ASSESSING THE SEASONAL IMPACT OF STORM DRAINS ON WATER QUALITY IN WESTERN NEWPORT BAY, SOUTHERN CALIFORNIA

A report prepared for the State Water Resources Control Board (SWRCB) by

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Funded by

State Water Resources Control Board, California

Contents

EXECUTIVE SUMMARY

The Western Newport Bay (WNB) region is a historical hot spot for fecal indicator bacteria (FIB) impairment. It was hypothesized that storm drains in the WNB region have an impact on the water quality and thus studies were conducted in the summer and winter seasons to assess the role of storm drains in contributing FIB to WNB. Water samples were collected from approximately 10 storm drains and corresponding within Bay sites (located near the end of the respective storm drain in the center of the channel), and analyzed for fecal indicator bacteria (total coliform, *E. coli*, enterococcus) and a suite of water quality parameters including pH, salinity and turbidity. An analysis of the results shows that FIB is approximately an order of magnitude higher in Bay and storm drain samples in the wet weather season compared to FIB in the summer. Winter FIB log-mean concentrations exceeded the geomean standards for TC, EC and ENT in all within Bay water samples and in most storm drain water samples (100, 80, 100%, respectively). Winter FIB concentrations at within Bay sites were higher or equal to corresponding storm drain sites, while in the summer, FIB concentrations were higher in storm drain sites compared to within Bay sites. (Geomean standards for TC, EC and ENT are 1000, 200 and 35 MPN/100ml, respectively.)

In summer, exceedences were not as frequent as in the winter. Summer FIB log-mean concentrations exceeded the geomean standards for TC, EC and ENT in 100, 75 and 75% of storm drain samples, while there were no exceedences for EC and ENT and only 50% exceedences for TC in within Bay sites. In summer, average within Bay and storm drain FIB concentrations trends were similar (Fig 19). In winter, freshwater inputs from storm drains appear to be a contributing factor to higher TC, EC and ENT concentrations in the Bay. In winter, high FIB concentrations in the WNB could result from the combined effect of the FIB contributions from numerous storms drains to a relatively small channel, tidal influxes, unusually high residence times and other processes.

The possibility of biofilm being a contributor of FIB to the water column in storm drains was also evaluated in the studies. Based on FIB biofilm/water ratios, biofilm does not appear to be a major contributor of FIB to the water column in storm drains in winter,

most likely due to the already high concentrations of FIB in storm water runoff and/or the high flow rates of storm water through the drains (desorption of bacteria may be slow). However, biofilm could be a source of FIB in the summer since FIB biofilm/water ratios were >1, and FIB concentrations in storm drain water tended to be higher than concentrations in the Bay. The role of biofilm needs to be further investigated by conducting field studies to sample biofilms more intensively. The data collected in these studies provide high frequency monitoring data in the WNB region and are an important supplement to the source control planning of the existing Fecal Coliform TMDL.

1. Introduction and Study Objectives

The western portion of Lower Newport Bay, hereafter referred as Western Newport Bay (WNB), is a historical hot-spot of fecal coliform impairment (Orange County Health Care Agency monitoring data); presumably due to the myriad of non-point sources of these bacteria that drain from the surrounding urban landscape, and the poor tidal circulation in this portion of the Bay. This study was designed to yield data on storm drain inputs to WNB in winter and summer, and will demonstrate which drains or parts of WNB exceed water quality criteria and may be sources of fecal indicator bacteria in the WNB region. These data will contribute to the formulation of a Fecal Coliform Source Management Plan, which will be used to implement the Fecal Coliform TMDL for Newport Bay. Specifically, these data will provide information to prioritize problem areas and bacterial sources so that appropriate BMPs may be selected for the WNB area that are most likely to reduce fecal coliform impairment in this region during both summer dry weather and winter storm seasons.

Studies were carried out to:

(1) Measure the spatial distribution of fecal indicator bacteria within WNB, and determine how this spatial distribution changes in response to tidal transport processes (rising and falling tides), tide stage (high-high vs. low-low tides), and precipitation (storm vs. dry weather studies).

(2) Measure storm drain inputs to WNB during wet weather periods (winter study) and dry weather periods (summer study).

(3) Measure the distribution of fecal indicator bacteria between the fluid phase and biofilm layers in several storm drains that discharge to the WNB, and determine how this distribution changes in response to tidal pumping of ocean water in and out of the storm drains (dry weather studies) and storm events (wet weather studies).

The report begins with a description of the experimental design for the field studies and the laboratory analysis in Chapter 2. The results are discussed in Chapter 3. Chapter 3 is organized into spatial and temporal trends of the water quality parameters in sections 3.1 and 3.2 respectively. The results of the biofilm sampling are discussed in section 3.3. The overall results for the West Newport Bay water quality study are discussed in Chapter 4 followed by conclusions and recommendations in Chapter 5.

2. Methods

Overview. Water and biofilm samples were collected from sampling sites in the Western Newport Bay during storm events in the winter wet weather season and summer dry weather season. Samples were collected in Western Newport Bay from 10 storm drains in the winter and 8 storm drains in the summer (2 drains had no flow in the summer). Corresponding samples were also collected from 10 within Bay sites, from the center of the channel near the outlet of the storm drains, during each season. In general, water samples were collected every 3 hours, for a period of at least 45 hours. The specific details of each type of sampling are given below.

2.1. Within Bay Sampling

Water samples were collected at 10 locations in the WNB (B1- B10 in Figure 1). Two within Bay sampling events were carried out, once during a winter storm event (February 2005, see Figure S1) and once during a summer dry weather period (September 2005). The design of the two field studies was similar. In the winter, the collection of water samples was timed to coincide with the rising and falling limbs of the storm hydrograph, and several days thereafter. Specifically, the sampling schedule for the winter study was as follows:

a. 3 hour sampling frequency from 2/18/2005 18:00 – 2/20/2005 18:00
b. 6 hour sampling frequency from 2/20/2005 18:00 – 2/21/2005 12:00
c. Once a day sampling on 2/22/2005 and 2/24/2005.

Sampling during the summer study took place once every 3 hours for 45 hours from 9/17/2005 12:00 pm to 9/19/2005 09:00 am. The sampling schedule for the summer study was designed to capture several complete tidal cycles and reveal the influence of flood/ebb cycling on the fecal indicator bacteria signal at within Bay sites. Additional details on the sampling effort can be found in Table 1. Within Bay samples were collected from a small inflatable raft powered by an outboard motor. Sampling crews of 2-3 people arrived at the field site and traversed the Bay sampling grid in approximately one hour. At each Bay sampling site, water samples were collected from the surface of the water column using a pole affixed with a sterilized 500 ml (or 1L in the case of samples for particle size analysis) Nalgene bottle. After the bottles were filled with water they were capped and immediately placed on ice and transported a short distance (within the 6 hour holding time) to UCI.

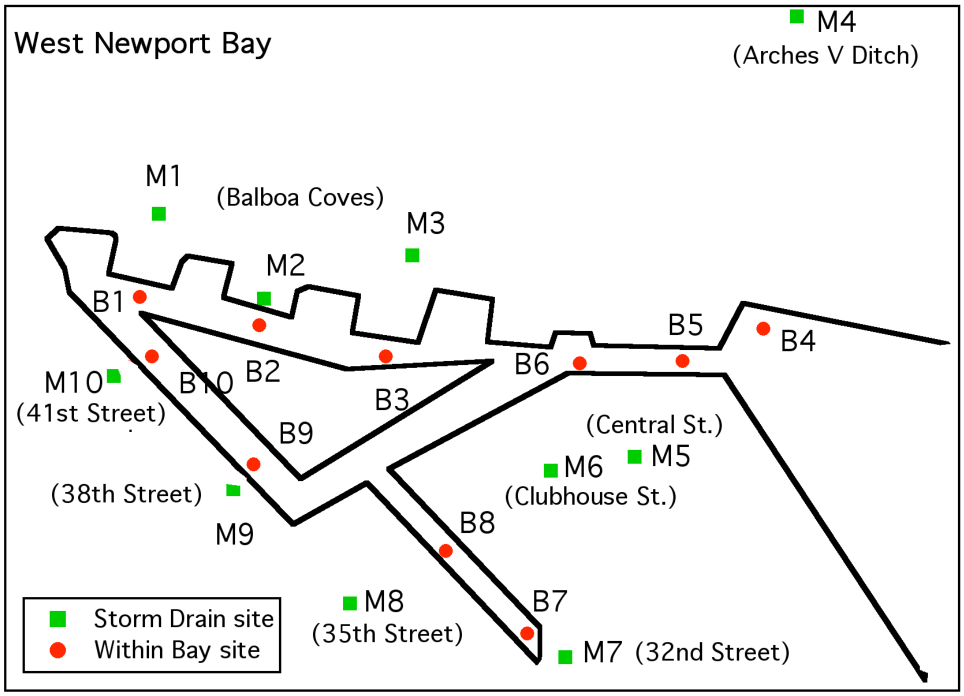

Figure 1. Map of West Newport Bay showing the location of storm drain (green squares) and within-Bay (red circles) sampling sites. Except M4, all the storms drains are tidally influenced.

The water samples were analyzed for fecal indicator bacteria, including total coliform (TC), *Escherichia coli* (EC) and enterococci bacteria (ENT) using defined substrate tests known commercially as Colilert-18 and Enterolert (IDEXX, Westbrook, Maine) implemented in a 97-well quantitray format. These particular tests were used because they are quantitative, relatively inexpensive and not labor intensive, thus facilitating the analysis of a large number of samples in a short period of time. For the microbiological analysis, a 1:10 dilution was prepared by pipeting 10 ml of sample into Butterfield's phosphate buffer solution (Hardy Diagnostics, Santa Maria, CA) for a total volume of 100 ml. The resulting mixture was analyzed for TC, EC and ENT using the IDEXX tests and the results reported in units of most probable number of bacteria per 100 ml of sample (MPN/100 ml). Metals were also analyzed but not included in this report. Water quality parameters of pH, salinity and turbidity were measured using the Thermo Orion® model 720A, Orion ® model 162A, and HF Scientific, Inc., Model Micro 100, respectively.

Table 1. Number of samples collected and processed for fecal indicator bacteria and physical parameters (numbers include 10% duplicates).

LOCATION	SUMMER	WINTER
Within Bay samples	159	248
Storm Drain samples	123	196
Biofilm samples	14	60

2.2 Storm Drain Sampling

Water samples were collected from 10 storm drains (M1- M10, Figure 1). Two storm drain sampling events were carried out, concurrently with within Bay sampling, once during a summer dry weather period (September 2005), and once during a winter storm event (February 2005, see Figure S1). During the summer it was discovered that sites M2 and M6 had negligible flow, and hence these sites were not sampled during the summer study. The sampling schedule for the winter study was as follows:

a. 3 hour sampling frequency from 2/18/2005 18:00 – 2/20/2005 18:00
b. 6 hour sampling frequency from 2/20/2005 18:00 – 2/21/2005 12:00
c. Once a day sampling on 2/22/2005 and 2/24/2005.

Sampling during the summer study took place once every 3 hours for 45 hours from 9/17/2005 12:00 pm to 9/19/2005 09:00 am. Additional details on the sampling effort can be found in Table 1. During winter sampling, storm drains were sampled by lowering a pole with an attached bottle into a manhole. During the summer sampling, water samples were collected using an ISCO 6700 automatic sampler pump to draw the water from the storm drain using a manhole access. Pump tubing was rinsed for approximately two to three minutes with distilled water followed by sample water before storm drain water samples were collected at each site. Water samples collected from the storm drain were analyzed for the same bacteria and suite of analytes described in Section 2.1.

2.3 Biofilm Sampling

The biofilm sampling was carried out to provide information on the role that bacterial regrowth might play in the fecal coliform impairment of WNB. A sampling effort was devised to answer the following question: *Are the biofilm layers inside the storm drain pipes enriched in fecal indicator bacteria, compared to the overlying water column?* If the answer to this question is "yes", then storm drain biofilm may be an important source of within Bay fecal indicator pollution. Biofilm layers were collected from 10 storm drains (M1 – M10) that discharge into WNB. The sampling protocol involved sampling the overlying water first, followed by sampling the biofilm. Biofilm samples were collected from each storm drain site 1 or 2 times in two 24-hour periods, during the winter storm study and the summer dry weather study (Table 1). The protocol for collecting biofilm samples was the same for the winter wet weather season and summer dry weather season and is outlined as follows. Biofilm samples were collected by scraping the bottom of the storm drain using a conical tube attached to the end of a pole. This yielded a slurry that contained a mixture of biofilm and water. After collection, biofilm samples were immediately placed on ice and transported to the lab for analysis. Once at the lab, biofilm samples were hand shaken for one minute and 10 ml of the biofilm slurry was mixed with 90 ml phosphate buffer, and analyzed for TC, EC, and ENT using Colilert-18 and Enterolert IDEXX® tests, as described above. The concentration of fecal indicator bacteria in the biofilm samples is reported in units of MPN/100ml of biofilm slurry. In the results section, the concentration of fecal indicator bacteria in the biofilm slurry is compared with the concentration of fecal indicator bacteria in the overlying water column. If the ratio of (biofilm slurry FIB concentration)/(overlying water FIB concentration) is greater than unity, then the biofilm slurry is enriched in fecal indicator bacteria compared to the overlying water; if the ratio is less than unity, the biofilm slurry is depleted in fecal indicator bacteria compared to the overlying water.

3. Results.

The data obtained from this study are tabulated in Table 2 and Table 3 and are presented graphically in Figures 2 through 14. Section 3.1 begins with a discussion of the spatial distribution of fecal indicator bacteria and physical parameters in the Bay and storm drains. This is followed in Section 3.2 by a discussion of temporal trends. Results of the biofilm sampling are presented in Section 3.3.

3.1 Spatial Distribution of water quality parameters

3.1.1 Winter Study: Within Bay Results.

TC concentrations were consistently near, or above, the upper-limit of detection of the testing protocol employed here (>24192 MPN/100ml). Almost all (97.2%) of the TC concentrations (max value >24192 MPN/100ml) exceeded the AB411 single-sample standard of 10,000 MPN/100ml. The spatial distribution of TC within WNB is uniform (i.e., shown by little color variation in the upper left panel of Figure 2). This spatial uniformity is due, at least in part, to the frequency with which TC concentrations exceeded the upper-limit of detection during the winter study. A majority of the EC (92%, max value>24192 MPN/100ml) and ENT (87%, max value>24192 MPN/100ml) concentrations exceeded single-sample standards (400 MPN/100ml and 104 MPN/100ml, respectively) in within Bay samples. EC log mean concentrations ranged from 10^{3} to $10^{3.5}$ MPN/100ml, and were highest at site B4 ($10^{3.4}$ MPN/100ml) which is located near the outfall of the Arches V-ditch, and site B5 ($10^{3.5}$ MPN/100ml) located near the entrance to WNB (Figure 4, Table 2). ENT log mean concentrations ranged from 10^{3} to $10^{3.7}$MPN/100ml. The highest log mean concentration of ENT, which is much higher than the geomean standard of $10^{1.54}$ MPN/100ml, was found at site B4 ($10^{3.7}$ MPN/100ml), near the Arches V-ditch outfall. At all within Bay sites, log means of TC, EC and ENT concentrations in winter exceeded the geomean standards of 10^{3}, $10^{2.3}$ and $10^{1.54}$ MPN/100ml respectively, (Figure 4).

Average pH varied over a fairly narrow range, from 7.7 to 8, with the lower range evident at site B4 near the Arches V-ditch outfall (7.8+/-0.22) (Figure 4 and Table 2). Average salinity ranged from 9 to 12 ppt for most of the stations (Table 2, Figure 4), except B4 where the average salinity was anomalously low (ca. 7 ppt +/- 6.27). Average turbidity ranged from 8.5 to 22 NTU. The highest mean turbidity (22+/- 12.8 NTU) was also found at site B4.

Table 2. West Newport Bay Data Summary- Winter Study (February 2005)

Station	TC		EC		ENT		pH		Salinity		Turbidity	
	Average	*Standard Deviation*	*Average*	*Standard Deviation*	*Average*	*Standard Deviation*	*Average*	*Standard Deviation*	*Average*	*Standard Deviation*	*Average*	*Standard Deviation*
B1	23996.2	923.2	2395.8	1412.1	6236	5730.7	7.96	0.15	9.01	4.18	16.83	15.14
M1	14438.6	9001.2	465.3	1098.3	1025.0	1493.2	7.68	0.30	2.5	1.97	27.23	26.63
B2	2395.8	1412.1	2818.0	1770.8	6742.6	6564.1	8.0	0.11	9.7	4.93	13.05	4.87
M2	22793.5	2677.8	212	201.5	277.9	132.8	7.82	0.6	0.12	0.12	11.19	8.46
B3	23996.2	923.2	2673.8	1505	6980.3	6205.7	7.97	0.09	9.45	5.14	13.78	4.89
M3	23860	1201	1209.7	1625.8	1567.1	1961.7	7.56	0.37	5.66	5.96	12.07	4.47
B4	22203.7	6477.8	5251.7	5475.2	8935.7	6720.8	7.86	0.22	7.68	6.27	22.23	12.82
M4	24193	0	10423.5	7784	7819.4	5680.1	7.49	0.27	0.48	0.41	27.07	15.73
B5	23640.1	2592.5	5248.7	5287.0	9258.2	8027.8	7.93	0.17	9.1	6.47	17.21	10.76
M5	24193	0	2457.6	2664.9	2719.5	3636.4	7.53	0.32	3.64	4.47	10.66	9.19
B6	23640.2	2592.5	3480.4	2386.8	7691.3	6175.8	7.97	0.11	9.42	6.03	17.63	13.32
M6	24193	0.3	2036.4	2255.4	3945.8	4129.4	7.66	0.28	7.49	6.56	11.14	3.86
B7	21319.0	5529.5	2807.3	2100.1	5643.3	4375.7	8.02	0.12	12.37	6.73	8.52	4.66
M7	23095.4	3310.9	8660.8	10029.3	9554.9	8628.6	7.63	0.31	9.99	7.13	16.3	19.84
B8	22489.3	4644.3	2660.5	2751.1	5056.9	5686.6	8.02	0.11	11.42	6.29	8.89	4.12
M8	24193	0	5332	7413	6423.0	7117.5	7.75	0.33	7.68	6.78	13.06	8.51
B9	22898.9	4189	3124.6	3210.5	6045.8	7107.7	7.99	0.09	10.75	5.55	10.03	4.033
M9	24193	0	5783.3	7088.1	4737.8	4741.4	7.83	0.30	7.14	7.22	10.13	4.63
B10	24193	0.2	2370.8	1354.3	4452.6	4102.3	7.97	0.08	10.45	4.66	10.6	3.3
M10	23072.6	5010.6	9625	8608.3	6360.1	4582.3	7.69	0.3	6.54	6.58	13.04	6.07

- TC, EC, ENT averages are reported in MPN/100 ml
- Salinity units are ppt and Turbidity units are NTU

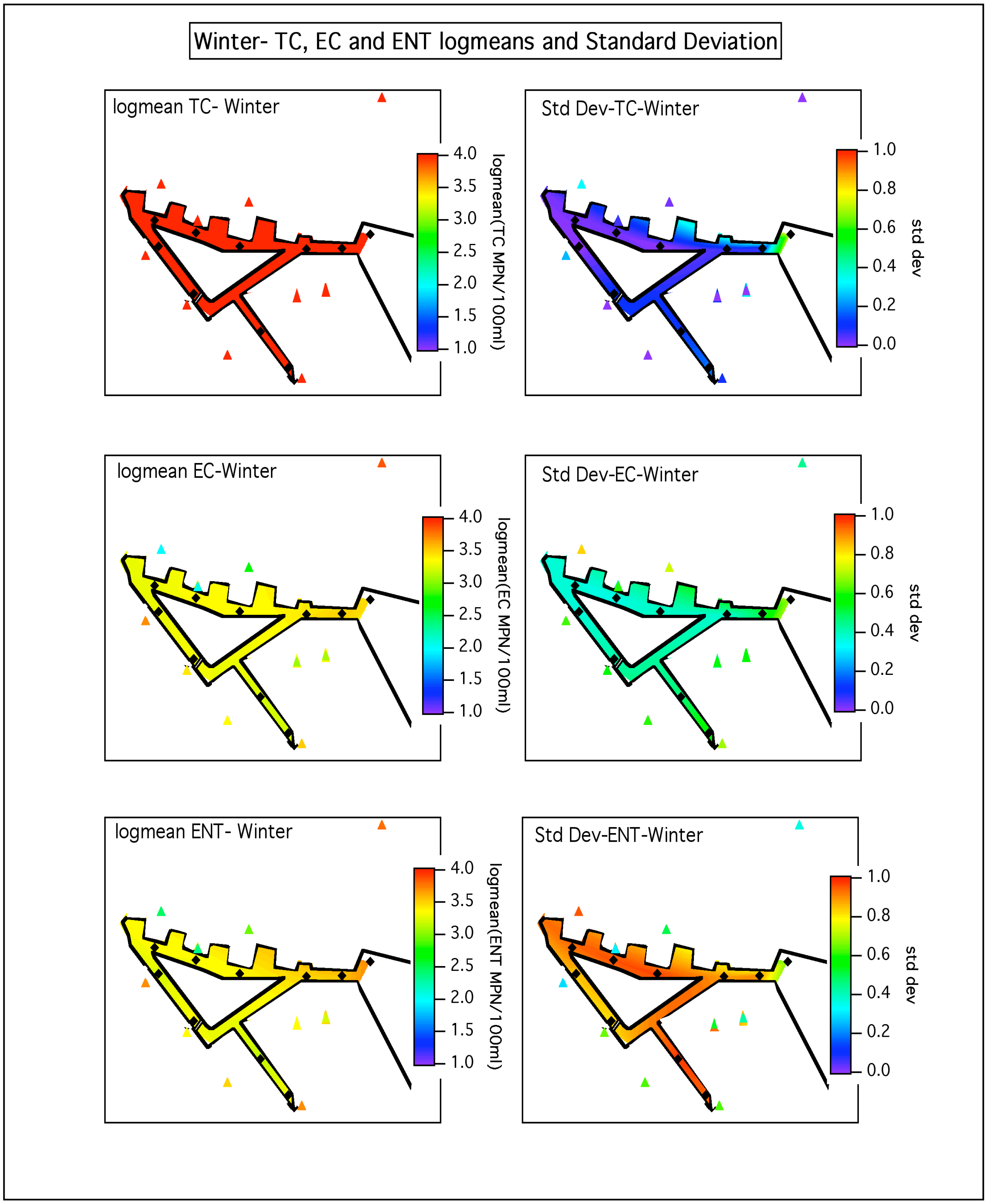

Figure 2. Log means and standard deviations of TC, EC and ENT measured at within Bay (small black dots) and storm drain (colored triangles) sites. Sampling occurred during a winter storm from February 18th, 2005 to February 24th, 2005. The log transformed single sample standard for TC, FC and ENT is 4, 2.6 and 2.0 respectively (log (TC, EC, ENT MPN/100 ml)). The geomean standards of TC, FC (note: EC is a subset of FC and hence the standard for FC is used) and ENT are 3, 2.3 and 1.54 respectively.

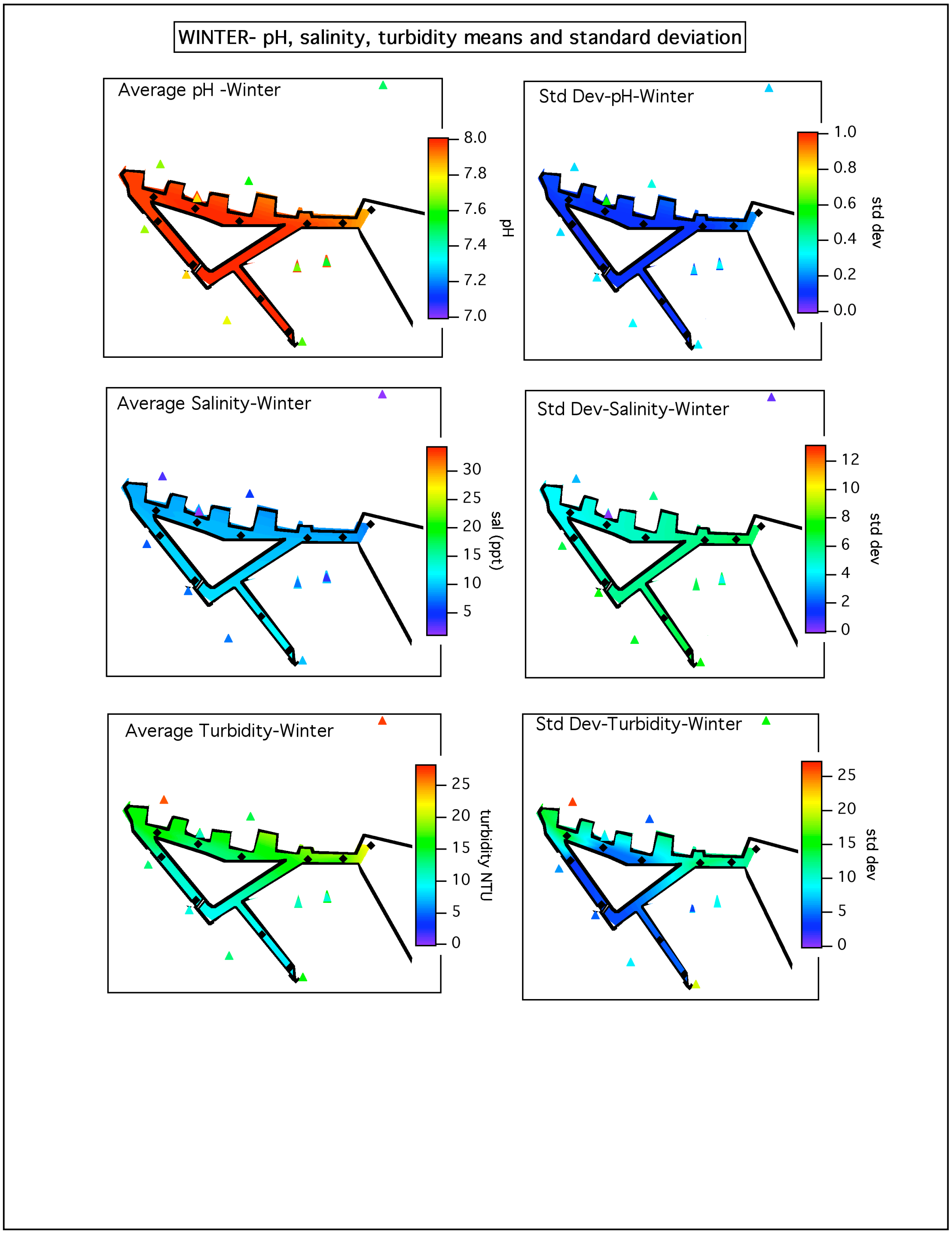

Figure 3. Averages and standard deviations of pH, salinity and turbidity at Bay (small black dots) and storm drain (colored triangles) sites. Sampling occurred during a winter storm from February 18th, 2005 to February 24th, 2005

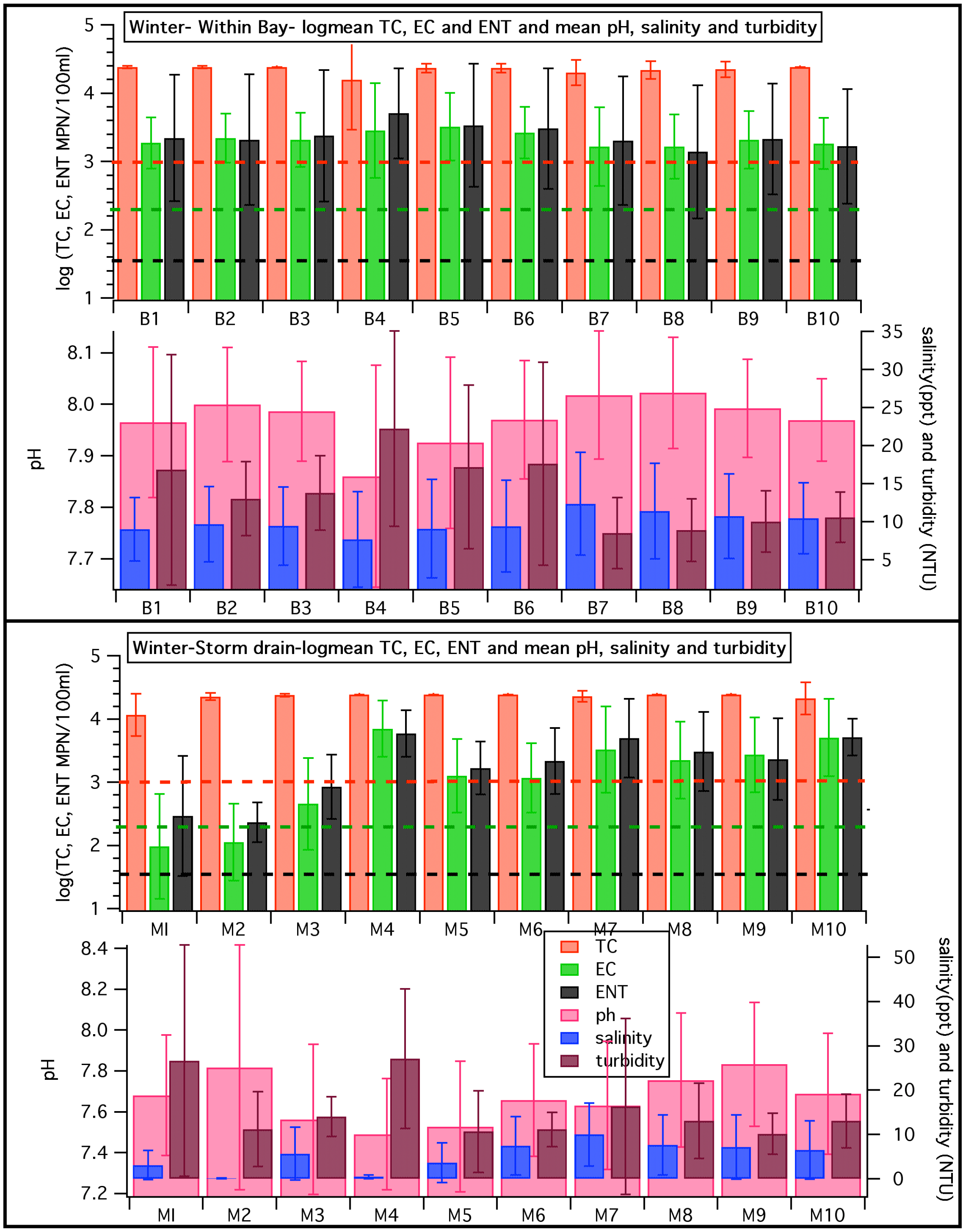

Figure 4. Bar charts showing log means of TC, EC and ENT and average ph, salinity and turbidity in the winter wet weather season. The red, green and black dotted lines represent the California marine water geometric mean standards for TC, FC and ENT. The geomean standards of TC, FC (note: EC is a subset of FC and hence the standard for FC is used) and ENT are 3, 2.3 and 1.54 respectively.

3.1.2 Winter Study: Storm Drain Results.

TC concentrations (Figures 2 & 4, Table 2) were consistently near or above the upper level of detection (>24192 MPN/100ml). Almost all (94%) of the TC concentrations (max value >24192 MPN/100ml) were above the AB411 single sample standard of 10,000 MPN/100ml. A majority of the EC (74%, max value >24192 MPN/100ml) and ENT concentrations (94%, max value >24192 MPN/100ml) exceeded the AB411 single sample standards (400 and 104 MPN/100ml). Log mean EC concentrations ranged from approximately 10^{2} MPN/100ml at stations M1 and M2 to 10^{4}MPN/100ml at station M4 (Arches V ditch). The geomean standard for EC is $10^{2.3}$ MPN/100ml. Log mean ENT concentrations ranged from approximately $10^{2.5}$ MPN/100ml at M1 and M2 (Balboa Coves community) to $10^{3.8}$ MPN/100ml at M4, which exceed the geomean standard of $10^{1.5}$ MPN/100ml for ENT . There is no significant correlation between the storm drain diameters and the microbiological water quality parameters in the corresponding within Bay sampling sites and in the storm drains (Figure S3, Supplementary section).

Average pH ranged from 7.5 to 7.8 with the lowest recorded at M4 (Figure 4, Table 2). Average salinity ranged from 3- 10 ppt with highest average salinity at M7 and lowest at M4 and M2. The lowest standard deviation for salinity is observed at M4 where the salinity was consistently low (site was outside of tidal influence) (Fig 3). Average turbidity ranged from 10-27 NTU, with highest average turbidity at M1 and M4.

3.1.3 Summer study: Within Bay results.

A small percentage (8%) of the TC concentrations (max value >24192 MPN/100ml) exceeded the single sample standard of 10,000 MPN/100ml. Log mean TC concentrations ranged from ~$10^{2.6}$ to $10^{3.3}$ MPN/100ml with the highest log mean concentrations at B10 and B1 (Figure 5-7, Table 3). (Log mean TC standard is 10^{3} MPN/100ml). Only 8% of the EC concentrations (max value 14136 MPN/100ml) exceeded the single sample standard of 400 MPN/100ml. Log mean EC concentrations ranged from approx. $10^{1.5}$ to 10^{2} MPN/100ml and all are below the EC geomean standard, with the highest log mean concentration at B7, B8 and B10 and lowest log mean at B3. Only 7.5% of ENT concentrations (max value> 24192 MPN/100ml) exceeded the single sample standard of 104 MPN/100ml. Log mean ENT concentrations ranged from 10^{1} to approx. $10^{1.5}$ MPN/100ml, with the highest log mean concentration at B4. (Geomean standards for EC and ENT are $10^{2.3}$ and $10^{1.5}$, respectively.)

Average pH (Figures 6-7) ranged from 7.88 to 7.96 with the lowest pH at B1 and highest average pH at B3. Average salinity ranged from 31.5 ppt to 33.5 ppt with the highest average salinity at station B8 and the lowest at B4 (Figure 7, Table 3). Average turbidity levels ranged from 1 to 5 NTU with the highest turbidity levels at station B3.

3.1.4 Summer study: Storm Drain results.

Less than half (39%) of the TC concentrations (max value >24192 MPN/100ml) exceeded the AB411 single sample standard of 10000 MPN/100ml. Log mean TC concentrations ranged from $10^{3.2}$ to $10^{4.2}$ MPN/100ml (Figure 5-7, Table 3), with the lowest log mean at M5 and the highest log mean at M4 (Arches V-ditch). (Geomean standard for TC is 10^{3} MPN/100ml). Slightly more than half (52%) of the EC concentrations (max value >24192 MPN/100ml) exceeded the AB411 single sample standard of 400MPN/100ml. Log mean EC concentrations ranged from $10^{1.4}$ to $10^{3.5}$ MPN/100ml with lowest log mean EC concentration at M1 and the highest at M3 and M4. (EC geomean standard is $10^{2.3}$ MPN/100ml). Less than half (41%) of the ENT concentrations (max value, 19863 MPN/100ml) exceeded the single sample standard of 104 MPN/100ml. Log mean ENT concentrations ranged from ~$10^{1.2}$ to $10^{3.5}$MPN/100ml, with the highest log mean concentrations at M3 and M4 and lowest at M10. (ENT geomean standard is $10^{1.54}$ MPN/100ml).

Average pH (Figure 7) ranged from 7.6 to 7.9 and was highest at M8 and M9 and lowest at M4 (Arches V Ditch). Average salinity ranged from 1.3 to 33.8 ppt and were lowest at M4 and highest at M5-M10. Average turbidity levels ranged from 1-10 NTU with highest levels at M4 (10.69 +/- 3.72 NTU) and lowest at M10 (1.09+/-0.76 NTU).

Table 3. West Newport Bay Data Summary- Summer Study (September 2005)

Station	TC		EC		ENT		pH		Salinity		Turbidity	
	Average	*Standard Deviation*	*Average*	*Standard Deviation*	*Average*	*Standard Deviation*	*Average*	*Standard Deviation*	*Average*	*Standard Deviation*	*Average*	*Standard Deviation*
B1	3055	5005.1	64.1	65.6	23.6	27.7	7.88	0.2	33.03	0.97	1.11	0.68
M1	9378.4	8556.7	107.1	229.2	139.1	305.4	7.65	0.2	10.87	12.68	8.56	11.67
B2	1208.6	1834.6	50.6	55.3	30.4	39.1	7.94	0.13	33.47	0.55	0.93	0.522
M2												
B3	1913.3	5954.0	293.6	833.2	43	99.5	7.96	0.10	33.54	0.41	4.63	14.51
M3	18118.5	8524.4	5048.9	5042.7	3321.2	4743.5	7.84	0.22	24.95	9.72	8.75	9.18
B4	3267.8	6532.4	892	2982	1552.2	6038	7.94	0.08	31.59	6.18	1.26	0.64
M4	19490.9	7666.9	5016.6	6272	4572.3	5310.7	7.56	0.17	1.3	0.24	10.69	3.72
B5	2371.2	5996.9	510.3	1416	834.9	3243.6	7.92	0.12	32.62	3.99	1.02	0.44
M5	2174.5	1854.8	249.8	210.7	44.5	57.03	7.83	0.11	33.54	0.28	2.34	3.01
B6	3695.6	8325.9	1135.2	3623.7	897.1	2742.4	7.92	0.13	32.72	2.67	1.34	1.08
M6												
B7	2854.6	4577.5	162.9	204.1	20.1	25.5	7.95	0.05	33.2	0.72	0.8	0.37
M7	8465.3	9050	485.8	1102.7	130.6	301.5	7.84	0.11	26.76	6.57	8.5	18.86
B8	2798	4101.5	157.4	133.0	11.1	5.7	7.95	0.05	33.81	0.22	0.66	0.14
M8	7826.3	8054.1	2990.8	5942.9	209.4	513.9	7.91	0.10	30.78	8.35	3.07	4.09
B9	2285.1	3001.8	492.1	1712.2	521.6	2037.9	7.96	0.06	33.57	0.79	0.85	0.3
M9	11165.3	8412.4	3990	4476.6	2016.3	3193.4	7.92	0.07	28.06	9.46	2.67	3.38
B10	5209.3	6391.9	321.25	838.8	18	19.1	7.95	0.06	33.79	0.34	0.84	0.28
M10	10112.5	8015.1	1474	2583.3	20.2	18.2	7.78	0.12	32.19	2.09	1.09	0.76

- TC, EC, ENT averages are reported in MPN/100 ml
- Salinity units are ppt and Turbidity units are NTU.

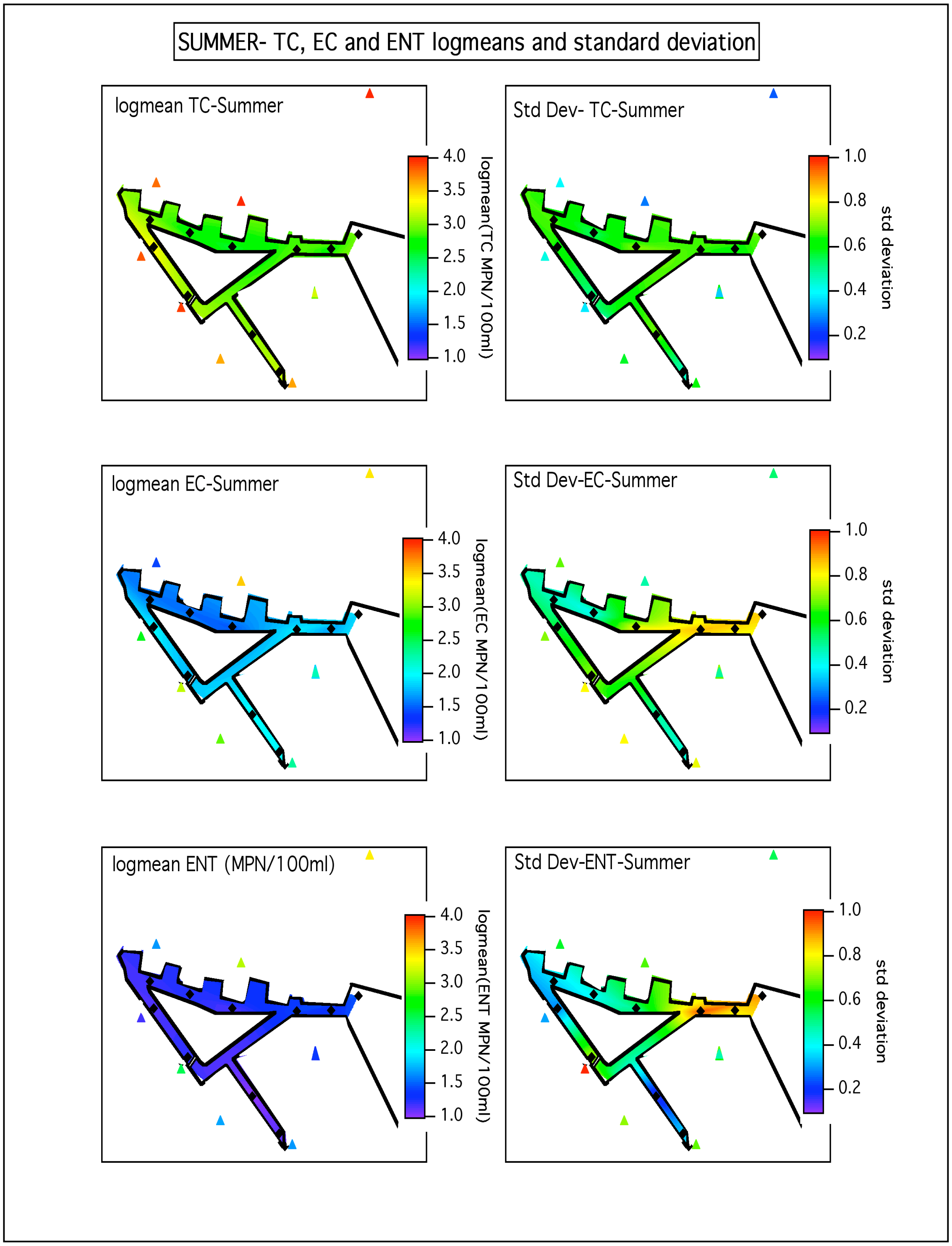

Figure 5. Log means and standard deviations of TC, EC and ENT measured at 10 within Bay sites (indicated by small black dots) and 8 storm drain sites (locations and log mean concentrations indicated by colored triangles). Sampling for this study occurred during dry weather in September 17th, 2005 to September 19th, 2005. The geomean standards of TC, FC (note: EC is a subset of FC and hence the standard for FC is used) and ENT are 3, 2.3 and 1.54 respectively.

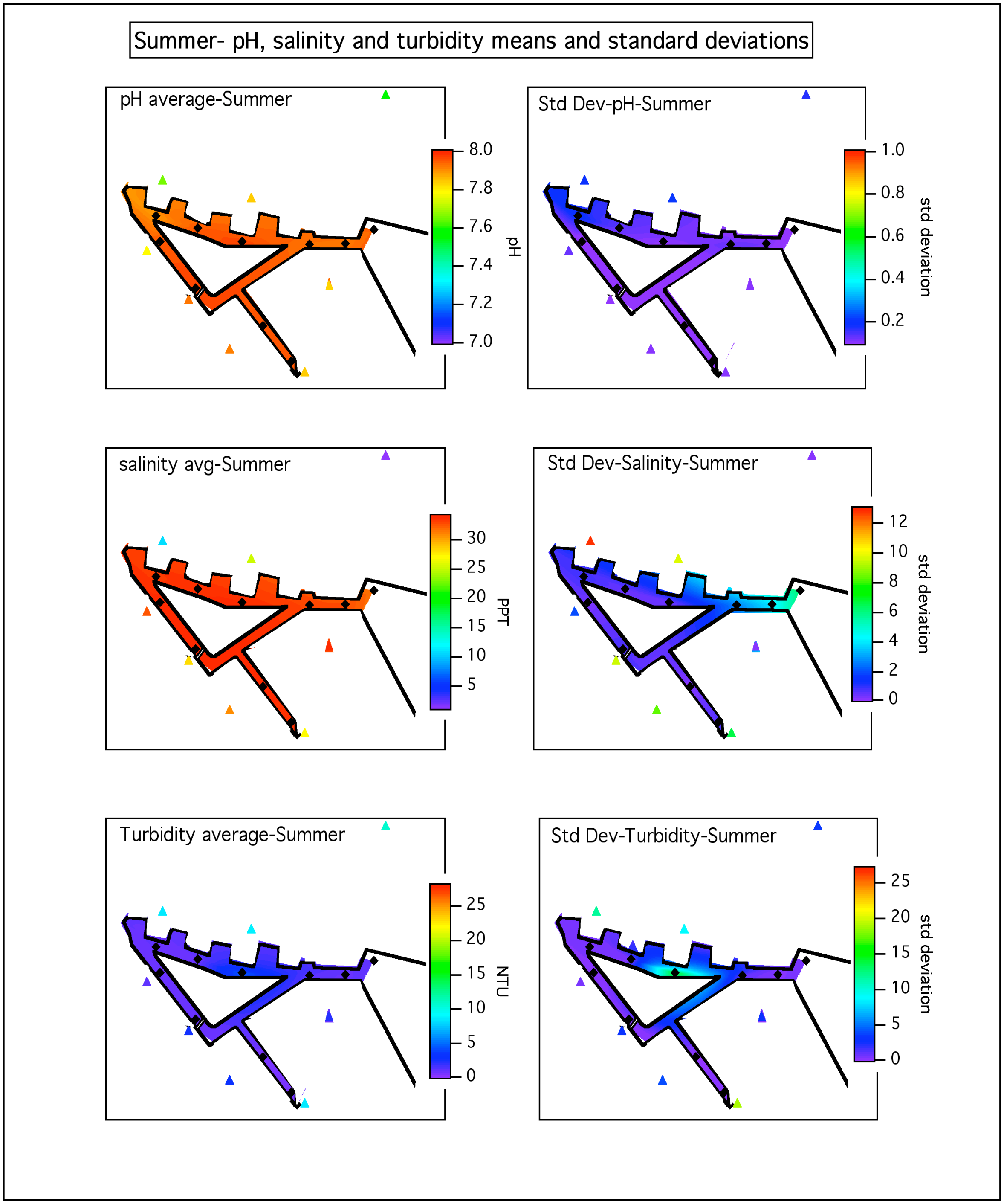

Figure 6. Averages and standard deviations of pH, salinity and turbidity measured at 10 within Bay sites (indicated by small black dots) and 8 storm drain sites (locations and average concentrations indicated by colored triangles). Sampling for this study occurred during dry weather in September 17th, 2005 to September 19th, 2005.

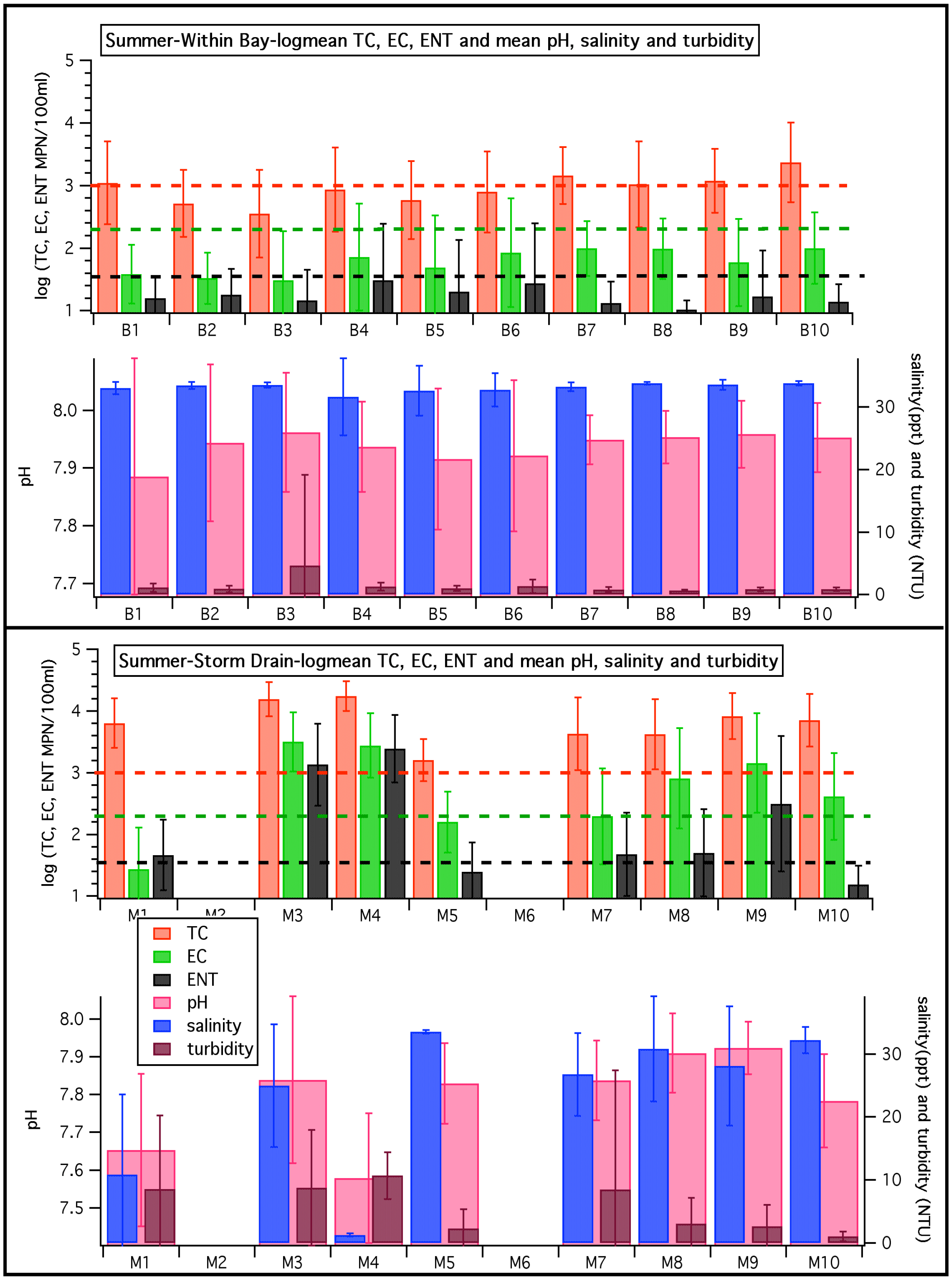

Figure 7. Bar charts showing log means of TC, EC and ENT and average ph, salinity and turbidity. The red, green and black dotted lines represent the California marine water geometric mean standards for TC, EC and ENT. The geomean standards of TC, FC (note: EC is a subset of FC and hence the standard for FC is used) and ENT are 3, 2.3 and 1.54 respectively.

3.2 Temporal trends of water quality parameters

3.2.1 Winter study: Within Bay results.

Most (88%) of the TC concentrations were above the upper level of detection (>24192 MPN/100ml) and the AB411 single sample standard of 10,000 MPN/100ml throughout the duration of the study at almost all of the stations (Figure 8). EC and ENT concentrations were near or below the AB411 single sample standards at the start of the storm study and increased (0.5-1 order of magnitude for EC and 2 orders of magnitude for ENT) to above the standards as the storm progressed, then stayed at elevated levels. EC and ENT concentrations eventually decreased on the last day of sampling, when it had stopped raining. The within Bay TC, EC and ENT concentrations, in winter group tightly with each other unlike the storm drain measurements.

pH and salinity gradually decreased towards the middle of the study. Turbidity started low and slightly increased (by 5-10NTU) as the amount of rainfall increased towards the middle of the study (Figure 9). pH, salinity and turbidity measurements at all the stations group tightly with each other for the most part.

3.2.2 Winter study: Storm Drain results.

TC concentrations were mostly above detection limits (>24192 MPN/100ml) in the majority of the storm drains and above the AB411 single sample standard of 10,000 MPN/100ml, except at site M1 which averaged 14438.6 (+/- 9001.2)(Figure 10). Most EC and ENT concentrations at the sampling sites were above the AB411 single sample standards of 400 and 104 MPN/100ml, but the data are not as tightly grouped compared to the within Bay EC and ENT concentrations (Figure 10).

pH and salinity levels at most of the stations decreased gradually as the storm study progressed (Figure 11). Turbidity levels at most of the stations did not vary much over the course of the winter wet weather study

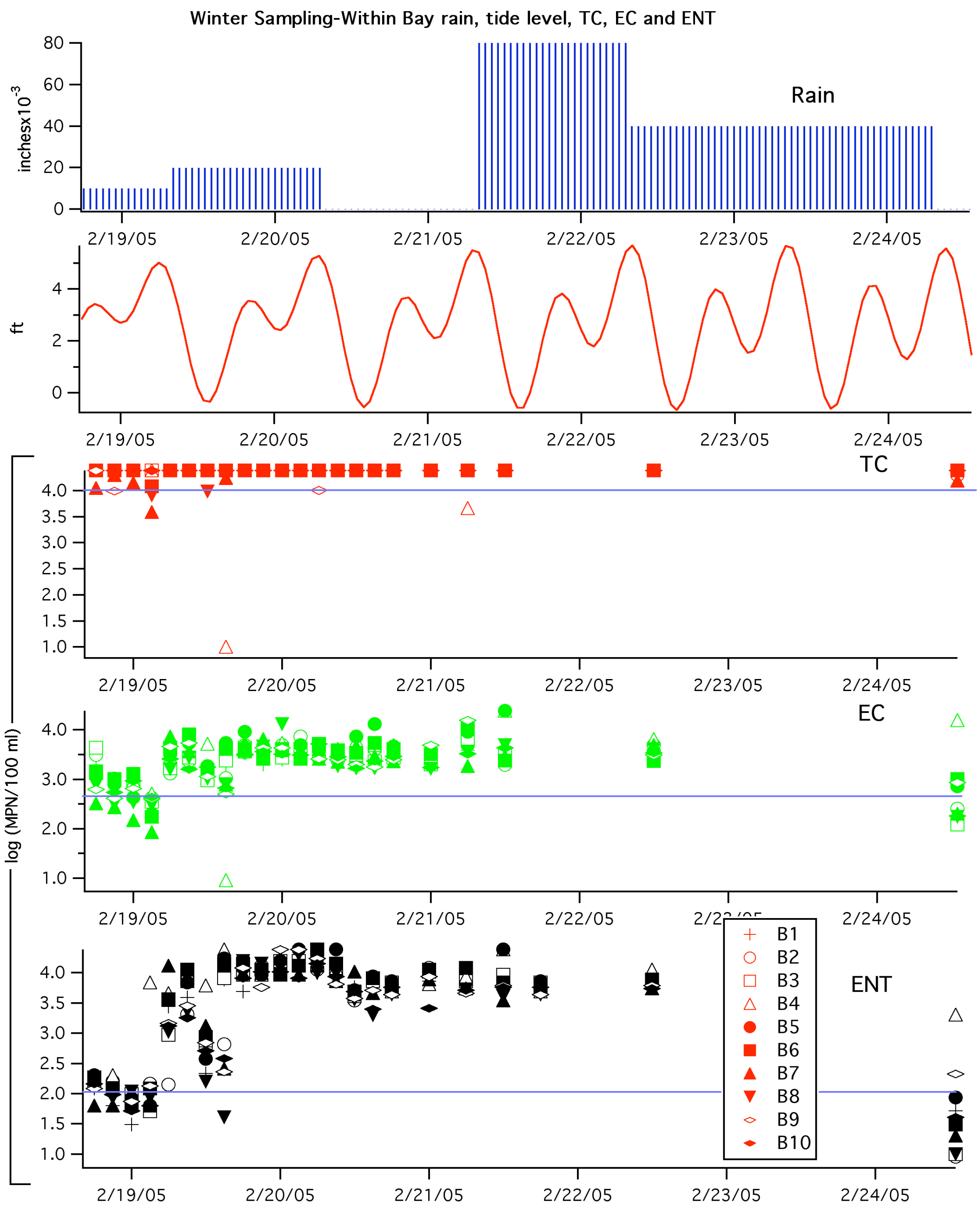

Figure 8. Time series of rainfall, tide level, TC, EC and ENT concentrations measured at within Bay sites in the winter wet weather study. The log transformed single sample standard (blue line) for TC, EC and ENT is 4, 2.6 and 2.0 respectively (log (TC, EC, ENT MPN/100 ml)).

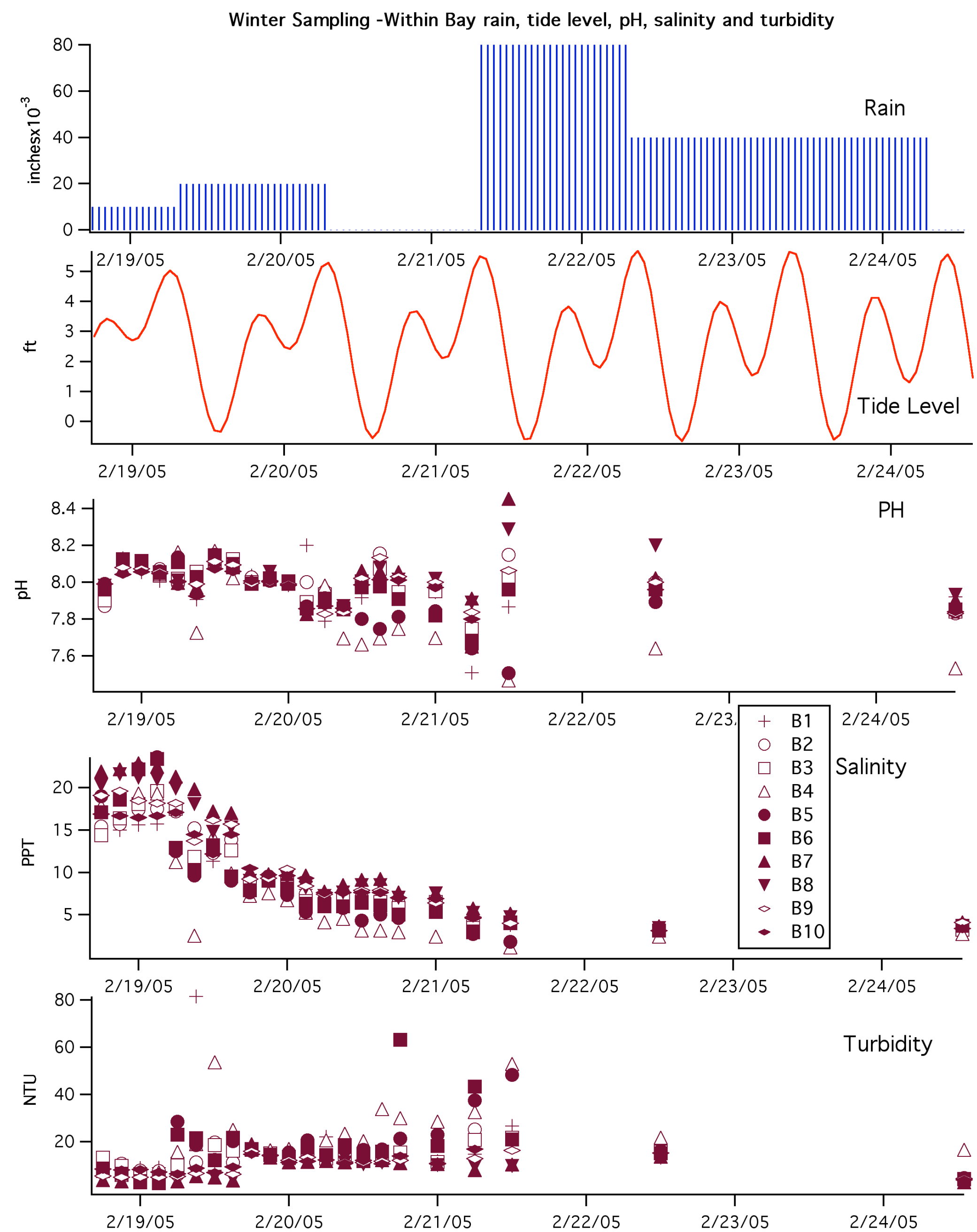

Figure 9. Time series of rainfall; tide level, pH, salinity and turbidity measured at within Bay stations in the winter wet weather study.

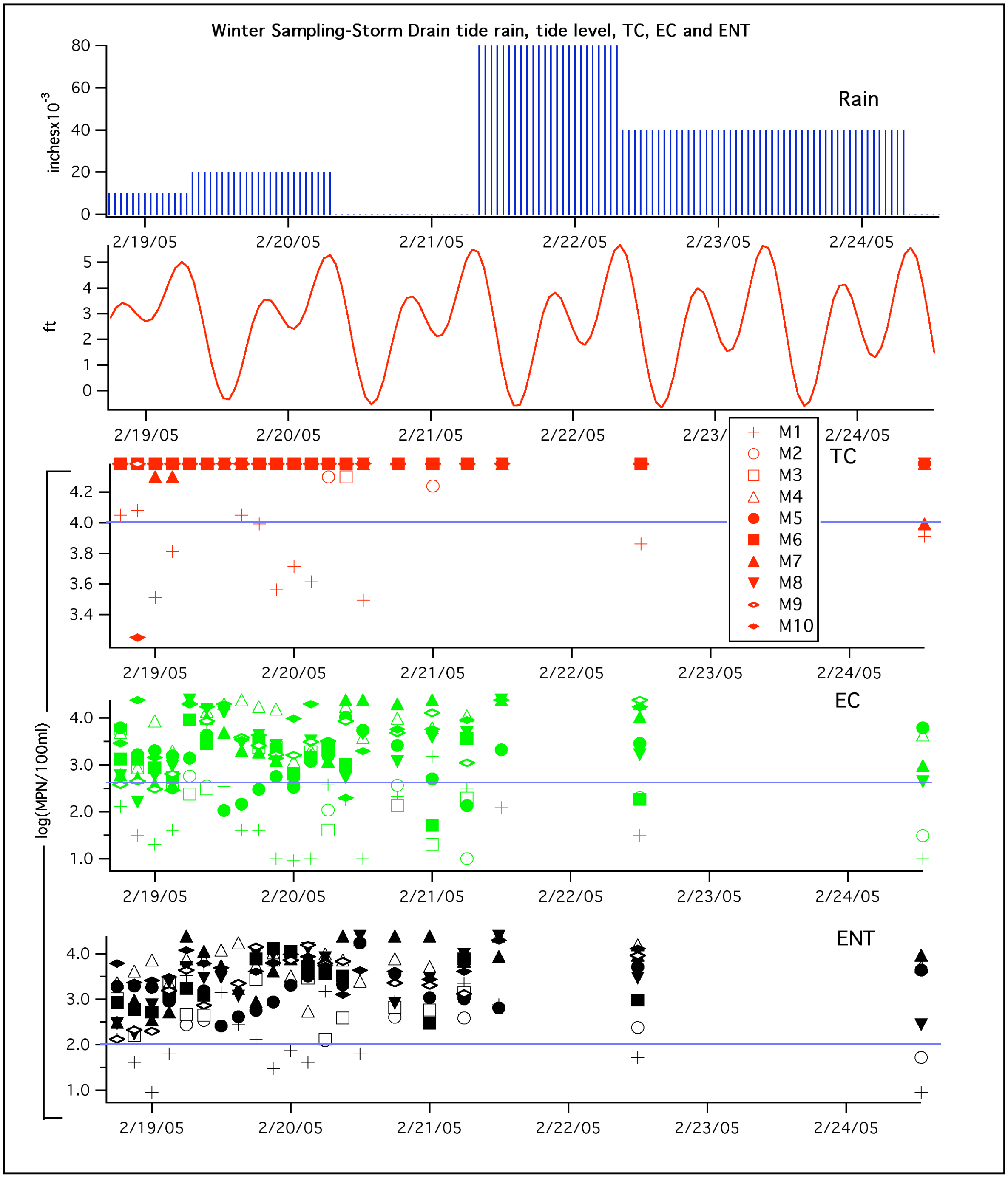

Figure 10. Time series of rainfall; tide level TC, EC and ENT measured at storm drain sites in the winter wet weather study. The log transformed single sample standard (blue line) for TC, EC and ENT is 4, 2.6 and 2.0 respectively (log (TC, EC, ENT MPN/100 ml)).

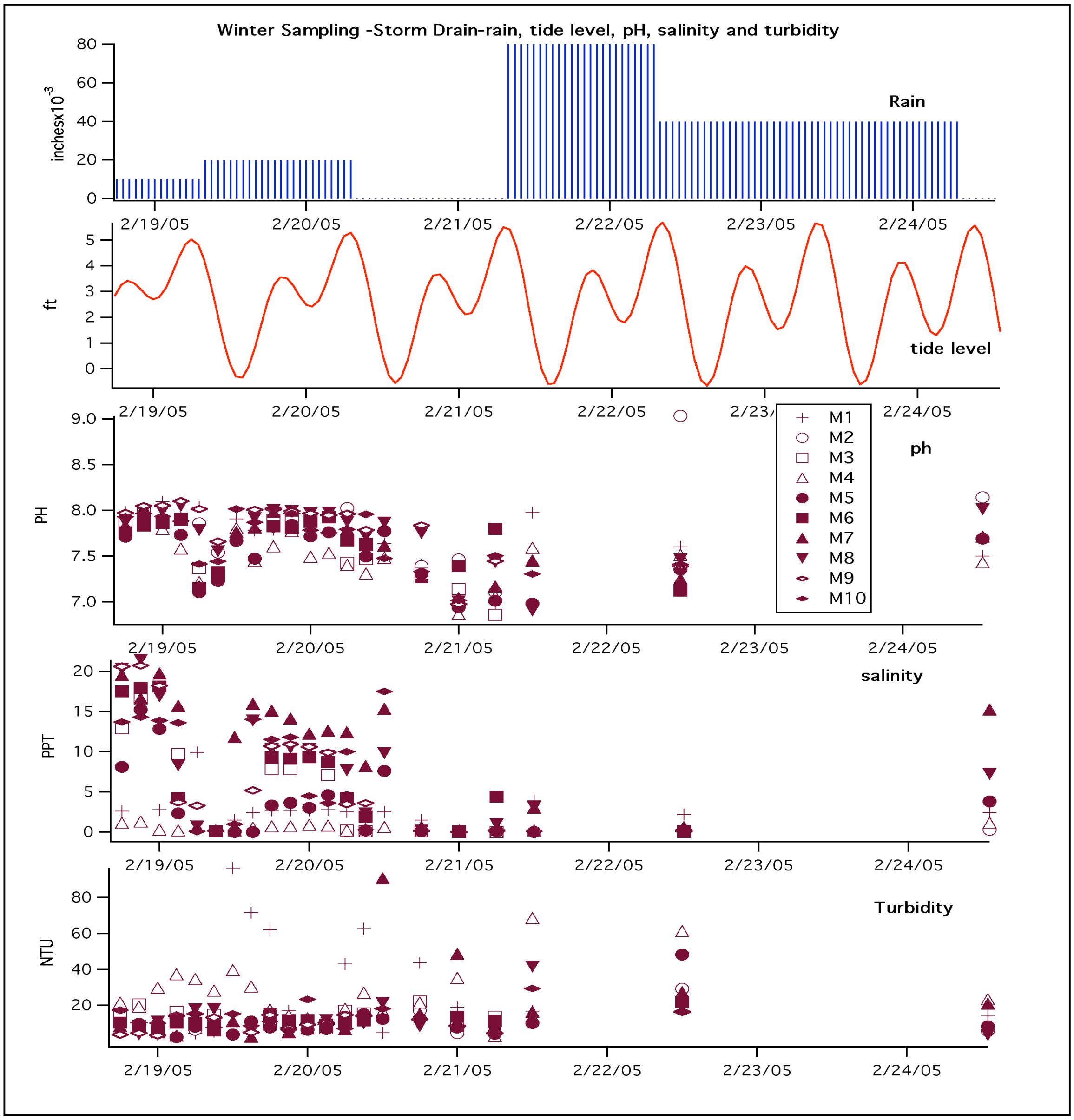

Figure 11. Time series of rainfall; tide level pH, salinity and turbidity measured at storm drain sites in the winter wet weather study.

3.2.3 Summer study: Within Bay results.

TC concentrations (92%) were mostly below the AB411 single sample standard of 10,000 MPN/100ml; they gradually decreased from midnight to late evening (9/18) and then gradually increased from late evening to early morning (9/19) (Figure 12). EC and ENT concentrations were mostly below the AB411 single sample standards of 400 and 104 MPN/100ml; they peaked at approximately 6 am, particularly at stations B3, B4, B5 and B6, and appeared to peak during ebb tides at these sites. (These sites are just outside (B4) or closest to the entrance of WNB.) Generally speaking, TC, EC and ENT concentrations were lower in the day compared to midnight through early morning. This can be attributed to die off of bacteria due to solar radiation. This phenomenon is not obvious during the wet weather study, possibly due to lower magnitude of insolation.

Decreased levels of pH were observed on the flood tides during the first half of the study. Salinity was constant for most of the sampling sites except for B4, B5 and B6, which showed some drops at 3am, 6pm, and 3am respectively, (Figure 13). Turbidity did not vary much over the course of the study except for peaks at 6pm and 6am.

3.2.4 Summer study: Storm Drain results.

Most of the TC concentrations (51%) were below the AB411 single sample standards of 10,000 MPN/100ml, but at some stations (M5, M8, M10) TC concentrations appeared to spike on ebb tides. Nearly half of the EC (48%) and ENT concentrations (59%) were below the AB411 single sample standards of 400 and 104 MPN/100ml; they also appeared to peak during ebb tides for storm drains M1, M8, M10 (Figure 14). The diurnal variability of fecal indicator bacteria is not as evident in the storm drain water samples as it is in the within Bay samples, probably due to minimal exposure to insolation.

The pH seems to be tighter in the first half but after the low low tide it is more dispersed (Figure 15). M4 and M1 seem to have a lower pH than the other sites. Salinity was lowest, 2 ppt, for station M4, and highest for station M5, 32 ppt, and does not vary much for the entire duration of the study. Low salinity at M4 was likely due to the location of the site which was above tidal influence. Increased turbidity levels were seen at station M7 and M1 during ebb tides but this observation is not consistent for all the ebb tides.

3.3 Biofilm Sampling results

Although there are no current standards for biofilm, AB411 water quality standards will be used as references as a conservative approach since diffusion rates from biofilm into water were not tested. In the winter, log mean TC concentrations in the biofilm samples ranged from $10^{3.3}$ to $10^{4.3}$ MPN/100ml (Figure 16). (All biofilm TC concentrations exceeded the geomean water quality standard of 10^{3} MPN/100ml.) Logmean EC concentrations ranged from 10^{1} to 10^{3} MPN/100ml. (The EC geomean standard for water is $10^{2.3}$ MPN/100ml, which was exceeded by 50%) The highest EC concentrations were measured at sites M4 and M10. ENT concentrations were similar to the EC concentrations, with the highest log mean concentrations recorded at M4 and M10. (ENT geomean standard for water is $10^{1.54}$ MPN/100ml, and was exceeded by 90% of the ENT biofilm concentrations).

In the summer (Figure 16), log mean TC concentrations in the biofilm samples ranged from 10^3 to 10^4 MPN/100ml at all the stations. (All biofilm TC concentrations exceeded the geomean water quality standard.) Log mean EC concentrations ranged from $10^{1.9}$ to $10^{3.6}$ MPN/100ml with the highest log mean concentrations at M8 and M10. Log mean ENT concentrations ranged from $10^{1.5}$ to $10^{3.3}$ MPN/100ml with highest log mean concentrations recorded at M1 and M5. (87.5% EC and 75% ENT biofilm concentrations exceeded the geomean water quality standards.)

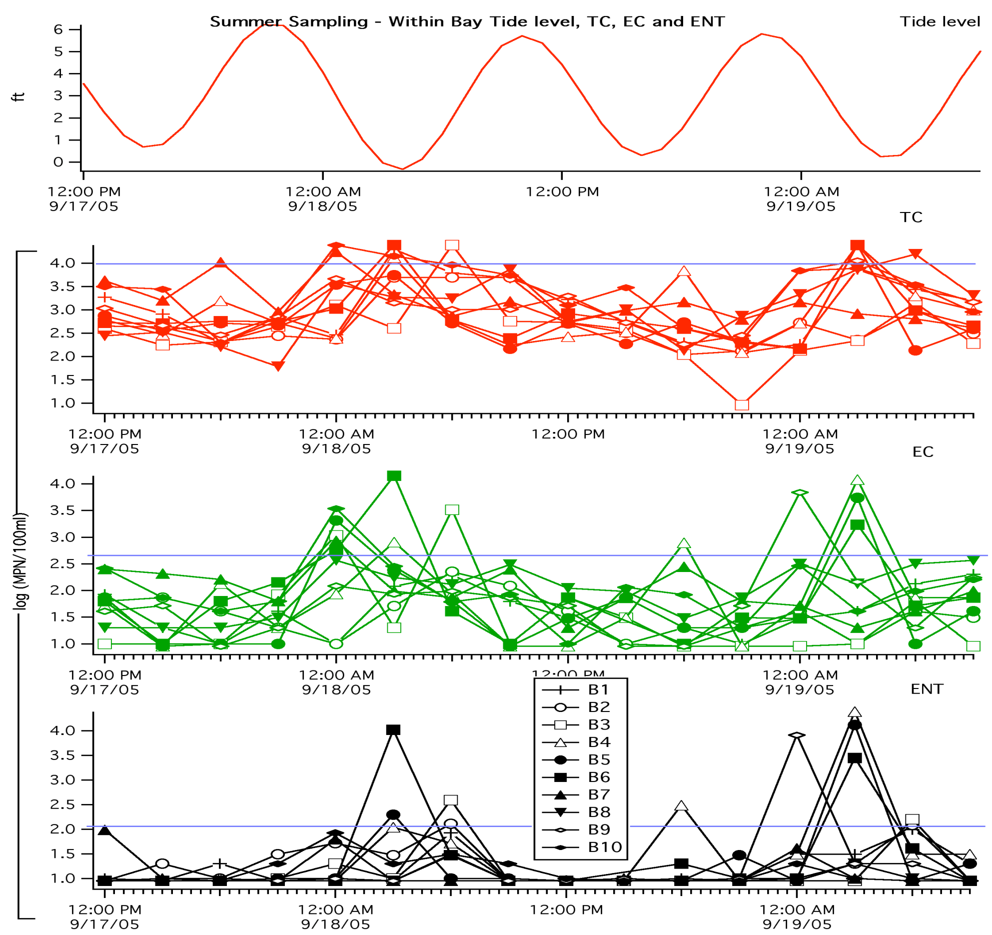

Figure 12. Time series of tide level, TC, EC and ENT concentrations measured at within Bay stations in the summer (dry weather) study of September 2005. The log transformed single sample standard (blue line) for TC, EC and ENT is 4, 2.6 and 2.0 respectively (log (TC, EC, ENT MPN/100 ml)).

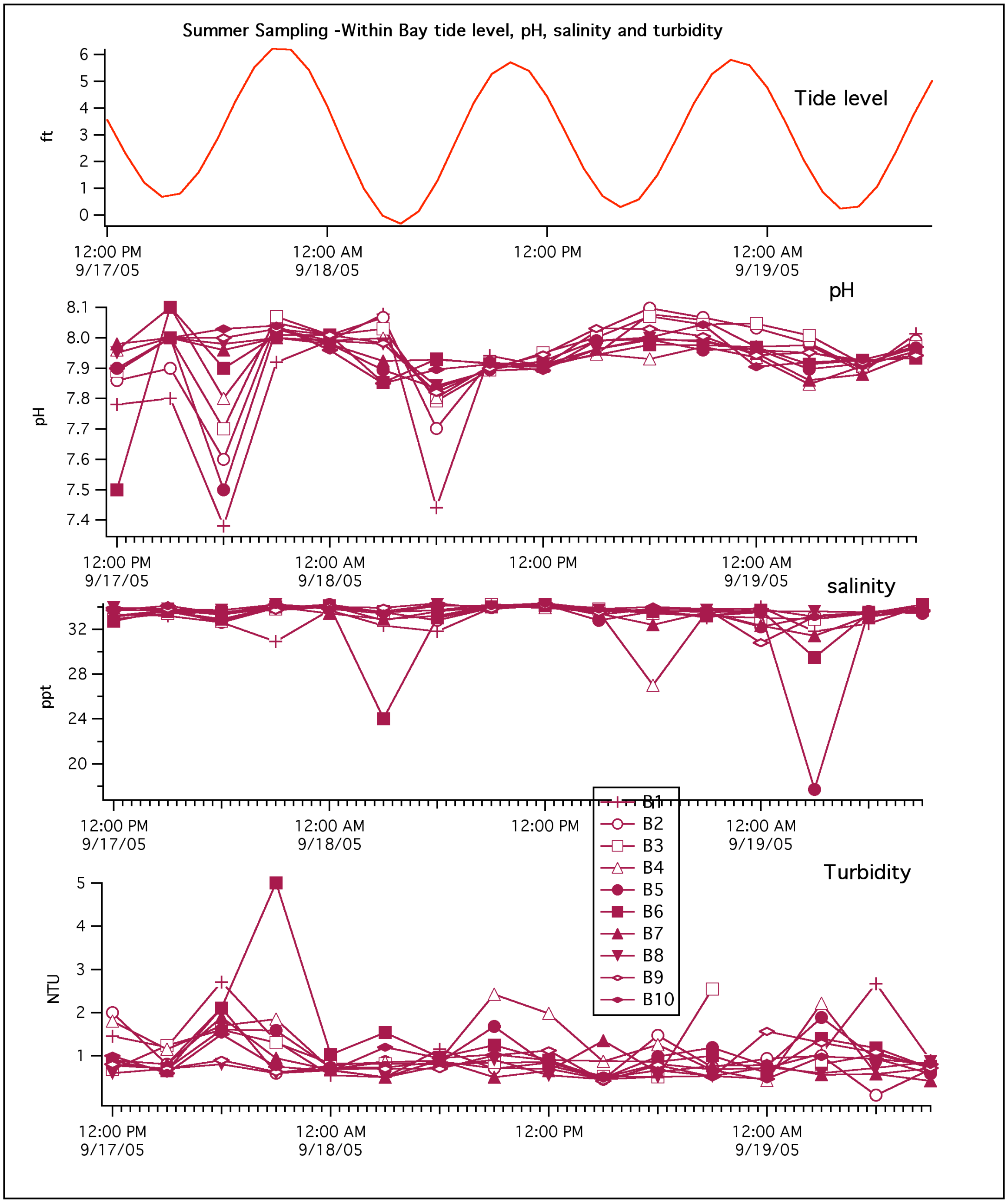

Figure 13. Time series of tide level, pH, salinity and turbidity measured at within Bay stations in the summer (dry weather) study of September 2005.

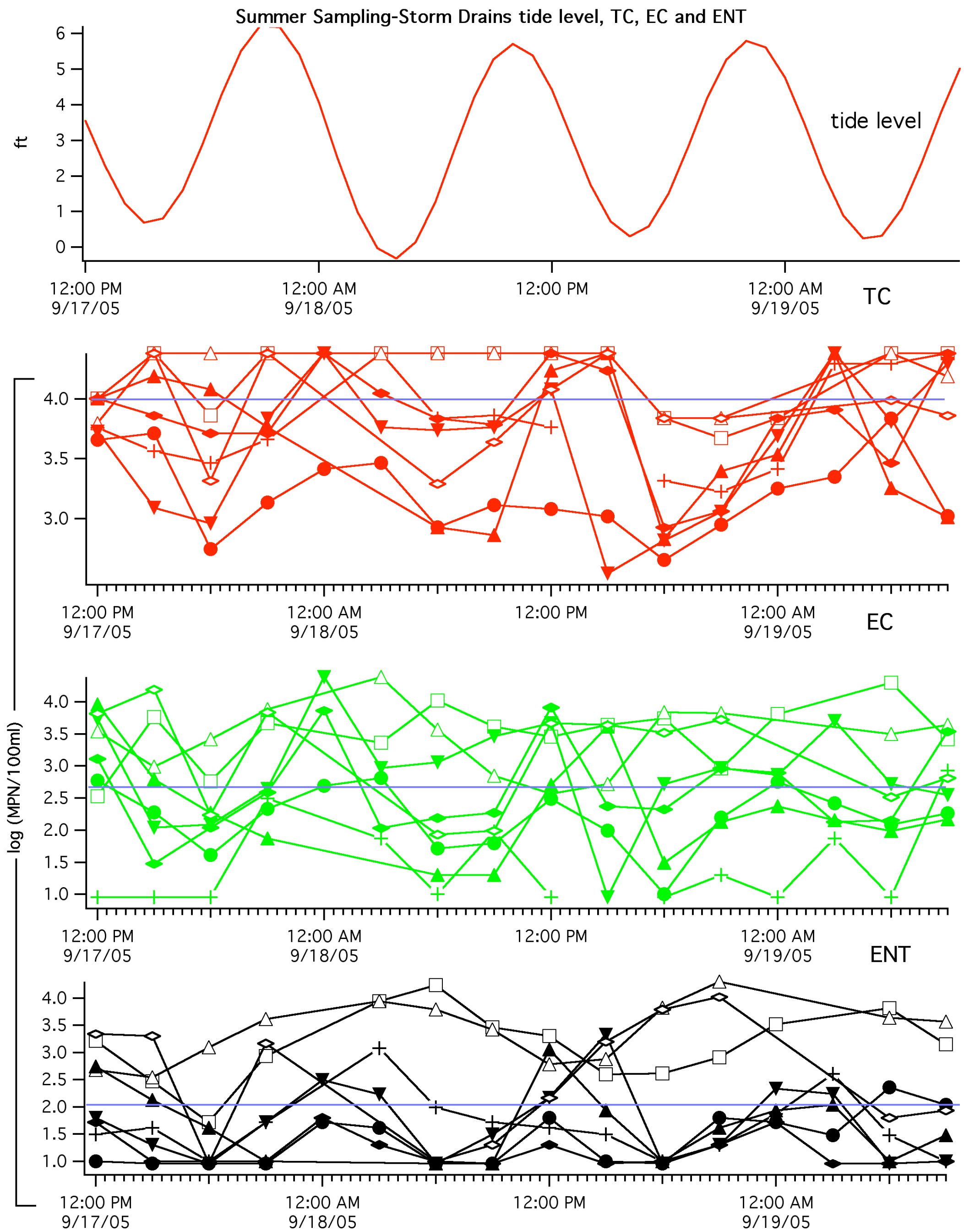

Figure 14. Time series of tide level, TC, EC and ENT measured at storm drain sites in the summer (dry weather) study of September 2005. The symbol key for the storm drain stations is the same as that for Figure 13. . The log transformed single sample standard for TC, EC and ENT is 4, 2.6 and 2.0 respectively (log (TC, EC, ENT MPN/100 ml)).

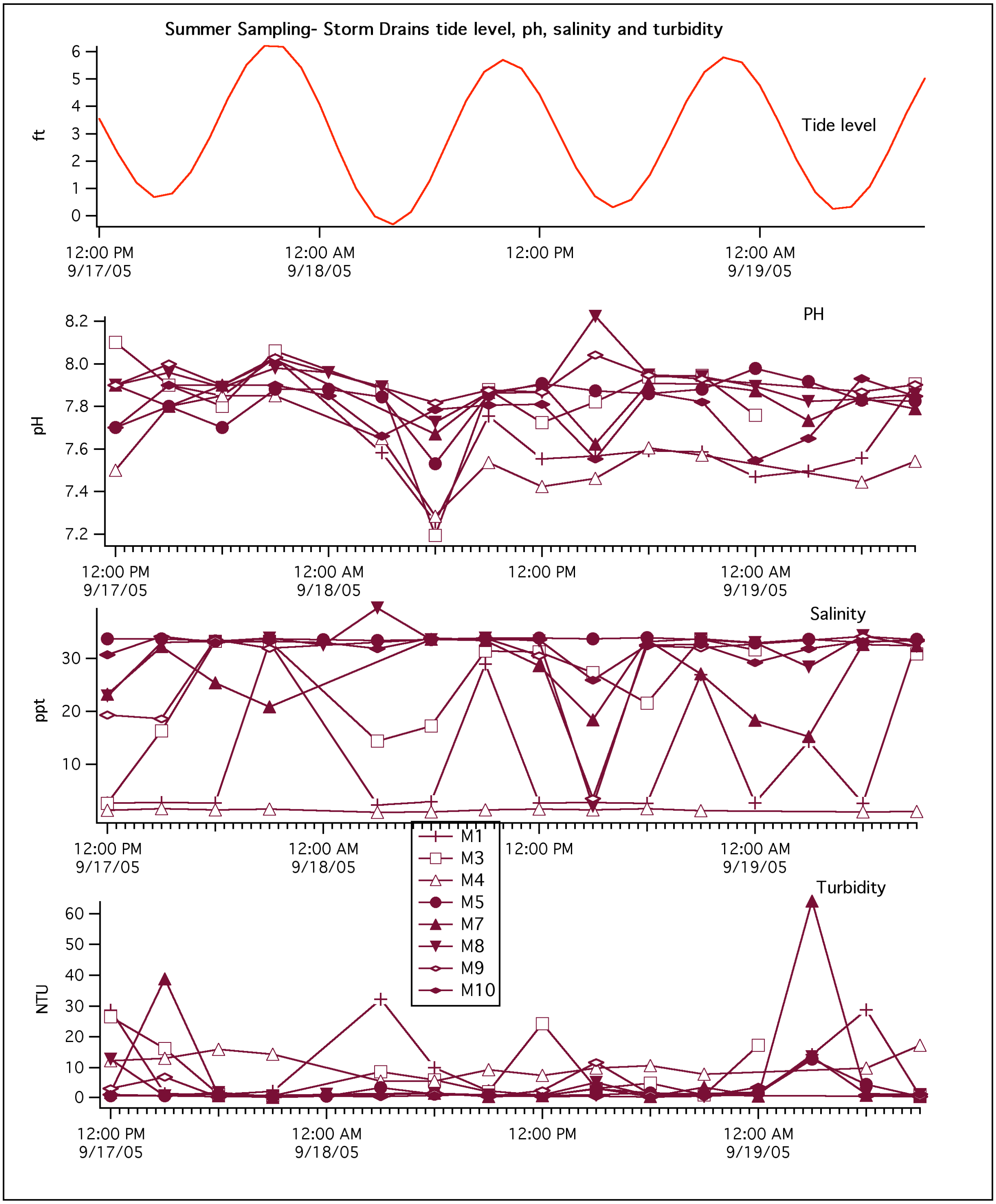

Figure 15. Time series of tide level; pH; salinity and turbidity measured at storm drain sites in the summer (dry weather) study of September 2005.

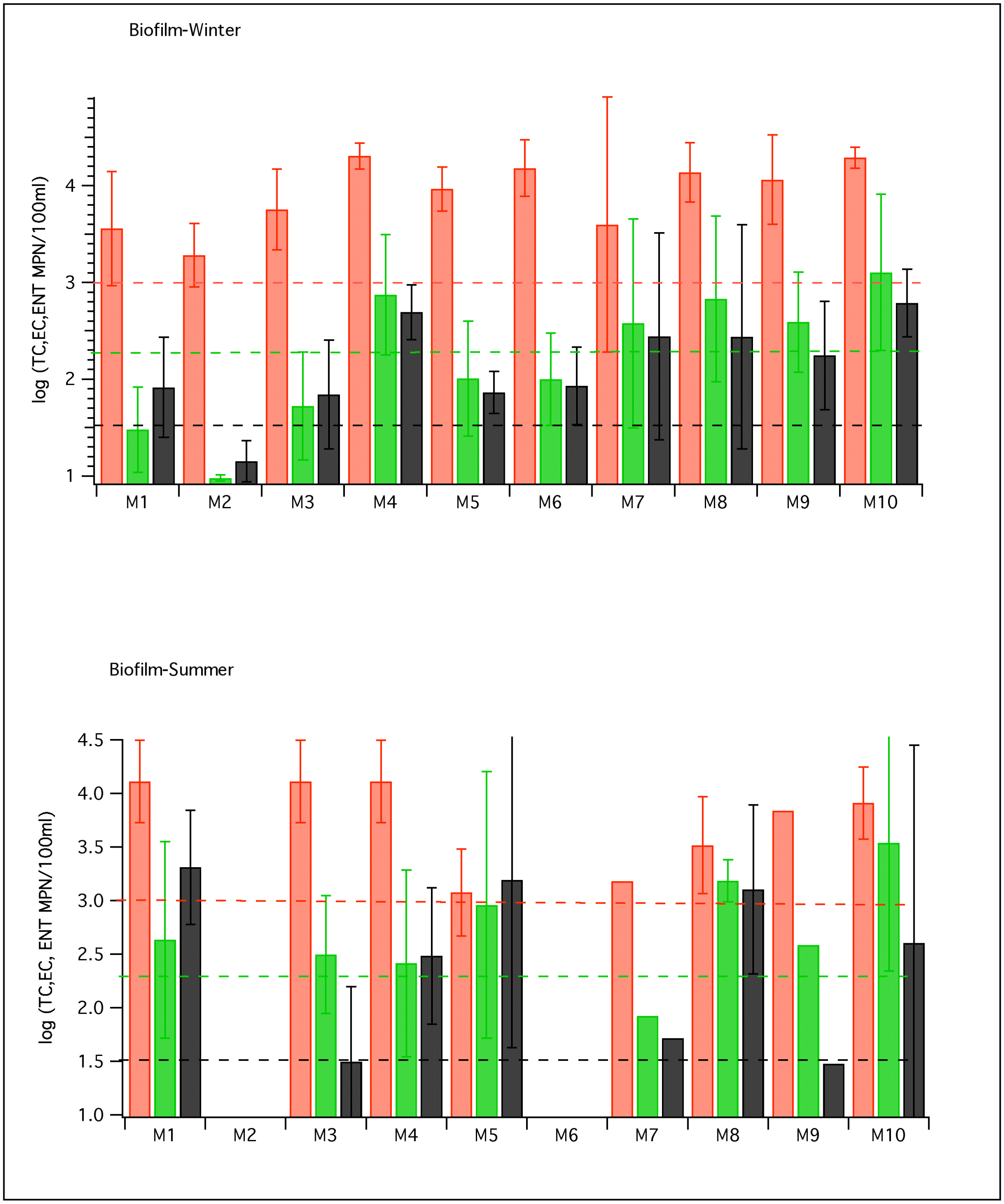

Figure 16. Log means and standard deviations of TC, EC and ENT concentrations in the biofilm samples. The first panel indicates log mean fecal indicator bacteria concentrations in the winter study of February 2005 and the last panel is for the summer study of September 2005. The red, green and black dotted lines represent the California marine water geometric mean standards for TC, EC and ENT. The geomean standards of TC, FC (note: EC is a subset of FC and hence the standard for FC is used) and ENT are 3, 2.3 and 1.54 respectively. (Summer numbers for M7 and M9 are single values.)

4. Discussion

Winter vs. Summer. Log mean fecal indicator bacteria concentrations were higher in the winter wet weather season and lower in the summer dry weather season by approximately an order of magnitude in both Bay and storm drain samples (Tables 2 and 3, Figures 4 and 7). In winter, 97.2% of within Bay and 94% of storm drain TC concentrations exceeded the AB411 single sample standard, compared to the summer in which TC exceedances were 8% of within Bay samples and 39% of storm drains samples. In winter, 92% of within Bay and 74% of storm drain EC concentrations exceeded the AB411 single sample standard, compared to the summer in which EC exceedances were 8% of within Bay samples and 52% of storm drain samples. Similarly, in winter 87% of within Bay and 94% of storm drain ENT concentrations exceeded the single sample standard for ENT, compared to the summer in which ENT exceedences were 7.5% of within Bay samples and 41% of storm drain samples.

Spatial distribution. The distribution of fecal indicator bacteria was, for the most part, spatially uniform all across the WNB, both in the winter storm season and the summer dry season. As expected, TC concentrations were generally higher than EC and ENT concentrations for both seasons. EC and ENT concentrations, in both summer and winter, were slightly higher (~0.5 log units higher) at the entrance to the WNB (near the site B4, Arches V ditch), compared to the rest of the study sites, and lower in the Rivo Alto channel (B7 and B8). In winter, all the TC concentrations exceeded the upper detection limit so no spatial differences were seen, while in the summer, the log mean TC concentration was highest at site B10 near 41st street. The distribution of FIB across the storm drains is more variable than the within Bay FIB distribution. The storm drain site M4, at the Arches V ditch location, had the highest fecal indicator bacteria concentrations in comparison with the rest of the storm drain sites, while storm drain sites within the Balboa Coves community (M1, M2, M3) had the lowest log mean EC and ENT concentration in the winter (Table 2).

Average pH and salinity, in the summer and winter, were spatially uniform all across the WNB and were lower in the storm drains compared to within Bay averages. Average turbidity in the winter was highest near the Newport Blvd bridge (B3, B4) and lowest in the Rivo Alto channel (B7, B8).

Within Bay sites vs. storm drain sites. In the winter, the storm drain sites had lower log mean EC and ENT concentrations compared to within Bay concentrations, the exceptions being M4 (Arches V ditch), M7 (end of Rivo Alto channel), and M10 (41st street) where consistently high concentrations were recorded (also generally higher than within Bay concentrations). In the summer, however, it is the reverse; the storm drains had higher concentrations of fecal indicator bacteria (TC, EC and ENT) than the Bay sites, except for EC in site M1. In the summer, site M4 had higher fecal indicator bacteria concentrations than other drains or Bay sites. With respect to the above discussion, it could be hypothesized that in summer some storm drains like M4 may contribute to the fecal indicator bacteria contamination in Western Newport Bay, and in winter high FIB concentrations in the WNB could result from the combined effect of the FIB contributions from numerous storms drains to a relatively small channel, unusually high residence times, tidal influxes and other processes.

Temporal distribution. The temporal plots (Figures 8- 15) showed that the flood-ebb cycling had an influence on the fecal indicator bacteria signal. In order to explore this further, Spearman rank correlation coefficients were computed between fecal indicator bacteria and salinity. (Correlations were calculated for EC and ENT, but not TC, since TC concentrations were mostly over the detection limit of 24192 MPN/100ml.) The correlation coefficients are depicted in Figure 17. The significant correlations ($p<0.05$) are marked with black solid/hollow circles in the contour plots. In winter, correlations with EC, ENT and salinity are mostly negative at within Bay sites. The correlations are significant and negative at B4, B5, B8 and B9 for EC vs. salinity, and significant and negative at B5, B1, B9 and B8 for ENT vs. salinity. This data demonstrates that in the winter, low salinity storm water entering WNB via storm drains (i.e. freshwater input) is likely to be a contributing factor to high concentrations of EC and ENT. In the summer, negative and significant correlations with salinity are observed at within Bay sites for TC at B4, EC at B4, and ENT at B4 and B5. This data demonstrates that stations B4 and B5 may be impacted by fresh water runoff from the storm drains and may contribute to EC and ENT in the WNB in summer, although within Bay concentrations are not significantly increased by runoff from storm drains in summer compared to winter.

Role of Biofilm. Mean biofilm TC, EC and ENT concentrations were higher in winter at M4, M7 and M9, while concentrations were higher in summer for all FIB at M1 and M3 (except ENT at M3) (M2, M6 not sampled in summer). Concentrations were also higher in summer for EC (M3, M5, M10) and ENT (M5); while concentrations were higher in winter for TC (M5, M10) and ENT (M3, M10). In general log mean TC and ENT concentrations were higher in the winter compared to the summer. Most mean concentrations were above the geomean water quality standards for TC (all), EC (>50%) and ENT (>75%) in both summer and winter. (Data not shown.) (Mean biofilm concentrations were compared to water quality geomean standards since no standards exist for biofilm.)

To compare the biofilm fecal indicator bacteria concentrations of TC, EC and ENT with those found in the water column, (Figure 16 and Supplementary Figure S3 and S5) an [FIB biofilm/FIB water column] concentration ratio was computed for each storm drain in summer and winter, and the average ratios are shown in Figure 18. Biofilm samples were collected twice per day for each storm drain. In winter, the average FIB biofilm/FIB water column concentration ratios for TC, EC and ENT were all less than one (0.55 for TC, 0.24 for EC and 0.15 for ENT biofilm FIB < water column FIB). . This shows that in winter, the biofilm is not a likely source of the fecal indicator bacteria concentrations to the water column. (Possibly due to the high FIB concentrations already in storm water.) In the summer for a majority of the locations, the biofilm/watercolumn FIB ratio was greater than 1 for TC at 6/8 sites (average ratio: 1.47+/-1.15), EC at 4/8 sites (average ratio: 24.14+/-62.84), and ENT at 4/8 sites (average ratio: 98.18+/-170.78). The highest biofilm ratios for TC, EC and ENT were 4.13 (M1), 224 (M10) and 484.46 (M5), respectively. This implies that in the summer, the bacteria in the biofilm could be a major contributor to the bacteria in water column.

The data shows that biofilm appears to be a prime medium for regrowth of FIB in the summer season and could be a major contributor of FIB in the water column depending on the release rate of bacteria from the biofilm. In this study, however, the number of biofilm samples collected in the summer was far less than that in the winter

(14-summer, 60-winter), and hence this conclusion should be further investigated by conducting more extensive biofilm studies (longer sampling period, more samples). In the winter storm samples, biofilm FIB concentrations were less than those in the water column, which demonstrates that storm water, rather than biofilm, contributes more FIB into the Bay during winter storms. The question remains then - *What is the source of FIB in storm water?*, which is another area that requires further study.

<u>*Average FIB trends over time.*</u> Illustrated in Figure 19, logmean FIB concentrations were computed at each sampling time for all the sampling sites, to compare the general temporal trends for within Bay FIB concentrations and storm drain FIB concentrations. Spearman rank correlations were also calculated between average temporal trends. In summer and winter, EC, ENT and TC (summer only) temporal trends tracked well with each other and were significantly and positively correlated with each other. In summer, within Bay and storm drain TC trends tracked closely (Spearman rank correlation (Sp)=0.609, $p<0.05$), while EC trends tracked closely for the first half of the study and then follows an almost contrasting pattern. There was no significant statistical correlation between storm drain and within Bay EC and ENT temporal trends in the summer. In winter, TC trends could not be compared statistically since TC concentrations were mostly above detection limits. There was no significant correlation for winter storm drain and within Bay EC and ENT temporal trends.

Within each study, winter and summer, fecal indicator bacteria at each station tracked well with each other, especially EC and ENT (Figures 6, 8, 10, 12). The TC trend in the winter was not possible to track, because the concentrations were consistently higher than the detection limits at the majority of sites. The supplementary Figures S6 and S7 in Appendix 2 give a much clearer idea of the spatial distribution of FIB in within Bay samples by comparing the log mean FIB concentration at each sampling site to an overall log mean across all the sampling sites within Western Newport Bay. This data indicates the hot spots of FIB contamination within the Bay. In winter at within Bay sites, the highest EC and ENT concentrations were found at B4 and B5 near the Arches V ditch drain. In summer at within Bay sites, the highest TC and EC concentrations were found at B10 (near 43rd street beach), B7 (end of Rivo Alto channel) and B4 (near Arches). ENT concentrations were highest at B4 (near Arches V ditch). In the summer, the log mean

FIB concentrations at all the storm drain sites were higher than the overall log mean FIB concentration at within Bay sites.

5. Conclusions and Recommendations

Within Bay sampling: In the summer about 8% of water samples from within Bay sites exceed single sample standards, which is typical of tidal embayments in southern California (Taggart M., A report on the enclosed beach symposium and workshop, State Water Resources Control Board. **2006**, 30-31). However, in the winter wet weather study, about 90% of samples from within Bay sites exceeded single sample standards, which is higher than the typical percentage (50%) of exceedences found in southern California (Taggart M. et. al). In both the summer and winter, the FIB concentrations were relatively similar site to site, which implies that WNB is relatively well mixed.

Storm Drain sampling: In the summer dry weather study about 50% of samples and in the winter wet weather study >80% of the samples exceeded one or more single sample standards. There was a high degree of site-to-site variability with respect to FIB concentrations in the storm drains.

Within Bay and storm drain sites had high concentrations of FIB in the winter (exceedences of 97%, 94% -TC, 92%, 74% - EC, 87%, 94% -ENT), and Bay concentrations were equal to or higher than some storm drain sites (Figure 4). In the summer, Bay and storm drain concentrations decreased compared to the winter (exceedences of 8%, 39% -TC, 8%, 52% - EC, 7.5%, 52% -ENT), and Bay FIB concentrations were much lower than storm drain concentrations (Figure 7).

Biofilm sampling: TC mean concentrations were higher in winter at 6/8 sites (except M1 and M3), ENT mean concentrations were higher in winter at 5/8 sites (except M1, M5 and M8), and EC mean concentrations were higher in summer at 5/8 sites (except M4, M7 and M9) (M2 and M6 not sampled in summer). In the winter wet weather study, biofilm lining the storm drain is probably not enriched in FIB compared to the overlying water column. However, in the summer, biofilm may be enriched in FIB compared to the overlying water.

Recommendations: The development of a modeling tool to assess which storm drains, or other sources outside of WNB, are the primary cause of water quality impairment is highly recommended. Further focused studies investigating the role of biofilms in FIB contribution to the water column (viz. studying the flux rates of FIB from the biofilm layer to the water column) are also recommended.

The data above will supplement the existing fecal coliform database that is maintained by the county by providing a high frequency data set for a specific location, Western Newport Bay, which has consistently high fecal indicator bacteria counts all year round. The data provides insights into the impact of storm drains on water quality in the WNB and is a useful supplement in the implementation of the Fecal Coliform TMDL.

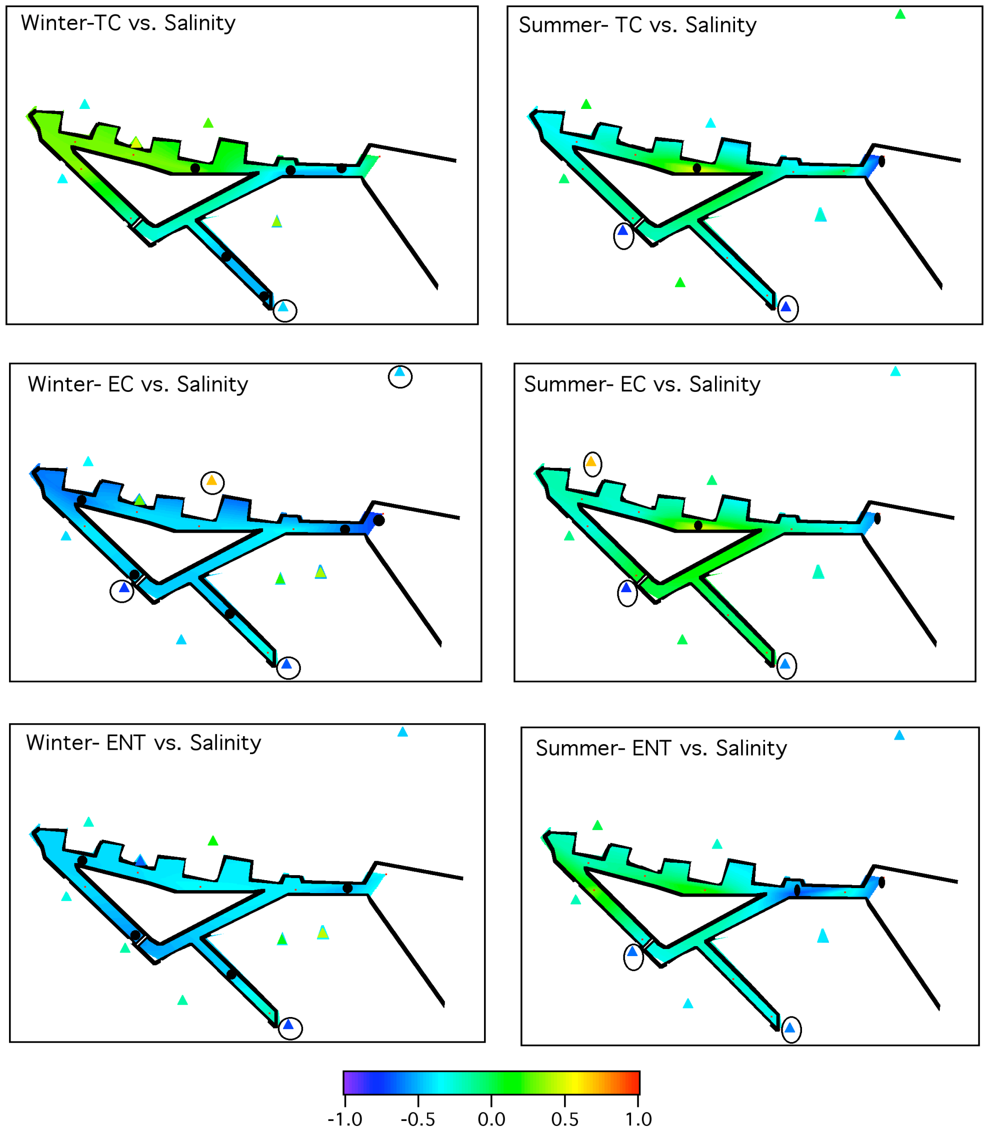

Figure 17. Spearman rank correlations between fecal indicator bacteria concentrations and salinity measurements. The left side indicates the correlations in the winter and the right side corresponds to the correlations in the summer. The color scale indicates the strength of the non-parametric correlation. All significant correlations ($p<0.05$) are marked with a solid black circle, for within Bay sampling sites or a hollow black circle, for storm drain sampling sites.

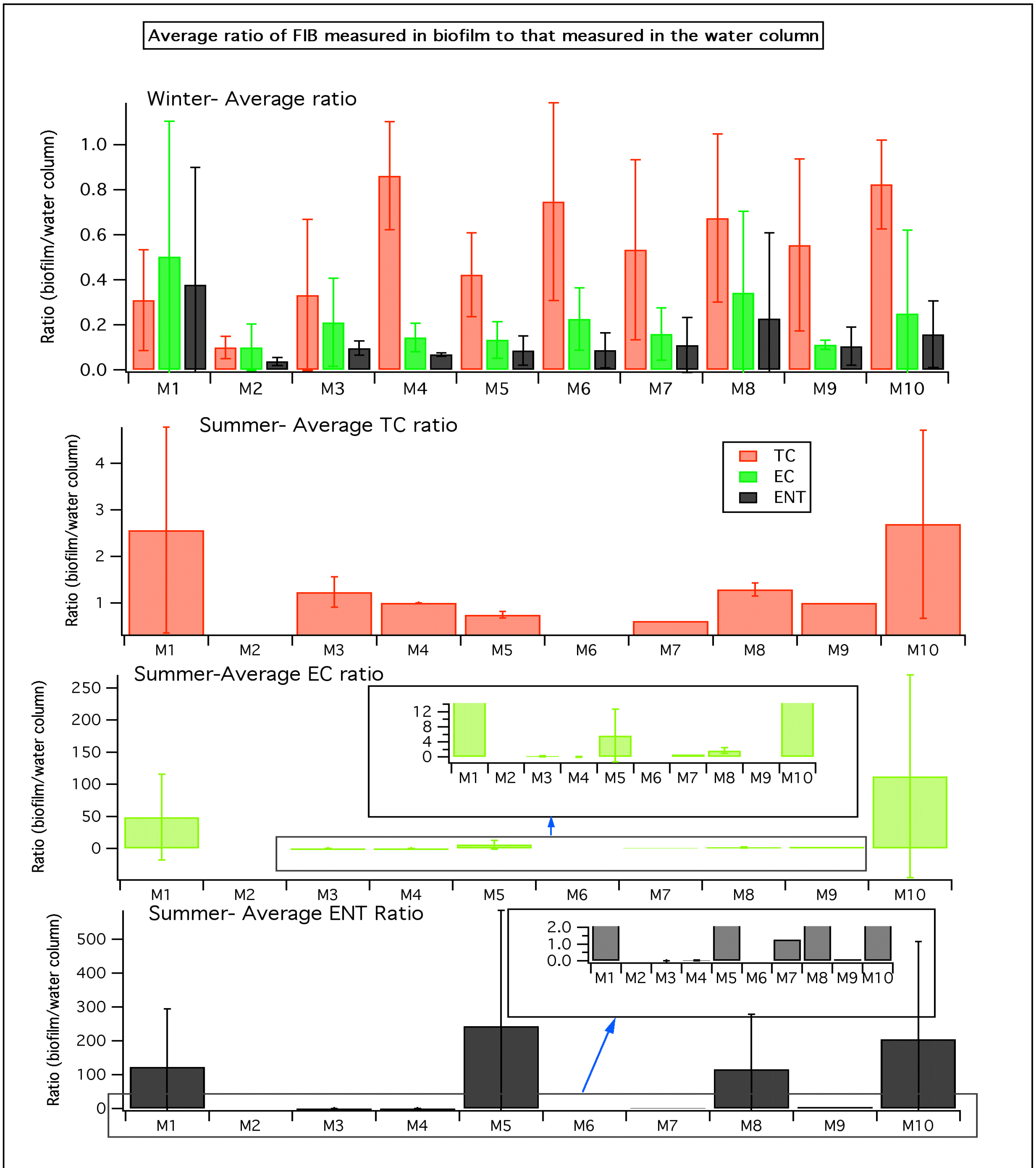

Figure 18. Average ratio of fecal indicator bacteria in biofilm to that of fecal indicator bacteria in the water column in storm drains. A ratio of greater than 1 indicates biofilm enriched fecal indicator bacteria concentrations and a ratio of less than one indicates water enriched fecal indicator bacteria concentrations.

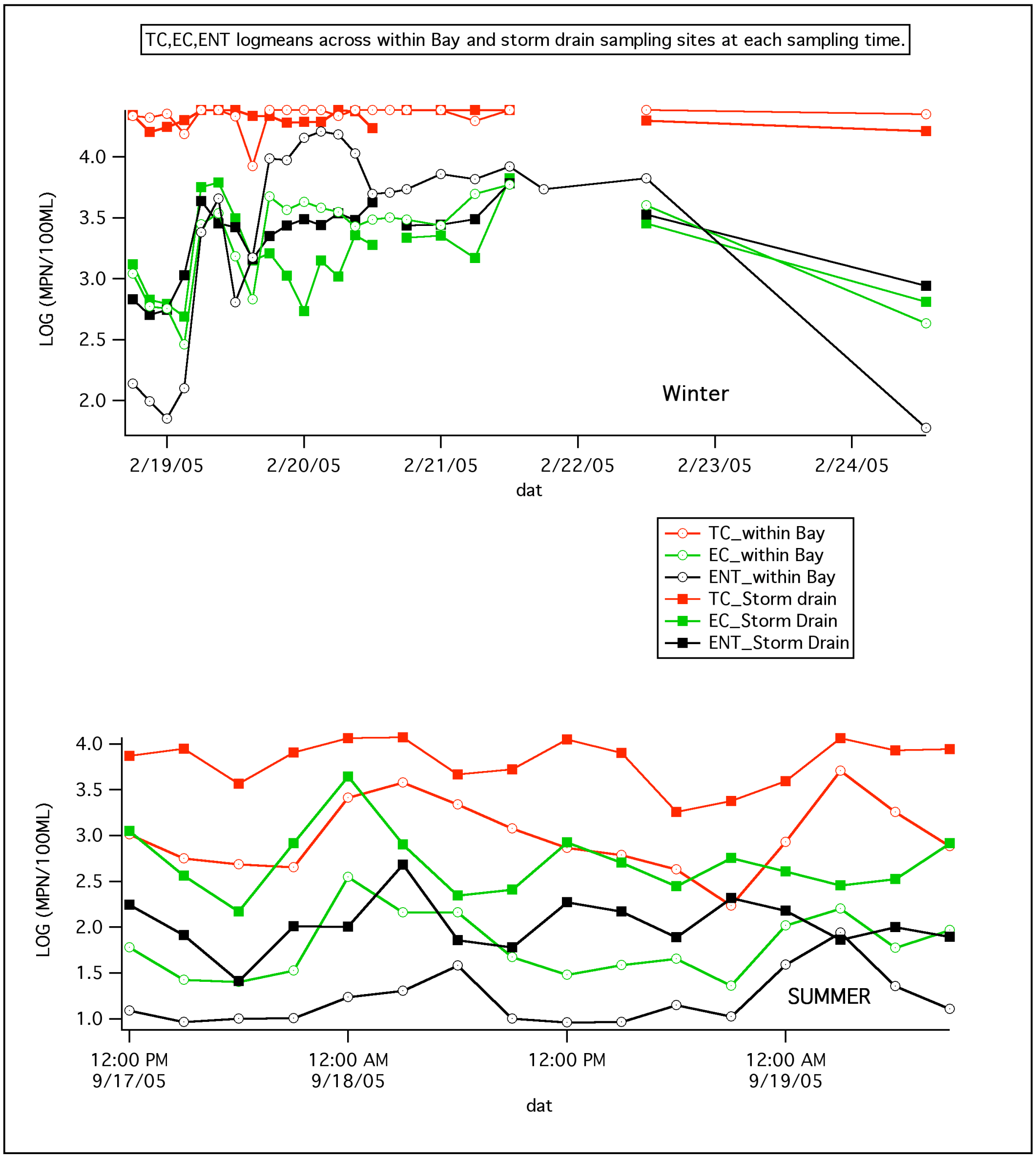

Figure 19. FIB log means computed at all the sampling stations for each sampling time, in the summer and winter studies at WNB.