Water Quality of North Campus Open Space & Devereux Slough:

Fall 2015 – Spring 2016

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CCBER

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INTRODUCTION

In preparation for the North Campus Open Space (NCOS) restoration project, the Cheadle Center for Biodiversity and Ecological Restoration (CCBER) has been monitoring and studying some of the key indicators of water quality in Devereux Slough and in the streams and groundwater of the NCOS area. In this report, we summarize and discuss trends in data collected on the following water quality parameters between August 2015 to May 2016: the dissolved oxygen, chlorophyll, blue-green algae, and salinity concentrations in the slough; the dissolved oxygen and salinity in NCOS surface waters and the salinity of NCOS groundwater; and a study of the nutrient and fecal indicator bacteria concentrations in storm drain run-off entering NCOS.

GENERAL TRENDS IN DEVEREUX SLOUGH – YSI EXO1 DATA

CCBER has been monitoring several parameters of the hydrology and water quality of Devereux Slough by collecting data continuously with a YSI EXO1 sonde. In addition to the water level, the sonde is equipped with sensors that record conductivity/salinity and temperature, dissolved oxygen, pH, and chlorophyll and blue-green algae. The sonde is deployed in the main channel of the slough, at the location of the "pier" (what used to be a bridge). It is secured to the pier deck with a stainless steel cable, and is housed in an open-bottom, perforated PVC pipe that is anchored to a pile on the south side of the pier (Figure 1). The bottom of the sonde is estimated to rest at approximately one foot above the floor of the slough.

The sonde records all parameters every 15 minutes. To download the data, replace the batteries, and clean and calibrate the sonde, it is removed from the slough every 6 to 8 weeks, which usually results in a 4 to 24-hour gap in the data. This is scheduled to occur when there is no rainfall or other events that could affect the water quality data. In the following two sections we report and discuss some of the trends in the dissolved oxygen (DO), chlorophyll (CP), blue-green algae (BGA), and salinity data recorded by the sonde from August 2015 to May 2016.

DISSOLVED OXYGEN, CHLOROPHYLL & BLUE-GREEN ALGAE

Apart from some potential anomalies, the general trends in the DO, CP and BGA concentrations in Devereux Slough were as expected. From mid-summer through to late autumn, DO and CP concentrations remained primarily within in the ranges considered by the EPA to indicate poor water quality (Table 1). This is primarily a consequence of the dry season in summer and autumn, during which there is typically no flow of water into the slough, and the existing water volume decreases to a low level due to evaporation. With cooler temperatures and rainfall in late autumn, winter and spring, DO, and eventually CP, improved to within the EPA's fair and good quality ranges. BGA followed trends similar to CP, and the data also contained a few lengthy periods with zero DO, which may have been a malfunction in the YSI sensor. The following paragraphs describe these trends in further detail.

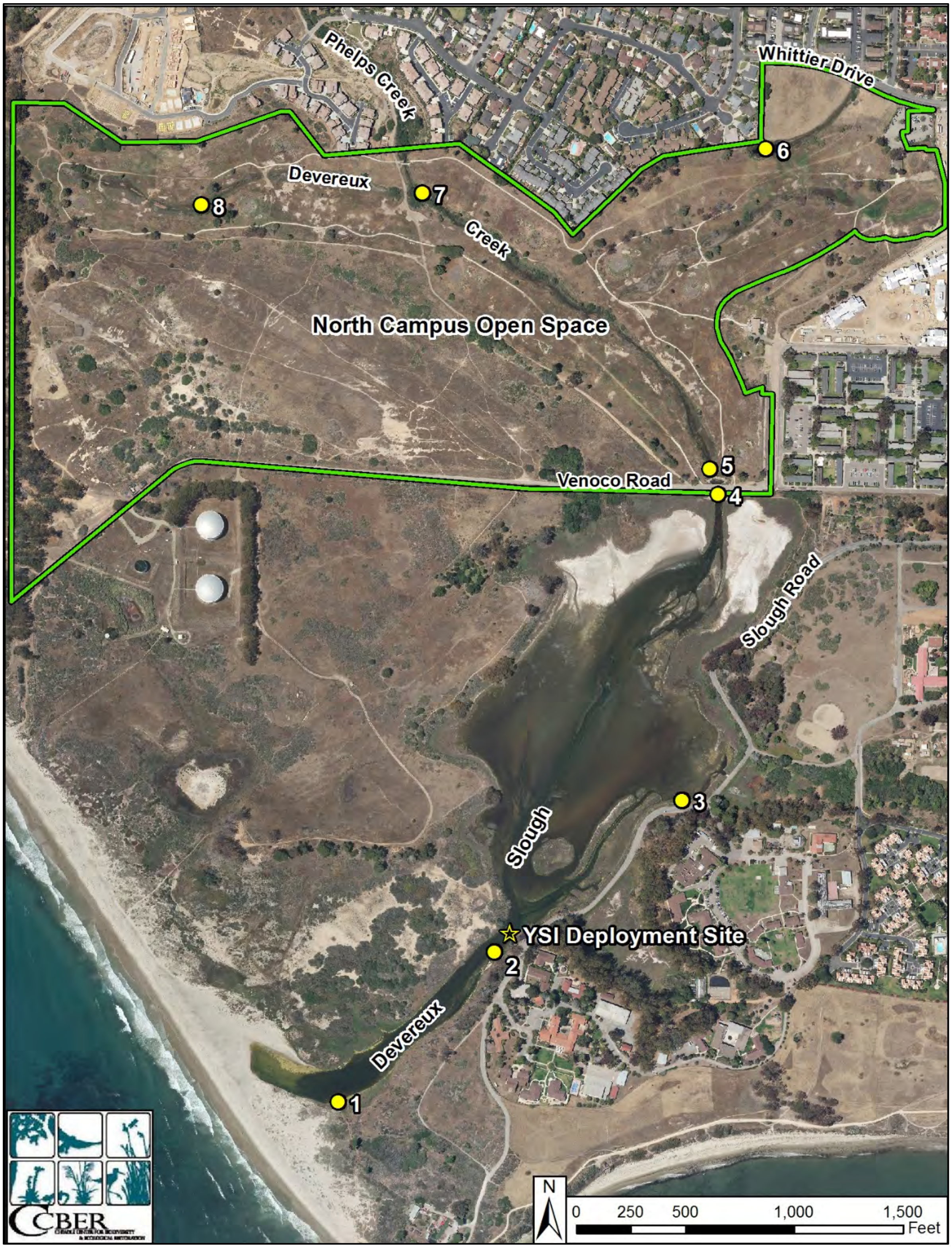


Figure 1. Map of the dissolved oxygen and salinity sampling sites in Devereux Slough and North Campus Open Space. The star indicates the deployment site of the YSI EXO1 sonde in the slough.

Table 1. The US Environmental Protection Agency (EPA) threshold limits for Dissolved Oxygen and Chlorophyll *a* in the assessment of Poor, Fair and Good water quality (EPA 2012a).

Water Quality Indicators	**Poor Quality**	**Fair Quality**	**Good Quality**
Dissolved Oxygen	< 2 mg/L	2 - 5 mg/L	> 5 mg/L
Chlorophyll *a*	> 20 ug/l	5.0 - 20 ug/l	< 5.0 ug/l

From August to November 2015, DO remained very low to zero. A 10°C drop in water temperature in early November appeared to lead to a rise in DO, which then fluctuated around 6 mg/L into December (Figure 2). CP and BGA concentrations tended to be relatively high during this period, with some particularly large and rapid changes in CP concentration. For example, on the morning of September 29, CP increased from an overnight low of 15 ug/L to more than 200 ug/L. BGA also rapidly increased from less than 1 to 7 ug/L, and pH increased 1 point, from 7.5 to 8.5 (Figure 2). The cause of the rapid and large increases in CP is unclear. Climate data from the ERI weather station does not suggest a possible association with changes in atmospheric pressure, wind speed or direction. Tidal data (obtained from NOAA) suggests that a series of relatively higher than average tides in late September may have caused a small amount of spill over into the slough that could possibly have forced higher pH, CP and BGA water down to the level of the YSI sensor. In contrast, CP and BGA decreased sharply following 13 mm of rainfall on October 4. The amount of rain appears to have been enough to add and mix fresh, clear water into the deeper areas of the water column. An increase in DO would have been expected from the same rain event; yet, DO decreased and remained at zero for a month until the temperature dropped in early November.

In winter, DO continued to average around 5 mg/L, and CP and BGA concentrations increased until January 6, when the slough breached and emptied into the ocean following two consecutive days of high rainfall, tides and surf (Figures 3 and 4). This caused CP and BGA to rapidly drop to low concentrations (near or less than 2 ug/L), and DO increased from 1 to 8 mg/L. Over seven days, the slough remained tidally connected with the ocean, and DO fluctuated between 4 to 8 mg/L in conjunction with the tidal flux (Figure 4). Within a few days after the slough became closed to the ocean, DO dropped to and remained at zero until March. CP and BGA concentrations increased slightly after the breach event, partly due to the increased DO and probably the influx of nutrients from the rainfall run-off (see the Nutrients section of this report), but concentrations then dropped and stabilized at low levels through February and into March (Figures 3 and 5). Temperature and pH were also very stable from late January into March, and, surprisingly, no parameters were affected by the relatively high rainfall (third largest amount of the entire rain season) on January 31 (Figure 3).

DO rose from zero to 8 mg/L following a second breach event on March 6, then again dropped to zero about 1 week later (Figures 5 and 6). At the end of March, DO concentrations began to rise above zero and fluctuated primarily with temperature, most notably in late April (Figure 5). CP and BGA concentrations remained low until late March, when they both increased (particularly CP). After rainfall in early April, CP and BGA rapidly decreased, then fluctuated similarly to DO into May (Figure 5).

The long periods of zero DO (*e.g*. January 20 to March 6) could potentially be due to malfunctioning of the sensor on the YSI EXO1 sonde. DO data collected by hand with a portable YSI Pro 2030 (described in the next section of this report) supports this by showing that, between January 24 to April 29, DO concentrations near the bottom of the water column at sampling site 2 (the site closest to the YSI EXO1 deployment site) ranged from 2 to 10 mg/L. The period from late January to early March, when there was almost no change in any parameter, even after a couple of rainfall events, also suggests a malfunction in the YSI EXO1 sonde. Subsequently, in mid-May, we determined that the YSI sonde needed to be submitted for repair.

SALINITY

The overall trend in salinity also followed our expectations. The salinity near the bottom of the central, main channel of the slough, as recorded by the YSI EXO1 sonde, was relatively high throughout the fall. As the water level in the slough gradually decreased from evaporation, the salinity increased from 50 to more than 60 parts per thousand (ppt), and eventually decreased to approximately 55 ppt when water temperatures began to decline in November (Figure 7). From fall into winter, the salinity remained above 50 ppt until early January 2016, when two consecutive days of high rainfall, coupled with high tides and surf, led to a rapid increase in the amount of water in the slough and, consequently, a breach that resulted in a tidal connection and fluctuation with the ocean for about seven days (Figure 8a).

During the initial breach of the slough into the ocean, the salinity rapidly decreased to as low as 3 ppt due to the fresh surface water reaching the YSI sensor. Six hours later, at high tide, the influx of sea water raised the salinity above 30 ppt, and after some subsequent minor fluctuation, it stabilized near the average sea water salinity of 35 ppt (Figure 8b). A second, shorter breach and tidal fluctuation event between March 6th and 8th, 2016 also resulted in a brief, sharp fluctuation in salinity down to 14 ppt and back to 34 ppt, after which the salinity remained fairly stable around 30 ppt into May (Figure 9).

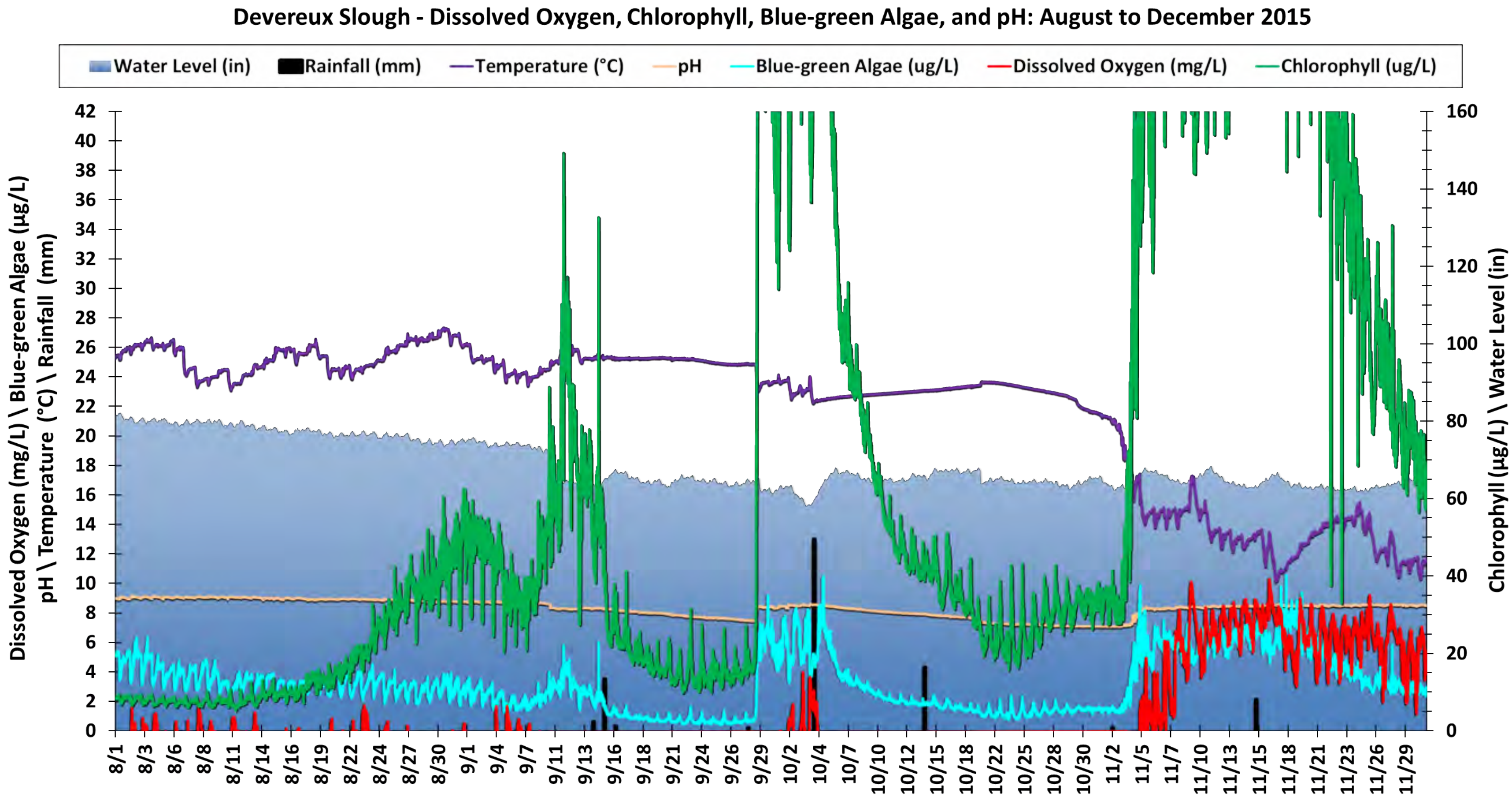


Figure 2. The dissolved oxygen (mg/L), chlorophyll (µg/L), blue-green algae (µg/L), pH, temperature (°C) and water level (in inches) in Devereux Slough between August 1 and November 30, 2015. The data were recorded by a YSI EXO1 sonde deployed approx. 1 foot above the bottom of the main channel of Devereux Slough (see Figure 1). Rainfall (mm) data were recorded by the meteorological station on the roof of Ellison Hall at the UCSB campus.

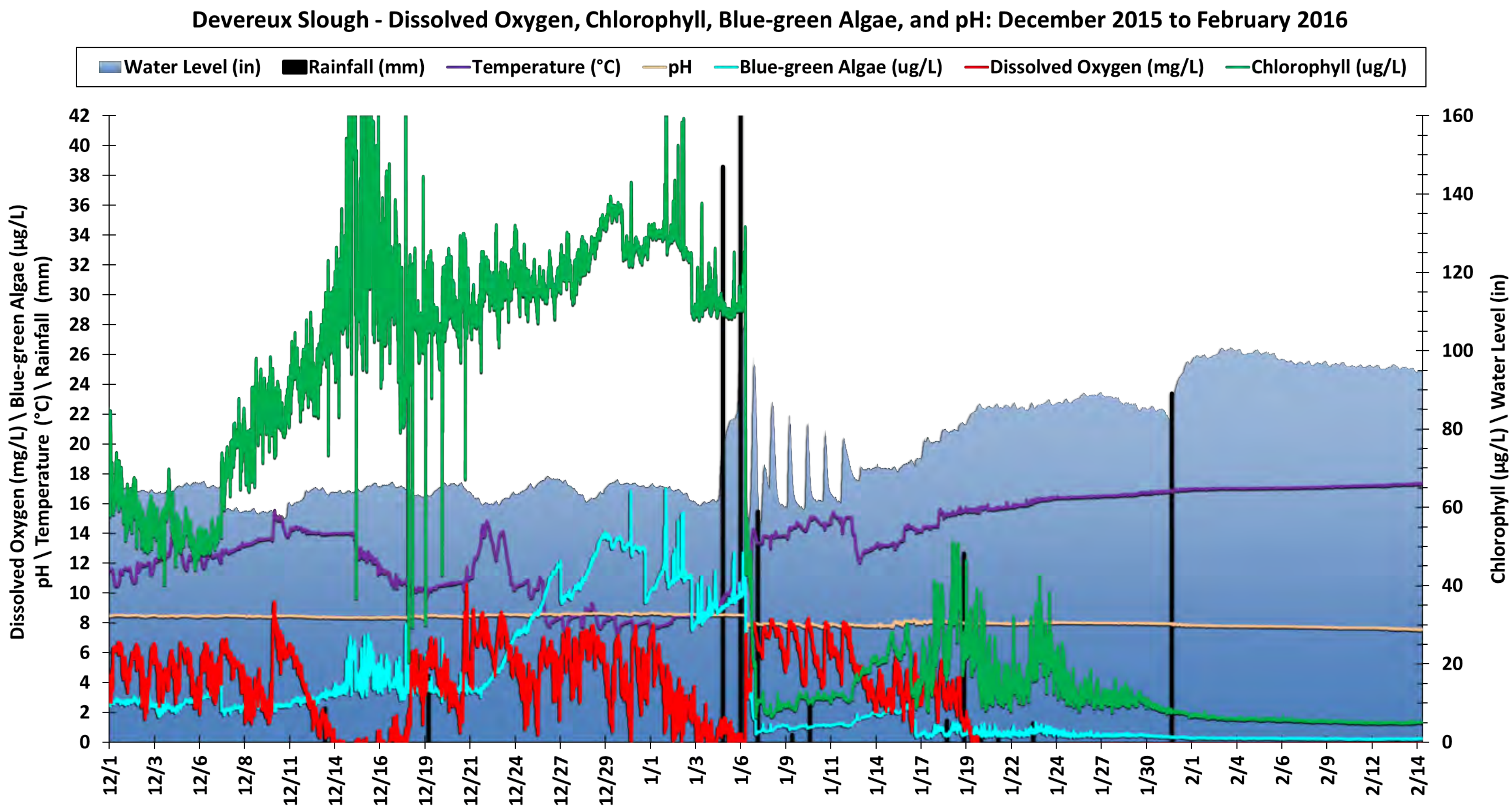


Figure 3. The dissolved oxygen (mg/L), chlorophyll (µg/L), blue-green algae (µg/L), pH, temperature (°C) and water level (in inches) in Devereux Slough between December 1, 2015 and February 14, 2016. The data were recorded by a YSI EXO1 sonde deployed approx. 1 foot above the bottom of the main channel of Devereux Slough (see Figure 1). Rainfall (mm) data were recorded by the meteorological station on the roof of Ellison Hall at the UCSB campus.

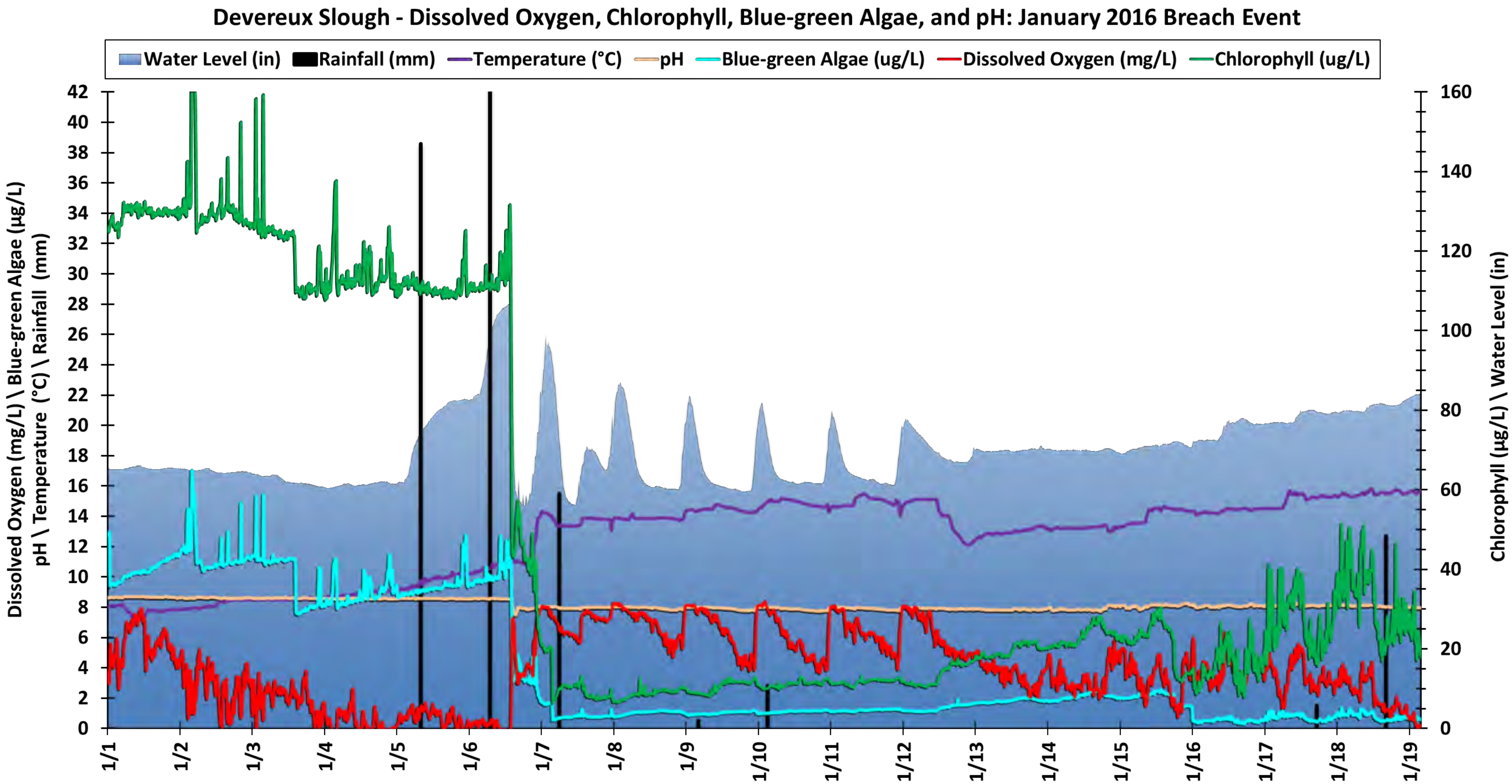


Figure 4. The dissolved oxygen (mg/L), chlorophyll (µg/L), blue-green algae (µg/L), pH, temperature (°C) and water level (in inches) in Devereux Slough during a winter storm and breach event in January 2016. The data were recorded by a YSI EXO1 sonde deployed approx. 1 foot above the bottom of the main channel of Devereux Slough (see Figure 1). Rainfall (mm) data were recorded by the meteorological station on the roof of Ellison Hall at the UCSB campus.

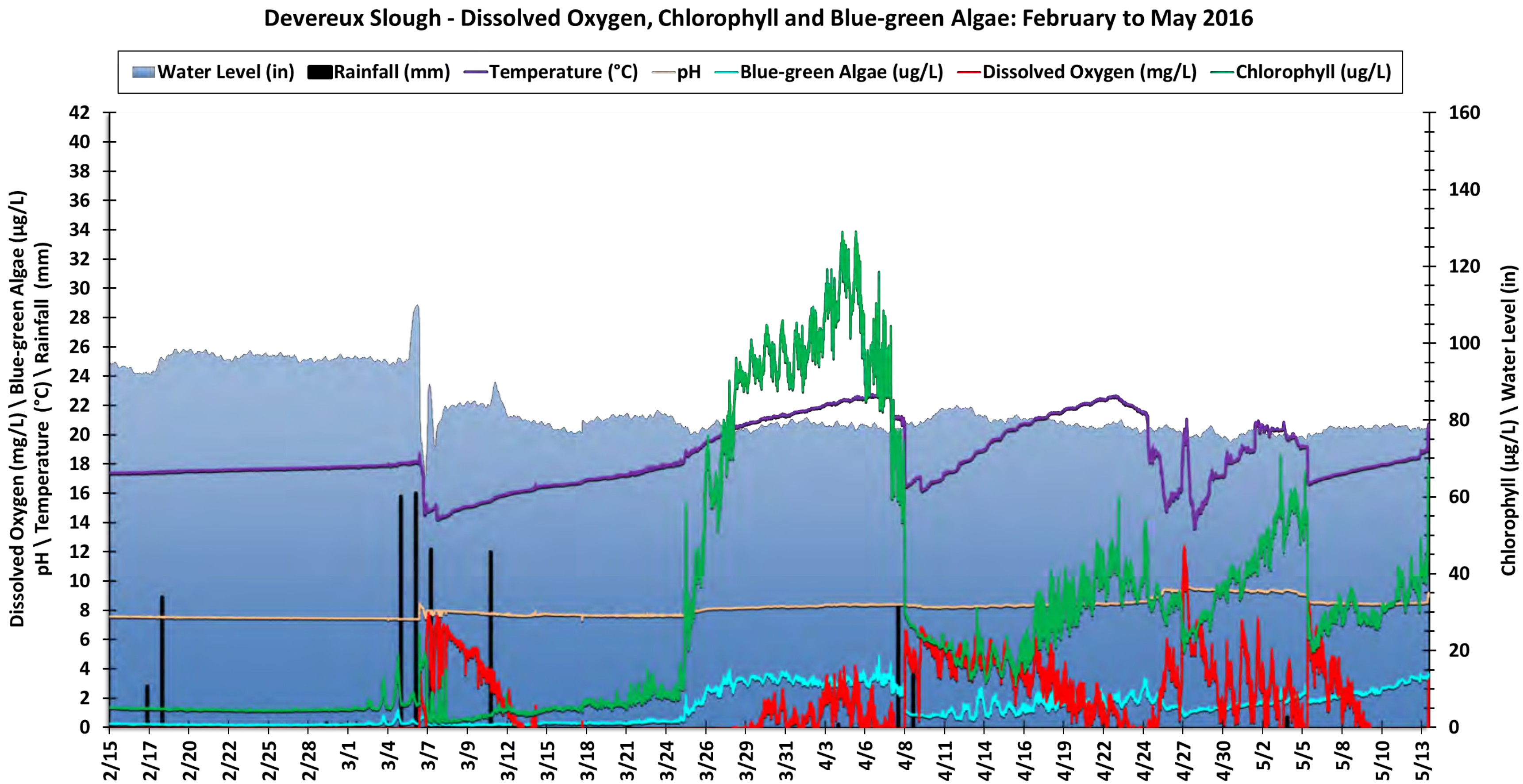


Figure 5. The dissolved oxygen (mg/L), chlorophyll (µg/L), blue-green algae (µg/L), pH, temperature (°C) and water level (in inches) in Devereux Slough between February 15 to May 13, 2016. The data were recorded by a YSI EXO1 sonde deployed approx. 1 foot above the bottom of the main channel of Devereux Slough (see Figure 1). Rainfall (mm) data were recorded by the meteorological station on the roof of Ellison Hall at the UCSB campus.

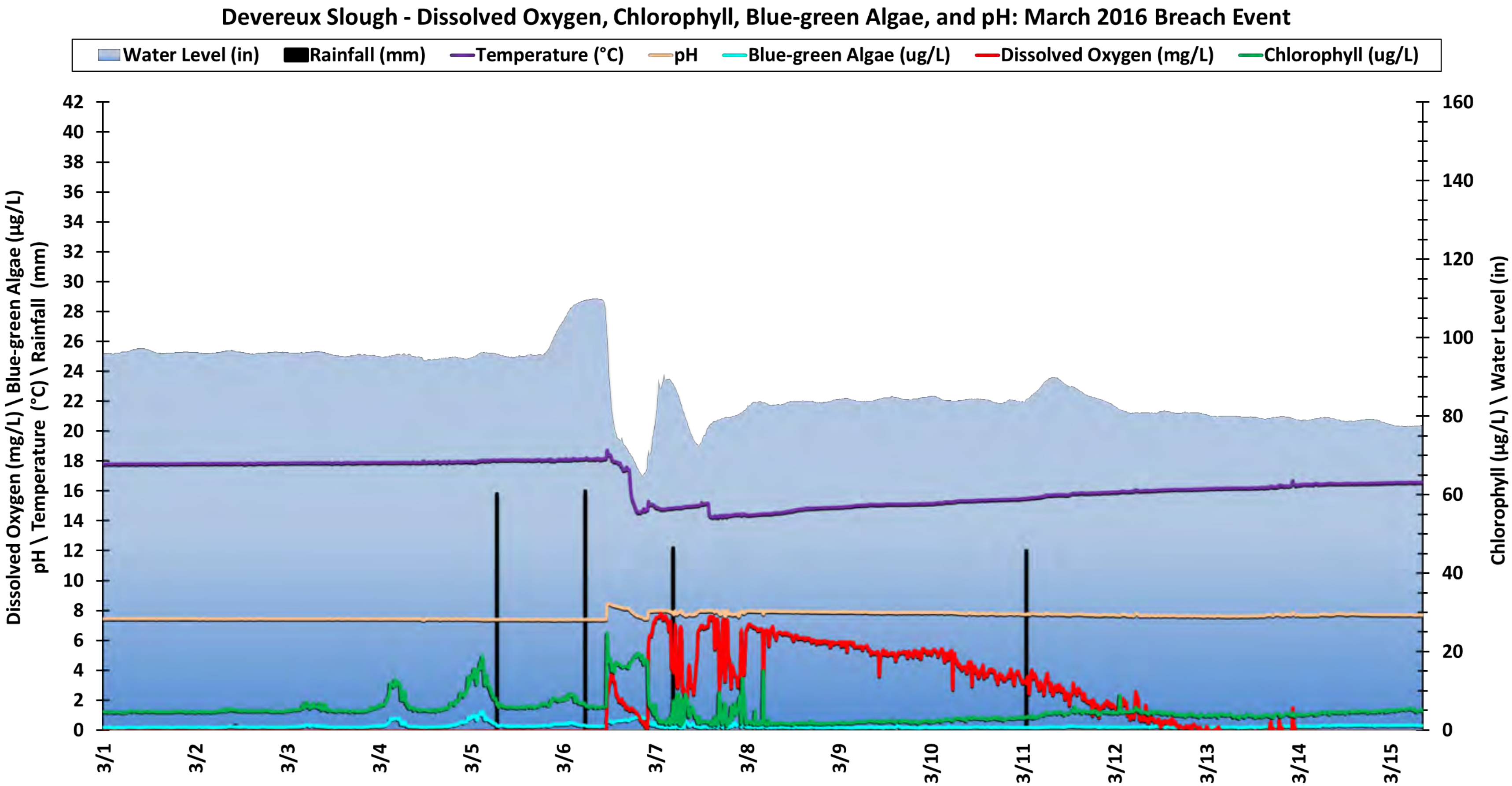


Figure 6. The dissolved oxygen (mg/L), chlorophyll (µg/L), blue-green algae (µg/L), pH, temperature (°C) and water level (in inches) in Devereux Slough during a winter storm and breach event in March 2016. The data were recorded by a YSI EXO1 sonde deployed approx. 1 foot above the bottom of the main channel of Devereux Slough (see Figure 1). Rainfall (mm) data were recorded by the meteorological station on the roof of Ellison Hall at the UCSB campus.

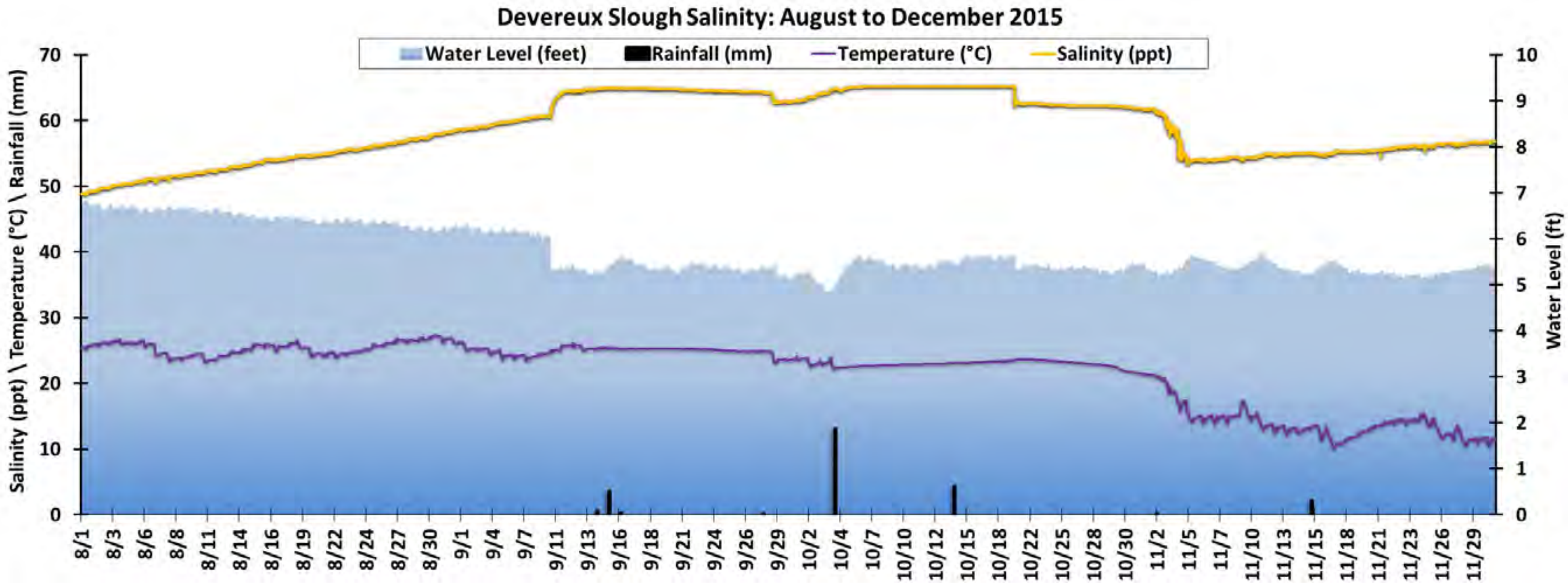


Figure 7. The salinity (in parts per thousand, ppt), temperature (°C) and water level (feet) in Devereux Slough between August 1 and November 30, 2015. The data were recorded by a YSI EXO1 sonde deployed approx. 1 foot above the bottom of the main channel of Devereux Slough (see Figure 1). Rainfall (mm) data were recorded by the meteorological station on the roof of Ellison Hall at the UCSB campus.

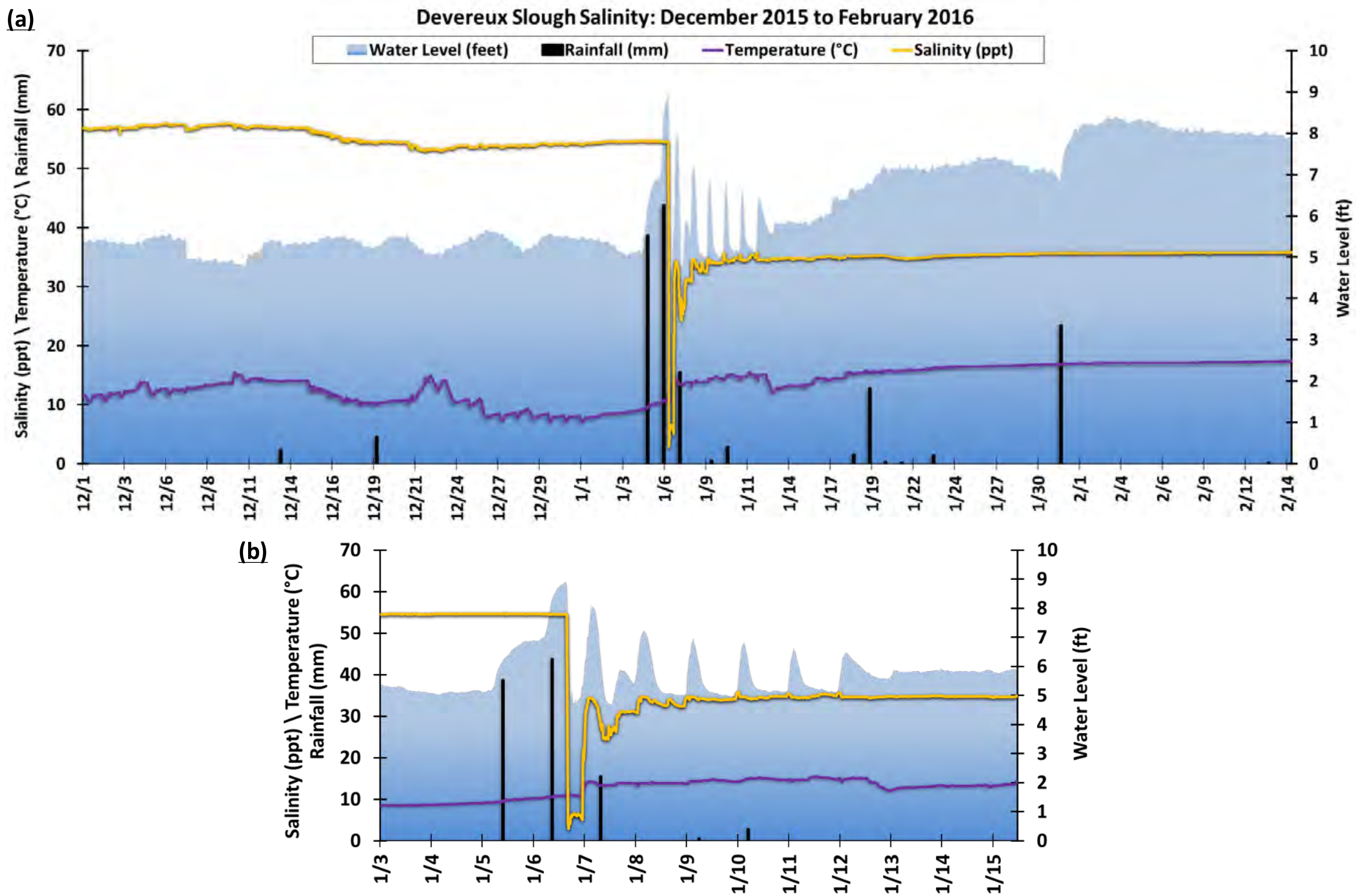


Figure 8. (a) The salinity (in parts per thousand, ppt), temperature (°C) and water level (feet) in Devereux Slough between December 1, 2015 and February 14, 2016, and **(b)** during a winter storm and breach event in January, 2016. The data were recorded by a YSI EXO1 sonde deployed approx. 1 foot above the bottom of the main channel of Devereux Slough (see Figure 1). Rainfall (mm) data were recorded by the meteorological station on the roof of Ellison Hall at the UCSB campus.

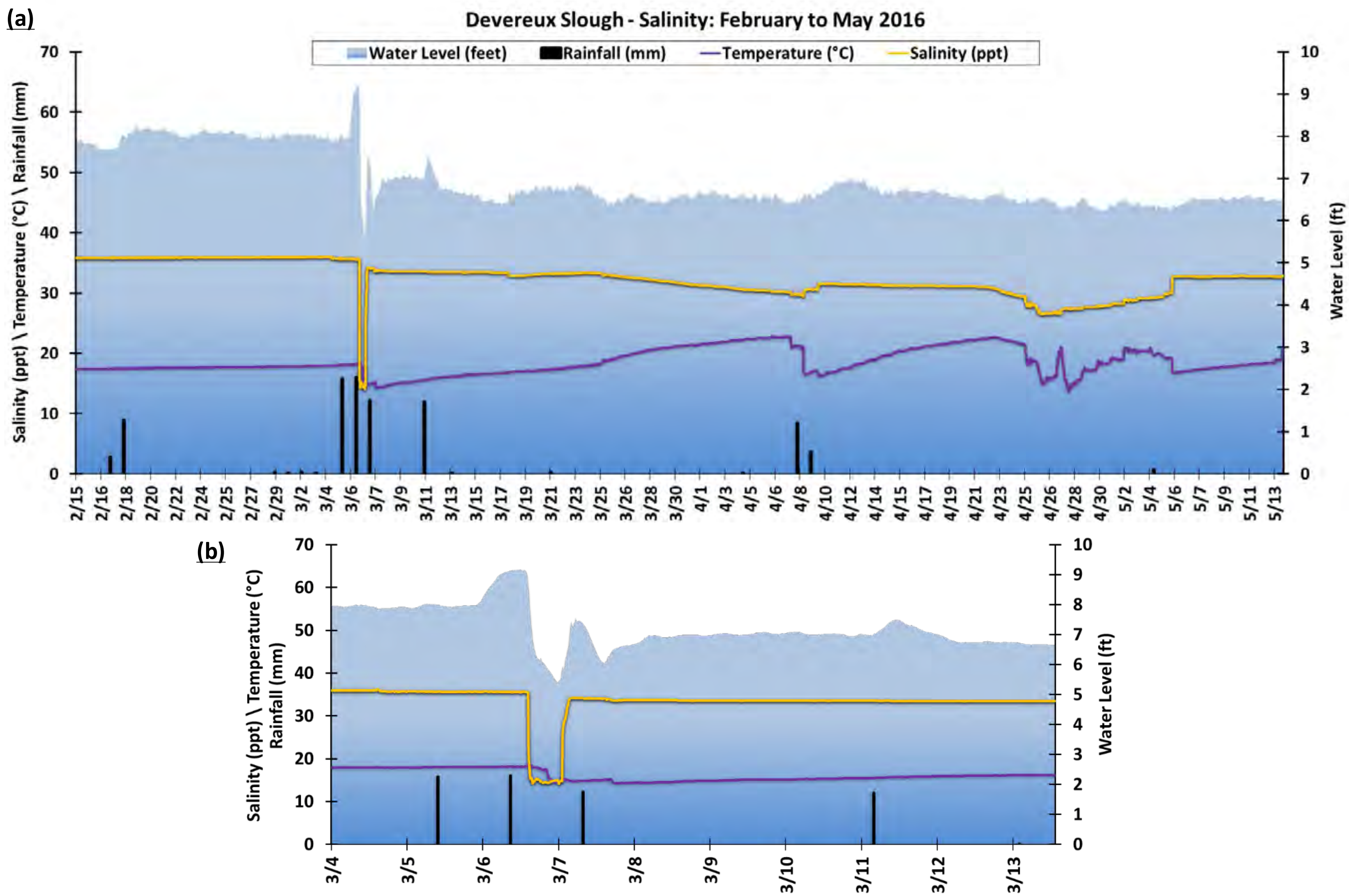


Figure 9. (a) The salinity (in parts per thousand, ppt), temperature (°C) and water level (feet) in Devereux Slough between February 15 to May 13, 2016, and **(b)** during a winter storm and breach event in March, 2016. The data were recorded by a YSI EXO1 sonde deployed approx. 1 foot above the bottom of the main channel of Devereux Slough (see Figure 1). Rainfall (mm) data were recorded by the meteorological station on the roof of Ellison Hall at the UCSB campus.

DISSOLVED OXYGEN & SALINITY GRADIENTS

In order to characterize the spatial and temporal variation in DO and salinity in the water column of the slough and surface waters of NCOS, we collected data at each foot of depth from the surface to the bottom with a portable YSI Pro 2030 at four locations in the slough and four locations in NCOS streams and pools (Figure 1) This data was collected approximately every two to three weeks beginning in late January through April 2016. At some of the sampling sites, it was not possible to consistently collect data at the same exact location, particularly when water levels increased following rainfall. Consequently, the elevation of samples at some sites appeared to fluctuate abnormally, such as the surface or bottom depth elevations at sampling site 1 near the mouth of Devereux Slough (Figure 10).

The data collected with the portable YSI Pro 2030 revealed that the DO concentration in Devereux Slough generally decreases with depth (Table 2, Figures 10 - 13), while salinity conversely increases with depth (Table 3, Figures 15 - 18). During the sampling period, salinity in the slough generally decreased following rainfall events, while DO did not appear to be affected much by rainfall but generally increased by the end of April. At the four NCOS sampling sites there was little to no variation in DO and salinity with depth (Tables 2 and 3), and only slight variation over the entire sampling period (Figure 14).

The trends in DO and salinity observed in the slough were particularly evident at sites 2 and 4, where a greater depth of water could be sampled (Figures 11, 13, 16 and 18). At these two sites, the DO concentration decreased with depth by as much as 10 mg/L, while salinity often increased with depth, sometimes to more than double the salinity at the surface. For example, the DO recorded at site 4 on March 17 decreased from 10.5 mg/L at the surface to 1.5 mg/L at the bottom, while salinity increased from 8 ppt at the surface to 28 ppt near the bottom (3.5 feet from the surface).

The average DO concentration recorded at the four sampling sites in the slough over the sampling period (January to April 2016) ranged from 6.5 to 8.9 mg/L (Table 2), and the average salinity ranged from 16.4 to 22.1 ppt (Table 3). Maximum DO concentrations were recorded in the surface layer of water at three of the four sites and ranged from 11.8 to 16.4 mg/L. Minimum salinities ranged from 0.3 to 8 ppt and were always recorded at the surface following rainfall events. Minimum DO and maximum salinities were usually recorded from the bottom of the water column and ranged between 0.8 to 6.6 mg/L for DO and 26.2 to 32.9 ppt for salinity. The maximum salinities correspond with the data recorded by the YSI EXO1 sonde at the pier between January to May. The lowest DO concentrations near the bottom of the water column at site 2 were recorded in February, while the largest DO values near the bottom at site 2 were recorded in April (Figure 11). These recordings appear to correspond with the fluctuations in DO recorded by the EXO1 sonde at the pier for the same time period, yet it is not clear why the sonde recorded zero DO for the entire month of February (Figures 3 and 5).

In contrast to the slough, the mean, maximum and minimum DO concentrations recorded at the four NCOS sampling sites (sites 5 through 8) were all lower on average (Table 2), and the overall average salinity was near 1 ppt (Table 3). The smallest average (0.2 ppt) and smallest maximum (0.4 ppt) salinities were recorded at site 6 (Whittier pond), which receives water from a different drainage than sites 5, 7 and 8 (Figure 1). Unexpectedly high salinity values were recorded at site 5 on February 15 and March 5 (Figure 19). It is not known whether these values were recording errors or possibly due to slough water that may have been forced upstream during high levels, through the culvert or over the sill that currently separates Devereux Creek from the slough. If these values are excluded, the average salinity at site 5 would be 0.8 ppt.

Table 2. The mean, minimum and maximum dissolved oxygen (DO) concentration (mg/L) recorded at each foot of depth from the surface at four sites in Devereux Slough (sites 1-4) and in open water locations in North Campus Open Space (sites 5-8). Figure 1 in this report contains a map of the sampling sites. The data were collected from January 24 to April 29, 2016 with a YSI Pro 2030.

Depth from Surface (feet)	0.0	1.0	2.0	3.0	4.0	5.0	6.0	7.0	Overall
Site 1 – Slough Mouth									
Mean DO (mg/L)	9.0	9.1	7.5						8.9
Minimum DO (mg/L)	7.2	6.6	7.5						6.6
Maximum DO (mg/L)	11.9	12.0	7.5						12.0
Site 2 – Main Channel									
Mean DO (mg/L)	9.0	8.9	8.1	6.7	5.4	3.0	4.1		7.4
Minimum DO (mg/L)	6.5	6.5	4.5	3.8	2.6	2.1	4.1		2.1
Maximum DO (mg/L)	11.4	11.2	11.8	11.2	10.2	4.5	4.1		11.8
Site 3 – Side Channel									
Mean DO (mg/L)	8.7	7.8							8.3
Minimum DO (mg/L)	6.0	5.7							5.7
Maximum DO (mg/L)	16.4	12.5							16.4
Site 4 – Venoco Bridge									
Mean DO (mg/L)	8.5	8.4	7.7	6.4	3.9	3.2	2.8	2.5	6.5
Minimum DO (mg/L)	5.8	6.1	5.3	2.5	1.5	0.8	2.8	2.5	0.8
Maximum DO (mg/L)	12.1	10.9	11.0	9.5	7.4	6.2	2.8	2.5	12.1
Site 5 – Devereux Creek Sill									
Mean DO (mg/L)	5.4	3.7	4.2	4.9					4.6
Minimum DO (mg/L)	4.5	0.0	3.3	4.8					0.0
Maximum DO (mg/L)	7.1	4.7	5.1	5.0					7.1
Site 6 – Whittier Pond									
Mean DO (mg/L)	5.6	5.9	4.9	4.9					5.5
Minimum DO (mg/L)	3.8	4.7	2.8	4.9					2.8
Maximum DO (mg/L)	7.9	7.7	7.7	4.9					7.9
Site 7 – Phelps & Devereux Confluence									
Mean DO (mg/L)	4.6	4.2	4.9	4.8					4.5
Minimum DO (mg/L)	2.2	1.9	4.9	4.8					1.9
Maximum DO (mg/L)	9.2	6.5	4.9	4.8					9.2
Site 8 – West Devereux Creek Pond									
Mean DO (mg/L)	5.8	6.1							5.8
Minimum DO (mg/L)	3.9	4.1							3.9
Maximum DO (mg/L)	9.4	7.5							9.4

Table 3. The mean, minimum and maximum salinity in parts per thousand (ppt) recorded at each foot of depth from the surface at four sites in Devereux Slough (sites 1-4) and in open water locations in North Campus Open Space (sites 5-8). Figure 1 in this report contains a map of the sampling sites. The data were collected from January 24 to April 29, 2016 with a YSI Pro 2030.

Depth from Surface (feet)	0.0	1.0	2.0	3.0	4.0	5.0	6.0	7.0	Overall
Site 1– Slough Mouth									
Mean salinity (ppt)	20.4	19.3	25.4						20.1
Minimum salinity (ppt)	8.2	8.2	25.4						8.2
Maximum salinity (ppt)	32.5	30.5	25.4						32.5
Site 2 – Main Channel									
Mean salinity (ppt)	17.1	18.5	22.1	24.5	27.0	28.3	27.9		22.1
Minimum salinity (ppt)	8.1	9.1	13.8	16.8	21.5	26.0	27.9		8.1
Maximum salinity (ppt)	24.9	26.9	31.0	32.5	32.8	30.5	27.9		32.8
Site 3 – Side Channel									
Mean salinity (ppt)	15.7	17.4							16.4
Minimum salinity (ppt)	6.5	6.7							6.5
Maximum salinity (ppt)	26.1	26.2							26.2
Site 4 – Venoco Bridge									
Mean salinity (ppt)	13.6	15.6	18.7	21.6	23.9	22.5	16.7	16.9	18.8
Minimum salinity (ppt)	0.3	0.7	2.1	16.1	16.6	0.8	16.7	16.9	0.3
Maximum salinity (ppt)	22.9	23.8	30.1	32.9	28.8	30.5	16.7	16.9	32.9
Site 5– Devereux Creek Sill									
Mean salinity (ppt)	0.8	3.2	4.0	7.9					2.8
Minimum salinity (ppt)	0.2	0.2	0.2	0.8					0.2
Maximum salinity (ppt)	1.6	10.5	14.0	15.0					15.0
Site 6 – Whittier Pond									
Mean salinity (ppt)	0.2	0.2	0.2	0.4					0.2
Minimum salinity (ppt)	0.1	0.1	0.1	0.4					0.1
Maximum salinity (ppt)	0.4	0.4	0.4	0.4					0.4
Site 7– Phelps & Devereux Confluence									
Mean salinity (ppt)	0.9	0.8	0.2	0.2					0.8
Minimum salinity (ppt)	0.2	0.2	0.2	0.2					0.2
Maximum salinity (ppt)	1.5	1.5	0.2	0.2					1.5
Site 8– West Devereux Creek Pond									
Mean salinity (ppt)	0.6	1.0							0.7
Minimum salinity (ppt)	0.1	0.1							0.1
Maximum salinity (ppt)	1.9	2.0							2.0

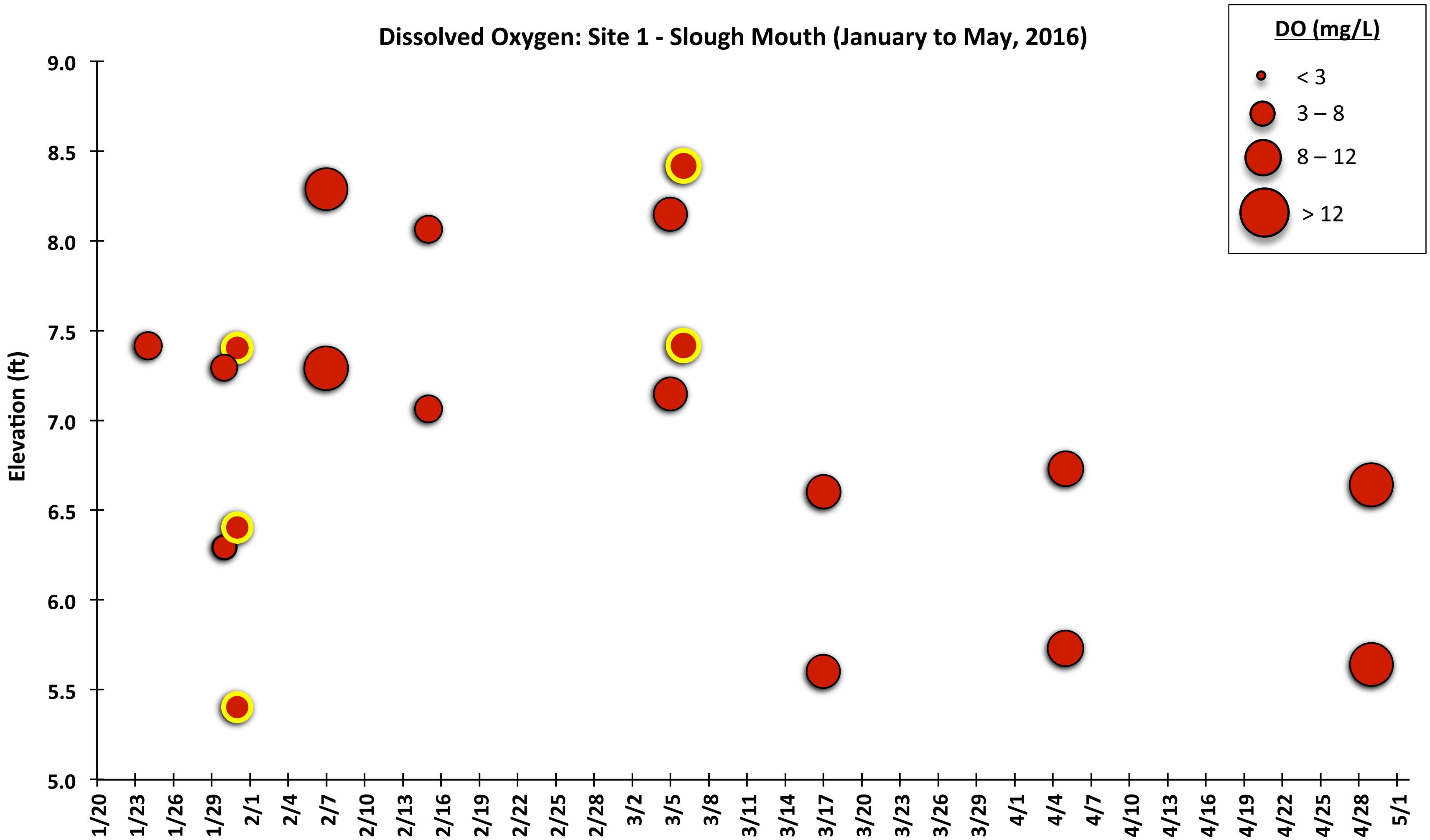


Figure 10. Dissolved oxygen (DO) concentration (mg/L) recorded at each foot of depth from the surface to the bottom with a portable YSI Pro 2030 at Site 1 - near the mouth of Devereux Slough (see Figure 1), from January 24 to April 29, 2016. DO concentration is indicated by the bubble size (legend provided). Bubbles outlined in yellow represent samples collected within 24 hours of relatively high rainfall. Sample elevations are based on YSI EXO1 water level data adjusted to feet (NAVD 88).

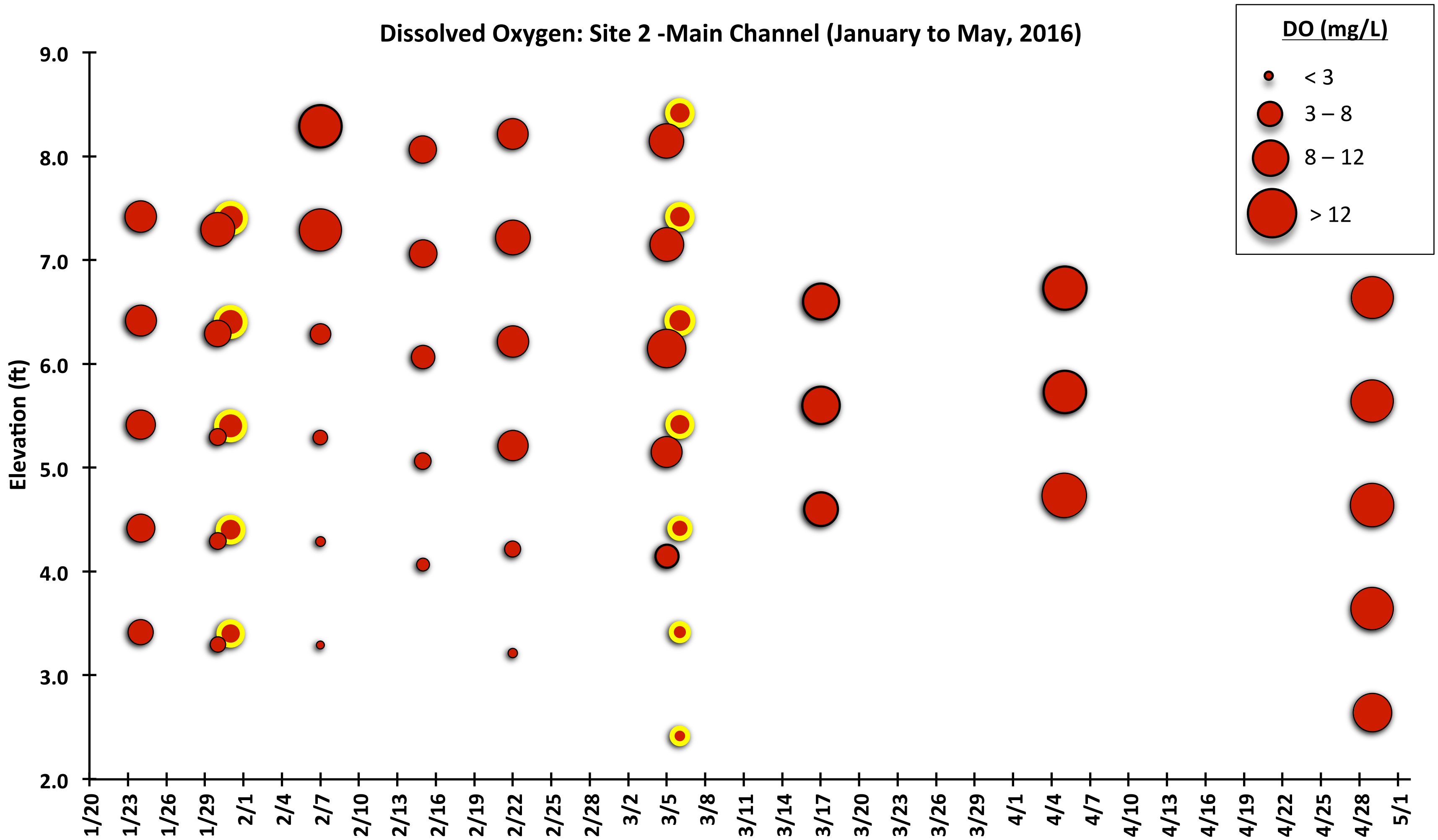


Figure 11. Dissolved oxygen (DO) concentration (mg/L) recorded at each foot of depth from the surface to the bottom with a portable YSI Pro 2030 at Site 2 - the main channel of Devereux Slough (see Figure 1), from January 24 to April 29, 2016. DO concentration is indicated by the bubble size (legend provided). Bubbles outlined in yellow represent samples collected within 24 hours of relatively high rainfall. Sample elevations are based on YSI EXO1 water level data adjusted to feet (NAVD 88).

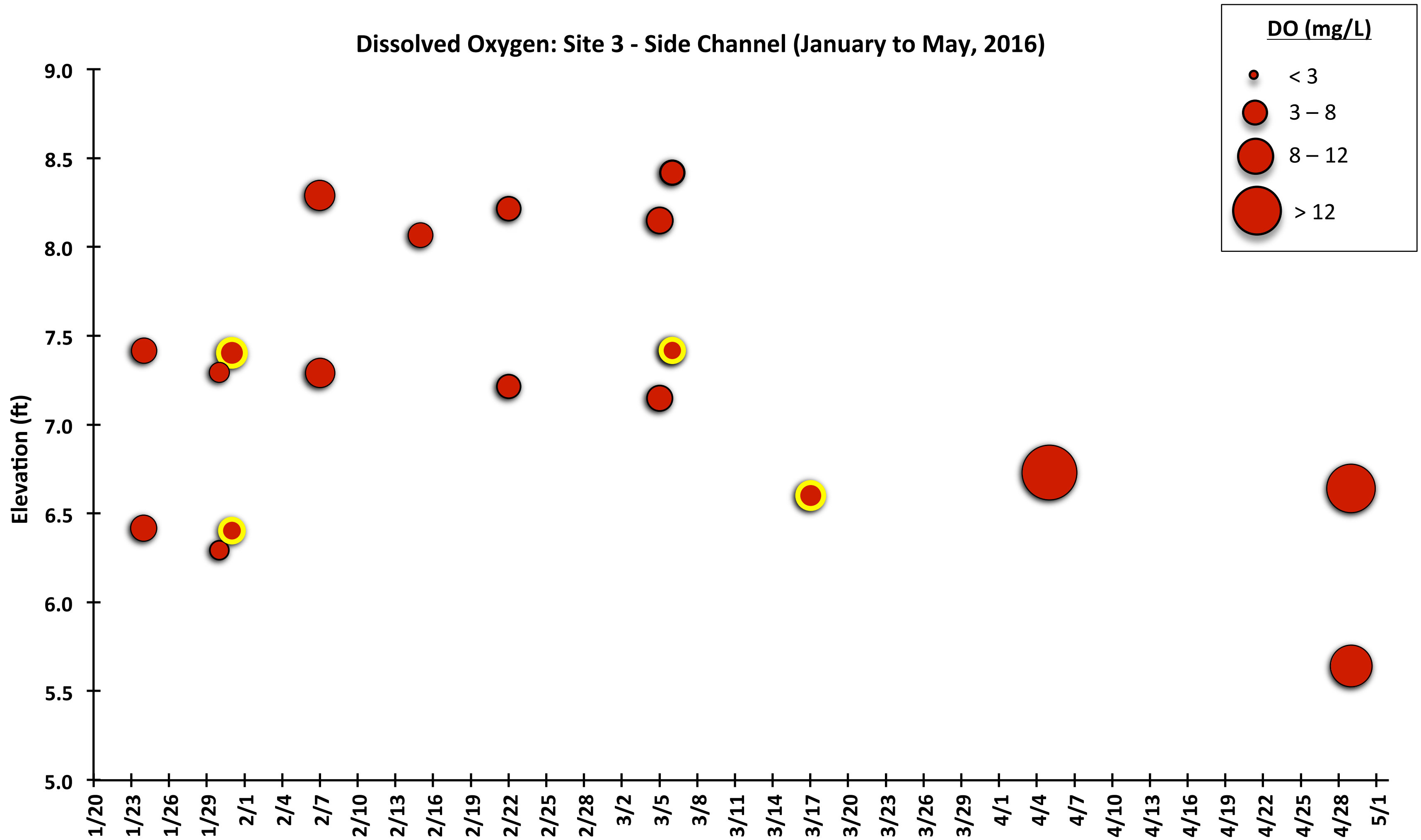


Figure 12. Dissolved oxygen (DO) concentration (mg/L) recorded at each foot of depth from the surface to the bottom with a portable YSI Pro 2030 at Site 3 - the side channel of Devereux Slough near Slough Road (see Figure 1), from January 24 to April 29, 2016. DO concentration is indicated by the bubble size (legend provided). Bubbles outlined in yellow represent samples collected within 24 hours of relatively high rainfall. Sample elevations are based on YSI EXO1 water level data adjusted to feet (NAVD 88).

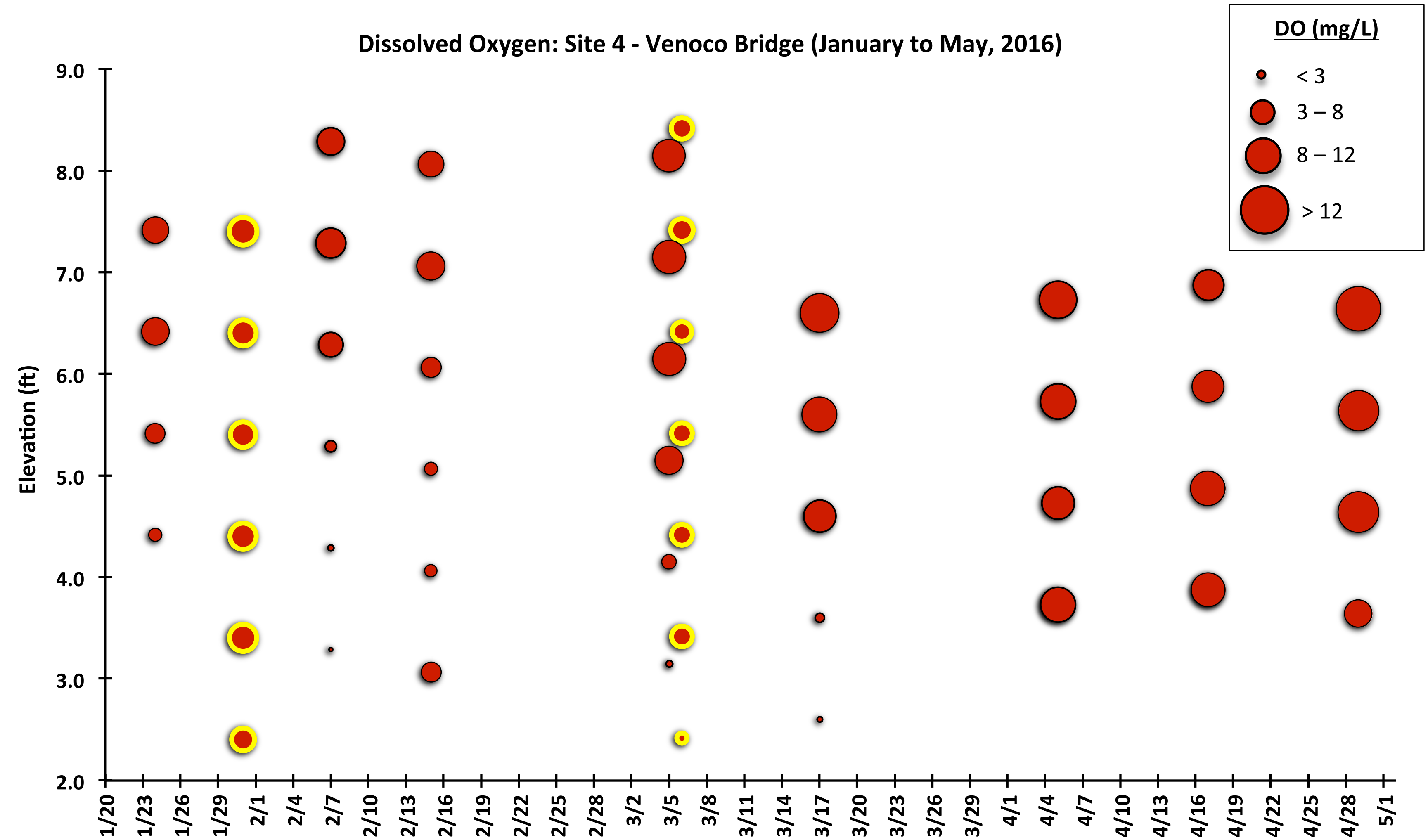


Figure 13. Dissolved oxygen (DO) concentration (mg/L) recorded at each foot of depth from the surface to the bottom with a portable YSI Pro 2030 at Site 4 - the south side of Venoco Bridge (see Figure 1), from January 24 to April 29, 2016. DO concentration is indicated by the bubble size (legend provided). Bubbles outlined in yellow represent samples collected within 24 hours of relatively high rainfall. Sample elevations are based on YSI EXO1 water level data adjusted to feet (NAVD 88).

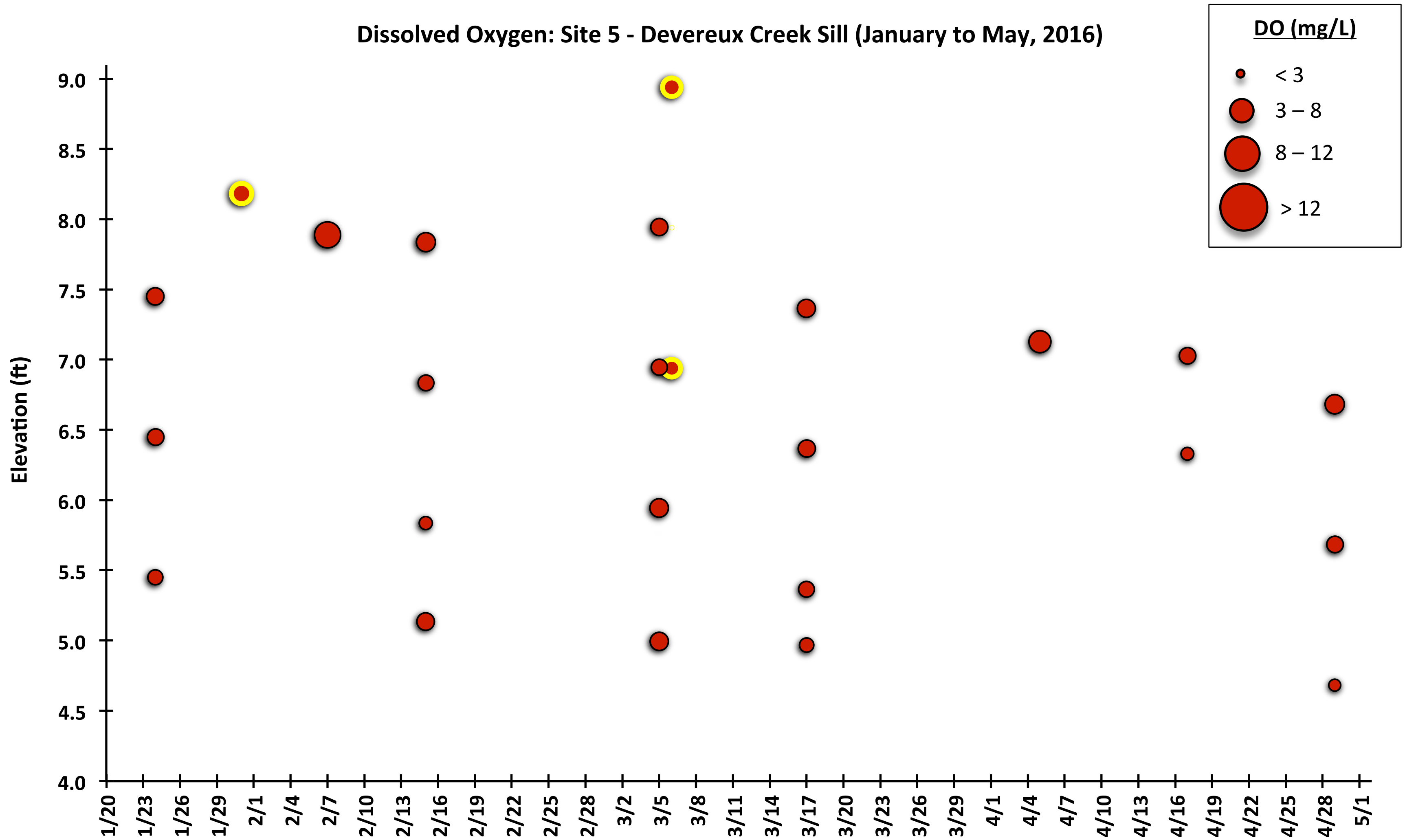


Figure 14. Dissolved oxygen (DO) concentration (mg/L) recorded at each foot of depth from the surface to the bottom with a portable YSI Pro 2030 at Site 5 – Devereux Creek upstream of the sill (see Figure 1), from January 24 to April 29, 2016. DO concentration is indicated by the bubble size (legend provided). Bubbles outlined in yellow represent samples collected within 24 hours of relatively high rainfall. Sample elevations (adjusted to feet NAVD 88) are based on water level data recorded with a Solinst Levelogger deployed near the sampling site.

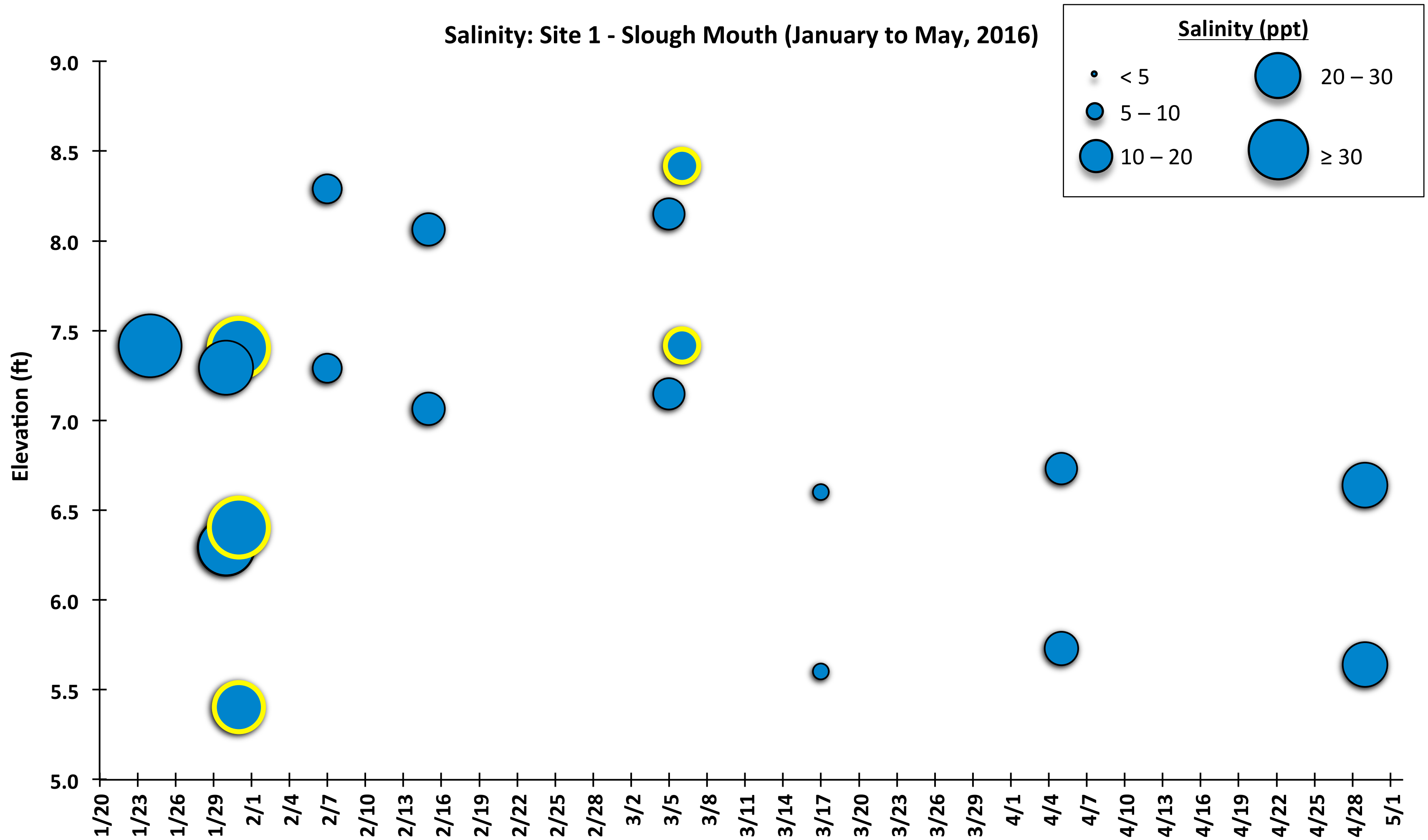


Figure 15. Salinity in parts per thousand (ppt) recorded at each foot of depth from the surface to the bottom with a portable YSI Pro 2030 at Site 1 - near the mouth of Devereux Slough (see Figure 1), from January 24 to April 29, 2016. Salinity (ppt) is indicated by the bubble size (legend provided). Bubbles outlined in yellow represent samples collected within 24 hours of relatively high rainfall. Sample elevations are based on YSI EXO1 water level data adjusted to feet (NAVD 88).

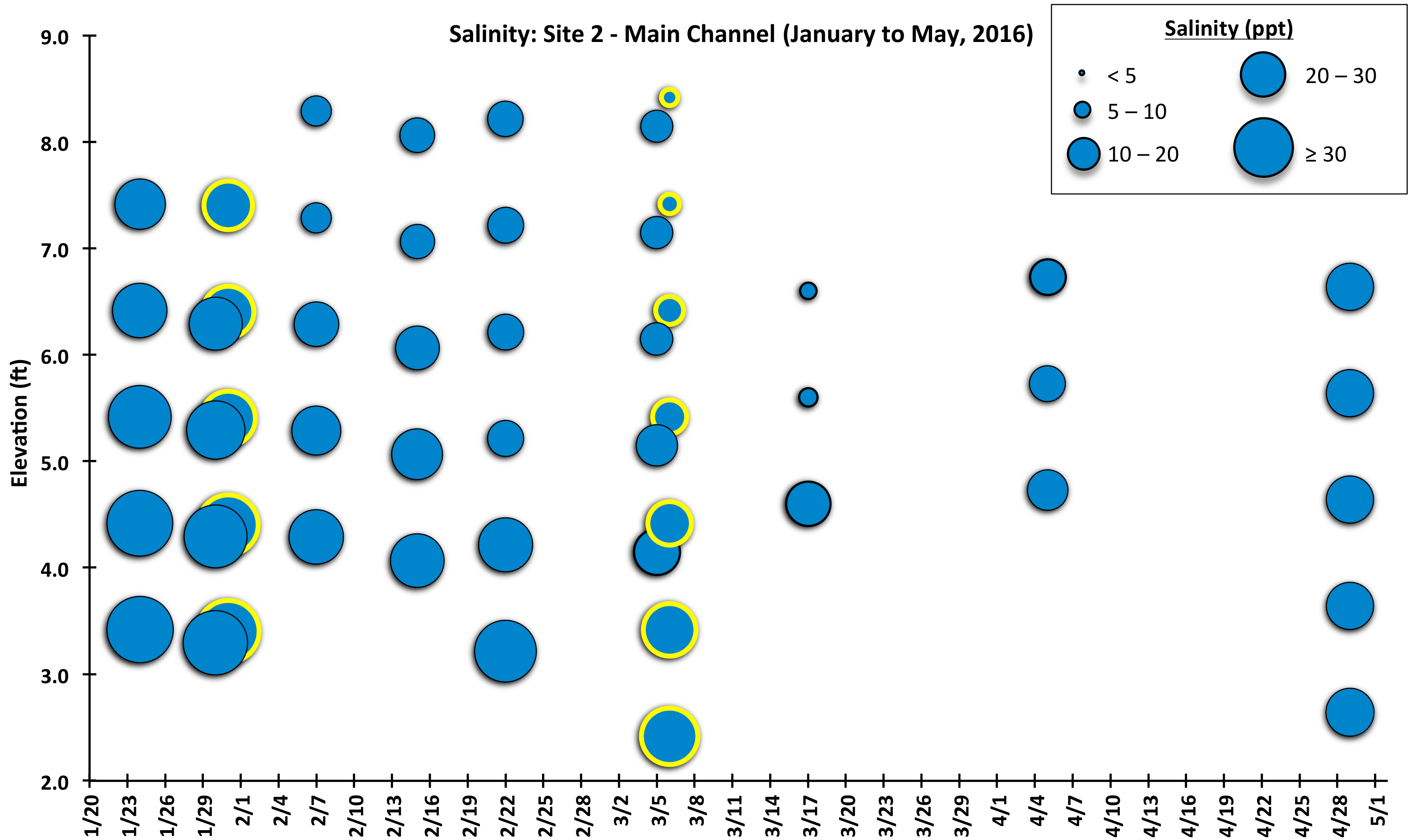


Figure 16. Salinity in parts per thousand (ppt) recorded at each foot of depth from the surface to the bottom with a portable YSI Pro 2030 at Site 2 - the main channel of Devereux Slough (see Figure 1), from January 24 to April 29, 2016. Salinity (ppt) is indicated by the bubble size (legend provided). Bubbles outlined in yellow represent samples collected within 24 hours of relatively high rainfall. Sample elevations are based on YSI EXO1 water level data adjusted to feet (NAVD 88).

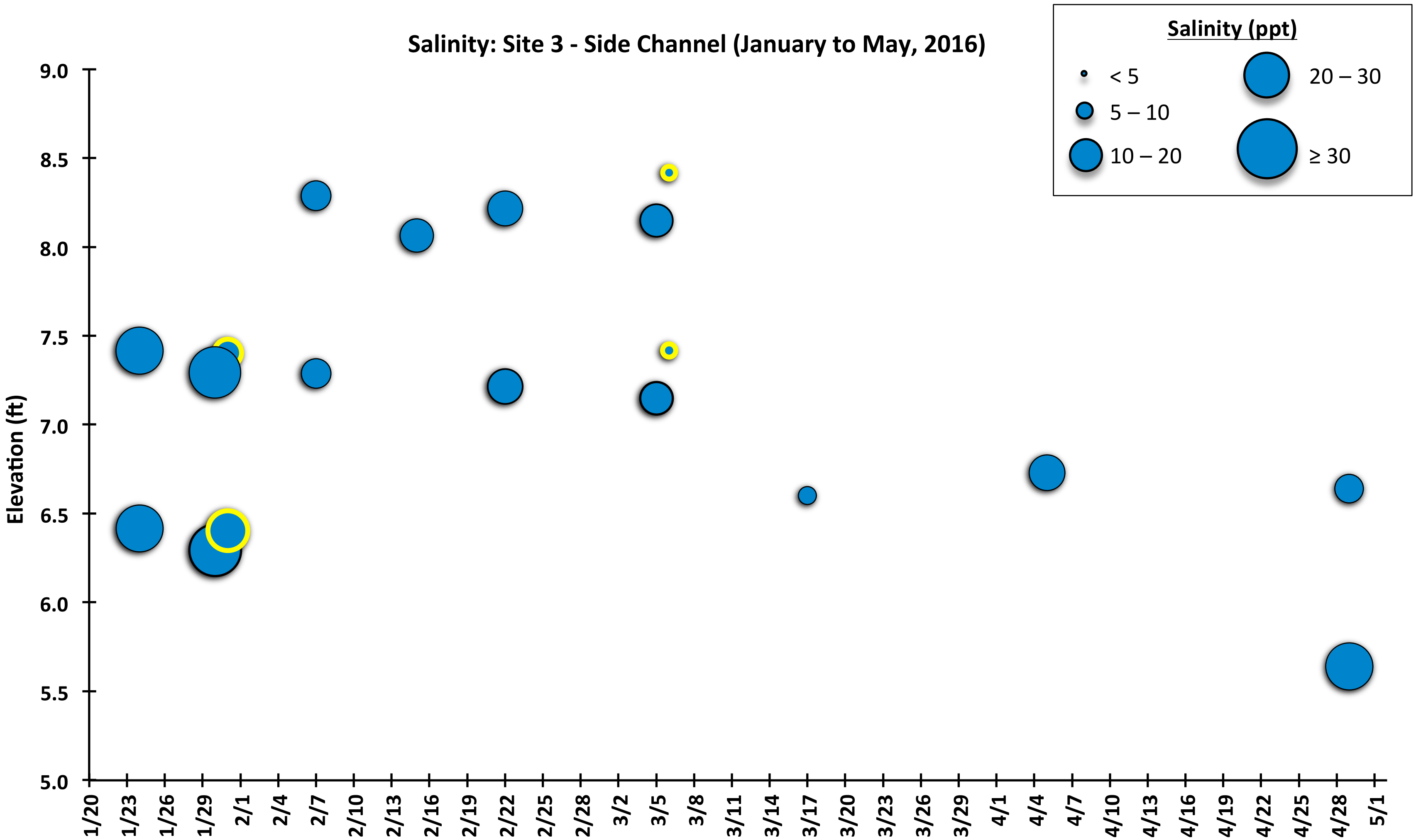


Figure 17. Salinity in parts per thousand (ppt) recorded at each foot of depth from the surface to the bottom with a portable YSI Pro 2030 at Site 3 - the side channel of Devereux Slough near Slough Road (see Figure 1), from January 24 to April 29, 2016. Salinity (ppt) is indicated by the bubble size (legend provided). Bubbles outlined in yellow represent samples collected within 24 hours of relatively high rainfall. Sample elevations are based on YSI EXO1 water level data adjusted to feet (NAVD 88).

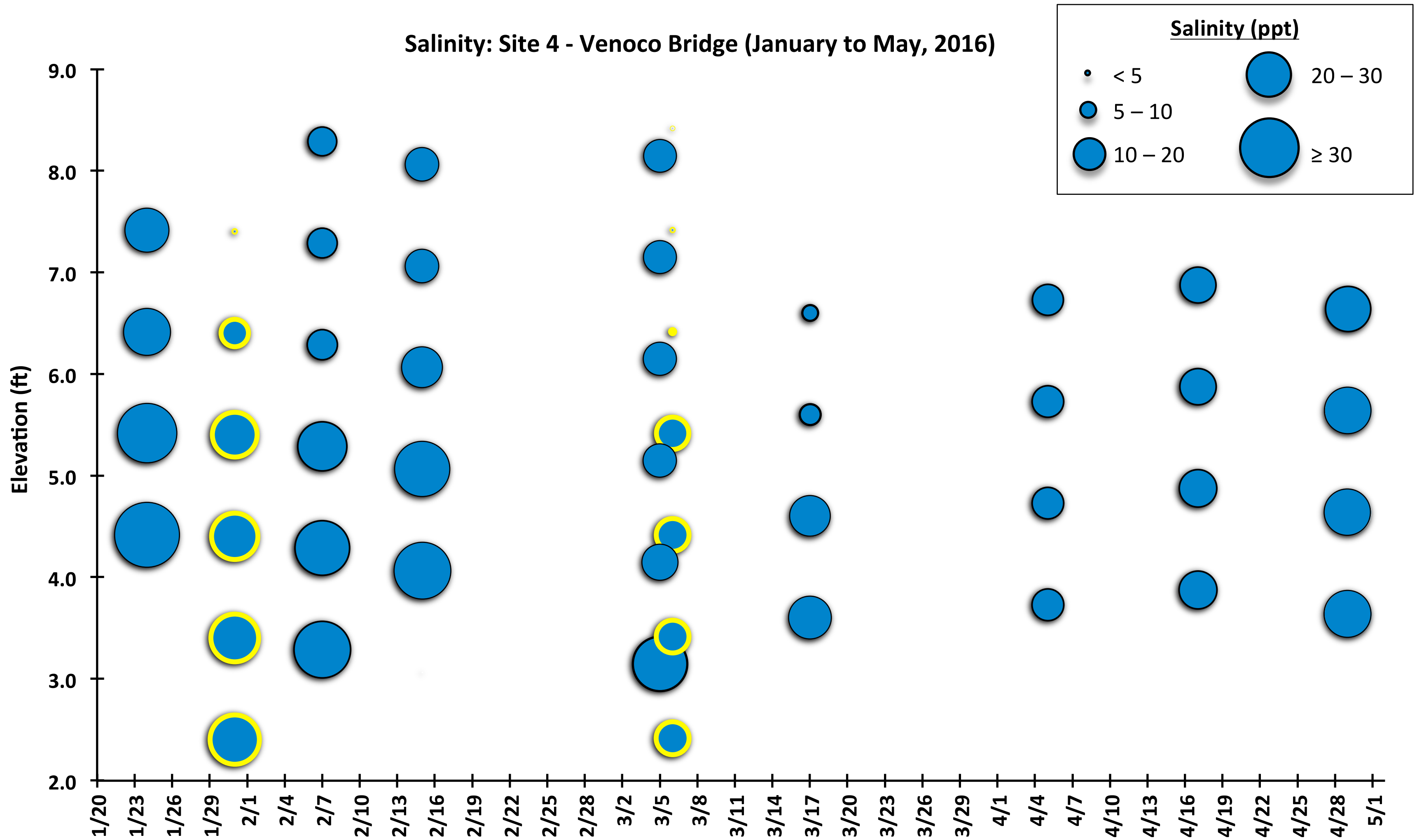


Figure 18. Salinity in parts per thousand (ppt) recorded at each foot of depth from the surface to the bottom with a portable YSI Pro 2030 at Site 4 - the south side of Venoco Bridge (see Figure 1), from January 24 to April 29, 2016. Salinity (ppt) is indicated by the bubble size (legend provided). Bubbles outlined in yellow represent samples collected within 24 hours of relatively high rainfall. Sample elevations are based on YSI EXO1 water level data adjusted to feet (NAVD 88).

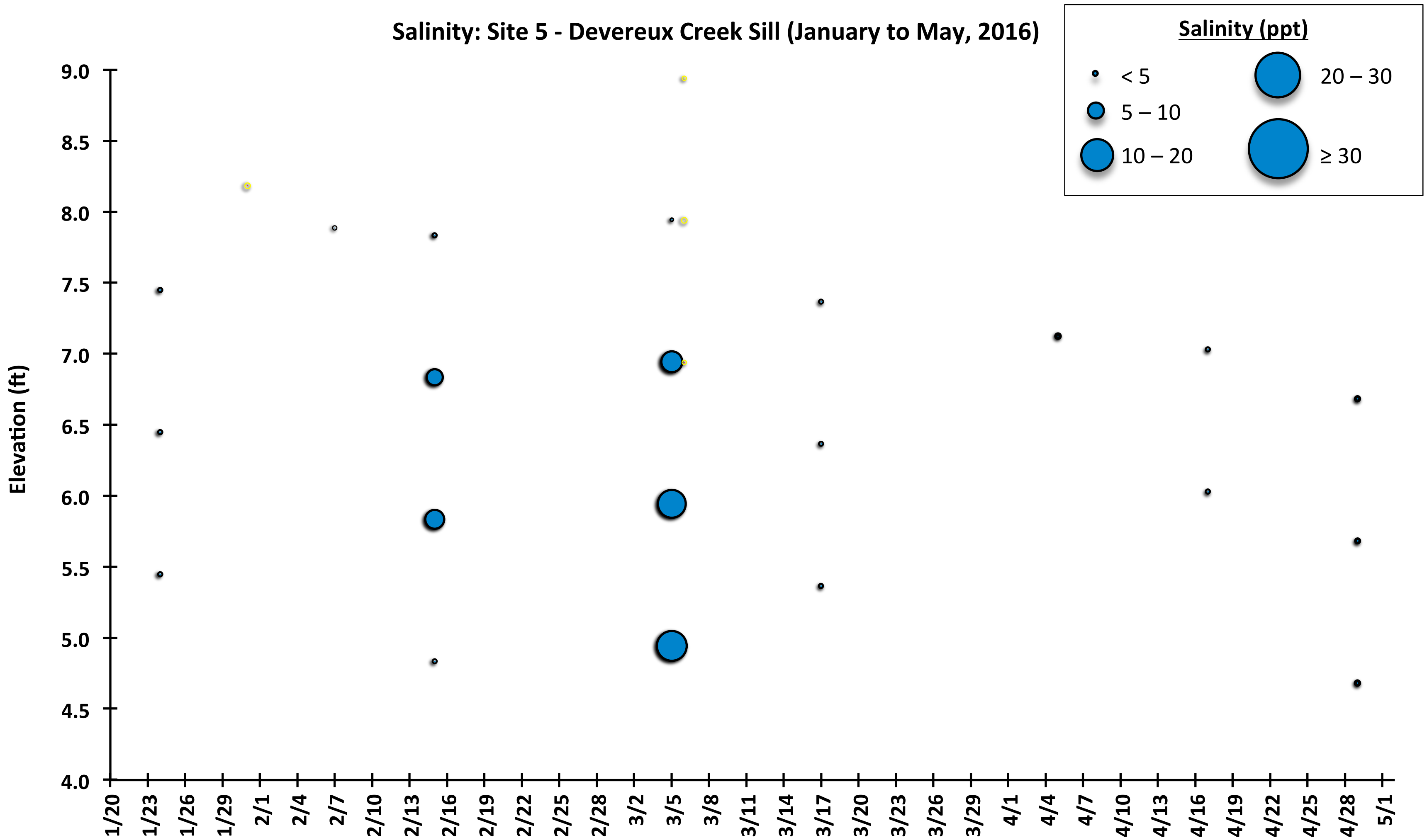


Figure 19. Salinity in parts per thousand (ppt) recorded at each foot of depth from the surface to the bottom with a portable YSI Pro 2030 at Site 5 - upstream of the sill at the mouth of Devereux Creek (see Figure 1), from January 24 to April 29, 2016. Salinity (ppt) is indicated by the bubble size (legend provided). Bubbles outlined in yellow represent samples collected within 24 hours of relatively high rainfall. Sample elevations (adjusted to feet NAVD 88) are based on water level data recorded with a Solinst Levelogger deployed near the sampling site.

NCOS GROUNDWATER SALINITY

CCBER monitors the level and salinity of the groundwater of NCOS using 19 piezometer wells distributed across the upper (South Parcel) and lower (previously Ocean Meadows Golf Course, OMGC) areas of the site (Figure 20). The South Parcel wells are two inches in diameter, while the diameter of the OMGC wells is one-inch, and most of the wells are more than 10 feet in length with between 7 to 9 feet of the well beneath the ground surface.

Groundwater level and salinity data were collected every two weeks, except between January 8 to March 25, 2016 (the "rainy" season), when well data was collected on a weekly basis. We measured salinity in parts per thousand (ppt) by extracting a sample of groundwater in a small vial attached to the end of a measuring tape (used for measuring the groundwater level), and applying the sample to a portable refractometer.

The data collected from the wells show a high amount of spatial and temporal variation in groundwater salinity across NCOS. During the data collection period (September 2015 to May 2016), groundwater was recorded in only half of the ten wells in the upper area (wells 1, 6, 8, 9 and 10), and the average salinity in these wells was between 0 to 2 ppt (Table 4). In contrast, the average groundwater salinity in the nine wells in the lower (golf course) area ranged from a low brackish 4 ppt to a highly saline 80 ppt (Table 4). The average salinity in four of the lower wells (13, 16, 18 and 19) was above 50 ppt, while in three other wells (14, 17 and 20), the average was a relatively low 4 to 8 ppt. This high spatial variation in groundwater salinity reflects the historic extent of Devereux Slough. The wells with higher average salinities are located nearest to the current drainage channels, which historically would have been the main upper arms of the slough (Figure 20). Much of the slough water evaporates and becomes highly saline during the summer and fall, and the salt deposits build up over time in the shallow areas where the water completely evaporates. Therefore, the high salinities recorded in most of the lower wells could be a result of the historic salt deposits under the golf course soil dissolving into groundwater. The wells with lower salinities are located near or within rain water run-off drainages (*e.g.* wells 8, 9, 10 and 20), or near freshwater seeps or springs (*e.g.* well 14).

The temporal variation in groundwater salinity was particularly evident in the lower wells with high average salinities (Figure 21). Following the first significant winter rainfall (January 5 and 6, 2016), the salinity recorded from wells 13, 16 and 18 quickly dropped from above 80 to less than 40 ppt. With subsequent rainfall events into mid-March, the salinity recorded in these three wells fluctuated between 30 to 50 ppt, and then began to increase during Spring to around 60 ppt in mid-May. The salinity in wells 15 and 19 also decreased by more than 40 ppt following winter rainfall, though more gradually than wells 13, 16 and 18. In contrast, the salinity in well 12 decreased by about 10 ppt, and there was no significant temporal variation in the salinity in wells 14, 17 and 20 (Figure 21).

Figure 20. Map of the distribution of groundwater piezometer wells in the North Campus Open Space, University of California, Santa Barbara. The points that represent the location of the wells are labeled with the well ID number and surveyed elevation (in feet NAVD 88) of the top of the well. The historic extent of Devereux Slough is indicated in transparent blue color.

Table 4. Average, minimum and maximum salinity (parts per thousand – ppt) of groundwater recorded between September 25, 2015 to May 16, 2016 in 19 piezometer wells distributed across the North Campus Open Space site at the University of California, Santa Barbara. No groundwater was recorded during this period in wells 2 through 5 and 7.

Well ID	Average Salinity (ppt)	Minimum Salinity (ppt)	Maximum Salinity (ppt)
1	2	0	5
6	1	0	10
8	0	0	1
9	0	0	3
10	2	0	18
12	39	34	49
13	55	27	87
14	4	0	7
15	24	5	55
16	54	22	94
17	8	5	15
18	58	22	90
19	80	52	100
20	4	1	10

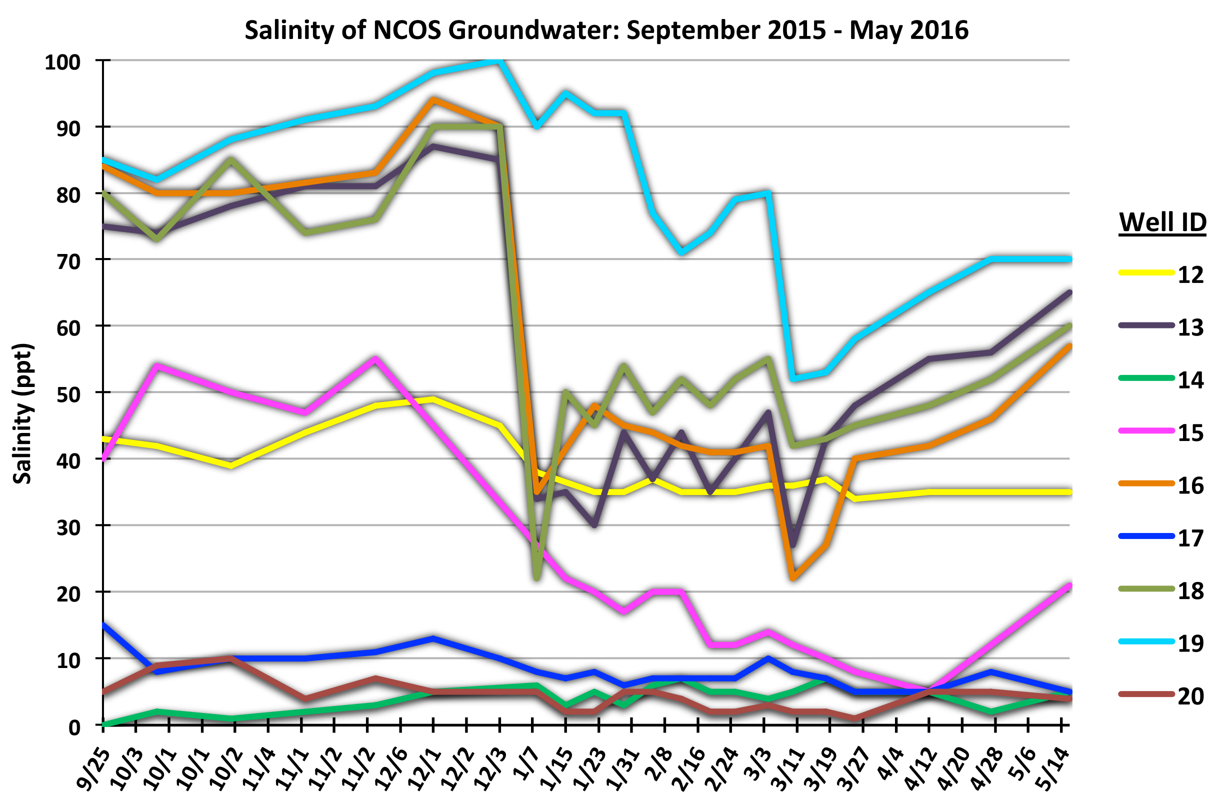


Figure 21. Temporal variation in salinity (ppt) in groundwater samples from nine piezometer wells distributed across the former Ocean Meadows Golf Course portion of the UCSB North Campus Open Space (see Figure 20).

NUTRIENTS

BACKGROUND AND METHODS

Nitrogen (N) and phosphorous (P) are two key nutrients that influence plant and phytoplankton growth and health. However, run-off from agriculture, urban and other sources, as well as animal waste and the decomposition of organic matter, can cause the concentrations of these nutrients to exceed natural background levels. In particular, excess concentrations of dissolved inorganic N (nitrate, nitrite and ammonium) and P (orthophosphate) (*i.e.* not sorbed in sediments or assimilated by phytoplankton, algae and/or aquatic plants) can lead to eutrophication and create hypoxic conditions that are detrimental for most aquatic animals (EPA 2012a). The same sources of excess N and P can also result in excessive concentrations of unionized ammonia, which can be toxic to fish and other aquatic organisms, including bacteria (EPA 1989, EPA 2013). The amount of dissolved inorganic N and P, and ammonia entering NCOS waterways and Devereux Slough could impact the effectiveness of the NCOS restoration project, particularly with regard to providing suitable habitat for threatened and endangered species such as the tidewater goby (*Eucyclogobius newberryi*). Therefore, CCBER evaluated the amount of dissolved inorganic N and P, and ammonia in run-off samples against water quality threshold limits determined by the US Environmental Protection Agency (EPA) (Tables 5 and 6).

We collected two “dry” (baseline or low/no flow conditions) and two “wet” (rainfall) run-off samples from four locations: the outfall of three storm drains into NCOS, and the outlet of a culvert through which Devereux Creek drains into the Slough (Figure 22). The first “wet” sample occurred during the first significant rainfall of the winter (January 5, 2016). Grab samples were collected using sterile 100 mL bottles, and each sample was prepared for analysis within 24 hours of collection. Preparation for analysis included filtering with Whatman glass microfiber filters and transferring of the filtered samples to a sterile 20 mL glass scintillation vile that was frozen until analysis. We also included a “blank” sample consisting of Nanopure water with each of the four groups of samples. Analysis of the nutrient samples was conducted by the UCSB Marine Science Institute (MSI) Analytical Lab. The amount of N in the samples was determined by analyzing the amount of nitrate plus nitrite, and P was determined by the amount of orthophosphate. The amount of ammonia was determined from the ammonium portion of dissolved inorganic N in the samples.

Table 5. The US Environmental Protection Agency (EPA) threshold limits for Dissolved Inorganic Nitrogen and Phosphorous in the assessment of Poor, Fair and Good water quality (EPA 2012a).

Water Quality Indicators	Poor Quality	Fair Quality	Good Quality
Dissolved Inorganic Nitrogen	> 1.0 mg/L	0.5 - 1.0 mg/L	< 0.5 mg/L
Dissolved Inorganic Phosphorous	> 0.1 mg/L	0.07 - 0.1 mg/L	< 0.07 mg/L

Table 6. Criteria for the maximum acute (or Criteria Maximum) and chronic (or Criteria Continuous) concentrations of unionized ammonia for aquatic life in fresh and saltwater, as determined by the US Environmental Protection Agency (EPA 1989, EPA 2013). The freshwater criteria are for water with a pH of 7.0 and a temperature of 20°C. None of the criteria concentrations should occur more than once every three years on average.

Criterion	Freshwater (mg/L)	Saltwater (mg/L)
Acute (1-hour average)	17	0.233
Chronic (4-day average)	4.8	0.035
Chronic (30-day rolling average)	1.9	N/A

RESULTS

The results of the analyses suggest that there is a flux of nutrients in run-off entering NCOS streams that peaks during the first significant winter rainfall, then declines. This pattern was especially evident for N, the amount of which was below the EPA maximum threshold for "Good" water quality (0.5 mg/L) except in the "wet" samples collected during the first significant winter storm, and the first "dry" sample collected at the Devereux Creek outlet site (Figure 23a). For those five samples, N was greater than the EPA threshold for "Poor" water quality. We expected the high pulse in N in the first "wet" sample from each site since a large portion of the sources of excess N (*e.g*. fertilizer, animal and other organic waste) that accumulate over the dry season are typically flushed into drainages and creeks by the first heavy winter rainfall. The very high N (9.12 mg/L) in the first "dry" sample at the Devereux Creek outlet may have been due to an error in the analysis as this sample was reported to be out of the calibration range for nitrate plus nitrite. Alternatively, the high N may have resulted from a high concentration of animal waste and/or other decaying organic matter that could have accumulated in the water that had been standing in the culvert pipe for many weeks before the sample was collected.

The amount of P was also greatest in all but one of the first "wet" samples; however, unlike N, the amount of P was above the EPA threshold for "Poor" water quality in 12 of the 16 samples (Figure 23b). Both "dry" and the first "wet" samples collected at the "Whittier West" site contained the greatest concentrations of P (near 0.5 mg/L), and the "wet" samples with the greatest N concentration were also from this site. The "Whittier West" site is at the outfall end of a storm drain that flows into the western side of a collection pond (Figure 22). The drain collects run-off from a residential area that includes a park with several sports fields (Girsh Park). Therefore, the relatively high amounts of P and N in the "Whittier West" samples likely come from fertilizers applied to the sports fields and residential lawns within the drainage area of the site. The pond that the two "Whittier" sites drain into does not currently flow into Devereux Creek and the Slough, except during high rainfall events.

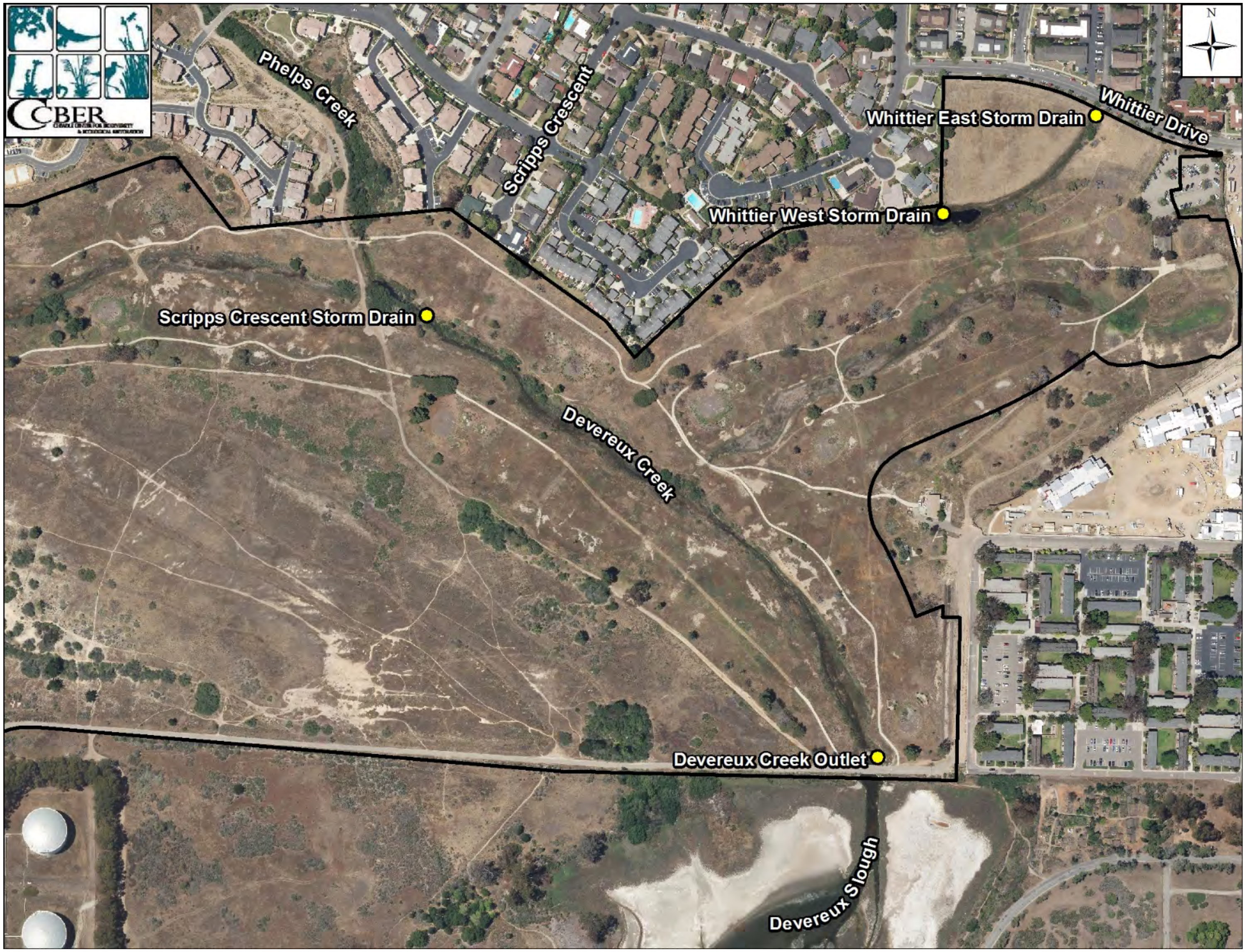
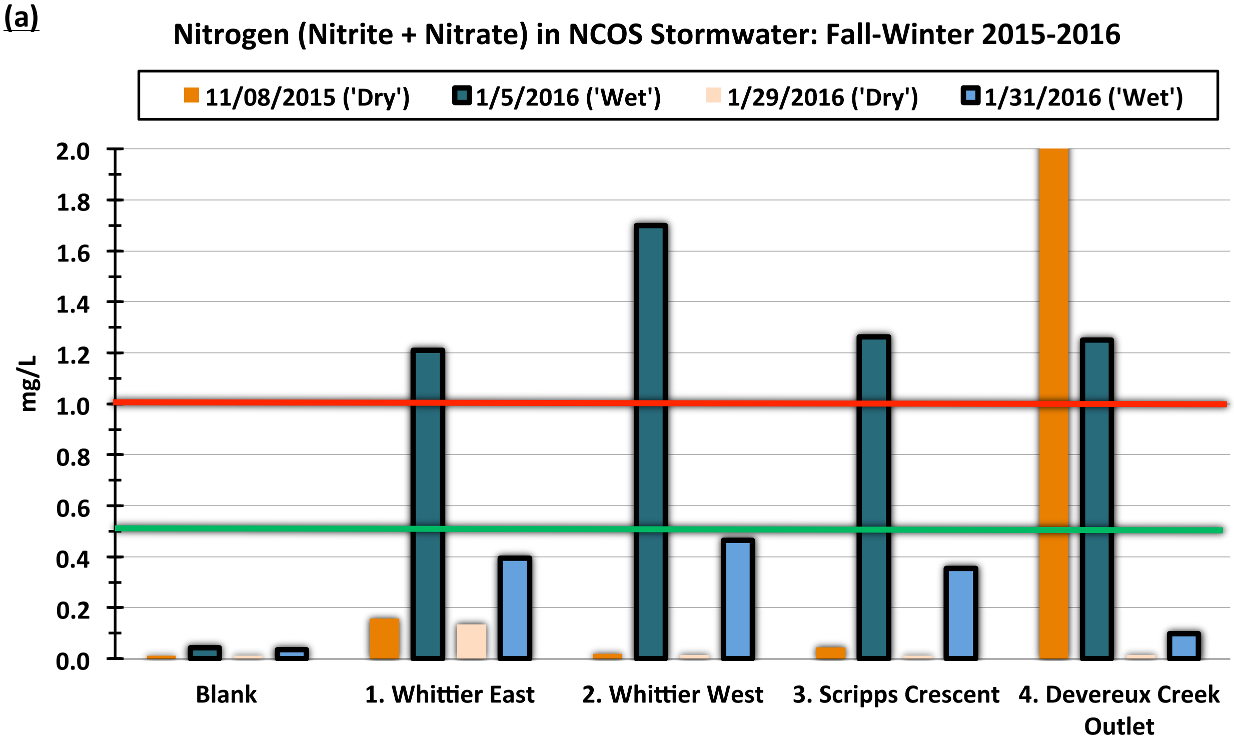


Figure 22. Map of the sample locations for the analysis of nutrients and bacteria in stormwater and "dry" or baseline run-off at the North Campus Open Space, University of California, Santa Barbara, 2015-2016.

(a)



(b)

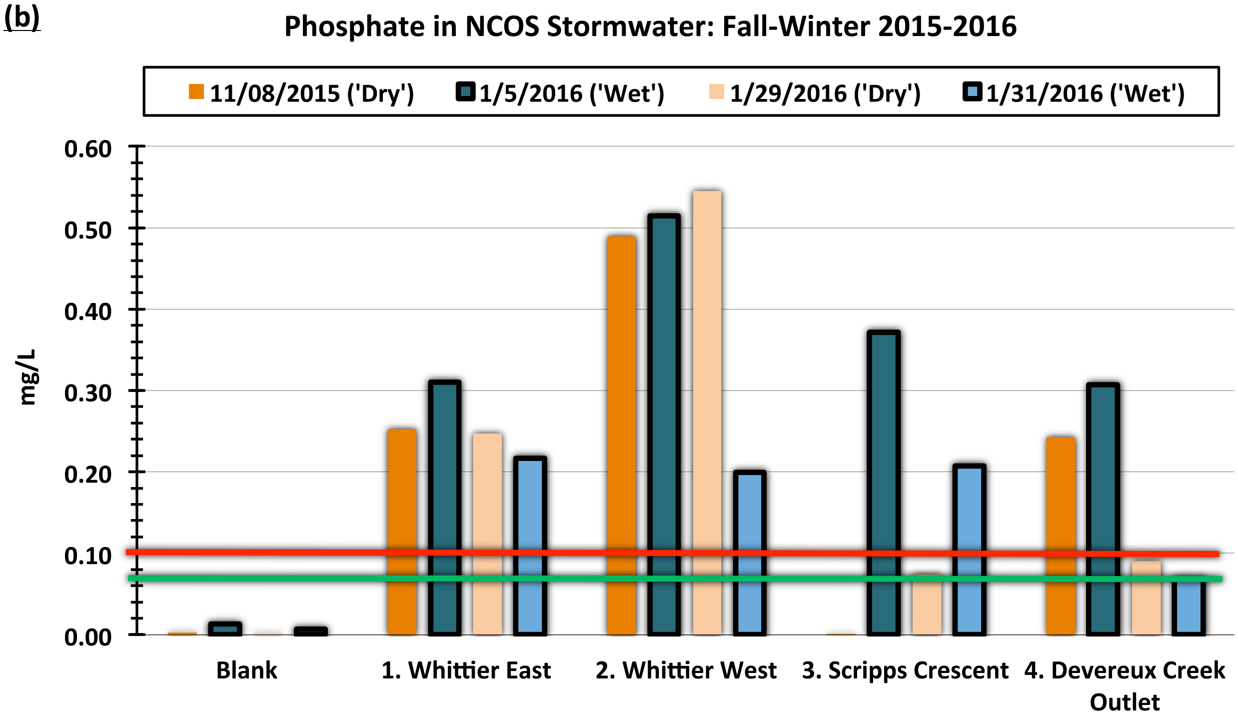


Figure 23. (a) Nitrogen concentration (mg/L), derived from the nitrogen portion of nitrite and nitrate, and **(b)** ortho-phosphate concentration (mg/L) in two "Dry" (or baseline) and two "Wet" (or storm) surface water samples collected at four locations in North Campus Open Space (see map in Figure 22). The Red and green lines represent the EPA's poor and good water quality threshold limits for nitrogen (see Table 1). The results for a "Blank" sample of Nano-pure water are also presented.

Ammonia levels were well below all of the EPA criteria for freshwater (Table 3), and, apart from one exception, were less than 0.20 mg/L (Figure 24). The exception was the first "dry" sample from the Devereux Creek outlet site, which had a high amount of ammonia (1.6 mg/L) relative to all other samples. The reasons for this are the same as for the relatively high amount of N reported for this sample. While these results suggest that the amount of ammonia entering NCOS waterways is low enough to not have a negative effect on aquatic life, additional sampling would be needed, particularly from within Devereux Slough, in order to assess the levels of ammonia relative to the EPA water quality criteria for saltwater.

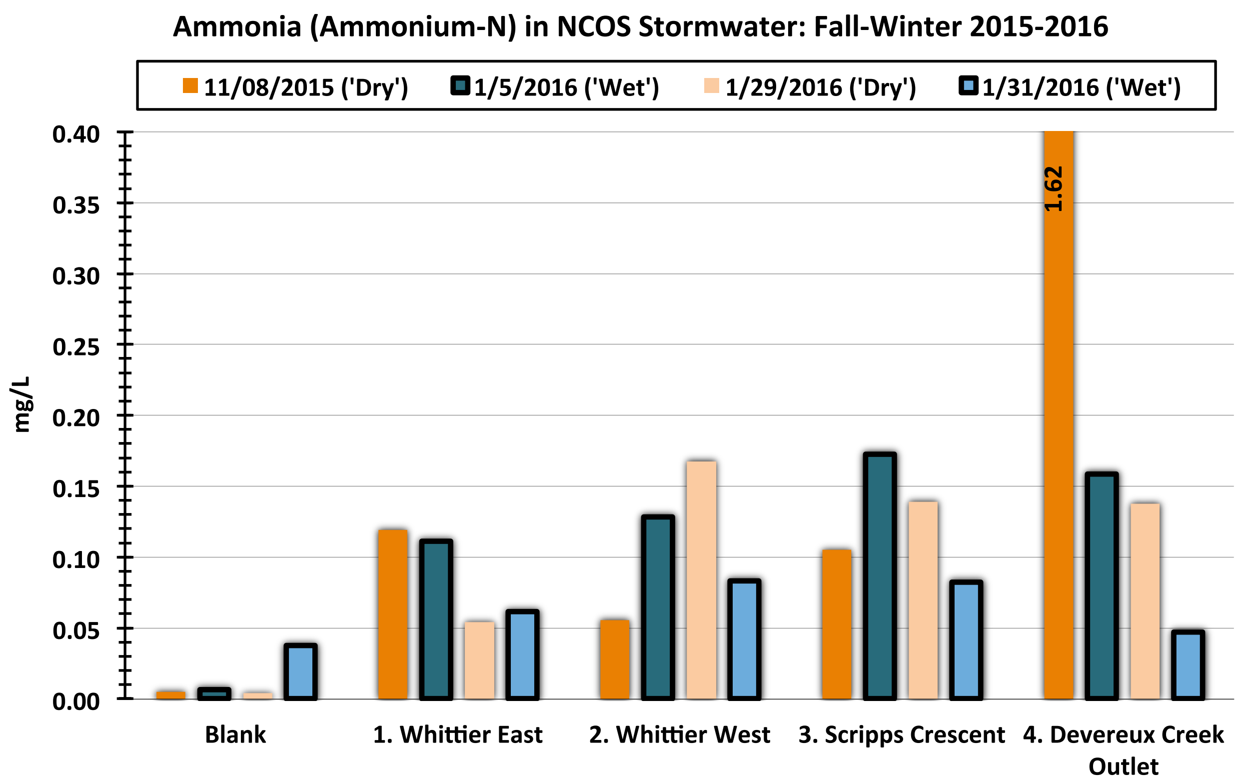


Figure 24. Ammonia concentration (mg/L), derived from the Nitrogen obtained from Ammonium, in two "Dry" (or baseline) and two "Wet" (or storm) surface water samples collected at four locations in North Campus Open Space (see map in Figure 22). The results for a "Blank" sample of Nano-pure water are also presented. All samples were well below the EPA criteria for ammonia in freshwater (see Table 6).

BACTERIA

BACKGROUND AND METHODS

EPA and California state water quality guidelines and criteria for fecal, or pathogenic indicator bacteria are set for recreational waters, *i.e.* where swimming and other activities occur on or in the water. No swimming or related activities occur in Devereux Slough and the waterways of NCOS, though many people walk dogs through the area, and they may enter and/or drink from the water. In addition, usually at least once every winter, Devereux Slough breaches and empties into the ocean as a result of rising water levels from rainfall in conjunction with high surf and tides. This outflow of slough water into the ocean would then become part of coastal recreational waters.

To detect for any possible contamination of fecal-borne pathogens in the run-off that drains into NCOS (and subsequently Devereux Slough), we analyzed water samples for the presence and amount of three key types of indicator bacteria: total coliforms, *E. coli*, and enterococci. Total coliforms comprise a large and diverse group of bacteria that occur not only in human and animal feces, but almost anywhere else in the environment (Leydecker and Grabowsky, 2004). The group alone is not a particularly useful indicator of fecal contamination and is not used as an indicator by the EPA. *E. coli.* is a species of fecal coliform bacteria that is specific to human and other warm-blooded animal feces, while enterococci are more specific to humans and can survive in saltwater (Leydecker and Grabowsky, 2004).

Water samples were collected in sterile 100 mL IDEXX Laboratories vials at the same locations and times as the nutrient samples. Analysis for bacteria was carried out at the Biogeochemistry lab at the UCSB Bren school, and the processing of samples took place on the day of collection. We used a chromogenic substrate method for estimating the most probable number (MPN) of bacteria per 100 mL, and 95% confidence intervals of each of the three bacteria types. IDEXX Laboratories Colilert reagent was used for the analysis of total coliforms and *E. Coli*, and the Enterolert reagent was used for enterococci. Two 1:10 dilutions of each sample in Nanopure water (10 mL sample + 90 mL Nanopure water) were created, one for each reagent. As with the nutrient samples, we also included a blank sample of 100 mL Nanopure water for each of the four groups of samples. After thoroughly mixing and dissolving the reagent, each diluted sample was sealed in an IDEXX Quanti-Tray/2000. All sample trays were incubated for 24 hours, with Colilert trays incubated at 35° C, and Enterolert trays at 41° C.

To calculate the MPN of total coliforms, *E. coli*, and enterococci, we first obtained the number of positive wells in each incubated sample tray. The incubated Colilert trays were compared with a Colilert Quanti-Tray/2000 Comparator, and the number of wells with a yellow color intensity equal to or greater than the Comparator were marked and counted as positive for total coliforms. The Colilert tray was examined for fluorescence under a UV light, and the number of wells marked positive for total coliforms that had a fluorescence intensity equal or greater to the Comparator were counted positive for *E. coli.* For enterococci, we tallied the number of wells in the Enterolert tray with blue fluorescence under a UV light. To obtain the MPN and 95% confidence intervals, the number of positive wells for each bacteria type in each sample tray were entered in the IDEXX MPN Generator software, version 1.4. We compared

MPN values against State of California recreational water quality recommended limits for single sample analyses, as in Leydecker and Grabowsky (2004), Noble et al. (2004), and EPA (2012b):

- 10,000 per 100 mL for Total Coliforms
- 400 per 100mL for *E. Coli*
- 104 per 100mL for Enterococci

RESULTS

Overall, MPN values were greatest and above the recommended limits for all three bacteria types in all of the “wet” samples (Table 7). High MPN values in the “wet” samples are not surprising, especially for the first significant winter rainfall, which, as with nutrients, also flushes a lot of the accumulated sources of these bacteria (*e.g*. soil, dead vegetation, animal feces, loose garbage) into storm drains. For the most part, the “dry” samples from the three storm drain sites had MPN values below the state recommended limits for each bacteria group. Two notable exceptions were the MPN for Enterococci in the second “dry” sample at the Whittier West and Scripps Crescent sites, though these two MPN values were not far above the recommended limit of 104.

At the Devereux Creek outlet site, MPN values were above state recommended limits in all samples except for Enterococci in the second “dry” sample. Despite this result, when compared with the three storm drain sites, the MPN of Enterococci in both “wet” samples, and of *E. coli* in the second “wet” sample, were lowest at the Devereux Creek outlet site (Table 4). The relatively high *E. coli* and Enterococci MPN in three of the “dry” samples at this site may be due to an accumulation of animal feces, particularly waterfowl and wading birds that frequently use the ponds and other open water areas of NCOS. A link between heavy use of open water near storm drain outfalls by birds and increased Enterococci concentrations has been observed in other studies (*e.g.* EPA 2012b).

Since Devereux Slough is not a recreational water body as defined by the EPA and California State water quality criteria (in the sense that there is little, if any direct human contact with the water), the relatively high inputs of fecal-indicator bacteria from storm water run-off may not pose a health risk to humans. Collection and analysis of samples in and near the slough mouth, particularly during a breach event, would provide information about the quality of water that flows into the ocean and onto adjacent beaches. In addition, a more in-depth study would be needed to determine any effects of high bacteria concentrations on wildlife.

Table 7. The most probable number (MPN) and lower and upper 95% confidence intervals (CI) for Total Coliforms, *E. coli*, and Enterococci bacteria in 100 mL water samples collected at three storm drain outlets (sites 1 – 3), and the outlet of Devereux Creek into Devereux Slough. A map of the sample locations is provided in Figure 22. MPN values highlighted in red are above California state recommended single sample limits for recreational water quality (listed in the first row of the table). Results are listed for two sample types ('Dry' = no rain and low or no flow, 'Wet' = high flow from rainfall) collected twice each on two different dates. 24196 is the maximum MPN that can be estimated by the analysis method.

	Total Coliforms			E. coli			Enterococci		
	MPN	Lower 95% CI	Upper 95% CI	MPN	Lower 95% CI	Upper 95% CI	MPN	Lower 95% CI	Upper 95% CI
CA State RWQ Limit	**10,000**			**400**			**104**		
1. Whittier East									
11/8/2015 ('Dry')	15531	10162	23531	336	220	489	75	36	149
1/5/2016 ('Wet')	>24196	14395	Infinite	4884	3100	7215	12997	8504	18966
1/29/2016 ('Dry')	5475	3582	8045	10	1	55	52	18	108
1/31/2016 ('Wet')	>24196	14395	Infinite	5172	3384	7636	6131	4012	8792
2. Whittier West									
11/8/2015 ('Dry')	4106	2606	6189	122	68	214	74	32	144
1/5/2016 ('Wet')	>24196	14395	Infinite	7270	4757	10489	24196	16304	47161
1/29/2016 ('Dry')	15531	10162	23531	288	183	427	160	92	264
1/31/2016 ('Wet')	>24196	14395	Infinite	9804	6606	14102	7270	4757	10489
3. Scripps Crescent									
11/8/2015 ('Dry')	7701	5490	10940	20	3	71	30	6	73
1/5/2016 ('Wet')	>24196	14395	Infinite	24196	16304	47161	11199	7546	16140
1/29/2016 ('Dry')	6131	4012	8792	109	56	195	135	78	234
1/31/2016 ('Wet')	>24196	14395	Infinite	3873	2459	5670	3441	2453	4725
4. Devereux Creek Outlet									
11/8/2015 ('Dry')	>24196	14395	Infinite	1201	879	1598	3968	2751	5555
1/5/2016 ('Wet')	>24196	14395	Infinite	9208	6205	12820	6488	4245	9415
1/29/2016 ('Dry')	24196	16304	47161	842	650	1064	51	16	106
1/31/2016 ('Wet')	>24196	14395	Infinite	2098	1455	3011	2909	1904	4461

CONCLUSION

The overall trends observed in the water quality of Devereux Slough largely reflect the seasonal hydrology of the watershed. The water quality of the slough is best in the winter and spring, when rainfall and cooler temperatures increase dissolved oxygen and nutrient concentrations, and keep salinity at levels equivalent to sea water. In the dry and warm summer and autumn months, evaporation and a lack of inflow of fresh or sea water drives up salinity, and may also increase chlorophyll and blue-green algae concentrations, while dissolved oxygen becomes depleted and drops to very low levels. The influx of high concentrations of nutrients in winter rainfall run-off entering NCOS waterways could be contributing to the high Chlorophyll concentrations in the slough throughout much of summer and autumn, but also periodically in winter and spring.

The salinity in the NCOS streams and ponds tends to remain at levels much lower than the slough, while groundwater salinities reflect the historical extent of the slough that existed before the Ocean Meadows Golf Course was developed in the 1960s.

Our study of fecal indicator bacteria concentrations in run-off entering NCOS waterways suggests that there may at times be levels of pathogens that are a health risk to humans. However, this may only be a concern when Devereux Slough breaches and empties into the ocean. Sampling and analysis of indicator bacteria levels in the slough are needed to determine if there is a potential health risk, and further research is needed to assess any ecological effects from the bacteria concentrations observed in the run-off entering NCOS.

By expanding the capacity of the slough and increasing the water holding capacity and expanse of salt marsh habitat and interfacing freshwater ponds, the NCOS restoration project should help improve water quality trends. The changes that the restoration project will implement could allow for greater filtration of high flows, increased opportunities for denitrification and greater opportunities for fresh water to be retained by the system. These processes may reduce the amount of nutrients available to phytoplankton and algae which should reduce eutrophication and allow healthier levels of dissolved oxygen to persist longer into summer and autumn.

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