UNIVERSITY OF THE
PACIFIC
ECOLOGICAL
ENGINEERING
RESEARCH PROGRAM

High Resolution Dissolved Oxygen Profiling of the Stockton Deep Water Ship Channel during the Summer of 2012

Report 4.8.6

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December, 2013

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List of Acronyms

CDEC	California Data Exchange Center
CMS	Continuous monitoring station
DO	Dissolved Oxygen
DWR	Department of Water Resources
DWSC	Deep Water Ship Channel
EERP	Ecological Engineering Research Program
RRI	Rough and Ready Island
SJR	San Joaquin River
TMDL	Total Maximum Daily Load

Introduction

In the San Joaquin River (SJR), the numeric water quality objectives for minimum dissolved oxygen (DO) concentrations is 5.0 milligrams per liter (mg/L), with the exception of 6.0 mg/L from September 1st through November 30th between the City of Stockton and Turner Cut (Gowdy et al. 2005). The Deep Water Ship Channel (DWSC) on the SJR adjacent to Stockton was first dredged in the 1930s (Newcomb et al. 2010). The low DO conditions in the lower SJR and its negative effects on migrating fish populations were widely recognized by the early 1960's and in 1967 a water quality objective of "5.0 mg/L at all times on the SJR within the Delta" was included in the Central Valley Regional Water Quality Control Board's Basin Plan (Gowdy et al. 2005; Newcomb et al. 2010). Low DO conditions in the DWSC are most frequent between June and October, and in low flow years, but low DO incidents can occur year-round (Gowdy et al. 2005). In 1998, the State Water Resources Control board included the San Joaquin River Stockton's DWSC on the Clean Water Act 303(d) list for DO impairment and a total maximum daily load (TMDL) for oxygen-demanding substances is being implemented by the Central Valley Regional Water Quality Control Board for the SJR (the SJR DO TMDL). The SJR is part of a historically important salmon migration route and the low DO condition of the SJR is an impediment to the restoration of salmon and other fishes (Gowdy et al. 2005).

The Ecological Engineering Research Program (EERP) at the University of the Pacific was hired as the lead scientific agency for the San Joaquin River Dissolved Oxygen Total Maximum Daily Load Project (SJR DO TMDL) (Project: E0883006, ERP-08D-SO3) in order to provide a scientific basis for management actions taken to meet TMDL requirements. As part of the adaptive management portion of this project, sonde surveys of the DWSC, between the Turning Basin and approximately 1 km downstream of Rough and Ready Island (RRI), were conducted. Dissolved oxygen was one of many water quality parameters measured in these surveys.

An independent review panel of the SJR DO TMDL project was asked to evaluate if the portion of the DWSC near the Department of Water Resources (DWR)'s water quality monitoring station on Rough and Ready Island (RRI) represents the lowest DO conditions in the DWSC and if it is a suitable compliance point for DO for the entire DWSC. The location of the aeration facility and the RRI sensors were originally chosen after numerous boat survey's found this to be near lowest DO within the DWSC and it was determined to be a feasible location for construction of the aeration facility (Daum 2005; ICF International 2010). The objective of this report is to aid the panel in answering this question by: 1) examining where in the DWSC, between the Turning Basin and approximately 1 km downstream of RRI, DO excursions occur and when and where they are most frequently occurring, 2) reporting the variation in DO concentration with respect to depth and location within this section of the DWSC, 3) reporting the variation in DO concentration between the three continuous RRI sensors over time, and 4) comparing DO concentrations measured in surveys to the DO concentration at the RRI continuous monitoring sensors over the same time period.

Methods

Study Area

Stockton's deepwater ship channel (DWSC), located on the San Joaquin River upstream in the San Francisco-Bay Delta, is a slow, tidally influenced body of water dredged to approximately 9-13 m deep and 150-350 m wide (Figure 1) (Smith et al. 2004). The SJR, upstream of the DWSC (south of Channel Point), is not dredged and is typically 2 - 3 m deep and 55 – 80 m wide (Smith et al. 2004). Water velocities drop significantly at Channel Point where the shallow SJR enters the DWSC. This drop in water velocity and change in channel geometry has been suspected as a contributing factor to the low DO problem (Gowdy et al. 2005).

Data Collection

The Ecological Engineering Research Program (EERP) scientists conducted four water quality surveys in the DWSC on July 5th, August 2nd, August 16th, and September 6th of 2012 between 8am and 2:30pm. On September 6th, 2012 the aerator at RRI was operating beginning at 9:15 am and continued throughout the rest of the day. YSI 6600 sonde water quality sensors were deployed from a boat while slowly trolling along 3-5 km of the DWSC from the Turning Basin to approximately 1 km downstream of the RRI monitoring station at the northwest end of Rough and Ready Island (Figure 2). Latitude, longitude, and depth were recorded for spatial reference while temperature, specific conductance, pH, dissolved oxygen, turbidity, chlorophyll fluorescence, and phycocyanin were recorded with a time-stamp every 4 seconds. During each of the surveys, the sampling crew stopped at some or all of the following locations: Rough and Ready Island, Light 45, Luis Park, Channel Point, Berth 12/13, Berth 10/11, and the Turning Basin and the water quality sensors were slowly raised and lowered between the surface and bottom of these fixed locations, which will be referred to as "vertical profile data" in this report (Figure 3). "Survey data" will refer to all data taken during the four surveys, including vertical profile data and data taken between these profiles at various depths. The sonde instruments were calibrated before and after each study following EERP's Quality Assurance Project Plan guidelines (Spier et al. 2011). The dates and locations of this study were originally chosen to conduct a preliminary investigation into the impacts of ballast water discharges from ocean going barges docking in the port of Stockton in 2012.

A continuous monitoring station located at the Port of Stockton on RRI (Figure 1) has measured DO and other water quality parameters since 1983 at 1 m depth and since 2008 at 3 and 6 m depths. The Department of Water Resources provided EERP with quality assurance checked data collected at 1, 3 and 6 m depths at the RRI continuous monitoring station. Data collected at this station since 8/28/2000 is available publically through the California Data Exchange Center (CDEC) webpage.

Survey data collected by DWR in the DWSC was provided by Christine Joab with the Central Valley Regional Water Quality Control Board for comparison to data collected by EERP. DWR's surface dissolved oxygen samples were collected using a through-hull pump and were analyzed with the modified Winkler titration method. DWR's bottom measurements and EERP

measurements were made in-situ using a YSI 6600 multiparameter data sonde equipped with an optical dissolved oxygen sensor.

Data Analysis

Data was reviewed to remove erroneous sensor readings such as the sensor hitting the channel bottom and stirring up sediment. All data with turbidity values greater than 30 NTU, which is not normally observed in the DWSC, were assumed to have hit the bottom of the channel and were removed. Reviewed data was visualized in Grapher (Golden Software, Inc.) as contour plots using an inverse distance algorithm. Contour plots included the entire up to downstream transect on a given survey date. Each vertical profile was plotted on XY scatter plots in Grapher. The data was geospatially analyzed using ArcGIS 10.0 (Esri, Redlands, CA). Data collected at RRI monitoring station corresponded to the same time period as the surveys conducted by EERP (to the closest 15 minute interval) for statistical comparisons between the two data sets. Statistical analyses were performed using JMP 9.0 software (SAS, Cary, NC). Significance was tested by pairwise student's t-test ($\alpha = 0.05$).

Results and Discussion

Location and Frequency of Minimum DO Criteria Exceedances

The locations and frequency of low DO events occurring in the DWSC were examined during four water quality survey's conducted between July and September 2012. Minimum DO water quality criteria are 6.0 mg/L from September 1 through November 30 and 5.0 mg/L at all other times within the study area. Contour plots of the four surveys indicate that the frequency of DO excursions near the RRI monitoring station may underestimate the occurrence of low DO conditions upstream (Figures 3-7).

For statistical analysis, the DWSC was divided into three vertical sections: 0 -2 m, 2 - 4.5 m and greater than 4.5 m. These depths were chosen because they represent mid-points between each continuous DO sensor at the RRI monitoring station. Additionally, the DWSC was divided into three lateral sections: Light 45 and downstream, Berth 12/13 to Light 45, and upstream of Berth 12/13 (Figure 3). The area upstream of Berth 12/13 is a dead-end reach of the DWSC and is not part of the primary migratory route for critical fish species. A pairwise t-test between these sections of the river indicated that the lowest DO concentrations were found upstream of Berth 12/13 at depths greater than 4.5 m (Table 1). The percentage of vertical profile measurements below 5.0 mg/L and below 6.0 mg/L are shown in Tables 2 and 3 respectively for each section of the DWSC. Figures 8, 9 and 10 show the percentage of survey measurements below 5.0 mg/L and 6.0 mg/L at 1 m depth intervals and for each of the three lateral sections of the DWSC. Most measurements (> 90 %) were below 6.0 mg/L at depths greater than 4.5 m throughout the DWSC (Table 3 and Figures 8 – 10). Similar to what was observed in the contour plots, a higher fraction of measurements were below 5.0 mg/L upstream of Light 45 as compared to downstream of Light 45 in each depth region (Table 2 and Figures 8 - 10).

Spatial and Temporal Variation in Dissolved Oxygen Concentrations in the DWSC

DO in the DWSC varied with depth. Water near the surface had the highest DO and decreased with increasing depth. For each of 24 vertical profiles taken during the 4 surveys, data taken at depths greater than 4.5 m had significantly lower dissolved oxygen concentration than measurements taken at depths less than 4.5 m (t-test, $\alpha = 0.05$). Measurements taken between 2 – 4.5 m depth had significantly lower DO concentrations than measurements taken at 0 – 2 m depth, for all vertical profiles except two which were not significantly different between these depths (t-test, $\alpha = 0.05$). Box and whisker plots of DO concentration measured, at 1 m depth intervals during all four surveys are shown in Figures 11, 12 and 13 for each of the three lateral sections of the DWSC. Both the maximum and minimum DO concentrations were typically observed upstream of Berth 12/13 (Table 4 and Figures 11 - 13). Stratification of dissolved oxygen was only observed in the Turning Basin, upstream of Berth 12/13 (Figures 14 - 17). This is consistent with previous measurements which found little stratification in the DWSC except within the Turning Basin and occasionally downstream of the Turning Basin, but only in the afternoons on warm days (Litton 2003; Grimes 2004; Schmieder et al. 2008).

Variation in DO concentration between the three RRI Monitoring Station Sensors

The fraction of DO measurements below 5.0 and 6.0 mg/L measured at each of the 3 RRI monitoring station sensors is highest during the summer months in 2012 (Table 5). The frequency of low DO events is higher for the 3 and 6 m sensors as compared to the 1 m sensor (Table 5). The daily fluctuation in DO is greater for the 1 m sensor than for the 3 and 6 m sensors at RRI on the days of survey and the difference between the 3 sensors is greatest between 10 am and 8 pm (Figure 18).

Comparisons between RRI Monitoring Station, DWR survey data, and EERP Data

In comparison to survey data, the continuous monitoring station sensors at RRI regularly measured lower DO concentration and more excursions of the 5.0 and 6.0 mg/L water quality criteria at similar depths (Tables 2 – 3 and Figures 8 – 17 and Figure 19). The sensors at RRI do not reflect the minimum and maximum DO conditions observed upstream of Berth 12/13 (Table 4 and Figure 13), but even in this reach of the river the fraction of measurements with DO concentrations below 5.0 and 6.0 mg/L does not exceed what is reported by the RRI sensors at the same depths (Tables 2 – 3 and Figure 10). Upstream of Berth 12/13 is a dead-end slough ending at the Turning Basin which receives less tidal exchange, less mixing and is more subject to stratification then the rest of the DWSC. The channel geometry and reduced mixing in this part of the DWSC is likely responsible for the difference between RRI sensors the lowest DO conditions observed upstream of Berth 12/13.

DWR surveys were conducted at 1 m below the water's surface and 1 m above the river bottom within a few days of each survey made by EERP and at approximately the same location as four of the profile locations used by EERP. Bottom measurements made by DWR were very similar to profile measurements at the same depths (Figures 14-17). However, surface measurements made by DWR were typically higher than profile measurements at the same depths (75% of the time). The difference between surface measurements made by DWR and in the profiles may be

a result of DWR using a different method to measure surface sample than was used for bottom samples and vertical profiles or it may be due to the higher variation in DO at the surface and the samples being collected at slightly different locations and dates between the two groups.

Conclusions

The minimum DO criteria of 6.0 mg/ L from September 1 through November 30 and 5.0 mg/L at all other times was not met in 43.3 % of the vertical profiles measurements made between July and September of 2012. On September 6th, 89.6% of vertical profile measurements were below the more stringent water quality criteria of 6.0 mg/L. The surveys and vertical profile measurements conducted by EERP indicated that DO conditions near the RRI monitoring station may under estimate the frequency of low DO conditions upstream of Light 45 in the DWSC. However, the RRI monitoring data was found to consistently report lower DO concentrations and a higher frequency of DO excursions than survey and profile data collected at similar depths throughout the DWSC.

Acknowledgements

We gratefully acknowledge the Ecosystem Restoration Program and its implementing agencies (California Department of Fish and Wildlife, U.S. Fish and Wildlife Service, and the National Marine Fisheries Service) for supporting this project (E0883006, ERP-08D-SO3). We are also grateful for the assistance of Chris Joab of the Central Valley Regional Water Quality Control Board TMDL section, and Carol Atkins of the California Department of Fish and Wildlife.

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Table 1. Significance of difference between DO in different sections of the DWSC (pairwise t-test, alpha = 0. Significance: Each pair student's t-test ($\alpha = 0.05$). A different letter indicates statistical difference between groups. "A" indicates the highest dissolved oxygen; "B" indicates the second highest dissolved oxygen, etc.05). Data was compiled from vertical profiles collected on July 5th 8:16am – 11:56 am, August 2nd 8:41am – 12:08pm, August 16th 8:51am – 1:55pm, and September 6th 8:55am – 1:16pm.

	Downstream ← Upstream		
Depth Group	**Light 45 to 1 km downstream of RRI**	**Berth 12/13 to Light 45**	**Upstream of Berth 12/13**
0-2 m	A, B	B	A
2-4.5 m	C	C	C
>4.5 m	D	E	F

Table 2. Percent of profile measurements below 5.0 mg/L in each river section compared to the RRI monitoring station. Data compiled from vertical profiles was collected on July 5th 8:16am – 11:56 am, August 2nd 8:41am – 12:08pm, August 16th 8:51am – 1:55pm, and September 6th 8:55am – 1:16pm of 2012. RRI monitoring data was compiled from July 5th 8:15am – 12:00 pm, August 2nd 8:45am – 12:15pm, August 16th 8:45am – 2:00pm, and September 6th 9:00am – 1:15pm of 2012.

		Downstream ← Upstream		
Depth Group	**RRI**	**Light 45 to 1 km downstream of**	**Berth 12/13 to Light 45**	**Upstream of Berth 12/13**
0-2 m	2.8	0	0.9	4.8
2-4.5 m	54.2	2.1	2.5	12.1
>4.5 m	58.3	33.9	22.3	48.2

Table 3. Percent of profile measurements below 6.0 mg/L in each river section compared to the RRI monitoring station. Data compiled from vertical profiles was collected on July 5th 8:16am – 11:56 am, August 2nd 8:41am – 12:08pm, August 16th 8:51am – 1:55pm, and September 6th 8:55am – 1:16pm of 2012. RRI monitoring data was compiled from July 5th 8:15am – 12:00 pm, August 2nd 8:45am – 12:15pm, August 16th 8:45am – 2:00pm, and September 6th 9:00am – 1:15pm of 2012.

		Downstream ← Upstream		
Depth Group	**RRI**	**Light 45 to 1 km downstream of**	**Berth 12/13 to Light 45**	**Upstream of Berth 12/13**
0-2 m	84.7	55.5	80.1	86
2-4.5 m	100	97.6	92.8	86.8
>4.5 m	100	100	100	97.3

Table 4. Maximum (Max), mean and minimum (Min) DO concentration (mg/L) of individual vertical profiles taken during the four surveys. (CMS) indicates data from a continuous monitoring station sensor at RRI.

		0 – 2 m Depth			2 – 4.5 m Depth			> 4.5 m Depth			Difference between Min
Site Names	**Date**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**and Maximum DO**
Berth 10/11	7/5/2012	**5.2**	5.2	5.2	5.2	5.1	4.9	5.0	4.8	**4.6**	**0.6**
Berth 12/13	7/5/2012	**5.4**	5.2	5.1	5.3	5.0	4.6	5.3	4.9	**4.6**	**0.7**
Channel Point	7/5/2012	**5.0**	4.9	4.9	5.0	4.9	4.9	4.9	4.9	**4.8**	**0.2**
Luis Park	7/5/2012	**5.8**	5.6	5.3	5.7	5.4	5.2	5.4	4.9	**4.5**	**1.4**
Light 45	7/5/2012	**5.8**	5.5	5.1	5.8	5.4	5.1	5.4	4.8	**4.2**	**1.6**
RRI	7/5/2012	**6.0**	5.8	5.6	5.9	5.6	5.4	5.7	5.5	**5.4**	**0.6**
RRI (CMS)	7/5/2012	**6.1**	5.5	5.3	5.5	4.9	4.1	5.5	5.1	**4.4**	**1.8**
Turning Basin	8/2/2012	**10.2**	9.9	9.7	9.7	8.8	5.8	5.8	3.7	**1.7**	**8.5**
Channel Point	8/2/2012	**6.5**	6.4	6.3	6.3	6.1	5.9	5.8	5.2	**5.0**	**1.5**
Luis Park	8/2/2012	**7.9**	7.4	6.4	6.2	5.8	5.6	5.5	4.8	**4.3**	**3.6**
Light 45	8/2/2012	**6.7**	6.3	5.9	5.9	5.8	5.7	5.7	5.1	**4.2**	**2.6**
RRI	8/2/2012	**6.4**	6.2	5.8	5.7	5.5	5.5	5.5	5.5	**5.4**	**1.0**
RRI (CMS)	8/2/2012	**6.3**	5.3	4.9	4.9	4.8	4.7	5.0	4.8	**4.4**	**2.0**
Turning Basin	8/16/2012	**7.4**	7.3	7.3	7.3	7.0	6.8	6.7	6.1	**5.0**	**2.3**
Berth 10/11	8/16/2012	**6.0**	5.8	5.5	5.6	5.5	5.5	5.5	5.0	**3.3**	**2.7**
Berth 12/13	8/16/2012	**5.8**	5.5	5.2	5.3	5.2	5.2	5.2	5.0	**4.6**	**1.2**
Channel Point	8/16/2012	**5.5**	5.4	5.4	5.5	5.4	5.3	5.4	5.3	**5.1**	**0.3**
Luis Park	8/16/2012	**5.5**	5.4	5.2	5.5	5.3	5.2	5.3	5.1	**5.0**	**0.6**
Light 45	8/16/2012	**5.6**	5.4	5.1	5.5	5.1	4.9	5.1	4.9	**4.8**	**0.8**
RRI	8/16/2012	**5.7**	5.6	5.6	5.5	5.4	5.2	5.3	5.1	**4.8**	**0.9**
RRI (CMS)	8/16/2012	**6.7**	6.0	5.2	5.8	5.1	4.8	5.3	4.7	**4.2**	**2.6**
Turning Basin	9/6/2012	**5.8**	5.7	5.7	5.8	5.7	5.7	5.8	5.2	**3.9**	**1.8**
Berth 12/13	9/6/2012	**5.7**	5.6	5.6	5.6	5.6	5.6	5.6	5.6	**5.5**	**0.1**
Channel Point	9/6/2012	**5.8**	5.8	5.7	5.7	5.7	5.7	5.7	5.6	**5.6**	**0.3**
Luis Park	9/6/2012	**5.9**	5.8	5.7	5.7	5.7	5.6	5.7	5.6	**5.4**	**0.5**
Light 45	9/6/2012	**6.0**	5.9	5.8	5.8	5.7	5.7	5.7	5.6	**5.3**	**0.7**
RRI	9/6/2012	**6.4**	6.2	5.9	6.1	6.0	5.9	6.0	5.9	**5.8**	**0.6**
RRI (CMS)	9/6/2012	**6.0**	5.6	5.2	5.4	5.2	5.0	5.3	5.0	**4.7**	**1.2**

Table 5. Percent of measurements at the RRI monitoring station with DO measurements below 5.0 and 6.0 mg/L in 2012

	Percent of Measurements under 5.0 mg/L			Percent of Measurements under 6.0 mg/L			Minimum Monthly DO (mg/L)		
Sensor depth	**1 m**	**3 m**	**6 m**	**1 m**	**3 m**	**6 m**	**1 m**	**3 m**	**6 m**
January	0.0	0.0	0.0	0.0	0.0	0.0	9.02	9.25	9.19
February	0.0	0.0	0.0	0.0	0.0	0.0	8.23	8.55	8.76
March	0.0	0.0	0.0	0.0	0.0	0.0	6.88	6.75	6.6
April	0.0	0.0	0.0	0.7	1.7	4.1	5.54	5.32	5.37
May	0.0	0.1	0.0	0.3	1.2	0.2	5.81	4.4	5.89
June	14.3	24.4	30.8	60.5	81.0	79.9	3.76	4.11	3.13
July	10.1	23.6	32.4	59.9	93.0	92.8	2.85	2.37	3.52
August	15.0	41.9	63.9	75.7	97.6	99.8	3.38	3.7	3.88
September	0.2	1.6	4.6	9.4	20.5	33.0	4.24	4.54	4.49
October	0.0	0.0	0.0	2.6	0.8	1.3	5.11	5.42	5.53
November	0.0	0.0	0.0	0.0	0.0	0.0	6.1	6.22	6.47
December	0.0	0.0	0.0	2.5	3.1	14.2	5.64	5.79	5.66

Figure 1. Deep Water Ship Channel (DWSC) study area. Geometry of the DWSC and un-dredged San Joaquin River south of Channel Point.

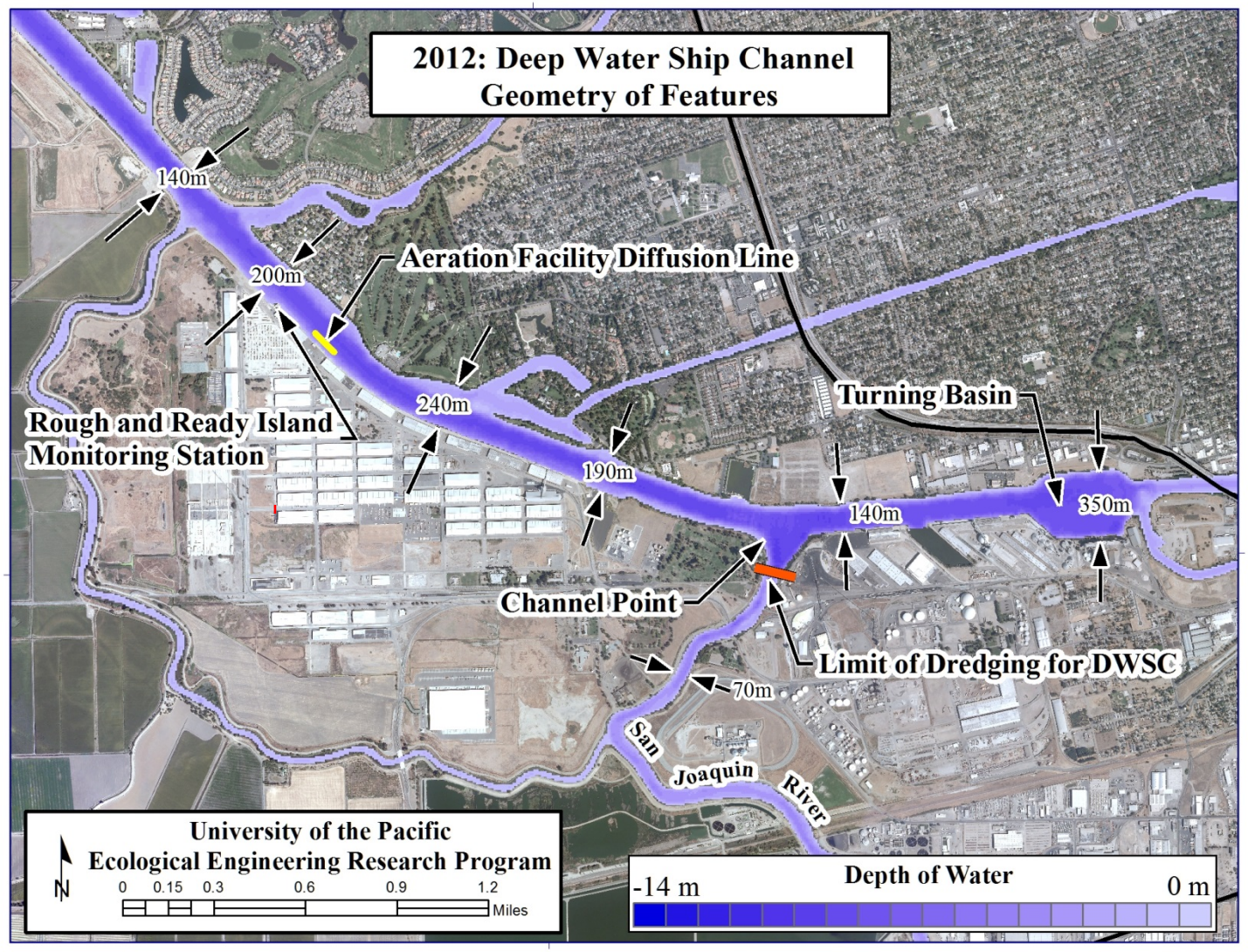

Figure 2. Deep Water Ship Channel (DWSC) study area. Lateral profile extent within the DWSC.

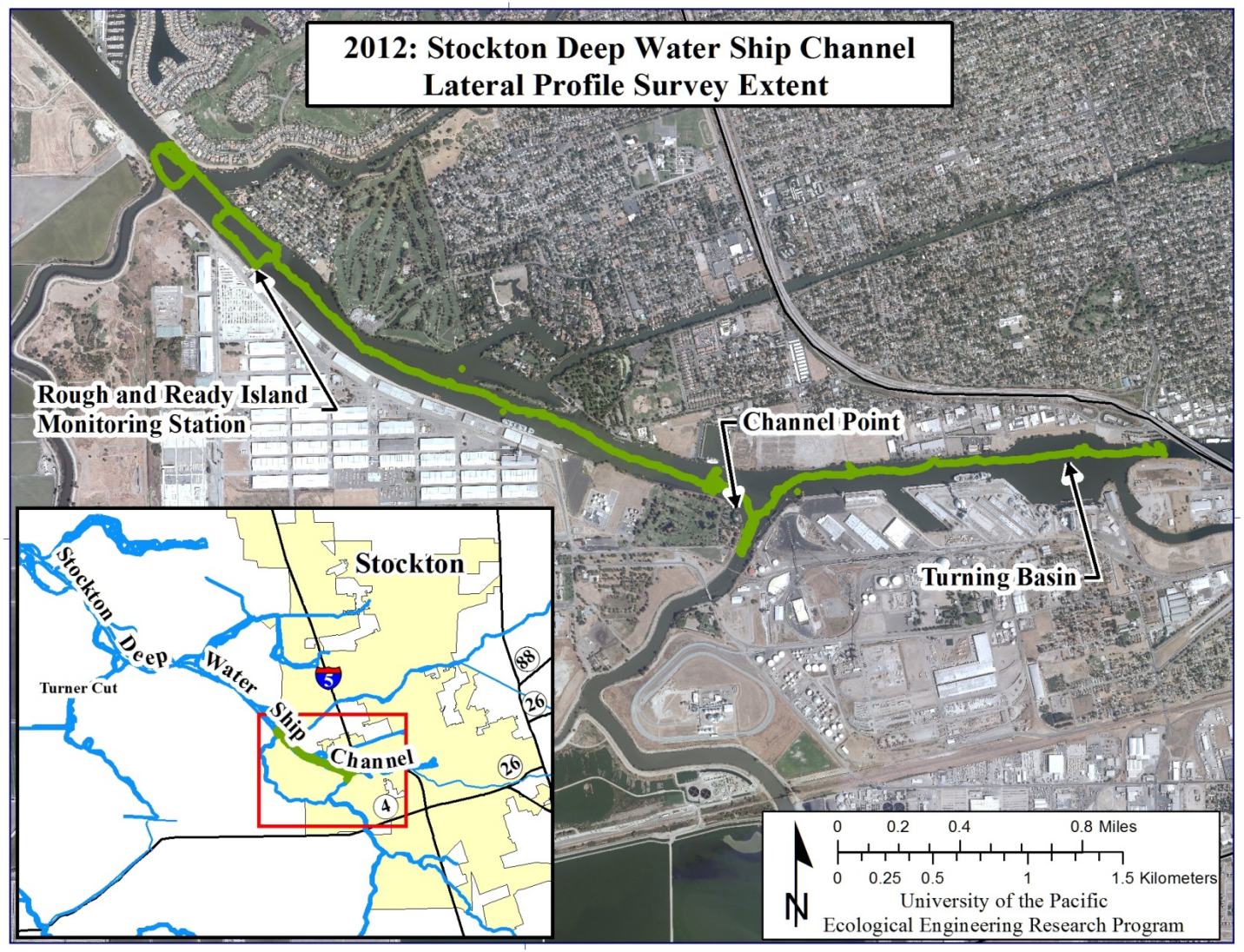

Figure 3. Deep Water Ship Channel (DWSC) study area. Locations of vertical profiles.

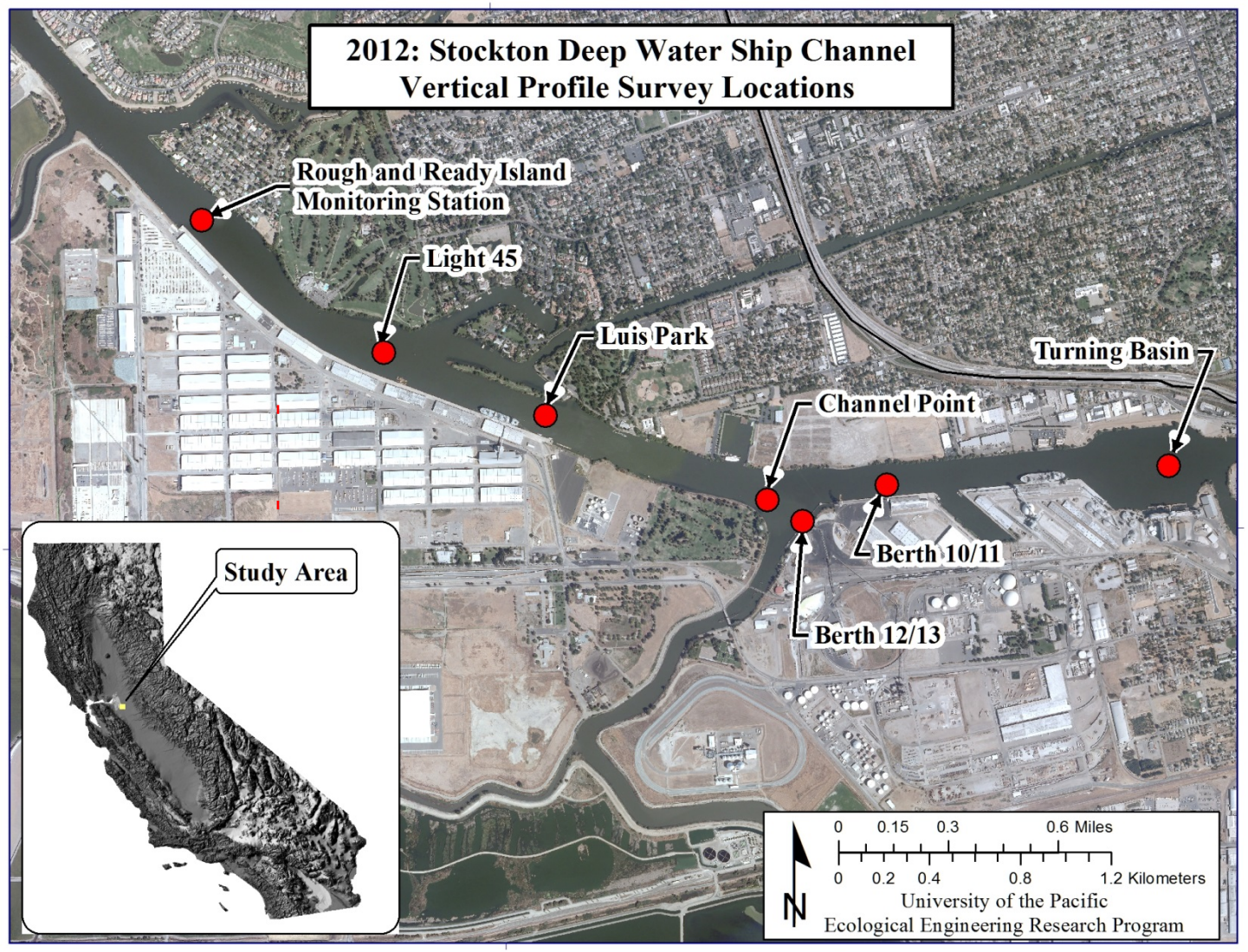

Figure 4. Contour plot of dissolved oxygen in the Stockton Deep Water Ship Channel on July 5th, 2012. The dissolved oxygen compliance value during this period was 5mg/l. This compliance value is not met below the top 3-11 m of water. Moving upstream of RRI the fraction of the water column with excursions of this DO requirement increases. This data was collected on an outgoing tide.

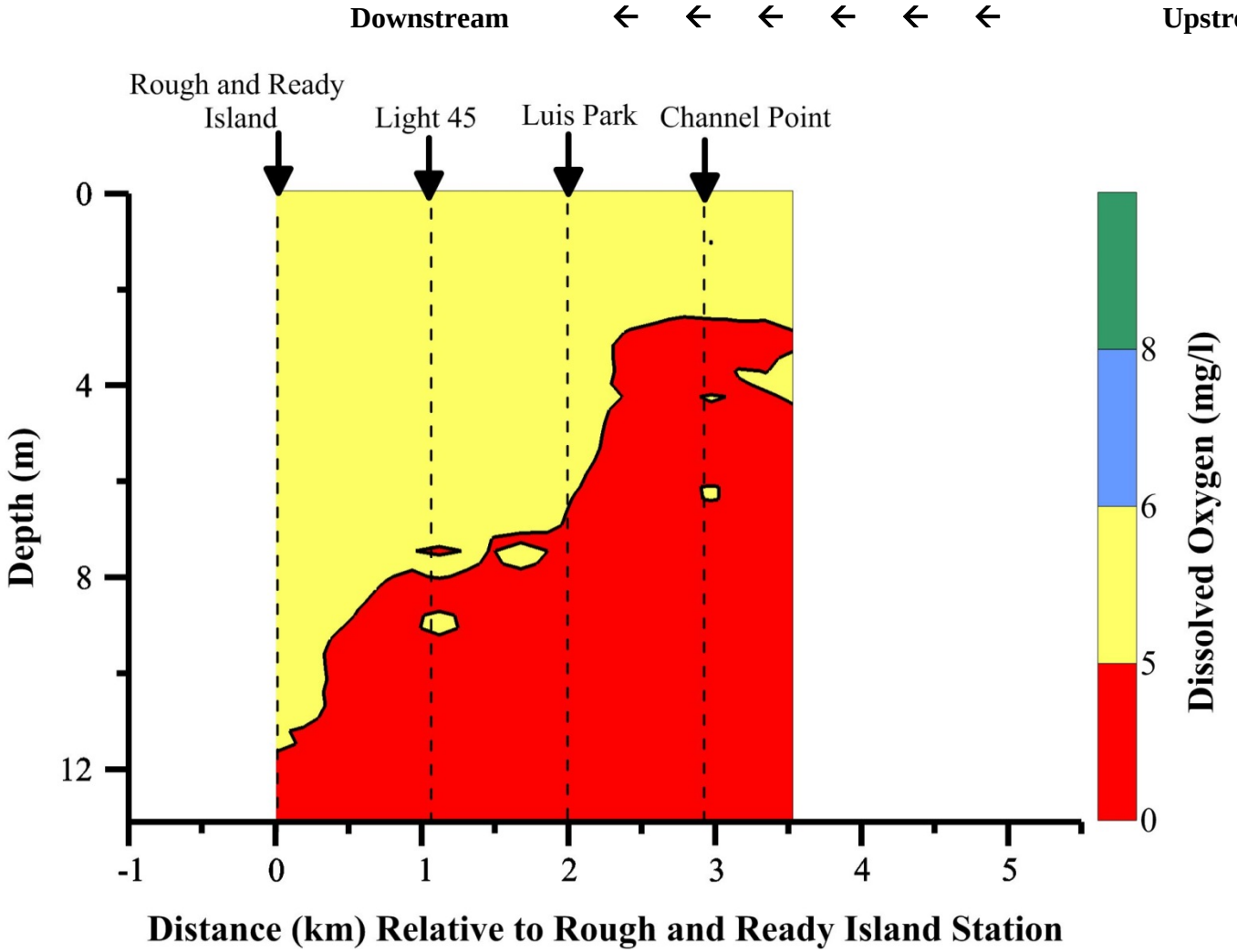

Figure 5. Contour plot of dissolved oxygen in the Stockton Deep Water Ship Channel on August 2nd, 2012. The dissolved oxygen compliance value during this period was 5mg/l. This compliance value is met at all depths downstream of Light 45, but is not met at depths greater than 7-9 m upstream of Light 45. This data was collected on an outgoing tide.

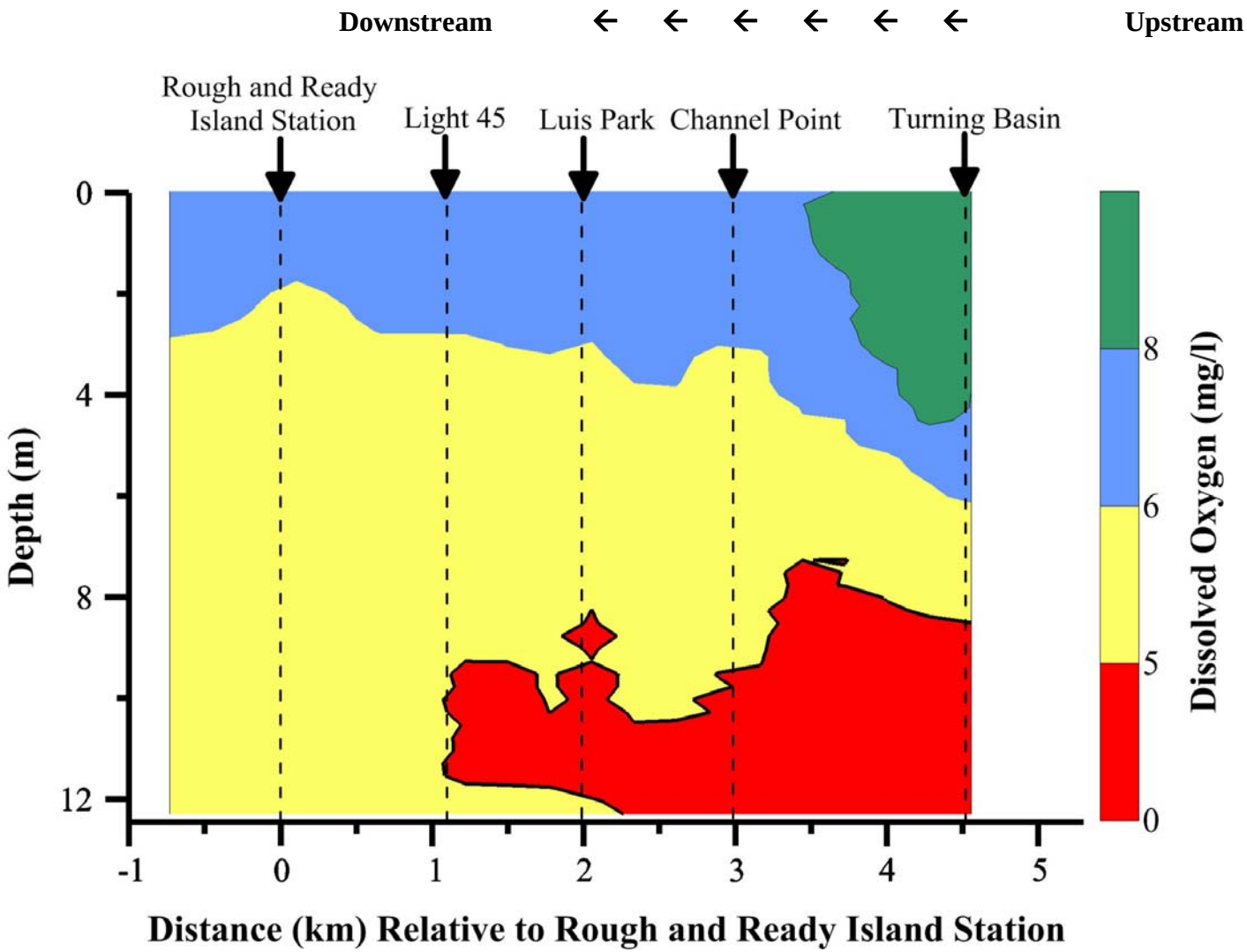

Figure 6. Contour plot of dissolved oxygen in the Stockton Deep Water Ship Channel on August 16th, 2012. The dissolved oxygen compliance value during this period was 5mg/l. This compliance value is met at all depths approximately 0.5 km downstream of Light 45, but is not met at depths greater than 7-9 m upstream of Light 45. This data was collected on an outgoing tide and ended in a slack tide.

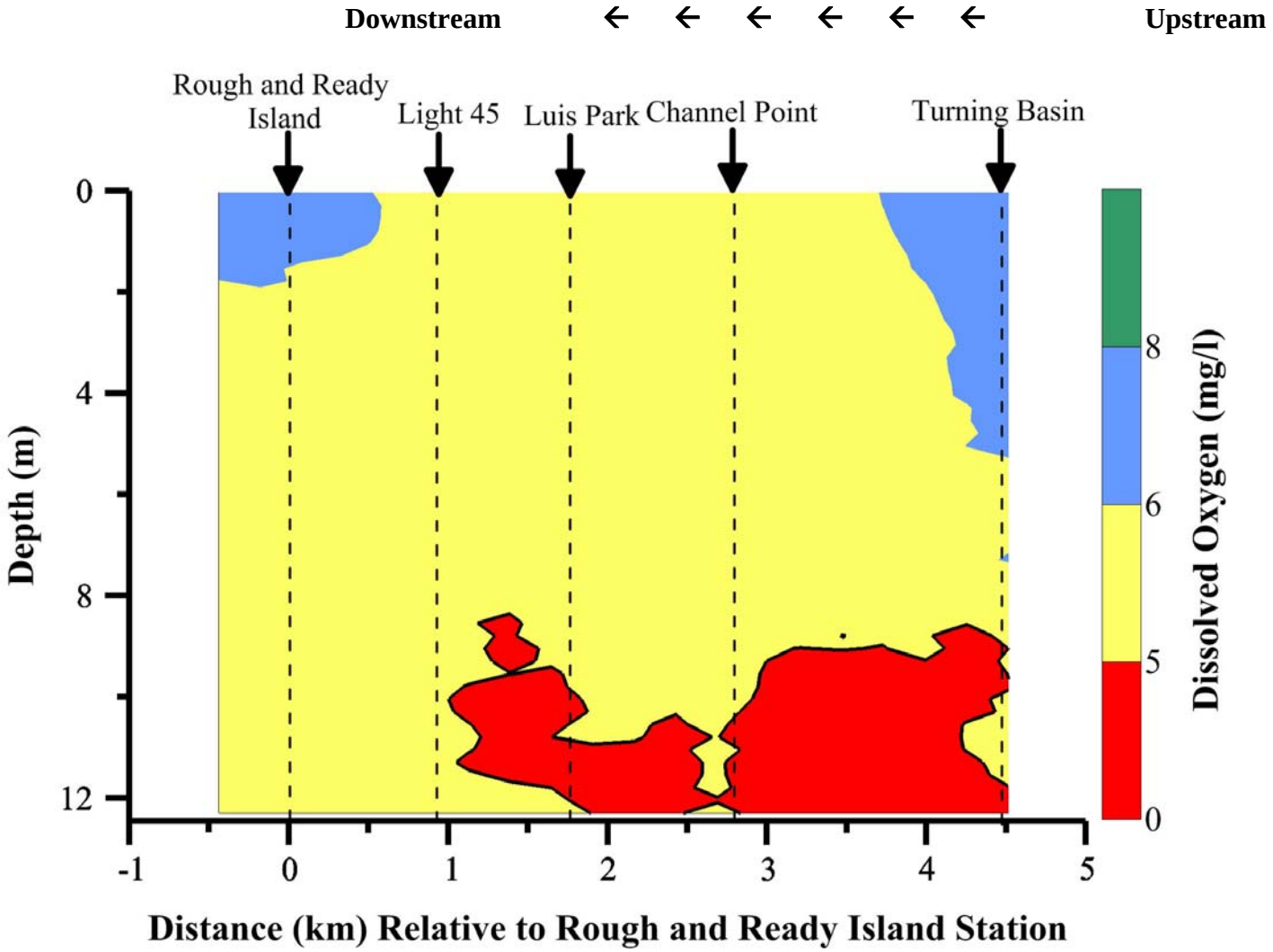

Figure 7. Contour plot of dissolved oxygen in the Stockton Deep Water Ship Channel on September 6th, 2012. The dissolved oxygen compliance value during this period was 6mg/l. This compliance value not met in most of the Deep Water Ship Channel with the exception of depths less than 4 m and within 1 km of the RRI monitoring station. This data was collected starting during an incoming tide and ending with an outgoing tide. The RRI aerator was actively running starting at 9 am on September 6th, 2012 during this transect.

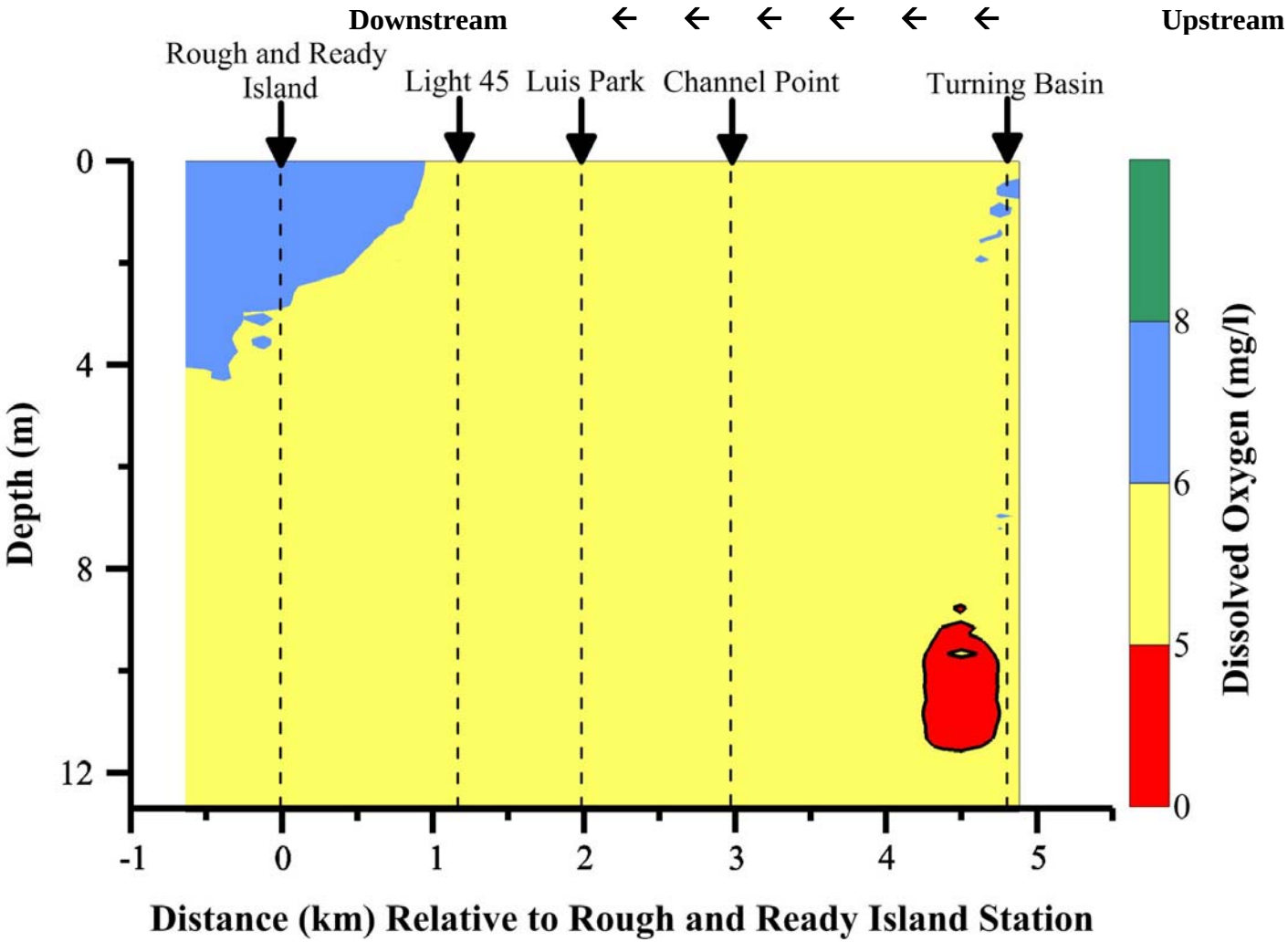

Figure 8. DO conditions between Light 45 and approximately 1 km downstream of Rough and Ready Island (RRI). Survey data from July 5th 8:08am – 12:58 pm, August 2nd 8:36am – 12:36pm, August 16th 8:38am – 2:17pm, and September 6th 8:34am – 1:52pm of 2012 are included. RRI monitoring station data from 1 m, 3m and 6m sensors are shown. RRI data was compiled from the following date/times July 5th 8:00am – 1:00 pm, August 2nd 8:30am – 12:45pm, August 16th 8:30am – 2:30pm, and September 6th 8:30am – 2:00pm of 2012.

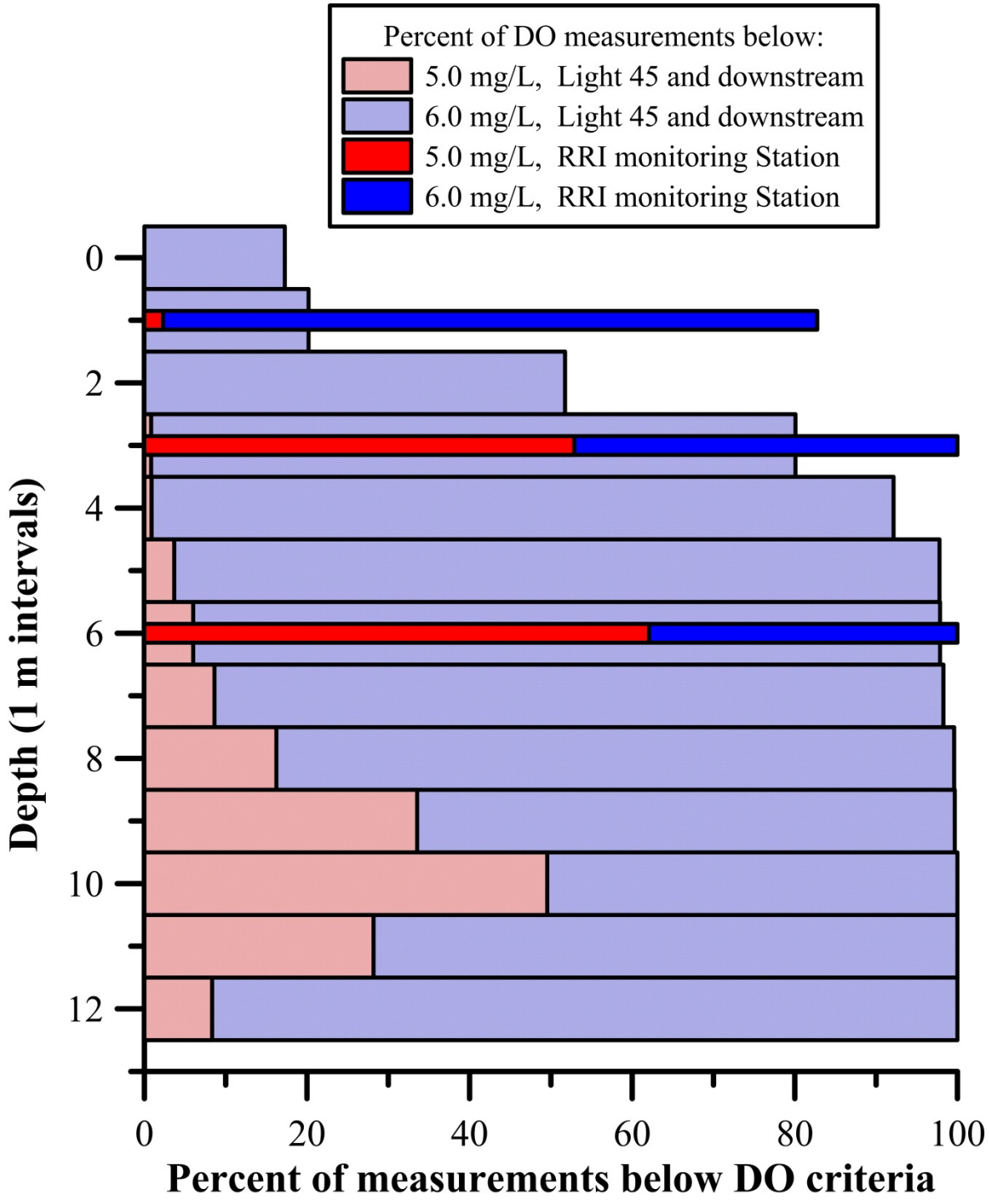

Figure 9. DO conditions between Berth 12/13 and Light 45. Survey data from July 5th 8:08am – 12:58 pm, August 2nd 8:36am – 12:36pm, August 16th 8:38am – 2:17pm, and September 6th 8:34am – 1:52pm of 2012 are included. RRI monitoring station data from 1 m, 3m and 6m sensors are shown. RRI data was compiled from the following date/times July 5th 8:00am – 1:00 pm, August 2nd 8:30am – 12:45pm, August 16th 8:30am – 2:30pm, and September 6th 8:30am – 2:00pm of 2012.

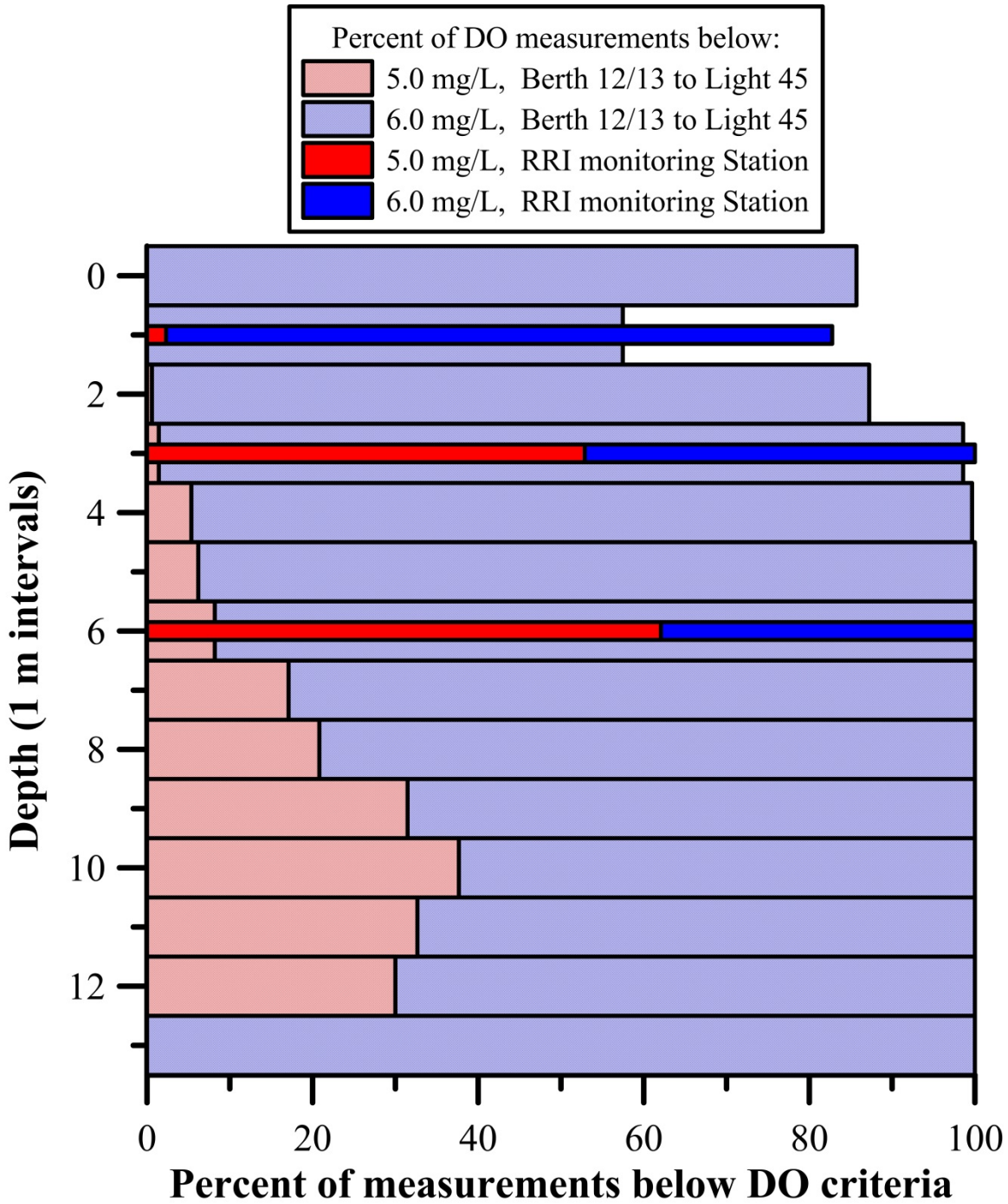

Figure 10. DO conditions upstream of Berth 12/13. Survey data from July 5th 8:08am – 12:58 pm, August 2nd 8:36am – 12:36pm, August 16th 8:38am – 2:17pm, and September 6th 8:34am – 1:52pm of 2012 are included. RRI monitoring station data from 1 m, 3m and 6m sensors are shown. RRI data was compiled from the following date/times July 5th 8:00am – 1:00 pm, August 2nd 8:30am – 12:45pm, August 16th 8:30am – 2:30pm, and September 6th 8:30am – 2:00pm of 2012.

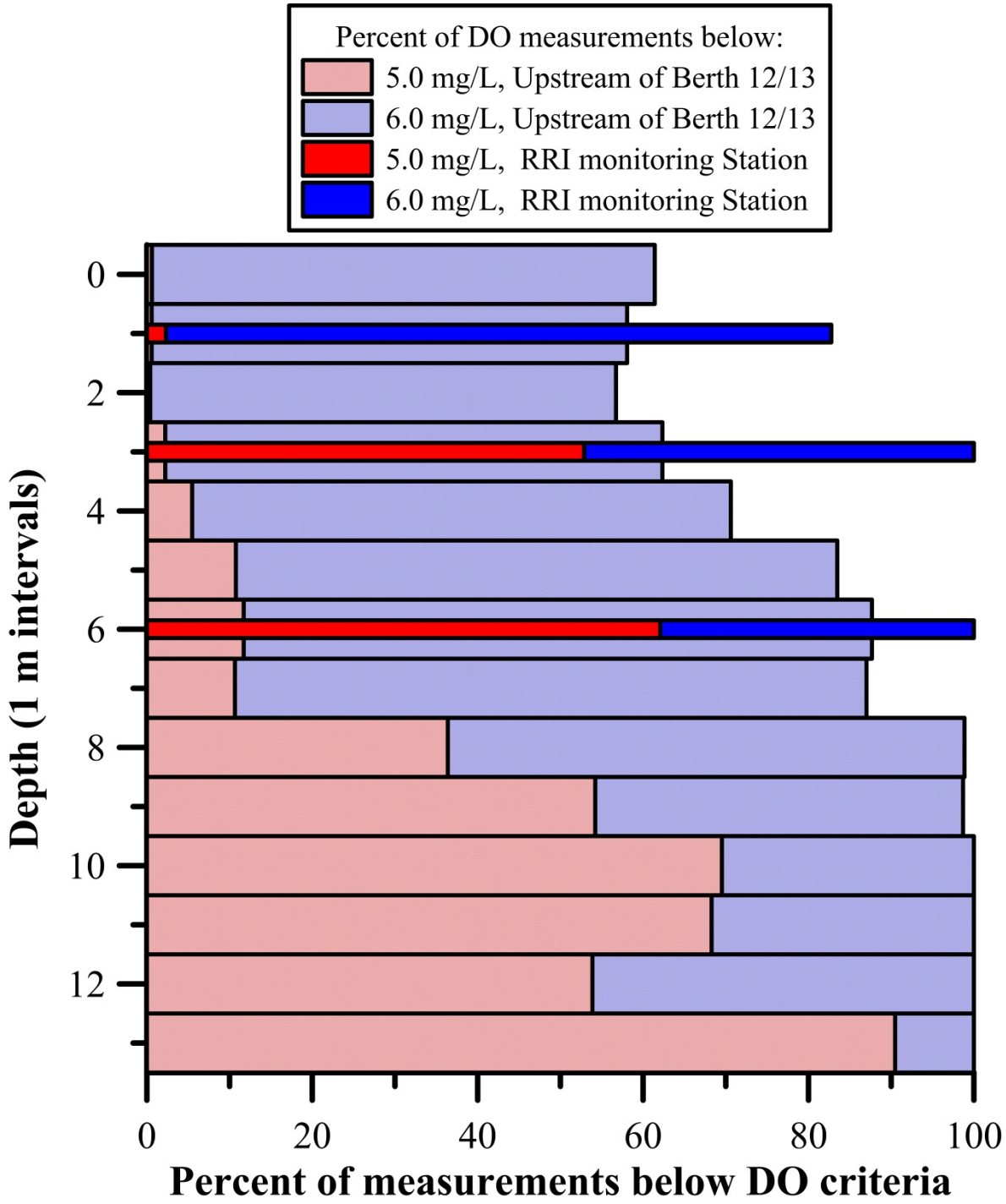

Figure 11. Box and whisker plot of DO conditions between Light 45 and approximately 1 km downstream of Rough and Ready Island (RRI). Survey data from July 5th 8:08am – 12:58 pm, August 2nd 8:36am – 12:36pm, August 16th 8:38am – 2:17pm, and September 6th 8:34am – 1:52pm of 2012 are included. RRI monitoring station data from 1 m, 3m and 6m sensors are shown. RRI data was compiled from the following date/times July 5th 8:00am – 1:00 pm, August 2nd 8:30am – 12:45pm, August 16th 8:30am – 2:30pm, and September 6th 8:30am – 2:00pm of 2012. Red dotted lines indicate the DO regulatory criteria points of 5.0 and 6.0 mg/L DO.

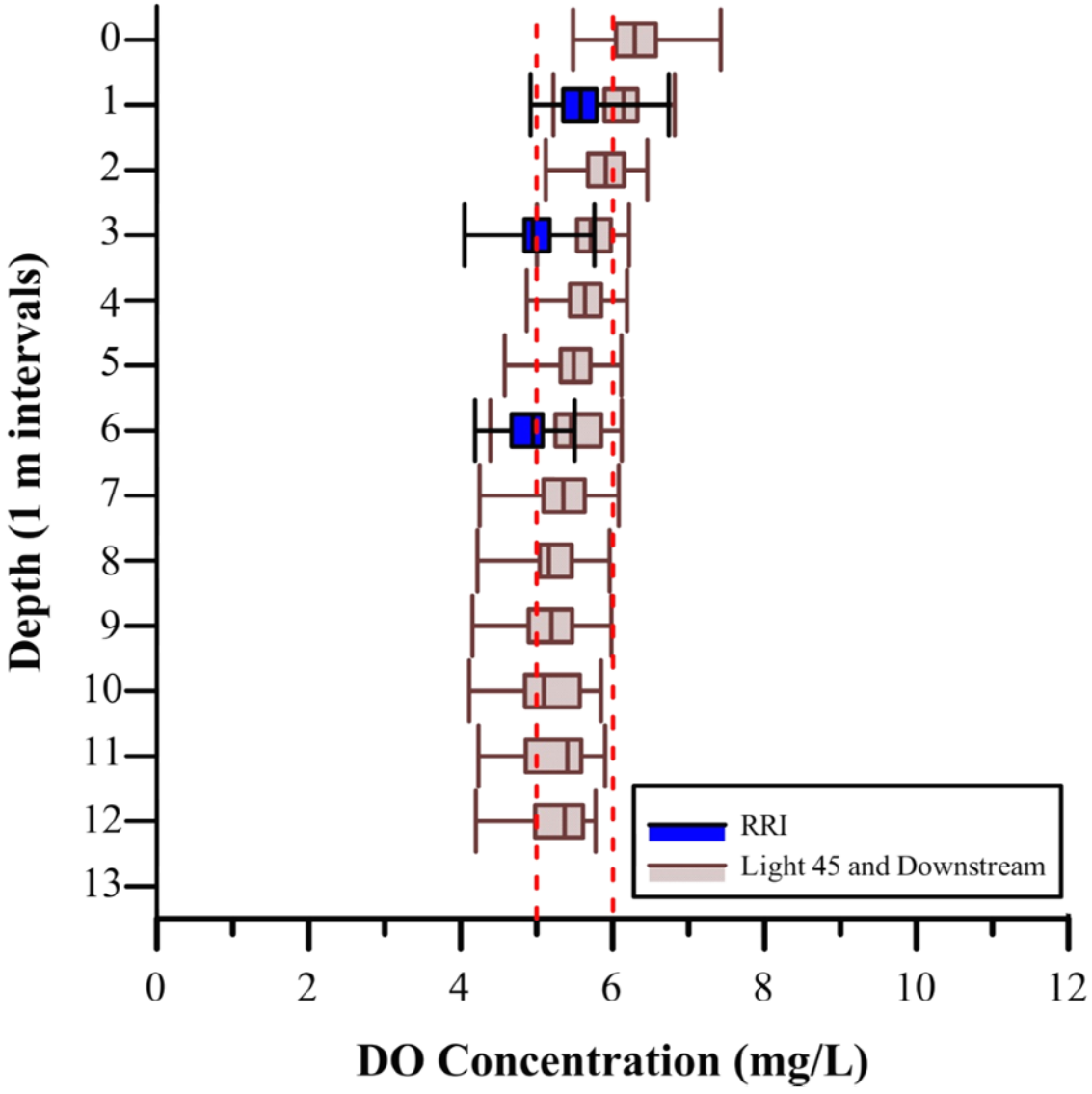

Figure 12. Box and whisker plot of DO conditions between Berth 12/13 and Light 45. Survey data from July 5th 8:08am – 12:58 pm, August 2nd 8:36am – 12:36pm, August 16th 8:38am – 2:17pm, and September 6th 8:34am – 1:52pm of 2012 are included. RRI monitoring station data from 1 m, 3m and 6m sensors are shown. RRI data was compiled from the following date/times July 5th 8:00am – 1:00 pm, August 2nd 8:30am – 12:45pm, August 16th 8:30am – 2:30pm, and September 6th 8:30am – 2:00pm of 2012. Red dotted lines indicate the DO regulatory criteria points of 5.0 and 6.0 mg/L DO.

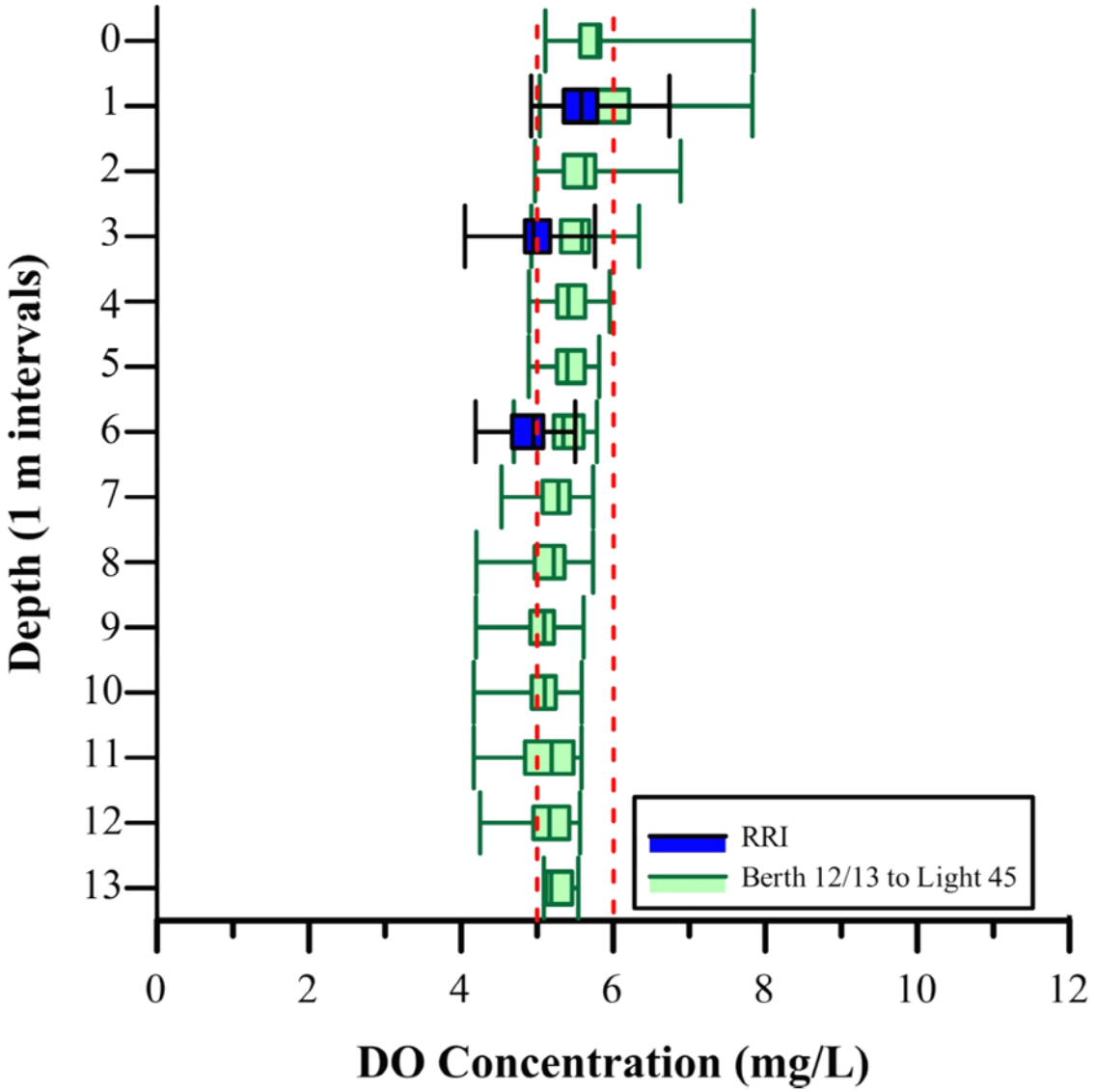

Figure 13. Box and whisker plot of DO conditions upstream of Berth 12/13. Survey data from July 5th 8:08am – 12:58 pm, August 2nd 8:36am – 12:36pm, August 16th 8:38am – 2:17pm, and September 6th 8:34am – 1:52pm of 2012 are included. RRI monitoring station data from 1 m, 3m and 6m sensors are shown. RRI data was compiled from the following date/times July 5th 8:00am – 1:00 pm, August 2nd 8:30am – 12:45pm, August 16th 8:30am – 2:30pm, and September 6th 8:30am – 2:00pm of 2012. Red dotted lines indicate the DO regulatory criteria points of 5.0 and 6.0 mg/L DO.

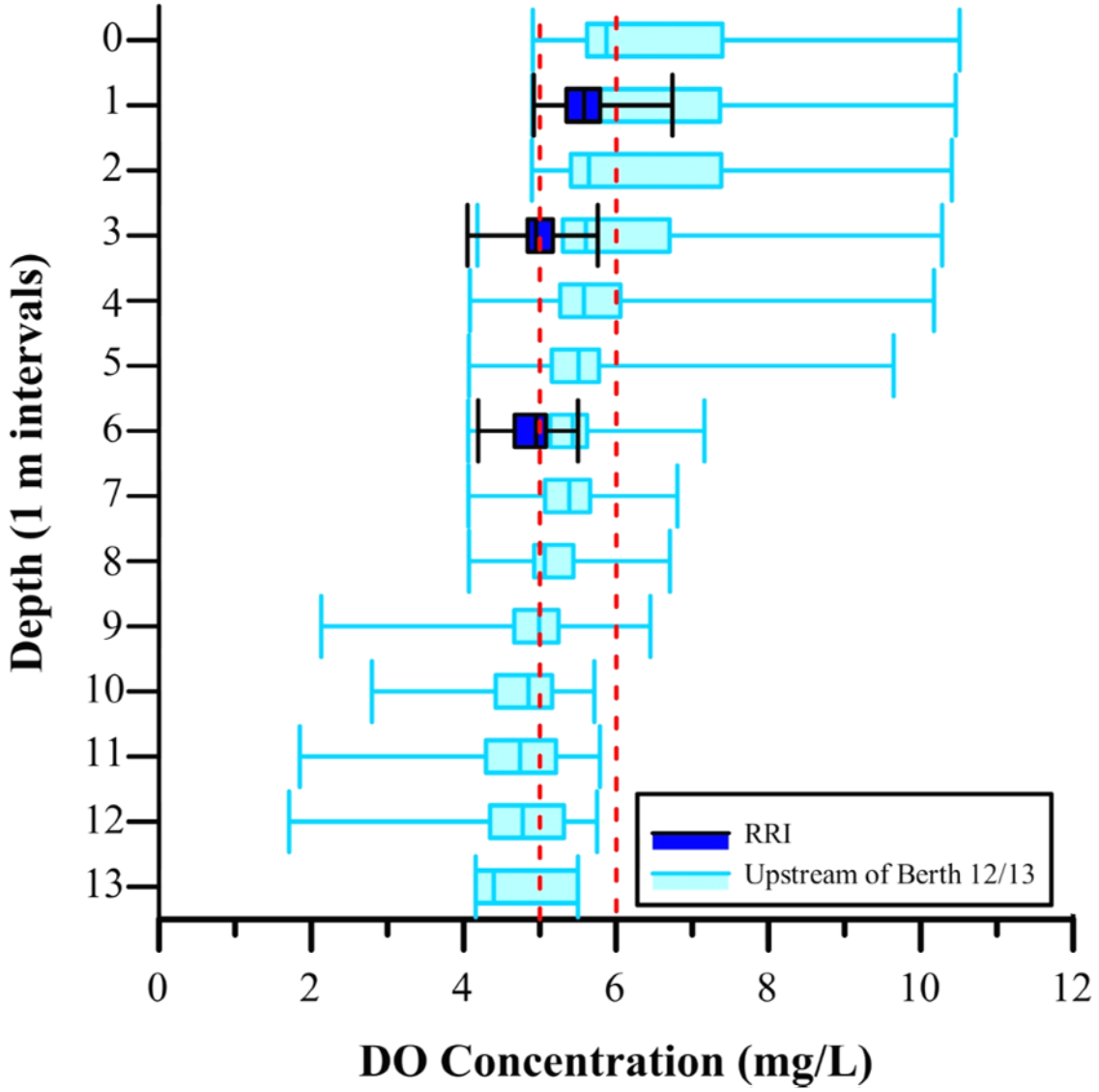

Figure 14. Dissolved oxygen profiles measured on July 5th 8:16am – 11:56 am, 2012 by the Ecological Engineering Research Program (EERP). Department of Water Resources (DWR) DO measurements 1 m below the surface and 1 m above the river bottom measured on July 2nd 11:15am - 11:55am, 2012 for comparison. DWR's surface dissolved oxygen samples were collected using a through-hull pump and were analyzed with the modified Winkler titration method. DWR's bottom measurements and EERP measurements were made *in-situ* using a YSI 6600 multiparameter data sonde equipped with an optical dissolved oxygen sensor.

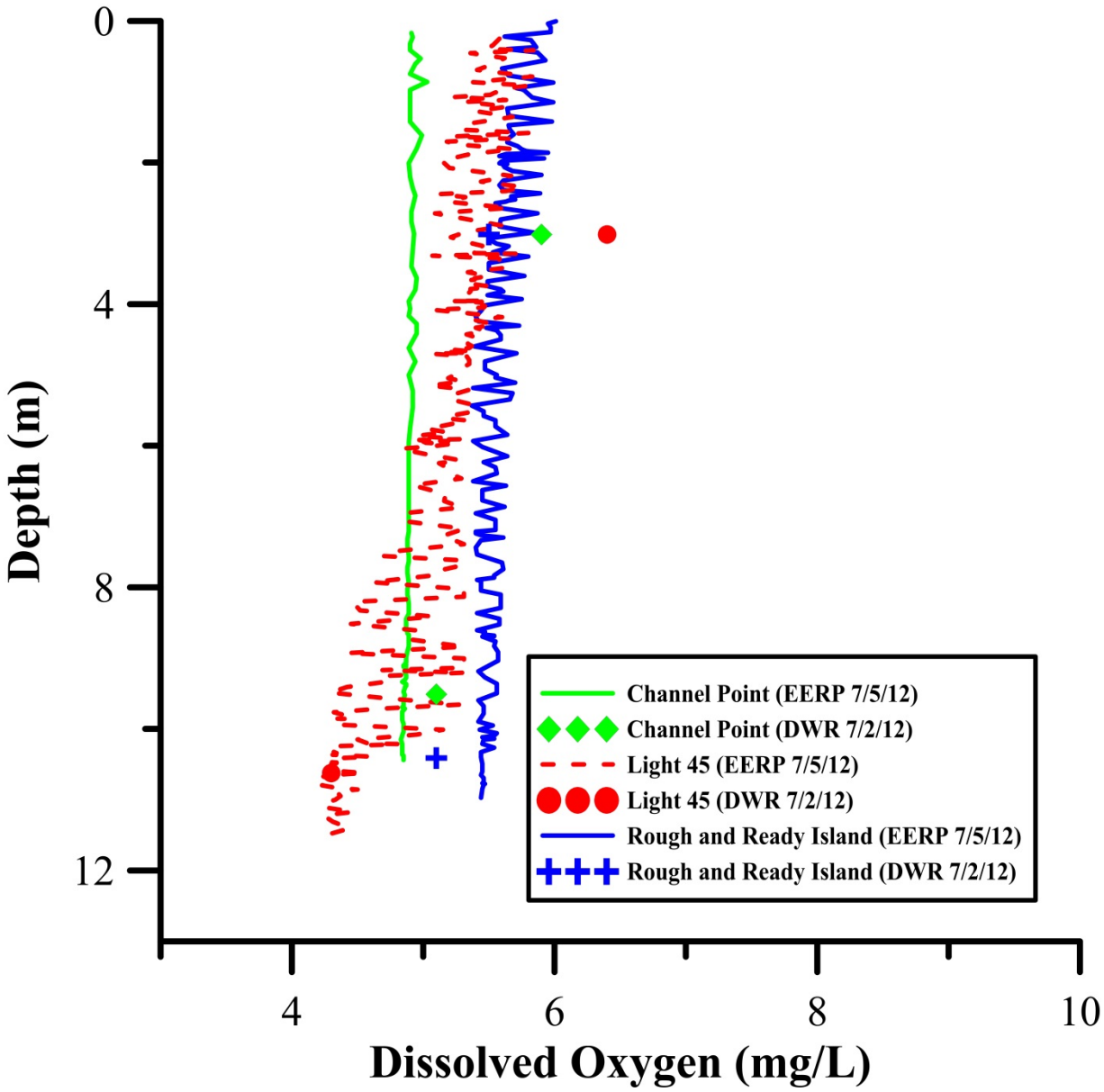

Figure 15. Dissolved oxygen profiles measured on August 2nd 8:41am – 12:08pm, 2012 by the Ecological Engineering Research Program (EERP). Department of Water Resources (DWR) DO measurements 1 m below the surface and 1 m above the river bottom measured on August 1st 11:15am – 12:00pm, 2012 for comparison. DWR's surface dissolved oxygen samples were collected using a through-hull pump and were analyzed with the modified Winkler titration method. DWR's bottom measurements and EERP measurements were made *in-situ* using a YSI 6600 multiparameter data sonde equipped with an optical dissolved oxygen sensor.

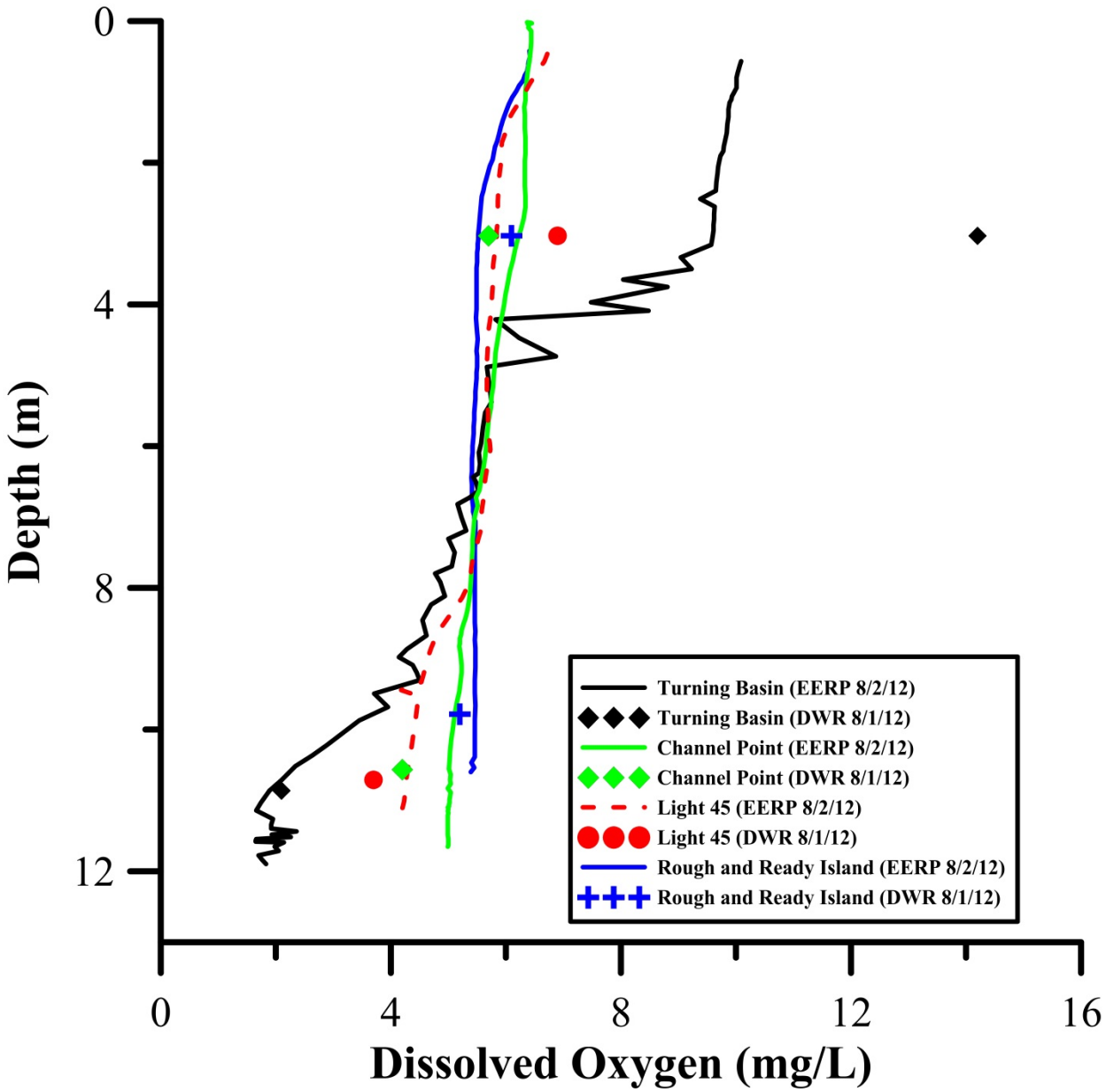

Figure 16. Dissolved oxygen profiles measured on August 16th 8:51am – 1:55pm, 2012 by the Ecological Engineering Research Program (EERP). Department of Water Resources (DWR) DO measurements 1 m below the surface and 1 m above the river bottom measured on August 16th 11:05am – 11:45am, 2012 for comparison. DWR's surface dissolved oxygen samples were collected using a through-hull pump and were analyzed with the modified Winkler titration method. DWR's bottom measurements and EERP measurements were made *in-situ* using a YSI 6600 multiparameter data sonde equipped with an optical dissolved oxygen sensor.

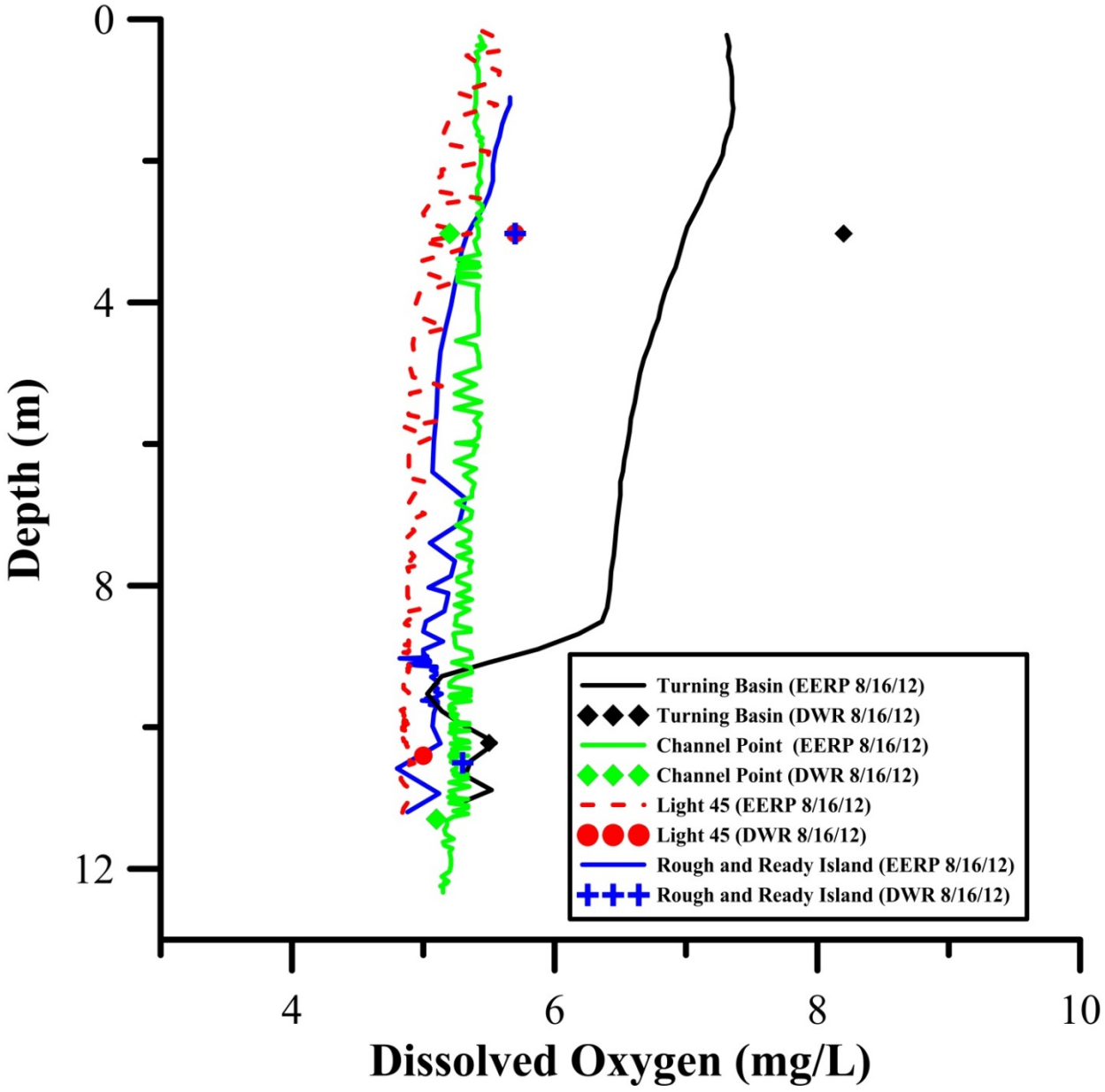

Figure 17. Dissolved oxygen profiles measured on September 6th 8:55am – 1:16pm, 2012 by the Ecological Engineering Research Program (EERP). Department of Water Resources (DWR) DO measurements 1 m below the surface and 1 m above the river bottom measured on September 4th 1:40pm – 2:20pm, 2012 for comparison. DWR's surface dissolved oxygen samples were collected using a through-hull pump and were analyzed with the modified Winkler titration method. DWR's bottom measurements and EERP measurements were made *in-situ* using a YSI 6600 multiparameter data sonde equipped with an optical dissolved oxygen sensor. The aerator at Rough and Ready Island was operational after 9:15 am on September 6th, 2012.

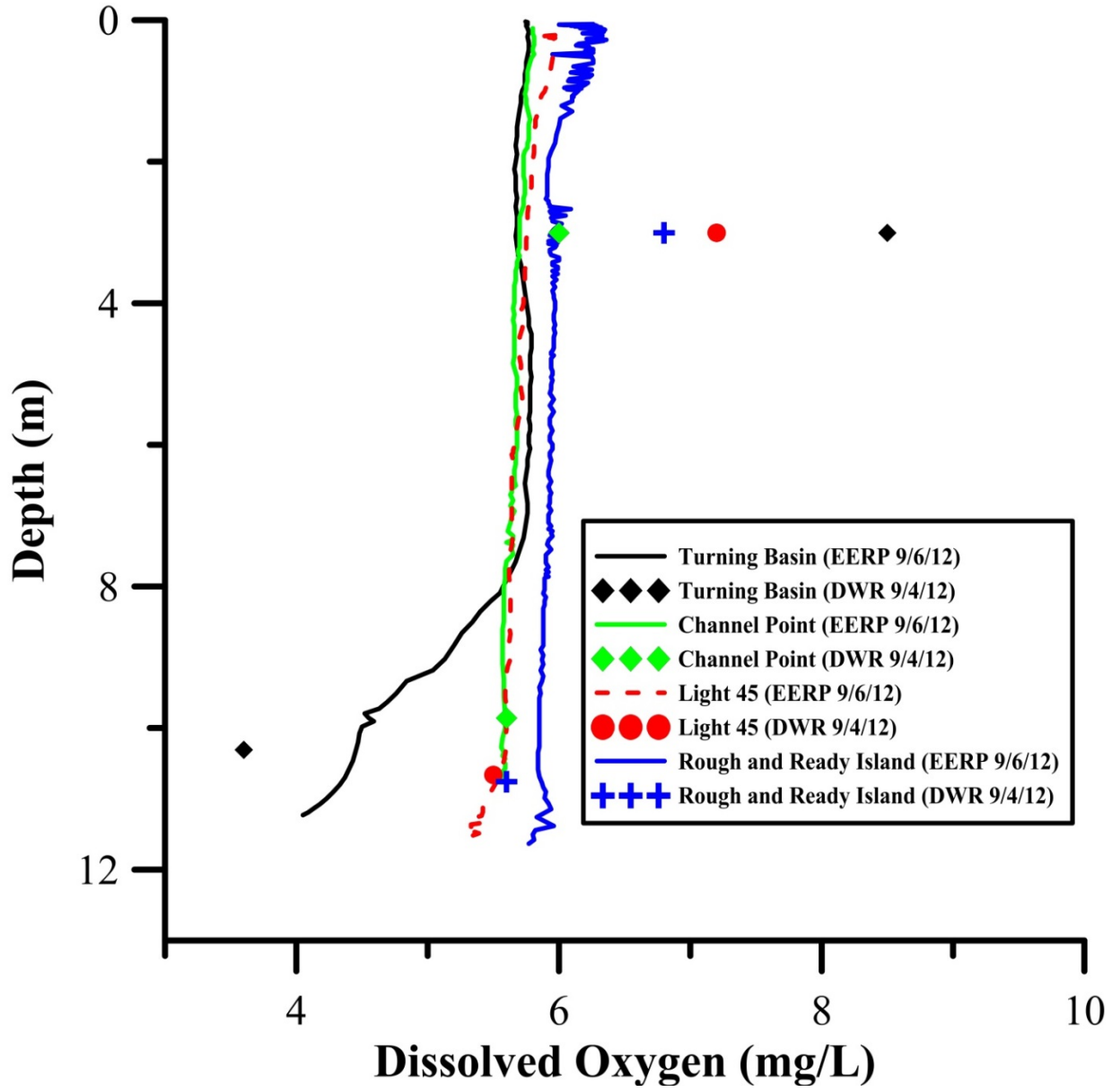

Figure 18. Running (3 point/45 minute) average of DO concentration on each of the four survey dates as measured by the three sensors at the RRI continuous monitoring station.

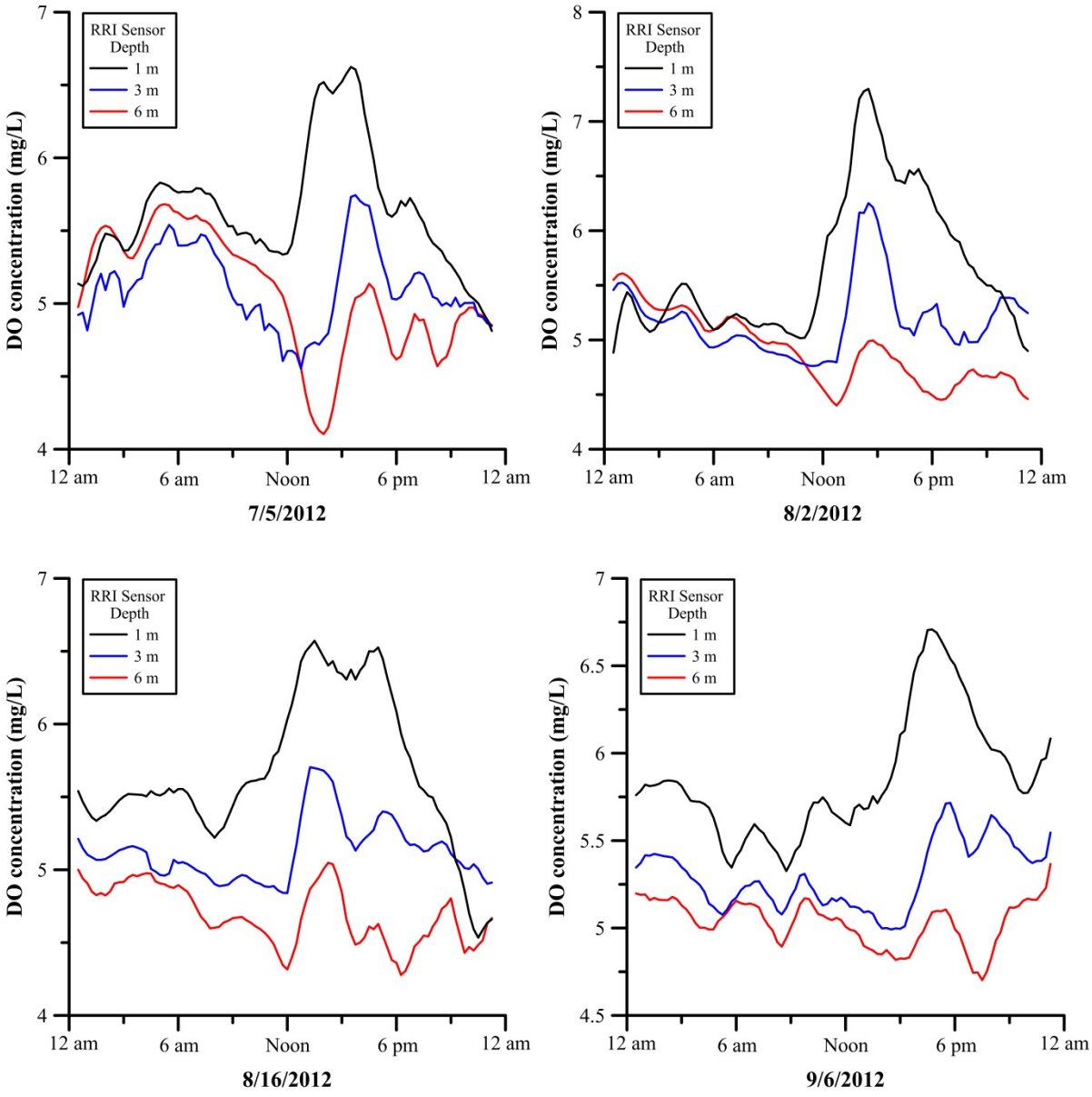

Figure 19. Vertical profiles of dissolved oxygen measured near the western end of Rough and Ready Island by the Ecological Engineering Research Program (EERP) (black lines) compared to measurements made at the Rough and Ready Island continuous monitoring sensors (red circles) at 1m, 3m, and 6m depths. Vertical profiles were taken by EERP on July 5th 11:00am – 11:14am, August 2nd 12:00pm - 12:08pm, August 16th 1:49pm - 1:55pm, and on September 6th 1:06pm – 1:16pm of 2012. RRI sensor data is from July 5th 10:45am – 11:15am, August 2nd 11:45am - 12:15pm, August 16th 1:30pm - 2:00pm, and on September 6th 1:00pm – 1:30pm of 2012.