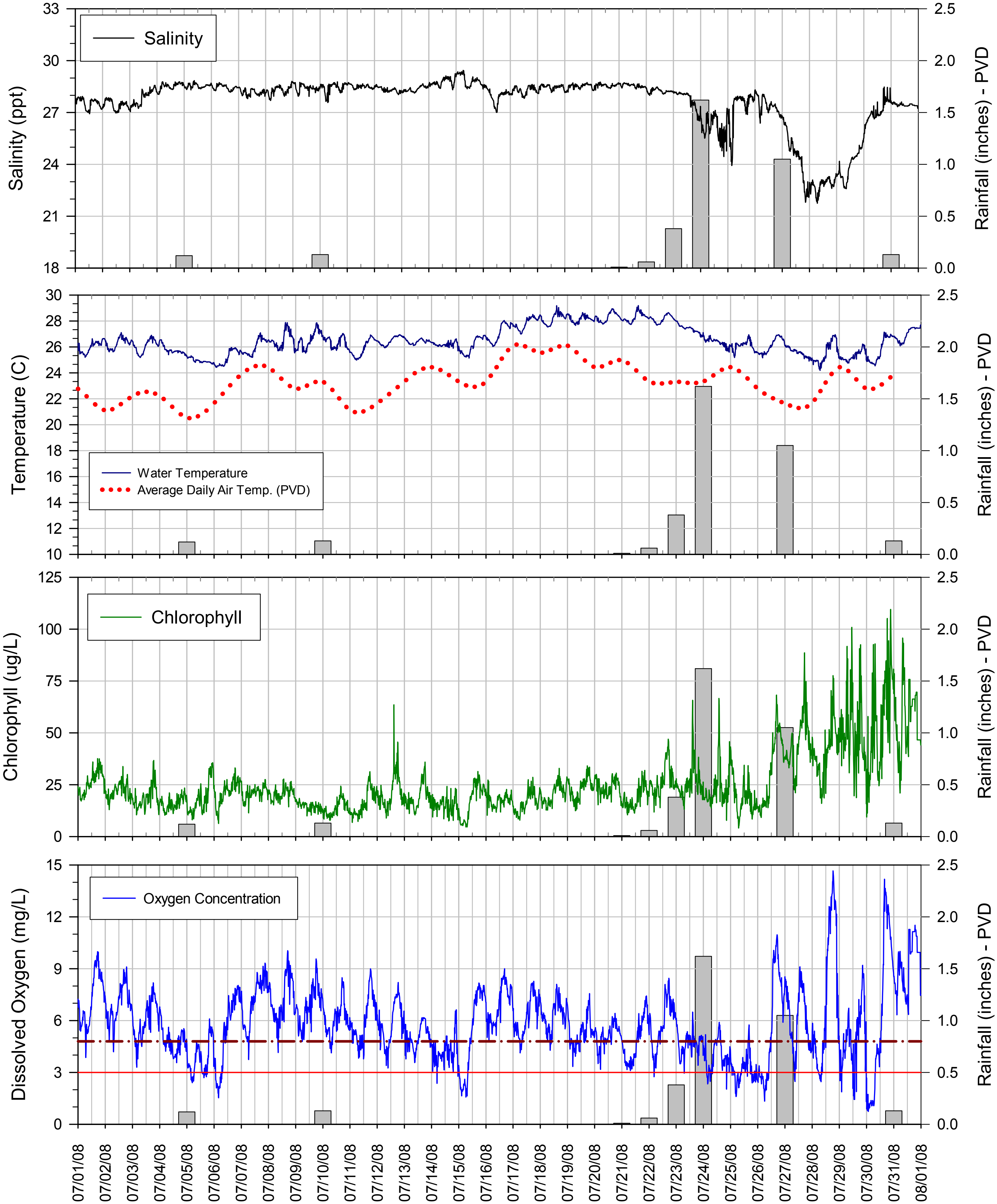

The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by RIDEM - Office of Water Resources and URI/GSO.

Bottom Sonde at Greenwich Bay Marina (Depth ~3 meters) June 2008




The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
This station is maintained by RIDEM - Office of Water Resources and URI/GSO.

Surface Sonde at Greenwich Bay Marina(Depth ~1 meter) July 2008

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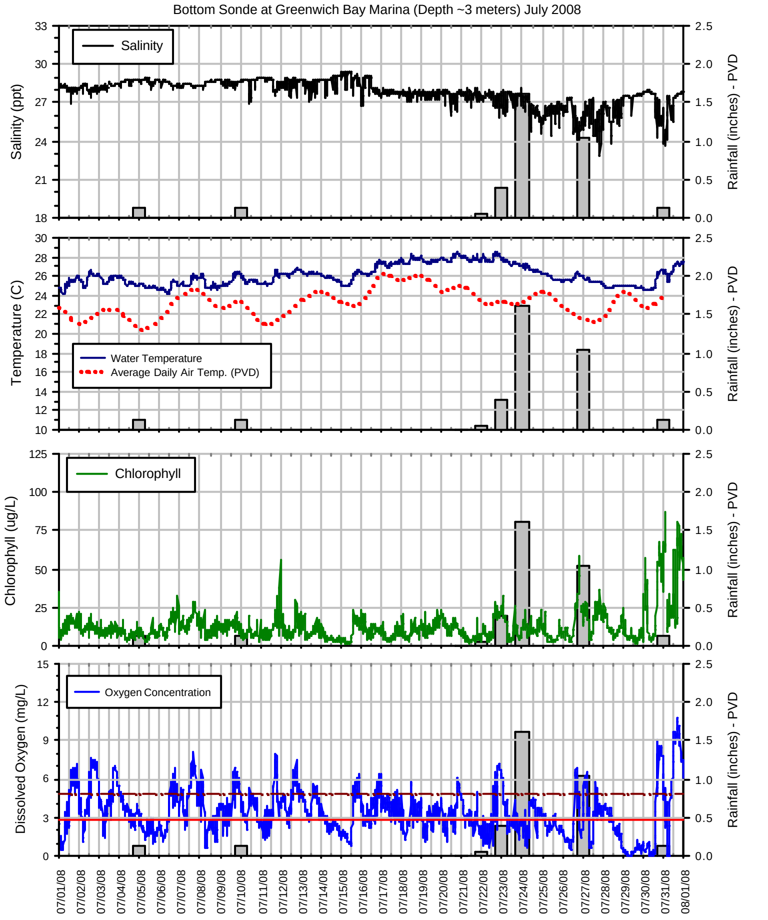
This station is maintained by RIDEM - Office of Water Resources and URI/GSO.

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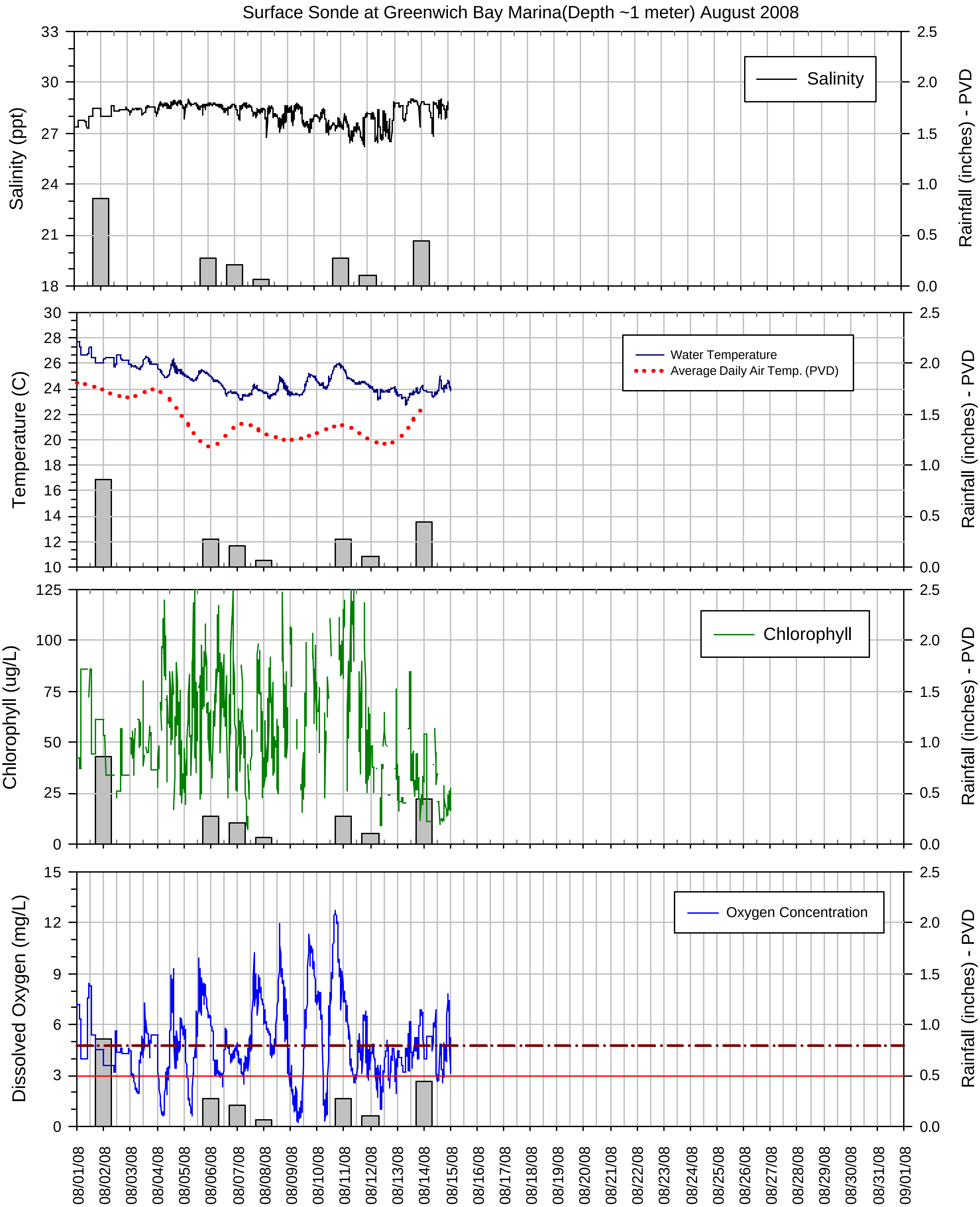
This station is maintained by RIDEM - Office of Water Resources and URI/GSO.

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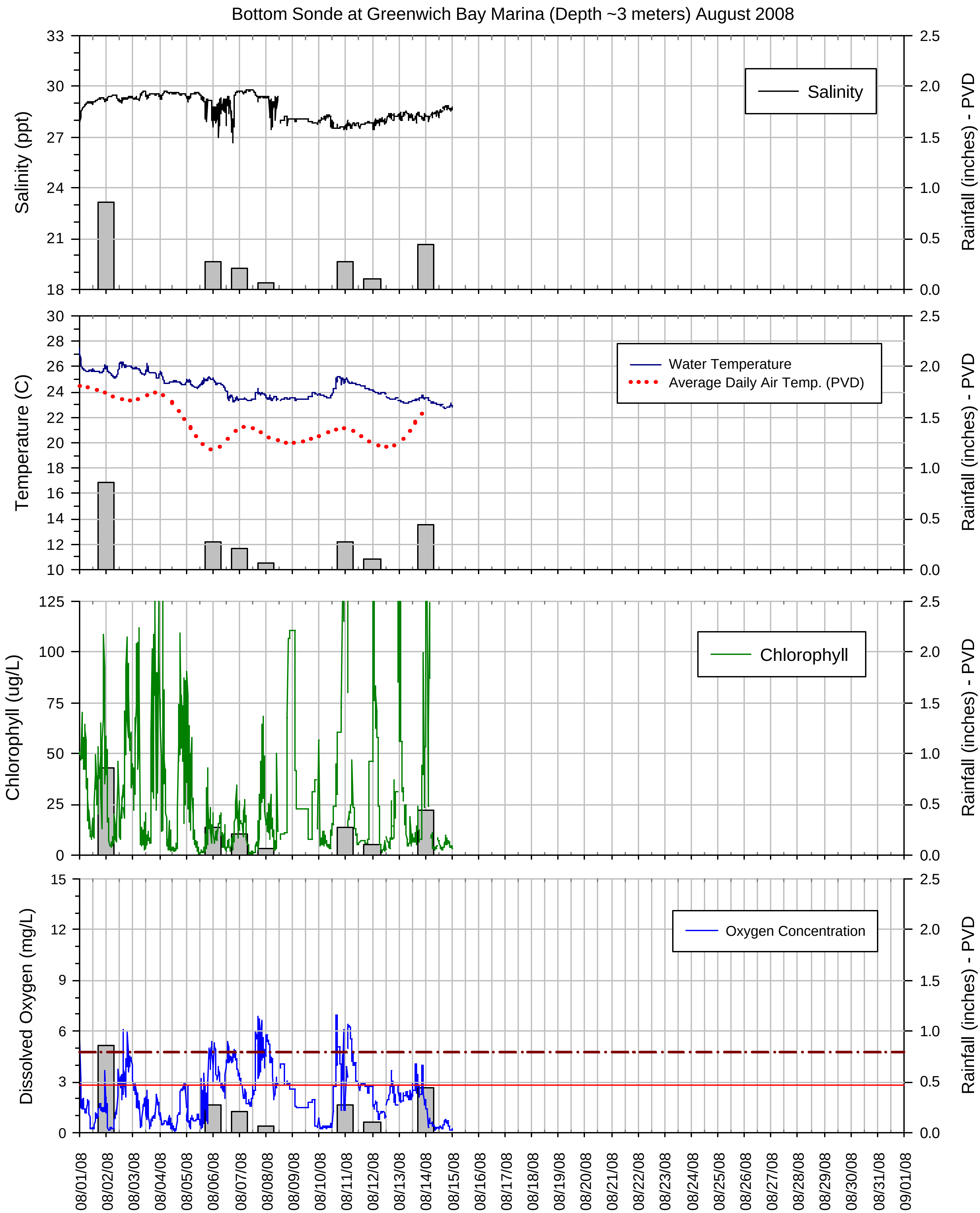


The data displayed on this chart is provisional and is subject to change based on post-season quality control analyses.
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