PERTURBATION OF NUTRIENT INVENTORIES AND PHYTOPLANKTON COMMUNITY COMPOSITION DURING STORM EVENTS IN A TROPICAL COASTAL SYSTEM:
HE‘EIA FISHPOND, O‘AHU, HAWAI‘I

A THESIS SUBMITTED TO THE GRADUATE DIVISION OF THE
UNIVERSITY OF HAWAI‘I AT MĀNOA IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE
IN
OCEANOGRAPHY

MAY 2011

By
Charles W. Young III

Thesis Committee:
Kathleen C. Ruttenberg, Chairperson
Margaret McManus
Brian Glazer

ACKNOWLEGEMENTS

I would like to express profound gratitude to my thesis committee for their support and supervision throughout this study. The unyielding enthusiasm Kathleen Ruttenberg dedicated towards mentoring and developing my capacity for scientific thought will be forever appreciated.

Thanks are due to my lab members, Rebecca Briggs, Danielle Hull, Kahoa Keahi, and Daniel McCoy. Their help during fieldwork and within the laboratory made the completion of this study possible. Without their dedicated efforts, the body of work presented herein would never have come to fruition.

I have appreciated the opportunity to work with the caretakers of He‘eia Fishpond, Paepae o He‘eia. Their welcome, into this place of such cultural significance within the Hawaiian community, is greatly appreciated and proven to be a special educational experience. Their participation was invaluable to the success of this study.

Thanks are also due to the many others who have contributed, directly or indirectly, to the success of this study. The list is much to long to include here, but this work would not have been possible without the support of my colleagues in the scientific community, fellow students, family, friends, and the administrative staff of the Department of Oceanography.

This study has been funded by a grant from the National Oceanic and Atmospheric Administration, Project R/AQ-84, which is sponsored by the University of Hawai‘i Sea Grant College Program, SOEST, under Institutional Grant No. #NA05OAR4171048 from NOAA Office of Sea Grant, Department of Commerce. The views expressed herein are those of the author and do not necessarily reflect the views of NOAA or any of its sub-agencies. This is University of Hawai‘i Sea Grant contribution number UNIHI-SEAGRANT-XM-09-02.

ABSTRACT

Tropical islands, characterized by highly variable rainfall, experience dynamic changes in coastal ocean dissolved nutrient inventories and particulate loads. Episodic storm events can impact nutrient concentrations and ratios such that the effects are felt throughout the coastal marine ecosystem. We report results from a 13-month study focusing on changes in marine biogeochemistry within a historical Hawaiian fishpond, He‘eia Fishpond, on the island of O‘ahu. The fishpond is influenced by freshwater and seawater inputs and receives fluvial sediment flux from the uplands. We observe storm-induced perturbations in nutrient inventories and resulting transformations in phytoplankton community composition. These seasonal changes in nutrient inventories are a function of the relationship between baseline and storm-induced discharge and the associated residence time of the tidally mediated fishpond receiving waters.

TABLE OF CONTENTS

Acknowledgements ii

Abstract iv

Table of Contents v

List of Tables ix

List of Figures x

Chapter 1: Introduction 1

  Research Goals 2

  Impacts of Fluvial Discharge in Hawai‘i 3

  Overview of Study Site 5

  Field Methods 9

  Sampling and Laboratory Methods 13

Chapter 2: Physical Processes in He‘eia Fishpond 36

  Regional Meteorological Overview 37

  Data Collection 38

    Rainfall 39

    Stream Discharge 40

    Wind and Solar Radiation 41

    He‘eia Fishpond in situ Instrumentation 42

  Dry vs. Wet Season 44

  Flow Rates and Rating Curves 44

  Tidal Spectra 47

He‘eia Fishpond Bathymetry and Volume 48

Mākāhā Water Flow Rate Comparison 49

He‘eia Fishpond Circulation Dynamics 53

He‘eia Fishpond Residence Time 55

Water Column Physical Properties 57

Spatial and Temporal Temperature Record 58

Monthly Water Column Profiles 59

Baseline vs. Storm Conditions 62

Storm Event Comparison 65

Summary and Conclusions 67

Chapter 3: Nutrient Cycling within He‘eia Fishpond 109

Sampling Strategy 111

Analytical Methods 112

Approach to Nutrient Data Analysis and Interpretation: Salinity as a Master Variable 113

Definition of Baseline Conditions vs. Storm Events 115

Defining a He‘eia Fishpond Storm Event 116

Estuarine Mixing Trends as Revealed by Property-Property Plots 117

Salinity Binning 119

Empirical Orthogonal Function (EOF) Defined Storm Events 121

Spatial and Temporal Nutrient Distribution Patterns 124

Baseline vs. Storm Event Salinity Distributions 124

Baseline vs. Storm Event Ammonium Distributions 128

Baseline vs. Storm Event (Nitrate + Nitrite) Distributions 130

Baseline vs. Storm Event Phosphate Distributions 132

Baseline vs. Storm Event Silicate Distributions 135

Temporal Evolution of the First-Flush Storm Event 136

Comparison to Kane‘ohe Bay Studies 138

Chapter 4: Suspended Particulate Matter in He‘eia Fishpond 169

Riverine and Water Column Suspended Particulate Matter 170

Summary and Conclusions 172

Chapter 5: Phytoplankton Community Composition Response to Storm-Induced Shifts in Nutrient Inventories 177

Analytical Methods 178

Chlorophyll-a Concentrations Across He‘eia Fishpond 179

Phytoplankton Community Composition 182

Phytoplankton Community Changes due to Evolution of Water Column Nutrients and Chl-a during the First-Flush Storm 183

Storm-Induced Changes in Phytoplankton Community Composition 185

Nutrient Limitation of Primary Production in Aquatic Systems 186

Role of Phosphorus in Marine Environments 187

Alkaline Phosphatase as a Nutrient Deficiency Indicator 188

Relationship between Chlorophyll-a and APA 189

Relationship between Dissolved Inorganic Phosphorus and APA .. 190

Spatial Variability of APA During Baseline Conditions 192

Temporal and Spatial Variability of APA During Storm 1 193

Chapter 6: Conclusions 214

Appendices 217

Overview 217

Appendix 1: 221

Appendix 2: 237

Appendix 3: 253

Appendix 4: 271

Appendix 5: 289

Appendix 6: 334

Appendix 7: 348

Appendix 8: 362

Appendix 9: 370

Appendix 10: 376

Appendix 11: 382

Appendix 12: 388

Appendix 13: 403

Bibliography 418

LIST OF TABLES

Table Page

1.1 Sampling Frequency and Rationale 18

1.2 He‘eia Fishpond Sample Site Locations 20

1.3 Instrumentation Deployed to Collect *in situ* Data 21

1.4 Parameters Measured by the YSI 6600 v2 22

1.5 Water Sample Collection and Processing 23

1.6 Field Sampling Regimen 24

2.1 Monthly Mean Rainfall and Stream Flow 68

2.2 He‘eia Fishpond Mākāhā Rating Curve Formulae 69

2.3 Site-Specific Mean Water Flow Per Tidal Cycle 70

2.4 Comparison of Significant Rainfall Events 71

3.1 Dissolved Nutrient Analytical Methods 142

3.2 Comparison of Dissolved Inorganic Nutrient Concentrations for Studies Conducted in Southern Kane‘ohe Bay 143

5.1 Photosynthetic Pigment Abbreviations 195

5.2 Comparison of Photosynthetic Pigment Concentrations for Studies Conducted in Southern Kane‘ohe Bay 196

LIST OF FIGURES

Figure Page

1.1 Fishpond Examples 25

1.2 Island of O‘ahu and He‘eia Fishpond Maps 26

1.3 Historic Maps of He‘eia Fishpond 27

1.4 He‘eia Fishpond Perimeter Outline and Mākāhā Locations 28

1.5 Mākāhā Dimensions 29

1.6 He‘eia Fishpond Permanent Stake Locations 30

1.7 He‘eia Fishpond Interior Monthly Sample Locations 31

1.8 He‘eia Fishpond Storm Transect Sample Locations 32

1.9 He‘eia Fishpond Perimeter Monthly Sample Locations 33

1.10 Instrument Deployment Locations 34

1.11 Sediment Core Sample Locations 35

2.1 He‘eia Fishpond Watershed and Locations of USGS Stream Discharge and NOAA Rain Gauge Measurements 72

2.2 Daily Rainfall Measured at the NOAA Rain Gauge Station 73

2.3 Daily Stream Discharge Measured at the USGS Stream Discharge Station 74

2.4 Daily Wind Measured at HIMB, Binned According to Direction and Occurrence 75

2.5 Daily Wind Measured at HIMB, Direction and Magnitude 76

2.6 Daily Solar Radiation Measured at HIMB 77

2.7 Site Locations and Types of Instruments Deployed 78

Figure Page

2.8 Rating Curves for Ocean Mākāhā 2 79

2.9 Rating Curves for Ocean Break 80

2.10 Rating Curves for Ocean Mākāhā 1 81

2.11 Rating Curves for Triple Mākāhā 82

2.12 Rating Curve for River Mouth 83

2.13 Rating Curve for River Mākāhā 3 84

2.14 Rating Curve for River Mākāhā 2 85

2.15 Tidal Spectra for Ocean Mākāhā 86

2.16 Tidal Spectra for River Mouth and River Mākāhā 87

2.17 He‘eia Fishpond Bathymetry Map 88

2.18 Tidal Range of Kane‘ohe Bay Measured at HIMB 89

2.19 Spring Flood Tide Mākāhā Flow Rates 90

2.20 Spring Ebb Tide Mākāhā Flow Rates 91

2.21 Neap Flood Tide Mākāhā Flow Rates 92

2.22 Neap Ebb Tide Mākāhā Flow Rates 93

2.23 Temperature Record, He‘eia Fishpond Sites Most Distal from Land 94

2.24 Temperature Record, He‘eia Fishpond Sites Most Proximal to Land 95

2.25 Mean Baseline Water Column Salinity Values 96

2.26 Mean Baseline Water Column Temperature Values 97

2.27 Mean Baseline Water Column Dissolved Oxygen Values 98

Figure Page

2.28 Mean Baseline Water Column pH Values 99

2.29 Mean Surface and Near Bottom Salinity Values for 08/11/07 100

2.30 Mean Surface and Near Bottom Salinity Values for 08/30/08 101

2.31 Mean Surface and Near Bottom Salinity Values for 11/05/07 102

2.32 Mean Surface and Near Bottom Salinity Values for 11/06/07 103

2.33 Mean Surface and Near Bottom Salinity Values for 11/07/07 104

2.34 Mean Surface and Near Bottom Salinity Values for 11/08/07 105

2.35 Mean Surface and Near Bottom Salinity Values for 11/11/07 106

2.36 Rainfall and Storm 1 Sampling Events for November 2007 107

2.37 Mean Surface and Near Bottom Salinity Values for 06/14/08 108

3.1 Salinity Empirical Orthogonal Function Variance 144

3.2 Water Column H_4SiO_4 Concentrations vs. Salinity for Non-storm and Storm Sampling Events 145

3.3 Water Column H_4SiO_4 Concentrations vs. Salinity for Storm 1 and Storm 4 146

3.4 Water Column $(NO_3^- + NO_2^-)$ Concentrations vs. Salinity for Non-storm and Storm Sampling Events 147

3.5 Water Column $(NO_3^- + NO_2^-)$ Concentrations vs. Salinity for Storm 1 and Storm 4 148

3.6 Water Column PO_4^{3-} Concentrations vs. Salinity for Storm 1 and Storm 4 149

3.7 Mean Annual Baseline Surface Water Salinity 150

3.8 Salinity Binned Sample Sites Map 151

3.9 Values of EOF Mode 1 Time Series Per Sampling Event 152

Figure Page

3.10 Mean Surface and Near Bottom Salinity Values for 12/09/07 153

3.11 Values of EOF Mode 1 Spatial Pattern Per Sample Site 154

3.12 Surface Water Salinity Values for Storm 1, Storm 2, and Storm 4, Binned Sample Sites 155

3.13 Surface Water Salinity Values for Storm 1-Transect 1 and Storm 4, Binned Sample Sites 156

3.14 Mean Surface Water NH_4^+ Concentrations for Non-storm and Storm Sampling Events, Binned Sample Sites 157

3.15 Surface Water NH_4^+ Concentrations for Storm 1, Storm 2, and Storm 4, Binned Sample Sites 158

3.16 Mean Surface Water $(NO_3^- + NO_2^-)$ Concentrations for Non-storm and Storm Sampling Events, Binned Sample Sites 159

3.17 Surface Water $(NO_3^- + NO_2^-)$ Concentrations for Storm 1, Storm 2, and Storm 4, Binned Sample Sites 160

3.18 Mean Surface Water PO_4^{3-} Concentrations for Non-storm and Storm Sampling Events, Binned Sample Sites 161

3.19 Near Bottom Water PO_4^{3-} Concentrations for Storm 1, Storm 2, and Storm 4, Binned Sample Sites 162

3.20 Water Column PO_4^{3-} Concentrations vs. Salinity for Non-storm and Storm Sampling Events 163

3.21 Mean Surface Water H_4SiO_4 Concentrations for Non-storm and Storm Sampling Events, Binned Sample Sites 164

3.22 Defining the Rainfall Storm Threshold 165

3.23 Dissolved Inorganic Nitrogen Concentrations over the Course of this Study 166

3.24 Dissolved Inorganic Phosphate Concentrations over the Course of this Study 167

Figure Page

3.25 Total Chlorophyll-a Concentrations over the Course of this Study 168

4.1 He‘eia Stream TSS vs. He‘eia Fishpond Annual Mean TSS 173

4.2 Water Column TSS Concentrations vs. Salinity for Non-storm and Storm Sampling Events 174

4.3 Water Column TSS Concentrations vs. Salinity for Storm 1 and Storm 4 175

4.4 Annual Mean TSS Concentration for Each Sample Site 176

5.1 Water Column Chlorophyll-a Concentrations vs. Salinity for Non-storm and Storm Sampling Events 197

5.2 Water Column Chlorophyll-a Concentrations vs. Salinity for Storm 1 and Storm 4 198

5.3 Mean Surface Water Chlorophyll-a Concentrations for Non-storm and Storm Sampling Events, Binned Sample Sites 199

5.4 Surface Water Chlorophyll-a Concentrations for Storm 1, Storm 2, and Storm 4, Binned Sample Sites 200

5.5 Chlorophyll-a Concentrations for All Sample Sites and the Evolution of Storm 1 201

5.6 Surface Water Chlorophyll-a Concentrations for All Sample Sites 202

5.7 Surface Water Chlorophyll-a Concentrations for Storm 1-Transect 1 203

5.8 Surface Water Chlorophyll-a Concentrations for Storm 1-Transect 2 204

5.9 Surface Water Chlorophyll-a Concentrations for Storm 1-Transect 4 205

5.10 Evolution of Storm 1, (NO_3^- + NO_2^-) and PO_4^{3-} Concentrations 206

Figure Page

5.11 Evolution of Storm 1, Chlorophyll-a Concentrations 207

5.12 Evolution of Storm 1, Marker Pigment Concentrations, Fucoxanthin and Zeaxanthin 208

5.13 Mean Annual Chlorophyll-a Concentration vs. APA 209

5.14 Baseline Mean APA Across He‘eia Fishpond 210

5.15 Dissolved Inorganic Nitrogen: Dissolved Inorganic Phosphorus Ratios for All Sample Sites 211

5.16 Evolution of Storm 1, Variability in APA Concentrations 212

5.17 Evolution of Storm 1, Temporal and Spatial Variability in APA Concentrations 213

CHAPTER 1

INTRODUCTION

Hawaiian fishponds have been dated back to 1,500-1,800 years before present (Costa-Pierce 1987) and are thought to be the birthplace of mariculture, seawater farming. Ancient Hawaiian fishponds cultivated aquatic resources found in local streams and coastal waters. Five different types of fishponds have been found throughout the Hawaiian Islands (Fig. 1.1): A. loko wai - freshwater fishpond; B. loko ʻumeʻiki - seashore pond with numerous stone lanes which led fish into areas where they could be netted with the ebb and flow of the tide; C. loko puʻuone - coastal body of brackish water isolated from the sea by sand dunes and fed by springs or streams; D. loko iʻa kalo - freshwater, taro fishpond; and E. loko kuapā - seashore pond with sluice gates, artificially enclosing the coastal reef with a stone wall (Apple and Kikuchi 1975; Henry 1993; Kikuchi 1976). Heʻeia Fishpond, the study site for this research project, is an enclosed, loko kuapā, located within Kaneʻohe Bay on the island of Oʻahu, Hawaiʻi (Fig. 1.2).

Heʻeia Fishpond, estimated to be as much as 800 years old, originally supplied fish to the Heʻeia region, on the windward side of Oʻahu. After Kamehameha conquered Oʻahu it became known as the "king's pond." Heʻeia Fishpond was later turned over to Abner Paki by Kamehameha III during The Great Mahele of 1848 (Kelly 1975). Heʻeia Fishpond covers an area of approximately 0.356 km^2 and displays a unique wall design that completely encircles the fishpond, rather than merely creating a pond perimeter on the seaward edge of the fishpond. A map of the fishpond made in 1913 (Fig. 1.3), indicates that the pond had much the same shape and size then as it has now (Kelly 1975), although, the fishpond's current usable square footage has been reduced by invasive mangrove growth to approximately 0.301 km^2, as estimated using ArcGIS software (this study).

He‘eia Fishpond receives freshwater from He‘eia Stream and saltwater from Kane‘ohe Bay. Proximity to these water sources allows fishpond managers to manipulate the water quality of the pond to promote growth of their desired crop. He‘eia Fishpond is of cultural importance to the Hawaiian community, as a link to the past and as a model for resource management. The fishpond is currently overseen by the nonprofit organization Paepae o He‘eia, whose mission is "to implement values and concepts from the model of a traditional fishpond to provide physical, intellectual, and spiritual sustenance for our community" (www.paepaeoheeia.org). The goal of Paepae o He‘eia is to restore the fishpond to its non-impacted ecological state. The research conducted in this study is aimed at identifying and evaluating the forcing mechanisms influencing the present ecology of He‘eia Fishpond and will contribute to the Paepae o He‘eia goal.

Research Goals

The specific goals of this research are to (i) quantify the nutrient (C, N, P, Si) inventories and nutrient ratios in He‘eia Fishpond using data collected on a variety of timescales (Table 1.1); (ii) quantify the external (riverine/marine) nutrient loading so that it can be contrasted to the internal (benthic flux) nutrient loading to the fishpond; and (iii) evaluate shifts in fishpond phytoplankton community composition as a function of event-driven nutrient loading. Monthly discrete sampling of the fishpond, and more frequent sampling during storm events, provide biogeochemical water column and sediment data to address these research goals. The pond was instrumented with in-situ current meters, pressure sensors, and temperature sensors to characterize pond hydrology and water column stratification (Table 1.1). During the monthly sampling efforts, water column profiles of salinity, temperature, pH, chlorophyll-a, dissolved oxygen, and turbidity were made. Water flow data combined with nutrient inventories and nutrient ratios are used to assess the relative importance of each of the pond’s mākāhā (sluice gates) for nutrient loading. Variations in nutrient loading, especially after storm events, affect nutrient ratios and often stimulate phytoplankton growth. Changes in algal composition within the fishpond due to storm-induced nutrification can propagate into phytoplankton community shifts (Cox et al. 2006; Fisher et al. 1999; Justic et al. 1995; Ringuet and Mackenzie 2005; Wetz and Wheeler 2003). The data presented in this study provide insight into dynamic, yet ephemeral, events occurring within the pond, and are viewed within the context of an annual synopsis of the physical and biogeochemical parameters that characterize the fishpond during non-storm (baseline) conditions.

Impacts of Fluvial Discharge in Hawai‘i:

Fluvial inputs of freshwater, suspended particulates, and dissolved nutrients can affect near shore water column biogeochemistry. Meybeck (2001) identifies streams as a primary source of nutrients to the coastal zone. Stream discharge, and its associated contents, can be highly variable and positively correlated with rain events

(Chanton and Lewis 2002; Cox et al. 2006; De Carlo et al. 2007; Hoover and Mackenzie 2009; Ringuet and Mackenzie 2005). The Hawaiian Islands, like other tropical environments, are subject to distinct seasonal changes in the amount of rainfall received. O‘ahu experiences rainfall throughout the year, but has an annual wet season (fall-winter) and dry season (spring-summer). Additionally, differing regions on the island receive varying degrees of rainfall, up to orders of magnitude in difference (www.prh.noaa.gov/hnl/pages/hydrology.php). Rainfall affects the groundwater inventory, and thus the volume and biogeochemistry of stream runoff (Carter and Driscoll 2006; Knee et al. 2010; Rodhe and Bockgard 2006). Stream runoff can increase nutrient and sediment loading in estuaries (Arhonditsis et al. 2000; Staver et al. 1996). Studies in Hawai‘i have shown that coastal water quality is linked to fluvial inputs and rain events (De Carlo et al. 2007; Hoover and Mackenzie 2009; Ringuet and Mackenzie 2005).

Watershed basin geography plays an important role in the delivery of particles and dissolved nutrients to the near shore water column (Eyre 1995; Milliman and Meade 1983; Milliman and Syvitski 1992). Tropical islands are characterized by steep mountains with small drainage basins, allowing for a rapid input and high loads of suspended particles and dissolved nutrients to the ocean. Freshwater discharge into coastal waters is a function of the frequency and magnitude of rainstorm events. Although storms in Hawai‘i, as in other tropical regions, occur as short-lived events, they can account for up to 80% of the total annual load of nutrients and sediments delivered to the coastal ocean (Eyre 1995). These episodic storm events can alter water column nutrient inventories and play a significant role in structuring plankton communities (Hoover et al. 2006) within coastal waters.

Overview of Study Site

He‘eia Fishpond is located along the southern bank of He‘eia Stream as it flows into Kane‘ohe Bay (Fig. 1.2). This location is the termination point of all waters flowing out of the ahupua‘a (watershed) associated with this region of the island. Upstream from the fishpond is a marshland of approximately 410.2 km^2, as estimated using ArcGIS software (this study). Historically used for taro farming, this marshland used water diverted from He‘eia Stream to irrigate the lo‘i kalo (taro patch) (Kelly 1975). Using stream water to flood the loi, suspended sediments in the stream settled out of the water column, reducing the suspended sediment load of the waters arriving at the fishpond (Henry 1975; Kelly 1975). Land use changes in the region from the early 1900’s have since promoted soil erosion, and He‘eia Fishpond has experienced increased sediment loading. Sedimentation has long been a concern for the managers of He‘eia Fishpond. Observations of the sediment composition within the fishpond clearly reveal gradients from terrigenous dominated, near-shore sediments to carbonate dominated, marine sediments further from the stream (Briggs, personal comm.). Under present day conditions, the natural dynamics of the fishpond are insufficiently energetic to flush the accumulating terrigenous particulate load (Henry, 1993; Kelly, 1975).

He‘eia Fishpond is fully surrounded by a kuapā (fishpond wall), approximately 2.5 km in circumference (Fig. 1.2). The fishpond has three freshwater sluice gates (mākāhā) on the north edge of the fishpond and five saltwater mākāhā towards the east and southeast (Fig. 1.4). The three freshwater mākāhā divert water from He‘eia Stream into the fishpond. Two of the three freshwater mākāhā (River Mākāhā 1 and River Mākāhā 2) experience unidirectional flow into the fishpond. The third freshwater mākāhā (River Mākāhā 3) is positioned at low enough elevation that it is affected by tidal activity within Kane‘ohe Bay and allows bi-directional water flow, into and out of the fishpond. All five saltwater mākāhā allow bi-directional flow, allowing waters from Kane‘ohe Bay to exchange with the fishpond over the semidiurnal tidal cycle.

In 1965, a large rain event caused severe flooding on the eastern side of O‘ahu resulting in extensive damage to the perimeter of the fishpond. The furthest upstream freshwater mākāhā (River Mākāhā 1) and surrounding kuapā were destroyed, and an approximately 50 m section of the eastern seaward kuapā was washed away. Only the seaward kuapā break was later adequately repaired. There is apparently no documentation of changes in sediment loading associated with or subsequent to the 1965 flood. It is known that remnants of the kuapā washed into the fishpond by this storm event resulted in the formation of an island in the northwestern corner of the fishpond.

Each mākāhā is a flume with a horizontal concrete floor and vertical basalt rock/concrete mortar walls. The horizontal floors of the mākāhā are higher than the natural bottom of the fishpond or the bay. It is unclear whether the mākāhā were constructed with a sill higher than the seafloor, or if waters flowing through the mākāhā scoured the seafloor subsequent to their construction, thus removing sediment from these high flow areas. For the purpose of this study, each mākāhā and the section of wall damaged in the 1965 storm were given names (Fig. 1.4). River Mākāhā 1 (RM1) is the northwestern most freshwater mākāhā and the first that He‘eia Stream encounters as it flows towards Kane‘ohe Bay along the perimeter of He‘eia Fishpond. RM1 has the highest elevation of the all the fishpond mākāhā and experiences unidirectional flow of freshwater into the fishpond. As noted above, RM1 was damaged in the 1965 flood of He‘eia Fishpond and was never repaired. Although RM1 is referred to as a mākāhā, in actuality RM1 is a diffuse flow region where the actual mākāhā used to be. River Mākāhā 2 (RM2) is the next highest freshwater mākāhā in elevation. RM2 is 1.75 m wide and has walls 1.50 m high; it is not tidally influenced and has unidirectional flow into the fishpond (Fig. 1.5). River Mākāhā 3 (RM3) is the lowest elevation freshwater mākāhā, nearest to the mouth of He‘eia Stream as it empties into Kane‘ohe Bay. RM3 is 1.76 m wide and has walls 1.25 m high (Fig. 1.5); it is tidally influenced and allows water to flow into and out of the fishpond.

There are five mākāhā in the seawall separating He‘eia Fishpond from Kane‘ohe Bay and one low section within the kuapā that allows water exchange. Triple Mākāhā (TM) is the northernmost saltwater mākāhā and nearest to the mouth of He‘eia Stream. TM is called such because in this area there are three similarly sized sluice gates in close proximity to one another. For the purpose of this study, TM is defined as a single mākāhā. The northernmost mākāhā at TM is 1.85 m wide, the middle mākāhā is 1.50 m wide, and the southernmost mākāhā at TM is 1.63 m wide. The walls of all three mākāhā within TM are 0.90 m high (Fig. 1.5). The largest mākāhā within the fishpond is Ocean Mākāhā 1 (OM1). OM1 is 6.60 m wide with walls 1.15 m high and faces eastward into Kane‘ohe Bay (Fig. 1.5). The 50 m section of the kuapā destroyed in the 1965 storm was repaired using concrete blocks. The repairs were adequate for retaining water within the fishpond, but the repaired concrete block wall is not as high as the existing kuapā. During spring tides the water level of Kane‘ohe Bay exceeds the height of the repaired section. This repaired section is called Ocean Break (OB). The break in the kuapā measures 50 m, but the replacement wall is actually 79 m in length. The wall within the fishpond is 0.90 m high and the wall on the bay side is 1.20 m high. Ocean Mākāhā 2 (OM2) is the southernmost saltwater mākāhā and furthest from the mouth of He‘eia Stream. OM2 is 1.82 m wide and has walls 1.12 m high (Fig. 1.5).

Twenty PVC stakes, approximately 3 m tall, driven into the seabed within He‘eia Fishpond had been used as a sampling grid in previous studies conducted within the fishpond. This study utilized these stakes as points of reference within the fishpond (Fig. 1.6). The stakes mark three distinct north to south transects across the fishpond: one transect follows the ocean kuapā (stakes 1-6); the second transect divides the fishpond in half (stakes 7-13); and the third transect follows the landward edge of the fishpond (stakes 14-20). For the purposes of this study, which focused on capturing both terrestrial and oceanic influences from He‘eia Stream and Kane‘ohe Bay, respectively, ten of the twenty stakes were sampled on a monthly basis (stakes 1, 3, 6, 7, 8, 9, 13, 15, 16, and 18) (Fig. 1.7). During intensive storm sampling a reduced number of sites arrayed in a “T” shaped sampling transect, extending from the river mākāhā to the southeastern most end of the fishpond, was sampled (stakes 6, 7, 9, 11, 13, and 18) (Fig. 1.8).

In order to fully characterize the nutrient dynamics of He‘eia Fishpond, the water sampling plan required measurements of input water endmembers. Freshwater and saltwater is constantly exchanged with water from the fishpond. Therefore, a He‘eia Stream (called "River") freshwater endmember was taken downstream of the marshland, and two saltwater endmembers from Kane‘ohe Bay were taken during monthly sampling events. Two saltwater endmembers were chosen because we were interested in measuring Kane‘ohe Bay water near the He‘eia Stream mouth (OCN1), but also wanted a less confounded water sample from Kane‘ohe Bay. Outside the fishpond kuapā, on the easternmost edge of He‘eia Fishpond, sample site Ocean 2 (OCN2) was chosen as a site that would be representative of Kane‘ohe Bay. For the purposes of this study, these three endmember sample sites were grouped with the mākāhā sample sites and together identified as the fishpond perimeter sites (Fig. 1.9). In addition to the in-pond sampling grid, all perimeter sites were sampled monthly and during intensive storm sampling. The exact location and abbreviated name for each sample site are outlined in Table 1.2.

Field Methods

Characterization of physical and biogeochemical parameters of the fishpond was accomplished through a combination of continuous monitoring via *in situ* instrumentation and discrete water sampling (Table 1.1). To quantify the physical movement of water passing through the mākāhā, a suite of current meters, current profilers, and pressure sensors were deployed at each mākāhā (Table 1.3, Fig. 1.10). Instrument specific anchors were developed to secure the instruments in place during deployment. Temperature throughout the fishpond was measured by deploying temperature sensors moored to the sampling grid stakes previously mentioned (Table 1.3, Fig. 1.10).

Discrete grab samples and vertically continuous water column profiles were taken and analyzed for a range of parameters at each water sample site during monthly and storm sampling efforts from August 2007-August 2008 (Figs. 1.4, 1.7). Water column temperature, conductivity, depth, pH, turbidity, fluorescence (proxy for chlorophyll-a), and dissolved oxygen were profiled using a YSI 6600 v2 multi-parameter water quality sonde (Table 1.4). Water samples were collected from the surface and near the seabed for analysis of dissolved nutrients, alkaline phosphatase activity, photopigments, and suspended particulates. A total of 2.25 liters of water was collected at each sample site. The specifics of how each sample split was collected and processed for analysis of each analyte is summarized in Table 1.5.

Monthly water sampling events included collecting water from He‘eia Stream, Kane‘ohe Bay, each mākāhā, and ten stake locations within the fishpond. A total of thirty water samples were collected during each monthly sampling effort. The ten perimeter sample sites were sampled for surface water only. These sites include the fishpond mākāhā locations (OM1, OM2, OB, TM, RM1, RM2, RM3), He‘eia Stream (River) upstream from the fishpond, but downstream from the marshland, and two Kane‘ohe Bay sites: Ocean 1 (OCN1), located south of He‘eia Stream mouth, which is characterized by terrestrially-influenced seawater, and Ocean 2 (OCN2), the representative sample for Kane‘ohe Bay surface water (Table 1.6, Fig. 1.9). These ten perimeter water samples were always taken outside of the fishpond kuapā and, when the water sample represented a mākāhā location, the collection was taken within the mākāhā channel. Only the northernmost mākāhā of the three gates that comprise TM was sampled for surface water.

Water samples taken within the fishpond were sampled for surface (sfc) and near-bottom (deep) water at the ten stake locations displayed in Fig. 1.7 and outlined in Table 1.6. Surface samples are defined as samples taken within 10 cm of the fishpond surface. Near-bottom water samples were collected near the benthos, not more than 10 cm above the seafloor. Where macroalgae were present, near-bottom water samples were collected not more than 10 cm above the top of the macroalgal canopy. Care was taken not to disturb the seabed while sampling. Surface water samples were collected by rinsing the hydrochloric acid (HCl) cleaned collection bottle with ambient surface water three times, then dipping the mouth of the bottle below the water surface. Near-bottom water samples were collected after rinsing the HCl cleaned collection bottle with ambient near-bottom water three times, by submerging a capped bottle to the appropriate depth, removing the bottle cap and allowing the bottle to fill, then replacing the cap and bringing the bottle to the surface.

At the onset of this project it was clear that the semi-diurnal tidal cycle affected the circulation of He‘eia Fishpond. Historically, fishpond managers have used rising and falling tides to manipulate water exchange and fish population migrations through the seaward mākāhā. As part of the monthly sampling rationale, sampling dates were chosen to capture the influence of tidal activity upon the fishpond. Four spring flood tides (08/11/07, 04/19/08, 05/17/08, 08/30/08), three spring ebb tides (09/15/07, 10/13/07, 12/09/07), three neap flood tides (02/16/08, 06/14/08, 07/26/08), and three neap ebb tides (11/17/07, 01/12/08, 03/15/08) were sampled over the course of this 13 month study, August 2007-August 2008.

Recognizing the importance of storm input to fishpond biogeochemistry and ecology, sample dates of opportunity were added to the monthly sampling schedule as rainstorms presented themselves. Hoover (Hoover 2002) defined the threshold for a storm event as occurring when 5.08 cm of rain falls within a 24 hour period. We used this definition in developing our storm sampling protocol. During rainfall or seasonal flooding, the concentration of dissolved nutrients are often higher during the rising segment of the stream hydrograph than during equivalent stream flow on the declining segment (Schlesinger 1997). Because one goal was to capture the flushing of terrigenous sourced dissolved nutrients during the first storm event of the wet season, particular importance was assigned to capturing the influence of a "first-flush" storm on the fishpond. As such, intensive sampling was planned around this event. The first-flush storm event occurred on 11/04/07 and was sampled on 11/04/07, 11/05/07, 11/06/07, 11/07/07, 11/08/07, and 11/11/07 (Table 1.6). Three other storms occurred during the course of this study. Two of the three occurred 48 hrs prior to a regularly scheduled monthly sampling event (12/07/08 and 06/12/08), fortuitously providing the opportunity to contrast the impacts of the first-flush storm with storm events occurring later in the wet season (12/07/08), and in the dry season (06/14/08).

Storm event water sampling sites included He‘eia Stream (River), Kane‘ohe Bay (OCN1 and OCN2), each mākāhā, and the ten stake locations within the fishpond (Table 1.6, Fig. 1.7, Fig. 1.9) on 11/05/07, and a reduced transect sampling effort on

11/04/07, 11/06/07, 11/07/07, 11/08/07 and 11/11/07 (Table 1.6, Fig.1.8). Although the first-flush storm occurred on 11/04/07, it was not possible to sample comprehensively prior to 11/05/07 due to severe weather conditions. Water samples were collected at only three sites on 11/04/07: River, Stk10 sfc, and Stk18 sfc. Water sampling on 11/05/07 included all sites and all depths, an equivalent sampling effort to that outlined in the monthly sampling plan (Table 1.6). The four sampling dates following the storm sampling event (11/05/07) are identified as: Storm Transect 1 (11/06/07), Storm Transect 2 (11/07/07), Storm Transect 3 (11/08/07), and Storm Transect 4 (11/11/07).

He‘eia Fishpond sediment was collected three times over the course of this study: Pre-storm (08/21/07), Storm (11/07/07), and Post-storm (11/11/07). Surface and bottom sediment was collected in order to characterize sediment grain size and composition, with emphasis on contrasting storm deposits from baseline sediment. Sediment was collected using push cores fabricated from a 60 cc plastic syringes. Cores were a minimum of 4 cm deep and were capped with overlying water. Pre-storm cores were taken at twenty stakes within the fishpond (Stk1-20). Storm and Post-storm cores were taken at fifteen stakes (Stk1, 2, 3, 5, 6, 7, 8, 9, 11, 13, 15, 16, 18, 19, and 20) (Table 1.6, Fig. 1.11). Sediment samples have been archived for future analysis and will not be discussed further in this thesis.

Sampling and Laboratory Methods

Sample processing was conducted in the field, under a permanent shelter provided by Paepae o He‘eia, to ensure minimal time between collection and processing. Surface and near-bottom water samples were processed for analysis of particulate and dissolved matter. Filters collected to investigate particulate associated carbon, nitrogen, and phosphorus were archived for future work. This study focused on total suspended solids (TSS); alkaline phosphatase activity (APA); chlorophyll-a (chl-a) or High Performance Liquid Chromatography (HPLC) photopigments; dissolved inorganic nutrients: Nitrogen (N) in the form of Ammonium (NH_4^+) and Nitrite + Nitrate ($NO_2^- + NO_3^-$), Phosphorus (P) in the form of Phosphate (PO_4^{3-}), Silicon (Si) in the form of Silicate (H_4SiO_4); Dissolved Organic Carbon (DOC); Total Dissolved Nitrogen (TDN) and Total Dissolved Phosphorus (TDP) (Table 1.5).

To minimize time elapsed between sample collection and processing, the sampling effort was divided into thirds. The perimeter sites (OM1, OM2, OB, TM, OCN1, OCN2, RM1, RM2, RM3, and River) were sampled first (Fig. 1.9). The first third of the samples were stored on ice, in coolers, immediately after collection, and returned to the field laboratory to be processed while the second third was collected, and so on. The second third of samples taken were at Stk1, 3, 6, 7, and 8. The third set included Stk9, 13, 15, 16, and 18 (Fig. 1.7). The entire water collection effort averaged five hours, and it is possible that temporal and spatial changes occurred within the water column over the time of sample collection.

Filtration of water samples used three types of filters: 47 mm diameter Pall GHP, 47 mm diameter Millipore GF/F, and 25 mm diameter Millipore GF/F. Prior to use, all GHP filters were soaked for a minimum of two days in a 10% HCl solution, rinsed with deionized water (DIW) and stored in a DIW covered bath. Total suspended solids (TSS) were collected on HCl cleaned, pre-weighed 47 mm diameter

Pall GHP filters with a pore size of 0.2 µm, and archived (-30 °C) for future sequential extraction of particulate bound P (SEDEX, Ruttenberg 1992) in a plastic Millipore 47mm diameter petri dish, on a 10% HCl washed plastic filter screen. To quantify TSS, the TSS filter was removed from the freezer and allowed to air dry for two days. Dry weight values were then collected for four days; the sample was judged to be completely dry when variability between replicate daily weight values was less than 2%. The original stable pre-weights were subtracted from stable weight, particle-loaded TSS filters, to determine TSS. A separate sample of filtered particles was collected for future sequential extraction of Iron (Fe) mineral bound P as described for TSS/SEDEX, except that these filters were not pre-weighed. Alkaline phosphatase activity (APA) samples were collected on combusted (500 °C for a minimum of four hours), 47 mm diameter Millipore GF/F filters with a nominal pore size of 0.7 µm. After particle collection, filters were wrapped in aluminum foil and frozen (-30 °C). To increase sample processing efficiency, APA processing used combusted GF/F filters so that the filtrate could be used for DOC and TDN analyses. Particulates for the analysis of chlorophyll-a (chl-a) were collected on 25 mm diameter Millipore GF/F filters with a nominal pore size of 0.7 µm. After collection, each filter was folded in half and placed in an aluminum foil wrapped 13 mm x 100 mm borosilicate glass test tube, capped, and frozen (-30 °C). Some of the chl-a designated samples were analyzed for the full spectrum of photopigments using HPLC; the processing methods described above are consistent with the requirements for HPLC analysis (Bidigare et al. 2005).

Samples for dissolved inorganic nutrient (NH_4^+, (NO_2^- + NO_3^-), PO_4^{3-}, H_4SiO_4, and Fe^{2+}) analyses, filtered through the TSS/SEDEX filters, were stored in 125 ml high-density polyethylene (HDPE) bottles. Filtrate splits for NH_4^+, (NO_2^- + NO_3^-), and H_4SiO_4 analyses were frozen (-30 °C), while filtrate splits for TDP, PO_4^{3-} and Fe^{2+} sample analyses were acidified to pH 1 using 12 N, trace metal clean HCl, and stored refrigerated. DOC/TDN samples were collected as the filtrate from the APA filter (previously described). For the initial five months of sampling (Aug 2007-Dec 2007), DOC/TDN samples were stored in combusted 40 ml screw cap glass vials and frozen (-30 °C). Later (Jan 2008-Aug 2008), DOC/TDN samples were stored in 60 ml HDPE bottles and frozen (-30 °C), after personal communication with Popp suggested that storage of DOC/TDN samples in HDPE bottles would not pose contamination problems if immediately frozen. Three DOC blanks were collected using DIW, treated and stored in the same method as the DOC samples, and later analyzed. Phytocount samples were collected by transferring 100 ml of sample water into an amber 250 ml HDPE bottle, adding 1 ml of glutaraldehyde ($CH_2(CH_2CHO)_2$) and storing in the dark at 25 °C. Phytocount samples were archived for future analysis.

Sediment samples were processed in the field alongside the water samples. Sediment push cores were uncapped in an inert N_2 environment within a glove bag to prevent oxidation artifacts. Each core was sectioned into two splits: 0-2 cm and 2-4 cm. The splits were homogenized and divided for individual analyses: porosity; grain size; chl-a; CHN; and Inorganic Carbon (IC). Porosity samples were placed into a 5 ml glass vial and capped. Grain size, CHN, and IC samples were stored in 2 in. x 3 in. plastic bags and frozen (-30 °C). Sediment chl-a samples were placed in aluminum foil wrapped 13 mm x 100 mm borosilicate glass test tubes, capped, and frozen (-30 °C). Analysis of sediment samples is beyond the scope of this research and these samples have been archived for future work.

The subsequent chapters outline the physical influences on water column structure within He‘eia Fishpond and define the rationale for studying baseline conditions vs. storm conditions (Chapters 2 and 3). In Chapter 3, nutrient inventories and ratios are examined during baseline and storm conditions. Particle loading is described in Chapter 4. The nutrient loading data from Chapter 3 is combined with seasonal APA and phytoplankton biomass in Chapter 5 in order to evaluate nutrient limitation and changes in phytoplankton community structure. Through discrete water sampling on monthly and daily time scales, event-driven and seasonal dynamics occurring within He‘eia Fishpond have been constrained for the study year 2007-2008. These data provide Paepae o He‘eia with a biogeochemical and physical management framework for He‘eia Fishpond that does not currently exist, and instigates what is hoped to be a long-term, time-series study of the influences of event-driven nutrient inputs to this subtropical, coastal ecosystem.

Table 1.1. Sampling frequency and rationale.

Data Type	Sampling Method	Sampling Frequency	Data Acquisition Frequency	Rationale
In situ Instrumentation:				
Current direction and magnitude in He‘eia Stream and He‘eia Fishpond mākāhā	Extended in-pond deployment of current meters and current profilers	Serial 1-3 month deployments	15 minutes	High frequency current data to quantify water movement into/out of mākāhā throughout the August 2007-2008 sampling year. Data used for creation of fishpond water and nutrient budgets.
Water Temperature	Extended in-pond deployment of thermistors	Serial 1-3 month deployments	15 minutes	High frequency water temperature data throughout the August 2007-2008 sampling year. Data used for creation of annual temperature time series.
Water Depth	Extended in-pond and in-air deployment of pressure sensors	Serial 1-3 month deployments	15 minutes	High frequency pressure data throughout the August 2007-2008 sampling year. Data used for creation of annual pond volume time series.
Local Precipitation	NOAA rain gauges	Continuous	3 hours	Rainfall data used for a record of daily, seasonal, and annual rainfall variability.
Tidal Height	NOAA tide gauge	Continuous	High tide Low tide	Tide data used for a record of daily, seasonal, and annual tidal variability.
Ha‘iku Stream Discharge	USGS stream discharge monitoring	Continuous	24 hours	Discharge data used for a record of daily, seasonal, and annual stream flow variability.
Local Wind Field	HIMB wind gauge	Continuous	24 hours	Wind data used for a record of daily, seasonal, and annual wind direction, magnitude.
Local Solar Radiation	HIMB PAR sensor	Continuous	24 hours	Data used for a record of daily, monthly, seasonal, and annual variability in incident solar radiation.

Table 1.1. (cont.) Sampling frequency and rationale.

Data Type	**Sampling Method**	**Sampling Frequency**	**Data Acquisition Frequency**	**Rationale**
Hand-held Instrumentation:				
Water column profiles of T, S, O_2, pH, fluorescence, turbidity	Vertical profiling using YSI multi-parameter water quality sonde	Monthly	2 seconds	Resolve water column stratification (T, S) and biogeochemistry (O_2, pH, fluorescence, TSS) at discrete sites. Detect and characterize monthly, seasonal, and annual variability.
Discrete Water Sampling:				
Nutrients, chlorophyll-A, photopigments, APA, TSS	Surface and Deep Grab Samples	a) Monthly sampling: (Aug. 11, 2007- Aug. 30, 2008) b) Daily storm sampling: (Nov. 4, 2007- Nov. 11, 2007)	N/A N/A	Resolve vertical and horizontal variability in biogeochemical parameters. Detect and characterize monthly, seasonal, and annual variability. After first flush rain event (Nov. 4, 2007), daily sampling during storm event to capture perturbations and post-storm return to background conditions within He‘eia Fishpond.

Definitions: PAR = photosynthetically active radiation, T = temperature, S = Salinity, O_2 = % DO saturation, TSS = total suspended solids, APA = alkaline phosphatase activity.

Table 1.2. He‘eia Fishpond sample site locations.

Site Name (Abbreviation)	**Site ID Number**	**Latitude**	**Longitude**
Ocean Mākāhā (OM2)	1	N 21.43388	W 157.80530
Ocean 2 (OCN2)	2	N 21.43487	W 157.80504
Ocean Break (OB)	3	N 21.43600	W 157.80542
Ocean Mākāhā 1 (OM1)	4	N 21.43723	W 157.80586
Triple Mākāhā (TM)	5	N 21.43839	W 157.80676
Ocean 1 (OCN1)	6	N 21.43938	W 157.80727
River Mākāhā 3 (RM3)	7	N 21.43949	W 157.80976
River Mākāhā 2 (RM2)	8	N 21.43818	W 157.81070
River Mākāhā 1 (RM1)	9	N 21.43724	W 157.81092
He‘eia Stream (River)	10	N 21.43544	W 157.81112
Stake 1-surface (Stk1 sfc)	11	N 21.43445	W 157.80540
Stake 1-deep (Stk1 deep)	12	N 21.43445	W 157.80540
Stake 3-surface (Stk3 sfc)	13	N 21.43661	W 157.80588
Stake 3-deep (Stk3 deep)	14	N 21.43661	W 157.80588
Stake 6-surface (Stk6 sfc)	15	N 21.43908	W 157.80785
Stake 6-deep (Stk6 deep)	16	N 21.43908	W 157.80785
Stake 7-surface (Stk7 sfc)	17	N 21.43919	W 157.80951
Stake 7-deep (Stk7 deep)	18	N 21.43919	W 157.80951
Stake 8-surface (Stk8 sfc)	19	N 21.43785	W 157.80893
Stake 8-deep (Stk8 deep)	20	N 21.43785	W 157.80893
Stake 9-surface (Stk9 sfc)	21	N 21.43663	W 157.80831
Stake 9-deep (Stk9 deep)	22	N 21.43663	W 157.80831
Stake 13-surface (Stk13 sfc)	23	N 21.43275	W 157.80635
Stake 13-deep (Stk13 deep)	24	N 21.43275	W 157.80635
Stake 15-surface (Stk15 sfc)	25	N 21.43331	W 157.80779
Stake 15-deep (Stk15 deep)	26	N 21.43331	W 157.80779
Stake 16-surface (Stk16 sfc)	27	N 21.43432	W 157.80871
Stake 16-deep (Stk16 deep)	28	N 21.43432	W 157.80871
Stake 18-surface (Stk18 sfc)	29	N 21.43705	W 157.81024
Stake 18-deep (Stk18 deep)	30	N 21.43705	W 157.81024
Stake 10-surface (Stk10 sfc)	31	N 21.43565	W 157.80771
Stake 11-surface (Stk11 sfc)	32	N 21.43466	W 157.80699

Note: Stk10 sfc and Stk11 sfc are water sample sites used only during the first-flush storm event, and not part of the monthly water sampling plan.

Table 1.3. Instrumentation deployed to collect *in situ*, continuous time series data for current direction and magnitude, water depth, and water temperature.[*]

Instrument Type	Aquadopp Current Meter	Argonaut-SW Current Profiler	HOBO U20 Pressure	TidbiT v2 Temperature
Manufacturer	Nortek	Sontek	Onset	Onset
Capabilities	3D-Single Point Current, Pressure, Temperature	2D-Current Profiler, Temperature	Pressure, Temperature	Temperature
Inventory	2	3	9	6
Sampling Frequency	900 Hz	900 Hz	900 Hz	900 Hz
Accuracy	1% of measured value ± 0.5 cm/s	1% of measured value ± 0.5 cm/s	± 1.5 cm	± 0.2 ºC

[*] Aquadopp measures current at a single point within the water column, while Argonaut-SW profiles current in 10 different bins throughout the water column.

Instrument specifications can be found at the following locations:
Aquadopp = http://www.nortek-as.com/lib/data-sheets/datasheet-aquadopp/view
Argonaut-SW = http://www.sontek.com/argonautsw.php
HOBO U20 = http://www.onsetcomp.com/specs.php?n=2273
TidbiT v2 = http://www.onsetcomp.com/specs.php?n=2347

Table 1.4. Parameters measured by the YSI 6600 v2 multi-parameter water quality sonde.

Probe (parameter)	**Range**	**Accuracy**	**Resolution**
Depth	0-61 m	± 0.12 m	0.001 m
pH	0-14 units	± 0.2 unit	0.01 unit
Temperature	-5 to +50 °C	± 0.15 °C	0.01 °C
Conductivity	0-100 mS/cm	± 5% of reading + 0.001 mS/cm	0.001-0.1 mS/cm (range dependent)
Optical % Dissolved O_2	0-500%	± 1% of reading or 1% of air saturation	0.1%
Optical Fluorescence (chl-a)	0-400 µg/l	± 0.1 µg/l	0.1 µg/l
Optical Turbidity	0-1000 NTU	± 2% of reading or 0.3 NTU, whichever is greater	0.1 NTU

Instrument and probe specifications can be found at the following location: http://www.ysi.com/productsdetail.php?6600V2-1

Table 1.5. Water sample collection and processing.

Sample Type	Filter Type	Volume Filtered	Filtrate Collected	Particulate Collected	Sample Storage
47 mm Filtration Rig, Filtration #1:					
Total Suspended Solids	47 mm dia., 0.2 µm GHP	500-800 ml	N/A	Particulate weighed for TSS	-Filter air dried and stored in petri dish at room temp.
47 mm Filtration Rig, Filtration #2:					
Dissolved inorganic nutrients, TDP, Particulate associated P (SEDEX)	47 mm dia., 0.2 µm GHP	500-800 ml	125 ml split acidified (pH 1) for TDP, PO_4^{3-}, Fe^{2+} 125 ml split for NH_4^+, $(NO_2^- + NO_3^-)$, H_4SiO_4	Particulate archived for later SEDEX analysis	-Acidified nutrient split refrigerated -Non-acidified nutrient split frozen -SEDEX filter stored in petri dish, frozen
47 mm Filtration Rig, Filtration #3:					
Particulate associated Fe (oxy)hydroxide extraction	47 mm dia., 0.2 µm GHP	500 ml	N/A	Particulate archived for later Fe_{Ox} analysis	-Fe_{Ox} filter stored in petri dish, frozen
47 mm Filtration Rig, Filtration #4:					
Alkaline Phosphatase Activity, DOC, TDN	47 mm dia., 0.7 µm GF/F	150 ml	60 ml split for DOC, TDN	Particulate analyzed for APA	-APA filter stored in petri dish, frozen -DOC, TDN split frozen
25 mm Filtration Rig, Filtration #1:					
Photopigments	25 mm dia., 0.7 µm GF/F	150 ml	N/A	Particulate analyzed for chl-a and accessory pigments	-Filter stored in air tight glass test tube in the dark, frozen
25 mm Filtration Rig, Filtration #2:					
CHN	25 mm dia., 0.7 µm GF/F	150 ml	N/A	Particulate archived for later CHN analysis	-Filter stored in combusted Al foil, frozen
No Filtration:					
Phytocount	N/A	100 ml	N/A	N/A	-Glutaraldehyde fixed, stored in dark bottle, at room temp.

Table 1.6. Field sampling regimen.

Event	Sample Dates	Sample Sites*	Sample Location	Sample # Collected
Monthly Water Sampling (fishpond perimeter)	08/2007-08/2008	OM1, OM2, OB, TM, RM1, RM2, RM3, River, OCN1, OCN2	surface	10
Monthly Water Sampling (fishpond interior)	08/2007-08/2008	Stk1, Stk3, Stk6, Stk7, Stk8, Stk9, Stk13, Stk15, Stk16, Stk18	surface/ deep	20
First-Flush Storm Water Sampling	11/04/07	River, Stk10, Stk18	surface	3
	11/05/07	Monthly sampling plan	surface/ deep	30
	11/06/07 11/07/07 11/08/07 11/11/07	Transect sites Stk6, Stk7, Stk9, Stk11, Stk13, Stk18	surface	6
Surface Sediment Push Cores (0-4 cm)	Pre Storm 08/21/07	Stk1-Stk20	Cores sectioned at two depths: 0-2 cm, 2-4 cm	20
	Storm 11/07/07 & Post Storm 11/11/07	Stk1, Stk2, Stk3, Stk5, Stk6, Stk7, Stk8, Stk9, Stk11, Stk13, Stk15, Stk16, Stk18, Stk19, Stk20		15

* Sample site abbreviations previously defined in Table 1.2.

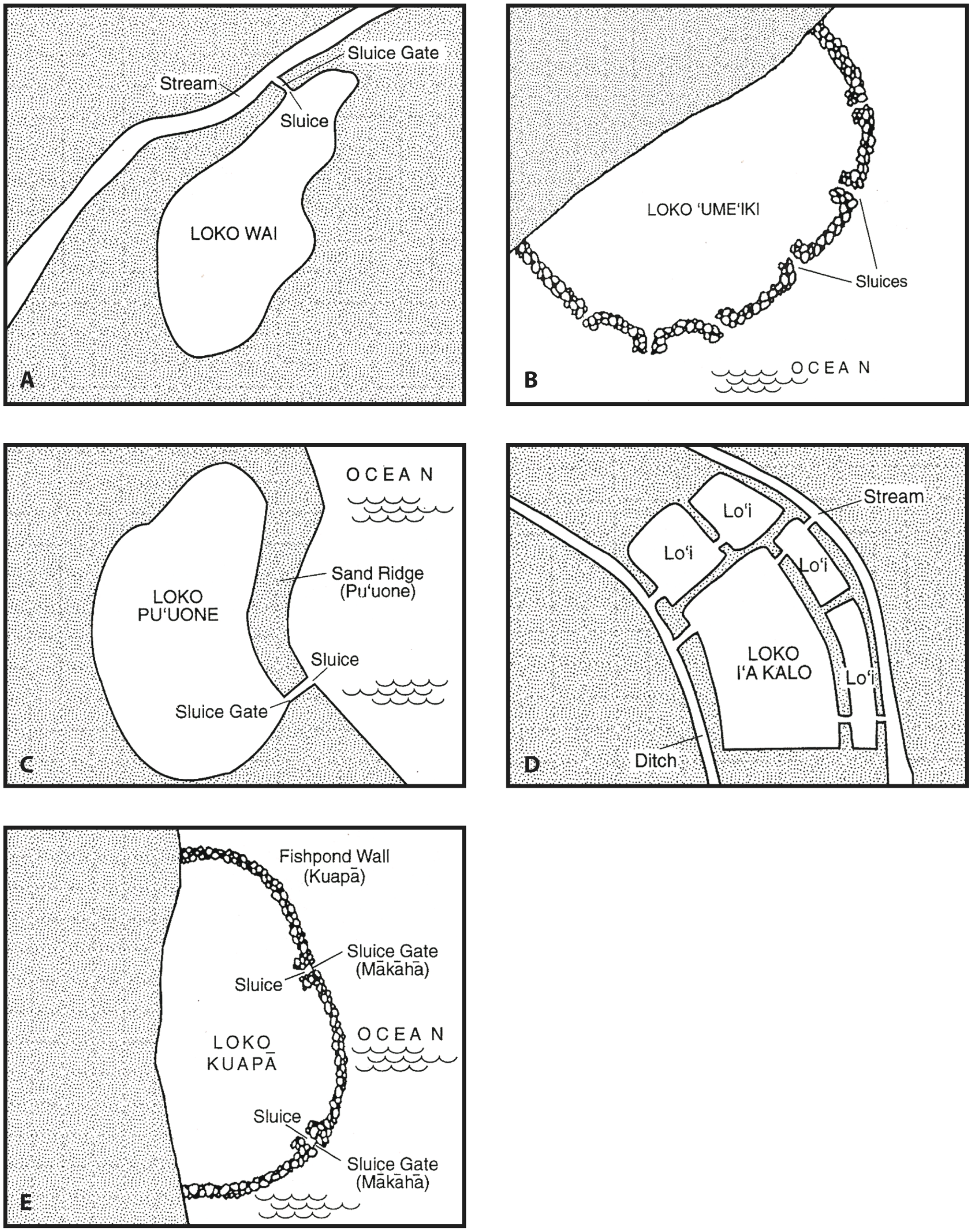


Figure 1.1. Fishpond examples: (A) Freshwater fishpond; (B) Seashore pond with numerous stone lanes which led fish into areas where they could be netted with the ebb and flow of the tide; (C) Coastal body of brackish water isolated from the sea by sand dunes and fed by springs or streams; (D) Freshwater, taro fishpond; (E) Seashore fishpond with sluice gates. (Images modified from Kikuchi 1976; Henry 1993)

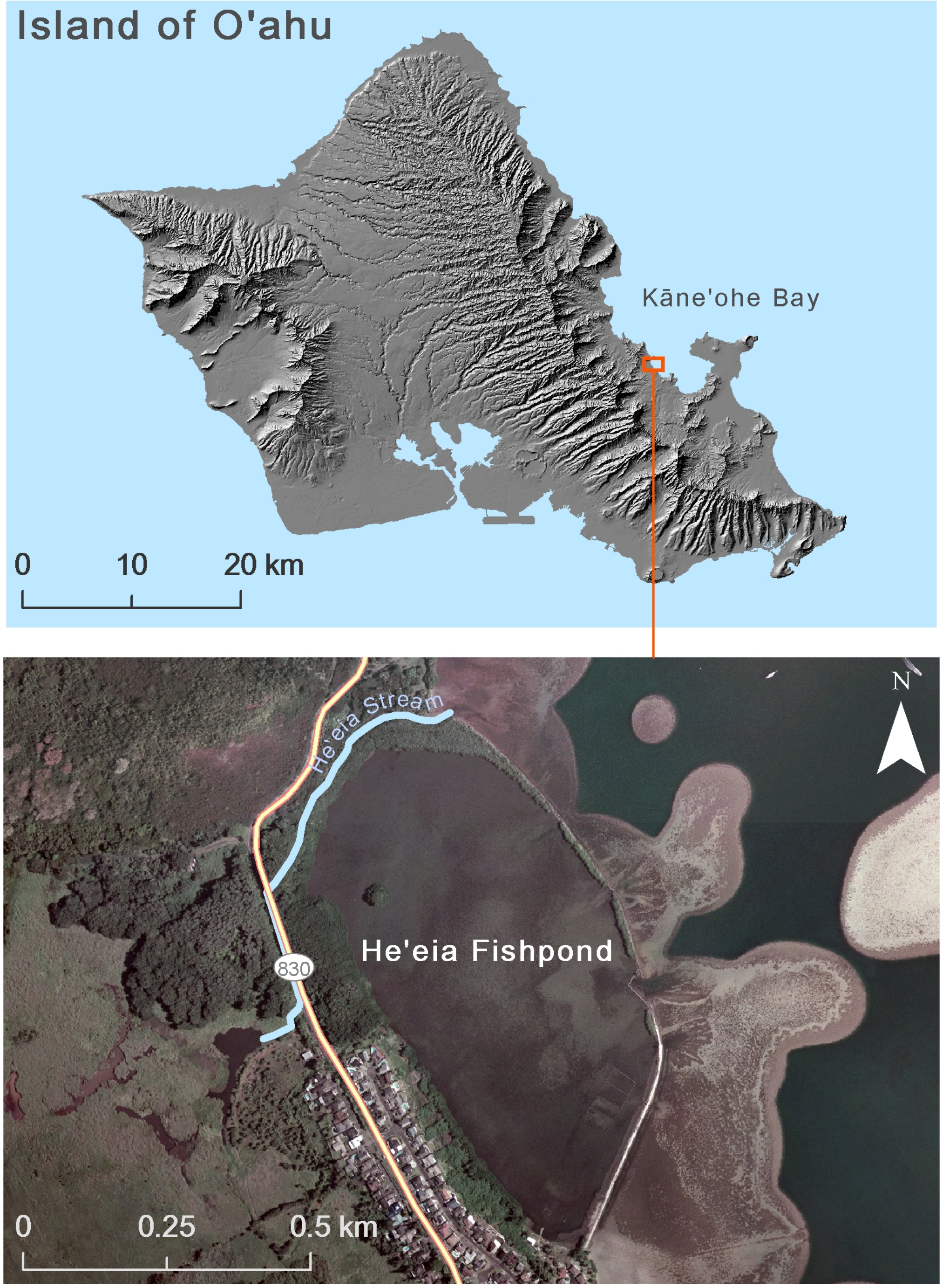


Figure 1.2. He‘eia Fishpond, an example of a loko kuapā, built on top of the near-shore coral reef flat. The “He‘eia Fishpond” label is placed in the center of the fishpond perimeter. The fishpond extends east from the land into Kane‘ohe Bay, south of He‘eia Stream, and is bounded by the kuapā seen as a thin line partitioning the fishpond from the reef flat. Photograph courtesy of the USGS High Resolution Orthoimagery for Honolulu, HI, 2009.

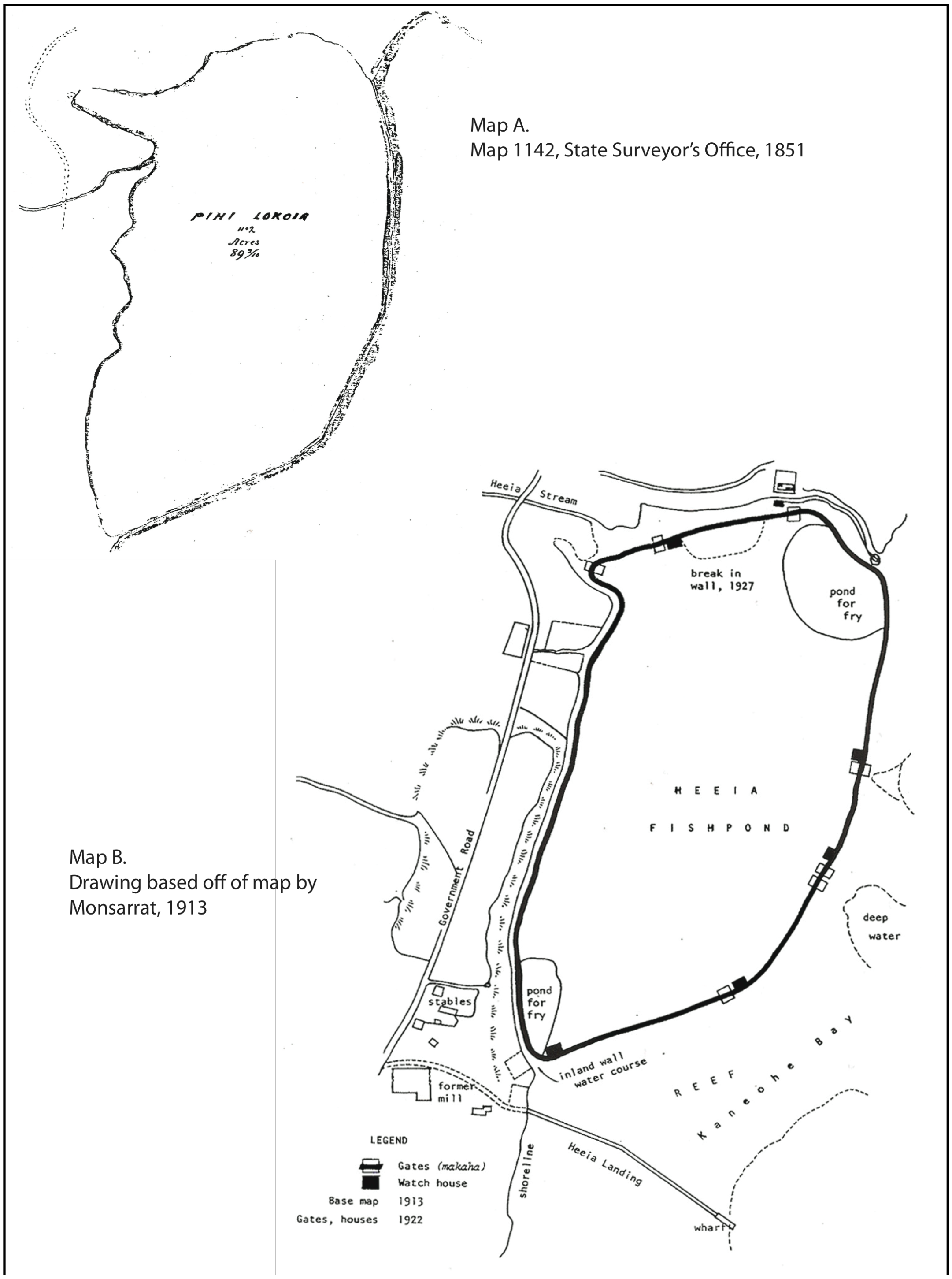


Figure 1.3. Historic maps of He'eia Fishpond reveal that the current size of He'eia Fishpond closely resembles that depicted in the earliest maps of the area drawn over 150 years ago (Kelly 1975). Map B is not scaled for size, but perimeter shape similarities are clearly seen with respect to earlier drawn maps (Map A) and modern aerial photography (Figure1.2).

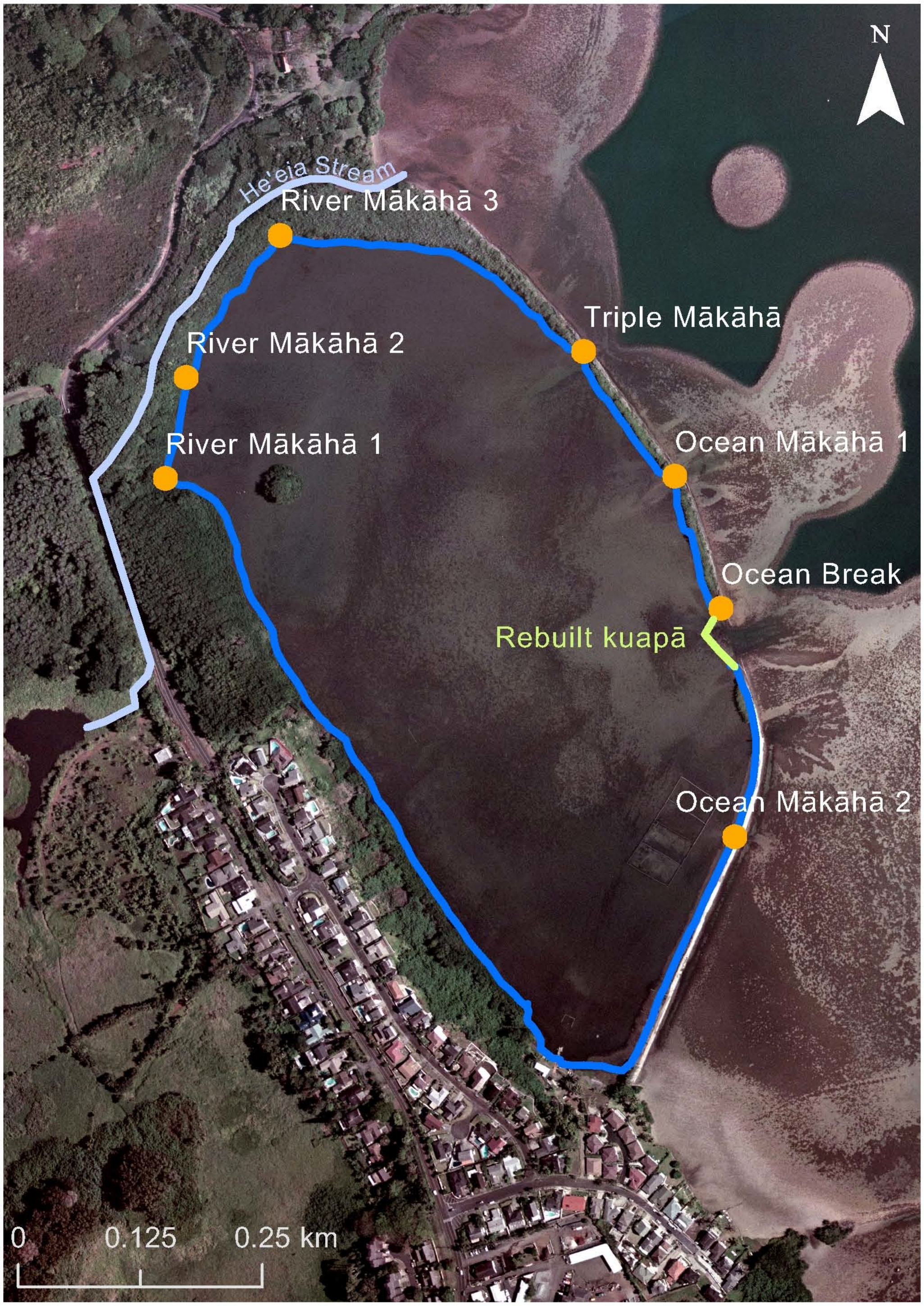


Figure 1.4. Heʻeia Fishpond perimeter and mākāhā (sluice gates). Three freshwater mākāhā: River Mākāhā 1 (RM1), River Mākāhā 2 (RM2), and River Mākāhā 3 (RM3). Three saltwater mākāhā: Triple Mākāhā (TM), Ocean Mākāhā 1 (OM1), and Ocean Mākāhā 2 (OM2). Rebuilt kuapā (fishpond wall): Ocean Break (OB).

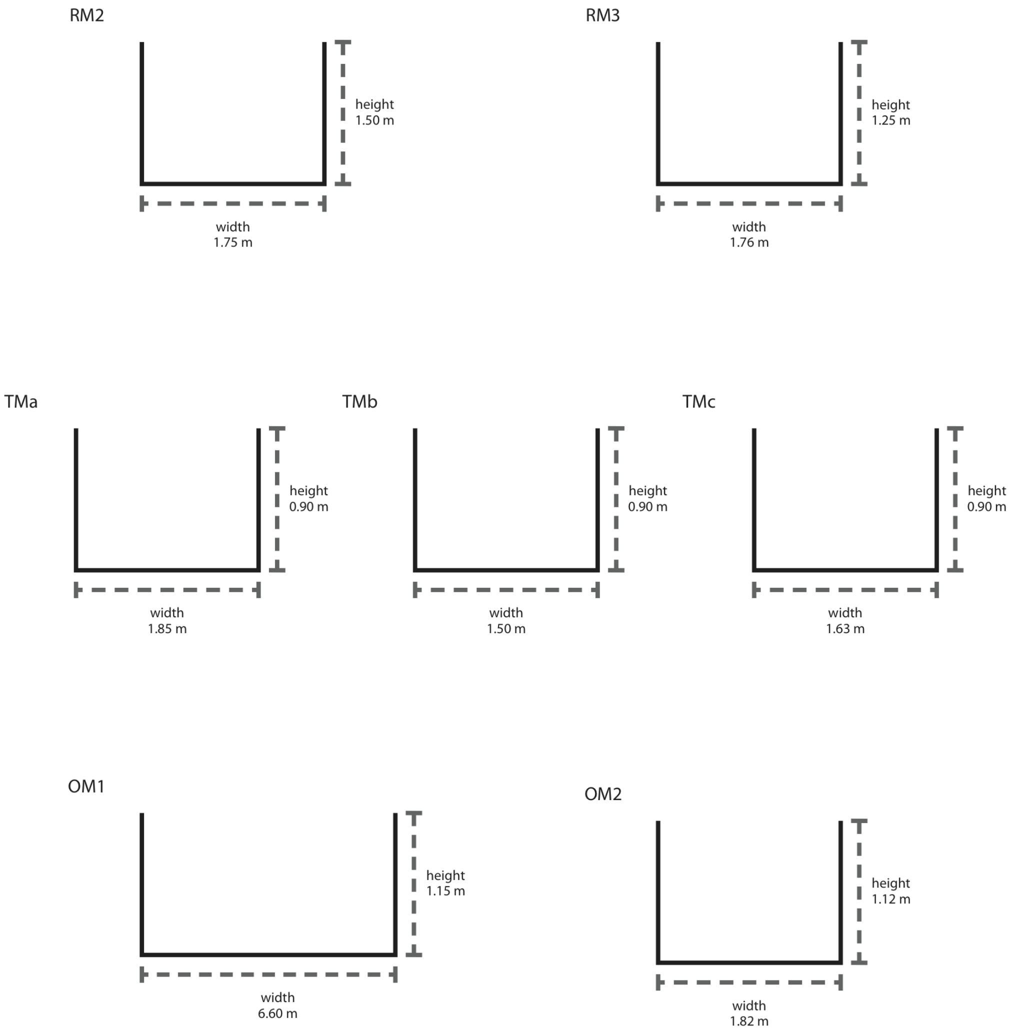


Figure 1.5. Mākāhā dimensions: River Mākāhā 2 (RM2), River Mākāhā 3 (RM3), Triple Mākāhā (TM) with its three sluice gates (TMa, TMb, TMc), Ocean Mākāhā 1 (OM1), and Ocean Mākāhā 2 (OM2).

Figure 1.6. He‘eia Fishpond permanent stake (1-20) locations. The monthly sampling plan collected water samples at stakes 1, 3, 6, 7, 8, 9, 13, 15, 16, and 18.

Figure 1.7. Monthly sample locations within He‘eia Fishpond: Stk1, Stk3, Stk6, Stk7, Stk8, Stk9, Stk13, Stk15, Stk16, and Stk18. Surface and near bottom (deep) water samples were taken at each site (see Table 1.2 for site name abbreviations).

Figure 1.8. Storm event transect sample locations within He‘eia Fishpond (surface only): Stk6, Stk7, Stk9, Stk11, Stk13, and Stk18. Surface water samples were taken at each site (see Table 1.2 for site name abbreviations).

Figure 1.9. Monthly sample locations around the perimeter of He‘eia Fishpond: OM1, OM2, OB, TM, RM1, RM2, RM3, OCN1, OCN2, and River. Surface water samples were taken at each site (see Table 1.2 for site name abbreviations).

Figure 1.10. Instrument deployment locations: Nortek Aquadopp (Aq), Sontek Argonaut (Ar), Onset HOBO water level logger (P), Onset TidBit v2 temperature logger (T).

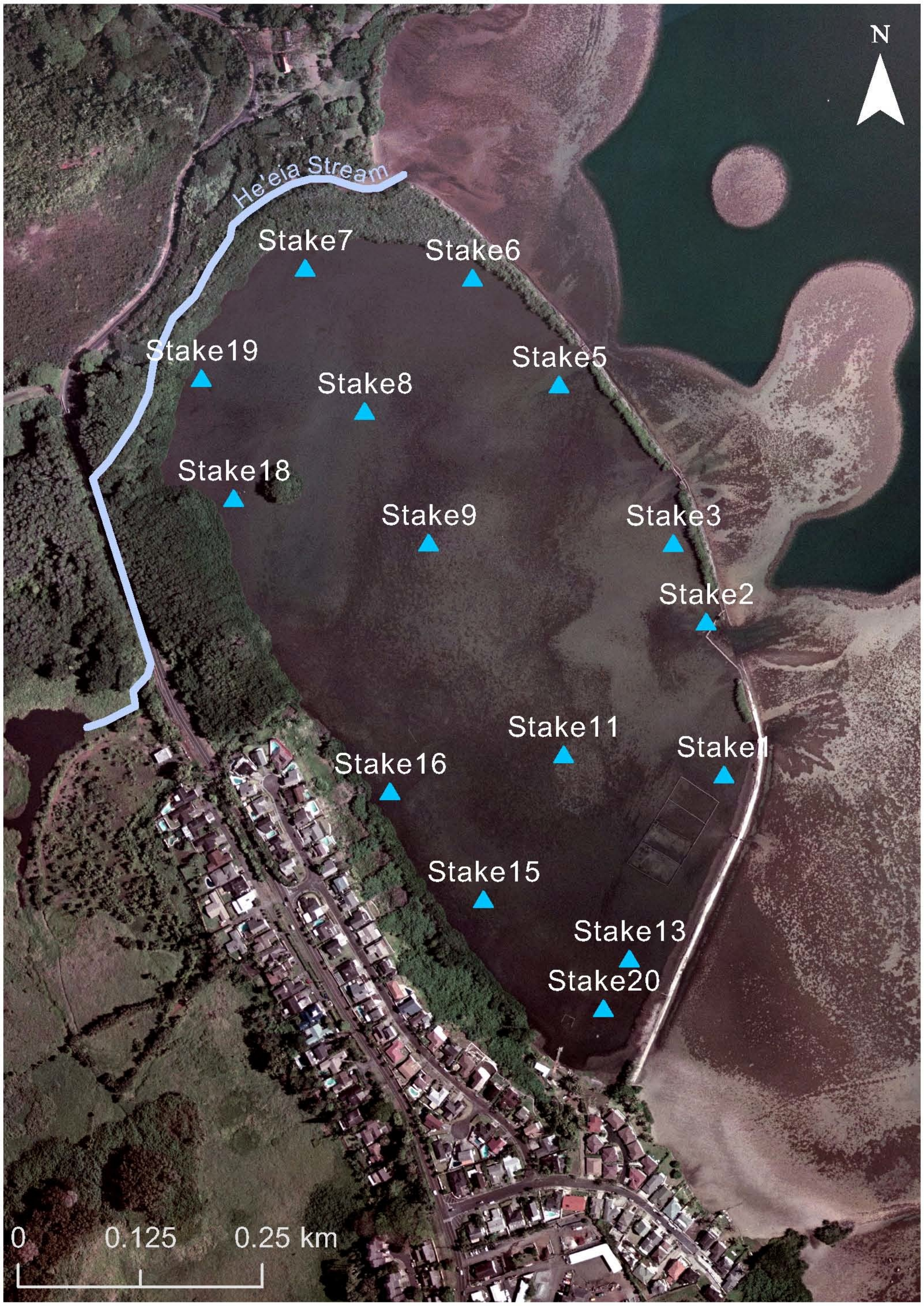


Figure 1.11. Sediment core sample locations within He‘eia Fishpond. Sediment was collected during Pre-storm, Storm, and Post-storm events: Stk1, Stk2, Stk3, Stk5, Stk6, Stk7, Stk8, Stk9, Stk11, Stk13, Stk15, Stk16, Stk18, Stk19, and Stk20 (see Table 1.2 for site name abbreviations).

CHAPTER 2

PHYSICAL PROCESSES IN HE‘EIA FISHPOND

Introduction

In order to quantify the nutrient loading to and within He’eia Fishpond it is necessary to first characterize the frequency and magnitude of fluvial and marine inputs. Rivers typically introduce higher concentrations of nutrients and suspended particulate matter to more oligotrophic marine waters, and introduction of land-derived runoff to the coastal ocean often changes the biogeochemical structure of the near shore water column (Bostater and Biggs 1985; Cox et al. 2006; Eyre and Balls 1999; Fisher et al. 1988; Hoover and Mackenzie 2009; Ringuet and Mackenzie 2005; Wetz 2006; Wollheim et al. 2006). As is the case in other mountainous, tropical drainage basins, discharge from Hawaiian streams is highly variable and positively correlated with rain events (Chanton and Lewis 2002; De Carlo et al. 2007; Drupp et al. 2011; Hoover and Mackenzie 2009; Ringuet and Mackenzie 2005; Tomlinson and De Carlo 2003). Field sampling strategies adopted during this study were designed to capture intense, ephemeral storm events, and contrast them to baseline conditions.

This study employed in-situ instrumentation within He‘eia Fishpond to collect data on currents, water depth, and temperature, and utilized data recorded by government agencies on regional weather conditions, rainfall, and stream discharge in order to evaluate the influence of each forcing mechanism on the body of water contained within He‘eia Fishpond. After describing the data compiled to elucidate He‘eia Fishpond water column dynamics, the strategies devised for achieving meaningful time series data sets in He‘eia Fishpond are summarized. A discussion of quantitative estimates of water flow rate into the fishpond follows, including how this flow rate is partitioned among the mākāhā under storm and non-storm conditions. Calculations of flow rates permit estimates of pond residence time and a discussion of circulation dynamics. The chapter concludes with a description of water column properties and how these vary during storm and baseline conditions.

Regional Meteorological Overview

The Hawaiian Islands, like other tropical environments, are subject to distinct seasonal changes in the amount of rainfall received. The steep mountains and relatively small drainage basins of the islands typically allow for rapid increases in runoff to the coastal ocean as streams respond to rainfall. The He‘eia Fishpond watershed is no different, but stream discharge timing and magnitude is modified by the presence of a marshland, approximately 410.2 km^2 (determined through ArcGIS during this study), situated between the ridgeline of the Ko‘olau Mountains and the coastline. The marshland serves as a buffer for runoff of water and suspended particulate matter, as it did in previous decades as a lo‘i kalo (taro patch), reducing runoff volume to He‘eia Stream. By comparing stream flow measured at the base of the Ko‘olau Mountains (USGS stream monitoring station, Fig. 2.1) with flow rates measured within He‘eia Stream (upstream of the fishpond), we calculate that the marshland reduces upper stream discharge by as much as 49.1% during low flow, dry season conditions. For this study, stream flow of He‘eia Stream was assumed to be half the measured flow recorded at the base of the Ko‘olau Mountains (Fig. 2.1).

The Koʻolaupoko region of Oʻahu, which includes Heʻeia Fishpond and the surrounding watershed, averages 193.10 cm of rainfall annually (Western Regional Climate Center, Kaneʻohe Mauka Station 781, 1949-1998). The state annual average rainfall is 177.80 cm (Western Regional Climate Center, Kaneʻohe Mauka Station 781, 1949-1998). Rainfall in the Hawaiian Islands is strongly related to wind direction and magnitude. The prevailing Hawaiian trade winds come from the northeast (0-90^o) during the dry season (spring-summer) and are more variable during the wet season (fall-winter) (Smith et al. 1981). Rainfall variability is historically greater during the wet season, although it is during this time that individual rain events contribute greatly to island annual rainfall totals. Conversely, during the dry season, trade wind initiated rain events are more common, but regionally limited in scope, with individual rain events contributing less towards annual rainfall totals.

Data Collection

Changes in rain, stream discharge, wind, solar radiation, and tidal activity all individually affect Heʻeia Fishpond dynamics and, in Hawaiʻi, intense short-lived rain events can result in runoff that swells streams within minutes to hours (Tomlinson and De Carlo 2003). Thus, for storm events, timescales relevant to the fishpond are on the order of hours to days, whereas, for baseline measurements, relevant time scales are on the order of months to a year. The field portion of this study was designed to address both short-term (storm) and long-term (seasonal/year-long) variability (Table 1.1).

Rainfall

Rainfall data for this study was assembled from National Oceanic and Atmospheric Administration (NOAA) rain gauge stations throughout the Koʻolaupoko region. Four rain gauge stations were initially monitored for rainfall: (1) Luluku Station (HI-15), (2) Ahuimanu Loop Station (HI-16), (3) Wilson Tunnel Station (HI-27), and (4) Waiheʻe Pump Station (HI-30). Ringuet and Mackenzie (2005) used Luluku Station rainfall data as an indicator for storm events within southern Kaneʻohe Bay. For this study we concluded that the Luluku Station (Fig. 2.1) best recorded the rainfall affecting Heʻeia Fishpond. NOAA rain gauge data for the Hawaiian Islands is updated in near real-time (station rainfall/3hr) and is available from the NOAA website (http://www.prh.noaa.gov/hnl/pages/hydrology.php). Luluku Station rainfall data provided the criteria for identifying the occurrence of storm activity of sufficient magnitude to trigger the high frequency “storm” sampling portion of the field program.

Individual rain events of variable magnitude occur throughout the year in Hawaiʻi. For the purposes of this study it was necessary to select a defining criterion to identify the occurrence of rain “storm” conditions. Rainfall creating a “storm,” as distinct from generally less intense, but possibly more prolonged rainfall events, can occur during either the wet or dry season. For this study, we adopted the Ringuet and Mackenzie (2005) definition of a “storm” as a rain event characterized by greater than or equal to 5.08 cm of rainfall within a twenty-four hour period over the watershed within which the study site is located.

Based on rainfall measurements, four storm events (11/04/07, 12/07/07, 12/31/07, and 06/12/08) occurred during the course of this study. Each of the storm events was characterized by 24-hour rainfall totals from the Luluku rain gauge station that exceeded the 5.08 cm/24 hrs threshold, measuring 14.63 cm, 8.23 cm, 5.97 cm, and 6.05 cm respectively. A fifth noteworthy rain event occurred on 05/21/08, during which 4.93 cm of rain fell within 24 hrs, falling slightly short of the storm threshold of 5.08 cm (Fig. 2.2).

Stream Discharge

Stream flow data for this study was assembled from USGS stream discharge data from the measuring station near He‘eia Fishpond within Ha‘iku Stream (Station #16275000) (http://waterdata.usgs.gov) (Fig. 2.1). Ha‘iku Stream is the primary, perennial freshwater source to the watershed and to He‘eia Stream (Fig. 2.1). During this study, efforts were made to measure stream flow within He‘eia Stream between the marshland and the fishpond, but rough terrain and dense vegetation prevented the establishment of an acceptable long-term monitoring location. As mentioned previously, for the purpose of this study the water volume flowing into the marshland from Ha‘iku Stream was defined as twice the volume of water flowing within He‘eia Stream. The USGS monitoring station #16275000 provides the best source of stream discharge data available, and He‘eia Stream discharge is calculated at 50% of that measured at the USGS monitoring station.

For the four storm events measured during this study, stream discharge varied in concert with rainfall (Figs. 2.2 and 2.3). Hoover (2002) compared historical stream discharge values for a number of streams on the island of O‘ahu and calculated an average discharge value of 0.074 m^3/s for He‘eia Stream using data representing annual flows of over 40 years. During this study He’eia Stream discharge averaged 0.058 m^3/s (n_{days}=396). The largest stream discharge value, which occurred during the 11/04/07 storm event, was 0.736 m^3/s and followed the largest rain event during the study. Lowest flows occurred during the dry season, with a mean value of 0.050 (+/- 0.009) m^3/s calculated over 6 months. Only one notable increase in stream discharge during the dry season occurred on 06/12/08; we have labeled this event a dry season storm.

Wind and Solar Radiation

Meteorological data from Moku o Lo‘e (Coconut Island), Hawai‘i Institute of Marine Biology (HIMB) (Fig. 2.1), provided data for daily mean wind direction and magnitude, solar radiation, and Kane‘ohe Bay surface water temperature. Wind direction and magnitude play a combined role in determining the weather throughout the Hawaiian Islands and the water circulation of Kane‘ohe Bay (Bathen 1968; Ostrander et al. 2008; Smith et al. 1981); thus, the HIMB meteorological data provided guidance when analyzing how local changes in weather affected He‘eia Fishpond. Daily winds recorded over the period of study were predominantly from the northeast (Fig. 2.4). Winds from this direction are known as trade winds. Average wind direction was from 80.1^o. Trade wind magnitude ranged from 1.12-8.63 m/s and averaged 5.23 m/s (+/- 1.59) over the study period. Only 14.9% (59 days) of the thirteen-month daily wind data set recorded wind directions other than 0-

90^{o}. Those 59 days were characterized by winds from a direction other than the NE trade wind direction at magnitudes ranging from 0.98-9.07 m/s, with an average magnitude of 3.07 m/s (+/- 1.86) (Figs. 2.4 and 2.5). All four “storm event” days were characterized by winds from directions other than the dominant trade wind direction (Fig. 2.5).

Daily solar radiation data collected by HIMB was unavailable for 10 months of this 13-month study due to lack of instrument maintenance. In lieu of data over the time frame of this study, we provide data from Smith et al. (1981) who reported HIMB solar radiation for three and one-half years (Fig. 2.6). The data clearly reveal a seasonal cycle in solar radiation with an approximate dry season range of 250-625 cal/cm^2/day and wet season range of 150-400 cal/cm^2/day. Daily variations are apparent, but a seasonal mean for the dry and wet seasons can also be approximated, 475 cal/cm^2/day and 275 cal/cm^2/day, respectively. The robust and repeatable dataset found in Smith et al. (1981) suggest that a similar pattern and similar magnitude in seasonal solar radiation intensity can be assumed for this study.

He‘eia Fishpond in situ Instrumentation

He‘eia Fishpond was instrumented to measure mākāhā water flow, changes in water depth due to tidal activity, and water temperature throughout the fishpond (Fig. 1.10). Although the number of instruments available during the period of this study varied, the suite of instrumentation remained consistent (Table 1.3). A summary of instruments deployed over the course of this study can be reviewed in Figure 2.7. The rationale for instrument placement was two fold: (1) measure the water flowing through each mākāhā at a frequency that would capture flood and ebb tides. This was achieved by deploying acoustic Doppler current profilers (ADCP) and current meters, or using pressure sensor data to derive rating curves for mākāhā when current meters were unavailable; and (2) measuring water temperature at specific locations, chosen to best cover the extent of the fishpond, to record spatial temperature variability across He‘eia Fishpond.

Nortek Aquadopp current meters were used to measure single point current direction and magnitude through RM3 and TM (Fig. 1.10). The fastest water currents through each mākāhā were observed to be at the water surface, but the water surface fluctuated with the rising and falling of the tide. As a consequence, the depth of the Aquadopp current measurement was chosen to best represent mid-water currents, ensuring that the instrument was deep enough to remain within the water column over the fullest extent of tidal range.

Sontek Argonaut-SW current profilers, deployed on the seafloor, were used to integrate water column current direction and magnitude at OM1, OM2, OB, and RM2 (Fig. 1.10). Onset Corporation HOBO water level loggers were deployed throughout the fishpond and He‘eia Stream to measure pressure (from which water depth is computed) and water temperature (Fig. 1.10). Onset Corporation TidBit v2 temperature data loggers were secured to the sample site stakes to measure water temperature in a grid across the fishpond (Fig. 1.10). All Onset Corporation instruments were installed 20 cm above the seafloor, which was deep enough to remain within the water column over the fullest extent of tidal range, and deep enough to be unaffected by daily surface water heating due to solar radiation.

Dry vs. Wet Season

The relationship between rainfall and stream flow has been documented in previous studies (De Carlo et al. 2007; Hoover and Mackenzie 2009), and was evident in this study as well. Monthly rainfall data from the Luluku rain gauge and monthly stream discharge data from the Ha‘iku Stream monitoring station (Fig. 2.1) show synchronous changes during storms and reveal a clear seasonal distinction in between the wet and dry season. The historical stream discharge data suggests that the Ko‘olaupoko region experiences a dry season during the months of May-October and a wet season from November-April (Table 2.1). During this study, however, the region experienced two large rain events during the dry season. The Luluku rain gauge measured a total of 189.41 cm of rainfall during this thirteen-month study. The sum of rainfall during the four storm events (11/04/07, 12/07/07, 12/31/07, and 06/12/08) accounted for 18.41% of the total rainfall measured during the period of study. Serendipitously, the first storm event of the 2007-2008 wet season was the largest storm experienced during the entire study and represented the watershed’s first-flush storm (as defined in Chapter 1 for this study, and see also Schlesinger (1997)). Prior to this first-flush storm event on 11/04/07, the Luluku rain gauge station had not recorded greater than 5.08 cm of rain in more than eight months, when a rain event totaling 5.97 cm of rainfall occurred over a two day time period (03/26/07-03/27/07).

Flow Rates and Rating Curves

Using current magnitude, water column depth, and mākāhā dimensions, flow rates (φ), in units of m^3/s, were determined for each of the rectangular-shaped mākāhā (TM, OM1, OM2, RM3) and for the low portion of OB in the fishpond wall (Fig. 1.4) from the equation:

$$\varphi = wdv\sin(\theta) \qquad \textbf{(1)}$$

where w is the mākāhā width (m), d is the water depth (m), v is the magnitude of the water velocity (m/s), and θ is the direction of the water flow, with $\theta = 0$ corresponding to flow directly through the mākāhā. Rating curve calculations at several mākāhā require further discussion. The repaired wall section at OB is lower than the main fishpond kuapā. When tides in Kane‘ohe Bay are high enough to crest over this repaired section of wall, the entire repaired section of OB acts like a mākāhā. Under these circumstances the flow rate over the repaired section of wall was determined by Equation (1), with w defined as the length of the repaired wall section, d is the water depth using a subset of the Argonaut-SW data set which includes only the days when water depth was greater than 0.86 m (the height of the repaired wall section above the seafloor), v is the magnitude of the water velocity, and θ is the direction of the water flow. Because He‘eia Stream waters flow through an irregularly shaped bed it was not possible to simply calculate the cross sectional area as wd. Instead, a cross sectional profile of the He‘eia Stream mouth was manually measured through systematic depth measurements to calculate the River Mouth flow rate. The areal aspect of Equation (1), wd, was calculated from the integrated cross sectional depth measurements. For RM2, the mākāhā has a perennial freshwater flow into the fishpond and functions similarly to a typical USGS stream flow-monitoring weir, where water flows over a partially dammed portion of the mākāhā. Diverted stream flow into the fishpond through RM2 changed with stream discharge, and flow rates through RM2 were calculated in the same way as the flow rates for River Mouth over an irregularly shaped bed.

Using calculated flow rates (m^3/s) and stage (height of water within a well-constrained weir, in this case the mākāhā), rating curves were developed for each mākāhā to relate the flow rates of water passing through each mākāhā to tidal height fluctuations (Figs. 2.8-2.14). It was challenging to develop rating curves for each mākāhā due to semi-diurnal tides and bidirectional water flow through the mākāhā as flood and ebb tides exchanged water into or out of the fishpond. Additionally, each mākāhā is gated with plastic mesh to prevent fish movement in or out of the fishpond. The gate mesh restricted flow through the mākāhā and caused enough friction that a hydraulic head formed on the upstream side of the gate as the tide filled or drained the fishpond. The resulting restricted flow caused a delay in fishpond tidal response when referenced to the tidal signal recorded by NOAA in Kane‘ohe Bay. The delay in flow caused by the mākāhā gates can be seen in the rating curves. Often, it was necessary to develop two rating curves for a single mākāhā in order to account for flood and ebb tides, moving water into or out of the fishpond, respectively. When two rating curves were required, these were identified by subscript “in” or “out.” Mākāhā OM2, OB, OM1, and TM required two rating curves (Table 2.2). Each of these mākāhā face eastward towards the trade winds and Kane‘ohe Bay, in contrast to the River Mouth and RM3, which face more northerly, and were amenable to bidirectional flow calculations with a single rating curve. The weir-like mākāhā at RM2 displayed unidirectional flow into the fishpond regardless of tidal state and required only a rating curve for water flow into the fishpond. Although RM1 is defined as a mākāhā for the purpose of this study, its location can only be estimated within the He‘eia Fishpond perimeter. An accurate rating curve could not be generated for this mākāhā, because it is no longer intact (see prior discussion).

The rating curves for OB, OM1, TM, and River Mouth are logarithmic curves:

$$x = ae^{\frac{y-b}{c}} \tag{2}$$

where x is flow rate (m^3/sec), y is water depth (m), a is the amplitude, b is the offset in the horizontal asymptote, and c is the degree of line curvature. The rating curves for OM2in/out are partial Gaussian curves:

$$x = a + be^{\frac{-(y-c)^2}{d}} \tag{3}$$

where x is flow rate (m^3/sec), y is water depth (m), a is the horizontal displacement from the origin, b is the amplitude of the peak, c is the peak offset from x-axis, and d is the width of the bell curve. The rating curve for RM2 is linear:

$$x = ay + b \tag{4}$$

where x is flow rate (m^3/sec), y is water depth (m), a is the slope of the best-fit line, and b is the y-intercept. Rating curves are shown in Figs. 2.8-2.14, and rating curve formulae are given in Table 2.2.

Tidal Spectra

Water pressure data for each mākāhā and River Mouth were evaluated using a Fourier transform to identify tidal constituents within each time series. A pressure sensor was deployed at the location estimated to be RM1, in order to measure tidal activity at this site, so that a complete analysis of tidal influence on He‘eia Fishpond mākāhā could be conducted. The resulting spectral analyses reveal that each tidal record has three peaks, one relating to approximately twelve hours and two distinct, but closely occurring peaks at approximately twenty-four hours (Figs. 2.15 and 2.16). Using a Matlab tidal harmonic analysis package (Pawlowicz et al. 2002), four dominant tidal constituents for O‘ahu have been calculated with 2009 data from the Office of Naval Research (Sevadjian, personal comm.). Two of the most important O‘ahu tidal constituents are semi-diurnal (principal lunar component (M_2) and principal solar component (S_2)) and two are diurnal (luni-solar component (K_1) and principal lunar component (O_1)). The first peak corresponds to the 12.42 hr M_2 tidal component, and is equally evident in every data set. The second and third peaks correspond to the 23.93 hr K_1 and 25.82 O_1 tidal components. A slight offset in frequency is apparent in the He‘eia Fishpond spectra when compared to the O‘ahu tidal data from 2009 (Sevadjian, personal comm.). This is most likely due to the limited time series data used in calculating the fishpond spectra; more accurate numbers might be given by a longer time series.

He‘eia Fishpond Bathymetry and Volume

He‘eia Fishpond bathymetry was manually measured over a period of three days. A total of 728 waypoints were taken with a Garmin 76 GPS, recording latitude and longitude, with a corresponding time stamp and water depth measurement. Water depth was measured via a deployed HOBO water level logger recording tidal fluctuations during the mapping. After the HOBO water level data was corrected for atmospheric pressure effects, the bathymetry data set was normalized to mean lower low water (MLLW) and a bathymetry map was constructed (Fig. 2.17). These bathymetric data were used in fishpond volume calculations. The fishpond volume at MLLW is 93,329 m^3. The volume of the fishpond at mean higher high water (MHHW) is 311,170 m^3. These values are the minimum and maximum calculated fishpond volume values for spring ebb tide and spring flood tide. Fishpond volumes during neap tides are 105,200 m^3 and 271,402 m^3 for average neap low tide and average neap high tide, respectively.

Mākāhā Water Flow Rate Comparison

Quantifying the external loading of water to He‘eia Fishpond requires determining the relative importance of water flow rate at each mākāhā. Tidal fluctuations in Kane‘ohe Bay affect the fishpond volume, making it necessary to calculate mākāhā discharge at different tidal heights. Four tidal stages, selected to include maximum and minimum tidal heights, were evaluated during the course of this research: spring flood, spring ebb, neap flood, and neap ebb. Tides in Kane‘ohe Bay are mixed semi-diurnal (Fig. 2.18), meaning there are two high tides and two low tides, of differing heights, within a day. The consequence of mixed semidiurnal tides for He‘eia Fishpond is that the influence of tidal activity from Kane‘ohe Bay is not consistent between tides, thus the magnitude of the flow rate of marine water filling and flushing the fishpond is variable over time. During this study the highest spring tide recorded in Kane‘ohe Bay was 1.02 m, the lowest was -0.25 m. The 13-month mean tidal height within the bay was 0.36 m with a standard deviation of +/- 0.29 m.

Using the rating curves, mean flow through each mākāhā for spring flood tide, spring ebb tide, neap flood tide, and neap ebb tide was determined (Table 2.3). These values reveal that TM and OM1 are the regions of greatest water exchange within the fishpond, together accounting for 75% of the total water exchanged through all fishpond mākāhā during spring or neap tidal cycles. Assuming the He‘eia Fishpond water balance is in steady state, the flow rate of water in must equal the flow rate of water out of the fishpond. However, when He‘eia Fishpond spring and neap tidal cycle flow rates, calculated as the sum of flow rate over all mākāhā for flood and neap directions, are compared to one another, a difference of 11,544 m^3/day exists. This unaccounted for flow rate between tidal cycles, which equates to 6.5% of the fishpond mean water flow rate through all mākāhā over a day, can be explained in a number of ways. First, it is possible that the mismatch of 6.5% results from uncertainties in the rating curve calculations, or to gains/losses of water through holes in the kuapā, or both. Every effort was made to calculate He‘eia Fishpond spring and neap volumes and flow rates with data collected over the same time frame, but this was not possible due to instrument supply limitations. Therefore, we were compelled to calculate rating curves using time series data sets of differing length, which undoubtedly gives rise to some uncertainty in the final flow rates calculated. Second, the importance of submarine groundwater discharge (SGWD) into He‘eia Fishpond could be a source of uncertainty in flow rate calculations. Measuring this process was outside the scope of this research, and SGWD remains to be constrained. In fact, water samples evaluated for dissolved nutrient concentrations and biogeochemical processes (further discussed in Chapters 3 and 5) suggest the possibility of SGWD in

He‘eia Fishpond. Lastly, the continuing efforts of Paepae o He‘eia in kuapā restoration will remove the possibility of water exchange through the fishpond wall. Paepae o He‘eia has made great progress in rebuilding the perimeter wall and, upon completion of work, a second water exchange study would greatly improve the flow rate calculations made here.

RM3 flow rates are also noteworthy. The ebb tide flow “out of” He‘eia Fishpond is much higher than the flood tide flow “into” the fishpond, for both the spring and neap tidal cycle (Table 2.3). This is in contrast to the general trend observed at other mākāhā, where flood and ebb tides are similar in their relative magnitudes. RM3 is the mākāhā furthest from Kane‘ohe Bay, and upstream from the river mouth of He‘eia Stream. Relative to other mākāhā, RM3 does not allow much water into the fishpond on flood tides, but it plays an important role in flushing He‘eia Fishpond on ebb tides. This is most likely due to two forces acting on the waters passing through RM3. First, flood tides must overcome water flowing out of He‘eia Stream before entering RM3 and the fishpond. In contrast, an ebb tide aids downstream flow in He‘eia Stream, allowing for uninhibited water flow out of He‘eia Fishpond through RM3. Second, wind-driven water set up in He‘eia Fishpond builds up on the NW perimeter. Although beyond the scope of this research, wind-driven water set up was observed to occur, and RM3 is the nearest mākāhā to provide hydraulic relief. Both explanations could be areas of future study, and would provide a better understanding of the processes influencing water exchange between He‘eia Fishpond and He‘eia Stream.

Having calculated flow rates for each mākāhā (Table 2.3), the relative importance of each individual mākāhā can be evaluated. The "Mākāhā Flow Rate Total" values from Table 2.3 were used to normalize individual mākāhā flow rates and rank the mākāhā relative importance in overall fishpond circulation (Figs. 2.19-2.22). During the 6-hour duration of a spring flood or ebb tide and neap flood or ebb tide, the importance of the two northeastern most mākāhā (TM and OM1) flow rates in overall pond circulation is evident. As mentioned, TM is actually comprised of three individual mākāhā grouped under the same name. If the TM ebb flow rates represented in Table 2.3 are divided by three to obtain an individual TM mākāhā flow rate (spring tide = 23,778 m^3/6 hrs and neap tide = 11,638 m^3/6 hrs), it is clear that each individual TM mākāhā remains important when compared to the other fishpond mākāhā; each individual TM mākāhā flow rate ranks third highest of all mākāhā. OM1 is dimensionally the largest mākāhā, approximately four fold wider than the fishpond mean mākāhā width (Fig. 1.5). In addition to TM and OM1 having the greatest cross sectional area and highest flow rates, these mākāhā are positioned such that they face directly into the predominant trade wind direction (northeast) blowing across Kane‘ohe Bay. Although wind-driven water set up was not part of this study, for the same reasons that RM3 flow rate reflected a build up of water along the northwestern interior perimeter of He‘eia Fishpond, the set up of Kane‘ohe Bay waters on the exterior perimeter of the fishpond kuapā likely enhance the flow of water through TM and OM1 into He‘eia Fishpond during flood tides. Conversely, the hydraulic pressure gradient created from inside the fishpond into Kane‘ohe Bay created by an ebb tide would aid in flushing the fishpond, especially through the two largest gaps in the fishpond kuapā, TM and OM1.

At the onset of this study, we believed that the low section within the fishpond kuapā (identified as OB) would only play a significant role in water exchange during spring high tides. Our data, however, suggest this is not the case. The low kuapā section at OB is in fact submerged during both spring and neap tides, as the water level is often higher than the 0.86 m required to crest the fishpond kuapā at this location. The range of tidal flow rate is from 20,382 m^3/6 hrs during neap tide to 35,884 m^3/6 hrs during spring tide, making the low section of the wall the second most influential mākāhā within the fishpond. The OB section is currently under repair by Paepae o Heʻeia. Reconstruction of the kuapā will result in a reduction of water exchange within the fishpond by as much as 19% once the flow through this section of kuapā is eliminated.

Heʻeia Fishpond Circulation Dynamics

Few studies exist of circulation, mixing, or water transport in Hawaiian fishponds. Ertekin et al. (1996) modeled the circulation in One Aliʻi Fishpond on Molokaʻi using the finite-element method (Rao 2005) to solve conservation of mass and momentum equations. One Aliʻi Fishpond circulation was modeled under two scenarios: (1) only one of the two mākāhā was open, and (2) both of the fishpond mākāhā were open. Mākāhā water velocity was found to be higher in scenario 1, but fishpond circulation was higher when both mākāhā were open. Ertekin et al. (1996) concluded that the number of mākāhā, as well as their location in relation to the physical forces at work (tidal activity, wind, fishpond bathymetry), were important in determining fishpond circulation.

Yang (2000) furthered the work of Ertekin et al. (1996) by modeling the influences of stream runoff and wind on fishpond circulation within One Aliʻi Fishpond, also using the finite-element method. The area of One Aliʻi Fishpond is approximately 27 acres. Heʻeia Fishpond is more than three-times larger, but both fishponds are of the loko kuapā design and possess similar forcing mechanisms. Yang (2000) concluded that the velocity of water moving through the mākāhā, as a function of tidal activity, was a primary driver of circulation within the fishpond, with wind stress acting as a secondary influence on fishpond circulation when the body of water is large enough. In the case of One Aliʻi Fishpond, wind did not appreciably affect fishpond circulation, but Yang (2000) suggested that in larger fishponds, of similarly shallow depth, wind could affect circulation. Heʻeia Fishpond is of sufficient size to allow small wind driven waves (<0.30 m in height) to develop. The minimum depth of Heʻeia Fishpond (less than 1 m) is shallow enough that wind may impact water column mixing and fishpond circulation. The importance of tidal flushing within Heʻeia Fishpond is evident upon examination of the tidally driven mākāhā water exchange (Figs. 2.19-2.22), consistent with the findings of Ertekin et al. (1996) and Yang (2000) in One Aliʻi Fishpond. Interestingly, tidal mixing has been shown to not be important in water column mixing within deeper Kaneʻohe Bay waters (Ostrander et al. 2008; Ringuet and Mackenzie 2005). Although outside the scope of this study, Yang (2000) added that wind altered the rate of water flow through the mākāhā by accelerating or dampening currents in the surrounding waters outside the mākāhā channel. As mentioned earlier in the Mākāhā Water Flow Rate Comparison section, TM and OM1 dominate the mākāhā water exchange in Heʻeia

Fishpond, suggesting the northern portion of the fishpond exchanges more of the water column than the southern portion. Additionally, limited visual observations suggest the exchange of Kane‘ohe Bay water through TM and OM1 bisects the fishpond, creating areas of slower circulation at Stk6 in the northeastern corner of He‘eia Fishpond, and Stk13 and Stk15 in the southwestern corner of the fishpond. These qualitative conclusions have been made by reviewing water column parameters such as salinity, temperature, dissolved nutrients, and APA, which support the contention that unmixed cells of water persist over multiple tidal cycles.

He‘eia Fishpond Residence Time

One goal of this study was to compute the external nutrient loading to He‘eia Fishpond. Nutrient concentrations and loading calculations are discussed in Chapter 3. In order to quantify the impact of external loading by He‘eia Stream and Kane‘ohe Bay on the fishpond, we calculated the minimum He‘eia Fishpond residence time (τ_{HF}) from a simple calculation based on the equation:

$$\tau_{HF} = \frac{\text{He‘eia Fishpond Volume (spring high tide)}}{\text{He‘eia Fishpond Volume Exchanged (spring high tide – spring low tide)}} \qquad \mathbf{(5)}$$

It was necessary to make the following assumptions when calculating τ_{HF}: (1) the fishpond water column was uniformly well mixed, (2) all flood and ebb tides were of the same magnitude, (3) all flood and ebb tides occurred on 6 hour intervals, and (4) water exchange occurred only through the mākāhā. While overly simplistic, these assumptions did provide us with an idea of the minimum fishpond residence time. We define the endmember states of the fishpond as: Spring flood tide, mean high-high water (MHHW), when maximum fishpond volume is 311,170 m^3; and spring ebb tide volume, mean low-low water (MLLW), when minimum fishpond volume is 93,329 m^3. As He‘eia Fishpond never fully drains, the water retained in the fishpond during the lowest tide is equivalent to the MLLW volume (approximately one-third the maximum volume of the fishpond).

We initiate the He‘eia Fishpond residence time calculation at high tide, with the fishpond at maximum volume, MHHW. Further, we divided the entire water column into three equal parts, based on the relationship between MHHW and MLLW volumes mentioned above. The difference between MHHW and MLLW is two-thirds the total volume of the fishpond. This two-thirds of water is assumed to be removed from the fishpond with the ebb tide, and then fully replenished with new Kane‘ohe Bay water from outside the fishpond during the flood tide. The one-third of remaining water, the MLLW volume, is assumed to be fully mixed with the incoming flood tide. We define the time required for one flushing cycle (t_{cycle}) as: a) begin at high tide, MHHW, and evacuate two-thirds of the total fishpond volume during an ebb tide, until achieving MLLW within the fishpond at low tide; then b) return the fishpond to MHHW during a flood tide, while incoming waters fully mix the water present in the fishpond. Time required for completing “one flushing cycle” is: $t_{cycle} =$ 12 hrs. Four flushing cycles are required to mix the initial MLLW to approximately 1% dilution. Therefore, the minimum residence time of He‘eia Fishpond is: $\tau_{HF} = 48$ hours or 2 days.

The preceding discussion treated calculation of τ_{HF} for the entire fishpond volume. However, the residence time of surface waters in He‘eia Fishpond is important when determining the impact of storm events on the fishpond water column, since freshwater introduced by storm runoff is largely restricted to a surface plume, at least initially. Storm events often cause brief but significant increases in freshwater flow into the fishpond, stratifying the water column. Although making precise surface water residence time calculations is beyond the scope of this research, we can make qualitative calculations to estimate the minimum residence time of surface waters in He‘eia Fishpond. Using the residence time calculation presented previously, we make two new assumptions: (1) no mixing occurs throughout the water column and (2) during the flood tide, while incoming waters return the fishpond to MHHW, the volume that had remained in the fishpond during low tide all moves to the surface. The residence time of surface water derived for this hypothetical situation is 15 hours, the time required for 1.25 tidal cycles (an ebb tide, flood tide, and ½ a second ebb tide).

Water Column Physical Properties

In order to evaluate water column stratification, and the way in which water column structure varied across time, space, and changes in meteorological conditions, electronic measurements were taken throughout He‘eia Fishpond with moored and water column profiling instrumentation. Salinity, temperature, % DO, and pH proved to be the parameters most useful in characterizing fishpond water column structure. Instrument details and sampling capabilities are outlined in Chapter 1, Tables 1.3 and 1.4, and Figure 1.10. Temporal and spatial trends of each of these parameters are discussed below.

Spatial and Temporal Temperature Record

Temperature data loggers (Onset Corporation TidBit v2) were deployed at six sites (Stk3, 6, 9, 13, 15, 18) throughout the fishpond to create a time-continuous spatial temperature record for the time period of this study. Deployed 20 cm from the seafloor, the TidBit recorded temperature on a frequency of 900 sec to capture 15-minute variability over the time series. The deployment depth allowed all instruments to stay submerged in the water column over all tidal fluctuations. All sample sites reflect annual changes in temperature, with water temperature dropping to below 20 °C in the winter months and up to 34 °C in the summer months (Figs. 2.23 and 2.24). Sample sites Stk3, 6, and 9 (Fig. 2.23) are strongly influenced by Kane‘ohe Bay waters and are most distal from the shoreline, while Stk13, 15, and 18 (Fig. 2.24) are located near the shoreline and are dominated by land-based influences. The temperature records for Stk13, 15, and 18 are similar (Fig. 2.24), suggesting that a relationship exists between water column inputs, circulation, and residence time. Stk3, 6, and 9 (Fig. 2.23) temperature records, in contrast, are not as similar, as these sample sites reflect influences from differing inputs of marine and terrigenous waters, differing currents, and surrounding water column residence time. Over the course of study, the sites most proximal to land, and thus influenced by freshwater input (Stk13, 15, 18) record cooler temperatures (18-20 °C) than the three sites most distal from land, which do not reach temperatures below 20 °C. Lastly, the variability in the temperature record of all sites suggests that many factors are influential in producing water column structure throughout He‘eia Fishpond, including changes in daily weather conditions (rainfall, wind, solar radiation), tidal activity, and stream and groundwater discharge.

Monthly Water Column Profiles

During monthly and storm event water sampling efforts, water column profiles of salinity, temperature, % DO, and pH were made using a YSI 6600A v2 multi-parameter water quality sonde (Table 1.4). In conjunction with discrete water sample collection, the YSI sonde was used to create water column depth profiles of these parameters at each sample site (Table 1.2, Figs. 1.7 and 1.9). Water column data for each sample site was organized into three data sets: mean (integrated) water column values, mean surface water values (upper 25 cm), and mean near-bottom (deep) water values (bottom 25 cm). For the purpose of discussion in this thesis, only mean values for water column properties are described (Figs. 2.25-2.35). The entire data set for monthly sampling efforts can be found in the appendices to this thesis. The monthly YSI water column profile data for temperature and salinity are reported in Appendix 1, % DO and pH data is reported in Appendix 2. The storm data set reveals the extent to which He‘eia Fishpond waters can become stratified after a large input of terrigenous freshwater. The lowest salinities are seen in surface waters in the sample sites closest to He‘eia Stream runoff (Figs. 1.7 and 1.9), but the freshwater plume often does affect the entire fishpond. Additionally, the storm influence persists for more than a week.

An important goal of this project was to determine how tidal activity affects water flow and biogeochemistry in He‘eia Fishpond. Because land derived freshwater and marine waters from Kane‘ohe Bay have distinctive temperature, salinity, % DO, and pH, the monthly YSI sonde data enabled the relative strength of these two sources to be evaluated on each sampling day. The balance between terrestrial and marine sources is different under baseline (non-storm) vs. storm conditions. Baseline conditions are discussed here and fishpond data during storm conditions are discussed in the next section. Mean salinity, temperature, % DO, and pH for all sample sites, during baseline conditions, are presented in Figures 2.25-2.28. By comparing the entire annual data set (Panel A) vs. the annual data set of sampling days occurring on flood tides (Panel B) vs. days collected on ebb tides (Panel C), it is evident that water column structure is strongly influenced by tidal activity. Flood tides have different salinity, temperature, % DO, and pH values than ebb tides, and a water sampling plan that fails to sample over a range of tidal influences may not correctly address short-term (6 hour) variability present within a relatively long-term (monthly/annual) time series of data. Flood tide sampling captures conditions of maximum external input into He‘eia Fishpond from Kane‘ohe Bay, while ebb tide samples are collected after the fishpond water column has had at least 6 hours to homogenize. No values for temperature, % DO, and pH exist for the River sample site (#10) because YSI sonde profiling was not possible due to inaccessibility of the sample site.

Features observed for all parameters reveal that temperature values across all sample sites have the greatest standard deviation and pH has the least (Figs. 2.26 and 2.28). Flood tide values are always different than ebb tide values, suggesting that physical and biogeochemical interactions within He‘eia Fishpond are changing the water column structure within12 hours, one tidal cycle. Additionally, % DO is the most variable while pH is again the least (Figs 2.27 and 2.28). The invariance of pH would be expected as changes in pH are buffered in fresh and salt water through carbonate ions. Further, pH values are calculated on a log scale, therefore, a 0.1 change in pH units is large, but may not appear large with the existing y-axis scaling (Fig. 2.28). Water mixing within He‘eia Fishpond is best represented in salinity (Fig. 2.25) flood tide values (Panel B) and ebb tide values (Panel C), where in these panels, sample sites #1-6 represent the mākāhā affected by the waters of Kane‘ohe Bay during flood tides and emptying into Kane‘ohe Bay from He‘eia Fishpond during ebb tides. When sites #1-6 are compared to the fishpond interior sites (#11-29) during flood tides, it is clear that the homogenous input waters from Kane‘ohe Bay mix with less, and more variable, saline water within the fishpond, resulting in a wider range of salinities. Upon ebb tide (Panel C), salinities measured at the same Kane‘ohe Bay mākāhā sites (#1-6) are not as similar because they represent water being evacuated from the fishpond. This pattern is revealed in the % DO and pH data sets as well.

Differences between surface and near-bottom values are present in varying degrees for all parameters. The most obvious differences are found in salinity values (Fig. 2.25). Not only are the mean values between surface and near-bottom samples different during flood and ebb tides, but the range of values varies as well. These differences can be attributed to the influence of freshwater. During flood tide, surface and near-bottom salinity values and standard deviations are invariant for Kane‘ohe Bay mākāhā sites (#1-6). Conversely, after incoming bay water has interacted with less dense, fresher water within the fishpond, the surface salinity values during ebb tide show increased variability and lower values across all sample sites.

Similar trends between two specific sites are observed at RM3 (#7) and RM1 (#9): (i) mean values for salinity, temperature, % DO, and pH at RM3 and RM1 are often outside of the range of values observed at all other sites; and (ii) the standard deviations for each value at RM3 and RM1 are frequently greater than those observed at all other sample sites, especially in salinity and pH (Figs 2.25 and 2.28). This greater variability is attributed to the fact that RM3 and RM1 are both heavily influenced by freshwater. However, RM3 and RM1 receive freshwater from different sources. On a flood tide, water flowing through RM3 is a mix of He‘eia Stream and Kane‘ohe Bay waters, while on an ebb tide only water from the fishpond exits through the mākāhā into He‘eia Stream. In contrast to RM3, RM1 does not experience bidirectional flow because the sample site is within He‘eia Fishpond itself and is not an actual mākāhā (previously discussed). It does, however, receive diffuse terrestrial freshwater originating from He‘eia Stream.

Baseline vs. Storm Conditions

Salinity is often used as a conservative tracer when studying water column mixing and is particularly useful in estuarine environments that are characterized by a gradient in salinity caused by the mixing of fresh and saltwater (Schlesinger 1997). Spatial representation of monthly surface and near-bottom water values of salinity and temperature, measured by the YSI sonde, are reported in Appendix 3 and Appendix 4, respectively. The timing and relative importance of freshwater and marine inputs into He‘eia Fishpond on a monthly basis, and during isolated storm events, were monitored by focusing on salinity values. Northwest to southeast gradients in salinity result from freshwater flow into the fishpond through RM1, RM2, and RM3. Occasionally less saline water was measured at Stk13, 15, and 16. Fresher water detected at these sample sites could be due to counter-clockwise, wind-driven circulation of fishpond waters transporting He‘eia Stream water along the southwest margin of the fishpond. Alternatively, it is possible that SGWD from water sources inland of He‘eia fishpond crops out at these sites. Constraining these possible freshwater sources is beyond the scope of this research, but may be interesting to pursue in further studies.

The Hawaiian Islands experience a dry and wet season, where meteorological conditions (rainfall, wind, and PAR) are markedly different. We define the dry season conditions as “baseline.” This is because, during the dry season, water column structure is the most stable. Short lived, but intense rain events punctuate the wet season. When these rain events cross the storm threshold (previously discussed), they have the potential to dramatically change the coastal marine biogeochemistry. One of the goals of this study was to evaluate the impacts of storm events on He‘eia Fishpond and make comparisons between nutrient inventories and phytoplankton community composition during baseline conditions and storm events.

During baseline conditions He‘eia Fishpond is well mixed. As an example, baseline salinity conditions in He‘eia Fishpond, for the dates of August 2007 and August 2008 (Figs. 2.29 and 2.30), illustrates relatively homogeneous salinity values across the fishpond and with depth. The month of August occurs in the middle of the dry season in Hawaiʻi (Table 2.1). For a full reporting of salinity values measured during monthly sampling efforts, see Appendix 3.

In contrast to baseline conditions, intense rainfall events during the wet season can cause water column stratification in Heʻeia Fishpond. Four rainfall events (Fig. 2.2) during the period of study exceeded the storm threshold. As our study progressed into the wet season (November-April), it was our expectation that every rainfall event that qualified as a storm would impact the fishpond. Storm impact was clearly evident during the first-flush storm event (11/04/07, Figs. 2.2 and 2.3), during which the surface waters across Heʻeia Fishpond became fresh, and salinity in the fishpond as a whole dropped dramatically relative to baseline salinities (Fig. 2.31). A "T" shaped transect was occupied during the intensive sampling effort during this first-flush storm (Fig. 1.8), as it was impractical to sample the entire monthly sampling grid on a daily basis. The storm transect was designed to capture the impact of storm input on fishpond water quality. This sampling scheme permitted the tracking of freshwater runoff entering the fishpond through the river mākāhā in the northwest and followed the dilution of freshwater across the long axis of the fishpond to the marine waters of Kaneʻohe Bay outside of OM2. For the purposes of the storm sampling effort, Stk11 was added to the regularly sampled stakes that were occupied on a monthly basis (Fig. 1.8). Salinity data collected during Transect sampling that occurred 2, 3, 4, and 7 days post-storm reveal that freshwater persists within the fishpond for over a week (Figs. 2.32-2.35). These data are consistent with other large storm events studied in Kaneʻohe Bay, in which the storm signal persisted as many as

7 days following the rain event (De Carlo et al. 2007; Drupp et al. 2011; Ringuet and Mackenzie 2005).

Storm Event Comparison

A comparison of the five significant rainfall events that occurred within the study site region between August 2007-August 2008, and the meteorological conditions associated with each (Table 2.4), include three wet season storms and one dry season storm that occurred during the period of study. Storm 1, the first-flush storm described previously, had the highest rainfall and stream discharge in a 24 hr period. Storm 2 had the second highest rainfall, but Storm 4, a dry season storm event, had the second highest stream discharge. Stream discharge regulates freshwater input to He‘eia Fishpond, and thus the water column biogeochemistry post-storm. A rain event that occurred just weeks before Storm 4 (Fig. 2.2) most likely recharged groundwater aquifers to carrying capacity, resulting in more surface water runoff. Storm 1 and Storm 4 were both characterized by a more prolonged impact on fishpond water quality than Storm 2. Interestingly, Storm 1 and Storm 4 occurred during a neap tidal cycle, while Storm 2 occurred during a spring tide. Spring tide mākāhā flow rates are greater than neap tide (Table 2.3). Neap tides have been shown to exchange less water through each mākāhā than spring tides (Table 2.3), resulting in conditions that favor persistence of the storm signal. With more water exchanging during a spring tidal cycle, the lack of a persistent storm signal for Storm 2 is consistent with the calculated residence time for He‘eia Fishpond discussed earlier in this chapter. Finally, wind direction and magnitude may play a role in water column mixing, but do not appear to affect the residence time of He‘eia Fishpond, as Storm 2 had the highest wind speeds and the least persistent storm signal (Table 2.4). Additionally, Storm 2 and Storm 4 had similar wind direction (Table 2.4), and we have shown in this chapter, and further in Chapter 3, that Storm 4 had a more lasting impact on He‘eia Fishpond than Storm 2. Therefore, we conclude that the dominant force in water circulation within He‘eia Fishpond is tidal forcing. This conclusion counters findings of studies focused on Kane‘ohe Bay circulation, in which it has been argued that water column mixing is driven by wind forcing (Drupp et al. 2011; Ostrander et al. 2008; Ringuet and Mackenzie 2005) but, as previously discussed, confirms observations made by Yang (2000).

Four storm events occurred during the period of study (Figs. 2.2 and 2.3). Storm 1 was the largest of the four storm events. Rainfall during Storm 1 was 14.63 cm of rain in 24 hours, almost twice that of Storm 2 (8.23 cm) and three times the rainfall experienced during Storm 3 (5.97 cm) and Storm 4 (6.05) (Fig. 2.2). Sampling of Storm 1 was by design; our regularly scheduled monthly sampling occurred fortuitously 48 hours after Storm 2 and Storm 4, so that the impact of these later storms could be evaluated as well. Storm 1 was sampled at high temporal resolution in order to capture the first-flush of terrigenous constituents into the fishpond, and to develop an understanding of the persistence of freshwater inputs within the fishpond after storm events (Fig. 2.36). Storm 1-Transect 1, Storm 2, and Storm 4 were sampled 48 hours after their associated rain events, and all display depressed salinities with mean salinities of 22.05 PSU, 26.96 PSU, and 20.79 PSU respectively. Surprisingly, when compared to the wet season storms (Storm 1 and

Storm 2), Storm 4, a dry season storm, has the lowest mean salinity across the fishpond 48 hours after the rain event (Fig. 2.37). This mean salinity is even lower than Storm 1, which experienced three times as much rainfall. It is likely that lingering low salinities after Storm 4 are the result of tidal flushing and wind patterns atypical of the dry season (Table 2.4, Fig. 2.5).

Summary and Conclusions

He‘eia Fishpond responds to tidal and meteorological forcing in much the same way that other Hawaiian fishponds and larger embayments of water react. Studies around O‘ahu have shown that baseline (dry season) water column conditions can be dramatically altered after large rain events (Cox et al. 2006; De Carlo et al. 2007; Drupp et al. 2011; Hoover and Mackenzie 2009; Hoover et al. 2006; Ringuet and Mackenzie 2005; Tomlinson and De Carlo 2003), and the same is true for He‘eia Fishpond. Through instrument measurements of atmospheric and water quality parameters we have shown that storm events deliver large volumes of freshwater from He‘eia Stream to the fishpond, resulting in salinity and temperature changes within the water column that can potentially persist for over a week. Additionally, we demonstrated the importance of tidal activity on flushing of He‘eia Fishpond, quantified the relative flow rates of water exchanging through each mākāhā, and calculated a minimum residence time for the fishpond. The following chapters will incorporate the findings presented here with dissolved nutrient, suspended particulate, and photopigment data to more clearly describe the biogeochemical response to changing dynamics of He‘eia Fishpond during baseline and storm conditions.

Table 2.1. Monthly mean rainfall and stream flow data during the study period (August 2007-August 2008), and historical mean data from 1943-2009: rainfall data from Luluku Station rain gauge and stream flow data from Ha‘iku Stream. Italicized months (Nov-Apr) represent the months chosen to represent the He‘eia Fishpond wet season, as estimated from historical stream flow data.

Month	**Mean Rainfall 2007-2008 (cm)**	**Mean Stream Flow 2007-2008 (m^3/sec)**	**Historical Mean Stream Flow 1943-2009 (m^3/sec)**
August	0.32	0.044	0.045
September	0.37	0.044	0.045
October	0.33	0.043	0.057
November	***1.02***	***0.080***	***0.079***
December	***1.45***	***0.113***	***0.076***
January	***0.55***	***0.076***	***0.074***
February	***0.42***	***0.053***	***0.074***
March	***0.09***	***0.046***	***0.093***
April	***0.29***	***0.051***	***0.071***
May	0.33	0.053	0.065
June	0.40	0.051	0.042
July	0.36	0.057	0.045
August	0.28	0.041	0.045

Table 2.2. He‘eia Fishpond rating curve formulae for each mākāhā and He‘eia Stream (River Mouth). Flow direction is water flow into or out of the fishpond, while “both” notes the same rating curve was used for flow both into and out of the fishpond.

Site	**Flow Direction (relative to He‘eia Fishpond)**	**Formula**
OM2_{in}	in	$x = 0.75 + 0.18e^{-\frac{(y-0.71)^2}{0.025}}$
OM2_{out}	out	$x = 0.017 + 0.15e^{-\frac{(y-0.73)^2}{0.043}}$
OB_{in}	in	$x = e^{\frac{y-0.9}{0.07}}$
OB_{out}	out	$x = 0.01e^{\frac{y-0.44}{0.08}}$
OM1_{in}	in	$x = 0.15e^{\frac{y-1.43}{0.08}}$
OM1_{out}	out	$x = 0.005e^{\frac{y-1.38}{0.06}}$
TM_{in}	in	$x = 0.15e^{\frac{y-0.9}{0.18}}$
TM_{out}	out	$x = 0.18e^{\frac{y-1.02}{0.126}}$
River Mouth	both	$x = 0.34e^{\frac{y-0.86}{0.07}}$
RM3	both	$x = 1.11y$
RM2_{in}	in	$x = 16.67y - 9.59$

Table 2.3. Site-specific mean water flow per portion of tidal cycle (m^3/6 hrs). In parentheses is the relative magnitude of each flow rate, represented as percent of the total flux measured for all locations, during each tidal cycle. "River Mouth" represents water flow measured moving through the basin where He'eia Stream meets Kane'ohe Bay. "River" represents He'eia Stream water flow upstream of He'eia Fishpond. Negative values represent water flow out of He'eia Fishpond or into Kane'ohe Bay. See Table 1.2 and Figs. 1.7 and 1.9 for site descriptions and locations.

Site	Spring Flood	Spring Ebb	Neap Flood	Neap Ebb
OM2	**3,489** (1.22%)	**-3,135** (1.16%)	**3,674** (2.36%)	**-3,276** (2.04%)
OB	**35,884** (12.53%)	**-32,609** (12.11%)	**28,628** (18.40%)	**-20,382** (12.68%)
OM1	**106,330** (37.13%)	**-100,180** (37.21%)	**57,863** (37.20%)	**-54,550** (33.93%)
TM	**76,355** (26.66%)	**-71,333** (26.50%)	**41,807** (26.88%)	**-34,914** (21.72%)
RM3	**1,667** (0.58%)	**-18,903** (7.02%)	**1,849** (1.19%)	**-7,436** (4.63%)
RM2	**179** (0.06%)	**179** (0.06%)	**179** (0.16%)	**179** (0.11%)
Mākāhā Flow Rate Total	***223,904***	***-225,981***	***134,000***	***-120,379***
River Mouth	61,619 (21.51%)	-42,163 (15.66%)	20,678 (13.29%)	-39,327 (24.46%)
River	879 (0.31%)	879 (0.33%)	879 (0.57%)	879 (0.55%)

Table 2.4. Comparison of five significant rainfall events occurring at He‘eia Fishpond over the course of this study: Aug 01, 2007-Aug 31, 2008. "Baseline Mean" values were calculated over all days with rainfall below storm threshold during the study period.

Event Date	Daily Rainfall (cm)	Rainfall Over "Storm" Threshold (Y/N)	Days Prior of "Non-Storm" Weather	Ha‘iku Stream Discharge (m^3/day)	Actual Sample Date	Tide	Wind Direction (deg)	Wind Magnitude (m^3/sec)
11/04/07 Storm 1	14.63	Y	223	63,610	11/05/07	Neap Flood	156 (SSE)	3.13
12/07/07 Storm 2	8.23	Y	33	46,485	12/09/07	Spring Ebb	202 (SSW)	4.56
12/31/07 Storm 3	5.97	Y	24	41,591	N/A	N/A	354 (NNW)	6.12
05/21/08	4.93	N	141	5,382	N/A	N/A	096 (ESE)	1.94
06/12/08 Storm 4	6.05	Y	22	59,695	06/14/08	Neap Flood	208 (SSW)	3.14
Baseline Mean	0.34	N/A	N/A	3,579	N/A	N/A	067 (ENE)	5.36

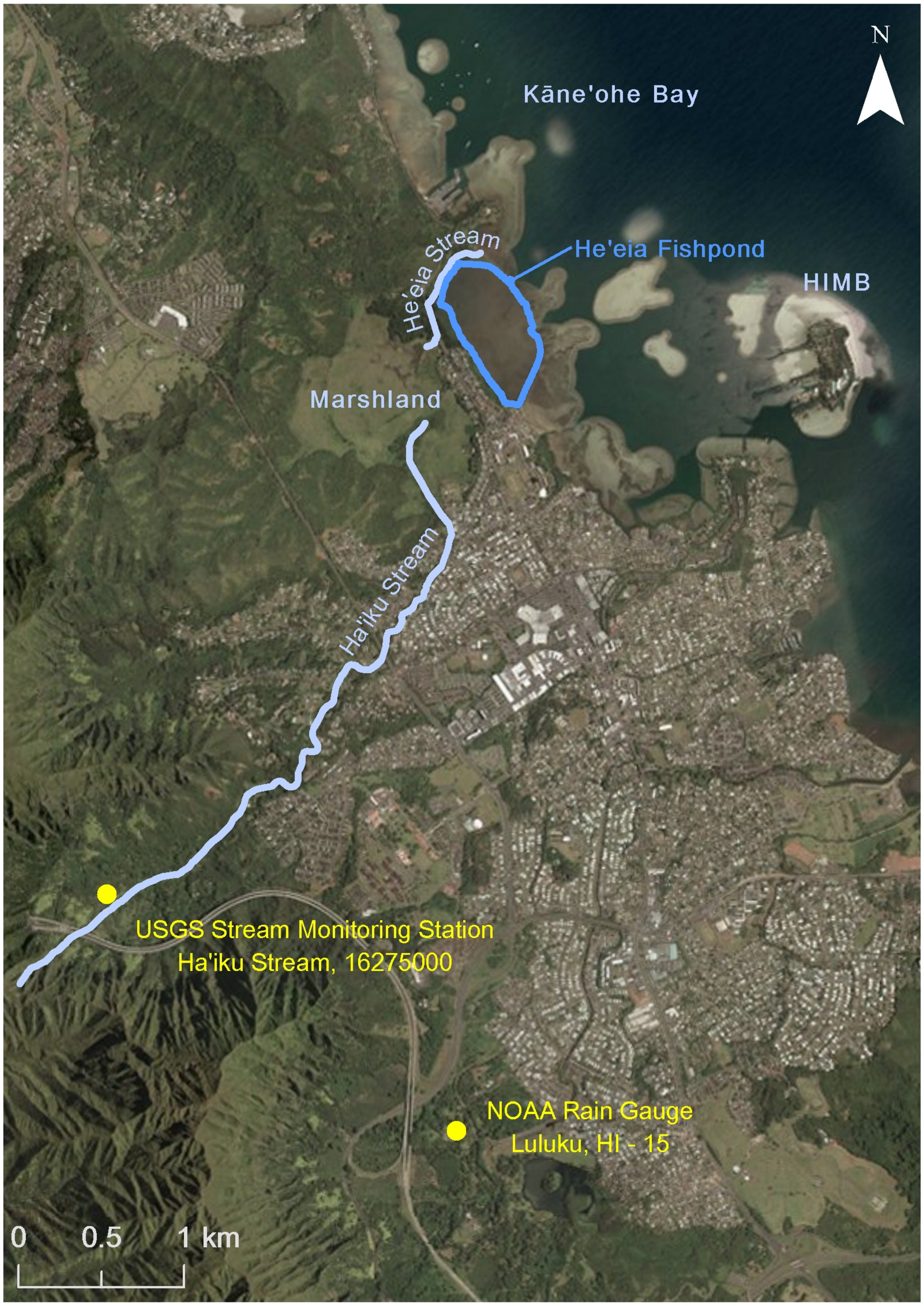


Figure 2.1. He‘eia Fishpond watershed and locations of the USGS monitoring station where daily stream flow data was collected (USGS Stream Monitoring Station 16275000), the NOAA rain gauge where rainfall data was collected (NOAA Rain Gauge HI-15), and the Hawai‘i Institute of Marine Biology where wind direction, wind magnitude, and solar radiation data were collected.

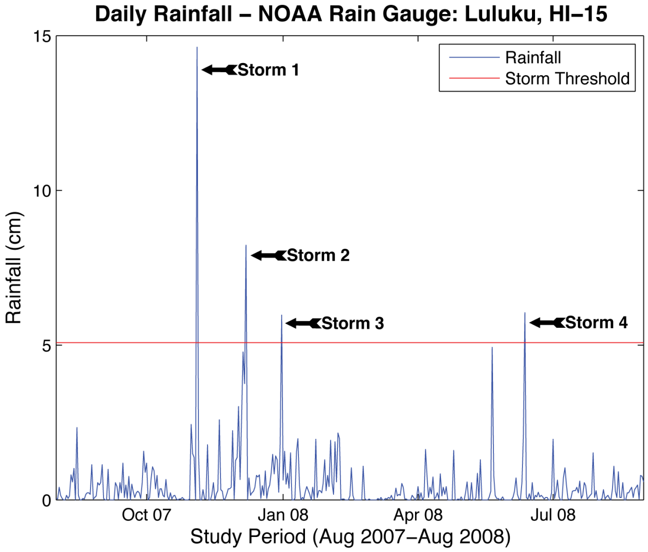


Figure 2.2. Daily rainfall measured at the Luluku rain gauge station (NOAA Rain Gauge HI-15) over the course of this study: Aug 01, 2007-Aug 31, 2008. Storm events, defined as > 5.08 cm of rainfall in 24 hrs, are annotated. 5.08 cm of rainfall is identified by the red horizontal line and labeled as "Storm Threshold" in the legend.

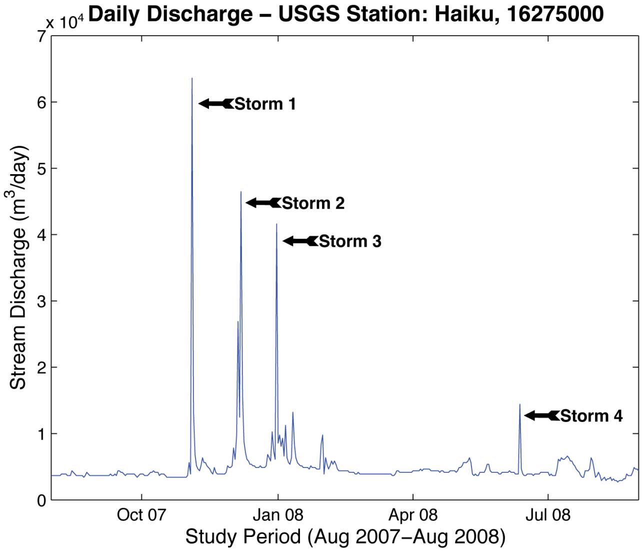


Figure 2.3. Daily stream discharge measured at the Ha‘iku Stream monitoring station (USGS Station 16275000), over the course of this study: Aug 01, 2007-Aug 31, 2008. Associated storm events, as defined by 5.08 cm of rainfall in 24 hrs, are annotated.

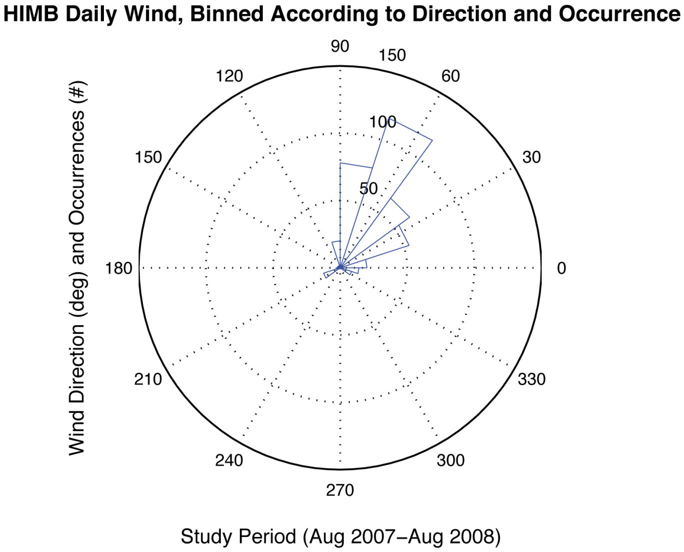


Figure 2.4. Daily wind direction measured at the HIMB monitoring station over the course of this study: Aug 01, 2007-Aug 31, 2008. The rose depicts wind direction binned in 18-degree intervals on the compass; counts reflect the number of occurrences of each wind direction bin from the center.

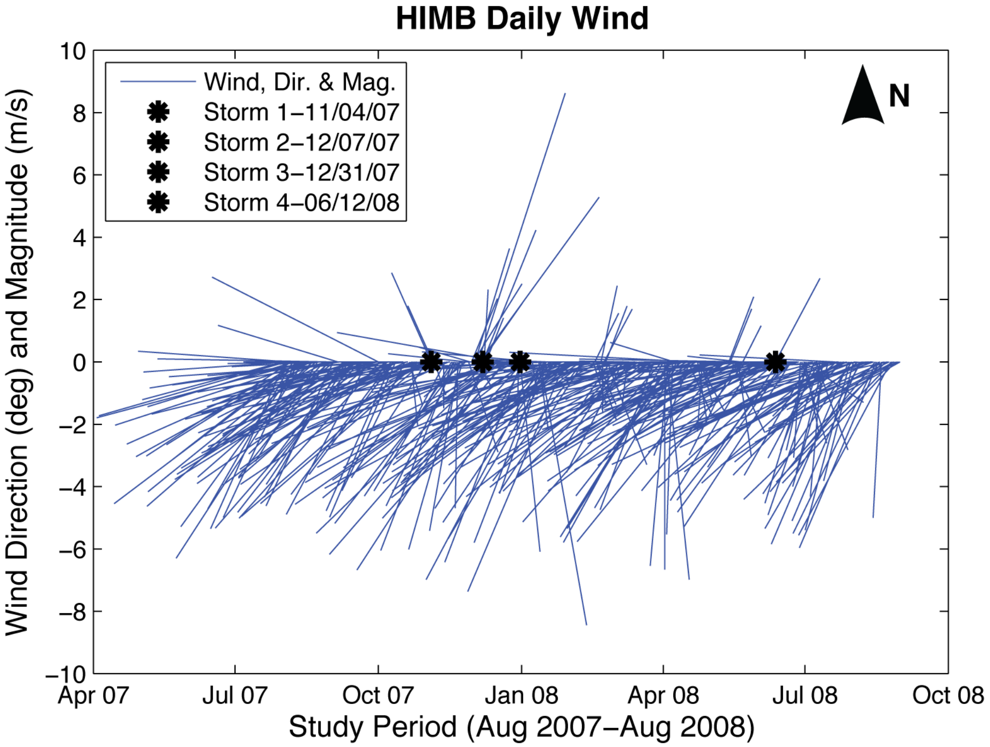


Figure 2.5. Daily wind direction and magnitude measured at the HIMB monitoring station over the course of this study: Aug 01, 2007-Aug 31, 2008. The stick line angle depicts wind direction on the compass and stick line length is relative wind magnitude.

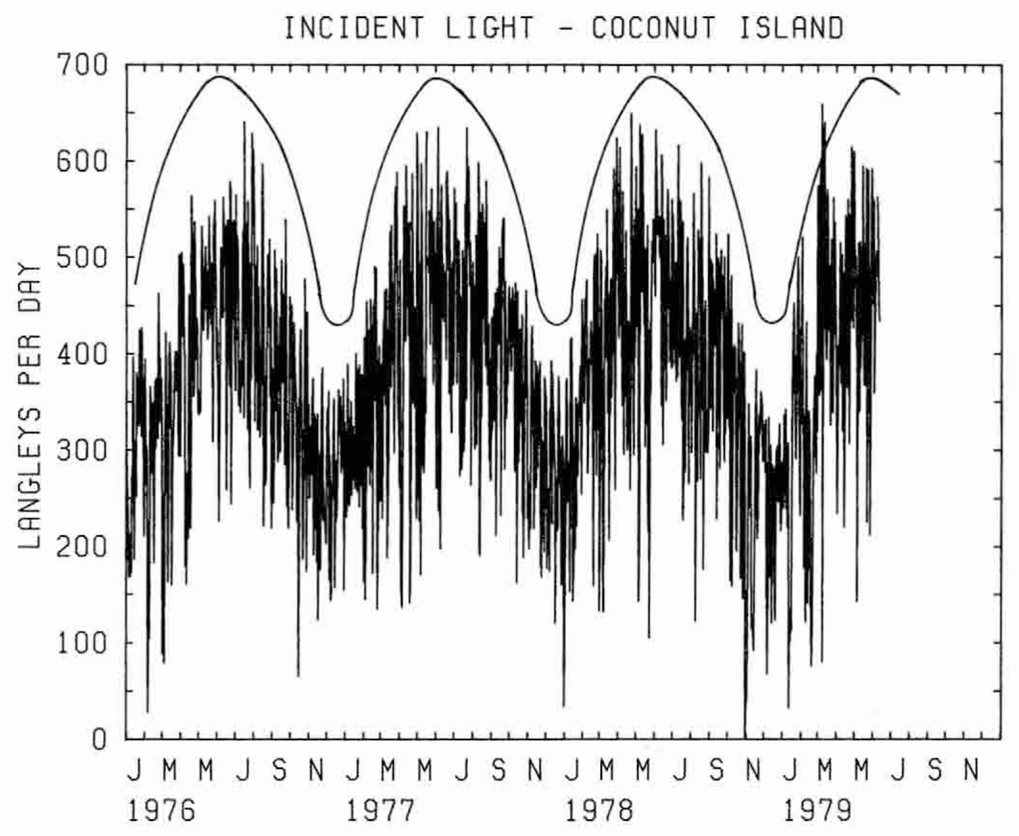


Figure 2.6. Daily solar radiation measured at HIMB from 1976-1979. Y-axis units are Langleys/day (cal/cm^2/day). Modified from Smith et al. (1981). A complete data set of solar radiation data during this study period was not available.

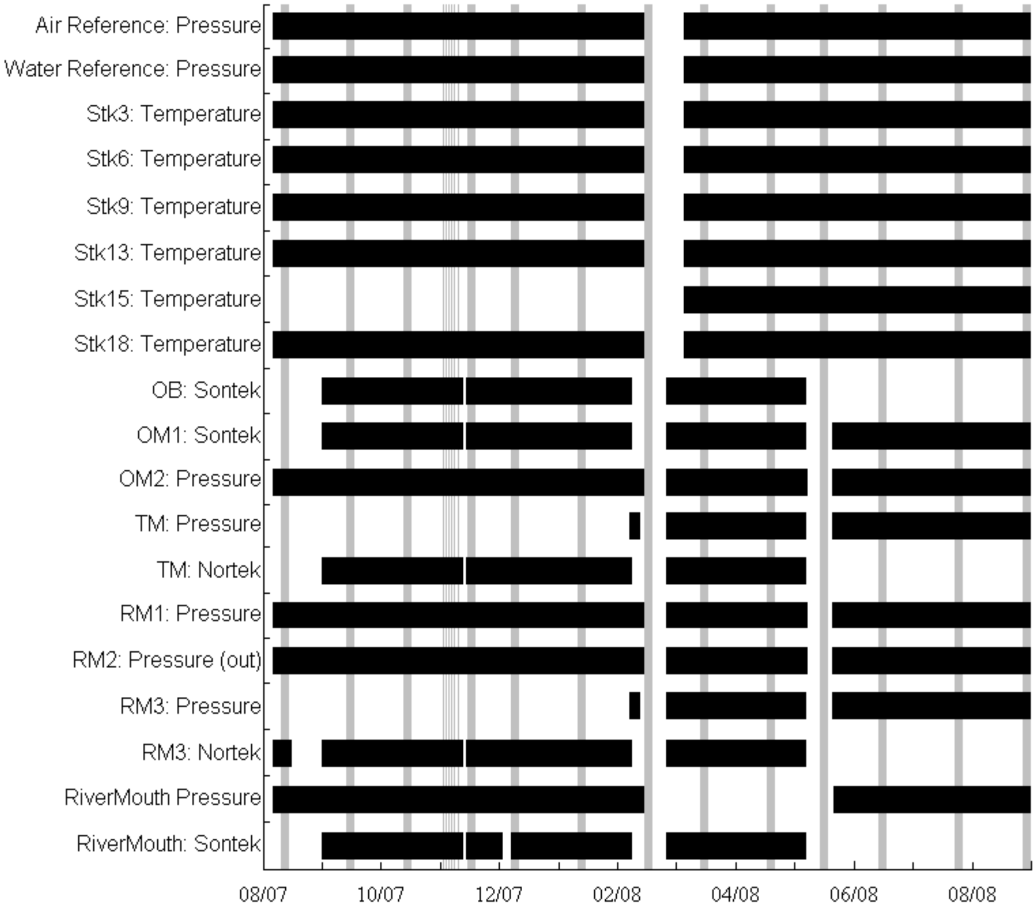


Figure 2.7. Site location and type of instrument deployed over the course of this study: Aug 01, 2007-Aug 31, 2008. See Figure 1.10 for site locations and Table 1.2 for site name abbreviations.

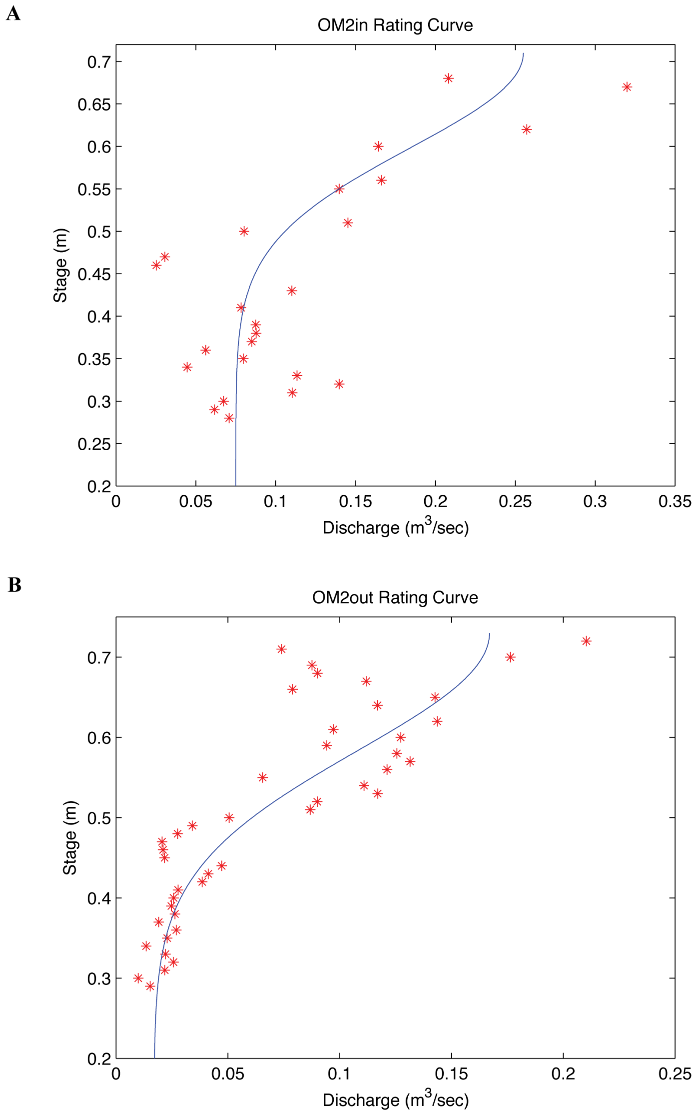


Figure 2.8. Rating curves for OM2 water flow (A) into and (B) out of He‘eia Fishpond. Note the different discharge (m^3/sec) scales on the x-axes.

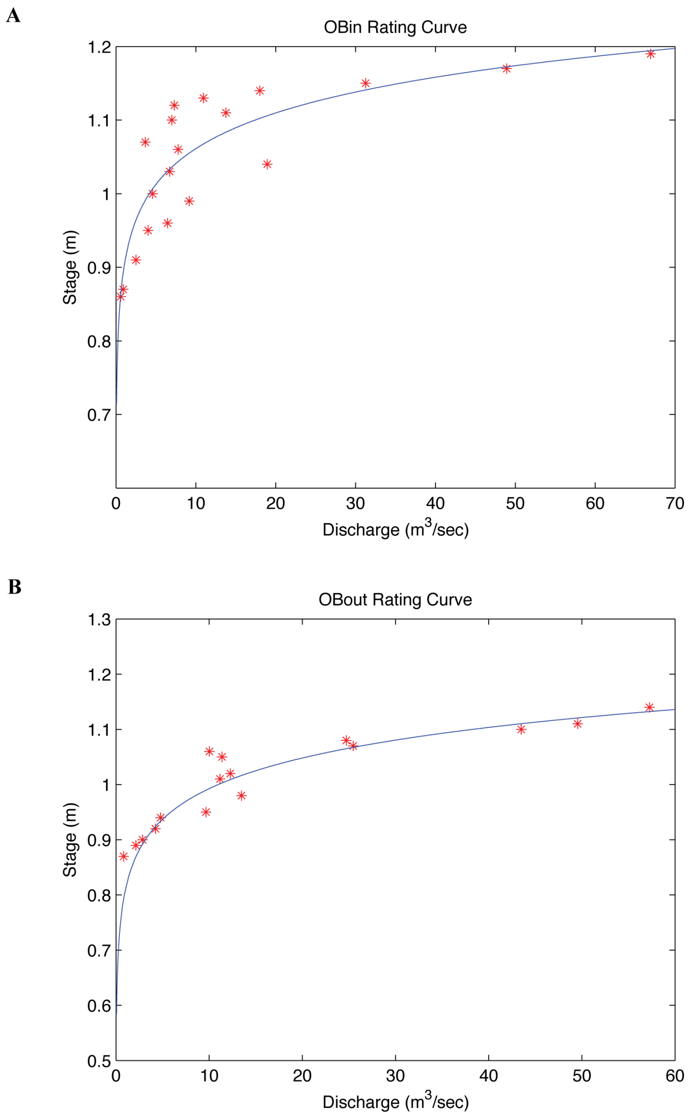


Figure 2.9. Rating curves for OB water flow (A) into and (B) out of He‘eia Fishpond. Note the different discharge (m^3/sec) scales on the x-axes.

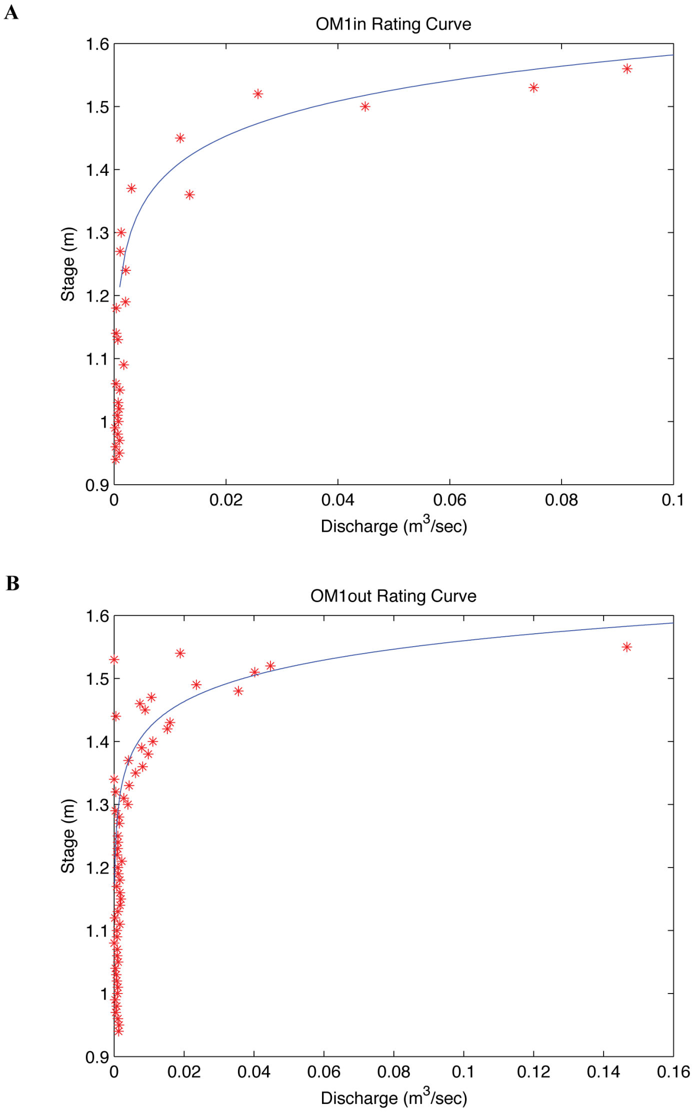


Figure 2.10. Rating curves for OM1 water flow (A) into and (B) out of He‘eia Fishpond. Note the different discharge (m^3/sec) scales on the x-axes.

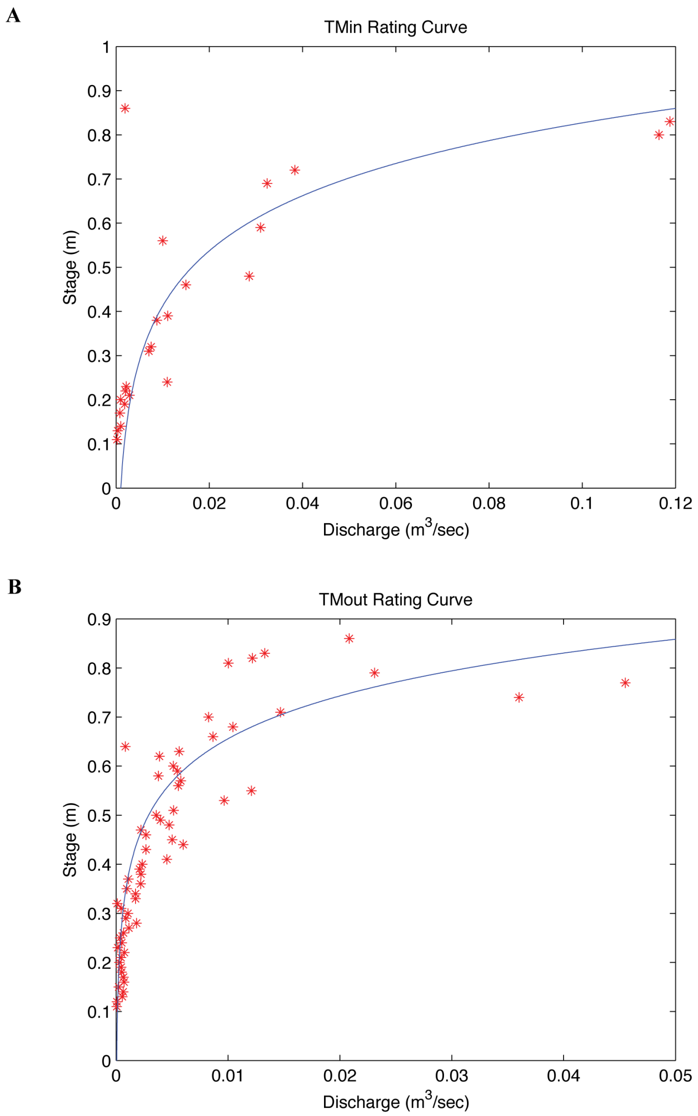


Figure 2.11. Rating curves for TM water flow (A) into and (B) out of He‘eia Fishpond. Note the different discharge (m^3/sec) scales on the x-axes.

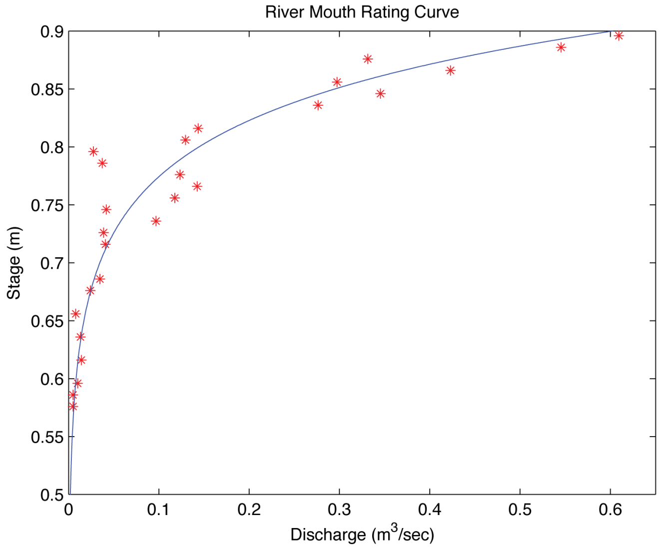


Figure 2.12. A single rating curve for River Mouth (He‘eia Stream) water flow upstream and downstream, as dictated by tidal activity.

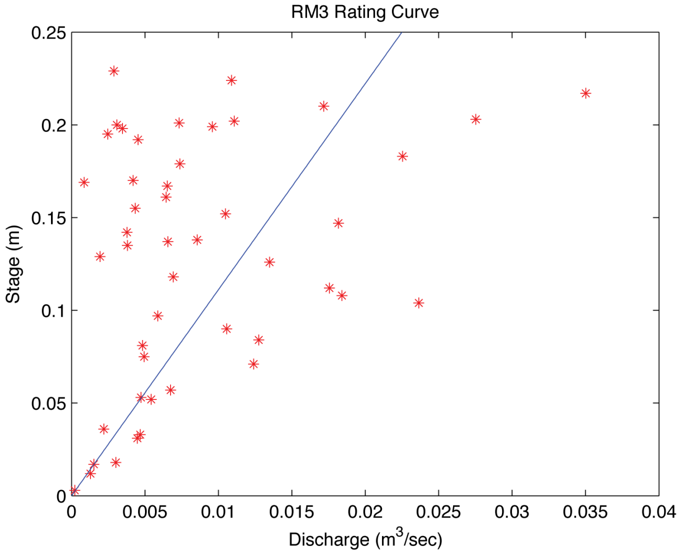


Figure 2.13. A single rating curve for RM3 water flow into and out of He‘eia Fishpond.

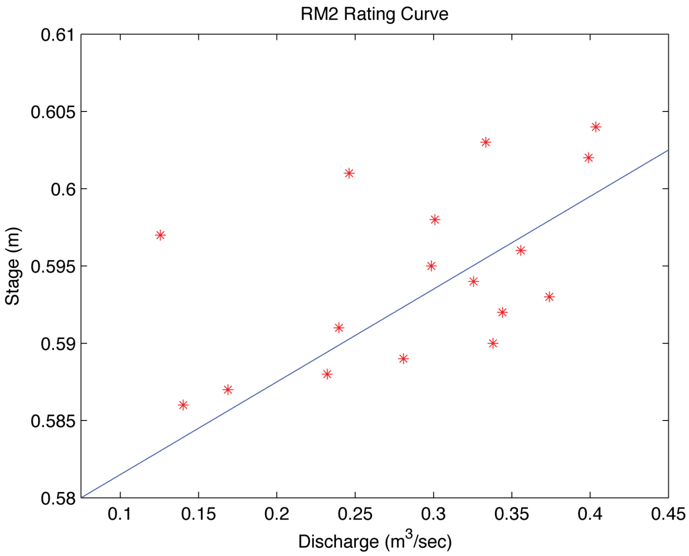


Figure 2.14. A single rating curve for RM2 water flow into He‘eia Fishpond only.

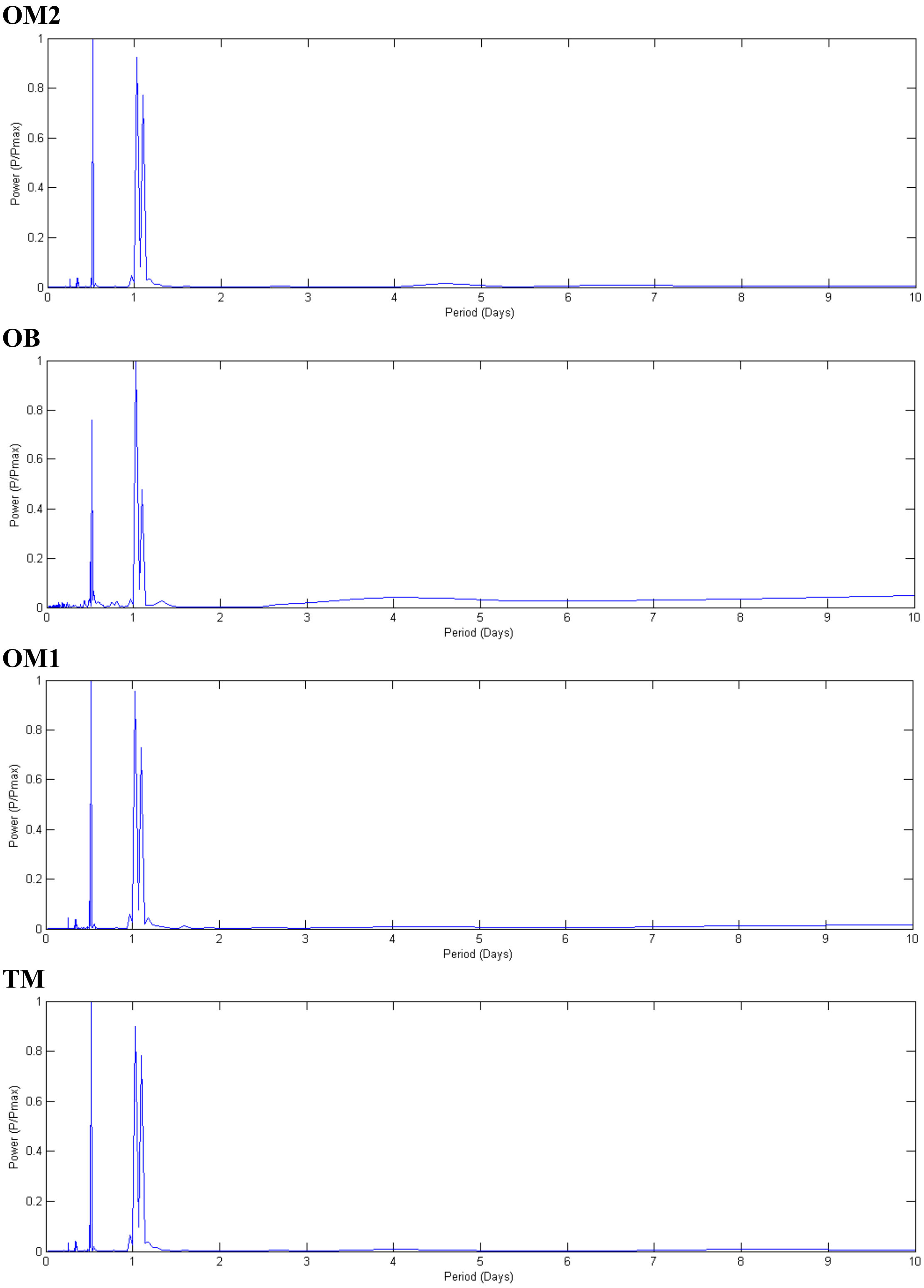
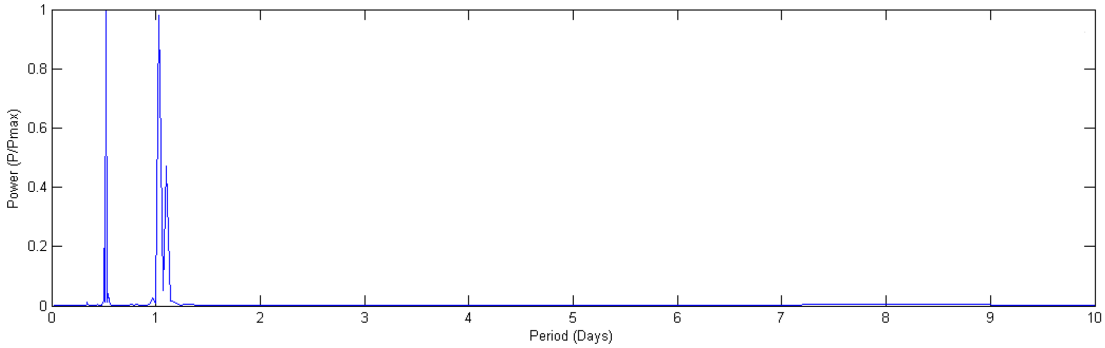
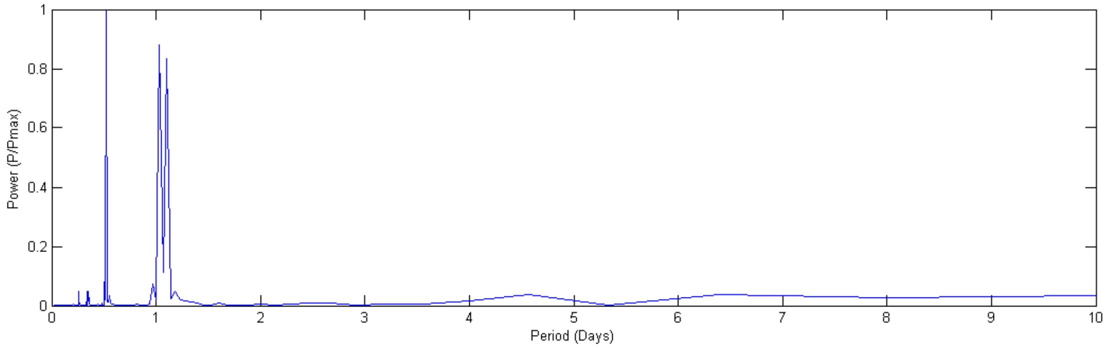


Figure 2.15. Spectral analysis of tidal activity for He‘eia Fishpond mākāhā that open directly into Kane‘ohe Bay (see discussion in text for identification of peaks).

River Mouth



RM3



RM1

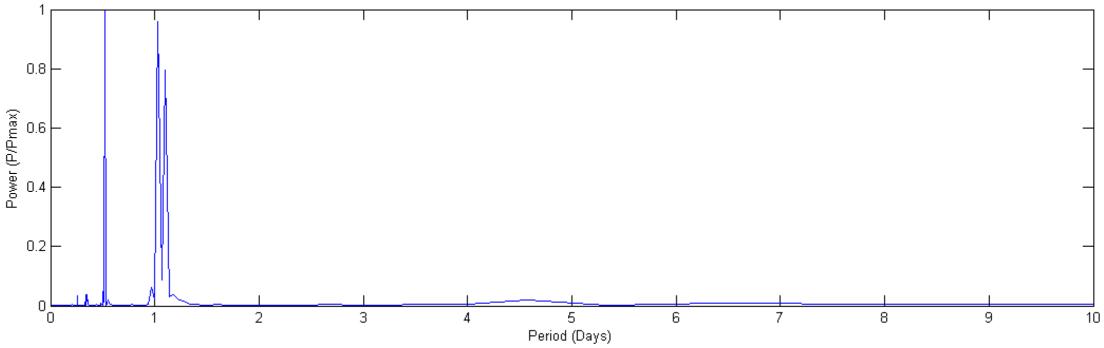


Figure 2.16. Spectral analysis of tidal activity for the He‘eia Stream mouth (River Mouth), the tidally influenced RM3, and the estimated position for RM1 within He‘eia Fishpond (see discussion in text for identification of peaks).

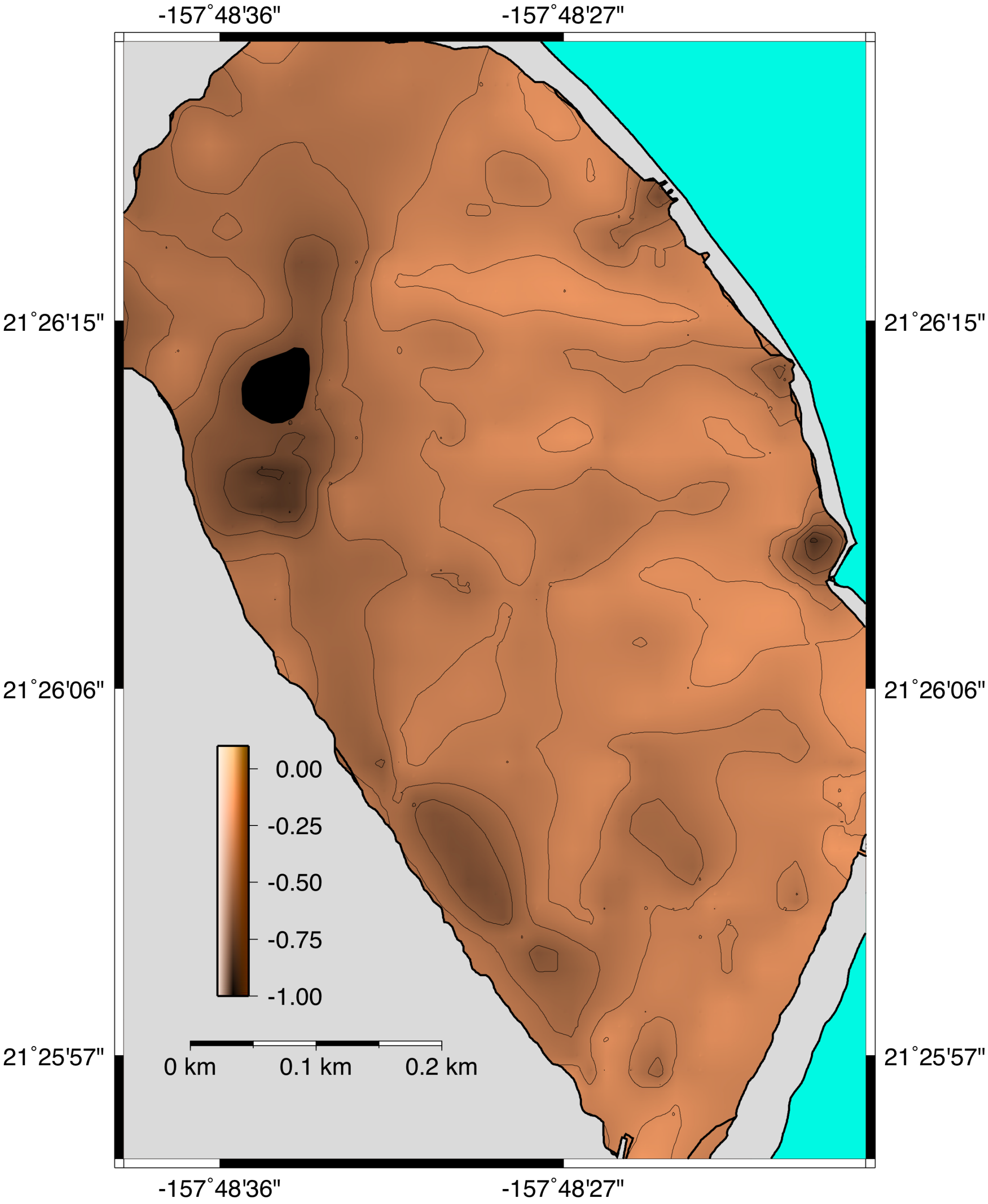


Figure 2.17. He‘eia Fishpond bathymetry map. Seafloor contour color scale in negative meters from mean. Latitude = North degrees; -Longitude = West degrees. Small island in NW corner of He‘eia Fishpond is shown as a black ovoid shape.

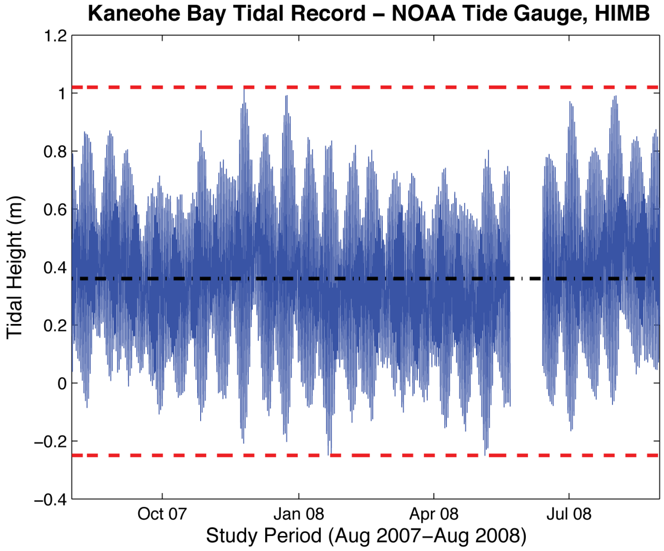


Figure 2.18. Tidal range measured at Hawaiʻi Institute of Marine Biology (HIMB) on Moku o Loʻe (Coconut Island), Kaneʻohe Bay, Oʻahu. Tide gauge maintained by NOAA, with a lapse in data 05/22/08-06/13/08. Red dashed lines indicate annual tidal range and black dashed line indicates annual mean tide.

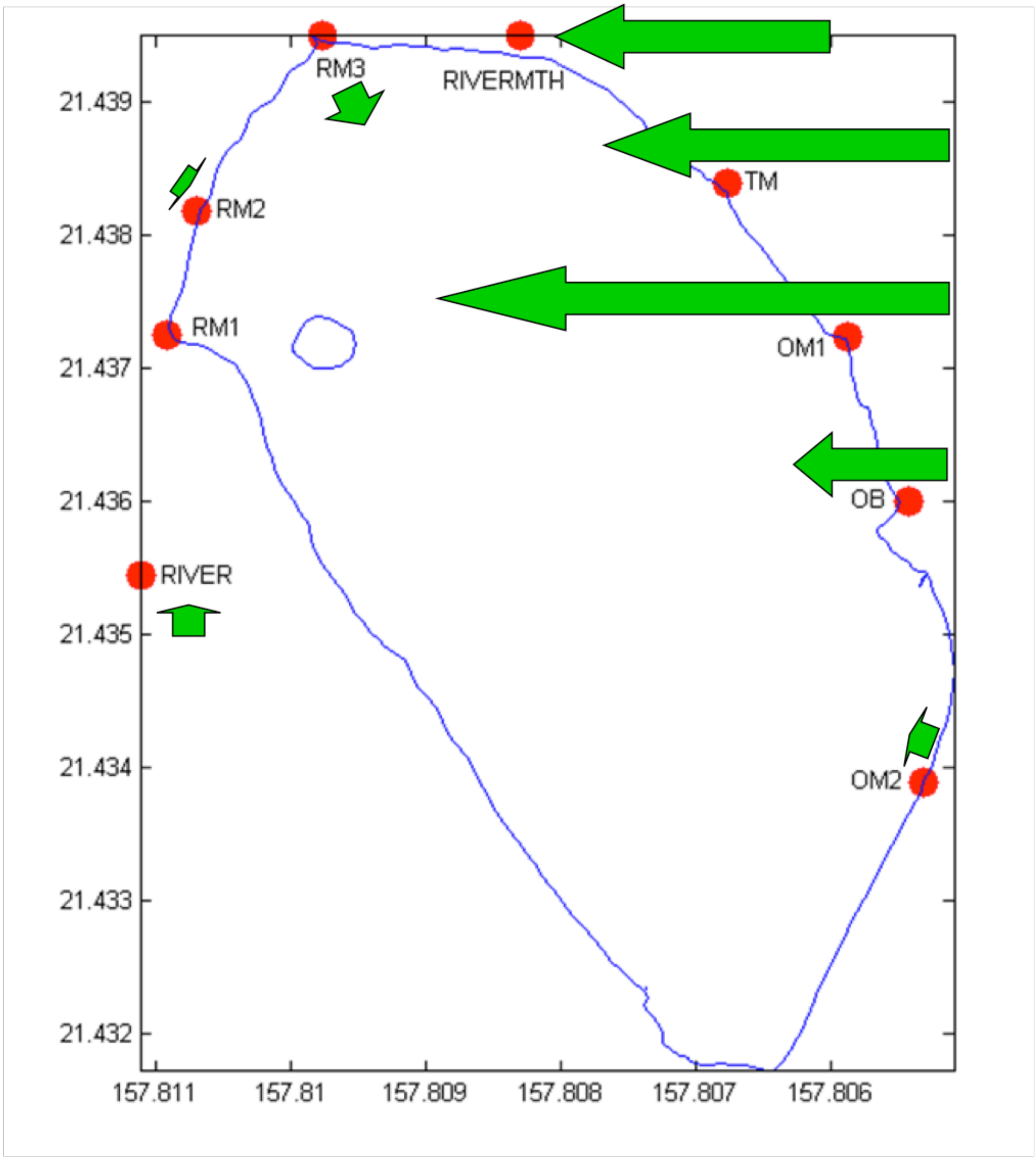


Figure 2.19. Relative water flow through each mākāhā during a spring flood tide. Arrow length is a visual representation of relative magnitude of water flux at each individual location, normalized to the total Spring Flood flux outlined in Table 2.3. Filled red circles indicate locations of mākāhā (Table 1.2, Fig. 1.9).

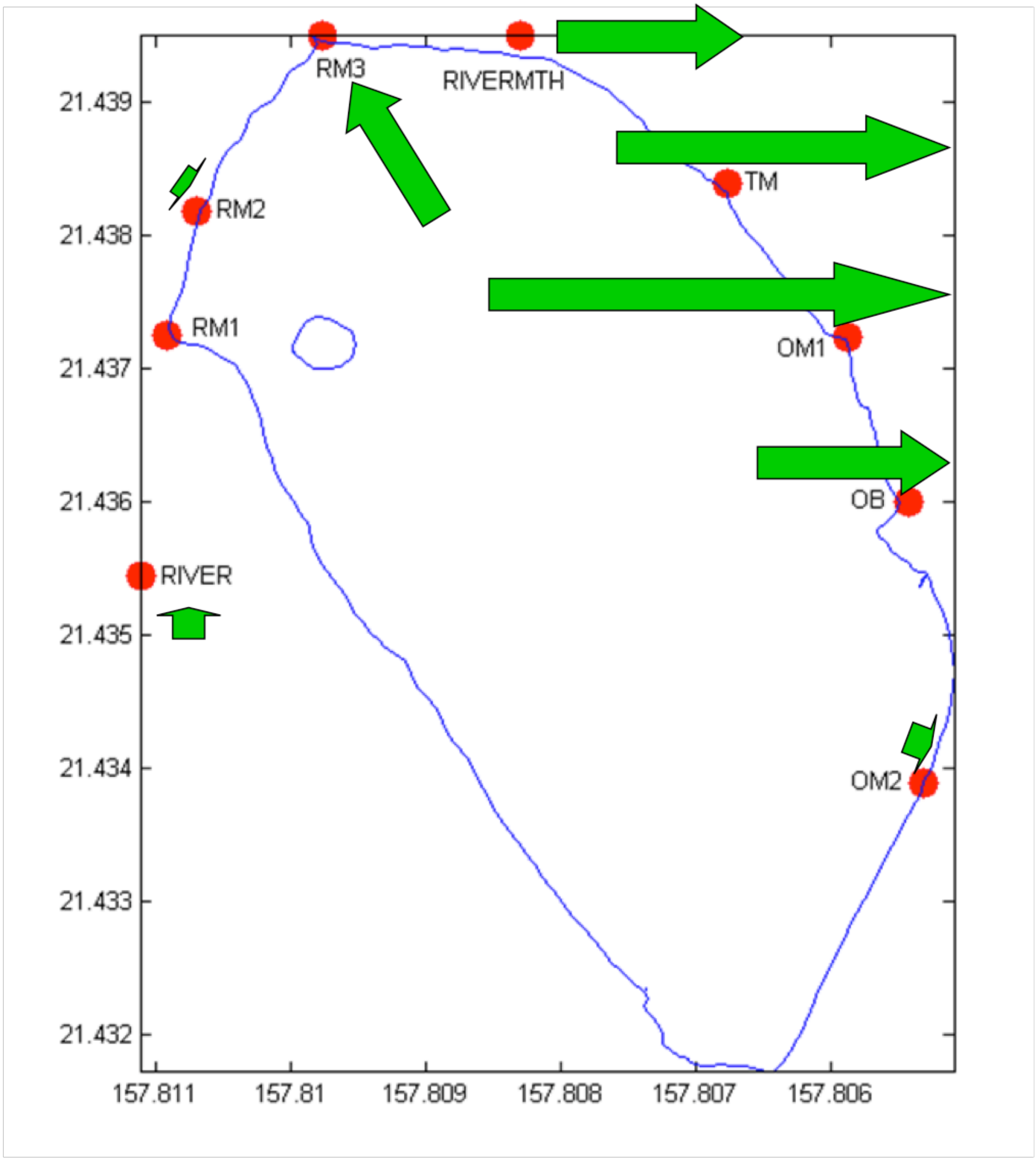


Figure 2.20. Relative water flow through each mākāhā during a spring ebb tide. Arrow length is a visual representation of relative magnitude of water flux at each individual location, normalized to the total Spring Ebb flux outlined in Table 2.3. Filled red circles indicate locations of mākāhā (Table 1.2, Fig. 1.9).

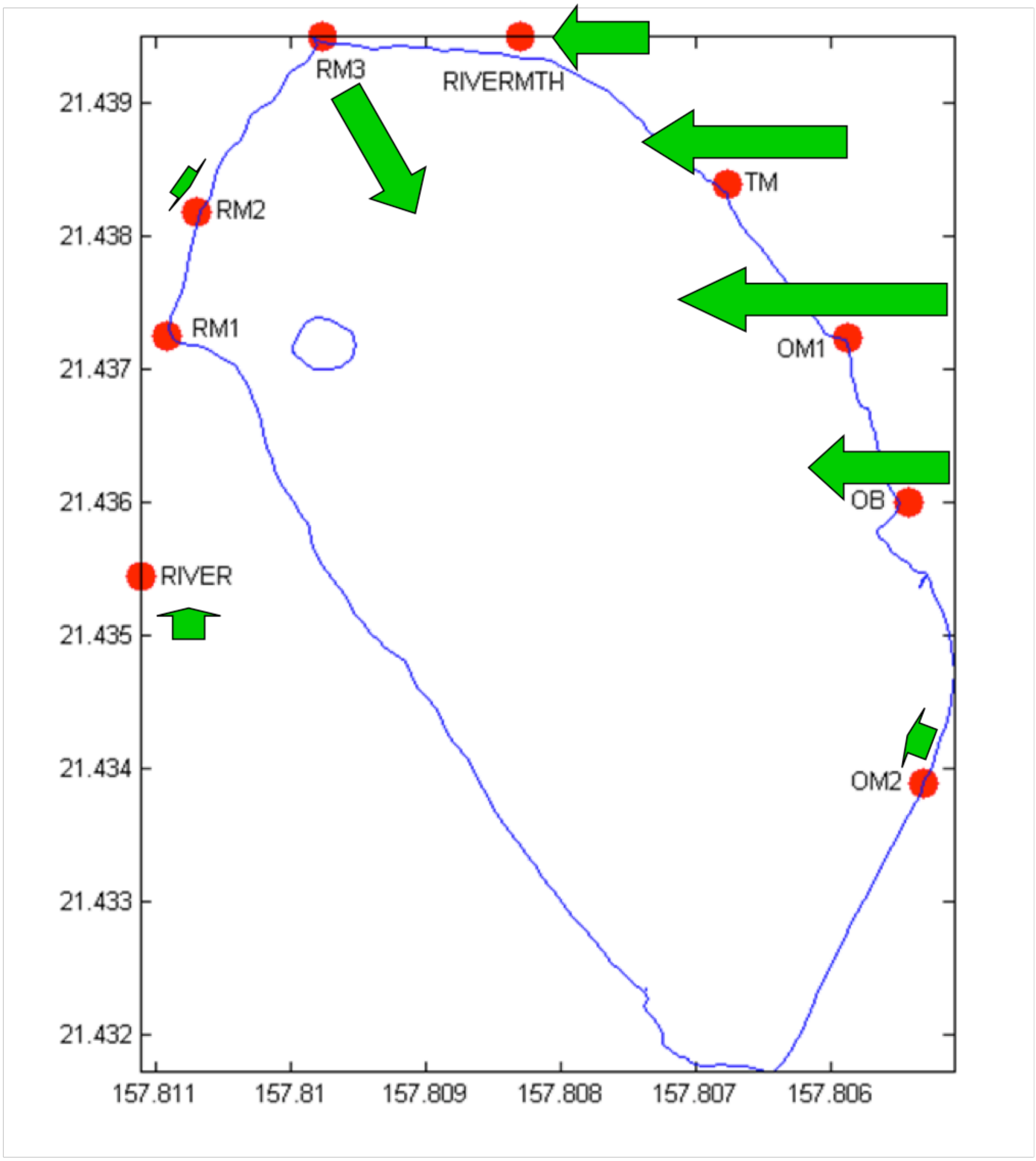


Figure 2.21. Relative water flow through each mākāhā during a neap flood tide. Arrow length is a visual representation of relative magnitude of water flux at each individual location, normalized to the total Neap Flood flux outlined in Table 2.3. Filled red circles indicate locations of mākāhā (Table 1.2, Fig. 1.9).

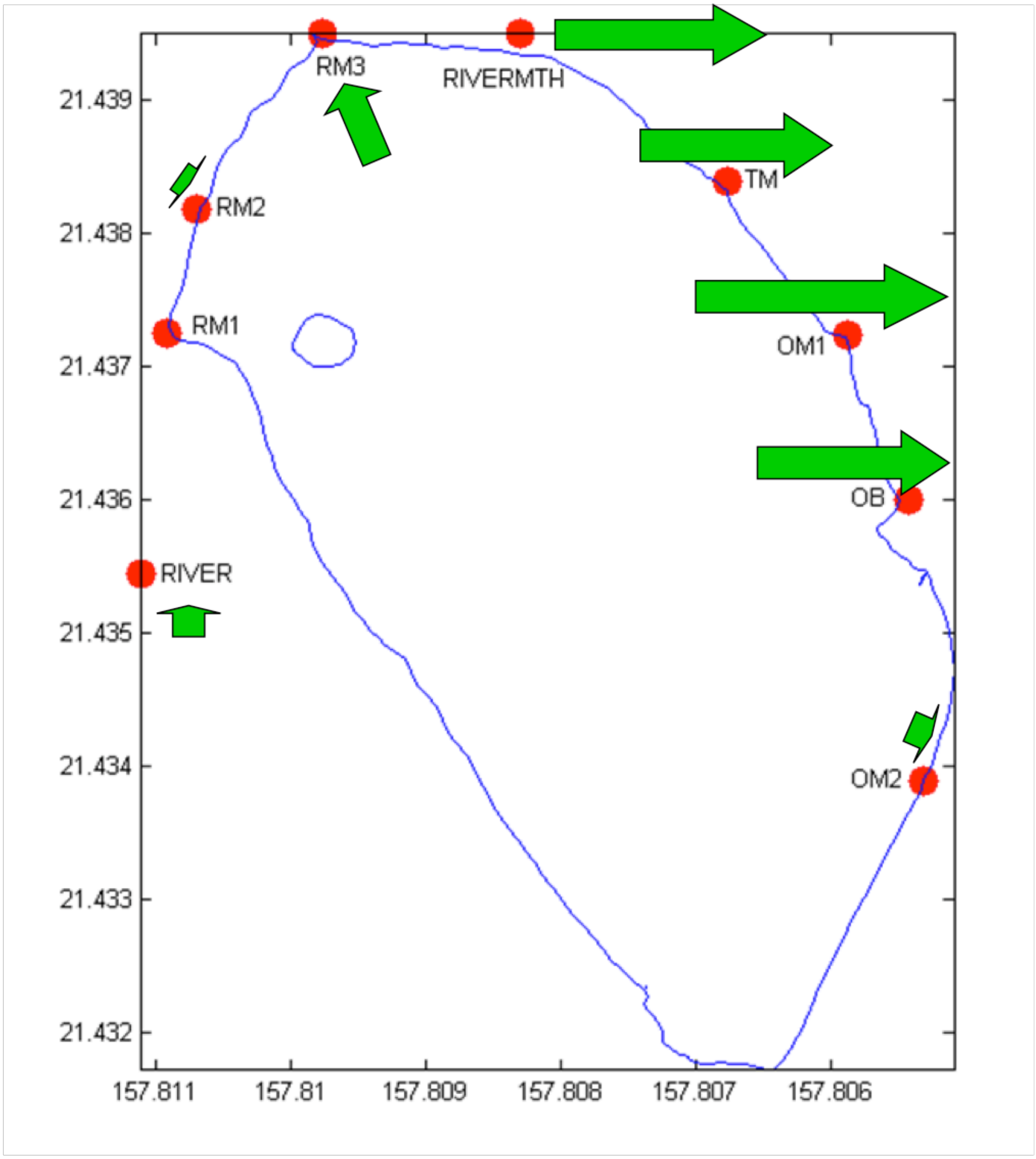


Figure 2.22. Relative water flow through each mākāhā during a neap ebb tide. Arrow length is a visual representation of relative magnitude of water flux at each individual location, normalized to the total Neap Ebb flux outlined in Table 2.3. Filled red circles indicate locations of mākāhā (Table 1.2, Fig. 1.9).

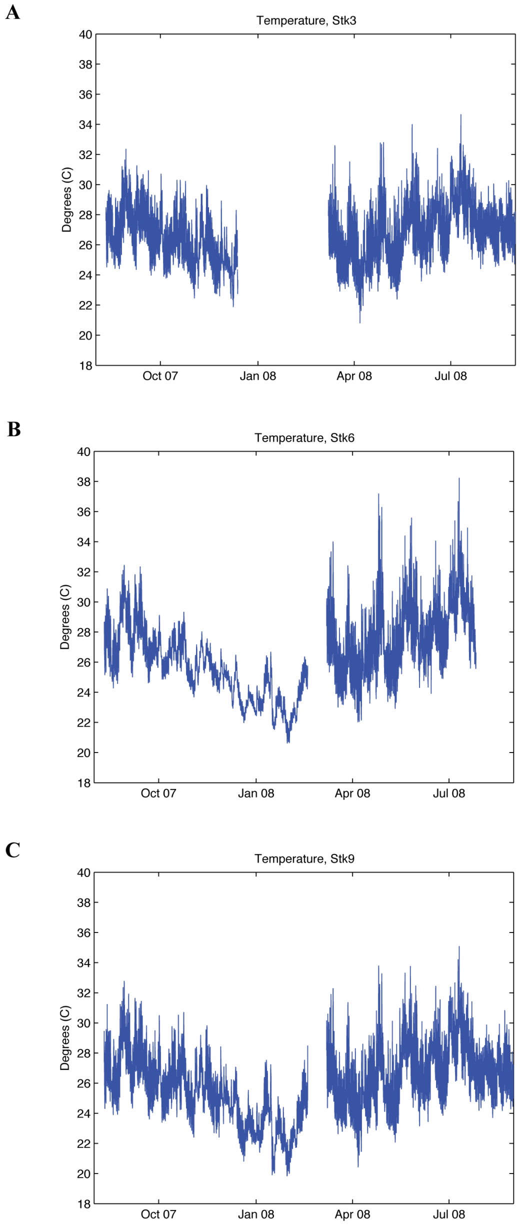


Figure 2.23. Onset Corporation TidBit v2 temperature measured at sites most distal from land, (A) Stk3, (B) Stk6, and (C) Stk9 over the course of this study: Aug 01, 2007-Aug 31, 2008.

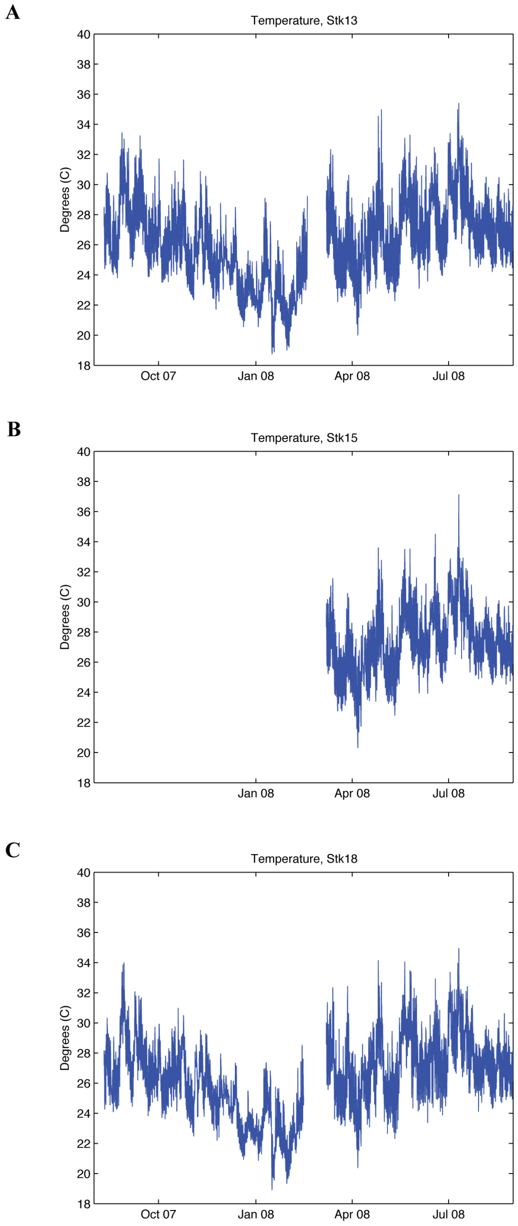


Figure 2.24. Onset Corporation TidBit v2 temperature measured at sites most proximal to land, (A) Stk13, (B) Stk15, and (C) Stk18 over the course of this study: Aug 01, 2007-Aug 31, 2008.

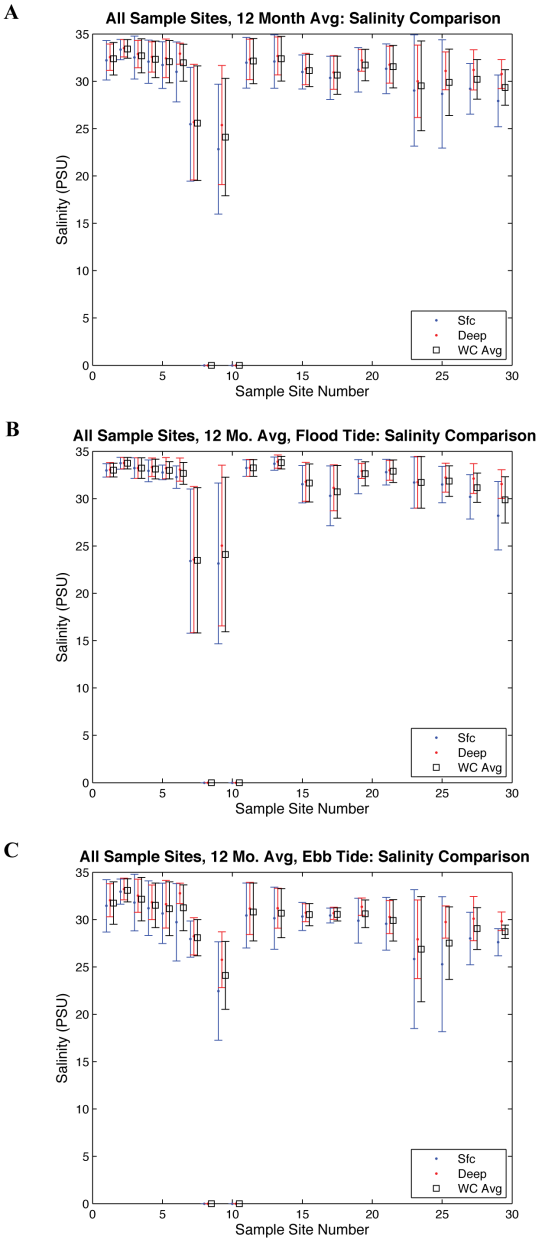


Figure 2.25. Mean baseline YSI sonde water column salinity values with standard deviations for all sample sites over the course of this study, Aug 01, 2007-Aug 31, 2008: (A) entire data set (n = 12), (B) flood tide data (n = 6), and (C) ebb tide data (n = 6). Baseline data are for sample dates characterized by rainfall less than the storm threshold, defined as < 5.08 cm rain/24 hrs. Sample site number: (1) OM2, (2) OCN2, (3) OB, (4) OM1, (5) TM, (6) OCN1, (7) RM3, (8) RM3, (9) RM3, (10) River, (11) Stk1, (13) Stk3, (15) Stk6, (17) Stk7, (19) Stk8, (21) Stk9, (23) Stk13, (25) Stk15, (27) Stk16, (29) Stk18.

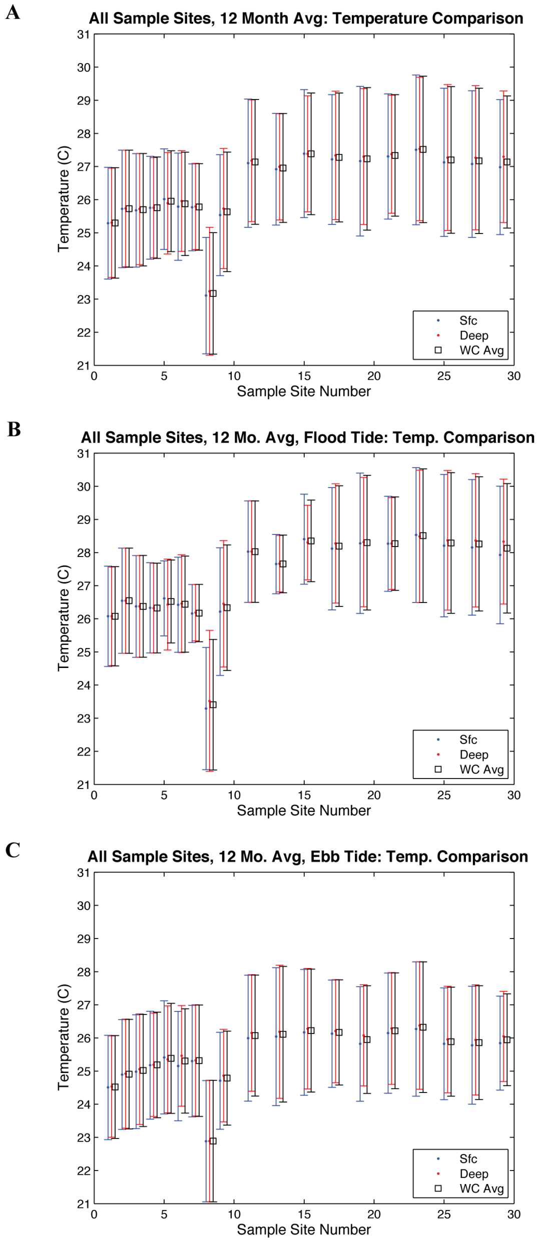


Figure 2.26. Mean baseline YSI sonde water column temperature values with standard deviations for all sample sites over the course of this study, Aug 01, 2007-Aug 31, 2008: (A) entire data set (n = 12), (B) flood tide data (n = 6), and (C) ebb tide data (n = 6). Baseline data are for sample dates characterized by rainfall less than the storm threshold, defined as < 5.08 cm rain/24 hrs. Sample site number: (1) OM2, (2) OCN2, (3) OB, (4) OM1, (5) TM, (6) OCN1, (7) RM3, (8) RM3, (9) RM3, (10) River, (11) Stk1, (13) Stk3, (15) Stk6, (17) Stk7, (19) Stk8, (21) Stk9, (23) Stk13, (25) Stk15, (27) Stk16, (29) Stk18.

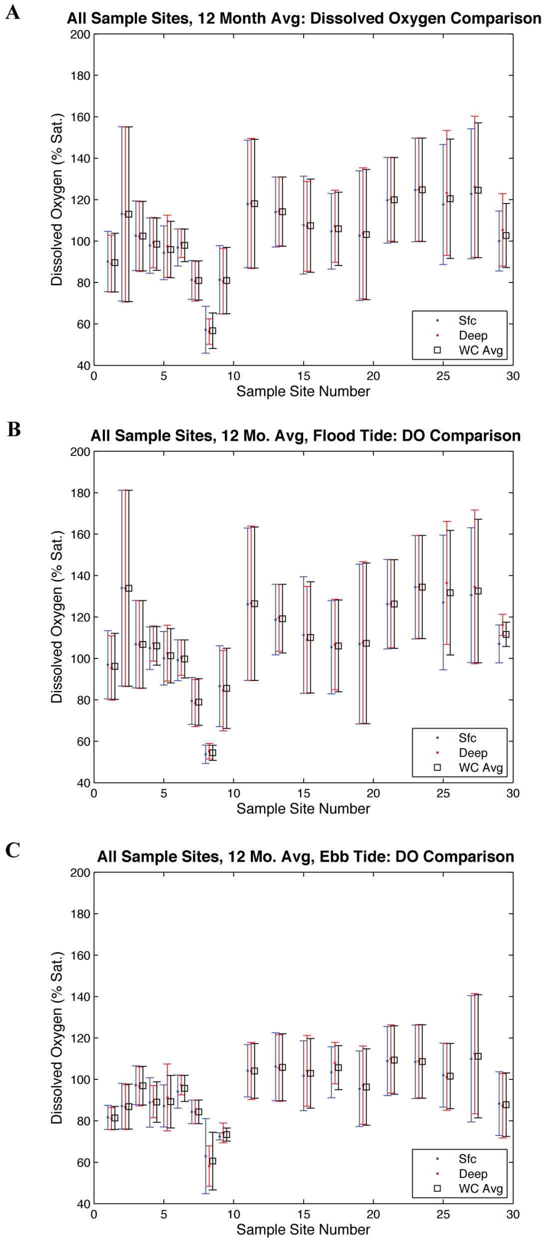


Figure 2.27. Mean baseline YSI sonde water column % DO values with standard deviations for all sample sites over the course of this study, Aug 01, 2007-Aug 31, 2008: (A) entire data set (n = 12), (B) flood tide data (n = 6), and (C) ebb tide data (n = 6). Baseline data are for sample dates characterized by rainfall less than the storm threshold, defined as < 5.08 cm rain/24 hrs. Sample site number: (1) OM2, (2) OCN2, (3) OB, (4) OM1, (5) TM, (6) OCN1, (7) RM3, (8) RM3, (9) RM3, (10) River, (11) Stk1, (13) Stk3, (15) Stk6, (17) Stk7, (19) Stk8, (21) Stk9, (23) Stk13, (25) Stk15, (27) Stk16, (29) Stk18.

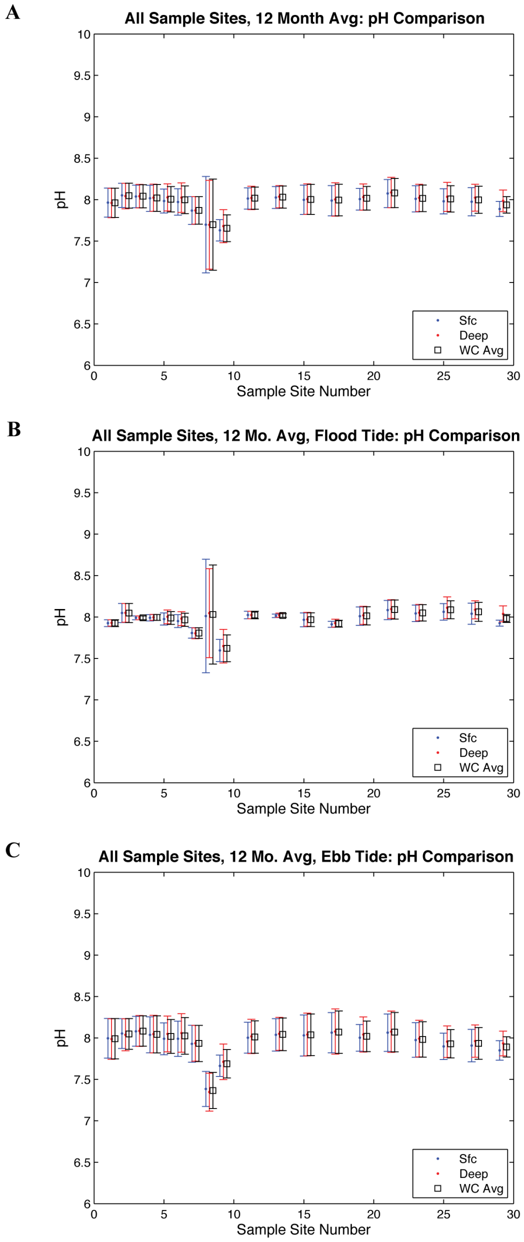


Figure 2.28. Mean baseline YSI sonde water column pH values with standard deviations for all sample sites over the course of this study, Aug 01, 2007-Aug 31, 2008: (A) entire data set (n = 12), (B) flood tide data (n = 6), and (C) ebb tide data (n = 6). Baseline data are for sample dates characterized by rainfall less than the storm threshold, defined as < 5.08 cm rain/24 hrs. Sample site number: (1) OM2, (2) OCN2, (3) OB, (4) OM1, (5) TM, (6) OCN1, (7) RM3, (8) RM3, (9) RM3, (10) River, (11) Stk1, (13) Stk3, (15) Stk6, (17) Stk7, (19) Stk8, (21) Stk9, (23) Stk13, (25) Stk15, (27) Stk16, (29) Stk18.

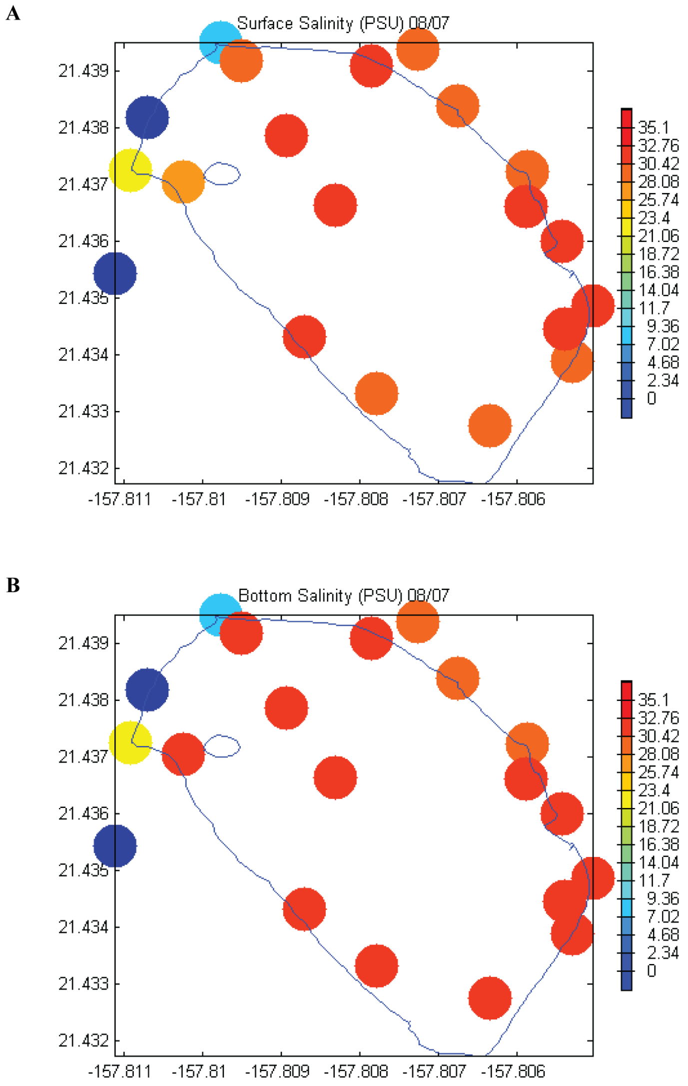


Figure 2.29. Sample site mean (A) surface and (B) deep salinity (PSU) values for the 08/11/07 monthly sampling event. Site locations are geo-referenced to the He‘eia Fishpond perimeter outlined in blue. He‘eia Stream is located to the northwest and Kane‘ohe Bay to the east (see Table 1.2 and Figs. 1.7 and 1.9 for sample site names and locations).

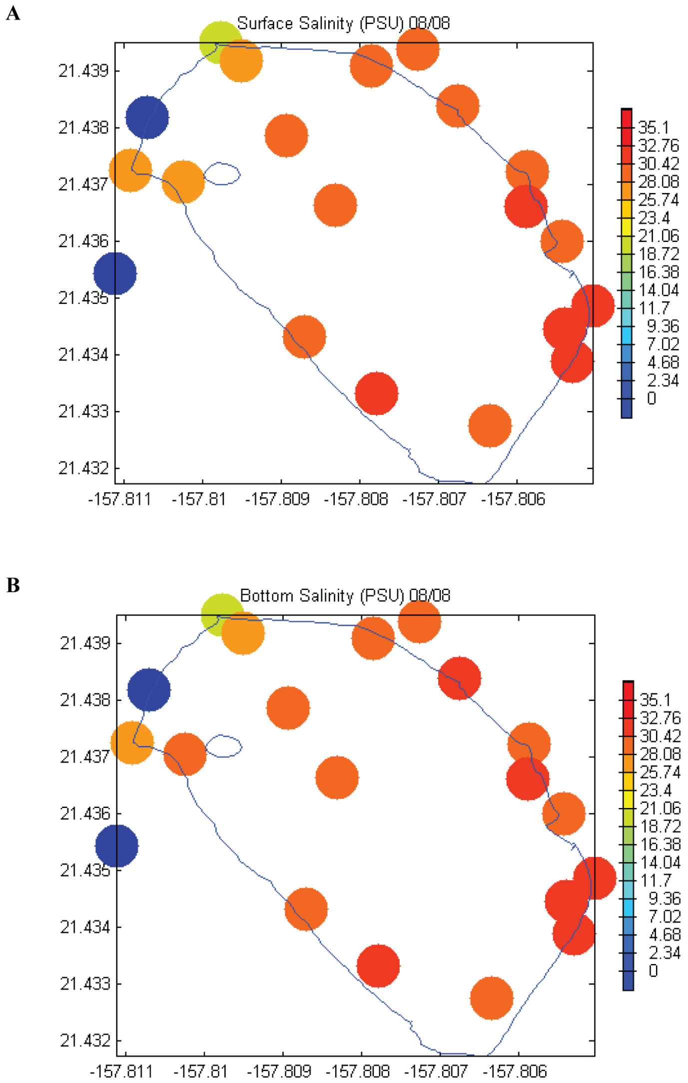


Figure 2.30. Sample site mean (A) surface and (B) deep salinity (PSU) values for the 08/30/08 monthly sampling event. Site locations are geo-referenced to the He‘eia Fishpond perimeter outlined in blue. He‘eia Stream is located to the northwest and Kane‘ohe Bay to the east (see Table 1.2 and Figs. 1.7 and 1.9 for sample site names and locations).

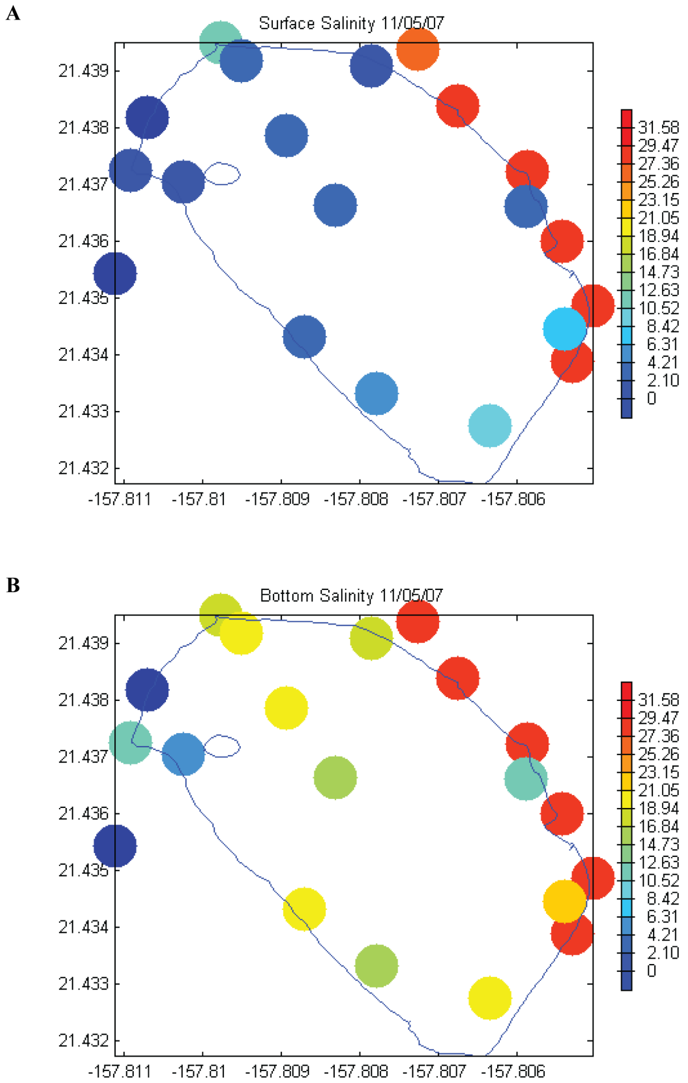


Figure 2.31. Sample site mean (A) surface and (B) deep salinity (PSU) values for the 11/05/07, Storm 1, sampling event. Site locations are geo-referenced to the He‘eia Fishpond perimeter outlined in blue. He‘eia Stream is located to the northwest and Kane‘ohe Bay to the east (see Table 1.2 and Figs. 1.7 and 1.9 for sample site names and locations).

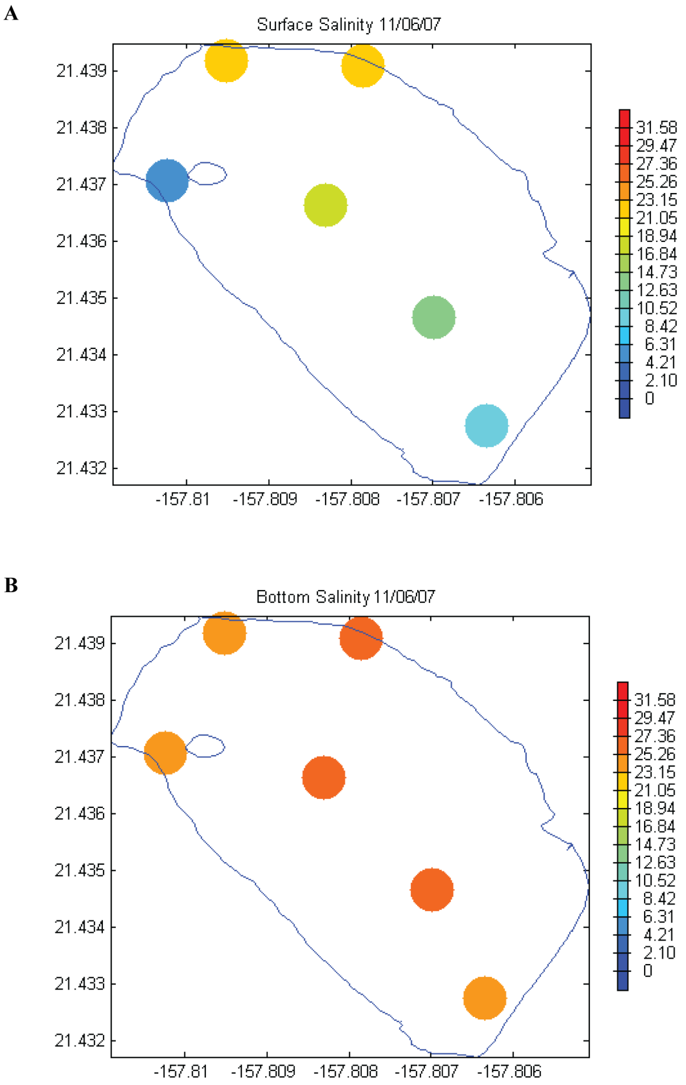
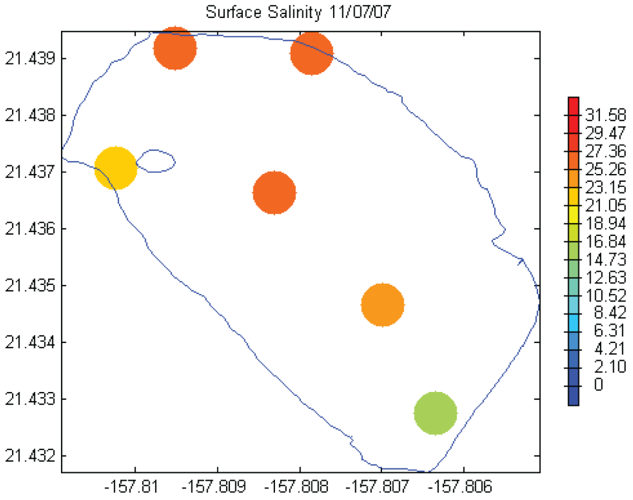


Figure 2.32. Sample site mean (A) surface and (B) deep salinity (PSU) values for the 11/06/07, Storm 1-Transect 1, sampling event. Site locations are geo-referenced to the He‘eia Fishpond perimeter outlined in blue. He‘eia Stream is located to the northwest and Kane‘ohe Bay to the east (see Table 1.2 and Fig. 1.8 for sample site names and locations).

A



B

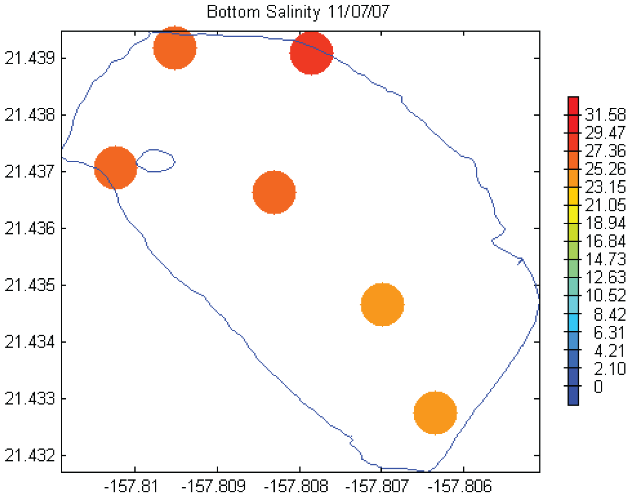


Figure 2.33. Sample site mean (A) surface and (B) deep salinity (PSU) values for the 11/07/07, Storm 1-Transect 2, sampling event. Site locations are geo-referenced to the He‘eia Fishpond perimeter outlined in blue. He‘eia Stream is located to the northwest and Kane‘ohe Bay to the east (see Table 1.2 and Fig. 1.8 for sample site names and locations).

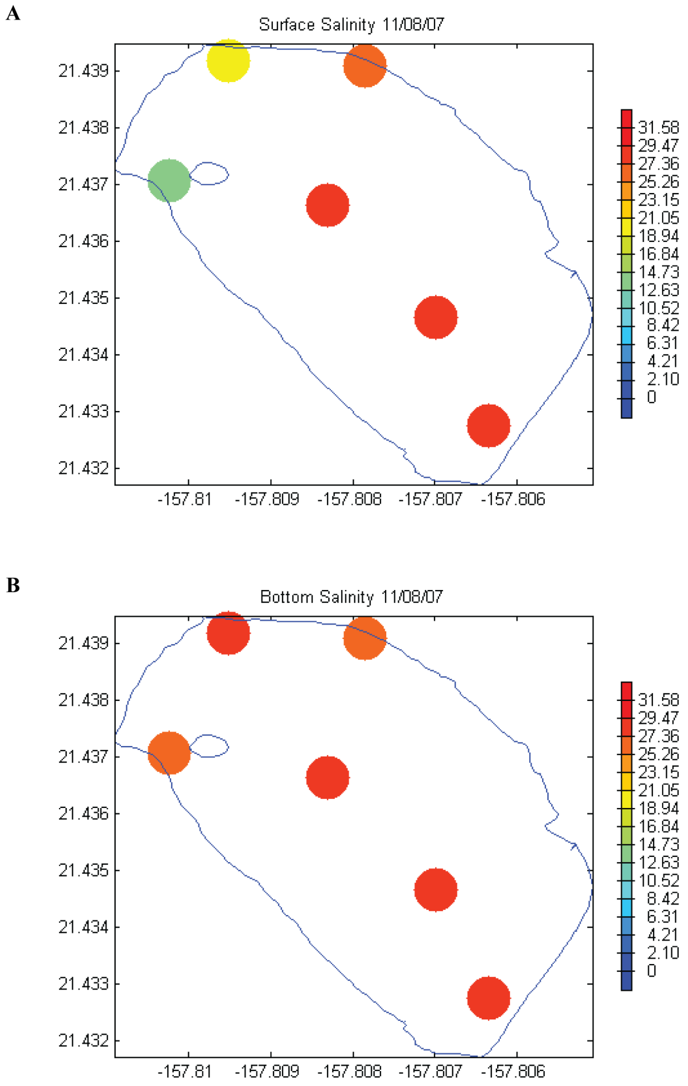


Figure 2.34. Sample site mean (A) surface and (B) deep salinity (PSU) values for the 11/08/07, Storm 1-Transect 3, sampling event. Site locations are geo-referenced to the He‘eia Fishpond perimeter outlined in blue. He‘eia Stream is located to the northwest and Kane‘ohe Bay to the east (see Table 1.2 and Fig. 1.8 for sample site names and locations).

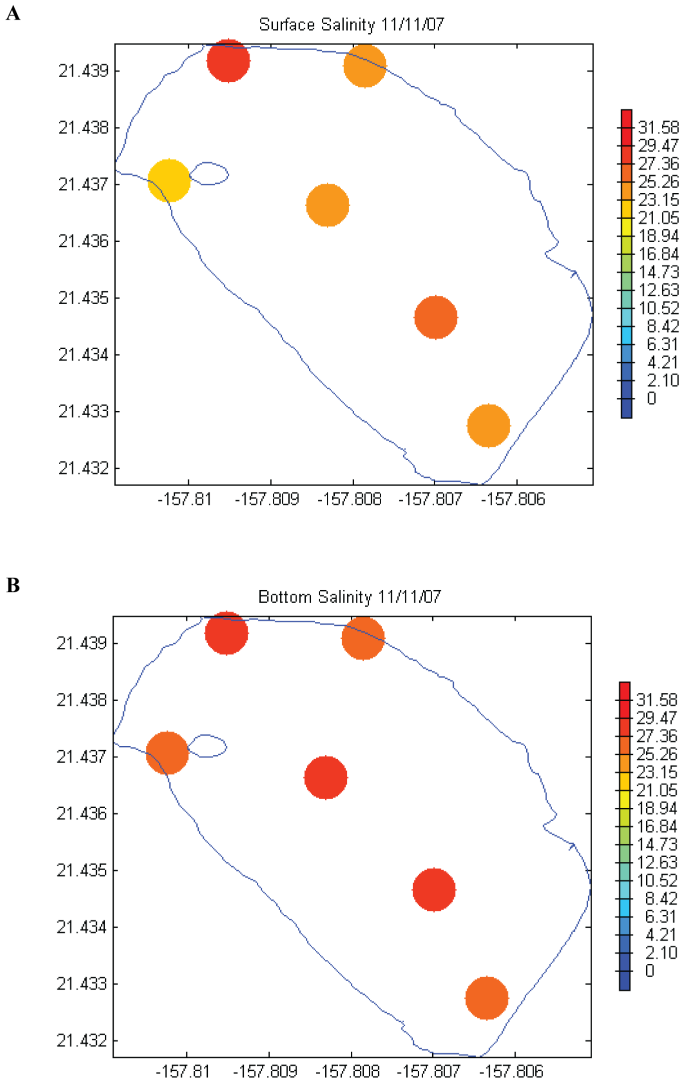


Figure 2.35. Sample site mean (A) surface and (B) deep salinity (PSU) values for the 11/11/07, Storm 1-Transect 4, sampling event. Site locations are geo-referenced to the He‘eia Fishpond perimeter outlined in blue. He‘eia Stream is located to the northwest and Kane‘ohe Bay to the east (see Table 1.2 and Fig. 1.8 for sample site names and locations).

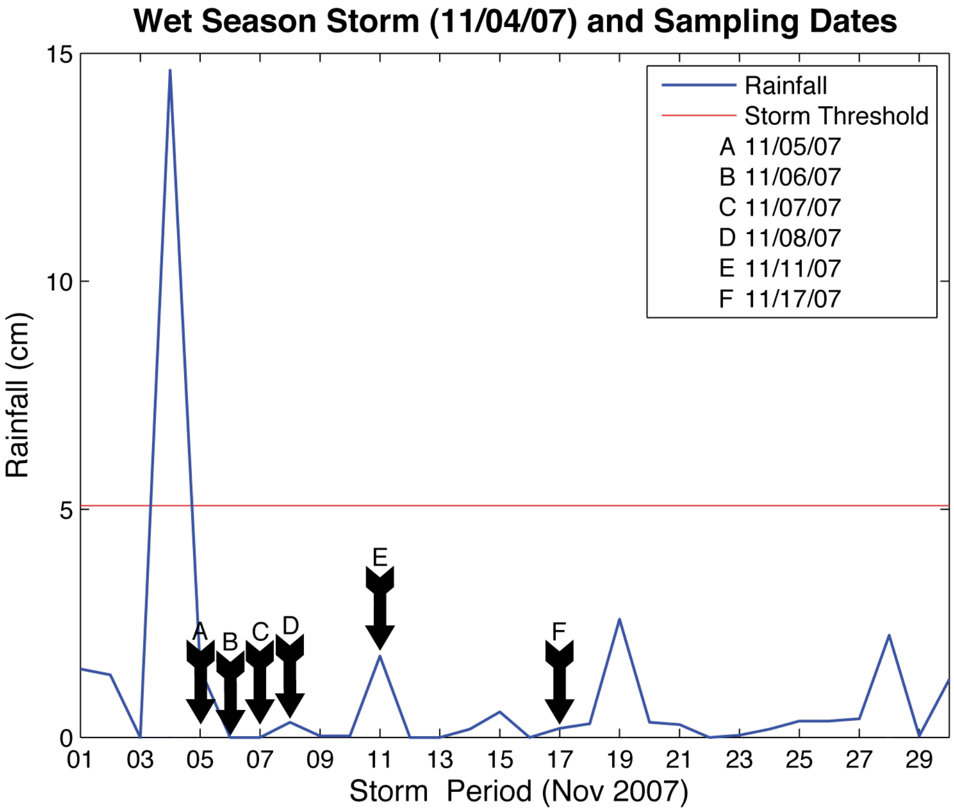


Figure 2.36. Rainfall for the month of November 2007, highlighting the storm event (>5.08 cm rainfall in 24 hrs) occurring on 11/04/07, and subsequent sample dates.

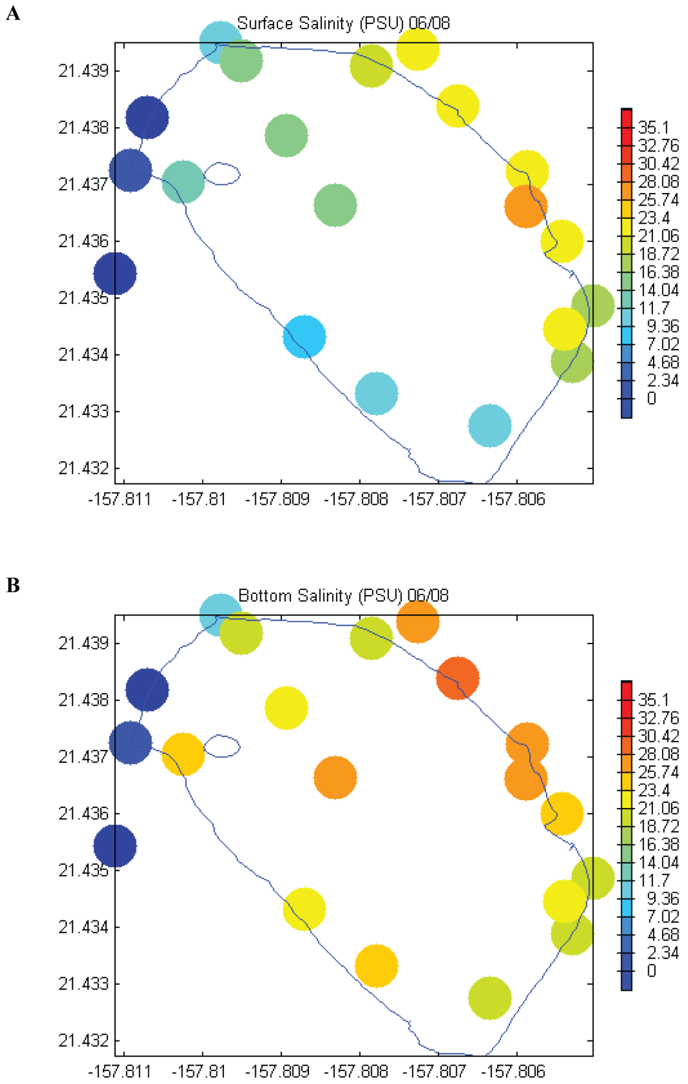


Figure 2.37. Sample site mean (A) surface and (B) deep salinity (PSU) values for the 06/14/08, Storm 4, monthly sampling event. Site locations are geo-referenced to the He‘eia Fishpond perimeter outlined in blue. He‘eia Stream is located to the northwest and Kane‘ohe Bay to the east (see Table 1.2 and Figs. 1.7 and 1.9 for sample site names and locations).

CHAPTER 3

NUTRIENT CYCLING WITHIN HE‘EIA FISHPOND

Introduction

He‘eia Fishpond is a fully enclosed body of water in coastal Kane‘ohe Bay that receives contributions from freshwater (He‘eia Stream) and saltwater (Kane‘ohe Bay) sources (Fig. 1.4). Sluice gates (mākāhā) within the kuapā enclosing the fishpond are the principle conduits through which external sources of water enter He‘eia Fishpond (Fig. 1.4). These gates were instrumented with current meters in order to quantify the direction and magnitude of water flow through each gate (Chapter 2, Table 2.3). When coupled with measured dissolved nutrient concentrations, these flow rates allow estimates of external loading to He‘eia Fishpond to be made. As a consequence of the constrained flow into/out of He‘eia Fishpond, this study site essentially functions as a natural “mesocosm” embedded in the coastal ocean, allowing quantification of nutrient (C, N, P, Si) inventories and nutrient ratios, as well as nutrient loading to He’eia Fishpond on a variety of timescales (Table 1.1).

He‘eia Fishpond can be described as an estuary, and is characterized by a gradient in salinity extending from the NW edge of the fishpond where freshwater mākāhā (RM1, RM2, RM3) are located (Table 1.2, Fig. 1.4), to the seaward edge where Kane‘ohe Bay water enters the fishpond through TM, OM1, OB, and OM2 (Table 1.2, Fig. 1.4). The salinity gradient in He‘eia Fishpond ranges from freshwater (0 PSU) to seawater (35 PSU) salinities over a distance of less than 0.80 km.

Estuarine water column nutrient inventories are controlled by biotic and abiotic uptake and release (Berner and Berner 1996).

This study focused on spatial and temporal changes in He‘eia Fishpond water column nutrient inventories (NH_4^+, (NO_3^- + NO_2^-), TDN, DON, PO_4^{3-}, TDP, DOP, H_4SiO_4, and DOC) and ratios as a function of water exchange with He‘eia Stream and Kane‘ohe Bay. The role of primary producers in nutrient uptake is evaluated in the context of estuarine mixing (nutrient vs. salinity) plots. The nutrient inventories and ratios during baseline and storm conditions described in this chapter provide the context for a discussion of biogenic nutrient uptake, nutrient limitation, and phytoplankton responses to nutrient inventory (Chapter 5). Suspended particulate matter collected from the water samples that were analyzed for dissolved nutrients described in this chapter have been archived for later analysis of associated nutrients. Nutrient availability is also impacted by adsorption onto the surfaces of organic matter and minerals such as clays (Berner and Berner 1996). Adsorbed nutrients on particulate matter represent a reservoir of nutrients that is in constant exchange equilibrium with the waters in which they are found (Sposito 1989). Ultimately, the intent is to contrast external nutrient loading estimates made in this study to benthic nutrient fluxes being estimated by a related study (Briggs, unpubl.) in order to evaluate the relative importance of external vs. internal sources of nutrients to He‘eia Fishpond.

Sampling Strategy

Dissolved nutrient concentrations from thirty discrete water sample sites were obtained during monthly sampling efforts in He‘eia Fishpond from August 2007 to August 2008. Surface water only was collected at the ten fishpond perimeter sites (Fig. 1.9). These samples allowed characterization of freshwater (River, RM2) and saltwater (OCN2) endmembers, as well as the nutrient composition of the water flowing through each mākāhā (RM3, TM, OM1, OB, and OM2) (Fig. 1.9). Both surface and near-bottom waters were collected at ten existing stake locations within the pond (Fig. 1.7). Sampling locations were chosen to capture endmember signals at the freshwater mākāhā on the landward, northwest edge of He‘eia Fishpond, and the saltwater mākāhā to the east, as well as to capture the spatial heterogeneity of the fishpond (Table 1.6). Monthly sampling allowed characterization of broad seasonal patterns in fishpond nutrient loading, inventories and ratios, including baseline dry season and wet season patterns. High temporal resolution water sampling efforts were executed during the first-flush storm event of November 2007. Because the mixed semi-diurnal tides experienced in Hawai‘i were expected to be a primary driver in fishpond circulation and water column nutrient concentrations, the monthly water sampling was distributed to capture the four endmembers of the tidal cycle: spring flood, spring ebb, neap flood, and neap ebb. During this 13-month study, four water sampling days occurred on spring flood tide and three water sampling days occurred on spring ebb, neap flood, and neap ebb tides.

Analytical Methods

Dissolved inorganic nutrient concentrations (NH_4^+, (NO_3^- + NO_2^-), PO_4^{3-}, H_4SiO_4), total dissolved nutrient concentrations (TDN and TDP), and dissolved organic carbon (DOC) were measured in all samples. Dissolved organic nitrogen and phosphorus (DON and DOP) were calculated as the difference between TDN and DIN, and TDP and DIP, respectively. Nutrient ratios (DIN:DIP, DOC:DON, DOC:DOP, DON:DOP) for surface and near-bottom water samples were calculated. Dissolved inorganic phosphorus (DIP) is defined as orthophosphate (PO_4^{3-}) concentration, and the two terms will be used interchangeably.

Dissolved inorganic nutrient concentrations (NH_4^+, (NO_3^- + NO_2^-), PO_4^{3-}) were measured colorimetrically on a Seal Analytical AA3 Auto-analyzer at the USF/USGS Nutrient Biogeochemistry Laboratory in St. Petersburg, Florida. H_4SiO_4 concentrations were measured colorimetrically on Bio-Tek Synergy HT Plate Reader using the Silicomolybdic method (Grasshoff et al. 1999). DOC and TDN were measured on a Shimadzu model TOC-V with the optional total nitrogen measuring unit model TNM-1 at the Water Resources Research Center Analytical Laboratory at the University of Hawai‘i at Mānoa, the non-purgeable organic carbon (NPOC) method (Shimadzu 2004) was used for analysis. TDP was analyzed by the high temperature ashing method of Monaghan and Ruttenberg (1999). Precision and detection limits of all methods are summarized in Table 3.1. In some instances it was not possible to resolve DON and DOP concentrations. This occurs when the total (organic + inorganic) nutrient pool is similar in concentration to the inorganic pool.

Approach to Nutrient Data Analysis and Interpretation: Salinity as a Master Variable

Salinity was used in two ways to identify and evaluate spatial and temporal trends in nutrient distributions within He‘eia Fishpond: (a) plots of nutrients (also temperature, %DO, pH, chl-a, and TSS) vs. salinity (property-property plots), and (b) salinity binning. The strategy for each approach is described below. Subsets of the full data set that illustrate important trends are highlighted in the body of this chapter. Data tables and plots of the full data set can be found in Appendices 5-10.

Use of property-property plots of individual physical properties or analyte concentrations vs. salinity is a standard approach for interpreting estuarine chemical mixing trends, and for identifying processes that cause release or removal of nutrients, particulates, and other substances within estuaries (Boyle et al. 1974; Eyre and Balls 1999; Eyre and Twigg 1997; Fisher et al. 1988; Hubertz and Cahoon 1999; Kaul and Froelich 1984; Liss 1976; Uncles et al. 2003; Wetz 2006). Our expectation was that we would observe nutrient concentrations to vary in a systematic way across He‘eia Fishpond, displaying progressive mixing of freshwater with more saline Kane‘ohe Bay water, following the theoretical mixing line for conservative elements, with positive or negative deviations from the conservative mixing line in cases of nutrient release or uptake, respectively, along the salinity gradient.

However, because He‘eia Fishpond has a circular, rather than the more linear geometry of traditional estuaries, the delivery of freshwater and saltwater is distributed at irregular intervals along the fishpond wall, rather than being delivered at a point source at either end. This resulted in nutrient vs. salinity trends that are considerably noisier than those observed in more traditional, linear estuaries (e.g., Wetz et al. 2006). For example, the mixing line for silicate (H_4SiO_4), which displayed the tightest adherence to a conservative mixing line, had an R^2 of 0.76, while ($NO_3^- + NO_2^-$) had the least significant relationship to salinity ($R^2 = 0.18$).

Recognizing the more complex geometry of He'eia Fishpond, it became useful to group sample sites together according to mean baseline salinity, each bin including sites exhibiting similar mean baseline salinities, and to then view mixing trends in the fishpond by contrasting the mean values and the variance of data for each of the six bins that resulted. This approach greatly facilitated data interpretation, as different "zones" with the fishpond tended to respond similarly to seasonal trends and perturbations.

We expected that storm events would impact He‘eia Fishpond water column structure, based on prior studies of storm impacts on Kane‘ohe Bay (De Carlo et al. 2007; Hoover and Mackenzie 2009; Hoover et al. 2006; Ringuet and Mackenzie 2005). We applied the rule for determining the occurrence of a storm event (>5.08 cm of rainfall in 24 hrs) defined in these previous studies, and evaluated the extent to which this storm threshold applied to He‘eia Fishpond. Once trends in monthly and storm data sets were identified across the fishpond using property-property plots, we then grouped individual sample sites into the bins described above in order to better portray relationships between different regions of the fishpond. Sample sites on the eastern perimeter of He‘eia Fishpond were most affected by the marine waters of Kane‘ohe Bay. The property-property plots and binning analysis allowed us to evaluate the extent to which sites on the western perimeter of the fishpond were impacted by saline, Kane‘ohe Bay waters. The binning approach allowed us to clearly represent regions in He‘eia Fishpond that are similarly impacted by fresh versus marine inputs, and provided additional insight into mixing patterns within He’eia Fishpond beyond that possible when individual data points representing individual sample sites are viewed in property-property plots.

During baseline conditions the fishpond appeared to be well mixed, but during large rain events increased freshwater runoff from He‘eia Stream created a storm plume, stratifying the water column. The evolution of the freshwater plume and the resulting changes in nutrient inventories can clearly be seen when illustrated in the binned groups, whereas these trends were not as clearly seen in property-property plots.

Definition of Baseline Conditions vs. Storm Events

Salinity was used as a conservative tracer to reveal the distribution of terrestrially derived freshwater and Kane‘ohe Bay-derived saline waters within the fishpond. Salinity gradients within estuarine environments are commonly used for comparative studies of biogeochemical processes because the chloride (Cl^-) ion concentration, from which salinity is calculated, is not only more abundant in seawater than freshwater but also because it is uninvolved in biotic and abiotic reactions (Fisher et al. 1988; Schlesinger 1997). We also used salinity to determine the magnitude (over space and time) of episodic storm events, as well as to map the spatial homogeneity or heterogeneity between sample sites within He‘eia Fishpond. Identifying the areal extent to which freshwater or saltwater influenced the fishpond was important to characterizing how the fishpond responded to external land-derived and marine influences.

Defining a He‘eia Fishpond Storm Event

As a test of the storm threshold as a robust predictor of storm impacts on Kane‘ohe Bay coastal waters, a mathematical model using an empirical orthogonal function (EOF) was employed to validate the definition of a storm event as a rain event during which greater than 5.08 cm of precipitation falls within 24 hours (De Carlo et al. 2007; Hoover and Mackenzie 2009; Hoover et al. 2006; Ringuet and Mackenzie 2005; Tomlinson and De Carlo 2003). The EOF analysis shows the temporal and spatial variation found within a single measured criterion, and has been successfully used in oceanographic and atmospheric research (Burd and Jackson 2002; Emery and Thomson 1998; Preisendorfer 1988). Using 13-months of salinity data collected throughout this study, the EOF analysis separated the salinity data into a number of “modes,” with each mode consisting of a time series and spatial patterns. The modes are ordered such that the first mode accounts for the largest amount of variance within the data set, the second mode accounts for the second largest amount, and so on (Fig. 3.1). The number of modes in an EOF is determined by the smallest data set within the salinity comparison over space and time, in this case it was the number of sampling events (n = 14) over the course of study. Every sample site data point (n = 447) was incorporated into the spatial data set for the EOF. One event, the first-flush storm event, dominates the variance found within the salinity data set, accounting for 78.82% of the variance. The second-most dominant mode, which accounts for only 7.89% of the data set variance, corresponds to the dry season storm (Storm 4) sampled during this study. Modes 3-14 account for progressively less variance.

The bulk of our analysis will focus on the dominant mode, hereafter defined as Mode 1, which accounts for more than ¾ of the annual salinity variance within the fishpond. Salinity variations result from land-derived runoff, submarine groundwater discharge, tidally mediated fluctuations in marine waters flushing the fishpond, and evaporation of surface waters. Due to the overwhelming dominance of Mode 1 in the 13-month data set, we conclude the dominant source of annual variance in He‘eia Fishpond is due to large rain events and the subsequent influx of terrestrially-derived freshwater into the fishpond from He‘eia Stream.

Estuarine Mixing Trends as Revealed by Property-Property Plots

The primary source of H_4SiO_4 in tropical marine environments is land-derived runoff (White and Blum 1995). H_4SiO_4 concentrations behave relatively conservatively across the estuarine mixing gradient in He‘eia Fishpond during both baseline (non-storm, dry season) and storm conditions, with R^2 of 0.79 and 0.73, respectively (Fig. 3.2). Non-storm data illustrate H_4SiO_4 release at ~22-32 PSU, while displaying conservative mixing at both lower (~5-15 PSU) and higher (~30-35 PSU) salinities. All storm data show release and uptake of H_4SiO_4 at various salinities. Removal of H_4SiO_4 is consistent with photosynthetic pigment data that indicate diatom blooms occur after storm events (Chapter 5), taking advantage of increased dissolved nutrient loads from storm runoff. Biogenic removal of H_4SiO_4

can best be seen when Storm 1 data is plotted alone (Fig. 3.3, Panel A) and, with an R^2 of 0.71, more closely approximating conservative mixing. Storm 4, however, displays an even tighter correlation between H_4SiO_4 and salinity ($R^2 = 0.80$) (Fig. 3.3, Panel B).

Mixing relationships for the other dissolved nutrients are not as strong as H_4SiO_4 and show considerably more scatter. For example, ($NO_3^- + NO_2^-$) concentrations show no relationship with salinity during baseline conditions ($R^2 = 0.03$) (Fig. 3.4, Panel A), and although correlations with salinity during Storm 1 ($R^2 = 0.37$) and Storm 4 ($R^2 = 0.17$) (Fig. 3.5) are superior to those obtained during baseline conditions, they are markedly weaker than the relationship between H_4SiO_4 and salinity. Interestingly, the freshwater endmember concentrations of ($NO_3^- + NO_2^-$) during Storm 1 and Storm 4 are quite different. During Storm 1 ($NO_3^- + NO_2^-$) concentrations measured in the River and RM2 sites (1.19 μM and 6.22 μM) (Fig. 3.5, Panel A) are much higher than those measured at the River site during Storm 4 (0.04 μM) (Fig. 3.5, Panel B). This suggests that the first-flush storm, Storm 1, transported higher nutrient loads to He‘eia Fishpond than the dry season Storm 4. Overall ($NO_3^- + NO_2^-$) concentrations within the fishpond are 2-10 fold greater during Storm 1 than during Storm 4. The salinities at which ($NO_3^- + NO_2^-$) release is seen are different in each storm event, as well. During Storm 1 the greatest release of ($NO_3^- + NO_2^-$) is seen at salinities less than 10 PSU. Storm 4 displayed the greatest addition of ($NO_3^- + NO_2^-$) at approximately 15 PSU. Release of ($NO_3^- + NO_2^-$) at different salinities helps delineate the extent of the freshwater plume and the location of high levels of primary productivity within He‘eia Fishpond; similar arguments have been made for Kane‘ohe Bay (Cox et al. 2006; Fisher et al. 1988; Morris et al. 1995; Ringuet and Mackenzie 2005; Wang et al. 2008). Focusing on Storm 1 data, (NO_3^- + NO_2^-) concentrations are above the conservative mixing line at two salinity ranges, 3-8 PSU and 20-25 PSU (Fig. 3.5, Panel A). The same Storm 1 samples, analyzed for chlorophyll-a concentration, also show the highest chl-a values at these two salinity ranges (Fig. 5.2, Panel A). Both (NO_3^- + NO_2^-) and chl-a rapidly drop to below the conservative mixing line outside of these salinity ranges. The PO_4^{3-} concentration maximum occurs at 20-22 PSU during Storm 1 (Fig. 3.6, Panel A), and its relationship to salinity yields an R^2 of 0.13. Details of controls on water column phosphate distributions are discussed later in this chapter.

Salinity Binning

In contrast to more conceptually traditional estuaries, which typically have a linear geometry with a freshwater source at one end and a saltwater source at the other (e.g. Tomales Bay (Smith et al. 1996), Chesapeake Bay and Delaware Bay (Fisher et al. 1999; Fisher et al. 1998; Sarin and Church 1994), Mississippi Delta (Perez et al. 2011)), freshwater and saltwater delivery to He‘eia Fishpond occurs via several mākāhā distributed along the landward and seaward edges of the kuapā, respectively, enclosing the fishpond. As a consequence of the geometry of He‘eia Fishpond, and the multiple source points of freshwater and saltwater entry to the fishpond, traditional estuarine mixing trends are often obscured. This can be seen in the property-property plots of various constituents (previous section), particularly during the dry season. Despite the imperfect nature, or even the absence of a clear relationship between nutrients and salinity in property-property plots, it was clear from close examination of the data that mixing of a more spatially diffuse nature was occurring within the fishpond.

In order to segregate zones within He‘eia Fishpond that represented different, progressive extents of chemical mixing, we adopted a binning strategy, based on salinity, which allowed us to group together multiple sites from the twenty distinct sample locations that comprise the field sampling grid, that displayed similar salinity values when averaged over the 13-month study. Thus, salinity was chosen as the master variable to identify similar water masses (i.e. as a proxy for the extent of mixing of freshwater and saltwater) within He‘eia Fishpond. Similar bins resulted whether mean surface water (upper 25 cm), mean near-bottom water (bottom 25 cm), or whole water column salinity values were used to establish sample site bins. Mean surface water salinities provided the largest contrast between freshwater dominated vs. marine dominated sites, and our subsequent discussion thus focuses on surface water data only.

Using mean surface water (0-25 cm depth) salinities, the twenty sample sites were binned into six distinct groups on the basis of salinity (Fig. 3.7). These groups are as follows (Fig. 3.8): River (He‘eia Stream) and RM2 comprise the “Freshwater Sites” and represent the freshwater endmember. RM1, RM3, and the four sample sites adjacent to the terrestrial boundary of He‘eia Fishpond (Stk13, 15, 16, 18) together represent “Terrigenous Dominated Sites.” Sites located in the middle of the fishpond, that typically display signals intermediate between freshwater and saltwater endmembers, comprise the “Mid-pond Sites” (Stk6, 7, 8, 9). Sample sites dominated by the oceanic endmember, “Ocean Dominated Sites,” were divided into two groups as a consequence of their distinctive response to runoff from He‘eia Stream during large rain events. Due to its proximity to He‘eia Stream outflow, “Ocean Dominated Sites, group 1” (OM1, TM, and OCN1) displays variability as a consequence of changes in stream discharge and tidal activity within Kane‘ohe Bay. “Ocean Dominated Sites, group 2” (OM2, OB, Stk1, Stk3), in contrast, the only group that has sample sites both within the fishpond (Stk1, 3) as well as sites on the fishpond perimeter (OM2 and OB) (Figs. 1.7, 1.9, 3.8), is comprised of sample sites closest to the Kane‘ohe Bay seawater endmember and furthest from terrigenous influences, and is less affected by He‘eia Stream input. The “pure” marine endmember is represented by sample site OCN2; this is the only bin that is comprised of a single site and is defined as the “Ocean Site” bin (Fig. 3.8).

Empirical Orthogonal Function (EOF) Defined Storm Events

The Mode 1 time series plot illustrates that storm events significantly affect fishpond baseline salinity (Fig. 3.9). The three negative peaks with mode weight < 0 (Fig. 3.9) occur on monthly sampling events #4 (Storm 1: 11/05/07), #6 (Storm 2: 12/09/07), and #12 (Storm 4: 06/14/08). Each of these sampling dates correspond to a water sample event that followed a rainfall event which exceeded the storm threshold defined as ≥ 5.08 cm of precipitation falling within 24 hours (Ringuet and Mackenzie 2005). Only the first-flush rain event, Storm 1 (occurring on 11/04/07), was purposefully sampled through a dedicated storm sampling effort. In contrast, the Storm 2 rain event (12/07/07) and the Storm 4 rain event (06/12/08) were both sampled during scheduled monthly sampling efforts that fell fortuitously two days after a heavy rainfall event.

Mode 1 results from these three sampling events allowed us to employ the EOF to refine the storm definition for He‘eia Fishpond. Results of the EOF analysis suggest that factors other than, or in addition to rainfall are required to dramatically change water column structure of the fishpond, even if the amount of rainfall was greater than the storm threshold. The two negative Mode 1 peaks at sample events #4 and #12 are conspicuous due to their occurrence in different seasons and their opposing value compared to all remaining sampling events. Twelve of the fourteen sampling events show Mode 1 weight between -0.2 and 0.2. The trends observed in the Mode 1 time series plot (Fig. 3.9) were used to define the non-storm and storm data sets for this study.

On the basis of the Mode 1 time series analysis, the 13-month data was divided into two groups: water samples collected during sampling events #4 (Storm 1) and #12 (Storm 4) were defined as the “EOF-defined Storm” data set, and the remaining data were defined as the “Non-storm” data set. The non-storm, Mode 1, range of annual salinity variance is within 0.2 weight units about the mean; therefore, sampling event #6 (Storm 2) is not statistically different than the mean annual variance and is not included in the EOF-Defined Storm data set for this study. Additionally, the lack of Storm 2 salinity variance reveals that the storm threshold definition of 5.08 cm of rainfall in 24 hours is not always applicable to He‘eia Fishpond (Fig. 3.9), as rainfall recorded for Storm 2 was above the storm threshold, but the rainfall did not result in a variance signal significant enough to be observed in the salinity data associated with Storm 2. Thus, Storm 2 is not an EOF-Defined Storm. The lack of salinity variance during Storm 2 may be a result of a combination of tidal flushing, wind direction and magnitude, the distance from He‘eia Fishpond to the rain gauge location, or sampling coverage; but as mentioned in Chapter 2, it is not possible to declare that an event, such as rainfall, is singularly capable of achieving a storm signal within He‘eia Fishpond.

Our EOF analysis suggests that He‘eia Fishpond requires not only sufficient rainfall, but also specific timing with respect to the tidal cycle such that increased freshwater input from large rain events persists for sufficient time to create a measurable shift in pond water column properties. Such was the case with neap tides occurring during Storm 1 and Storm 4, both of which were associated with water column properties significantly different from baseline (Figs. 2.29, 2.31, 2.37). Storm 2 water column data, however, although collected 2 days after rainfall exceeded the storm threshold, did not display salinity variance significantly different from baseline values (Figs. 2.29 and 3.10). Removal of the Storm 2 signal within 48 hours is consistent with the calculated minimum residence time for He‘eia Fishpond (Chapter 2), suggesting that the storm signal had been flushed out of the pond within 48 hours of the storm occurrence.

Further manipulation of the EOF reveals Mode 1 sample site-specific variance (Fig. 3.11). In concert with the Mode 1 time series (Fig. 3.9), site-specific salinity variability can be calculated. For example, OM2 has a sample site weight of 7 (Fig. 3.11). During sampling event #4 (Storm 1), OM2 has a Mode 1 time series weight of -0.8 (Fig. 3.9). The predicted change in salinity of water collected at OM2 during a storm event of equal magnitude to sampling event #4 should be as much as 5.6 PSU fresher than mean baseline values. This value is the product of the Mode 1 time series and spatial pattern values. While during the same sampling event (Storm 1), Stk18 sfc, with a site weight of 25 and time series weight of -0.8, may vary as much as 20 PSU fresher during storm conditions. Sample sites RM2 and River (He‘eia Stream) show no change throughout the year (Fig. 3.11), as their site weights are 0. These results provide a spatial overview of the variability in He‘eia Fishpond, where sample sites nearer Kane‘ohe Bay experience less annual variability than sites within the fishpond. This is consistent with results of the binning analysis, which clearly show smaller variance of sites nearest Kane‘ohe Bay (Fig. 3.7). Further, within the fishpond sample sites, surface waters experience more variability than near-bottom waters (Fig. 3.11).

Spatial and Temporal Nutrient Distribution Patterns

Baseline vs. Storm Event Salinity Distributions

During baseline (non-storm) conditions, apart from the Freshwater Sites (FW) which plot at 0 PSU, the mean salinity for nearly all other sites were statistically indistinguishable within the range of variability observed at each sample site (Fig. 3.7). The range of variability observed at sample sites in Terrigenous Dominated Sites (TD) bin is greater than for any other bin, reflecting the extremes in salinity experienced as a consequence of freshwater input and largely driven by tidal flushing. The Ocean Site (OCN) displays the smallest variance in salinity (Fig. 3.7). Despite the overlap in range, a systematic progression from fresher to more saline waters can be seen in the mean baseline salinity data (Fig. 3.7), with mean salinities in the TD bin ranging from 22.84-29.20 PSU, and the OCN bin at 33.35 PSU. Salinities of the Mid-pond Sites (MP) and Ocean Dominated Sites (OD) fall within a narrow range of 30.35-32.51 PSU.

When binned salinity data for the three storm events sampled over the course of the study are plotted separately, distinctions between the bins, based on salinity, become more evident (Fig. 3.12). This is particularly true for the two EOF-defined storms (Storm 1 and Storm 4), which are characterized by salinities less than 15 PSU throughout the fishpond interior during Storm 1 (Fig. 3.12, Panel A), and extending out to the TD bin during Storm 4 (Fig. 3.12, Panel B). The more extensive low salinity plume established during Storm 1 reflects the fact that this was the largest storm event of the season according to both rainfall and discharge (Figs. 2.2 and 2.3). Salinity distributions during Storm 4 show a more typical estuarine salinity profile, resulting from a progressive dilution of the freshwater plume from TD to MP to OD bins (Fig. 3. 12, Panel B). With the exception of Stk13 and Stk15 within the TD bin, Storm 2 salinities range from 22.83-32.51 PSU (Fig. 3. 12, Panel C) across all fishpond sample sites and indistinguishable from baseline salinity distributions (Fig. 3.7). We note that the Storm 1 sampling event occurred within 24 hrs of the storm rain event, while sampling for Storm 2 and Storm 4 occurred 48 hrs after the rain event. This 24-hr delay in sampling Storms 2 and 4 may have resulted in a more attenuated signal than may have been present during the first 24 hrs post storm; this fact should be kept in mind when comparing Storm 1 to Storms 2 and 4. To address this discrepancy in time elapsed between storm and sampling events, we contrast the salinity distributions observed during Storm 1-Transect 1, which occurred 48 hrs after the storm rain event, with Storm 4 salinity distributions. The six sites sampled during Transect 1 of Storm 1 are compared with Storm 4 salinity data in Figure 3.13; note that Transect 1 sampled two bins only, TD and MP. This salinity comparison reveals that the storm signal within He‘eia Fishpond is evident in both Storm 1 and Storm 4, 48 hours after the rain event (Fig. 3.13). On the basis of this comparison, and in the interest of simplifying inter-storm comparisons, we conclude that Storms 1 and 4 can be considered as comparable storm sampling events for the purposes of this study. The EOF results (Fig. 3.9) also support this conclusion.

As mentioned previously, Storm 2 salinity data are indistinguishable from baseline salinities (Fig 3.12, Panel C and Fig. 3.7, respectively). Although Storm 2 met the rainfall storm threshold criteria for storm event identification, it was not identified as a storm by the EOF analysis (Fig. 3.9). Thus, Storm 2 provides an interesting point of contrast between EOF-defined storm events (Storms 1 and 4), vs. the traditional rainfall threshold defined storm events (Storms 1-4). The rainfall associated with Storm 2 was 6.40 cm less than Storm 1, but 2.18 cm greater than Storm 4 (Table 2.5). Ha‘iku Stream discharge for Storm 2 was 1/3 less than Storm 1 and 1/5 less than Storm 4. Lower discharge equates to less freshwater runoff and a more subdued impact on the fishpond and coastal waters, as is evidenced by the baseline-like salinity distributions observed after Storm 2.

Similarities in salinity at RM3 and RM1 between the EOF-defined storms (Storms 1 and 4) vs. Storm 2 are illustrated in Figure 3.12. RM3 is a tidally influenced site and similar salinity values for both EOF-defined storms at RM3 suggests that both storms were sampled under similar tidal conditions, further supporting the notion that Storm 1 and Storm 4 are comparable. RM1 has significantly lower salinity (~3-4 PSU) than RM3 (~13 PSU) during both EOF-defined storms (Fig. 3.12, Panels A and B). Lower salinities at this site imply that RM1 is an important mākāhā for freshwater input to He‘eia Fishpond during storm events, and is less tidally influenced than RM3.

The depressed salinities seen at sample sites #5-12, 18, and 19 during Storm 1 (Fig. 3.12, Panel A) reveal that freshwater has intruded to the fullest extent of the fishpond perimeter. The high salinity values at sample sites representing Kane‘ohe Bay and all ocean mākāhā (sample sites # 13-17 and 20) during Storm 1 (Fig. 3.12, Panel A) suggest that the freshwater storm plume has yet to make it out of the fishpond and into the bay 24 hours after the onset of the storm. The freshwater plume established during Storm 4, a comparatively weaker storm (Table 2.5), failed to reach the perimeter limits by 48 hours post-storm (Fig. 3.12, Panel B).

In addition to the magnitude of precipitation and storm runoff, tidal state impacts the degree to which a freshwater storm plume intrudes into He‘eia Fishpond. For example, Storm 2 was sampled on an ebbing tidal cycle (Table 2.5), after a spring high tide had caused extensive mixing of the fishpond water column. Most fishpond sample sites during Storm 2 have high salinities (25-30 PSU) (Fig 3.12, Panel C), which we attribute to extensive water column mixing and flushing of the fishpond. Storm 1 and Storm 4, in contrast, were sampled on a neap tidal cycle. The less intensive mixing that occurs during a neap tide (Figs. 2.21 and 2.22) preconditions He‘eia Fishpond to display a more pronounced gradient in salinity following a storm event. During Storm 2, Stk13 and Stk15 have much lower salinities than the rest of the sample sites, suggesting the possibility of a freshwater pocket that was not mixed out during the flood tide. Another possibility is that SGWD occurs near Stk13 and Stk15. Baseline salinity values for Stk13 and Stk15 are the lowest observed throughout He‘eia Fishpond and are highly variable, sometimes reaching as low as ~23 PSU without even the influence of storm events (Fig. 3.7). The possibility of restricted water exchange and/or the presence of SGWD may have considerable influence on the nutrient dynamics of He‘eia Fishpond, and will be discussed further in this chapter as well as in Chapter 5.

Baseline vs. Storm Event Ammonium Distributions

Baseline NH_4^+ concentrations span a narrow range, with most sample sites falling between ~3-4 μM; River and river mākāhā sample sites are slightly higher (Fig. 3.14, Panel A). Mean NH_4^+ values, averaged over the two EOF-defined storms, are as much as 4-times higher than baseline NH_4^+ concentrations (Fig. 3.14, Panel B). Additionally, the range of NH_4^+ concentrations observed at sample sites during mean storm conditions is greater than that observed during baseline conditions.

Surface water concentrations of NH_4^+ measured during Storm 1 are higher than those observed following Storms 2 and 4 (Fig. 3.15). This is consistent with our expectation that the fishpond would respond more dramatically to the first-flush storm than it would to subsequent storm events. Elevated Storm 1 NH_4^+ data for sample sites within the fishpond, as binned according to salinity, suggest that the storm plume has reached the full extent of the fishpond. Storm 4 also was accompanied by elevated NH_4^+ concentrations relative to baseline across the fishpond. OCN2 displayed the highest concentration (21.77 µM) for any site sampled during Storm 4. At first glance, this concentration may seem unreasonably high for marine waters. However, the OCN2 concentration is comparable to NH_4^+ concentrations measured at 7 of the sample sites during Storm 1 (Fig. 3.15, Panels A and B), suggesting that this water derived from within He‘eia Fishpond, and is present at the OCN2 site as a consequence of tidal flushing of fishpond water into Kane‘ohe Bay.

All three storm events are characterized by freshwater endmember concentrations of ~5-10 µM NH_4^+ (Fig. 3.15). Interestingly, NH_4^+ concentrations of samples collected at the terrigenously dominated sites are often times higher than concentrations at the freshwater endmember sample sites. For example, during Storm 1, NH_4^+ concentrations at TD sites exceeded 25 µM (Fig. 3.15, Panel A). Elevated NH_4^+ concentrations are typically associated with respiration, and suggest that enhanced respiration may be fueled by the increase in TSS (see Chapter 4) and chl-a (see Chapter 5) concentrations during Storm 1. Immediately following the rain event, elevated TSS in the water column reduces light penetration, hindering photosynthetic activity even in the presence of higher nutrient availability, and leads to a situation in which microbially-derived consumer byproducts, such as NH_4^+, may accumulate in the water column. As time passes and particulates settle to the seabed, increased light penetration into the water column then allows for primary producers to take advantage of the NH_4^+ that built up during the post-storm high turbidity period.

Phytoplankton community responses to storm derived nutrient concentrations within the water column are discussed further in Chapter 5.

Baseline vs. Storm Event (Nitrate + Nitrite) Distributions

Baseline (NO_3^- + NO_2^-) concentrations are invariant across all sample sites in He‘eia Fishpond (Fig. 3.16), and average 0.19 μM (+/- 0.13) (Fig. 3.16, Panel A). In contrast, EOF-defined storm mean (NO_3^- + NO_2^-) concentrations are elevated relative to baseline (5.25 μM +/- 7.23), with three sample sites (Stk1, 3, 15) characterized by two-fold higher (NO_3^- + NO_2^-) concentrations than mean storm (NO_3^- + NO_2^-) concentrations (Fig. 3.16, Panel B). (NO_3^- + NO_2^-) concentrations show significant variability within all bins except for the Kane‘ohe Bay perimeter sites and the saltwater endmember (Fig. 3.16, Panel B). Storm input of land-derived (NO_3^- + NO_2^-) to coastal Hawaiian waters is well documented (De Carlo et al. 2007; Hoover and Mackenzie 2009; Ringuet and Mackenzie 2005). Baseline data show that non-storm conditions do not exhibit typical estuarine mixing relationships between (NO_3^- + NO_2^-) concentration and salinity (Fig. 3.4, Panel A). During storm events, however, with a greater influx of land-derived (NO_3^- + NO_2^-) into the fishpond, a relationship with salinity develops ($R^2 = 0.31$) (Fig. 3.4, Panel B). When the two EOF-defined storms are viewed separately, they reveal distinctive relationships with salinity. During Storm 1, lower salinities display elevated (NO_3^- + NO_2^-), consistent with (NO_3^- + NO_2^-) loading from land-derived sources (Fig. 3.5). In contrast to Storm 1, Storm 4 (NO_3^- + NO_2^-) concentrations display no significant relationship to salinity

(Fig. 3.5). This contrast suggests that He‘eia Fishpond requires the occurrence of a significant storm to elevate dissolved ($NO_3^- + NO_2^-$) above baseline values.

When comparing individual storm events, EOF-defined Storms 1 and 4 both have elevated ($NO_3^- + NO_2^-$) concentrations at sample sites within the fishpond kuapā; Storm 2 does not (Fig. 3.17, Panels A and B). Storm 2 has ($NO_3^- + NO_2^-$) concentrations similar to mean baseline concentrations, with very slightly higher values at the He‘eia Stream mouth (OCN1) and the Kane‘ohe Bay perimeter mākāhā sample sites (Fig. 3.17, Panel C). Elevated ($NO_3^- + NO_2^-$) at OCN1, which is located at the mouth of He‘eia Stream, is consistent with the observation that freshwater inputs of dissolved ($NO_3^- + NO_2^-$) are elevated in land-derived freshwater input and thus are prevalent at sites of stream discharge.

We observe that at high tide the lower drainage basin of He‘eia Stream receives significant input from Kane‘ohe Bay, which forces redirection of stream water into He‘eia Fishpond through RM3. During flood tides, which occurred during Storm 1 and Storm 4, He‘eia Stream waters are directed pond-ward through RM3 (Figs. 2.19 and 2.21), but during Storm 2, which occurred during ebb tide, fishpond waters were flowing out of RM3 into He‘eia Stream. Stream discharge during Storm 2 was less than Storm 1 and Storm 4 (Table 2.5). The lower discharge, when coupled with the tidal state during the storm sampling effort on 12/09/07 (Storm 2: spring ebb tide) is responsible for the weak ($NO_3^- + NO_2^-$) signal during Storm 2. Spring ebb tides are a time during which stream waters do not enter He‘eia Fishpond at RM3 (Fig. 2.20). The result of this tidal state is a reduction of freshwater input through RM3 by ~1,700 m^3/tidal cycle (Table 2.3). In the absence of tidal conditions that enhance stream runoff into He‘eia Fishpond, coupled to lower stream discharge, the relatively small amount of (NO_3^- + NO_2^-) that would be introduced to the fishpond through RM2 during Storm 2 would likely be rapidly consumed by primary producers (Table 2.3, Fig. 2.20).

Baseline vs. Storm Event Phosphate Distributions

PO_4^{3-} concentrations across all sample sites and sample times are surprisingly invariant (Fig. 3.18). Storm event mean PO_4^{3-} concentrations are only slightly higher than baseline mean values (Fig. 3.18). Concentrations of PO_4^{3-} are typically low in coastal tropical waters. For example, Ringuet and Mackenzie (2005) report a mean southern Kane‘ohe Bay surface water PO_4^{3-} concentration of 0.12 μM during baseline conditions. Mean He‘eia Fishpond PO_4^{3-} concentration during baseline and storm conditions are higher than the values reported by Ringuet and Mackenzie (2005), with mean surface water values of 0.47 μM (+/- 0.27) and 0.71 μM (+/- 0.35) for baseline and storm samples, respectively.

Although surface water PO_4^{3-} concentrations in He‘eia Fishpond are relatively invariant (Fig. 3.18), near-bottom PO_4^{3-} concentrations show substantial variability (Fig. 3.19), particularly in samples of TD and MP binned sample sites collected during all three storms (Fig. 3.19). Relative to mean surface water storm PO_4^{3-} concentration (0.71 μM), Storm 1 PO_4^{3-} concentrations in near-bottom water are elevated at fishpond-interior sample sites, while during Storms 2 and 4, the pond-interior sample sites become relatively depleted in PO_4^{3-} (Fig. 3.19). Dissolved nutrient concentrations would typically be expected to increase in the water column following a storm event, and then return to baseline concentrations as biological uptake removes them and lowers concentrations. The behavior observed for PO_4^{3-} concentrations, however, suggests that there may be abiotic controls of PO_4^{3-} concentration occurring during storm inputs to the fishpond. A large pool of PO_4^{3-} exists in association with riverine particulate matter (Ruttenberg 2003), some of which may be released, becoming available for biological uptake upon changes in ionic strength during estuarine mixing. A brief description of two processes, the phosphate buffering mechanism that describes interactions between PO_4^{3-} and particulate matter (e.g., Froelich 1988), and seabed reductive solubilization of ferric iron minerals accompanied by the release of sorbed P, follows.

The principal source of PO_4^{3-} to the marine environment is weathering and terrestrial runoff (Froelich et al. 1982; Ruttenberg 2003). PO_4^{3-} is highly particle reactive, with a particular chemical affinity for iron (oxy)hydroxide (FeO) minerals (Krom and Berner 1981; Sundby et al. 1992; Yamada and Kayama 1987). When FeO are present in an aquatic or soil environment, they will sorb dissolved PO_4^{3-} onto their surfaces. The Hawaiian Islands are formed from primordial basalt rock, composed of 6-15 wt % FeO minerals (Rubin, personal comm.). Thus, particulate matter eroded from basalt source rock in the He‘eia watershed contains FeO minerals. The FeO mineral pool is composed of FeO minerals such as ferrihydrite, lepidocrocite, magnetite, and goethite. All but magnetite have the capacity to adsorb PO_4^{3-} onto their surfaces (Ruttenberg 1992; Ruttenberg and Sulak 2011), removing PO_4^{3-} from the water column and lowering the DIP available for biological uptake. The presence of FeO minerals in oxygenated waters has been shown to adsorb 33-45% of the total

P in surface sediments, removing a significant portion of the potentially bioavailable PO_4^{3-} pool from the water column (Froelich 1988; Jensen and Thamdrup 1993; Poulton and Canfield 2005).

Release of PO_4^{3-} from mineral surfaces that occurs when stream particles are introduced to higher ionic strength water during estuarine mixing is a process included in the phosphate buffer mechanism (Froelich 1988). The phosphate buffer mechanism is the influence sediments may exert on maintaining a near constant DIP concentration in the water column, regardless of biological removal or abiotic input. Invariant PO_4^{3-} concentrations are observed from approximately 0-22 PSU for both Storm 1 and Storm 4 (Fig. 3.6), the EOF-defined storms, characteristic of a system exhibiting the PO_4^{3-} buffer mechanism (Froelich 1988). At ~22 PSU Storm 1 data (Fig. 3.6, Panel A) exhibit PO_4^{3-} release to the water column, but PO_4^{3-} concentrations are quickly drawn down in subsequent days (Fig. 3.6, Panel A), suggesting that the kinetics of phosphate buffering are on time scales longer than the biological uptake of PO_4^{3-}. In addition to release from suspended storm derived particulate matter, deposition on the seabed can expose FeO to a reducing benthic environment and contribute to the water column DIP inventory as it is released from reductively solubilized FeO.

Through field data and laboratory experiments, Fox (1986) modeled the ionic bond relationship between PO_4^{3-} and inorganic particulate matter in the Amazon River. Fox (1986) quantified the amount of PO_4^{3-} desorbed from river suspended particulate matter (RSPM) as a freshwater plume transported RSPM offshore and mixed with rising ionic strength waters found in the coastal ocean. The Fox (1986) study demonstrated that RSPM plays a major role in supplying DIP to estuarine waters as a function of varying salinities and exposure time, and reported that the highest concentrations of PO_4^{3-} were measured within 1 day of the RSPM being introduced to estuarine waters, with maximum release of PO_4^{3-} occurring in 20-24 PSU waters. He‘eia Fishpond responds similarly to the Amazon estuary during both baseline and storm conditions, producing a water column PO_4^{3-} maximum concentration between 22-24 PSU (Fig. 3.20).

Baseline vs. Storm Event Silicate Distributions

Baseline and storm H_4SiO_4 concentrations generally follow similar trends when plotted against salinity (Fig. 3.2), with H_4SiO_4 dropping below the conservative mixing line between 25-30 PSU. Biotic uptake by primary producers is the most likely cause of H_4SiO_4 concentration reductions as diatoms are most likely the dominant phytoplankton in the fishpond, as identified through HPLC photosynthetic pigment markers (Chapter 5). During baseline conditions (Fig. 3.21, Panel A) the majority of H_4SiO_4 delivered by the freshwater endmembers is consumed within the TD sample sites. During storm events, the signal is less dramatic, but describes the same trend of generally declining H_4SiO_4 concentration while transecting the fishpond from freshwater towards marine waters (Fig. 3.21, Panel B).

Previous studies conducted throughout Kane‘ohe Bay (Cox et al. 2006; De Carlo et al. 2007; Ringuet and Mackenzie 2005) report surface water baseline Kane‘ohe Bay H_4SiO_4 concentrations ranging from 1-10 μM, while the marine endmember for this study, OCN2, had a mean baseline concentration of 22.83 μM. A higher concentration at OCN2 is not surprising due to its proximity to He‘eia Fishpond. He‘eia Stream H_4SiO_4 mean baseline concentrations (414.70 µM +/-25.02) measured during this study are similar to the values reported by Hoover and Mackenzie (2009) for He‘eia Stream (392.48 µM).

Temporal Evolution of the First-Flush Storm Event

The islands of Hawai‘i experience one wet season and one dry season each year. Historically, the wet season begins in November and lasts through April (Table 2.1) and is punctuated with intense, but short-lived rain events. During our study the wet season began in November as well. Additionally, changes in stream discharge coincide with occurrence of rain events, as runoff increases stream volume on time scales of minutes to hours (De Carlo et al. 2007; Tomlinson and De Carlo 2003) (Fig. 3.22).

A principle goal of this study was to intensively sample the first rain event that exceeded 5.08 cm of rainfall in 24 hours, defining it as the first storm of the wet season, or the first-flush storm. Sampling the first-flush storm event was important because coastal marine biogeochemistry has been shown to dramatically change as a result of increased nutrient loads delivered through storm runoff (Cox et al. 2006; De Carlo et al. 2007; Drupp et al. 2011; Hoover and Mackenzie 2009; Hoover et al. 2006; Ringuet and Mackenzie 2005; Schlesinger 1997). To capture the effects of the first-flush storm event in He‘eia Fishpond a rigorous water sampling and sediment collection effort commenced on 11/05/07, 24 hours after the storm threshold was exceeded, and continued through 11/17/07. Water samples were collected using the monthly sampling regimen on the first and last day of sampling (Figs. 1.7 and 1.9), while higher frequency (daily) storm sampling was conducted, at a reduced number of sites (Fig. 1.8), to track the progression of the freshwater plume within the fishpond on days 2-7 (11/06/07-11/11/07) following the onset of the first-flush storm. Surface sediments (0-4 cm depth) were collected on 11/07/07 and 11/11/07 using push cores, and have been stored for further analysis.

Mean monthly water column nutrient inventories in He‘eia Fishpond are fairly invariant throughout the year, except during storm events. The impact of Storm 1 on nutrient delivery to He‘eia Fishpond is clearly revealed by the 8-fold increase in DIN ($NH_4^+ + NO_3^- + NO_2^-$) concentration above background observed on 11/05/07 (Fig. 3.23). Enhanced storm delivery of DIP (PO_4^{3-}) to He‘eia Fishpond is not as pronounced as that of DIN (Fig. 3.24). We attribute lower storm DIP concentrations to particle buffering (Froelich 1988), as previously discussed.

He‘eia Fishpond water column DIN:DIP ratios increase from a mean background value of 13.51 (+/-13.11) to a mean value of 27.64 (+/-16.33) during the first-flush storm, Storm 1. The increase in DIN:DIP is a result of high DIN loading and low DIP loading from freshwater runoff. Traditionally the Redfield ratio of 16:1, DIN to DIP, has been used to describe the ratio at which optimal phytoplankton growth occurs (Redfield et al. 1963). A ratio that exceeds 16:1 suggests insufficient DIP and a ratio lower than 16:1 suggests insufficient DIN to promote optimal phytoplankton growth (Redfield et al. 1963; Hecky and Kilham 1988). During background conditions, water column DIN:DIP ratios suggest that the fishpond may be N-limited, while during the days following Storm 1, water column DIN:DIP ratios suggest possible P-limitation. This reversal of nutrient limitation following storm events, from N- to P-limitation, has been suggested in other studies in Kane‘ohe Bay (Hoover and Mackenzie 2009; Ringuet and Mackenzie 2005).

The first-flush storm signal in He‘eia Fishpond persisted between 7-14 days. Elevated storm derived nutrient inventories within the fishpond are short lived, as phytoplankton uptake and water column mixing return nutrient concentrations to background levels by 11/17/07, 12 days post-storm. A large increase in chlorophyll-a concentration after Storm 1 suggests that phytoplankton may be the primary driver in consuming storm-derived dissolved nutrients in the water column (Fig. 3.25), and that tidal flushing of the post-storm freshwater plume was of secondary importance in drawing elevated storm-derived nutrients back to pre-storm values. Phytoplankton uptake of nutrients is discussed further in Chapter 5.

Comparison to Kane‘ohe Bay Studies

Fluvial inputs of freshwater, suspended particulates, and dissolved nutrients can affect near shore water column biogeochemistry. Numerous studies have investigated the effects of land-derived runoff on the coastal marine ecosystem of Kane‘ohe Bay, and how the magnitude and frequency of storm events may impact water column biogeochemistry and phytoplankton community structure (Cox et al. 2006; De Carlo et al. 2007; Drupp et al. 2011; Hoover and Mackenzie 2009; Hoover et al. 2006; Ringuet and Mackenzie 2005; Smith et al. 1981). The Hawaiian Islands, like other tropical environments, are subject to distinct seasonal changes in the amount of rainfall received. Storms in Hawai‘i, as in other tropical ecosystems, occur as short-lived events and can account for up to 80% of the total annual load of nutrients and sediments delivered to the coastal ocean (Eyre 1995).

Mean water column baseline and storm concentrations of NH_4^+, ($NO_3^- + NO_2^-$), PO_4^{3-}, and H_4SiO_4 reported by Ringuet and Mackenzie (2005), Cox et al. (2006), De Carlo et al. (2007), and Drupp et al. (2011) in Kaneʻohe Bay are summarized in Table 3.2, and contrasted to inorganic nutrient concentrations measured within Heʻeia Fishpond over the course of this study. Each data set was reported in a different format, and each derived from different sample site locations. Therefore, in assembling Table 3.2, every effort was made to best represent the most relevant data from each study, as it related to our research in Heʻeia Fishpond. The data from Ringuet and Mackenzie (2005) is from a southern Kaneʻohe Bay site, identified as D-buoy. The Mid-Plume (MP) sample site described by Cox et al. (2006) is situated near the mouth of Kaneʻohe Stream. De Carlo et al. (2007) sampled southern Kaneʻohe Bay at C-buoy; Drupp et al. (2011) also sampled near the C-buoy, using their Coral Reef Instrumented Monitoring Platform-CO_2 (CRIMP-CO_2) buoy. All four locations are located within southern Kaneʻohe Bay, and all are affected by land-derived inputs during storm events.

Unlike the other data sets summarized in Table 3.2, the data reported by De Carlo et al. (2007) did not distinguish between data collected during baseline vs. storm conditions, and Drupp et al. (2011) merely distinguished between summer (dry season) and winter (wet season) conditions. For the purposes of comparison to our data set and the other studies summarized in Table 3.2, we partitioned the C-buoy data reported by De Carlo et al. (2007) into baseline and storm conditions on the basis of salinity values reported in their study. Baseline conditions were assumed to occur when salinity values at C-buoy were high (02/24/2004, 34.23 PSU), and storm conditions were assumed during times when salinity values were at a minimum (12/01/2003, 13.76 PSU). For Drupp et al. (2011), baseline conditions were assumed to be equivalent to the summer data set and storm conditions were assumed to be equivalent to winter data.

As the data reported by the other studies summarized in Table 3.2 were derived from Kane‘ohe Bay, we limit our Kane‘ohe Bay comparison to data from the marine endmember of our study, which was taken just outside the He‘eia Fishpond kuapā, and thus within Kane‘ohe Bay. Baseline NH_4^+ levels are elevated in the He’eia Fishpond marine endmember site relative to baseline data at D-buoy and the MP site. This is likely because this sample includes some overflow from the fishpond, which is characterized by higher NH_4^+ concentrations than the more oligotrophic Kane‘ohe Bay. The baseline NH_4^+ from C-buoy reported by De Carlo et al. (2007) seem unreasonably high and we wonder whether these high reported levels may be due to analytical artifact. Storm values are substantially higher in our study than in the others and, again, this may be explained by the close proximity of our site to the fishpond. Interestingly, storm values at the MP and C-buoy sites were lower than baseline. Note that we cannot contrast storm vs. baseline nitrogen (N) data for D-buoy because Ringuet and Mackenzie (2005) combined all of their N data into DIN, and did not report values for individual DIN species. Baseline (NO_3^-+NO_2^-) data from the He‘eia Fishpond marine endmember is higher than baseline (NO_3^- +NO_2^-) reported for the other Kane‘ohe Bay sites, and like the NH_4^+ data can be explained by overflow from He‘eia Fishpond. Storm (NO_3^-+NO_2^-) is elevated relative to baseline for all Kane‘ohe Bay sites except for Drupp et al. (2011). This contrast is most extreme for C-buoy concentrations. Phosphate concentrations are lower during baseline than storm conditions for all sites, again, except for Drupp et al. (2011). Baseline phosphate data is most similar for the He‘eia Fishpond and C-buoy sites, both of which show slightly higher concentrations than the D-buoy, MP, or CRIMP-CO_2 sites. While storm phosphate concentrations are higher than baseline for all sites, this contrast is most extreme for D-buoy, and least pronounced for the MP site. Storm phosphate concentrations at the He‘eia Fishpond marine endmember site are lower than both C-buoy and D-buoy; this may be due to a higher particulate load in the water column more proximal to the fishpond. Baseline silicate values are quite variable across all sites, but in all cases are lower than storm values, with the exception of the MP site. In summary, the general trend of lower nutrient concentrations during baseline conditions, and higher nutrient concentrations during storm conditions, is fairly consistent across four of the five studies, consistent with the well-accepted model that storm events load coastal waters with an elevated (relative to baseline) but ephemeral inventory of dissolved nutrients. The variability seen among the studies during both baseline and storm conditions most likely reflects local conditions both in the adjacent watersheds, as well as the position of the sample site relative to the point source of land-derived inputs.

Table 3.1. Detection limits and precision of methods used to determine dissolved nutrients.

Analyte	Method	Detection Limit	Precision
NH_4^+	Seal Analytical AA3 Auto-analyzer	0.92 µM	0.5%
$(NO_3^- + NO_2^-)$		0.05 µM	0.5%
PO_4^{3-}		0.07 µM	0.5%
H_4SiO_4	Bio-Tek Synergy HT Plate Reader	1 µM	2%
DOC	Shimadzu model TOC-V	4 µg/L	6 maximum injections stnd. dev. +/- 0.1 coeff. of variation <2%
TDN	Shimadzu model TNM-1	4 µg/L	5 maximum injections stnd. dev. +/- 0.1 coeff. of variation <2%
TDP	High Temperature Ashing	0.06 µM	0.02 µM

Table 3.2. Comparison of mean water column dissolved inorganic nutrient concentrations for studies conducted in southern Kane‘ohe Bay. Concentrations in units of μM.

Study	Sample Site	NH_4^+	$NO_3^- + NO_2^-$	PO_4^{3-}	H_4SiO_4
He‘eia Fishpond (this study)					
Baseline (n = 24)	Freshwater Endmember, He‘eia Stream	7.58	0.16	0.89	387.30
Storm (n = 5)	Freshwater Endmember, He‘eia Stream	11.98	3.45	0.83	295.50
Baseline (n = 240)	He‘eia Fishpond	3.22	0.19	0.32	53.69
Storm (n = 66)	He‘eia Fishpond	10.42	5.51	0.68	132.55
Baseline (n=12)	Marine Endmember, Kane‘ohe Bay	2.12	0.30	0.23	22.83
Storm (n = 2)	Marine Endmember, Kane‘ohe Bay	12.70	0.68	0.39	78.59
Ringuet and Mackenzie[*]					
Baseline (n = 29)	D-buoy, Kane‘ohe Bay	0.21	0.12	0.12	7.08
02/2003 Storm (n = 1)	D-buoy, Kane‘ohe Bay	**DIN** = 25.73		0.99	88.00
Cox et al.[**]					
Baseline (n = N/A)	MP site, Kane‘ohe Bay	0.12	**NO_3^-** = 0.13	0.05	20.00
Storm (n = N/A)	MP site, Kane‘ohe Bay	0.09	**NO_3^-** = 0.23	0.08	15.00
De Carlo et al.[***]					
Baseline (n = 1)	C-buoy, Kane‘ohe Bay	15.74	0.05	0.25	1.2
Storm (n = 1)	C-buoy, Kane‘ohe Bay	0.59	34.30	0.85	106.2
Drupp et al.[****]					
Baseline	CRIMP-CO2, Kane‘ohe Bay	0.82 (n = 12)	1.33 (n = 18)	0.28 (n = 15)	28.58 (n = 15)
Storm	CRIMP-CO2, Kane‘ohe Bay	0.75 (n = 29)	1.17 (n = 70)	0.17 (n = 50)	8.34 (n = 53)

[*] Ringuet and Mackenzie (2005) report nutrient concentrations for one storm event only. N species reported as DIN, defined as the sum of $NH_4^+ + NO_3^- + NO_2^-$.

[**] Cox et al. (2006) report NO_3^- concentrations, not $NO_3^- + NO_2^-$.

[***] De Carlo et al. (2007) report nutrient concentrations by a single sample site over the course of their study (11/2003-03/2004). The mean values listed in this table reflect our attempt to group their C-buoy data in order to derive Baseline and storm condition means.

[****] Drupp et al. (2011) report mean nutrient concentrations for winter and summer seasons. These are reflected as baseline and storm values.

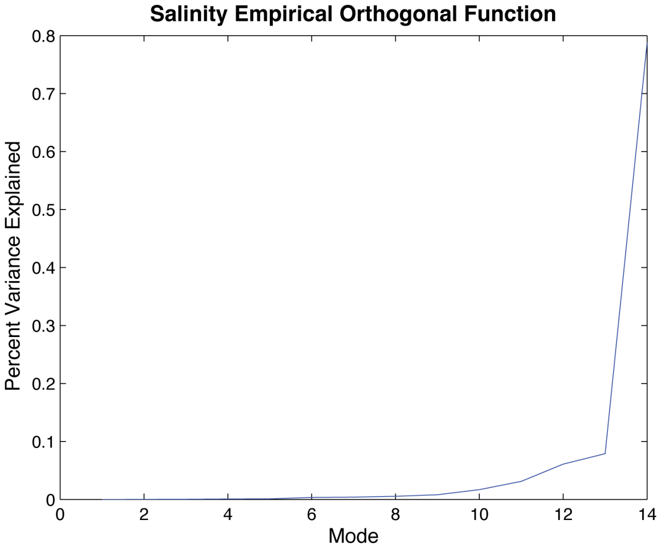


Figure 3.1. Amount of variance explained by each mode obtained from an EOF analysis of the He‘eia Fishpond salinity data set. Fourteen water sample events were evaluated (x-axis).

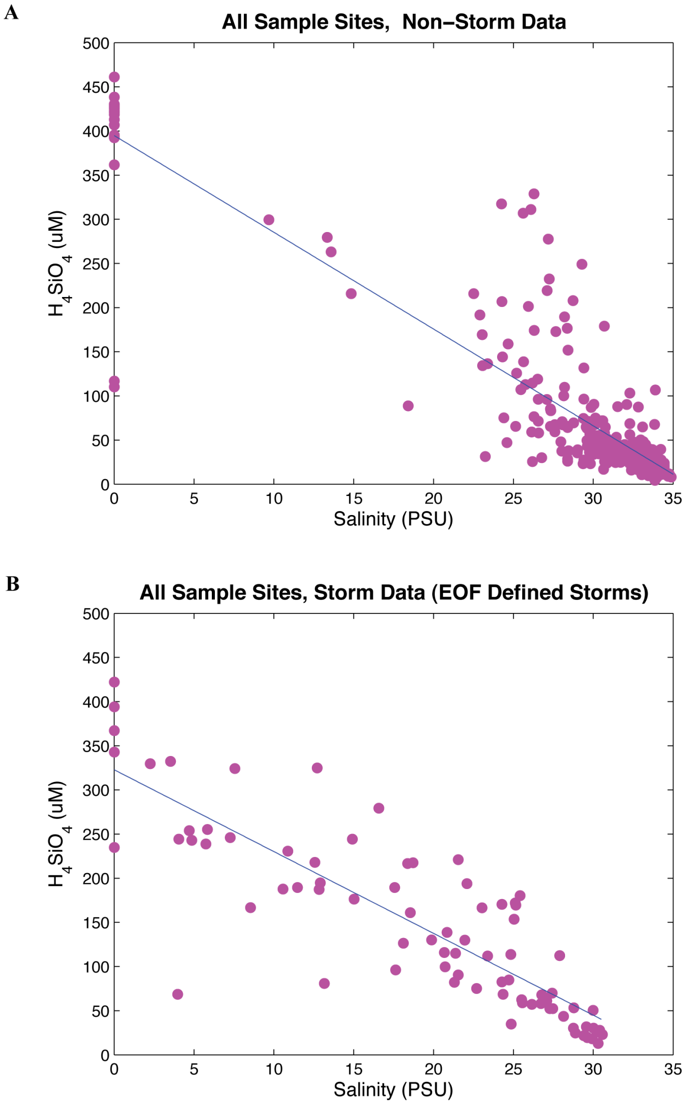


Figure 3.2. Water column H_4SiO_4 data for all sample sites during (A) non-storm monthly sampling events (12 months) and (B) storm sampling events (Storm 1, Transects 1-4, and Storm 4).

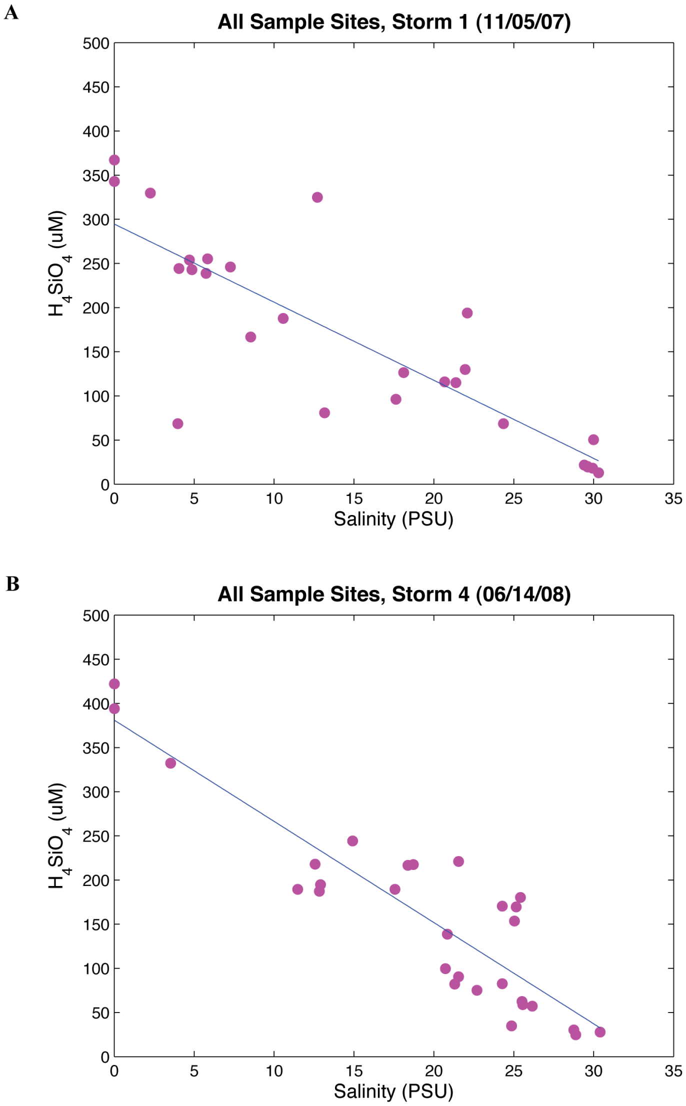


Figure 3.3. Water column H_4SiO_4 data for all sample sites during a (A) wet season storm (Storm 1) and (B) dry season storm (Storm 4).

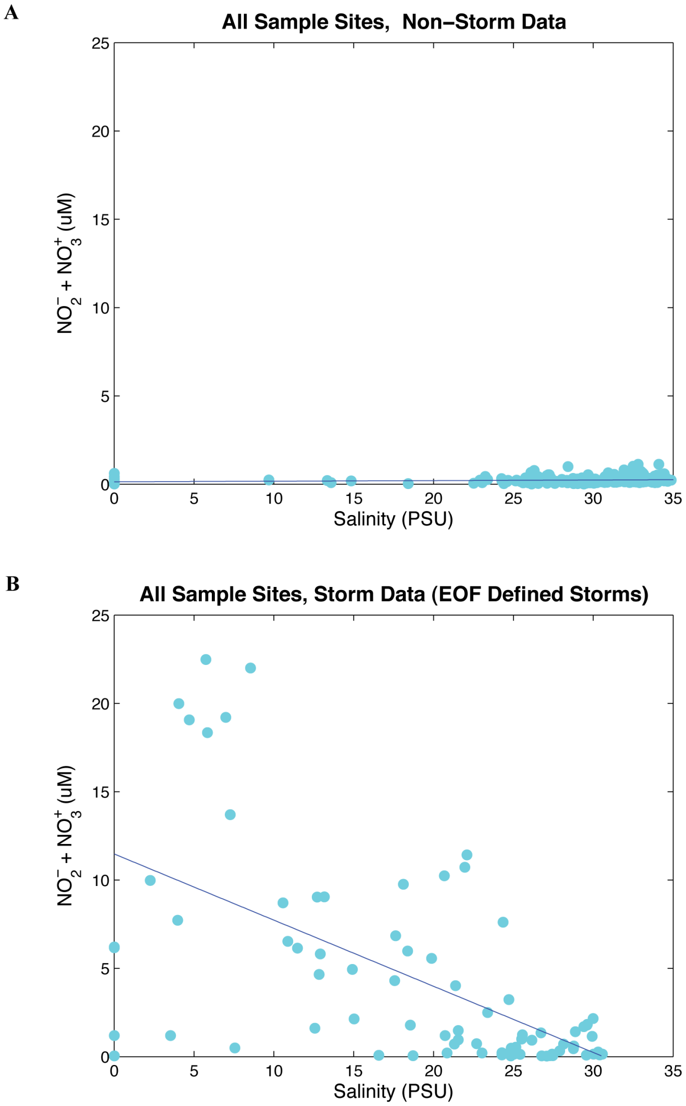


Figure 3.4. Water column (NO_3^- + NO_2^-) data for all sample sites during (A) non-storm monthly sampling events (12 months) and (B) storm sampling events (Storm 1, Transects 1-4, and Storm 4).

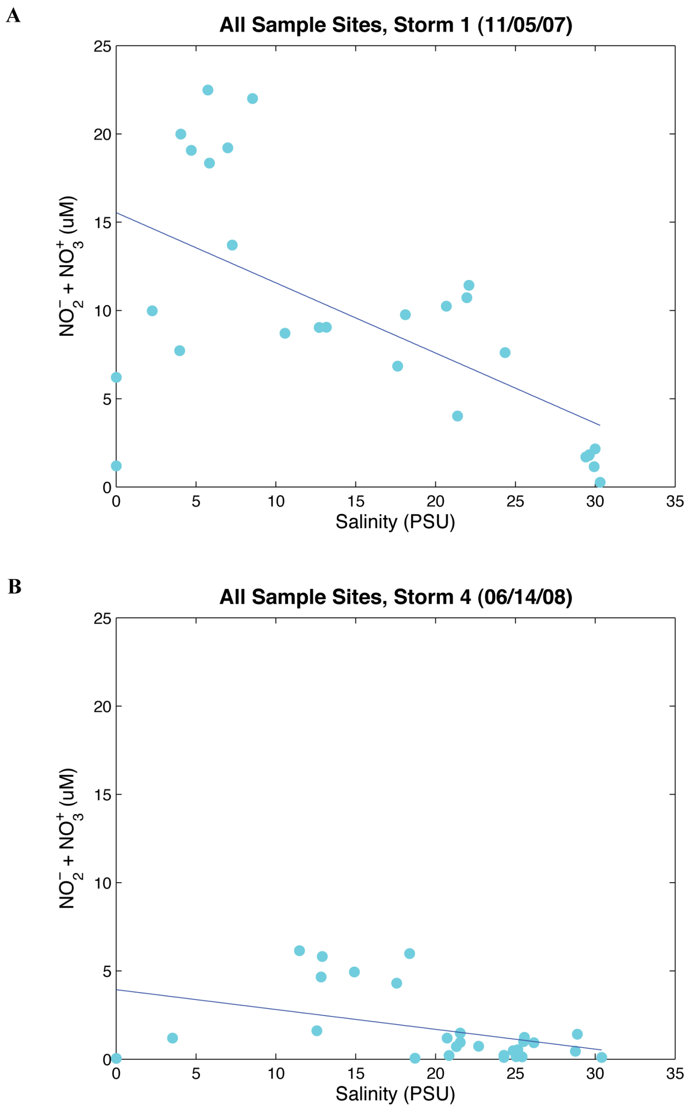


Figure 3.5. Water column (NO_3^- + NO_2^-) data for all sample sites during a (A) wet season storm (Storm 1) and (B) dry season storm (Storm 4).

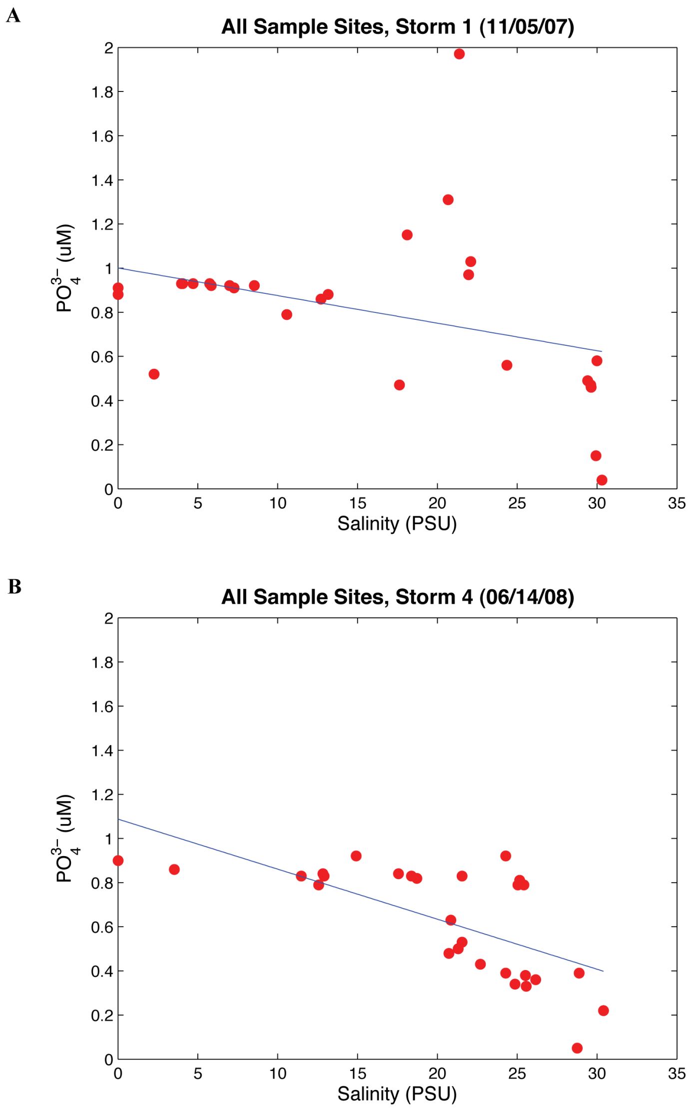


Figure 3.6. Water column PO_4^{3-} data for all sample sites during a (A) wet season storm (Storm 1) and (B) dry season storm (Storm 4).

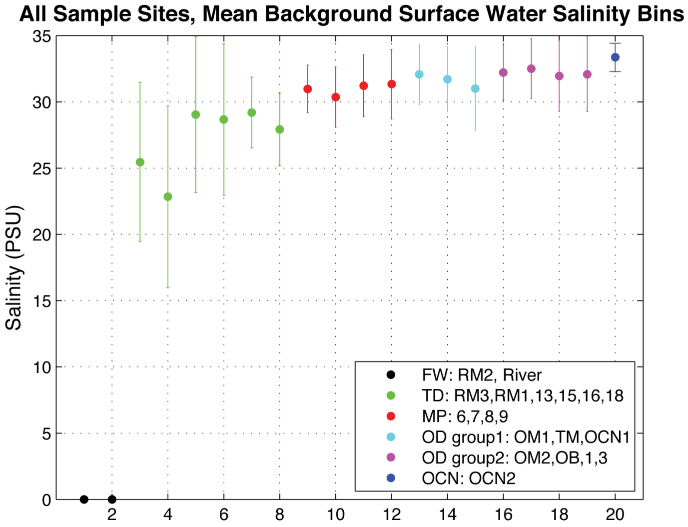


Figure 3.7. Mean annual baseline surface water salinity (PSU) and standard deviation for each sample site (12 months; n=12). Sample sites are organized by increasing salinity with freshwater end members on the left and seawater end member on the right. FW=Freshwater Sites, TD=Terrigenous Dominated Sites, MP=Mid-pond Sites, OD group1=Ocean Dominated group 1, OD group2=Ocean Dominated group 2, and OCN=Ocean Site. Binned sample sites are identified by color. X-axis numbers are assigned to sample site (**1=RM2, 2=River**, **3=RM3**, **4=RM1**, **5=Stk13**, **6=Stk15**, **7=Stk16**, **8=Stk18**, **9=Stk6**, **10=Stk7**, **11=Stk8**, **12=Stk9**, **13=OM1**, **14=TM**, **15=OCN1**, **16=OM2**, **17=OB**, **18=Stk1**, **19=Stk3**, **20=OCN2**).

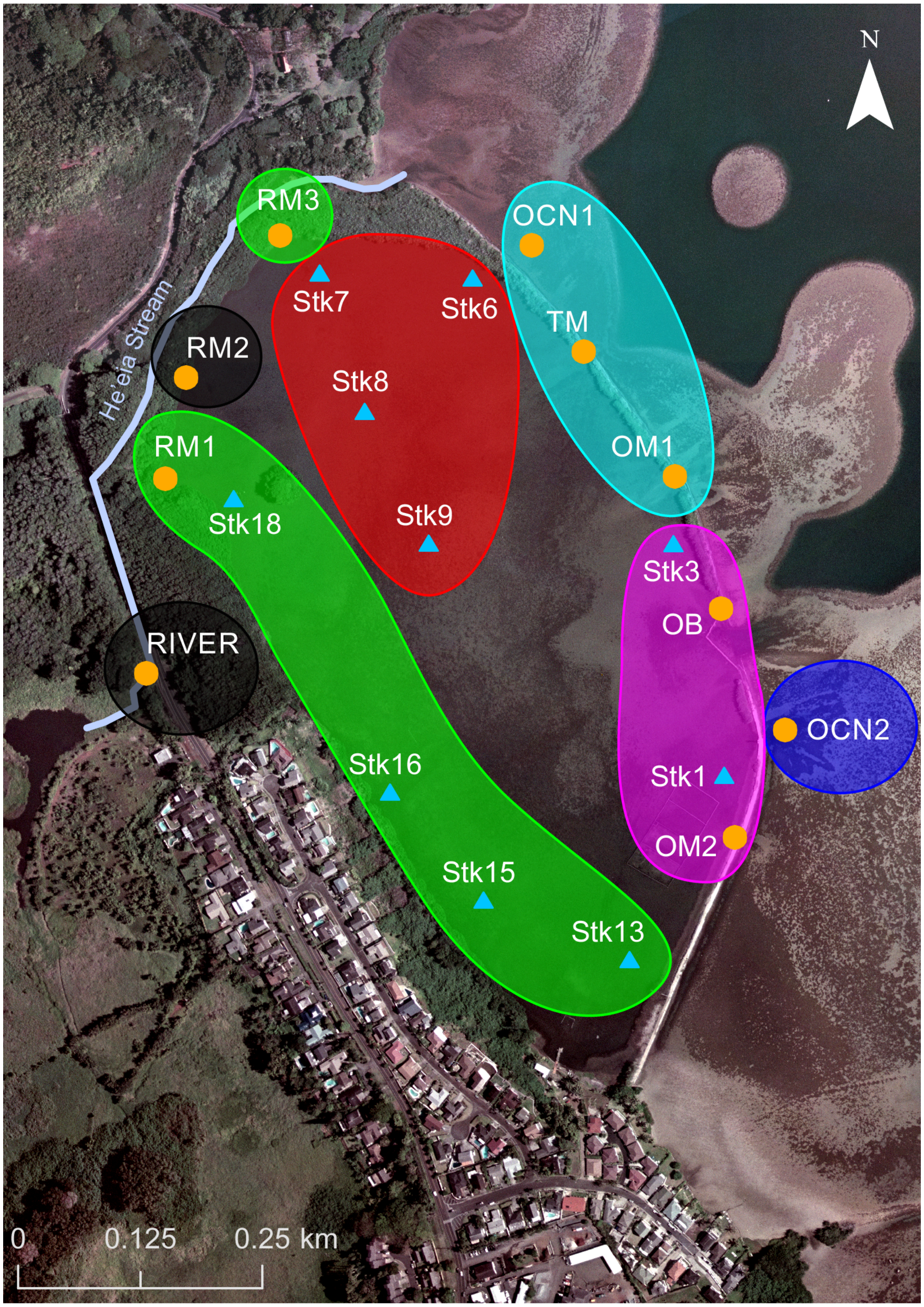


Figure 3.8. Spatial distribution of binned sample sites, grouped according to similarity in mean annual salinity. Black = Freshwater Sites, Green = Terrigenous Dominated Sites, Red = Mid-pond Sites, Cyan = Ocean Dominated group 1, Magenta = Ocean Dominated group 2, and Blue = Ocean Site.

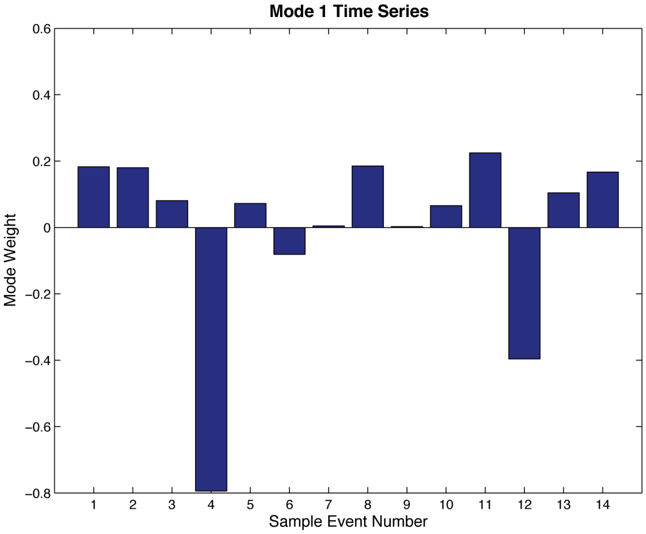


Figure 3.9. Values of Mode 1 time series per sampling event over the course of this study. Sample events are numbered sequentially, over time: (1) 08/11/07, (2) 09/15/07, (3) 10/13/07, (4) 11/05/07, (5) 11/17/07, (6) 12/09/08, (7) 01/12/08, (8) 02/16/08, (9) 03/15/08, (10) 04/19/08, (11) 05/17/08, (12) 06/14/08, (13) 07/26/08, and (14) 08/30/08. Events scoring > 0 show a positive trend about the mean salinity per sampling event. Events scoring < 0 show a negative trend about the mean salinity per sampling event.

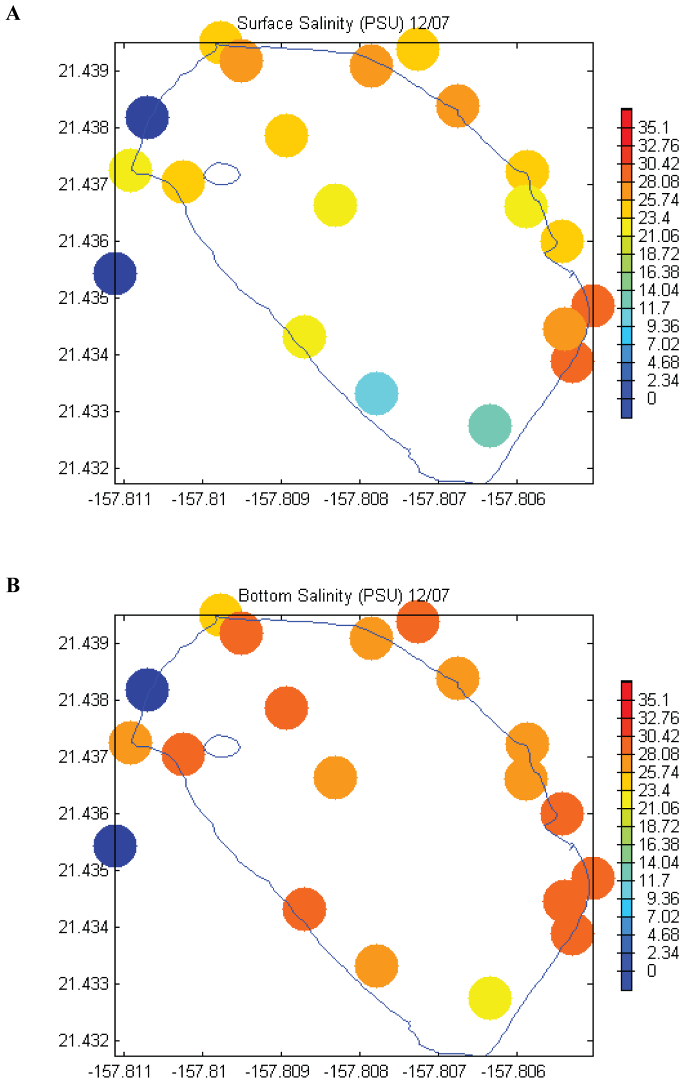


Figure 3.10. Sample site mean (A) surface and (B) deep salinity (PSU) values for the 12/09/07, Storm 2, monthly sampling event. Site locations are geo-referenced to the He‘eia Fishpond perimeter outlined in blue. He‘eia Stream is located to the northwest and Kane‘ohe Bay to the east (see Table 1.2 and Figs. 1.7 and 1.9 for sample site names and locations).

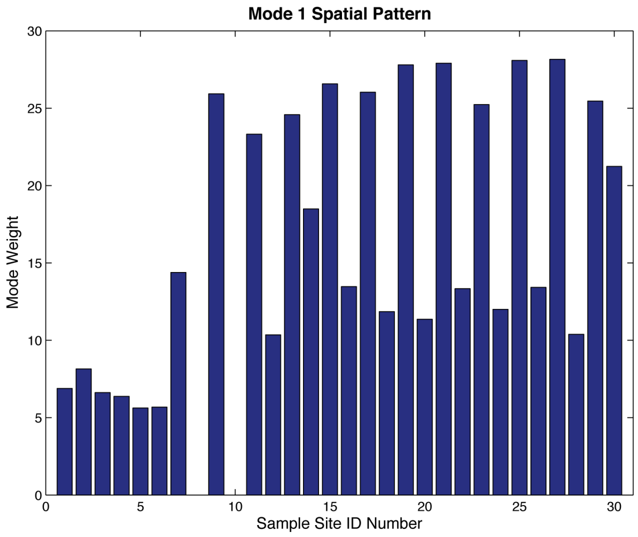
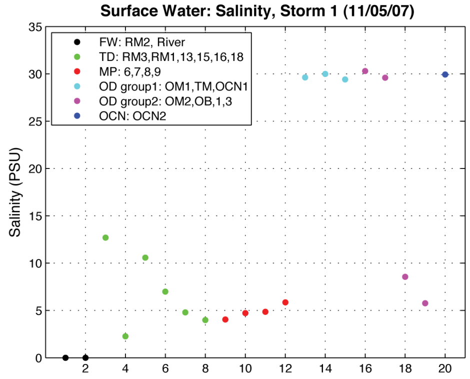


Figure 3.11. Values of Mode 1 spatial pattern per sample site. Sample Site ID Numbers are listed in order of sampling sequence: (1) OM2, (2) OCN2, (3) OB, (4) OM1, (5) TM, (6) OCN1, (7) RM3, (8) RM2, (9) RM1, (10) River, (11) Stk1 sfc, (12) Stk1 deep, (13) Stk3 sfc, (14) Stk3 deep, (15) Stk6 sfc, (16) Stk6 deep, (17) Stk7 sfc, (18) Stk7 deep, (19) Stk8 sfc, (20) Stk8 deep, (21) Stk9 sfc, (22) Stk9 deep, (23) Stk13 sfc, (24) Stk13 deep, (25) Stk15 sfc, (26) Stk15 deep, (27) Stk16 sfc, (28) Stk16 deep, (29) Stk18 sfc, and (30) Stk18 deep. Sample sites 8 and 10 have zero mode weight due to no changes in salinity for the freshwater end-members.

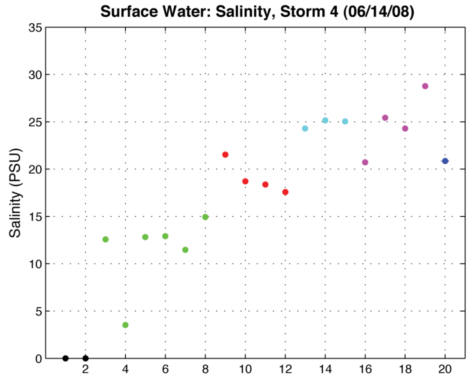
EOF Defined Storm:

A



EOF Defined Storm:

B



C

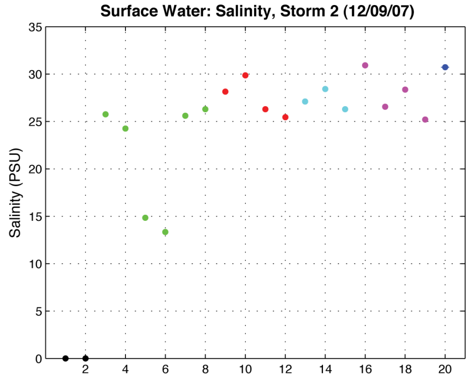


Figure 3.12. Surface water salinity data for all sample sites during the EOF defined storms: (A) wet season storm (Storm 1) and (B) dry season storm (Storm 4). (C) Storm 2 is added for reference and is not an EOF defined storm. Symbol colors follow the color key defined in Figs. 3.7 and 3.8, with each color reflecting binning of sample sites into groups that are characterized by similar mean annual salinity. Numbers on x-axis indicate the 20 sample sites (**1=RM2, 2=River, 3=RM3, 4=RM1, 5=Stk13, 6=Stk15, 7=Stk16, 8=Stk18, 9=Stk6, 10=Stk7, 11=Stk8, 12=Stk9, 13=OM1, 14=TM, 15=OCN1, 16=OM2, 17=OB, 18=Stk1, 19=Stk3, 20=OCN2**).

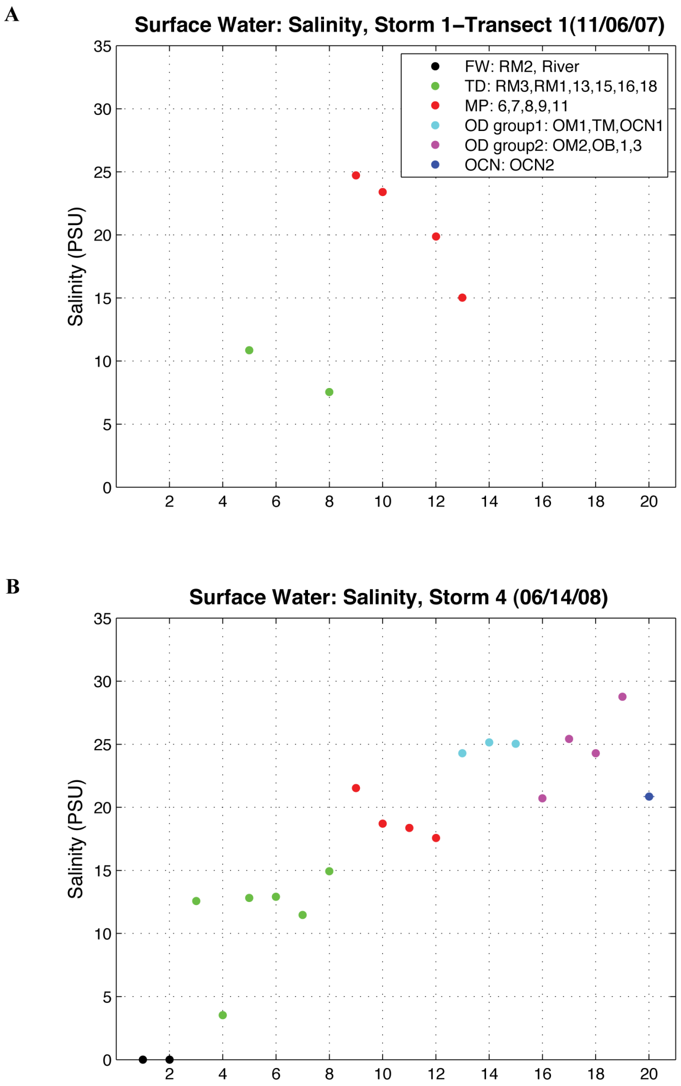
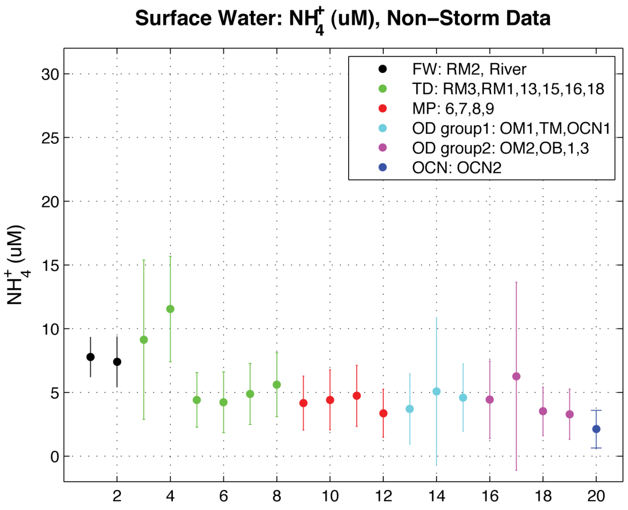


Figure 3.13. Surface water salinity data for all sample sites during (A) Day 2 post-Storm 1 and (B) Storm 4. Color bins are as defined in Figs. 3.7 and 3.8.

Numbers on x-axis indicate (A) Storm 1-Transect 1 sample sites (**5=Stk13**, **8=Stk18**, **9=Stk6**, **10=Stk7**, **12=Stk9**, **13=Stk11**). Note: storm grid sampling plan executed for Storm 1 incorporates Stk11. Stk11 is not part of the monthly sampling scheme (Fig. 1.8), and (B) Storm 4 sample sites (**1=RM2**, **2=River**, **3=RM3**, **4=RM1**, **5=Stk13**, **6=Stk15**, **7=Stk16**, **8=Stk18**, **9=Stk6**, **10=Stk7**, **11=Stk8**, **12=Stk9**, **13=OM1**, **14=TM**, **15=OCN1**, **16=OM2**, **17=OB**, **18=Stk1**, **19=Stk3**, **20=OCN2**). Note: Storm 4 sampling plan follows the monthly sampling scheme (Figs. 1.7 and 1.9).

A



B

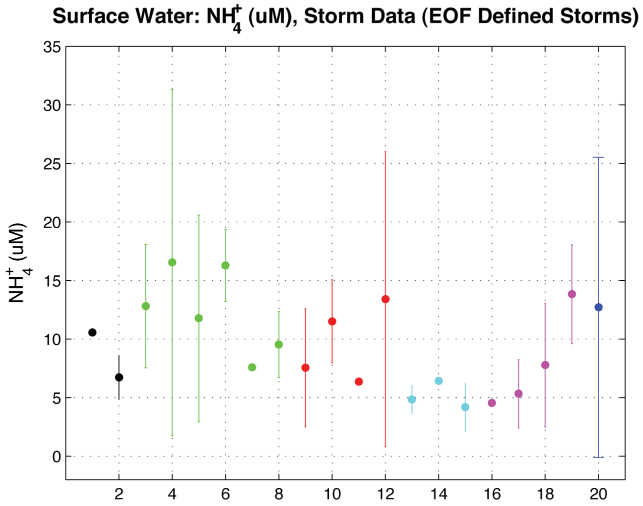


Figure 3.14. Mean surface water NH_4^+ data and standard deviation for each sample site during (A) non-storm monthly sampling events (12 months; n=12) and (B) EOF defined storm sampling events (Storm 1, Transects 1-4, Storm 4; n=6). Symbol colors follow the color key defined in Figs. 3.7 and 3.8, with each color reflecting binning of sample sites into groups that are characterized by similar mean annual salinity. Numbers on x-axis indicate the 20 sample sites (**1=RM2, 2=River, 3=RM3, 4=RM1, 5=Stk13, 6=Stk15, 7=Stk16, 8=Stk18, 9=Stk6, 10=Stk7, 11=Stk8, 12=Stk9, 13=OM1, 14=TM, 15=OCN1, 16=OM2, 17=OB, 18=Stk1, 19=Stk3, 20=OCN2**).

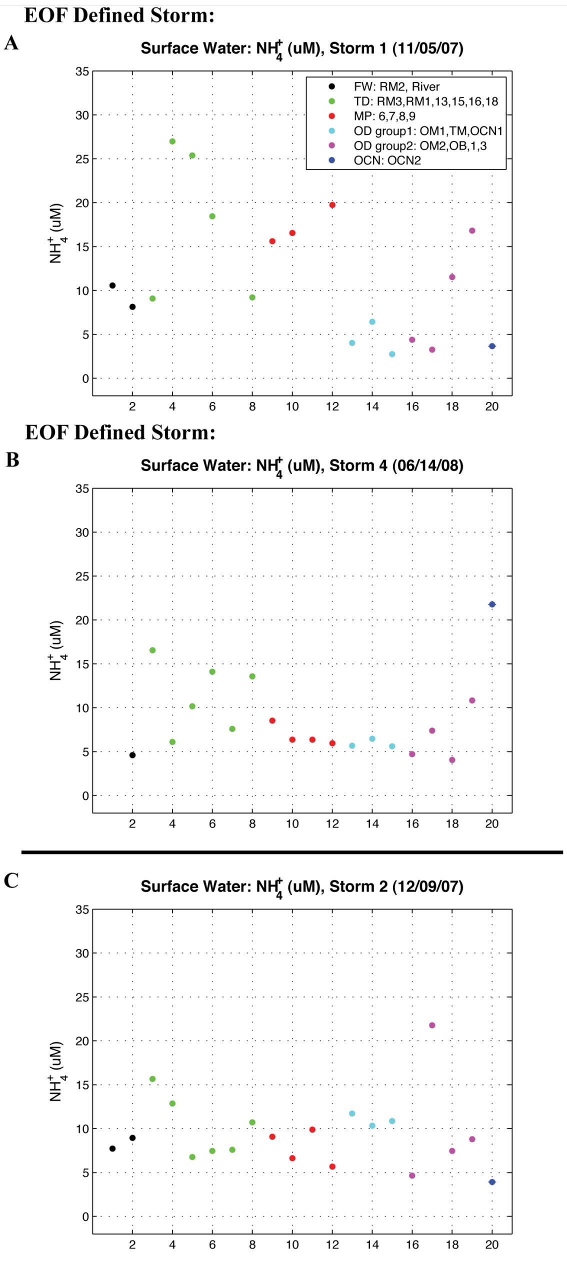


Figure 3.15. Surface water NH_4^+ data for all sample sites during the EOF defined storms: (A) wet season storm (Storm 1) and (B) dry season storm (Storm 4). (C) Storm 2 is added for reference and is not an EOF defined storm. Symbol colors follow the color key defined in Figs. 3.7 and 3.8, with each color reflecting binning of sample sites into groups that are characterized by similar mean annual salinity. Numbers on x-axis indicate the 20 sample sites (**1=RM2**, **2=River**, **3=RM3**, **4=RM1**, **5=Stk13**, **6=Stk15**, **7=Stk16**, **8=Stk18**, **9=Stk6**, **10=Stk7**, **11=Stk8**, **12=Stk9**, **13=OM1**, **14=TM**, **15=OCN1**, **16=OM2**, **17=OB**, **18=Stk1**, **19=Stk3**, **20=OCN2**).

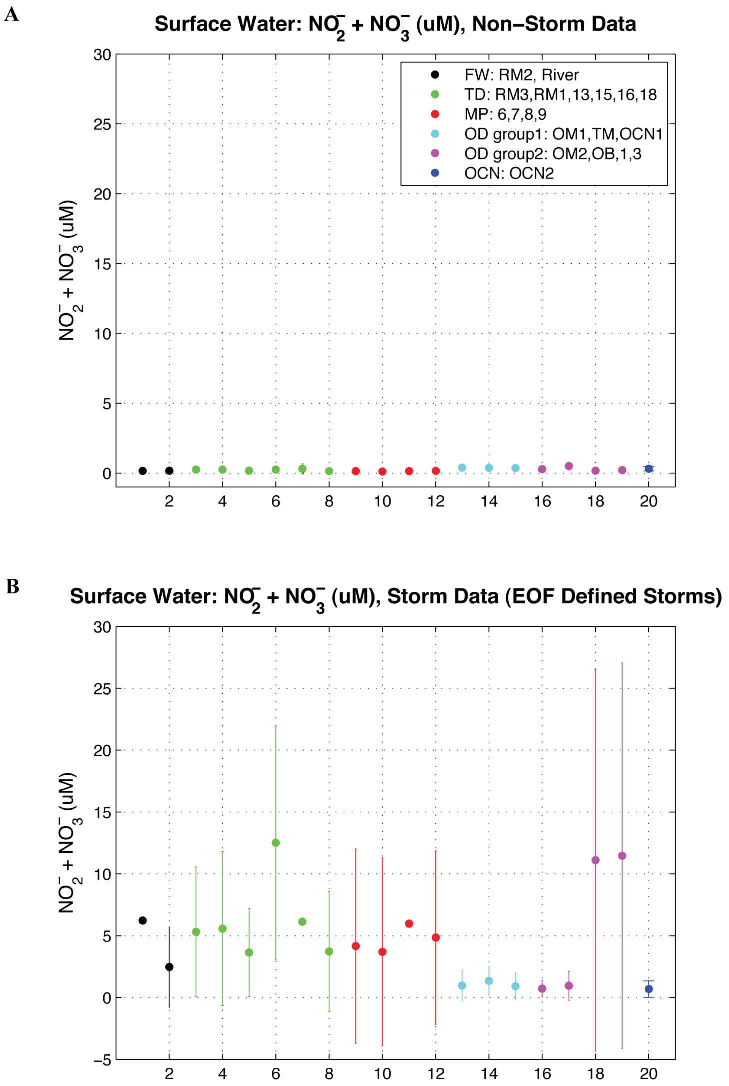
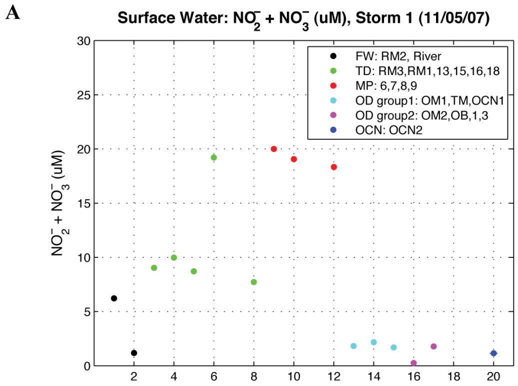
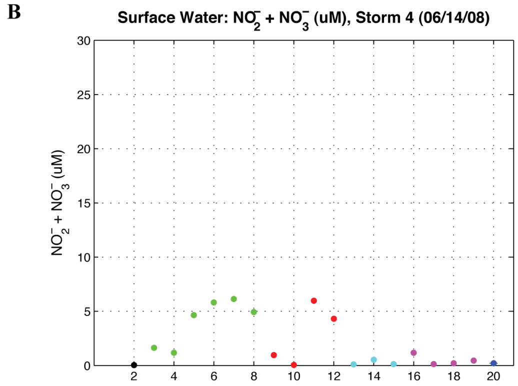


Figure 3.16. Mean surface water ($NO_3^- + NO_2^-$) data and standard deviation for each sample site during (A) non-storm monthly sampling events (12 months; n=12) and (B) storm sampling events (Storm 1, Transects 1-4, and Storm 4; n=6). Symbol colors follow the color key defined in Figs. 3.7 and 3.8, with each color reflecting binning of sample sites into groups that are characterized by similar mean annual salinity. Numbers on x-axis indicate the 20 sample sites (**1=RM2, 2=River, 3=RM3, 4=RM1, 5=Stk13, 6=Stk15, 7=Stk16, 8=Stk18, 9=Stk6, 10=Stk7, 11=Stk8, 12=Stk9, 13=OM1, 14=TM, 15=OCN1, 16=OM2, 17=OB, 18=Stk1, 19=Stk3, 20=OCN2**).

EOF Defined Storm:



EOF Defined Storm:



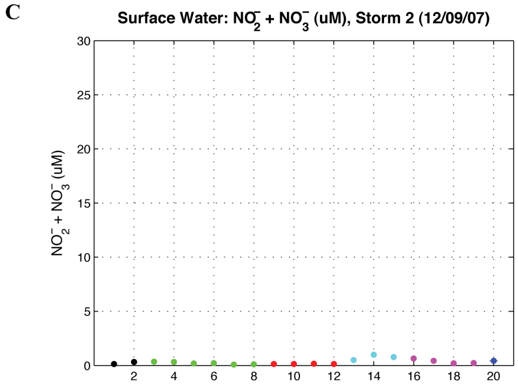


Figure 3.17. Surface water (NO_3^- + NO_2^-) data for all sample sites during the EOF defined storms: (A) wet season storm (Storm 1) and (B) dry season storm (Storm 4). (C) Storm 2 is added for reference and is not an EOF defined storm. Symbol colors follow the color key defined in Figs. 3.7 and 3.8, with each color reflecting binning of sample sites into groups that are characterized by similar mean annual salinity. Numbers on x-axis indicate the 20 sample sites (**1=RM2, 2=River,** **3=RM3**, **4=RM1**, **5=Stk13**, **6=Stk15**, **7=Stk16**, **8=Stk18**, **9=Stk6**, **10=Stk7**, **11=Stk8**, **12=Stk9**, **13=OM1**, **14=TM**, **15=OCN1**, **16=OM2**, **17=OB**, **18=Stk1**, **19=Stk3**, **20=OCN2**).

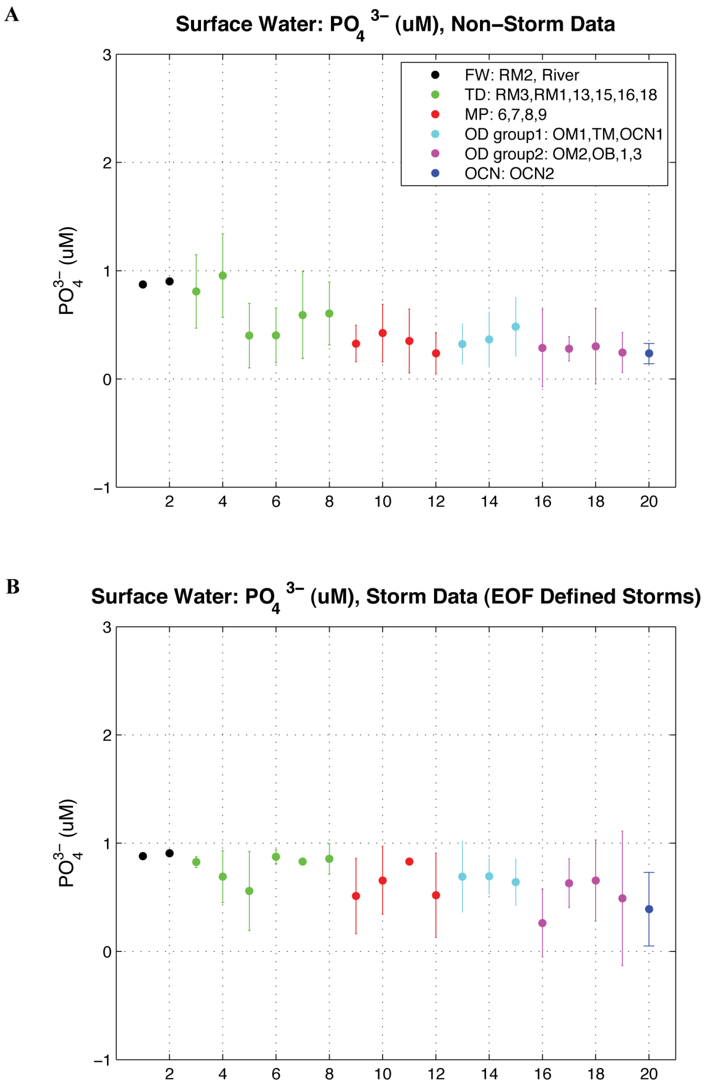
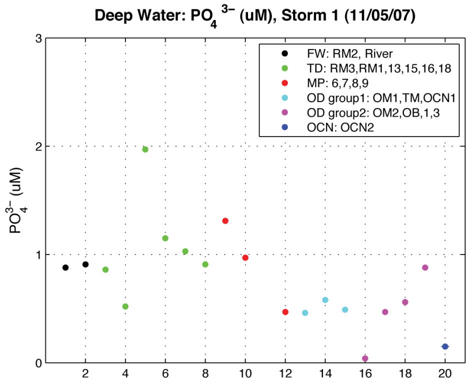


Figure 3.18. Mean surface water PO_4^{3-} data and standard deviation for each sample site during (A) non-storm monthly sampling events (12 months; n=12) and (B) storm sampling events (Storm 1, Transects 1-4, and Storm 4; n=6). Symbol colors follow the color key defined in Figs. 3.7 and 3.8, with each color reflecting binning of sample sites into groups that are characterized by similar mean annual salinity. Numbers on x-axis indicate the 20 sample sites (**1=RM2**, **2=River**, **3=RM3**, **4=RM1**, **5=Stk13**, **6=Stk15**, **7=Stk16**, **8=Stk18**, **9=Stk6**, **10=Stk7**, **11=Stk8**, **12=Stk9**, **13=OM1**, **14=TM**, **15=OCN1**, **16=OM2**, **17=OB**, **18=Stk1**, **19=Stk3**, **20=OCN2**).

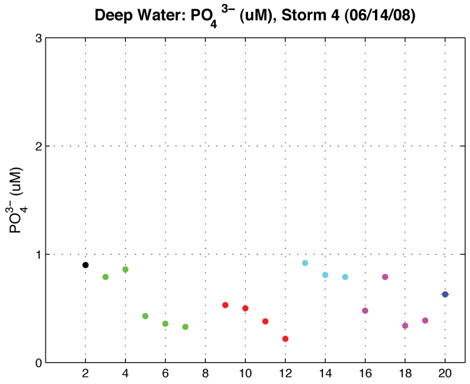
EOF Defined Storm:

A



EOF Defined Storm:

B



C

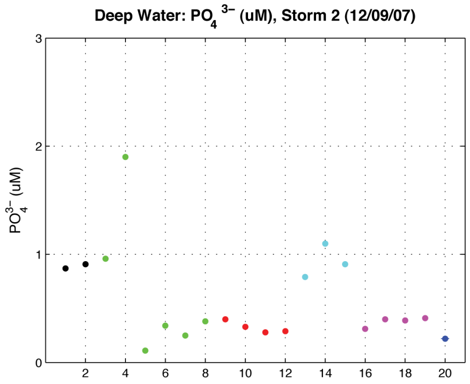


Figure 3.19. Near bottom (deep) water PO$_4^{3-}$ data for all sample sites during the EOF defined storms: (A) wet season storm (Storm 1) and (B) dry season storm (Storm 4). (C) Storm 2 is added for reference and is not an EOF defined storm. Symbol colors follow the color key defined in Figs. 3.7 and 3.8, with each color reflecting binning of sample sites into groups that are characterized by similar mean annual salinity. Numbers on x-axis indicate the 20 sample sites (**1=RM2, 2=River, 3=RM3, 4=RM1, 5=Stk13, 6=Stk15, 7=Stk16, 8=Stk18, 9=Stk6, 10=Stk7, 11=Stk8, 12=Stk9, 13=OM1, 14=TM, 15=OCN1, 16=OM2, 17=OB, 18=Stk1, 19=Stk3, 20=OCN2**).

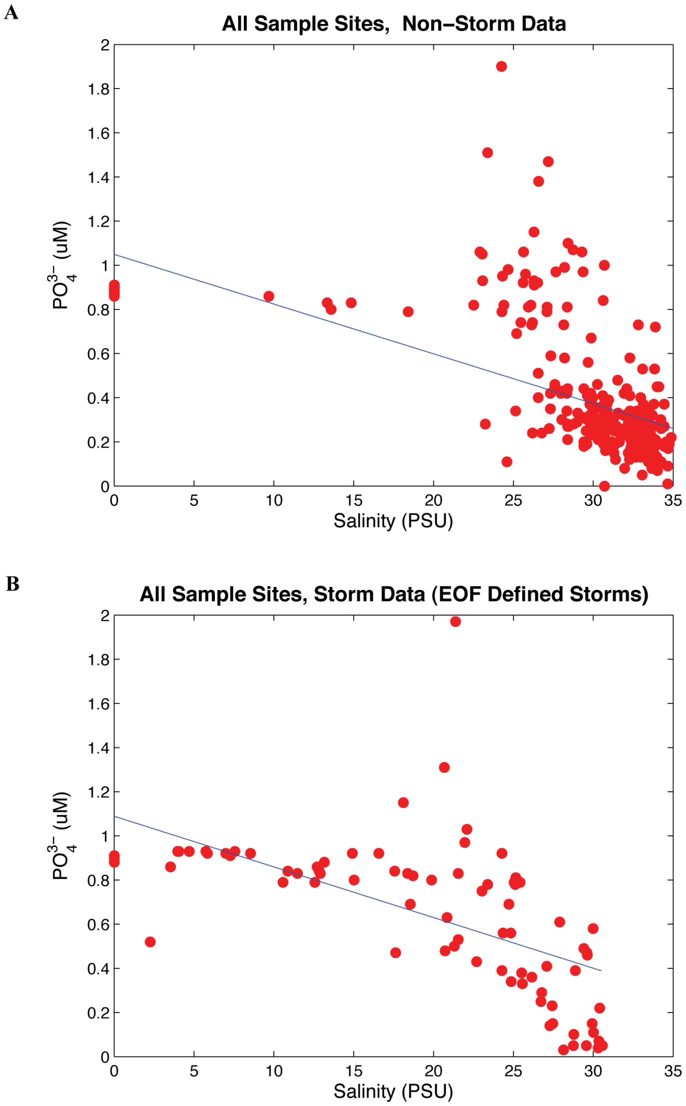


Figure 3.20. Water column PO_4^{3-} concentrations plotted vs. salinity for all sample sites during (A) non-storm monthly sampling events (12 months) and (B) storm sampling events (Storm 1, Transects 1-4, and Storm 4). The relatively invariant PO_4^{3-} concentrations that occur 0-22 PSU are the result of the phosphate buffer mechanism (see text for discussion).

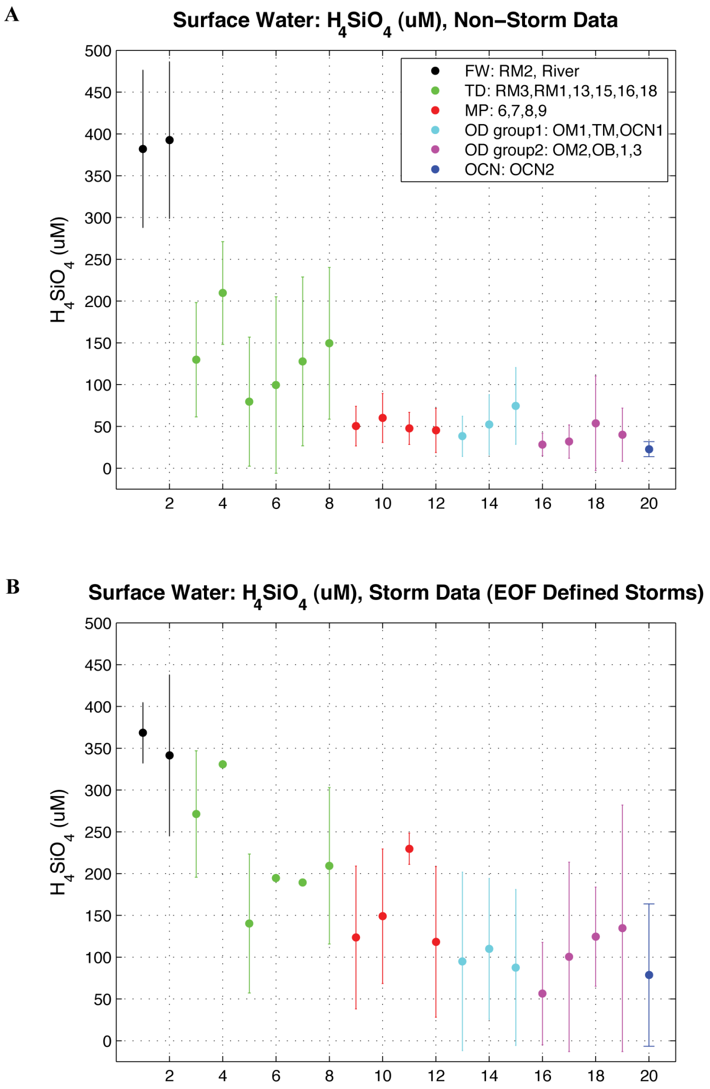


Figure 3.21. Mean surface water H_4SiO_4 data and standard deviation for each sample site during (A) non-storm monthly sampling events (12 months; n=12) and (B) storm sampling events (Storm 1, Transects 1-4, and Storm 4; n=6). Symbol colors follow the color key defined in Figs. 3.7 and 3.8, with each color reflecting binning of sample sites into groups that are characterized by similar mean annual salinity. Numbers on x-axis indicate the 20 sample sites (**1=RM2**, **2=River**, **3=RM3**, **4=RM1**, **5=Stk13**, **6=Stk15**, **7=Stk16**, **8=Stk18**, **9=Stk6**, **10=Stk7**, **11=Stk8**, **12=Stk9**, **13=OM1**, **14=TM**, **15=OCN1**, **16=OM2**, **17=OB**, **18=Stk1**, **19=Stk3**, **20=OCN2**).

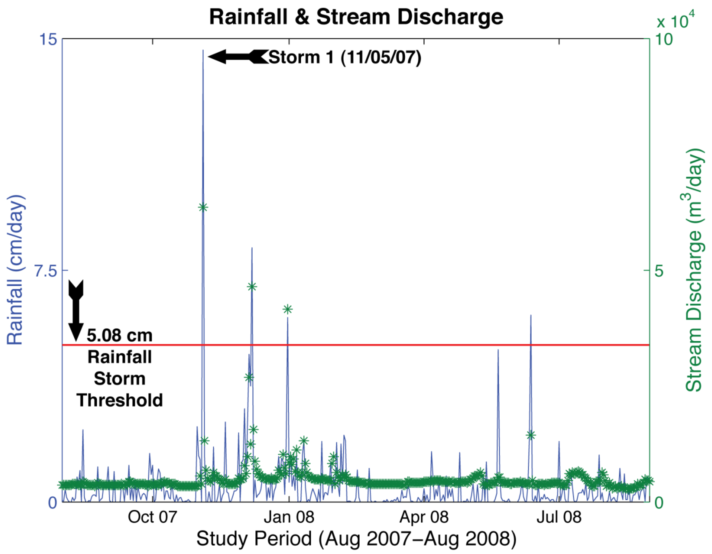


Figure 3.22. Daily rainfall, as measured by NOAA Luluku Station (HI-15), and daily Ha‘iku Stream discharge, as measured by USGS gauge station #16275000, over the course of this study: Aug 01, 2007-Aug 31, 2008. The first-flush storm, Storm 1, is identified by date and 5.08 cm of rainfall is identified by the red horizontal line and labeled as “Rainfall Storm Threshold.”

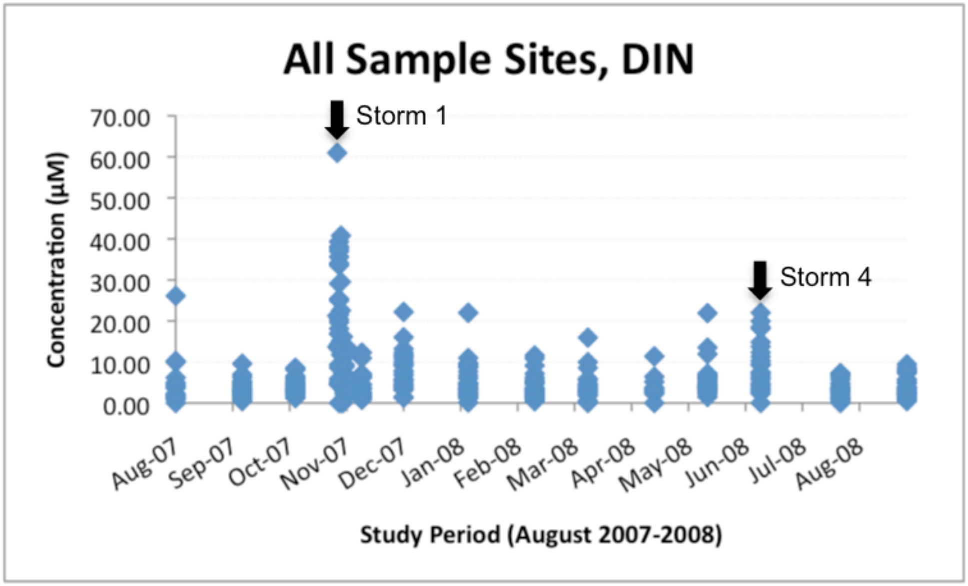


Figure 3.23. DIN ($NH_4^+ + NO_3^- + NO_2^-$) concentrations of all sample sites over the course of this study: Aug 01, 2007-Aug 31, 2008. DIN results from the wet season, first-flush storm, Storm 1, is identified on 11/05/07 and the dry season storm, Storm 4, is identified on 06/14/08 with black arrows.

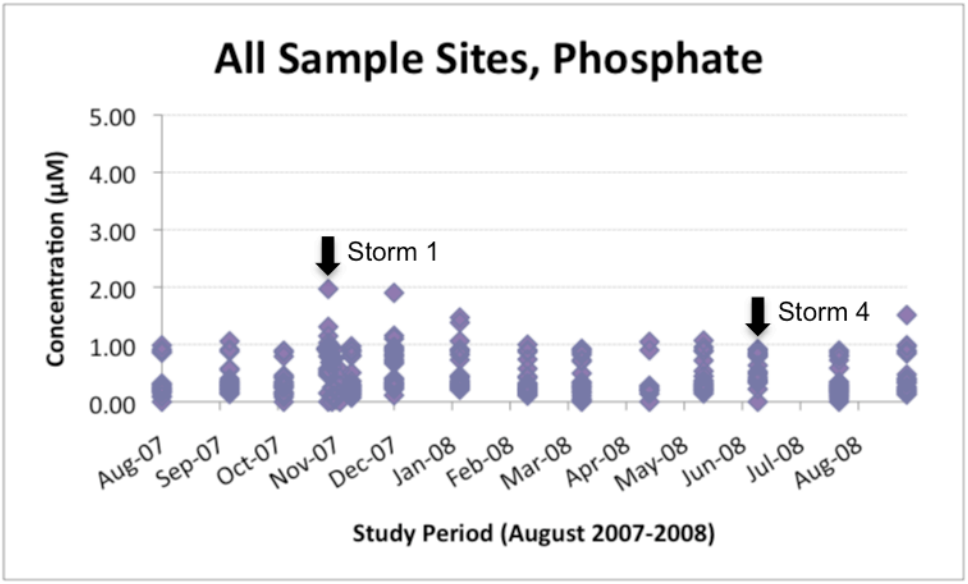


Figure 3.24. DIP (PO_4^{3-}) concentrations of all sample sites over the course of this study: Aug 01, 2007-Aug 31, 2008. DIP results from the wet season, first-flush storm, Storm 1, is identified on 11/05/07 and the dry season storm, Storm 4, is identified on 06/14/08 with black arrows.

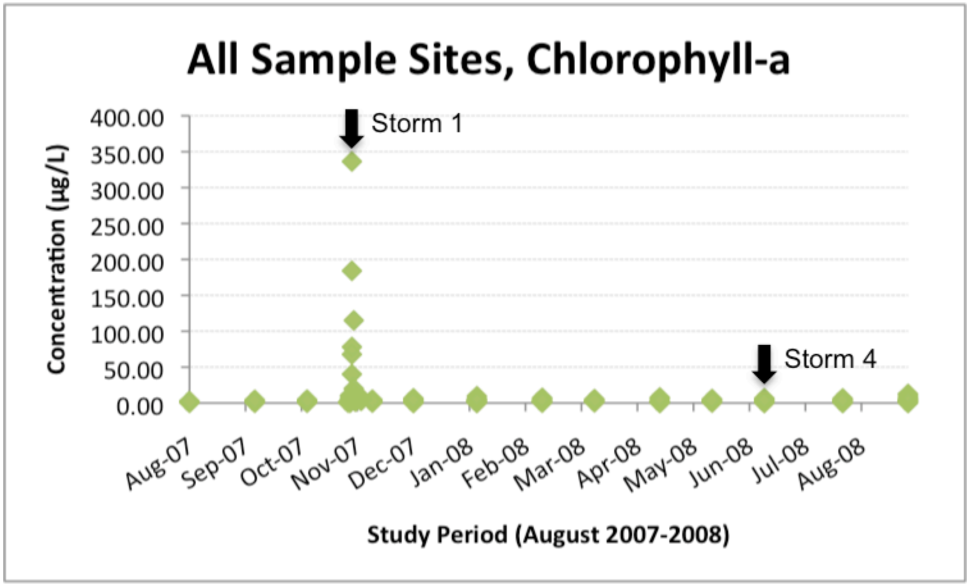


Figure 3.25. Total chlorophyll-a concentrations of all sample sites over the course of this study: Aug 01, 2007-Aug 31, 2008. TChl-a results from the wet season, first-flush storm, Storm 1, is identified on 11/05/07 and the dry season storm, Storm 4, is identified on 06/14/08 with black arrows.

CHAPTER 4

SUSPENDED PARTICULTATE MATTER IN HE‘EIA FISHPOND

Introduction

The basaltic mountains of the Ko‘olau are composed of minerals that are unstable in the surface-weathering regime. The combination of unstable weathering and steep terrain leads to a situation where weathering rates can be extreme (Milliman and Syvitski 1992). Weathering processes can be subdivided into two types of weathering. Chemical weathering is the process by which the minerals within rocks and soil chemically react with constituents found in rainwater, groundwater, or river water. Mechanical weathering is the physical breakdown of rock. In Hawai‘i, the primary mechanisms of weathering are a combination of wind abrasion, plant root growth, and erosion from rainfall and runoff. Delivery of land-derived particulate material is the primary source of the essential nutrients P and iron (Fe) to the oceans, and thus may stimulate primary productivity in the coastal ocean. On the other hand, suspended particulate matter will decrease the penetration of photosynthetically active radiation (PAR) in surface waters, and thus may suppress primary productivity during high-turbidity events, such as storms. The particles created from mechanical weathering of rock, along with sediment transport from the surface of the soil, dominate the particulate load carried by streams and rivers to the coastal ocean. It is this particle load that is measured as total suspended solids (TSS) in streams (Schlesinger 1997).

Riverine and Water Column Suspended Particulate Matter

Transport of suspended solids is affected by elevation, topographic relief, and the amount of runoff from the watershed (Milliman and Meade 1983; Milliman and Syvitski 1992). Rivers are the primary source of solid and dissolved material transported to the ocean (Milliman and Meade 1983). To quantify the amount of solid matter being introduced to He‘eia Fishpond, TSS was collected during monthly and storm sampling efforts. TSS data for all sampling events can be found in Appendix 11.

Our expectation was that TSS collected throughout He‘eia Fishpond would positively correlate with the increase in discharge and river suspended particulate matter (RSPM) from He‘eia Stream during storm events, and decrease during low flow, baseline conditions. This was not the case. TSS collected across the fishpond revealed that only during the first-flush storm event, Storm 1 (Fig. 2.2), did He‘eia Stream ever carry a particulate load that was higher than the annual mean TSS values for all sample sites (Fig. 4.1). The first-flush storm (11/04/07) carried a TSS burden that was twice the annual mean. This elevated TSS level was short lived, however, and diminished to levels below the annual mean TSS (0.015 mg/l) by 11/05/07, the day after the storm.

Despite large variations in stream discharge during baseline and storm conditions, the RSPM load of He‘eia Stream proved to be relatively constant. We hypothesize that the relative invariance in He‘eia Stream TSS is a result of sediment storage in the upstream marshland. Sediment storage has been observed in the Amazon River basin where large flood plains act as a sink for TSS (Meade et al.

1985). Further, only a weak, negative, correlation exists when TSS is plotted vs. salinity for the empirical orthogonal function (EOF) defined storm events (as described in Chapter 3) (Fig. 4.2). In fact, when the storm events are individually plotted (Fig. 4.3), only the first-flush storm shows a negative correlation of TSS with increasing salinity across He‘eia Fishpond, suggesting that RSPM is settling to the seabed as the storm plume moves away from land.

When annual mean TSS values for the 13-month study are evaluated by sample site, He‘eia Stream (River) values are lower than the fishpond perimeter sites by a factor of 2, and lower than the fishpond interior sites by a factor of 3 (Fig. 4.4). The fact that near-bottom TSS values for all but two sample sites (Stk3 and Stk15) are higher than the surface water values at the same sample sites (Fig. 4.4) implies that higher TSS values within the fishpond are due in large part to resuspension of benthic particulate matter.

The observation that mean fishpond TSS values are higher than He‘eia Stream values may seem counterintuitive. There is no question that terrigenous sediment enters He‘eia Fishpond, as visual observations throughout the fishpond basin clearly show accumulations of fine grain sediments adjacent to the landward boundary of the fishpond. However, on time scales reflected by our monthly TSS sample collection, the particulate load introduced to the fishpond from He‘eia Stream is only a small fraction of the total TSS collected on each filter. This suggests that processes within the fishpond lead to creation of TSS. Bottom sediment resuspension and generation of biogenic particles are two likely contributors to water column TSS.

Summary and Conclusions

The development of the silt layer seen along the northern edge of He‘eia Fishpond, within the TD and the MP sample sites (Fig. 3.8), could have taken decades to slowly accumulate. Alternatively, it could be a remnant of the 1965 flood that overran RM1, in an event that deposited large quantities of sediment that persist today in the northern portion of the fishpond.

TSS data from He‘eia Fishpond did not follow the typical estuarine mixing model in which terrestrial runoff, carrying high particulate loads, clearly serves as the source of suspended solids to marine waters (Figs. 4.2 and 4.3). The marshland upstream of He‘eia Fishpond, which serves as a sink for particulate matter today as it has for decades, continues to reduce the RSPM load to He‘eia Fishpond, even though it no longer functions as a lo‘i kalo. Filters archived for future CHN analysis may reveal the composition of the organic fraction of suspended particulate matter, and may provide clues as to the origin of He‘eia Fishpond TSS.

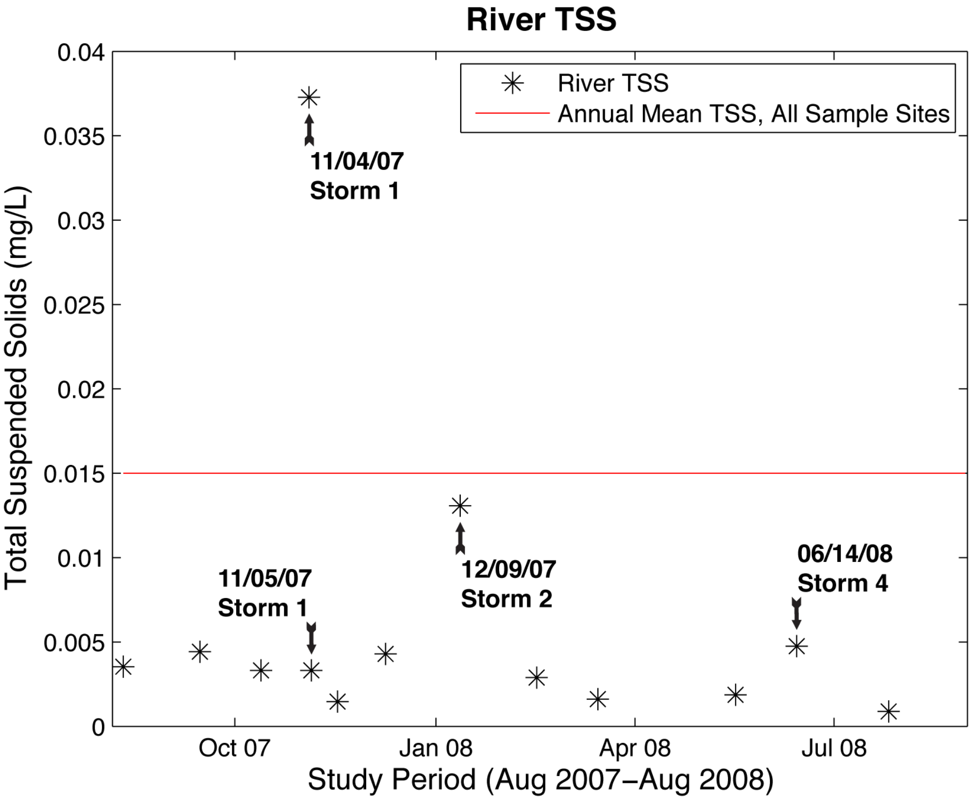


Figure 4.1. He‘eia Stream (River) TSS values collected over the course of this study: Aug 01, 2007-Aug 31, 2008. TSS samples collected during storm events are annotated.

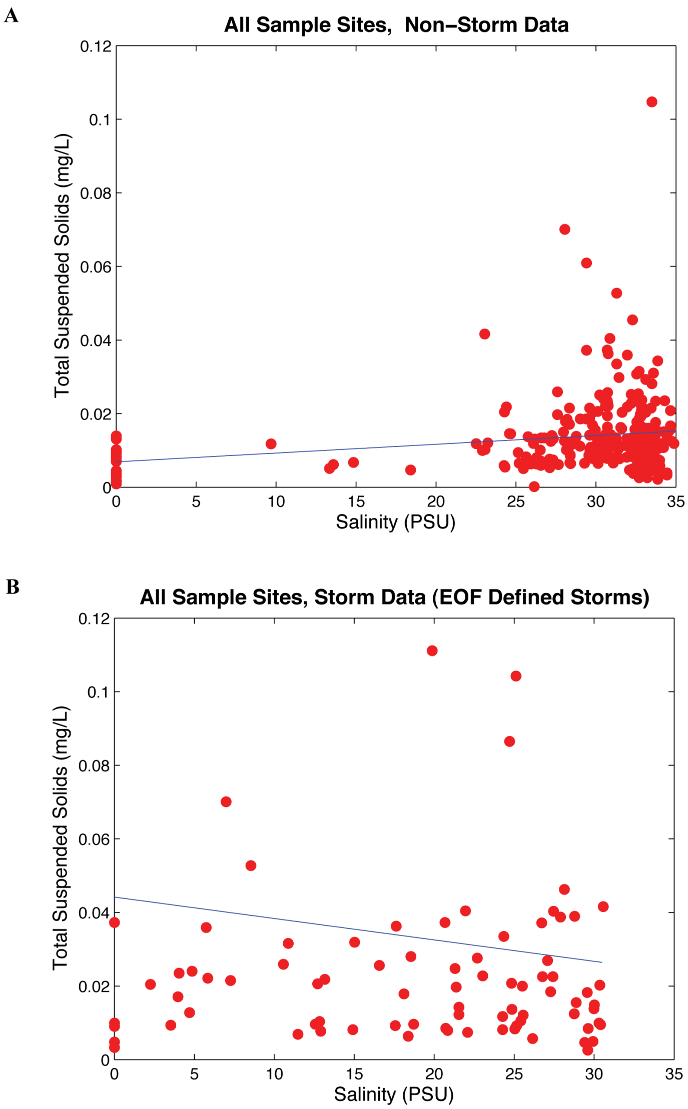


Figure 4.2. Water column TSS data for all sample sites during (A) non-storm monthly sampling events (12 months) and (B) storm sampling events (Storm 1, Transects 1-4, and Storm 4).

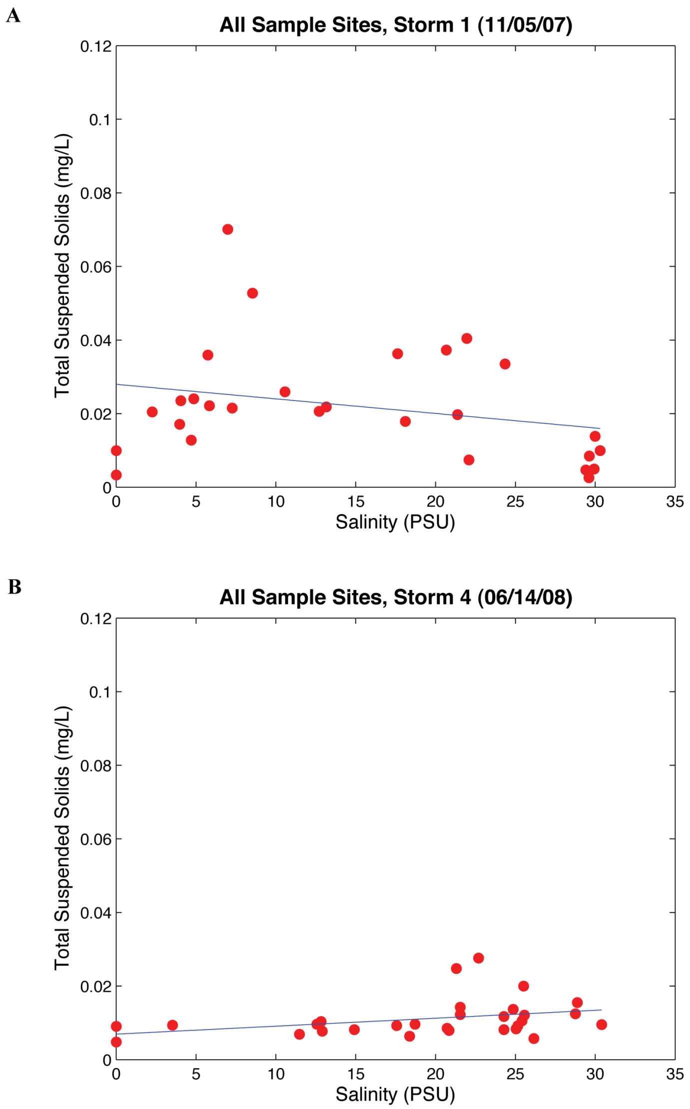


Figure 4.3. Water column TSS data for all sample sites during (A) the first-flush wet season storm (Storm 1) and (B) the dry season storm (Storm 4).

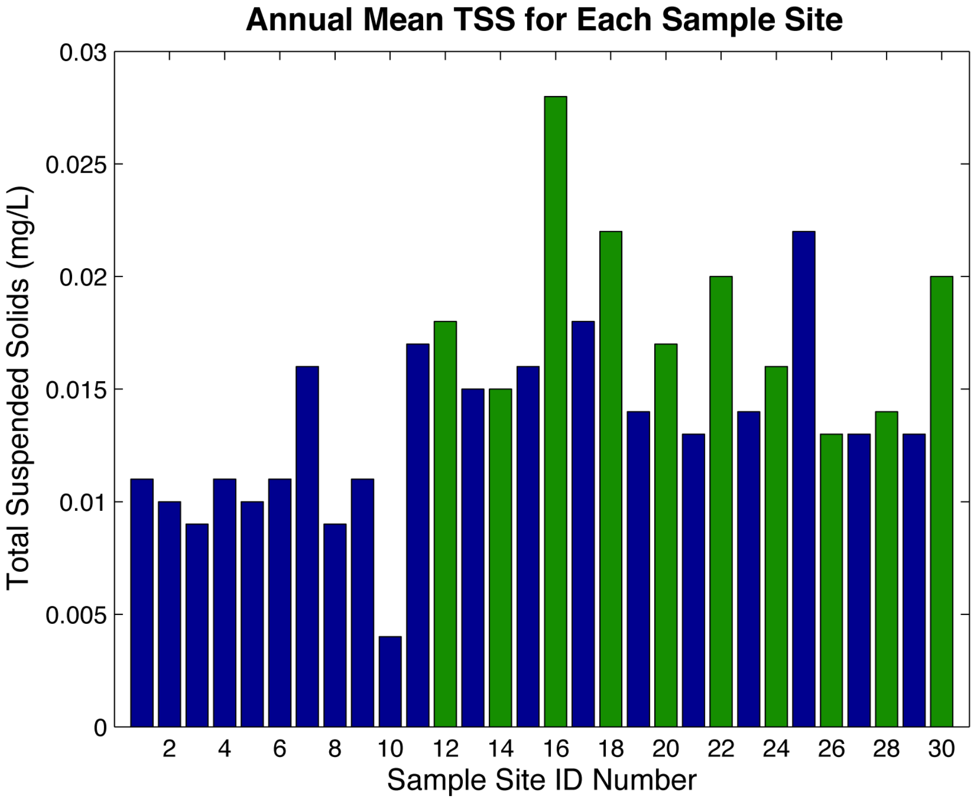


Figure 4.4. Annual mean TSS values for each sample site. Sample Site ID Numbers are defined in Table 1.2. Blue bars represent surface water samples; green bars represent near-bottom water samples. Sample site ID numbers 1-10 correspond to end-member sites and fishpond perimeter sites (e.g., mākāhā), while sites 11-30 correspond to sites within the fishpond. See Table 1.2 and Figs. 1.7 and 1.9 for sample site names, corresponding site ID numbers, and site locations.

CHAPTER 5

PHYTOPLANKTON COMMUNITY COMPOSITION RESPONSE TO STORM-INDUCED SHIFTS IN NUTRIENT INVENTORIES

Introduction

The dissolved, inorganic forms of macronutrients nitrogen (N), phosphorus (P), and silicon (Si) are available for direct uptake by phytoplankton and are often introduced to the coastal ocean through freshwater runoff (Chapter 3), where they can support blooms of coastal marine phytoplankton (Berner and Berner 1996; De Carlo et al. 2007; Drupp et al. 2011; Fisher et al. 1988; Hoover et al. 2006; Howarth 1988; Hubertz and Cahoon 1999; Rabalais et al. 2004; Rabalais et al. 2009; Ringuet and Mackenzie 2005; Turner et al. 1998). The photosynthetic pigment chlorophyll-a (chl-a), often used as a proxy for phytoplankton biomass (Gameiro and Brotas 2010; Monbet 1992), has been used in recent estuarine and coastal studies in Kane‘ohe Bay (De Carlo et al. 2007; Drupp et al. 2011; Hoover et al. 2006; Ringuet and Mackenzie 2005). We used fluorometry in combination with High Performance Liquid Chromatography (HPLC) to quantify chl-a and other photosynthetic pigments in the water column of He‘eia Fishpond. The quantity of chl-a allows us to estimate phytoplankton biomass within He‘eia Fishpond, while the presence and concentrations of other pigments permits us to evaluate changes in phytoplankton community composition due to event driven nutrient loading. Storm event driven shifts in dissolved inorganic N:P ratios, in conjunction with the presence and activity of the phosphohydrolytic enzyme alkaline phosphatase, are used as nutrient deficiency indicators (Dyhrman and Ruttenberg 2006; Hecky and Kilham 1988; Ruttenberg and Dyhrman 2005) to evaluate shifts in phytoplankton nutrient stress and potential nutrient limitation during baseline and storm conditions.

Analytical Methods

Water column samples designated for photosynthetic pigment analysis were collected in conjunction with other water column samples collected during monthly and storm sampling regimens. Samples were collected in amber HDPE bottles and kept on ice until filtration onto 0.7 μm, 25 mm, GF/F Whatman filters, typically within 2 hours of collection. Filters were stored in capped borosilicate glass test tubes wrapped in aluminum foil, to exclude light, and frozen (-30 °C). Samples designated for alkaline phosphatase activity (APA) were filtered within 2 hours of collection onto 0.7 μm, 45 mm, GF/F Whatman filters, folded, wrapped in aluminum foil, and stored frozen (-30 °C) until analyzed.

A subset of samples deemed important in time and site location were analyzed via HPLC for accessory photosynthetic pigments; the balance of photosynthetic pigment samples were analyzed for chl-a only, using fluorometric techniques. HPLC analysis of photosynthetic pigments were conducted in the Bidigare Lab at the University of Hawaiʻi, using a Varian 9300 auto-sampler, a Varian 9012 HPLC system, a reverse-phase Waters Spherisorb® 5 μm ODS-2 C_{18} column with a corresponding guard cartridge, and a Timberline column heater (Bidigare et al. 2005; Wright et al. 1991). Pigment identifications were based on absorbance spectra, co-chromatography with standards, and relative retention time. Peak identity was determined by comparing retention times with a standard and representative culture extracts using Spectra-Physics WOW® software (Mantoura and Llewellyn 1983; Wright et al. 1991). Abbreviations and significance of photosynthetic pigments discussed in this study are summarized in Table 5.1.

Samples analyzed for chl-a only were quantified after extraction in 90% acetone using a Turner Designs AU-10 fluorometer with a detection limit of 0.05 µg/l. Chl-a pigment concentrations were determined as described by Strickland and Parsons (1972).

Alkaline phosphatase activity was determined fluorometrically according to Hull (2010), after Dyhrman and Ruttenberg (2006).

Chlorophyll-a Concentrations Across He‘eia Fishpond

Baseline chl-a concentrations across He‘eia Fishpond sample sites over the 13 months of the study, not including storm data, are relatively invariant, with a mean of 2.42 µg/l (+/-1.72). During baseline conditions, when salinity over the majority of the fishpond is above 25 PSU, freshwater endmember chl-a concentrations are comparable to the concentrations found within the fishpond (Fig. 5.1, Panel A). When storm events introduce increased levels of land-derived nutrients, large variations in chl-a concentration occur. A number of the storm samples exhibit extremely high chl-a concentrations, orders of magnitude higher than mean baseline conditions (Fig. 5.1, Panel B). The Storm 1 chl-a maximum occurs between ~20-25 PSU (Fig. 5.2, Panel A), suggesting that these waters have yet to be influenced by the freshwater plume. In lower salinity waters Storm 1 recorded four times higher TSS

(Figure 4.3) than Storm 4. In estuarine waters, turbidity can limit primary productivity (Acha et al. 2008; De Carlo et al. 2007; Fisher et al. 1988; Monbet 1992; Ringuet and Mackenzie 2005). With depressed salinities still present throughout the fishpond during Storm 1 (Figure 2.31), it is possible that the suspended load introduced to the fishpond from storm runoff reduced light penetration into the water column, limiting phytoplankton growth. Mixing diagrams for NH_4^+, ($NO_2^+ + NO_3^+$), PO_4^{3-}, and H_4SiO_4 (Appendix 6) support this hypothesis, as each nutrient concentration measured during Storm 1 falls below the conservative mixing line above ~25 PSU, indicating biogenic uptake occurring at the extent of the storm plume, the margin between 20-25 PSU. In comparison, Storm 4 has higher chl-a values over a wider salinity range (~10-27 PSU) than Storm 1 (Fig. 5.2). It appears the storm plume present within He‘eia Fishpond was not as dominating during the time of sampling for Storm 4 as it was for Storm 1.

We also examine pond chl-a data partitioned into the 6 bins identified on the basis of salinity (see Chapter 3 for a full description of binning strategy, and see Fig. 3.2 for geographic location of bins within He‘eia Fishpond). The range of mean surface chl-a observed during non-storm conditions (Fig. 5.3, Panels A and B) is more restricted than the range observed during EOF-defined storms, with the exception of four sites that display significantly higher mean chl-a (Figure 5.3, Panel C). Storm sites that display high chl-a concentrations and variability, Stk7, 9, 13, and Stk18 (Fig. 5.3, Panel C), are part of the storm grid and reflect more sample values than other sample locations.

When partitioned according to our binning analysis (Fig. 5.3), a larger degree of variability in chl-a concentrations is observed in terrigenously dominated sites (green data points), and mid-pond sites (red data points) relative to freshwater (black data points) or ocean dominated sites (cyan, magenta, and blue data points; see Fig. 3.2 for geographical location of binned sites, and Chapter 3 for a full description of the binning strategy). We attribute the similarity in Storm 1 chl-a values (Figure 5.4, Panel A) and baseline (non-storm) chl-a levels (Figure 5.3, Panels A and B) to light limitation of phytoplankton production by the high levels of suspended particulate matter (Chapter 4) observed during Storm 1.

The time-evolution of chl-a variability due to Storm 1 plume movement across He‘eia Fishpond can be assessed by separately plotting Transects 1-4, which were taken on days 2, 3, 4, and 11, respectively, after the initiation of Storm 1, and water samples collected two weeks after the storm event (Figure 5.5). During Storm 1 the freshwater plume extended across the majority of the fishpond, all the way to the Kane‘ohe Bay side of the perimeter (Fig. 2.31), where only pond-interior sites display elevated chl-a concentrations (Fig. 5.6), suggesting either that all storm nutrients are consumed within the pond, thus promoting a bloom within the pond interior only, or that the storm runoff has not yet reached Kane‘ohe Bay. Low salinities continue through the first day following the storm (11/06/07) when Transect 1 sample sites display a dramatic increase in chl-a concentrations, with maximum values reaching 336.33 µg/l (Fig. 5.6), three orders of magnitude higher than mean baseline conditions of 2.42 µg/l (+/-1.72). Chl-a samples collected during Transect 2, three days post-storm, continue to exhibit elevated values up to 114.97 µg/l (Fig. 5.8).

Elevated chl-a values remain through the Transect 4 sampling event (11/11/07), one week following the Storm 1 rain event (Figure 5.9), although substantially diminished from the highest levels observed on Transect 1, sampled one day post-storm.

Phytoplankton Community Composition

HPLC pigment analysis can be used to differentiate phytoplankton present in natural waters by identifying photosynthetic pigments (Table 5.1) unique to specific algal groups. Often pigments are distinctive of one algal class or are present in only two or three classes allowing for a quantitative assessment of phytoplankton community composition (Jeffery and Vesk 1997). In order to investigate phytoplankton community composition within He‘eia Fishpond, specifically focused around the first-flush storm, HPLC analysis was performed on a select sample set. Ringuet and Mackenzie (2005) compiled HPLC pigment data for fucoxanthin, zeaxanthin, monovinyl chlorophyll b, 19'-hexanoyloxyfucoxanthin, and peridinin from samples collected within Kane‘ohe Bay (Laws and Allen 1996); this study evaluated water samples for the same pigments (Table 5.2).

Ringuet and Mackenzie (2005) reported that diatoms (fucoxanthin) accounted for approximately 45% of the phytoplankton community and cyanobacteria (zeaxanthin) made up approximately 25% during baseline conditions. Our data indicate that the fraction of the phytoplankton community within He‘eia Fishpond that is comprised by diatoms changes following storm events. During baseline (non-storm) conditions, less than half of the phytoplankton biomass (21%) in He‘eia Fishpond is comprised by diatoms, while during storm events diatoms account for

61% of the phytoplankton in the fishpond (Table 5.2). We also observed a smaller fraction of cyanobacteria within He‘eia Fishpond (0.003% during storm conditions, 0.05% during baseline) than was observed in the Kane‘ohe Bay studies, which observed that cyanobacteria comprised a quarter of the phytoplankton community (Ringuet and Mackenzie 2005). Within He‘eia Fishpond, dinoflagellates (peridinin) and cyanobacteria (zeaxanthin and monovinyl chlorophyll b) are present in similar proportions. In both studies diatoms dominate the phytoplankton community composition.

Phytoplankton Community Changes due to Evolution of Water Column Nutrients and Chl-a during the First-Flush Storm

Evaluating shifts in fishpond phytoplankton community composition due to event driven nutrient loading was a primary goal of this study. In Chapter 3 we demonstrated that the first-flush storm dramatically impacted the nutrient inventory of He‘eia Fishpond (Figs. 3.24 and 3.25) and that the phytoplankton community responded to that input, with chl-a concentrations increasing three orders of magnitude above baseline (Fig. 3.26) during Storm 1. The remainder of this section will focus on the first-flush storm, Storm 1, and the observed changes in phytoplankton community that occurred as a result of elevated nutrient concentrations delivered to He‘eia Fishpond through freshwater runoff.

During Storm 1 our water sampling efforts focused on capturing the evolution of the biogeochemistry throughout the fishpond as freshwater runoff was introduced through the river mākāhā. As mentioned in Chapter 1, the first day (11/05/07) and last day (11/17/07) of Storm 1 water sampling followed the monthly sampling regimen (Figs. 1.7 and 1.9). Days 2, 3, 4, and 7 followed the "T" shaped transect, the storm-sampling grid (Fig. 1.8), where six sample sites (Stk6, 7, 9, 11, 13, and 18) that created a linear transect across the fishpond were sampled.

On the first day of sampling the first-flush storm, both (NO_3^- + NO_2^-) and PO_4^{3-} concentrations measured across the storm grid are elevated above baseline concentrations (Figs. 5.10), where baseline is represented by concentrations on 11/17/07, fourteen days after the storm, which displays values similar to baseline nutrient concentrations discussed in Chapter 3 (Figs. 3.17 and 3.19). Nutrient concentrations subsequently decline during the days following initial storm input. This reduction in nutrient concentrations can be attributed to a combination of mixing of the high-nutrient storm plume with low-nutrient Kane‘ohe Bay water, and biogenic uptake. The immediate increase in chl-a concentrations measured at the transect sample sites 24 hrs after the storm plume was introduced, however, suggests that the role of phytoplankton in nutrient uptake is an important driver in nutrient cycling within He‘eia Fishpond (Fig. 5.11). Both nutrient and chl-a concentrations decrease as the storm signal return to baseline levels, as measured on 11/17/07 (Figs. 5.10 and 5.11). The fact that the highest chl-a concentration was seen at Stk7 on 11/06/07, the sample site directly in line with RM3 and the focal point of our storm transect, and the second highest chl-a concentration was observed at Stk18, the next closest sample site to a freshwater input (RM2) (Fig. 5.11), suggests that storm grid positioning (Fig. 1.8) was correctly oriented to capture He‘eia Stream input during storm events.

Storm-Induced Changes in Phytoplankton Community Composition

Cox et al. (2006) demonstrated that in the northern section of Kaneʻohe Bay, where nutrient conditions are similar to oligotrophic, open ocean environments, the phytoplankton community is dominated by cyanobacteria. In the southern portion of the bay, by contrast, where freshwater streams impact coastal marine waters by elevating nutrient concentrations in the water column, diatoms dominate the phytoplankton community (Cox et al. 2006). During our study of the evolution of Storm 1 we saw a shift in phytoplankton community composition, from a dominance of diatoms immediately following the introduction of land-derived nutrients to Heʻeia Fishpond, to a more mixed phytoplankton community during baseline conditions. Diatoms are identified by the marker pigment, fucoxanthin, and comprise up to 40% of the phytoplankton community during the initial days of Storm 1 (Fig. 5.12, Panel A), quickly responding to elevated nutrient inventories. Conversely, the cyanobacteria population (represented by the marker pigment zeaxanthin) appear to be depressed during the days immediately following Storm 1, but increase as the storm derived nutrients are consumed over time (Fig. 5.12, Panel B). Thus, the evolution of phytoplankton community composition following the first flush storm impacts on Heʻeia Fishpond follows a trend similar to that observed in greater Kaneʻohe Bay. The complete photosynthetic pigment data set generated during this study can be reviewed in Appendix 12.

Nutrient Limitation of Primary Production in Aquatic Systems

Primary productivity in coastal marine environments is often limited by nutrient availability (Schlesinger 1997). Redfield (1963) observed that phytoplankton intracellular C:N:P atomic ratios remained relatively constant at 106:16:1 throughout the world's oceans. The ratio of 106C:16N:1P, known as the Redfield ratio, is believed to represent the optimal ratio for dissolved nutrient uptake during phytoplankton photosynthesis (Redfield 1963, Hecky and Kilham 1988, but see also Arrigo 2005). When the N:P ratio is less than 16:1, this is interpreted as a situation where P is in excess and N may be limiting, while when the N:P ratio is greater than 16:1, it is assumed that N is in excess of phytoplankton requirements, an P may be limiting (Hecky and Kilham 1988).

Coastal ecosystems can be either N or P limited (Ringuet and Mackenzie 2005; Ruttenberg and Dyhrman 2005). Yet, defining a limiting nutrient can prove difficult. For example, Arrigo (2005) suggests the potential for nutrient co-limitation scenarios, defining three specific forms of co-limitation: a) multi-nutrient, b) biochemical, and c) community co-limitation. In addition, the bioavailability of nutrients present and the ability of biological organisms to adapt to low nutrient conditions should also be considered. When multiple nutrient deficiency indicators, such as enzymes produced under nutrient deficient conditions (e.g., alkaline phosphatase), dissolved nutrient ratios, and the composition of intracellular nutrients in biogenic material, can be evaluated in concert, the validity of a defined limiting nutrient is enhanced (Healey and Hendzel 1980; Hecky and Kilham 1988; Howarth 1988). Defining growth limiting factors enables an understanding of the effects that changes in nutrient inputs will have on primary productivity in an ecosystem, and ultimately how this will impact the productivity of higher trophic levels in that ecosystem.

Storm 1 nutrient loading induces a two-fold shift in the mean baseline Redfield ratio of 13.51 (+/- 13.11) to 27.64 (+/-16.33) within He‘eia Fishpond. This shift is driven by high dissolved inorganic nitrogen (defined for this study as DIN = $NH_4^+ + (NO_3^- + NO_2^-)$) loading and low dissolved inorganic phosphorus ($DIP = PO_4^{3-}$) loading. The fact that we see N:P above the Redfield ratio indicates that the phytoplankton community may become P-stressed following storm events. To explore this further we studied alkaline phosphatase activity (APA) within the water column.

The Role of Phosphorus in Marine Environments

In marine environments, the phosphorus (P) pool is comprised of dissolved inorganic phosphorus (DIP), dissolved organic phosphorus (DOP), and particulate bound phosphorus ($P_{particle}$). DIP represents the bioavailable component of the P pool, which can be directly assimilated by phytoplankton (Chróst and Overbeck 1987). DOP is not directly bioavailable and is often found at higher concentrations in the photic zone than DIP (Ruttenberg and Dyhrman 2005; Shan et al. 1994). Phytoplankton preferentially take up DIP, as no additional expenditure of energy is required for direct DIP uptake. Under low DIP conditions, the DOP pool can be accessed by phytoplankton through the use of alkaline phosphatase (APase), but this requires substantial investment of energy on the part of the phytoplankton and, hence, is only resorted to when DIP levels are low enough to cause physiological stress, and possible P-limitation (Chrost and Overbeck 1987).

Alkaline Phosphatase as a Nutrient Deficiency Indicator

Phosphatases are biologically produced enzymes that facilitate the production of DIP through catalyzing the hydrolytic cleavage of orthophosphate from a DOP molecule. A variety of enzymes are capable of the decomposition of DOP (e.g. diesterase, phytase, C-P lyase, 5' nucleotidase and alkaline phosphatase) and can be produced by bacteria, phytoplankton, and zooplankton (Dyhrman and Ruttenberg 2006). Once DIP is hydrolyzed it can be directly assimilated by organisms to meet their nutritional P demands (Sebastian et al. 2004).

In cases where APase is both inducible and repressible, meaning that its production is regulated by DIP concentrations, the production of APase will increase as available DIP in the water column is diminished. Conversely, as water column DIP concentrations increase, APase production will be repressed (Dyhrman and Ruttenberg 2006). This quality allows APase to be used as an indicator of phosphorus deficiency. APase has been used as a nutrient deficiency indicator in studies of both freshwater and saltwater systems, as the enzymatic activity, alkaline phosphatase activity (APA) measured within the water column is often a result of phytoplankton employing enzyme systems to access phosphate from DOP compounds for use in biological processes (Berman 1970; Chróst and Overbeck 1987; Koch et al. 2009; Reichardt et al. 1967; Rose and Axler 1997; Ruttenberg and Dyhrman 2005).

Relationship between Chlorophyll-a and APA

Chlorophyll-*a* is a robust proxy for phytoplankton biomass in aquatic systems (De Carlo et al. 2007; Gameiro and Brotas 2010; Monbet 1992; Ringuet and Mackenzie 2005). In this study, a positive correlation between chl-a concentration and APA was observed (Fig. 5.13). Samples from freshwater endmember sites, River and RM2, as well as terrigenous dominated sites, RM1 and RM3, deviate from this general trend, often exhibiting higher APA at lower chl-a concentrations. Given observed differences in biogeochemical parameters between freshwater and brackish or marine sites in the field, and the way in which nutrient cycling processes differ between freshwater and marine systems, it is not surprising that the freshwater influenced sites differ from the brackish fishpond sites in the relationship between chl-a concentration and APA. As previously discussed (Chapter 3), algal biomass (i.e. chl-a concentrations) may be limited in these locations, which are characterized by high TSS (Fig. 4.4), due to reduced DIP resulting from the P-uptake onto particle surfaces via the phosphorus buffering mechanism. Reactive iron (oxy)hydroxides have an extremely high affinity for phosphate sorption (Fox et al. 1985; Froelich 1988; Pomeroy et al. 1965; Ruttenberg and Sulak 2011). The loss of bioavailable P through sorption onto iron minerals is likely favored in the high-turbidity freshwater sites, and present a possible explanation for the observed higher APA in freshwater influenced sites, and for the deviation of freshwater samples from the linear chl-a vs. APA trend.

Relationship between Dissolved Inorganic Phosphorus and APA

Production of APase is triggered by low cellular phosphate levels, which typically correlate to low DIP concentrations in the surrounding water column. Thus, it is common to observe a negative correlation between APA and water column DIP concentrations in aquatic systems in which phytoplankton are P-stressed (Cembella et al. 1984; Chróst and Overbeck 1987; Jansson et al. 1988; Nausch et al. 2004). However, no significant correlation ($R^2 = 0.0004$) was observed in the He‘eia Fishpond data set as a whole (data not shown). We offer several possible explanations for the absence of a correlation between water column DIP and APA, outlined below.

Ruttenberg and Dyhrman (2005) compared two contrasting shore-perpendicular transects on the Oregon coast, one transect showed a negative correlation ($R^2 = 0.77$) between APA and DIP, the expected relationship for a system with P-stressed phytoplankton, while the other showed no correlation ($R^2 = 0.13$). Ruttenberg and Dyhrman (2005) argued that this difference arose from different water residence times that characterize the locations of the two transects. The waters that displayed a negative correlation had a residence time of ten days, whereas the site that displayed no correlation was characterized by rapid turnover of the water column, with flushing on the order of hours. Low residence times do not allow sufficient time for biogenic uptake of phosphorus to deplete DIP inventories, and consequently generate an observable APA response (Ruttenberg and Dyhrman 2005). With a minimum residence time of 48 hours (Chapter 2), and strong tidal induced water exchange through the mākāhā (Figs. 2.19-2.22), He‘eia Fishpond may often be too rapidly flushed to produce high concentrations of APA in response to high water column dissolved N:P ratios.

It is also possible that the lack of correlation between APA and DIP could be caused by micro-variations in DIP concentrations. In the vicinity of an individual cell, on a scale of microns, the DIP levels may have been low enough to promote production of APase as a phosphate stress response, despite the fact that the water body as whole did not exhibit low DIP concentrations. Micro-variations in DIP would not be resolvable with the sort of bulk water analyses typical of chemical oceanographic studies (Dyhrman and Palenik 2003; Dyhrman and Ruttenberg 2006; Ruttenberg and Dyhrman 2005). As the DIP data for this study was obtained from bulk water samples, any micro-variations in DIP are not resolvable for this study, and are beyond the scope of this work.

Lastly, the absence of a correlation between DIP and APA could be a reflection of the nutritional history of the cell. With transport of water and particles due to both freshwater input and tidal flushing it is possible that within He‘eia Fishpond the APA of cells isolated from one location (with high DIP) could actually have been produced at another location (one characterized by low DIP). The observation of cells with high APA in relatively high-DIP waters thus may not reflect *in situ* production of APA, but instead the past history of the cells (Dyhrman and Ruttenberg 2006; Ruttenberg and Dyhrman 2005).

Spatial Variability of APA During Baseline Conditions

APA levels are higher at freshwater influenced sample sites (freshwater endmember sites, terrigenously dominated sites, and mid-pond sites; see Fig. 3.2 for location of sample sites) and lower at marine dominated sample sites (Fig. 5.14). The highest levels of APA are seen in the freshwater endmembers and sample sites directly impacted by river mākāhā delivering freshwater to He‘eia Fishpond (RM1 and Stk7). In addition, elevated APA levels occur in the northeast corner of the fishpond at Stk6, as well as in the southwest corner of the fishpond, at Stk13 and 15 (Fig. 5.14). Two qualitative explanations may elucidate why there are higher concentrations of APA at these sites. First, the area around Stk6 is shielded from the trade winds and from direct flushing from TM. This could create an area where the water column that has a longer residence time than the whole-fishpond integrated time of 48 hours, allowing APase to accumulate. This explanation could also apply to the elevated APA measured at Stk13 and 15, as water exchange in the southwestern corner of the fishpond is less efficient than in the northern portions of He‘eia Fishpond (Figs. 2.19-2.22). Secondly, the possibility of SGWD in the proximity of Stk13 and 15 could drive an APA response within the fishpond to resemble the He‘eia Stream influenced mākāhā sample sites, where freshwater from He‘eia Stream greatly affects fishpond water column biogeochemistry.

Photosynthetic organisms can directly assimilate DIP for biogenic functions without an expenditure of energy. When DIP is needed for biological processes, but is unavailable in the water column, photosynthetic organisms produce enzymes to access the DOP pool and acquire the needed P. The most common enzyme is APase

(Dyhrman and Ruttenberg 2006; Ruttenberg and Dyhrman 2005). Almost all (96%) of He‘eia Fishpond water column samples assayed expressed APA. The production of inducible enzymes such as APA requires energy, thus diverting energy from other physiological activities; consequently APase is only produced when low DIP concentrations render it necessary. The prevalence of APA throughout He‘eia Fishpond indicates that the biological community is experiencing some degree of P-stress, and possible P-limitation.

Temporal and Spatial Variability of APA During Storm 1

He‘eia Fishpond is characterized by a mean baseline N:P ratio of 13.51 (+/-13.11) for all sample sites, below the N:P ratio of 16:1 as described by Redfield (1963) as being optimal for phytoplankton growth (Fig. 5.15). Following Storm 1 the mean N:P ratio for all sample sites increased to 27.64 (+/-16.33), but ratios as high as 75:1 were observed (Fig. 5.15). The two-fold (or more) increase in N:P is a result of high DIN loading and low DIP loading. N:P ratios exceeding the Redfield ratio would suggest that in the days following Storm 1 phytoplankton present within the water column could become P-stressed. APA measurements on samples collected during the high frequency storm sampling efforts reveal that APase production was induced (Figs. 5.16 and 5.17). Elevation of APA two days following the Storm 1 rain event (Fig. 5.16) indicates that phytoplankton within the fishpond developed the P-stress response of synthesizing APA upon being exposed to N:P ratios approximately twice that of the Redfield ratio (Fig 5.15). The complete data set of N:P ratios and the associated APA values can be reviewed in Appendix 13. By

11/11/07 (Transect 4), baseline water column concentrations of APA had been restored (Fig. 5.16).

The progression of Storm 1 impacts on APA concentrations across the fishpond is illustrated in Fig. 5.17. Stk7, the sample site closest to the freshwater mākāhā allowing storm derived runoff into He‘eia Fishpond, is the site of highest APA for the first two days of storm sampling. As the freshwater plume progresses across the fishpond the sample sites most distal to He‘eia Stream show elevated APA. By Day 3 post-storm, APA concentrations are higher at Stk11 and 13 than at Stk7 and 9 (Fig. 5.17). The progression of increasing APA across the fishpond positively correlates with the movement of the storm plume through the fishpond (Fig. 1.8). Additionally, these data suggest that the response time of phytoplankton to storm runoff induced P-stress is on the order of 24-48 hours.

Table 5.1. Abbreviations and significance of photosynthetic pigments separated in this study using HPLC. Pigment description from Jeffery et al. (1997).

Pigment name	**Abbreviation**	**Primary Pigment in Algae:**
Total chlorophyll a[*]	TChl a	All phytoplankton
Monovinyl chlorophyll a	MVChl a	All phytoplankton
Divinyl chlorophyll a	DVChl a	Prochlorococcus spp.
Chlorophyllide a	Chld a	Senescent diatoms
Monovinyl chlorophyll b	Chl b	Prochlorophytes
Chlorophyll $c_1 + c_2$	Chl c	Chromophytes
19'-Butanoyloxyfucoxanthin	But-fuco	Pelagophytes
19'-Hexanoyloxyfucoxanthin	Hex-fuco	Prymnesiophytes
Fucoxanthin	Fuco	Diatoms
Peridinin	Per	Dinoflagellates
Prasinoxanthin	Pras	Prasinophytes
Violaxanthin	Viola	Chrysophytes
Diadinoxanthin	DDX	Chromophytes
Alloxanthin	Allox	Cryptophytes
Diatoxanthin	DTX	Minor pigment in chromophytes
Zeaxanthin	Zeax	Cyanobacteria, prochlorophytes
β,ε-Carotene	α-Car	Prochlorophytes, cryptophytes
β,β-Carotene	β-Car	Many phytoplankton groups
[*] TChl a = MVChl a + DVChl a + Chld a		

[*] TChl a is the sum of monovinyl and divinyl chlorophyll a, as well as degradation pigment chlorophyllide a; and in this study abbreviated as "chl-a."

Table 5.2. Comparison of mean water column photosynthetic pigments for this study and Ringuet and Mackenzie (2005) conducted in southern Kane‘ohe Bay during baseline (non-storm) and storm conditions. Concentrations in units of µg/l, standard deviation or delta, for sample sets of 2 or less, in parenthesis, and n = sample size (see Table 5.1 for photosynthetic pigment abbreviation definitions).

Study	Sample Site	TChl-a	Fuco	Zeax	Chl-b	Hex-fuco	Per
He‘eia Fishpond (this study)							
Baseline	Freshwater Endmember He‘eia Stream	1.31 (0.96) (n = 24)	0.13 (0.10) (n = 8)	0.00 (0.10) (n = 8)	0.12 (0.11) (n = 8)	0.00 (0.00) (n = 8)	0.00 (0.00) (n = 8)
Storm	Freshwater Endmember He‘eia Stream	0.56 (0.22) (n = 5)	0.05 (0.02) (n = 2)	0.01 (0.02) (n = 2)	0.04 (0.08) (n = 2)	0.00 (0.00) (n = 2)	0.00 (0.00) (n = 2)
Baseline	He‘eia Fishpond	2.42 (1.72) (n = 325)	0.52 (0.66) (n = 69)	0.13 (0.17) (n = 69)	0.18 (0.13) (n = 69)	0.01 (0.01) (n = 69)	0.20 (0.53) (n = 69)
Storm	He‘eia Fishpond	14.36 (45.09) (n = 80)	8.72 (23.28) (n = 80)	0.05 (0.06) (n = 80)	0.11 (0.14) (n = 80)	0.01 (0.02) (n = 80)	0.15 (0.32) (n = 80)
Baseline	Marine Endmember Kane‘ohe Bay	1.19 (0.58) (n = 12)	0.13 (0.07) (n = 3)	0.04 (0.05) (n = 3)	0.04 (0.08) (n = 3)	0.00 (0.00) (n = 3)	0.08 (0.08) (n = 3)
Storm	Marine Endmember Kane‘ohe Bay	1.74 (1.78) (n = 2)	0.11 (n = 1)	0.03 (n = 1)	0.06 (n = 1)	0.00 (n = 1)	0.05 (n = 1)
Ringuet & Mackenzie*							
Baseline	D-buoy, Kane‘ohe Bay	0.76 (0.35) (n = 29)	0.09 (0.10) (n = 18)	0.17 (0.08) (n = 18)	0.14 (0.10) (n = 18)	0.06 (0.13) (n = 18)	0.01 (0.01) (n = 18)
02/2003 Storm	D-buoy, Kane‘ohe Bay	2.75 (n = 1)	N/A	N/A	N/A	N/A	N/A

*Ringuet and Mackenzie (2005) report baseline photosynthetic marker pigment (HPLC) data by combining their data (n = 3) with data from Laws and Allen (1996, n = 13) and the Coastal Intensive Site Network (CISNet, Nov. 1988-Jul. 2001, n = 2).

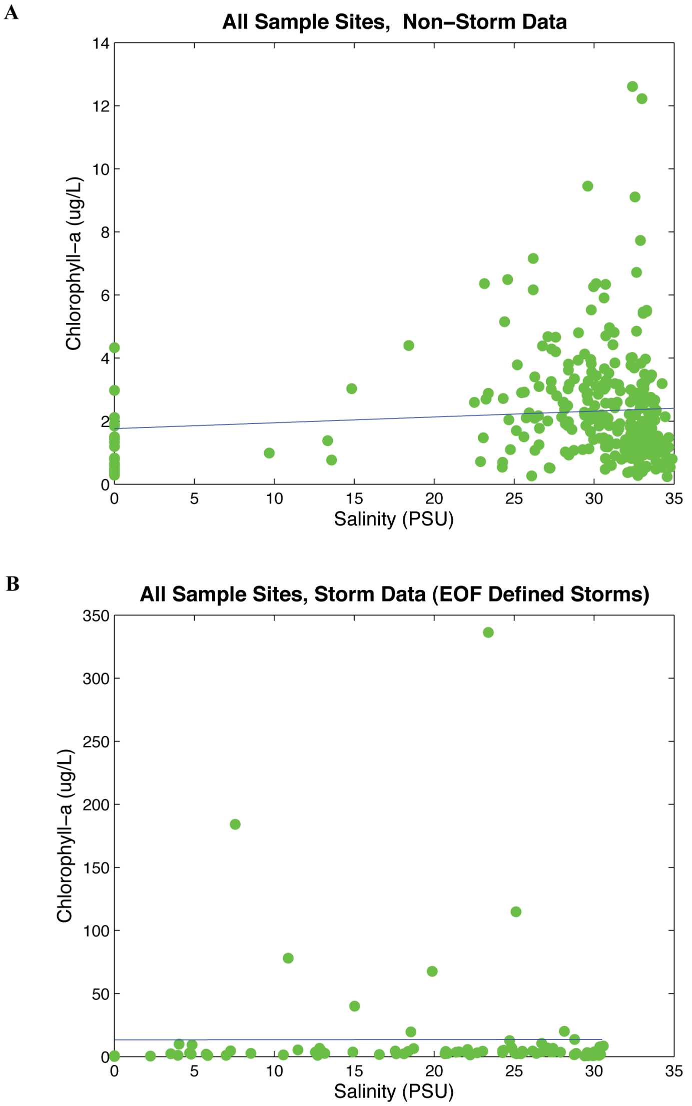


Figure 5.1. Water column chl-a concentrations for all sample sites during (A) non-storm monthly sampling events (12 months) and (B) storm sampling events (Storm 1, Transects 1-4, and Storm 4). Note different y-axes in (A) and (B) due to very high chl-a concentrations during Storm 1.

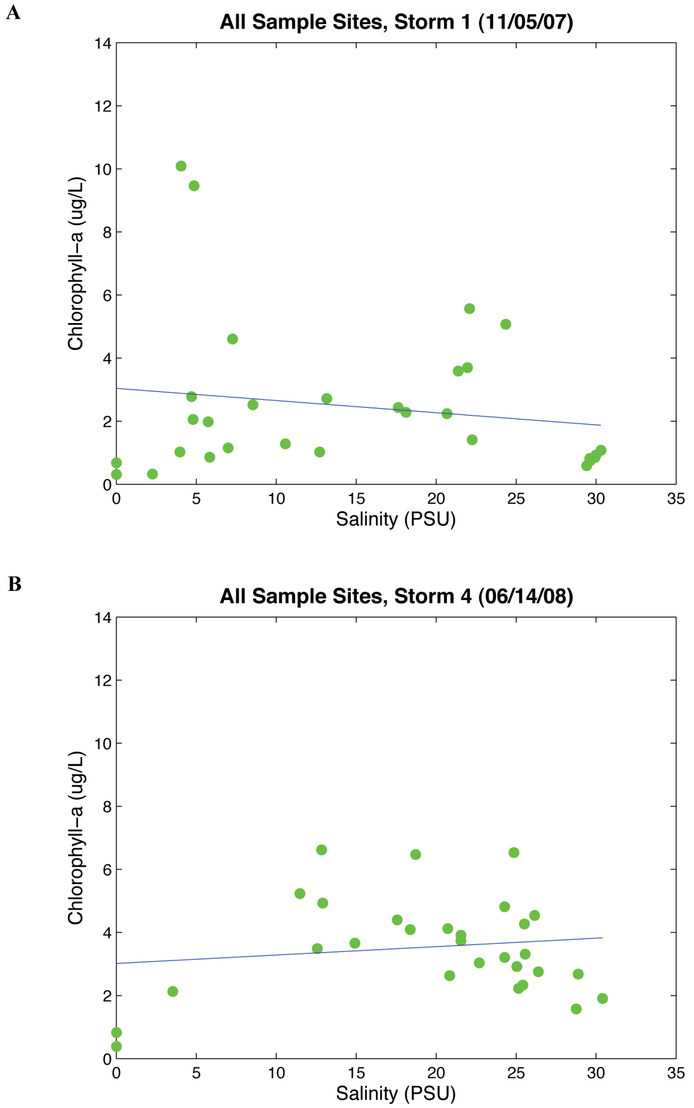


Figure 5.2. Water column chl-a data for all sample sites during a (A) wet season storm (Storm 1) and (B) dry season storm (Storm 4).

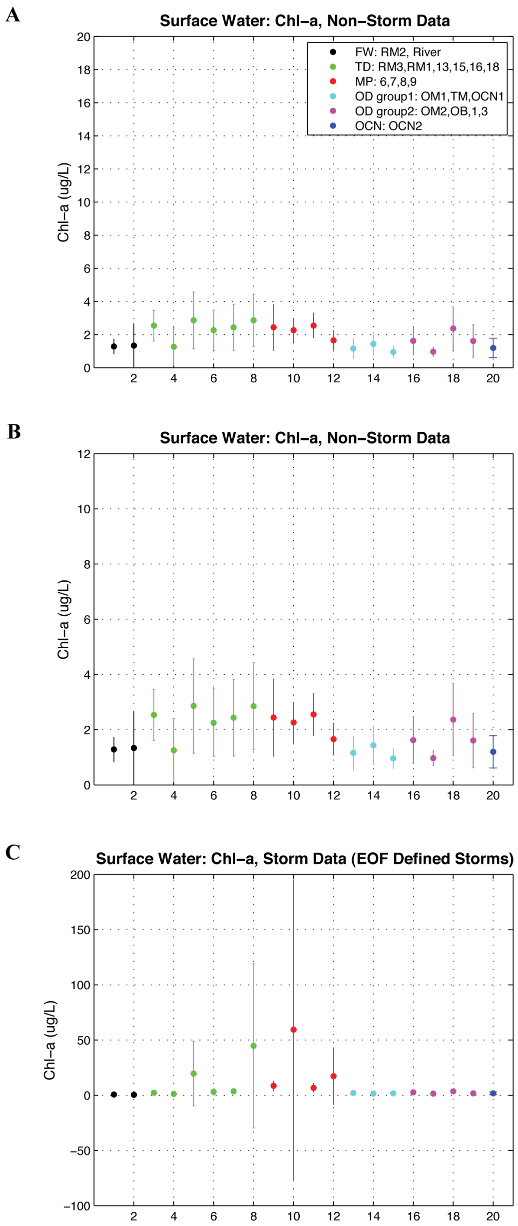
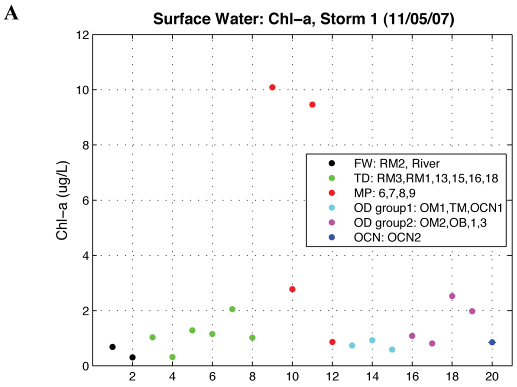
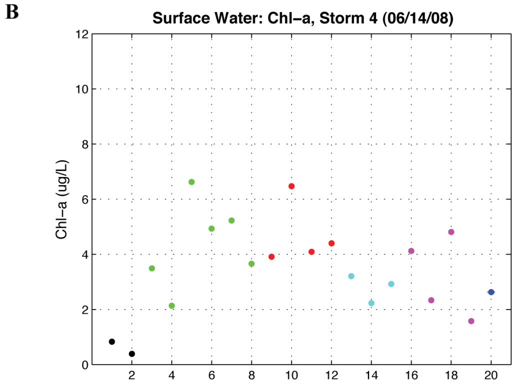


Figure 5.3. Mean surface water chl-a data and standard deviation for each sample site during (A and B) non-storm monthly sampling events (12 months) and (C) storm sampling events (Storm 1, Transects 1-4, and Storm 4). Note: y-axis scale for (A) is two orders of magnitude less than (C); y-axis for (B) is an expanded scale of (A). Symbol colors follow the color key defined in Figs. 3.7 and 3.8, with each color reflecting binning of sample sites into groups that are characterized by similar mean annual salinity. Numbers on x-axis indicate the 20 sample sites (**1=RM2, 2=River**, **3=RM3**, **4=RM1**, **5=Stk13**, **6=Stk15**, **7=Stk16**, **8=Stk18**, **9=Stk6**, **10=Stk7**, **11=Stk8**, **12=Stk9**, **13=OM1**, **14=TM**, **15=OCN1**, **16=OM2**, **17=OB**, **18=Stk1**, **19=Stk3**, **20=OCN2**).

EOF Defined Storm:



EOF Defined Storm:



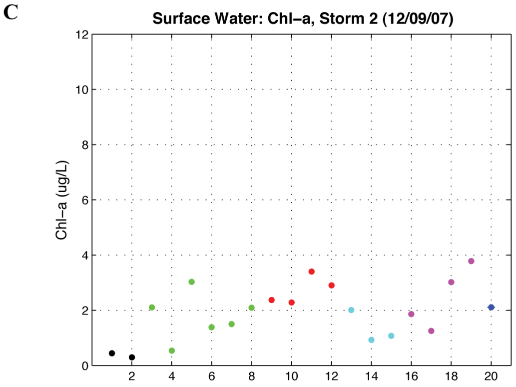


Figure 5.4. Surface water chl-a data and standard deviation for all sample sites during the EOF defined storms: (A) wet season storm (Storm 1) and (B) dry season storm (Storm 4). (C) Storm 2 is added for reference and not an EOF defined storm. Symbol colors follow the color key defined in Figs. 3.7 and 3.8, with each color reflecting binning of sample sites into groups that are characterized by similar mean annual salinity. Numbers on x-axis indicate the 20 sample sites (**1=RM2, 2=River, 3=RM3**, **4=RM1**, **5=Stk13**, **6=Stk15**, **7=Stk16**, **8=Stk18**, **9=Stk6**, **10=Stk7**, **11=Stk8**, **12=Stk9**, **13=OM1**, **14=TM**, **15=OCN1**, **16=OM2**, **17=OB**, **18=Stk1**, **19=Stk3**, **20=OCN2**).

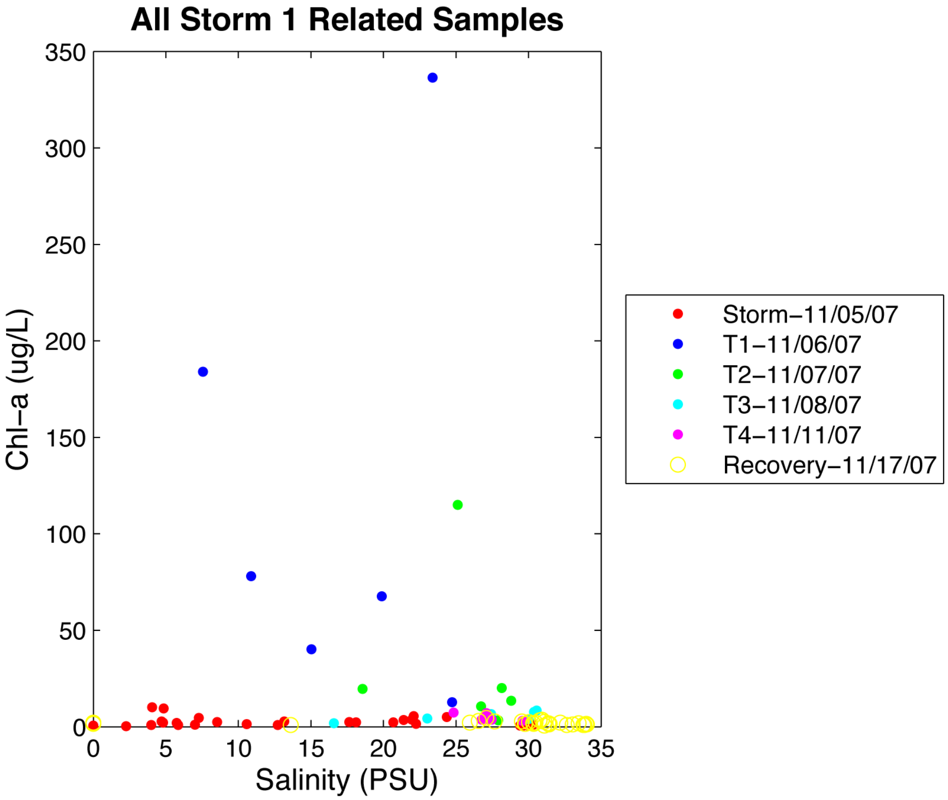


Figure 5.5. All chl-a data for the evolution of Storm 1 (11/05/07-11/17/07). Extremely high chl-a values during Transect 1 (T1-11/06/07) diminish over the following days and return to background by the November monthly sampling event (Recovery-11/17/07).

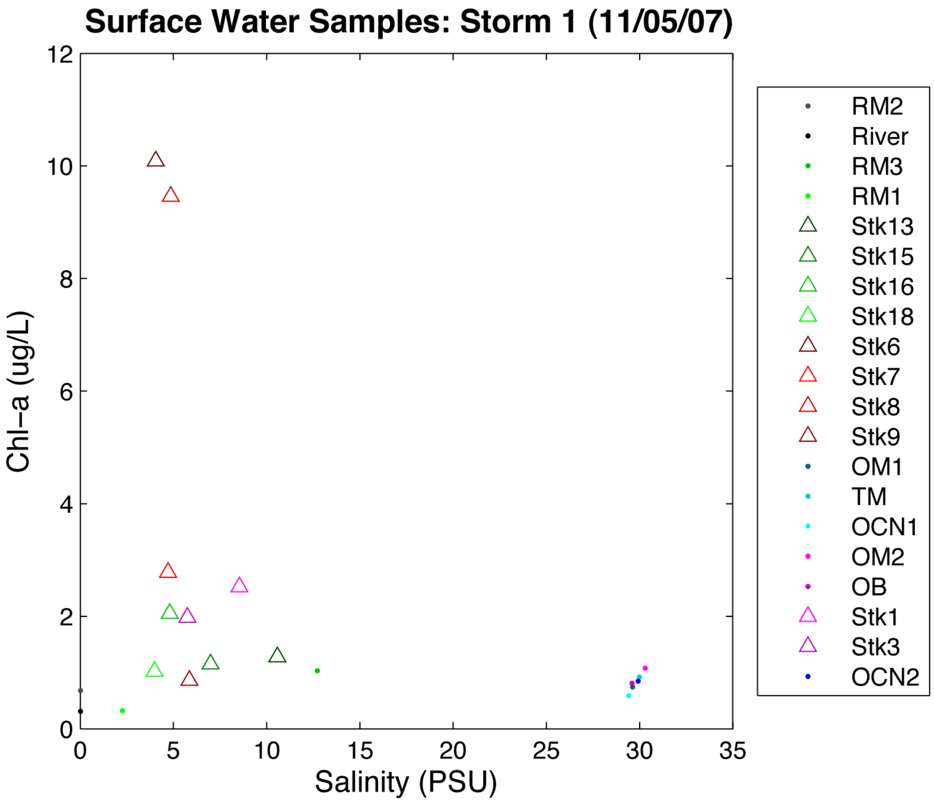


Figure 5.6. Surface water chl-a data for Storm 1 sampling event. Sample site color reflects binned groups: Freshwater Sites = black, Terrigenous Dominated Sites = variations of green, Mid-pond Sites = variations of red, Ocean Dominated group 1 = variations of cyan, Ocean Dominated group 2 = variations of magenta, and Ocean Site = blue.

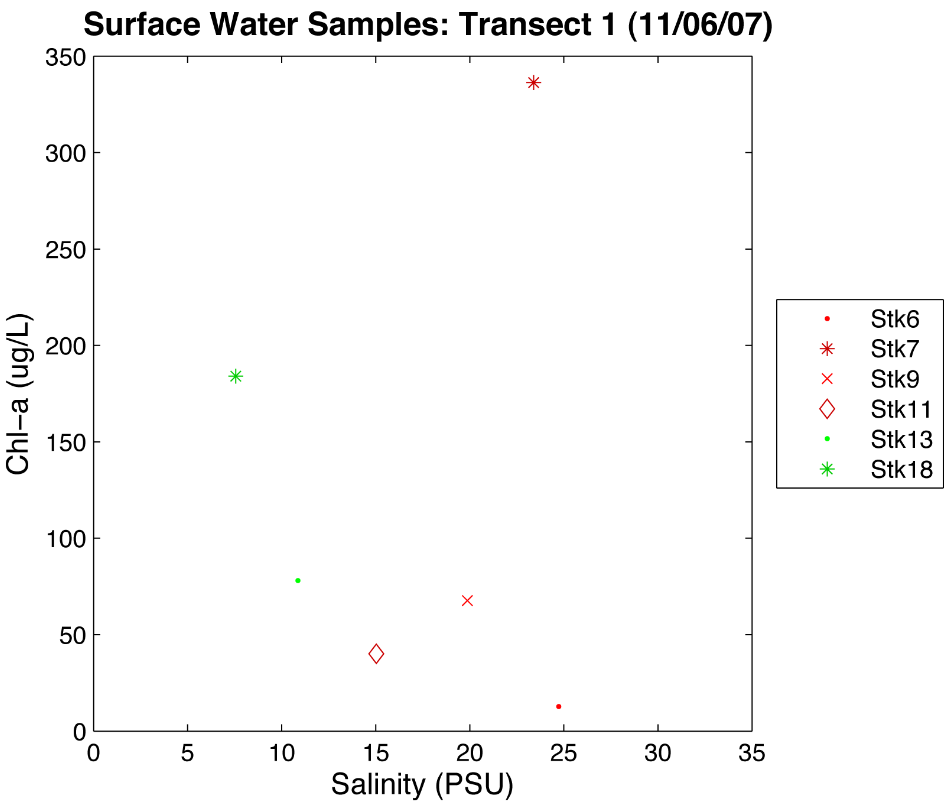


Figure 5.7. Surface chl-a data for Storm 1, Transect 1 sampling event. Sample site color reflects binned groups: Terrigenous Dominated Sites = variations of green, Mid-pond Sites = variations of red. Note: y-axis is two orders of magnitude greater than baseline chl-a values.

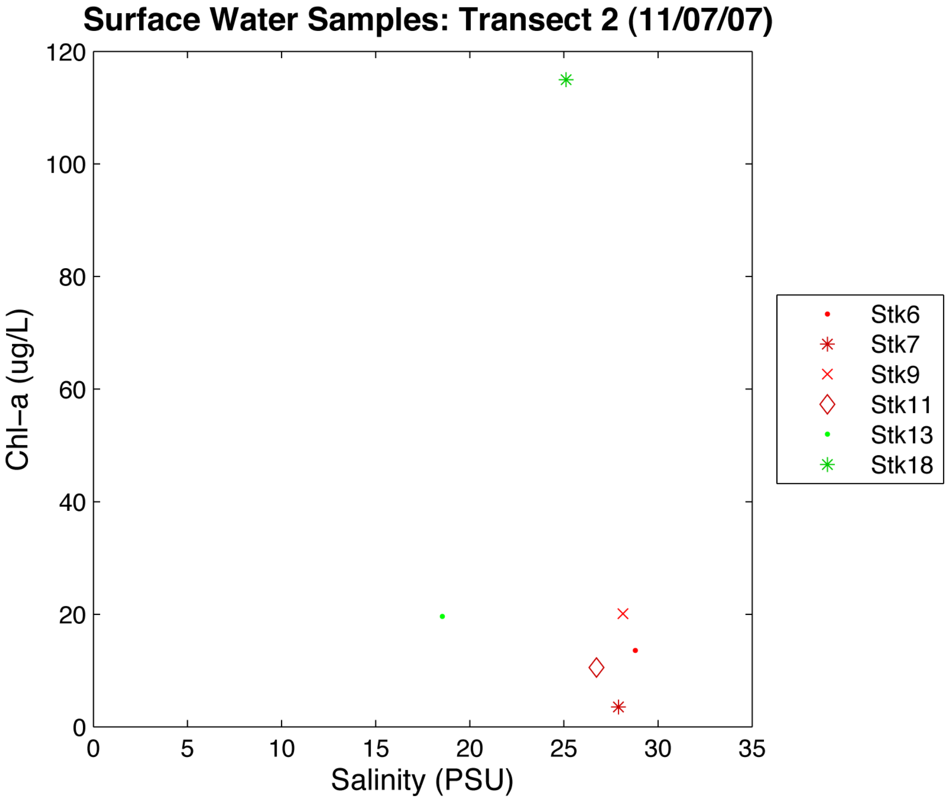


Figure 5.8. Surface chl-a data for Storm 1, Transect 2 sampling event. Sample site color reflects binned groups: Terrigenous Dominated Sites = variations of green, Mid-pond Sites = variations of red. Note: y-axis is 30-fold greater than baseline chl-a values.

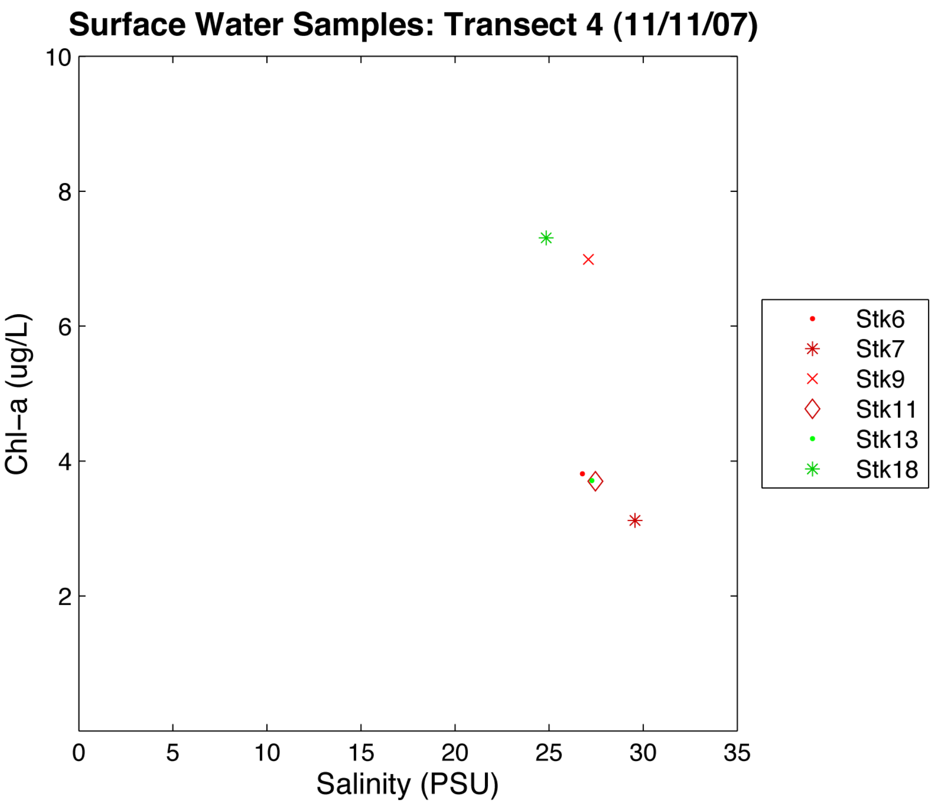


Figure 5.9. Surface chl-a data for Storm 1, Transect 4 sampling event. Sample site color reflects binned groups: Terrigenous Dominated Sites = variations of green, Mid-pond Sites = variations of red.

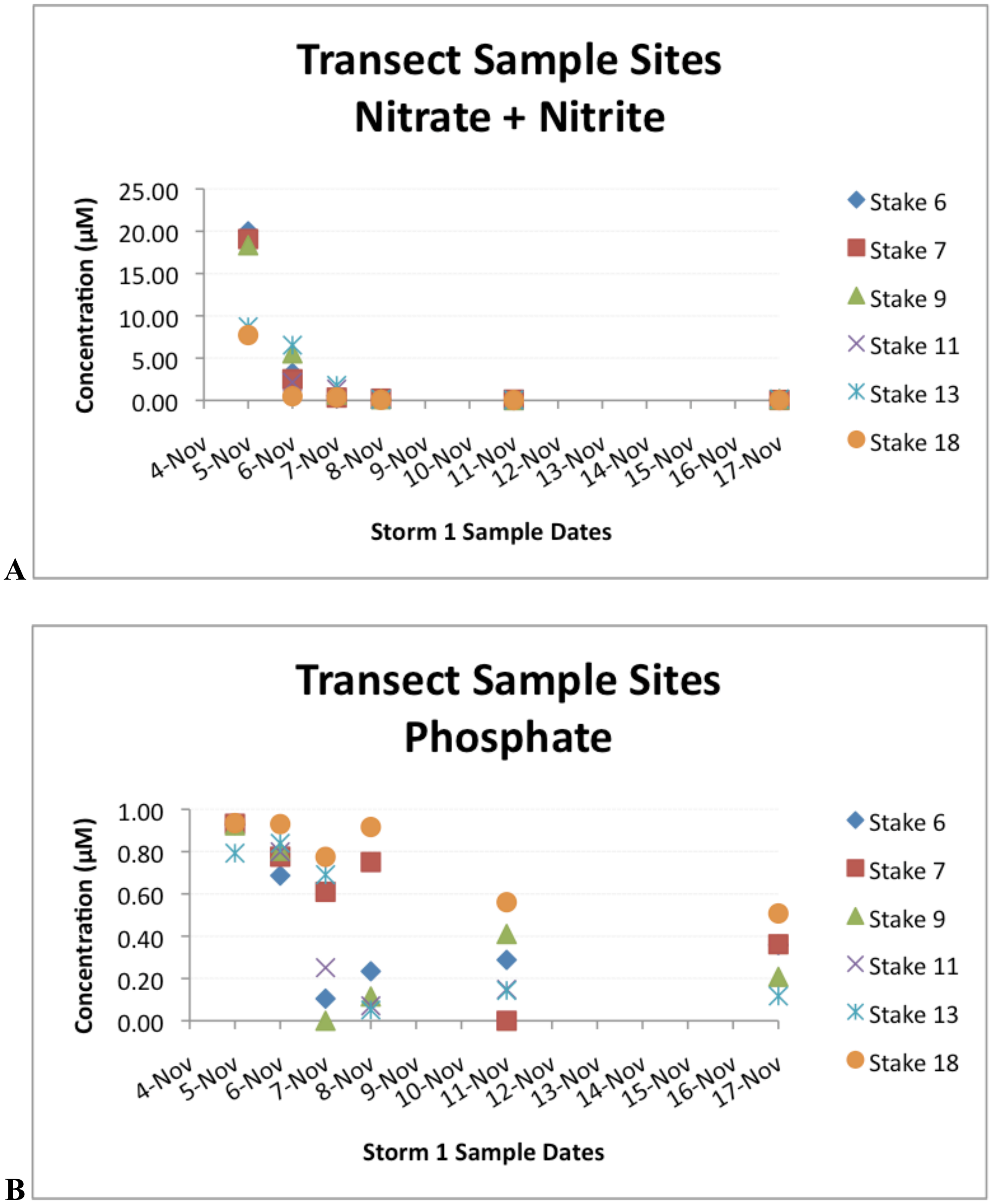


Figure 5.10. (A) ($NO_3^- + NO_2^-$) and (B) PO_4^{3-} concentrations for storm event transect sample locations (see Fig. 1.8 for site locations) during the dates associated with the first-flush storm, Storm 1.

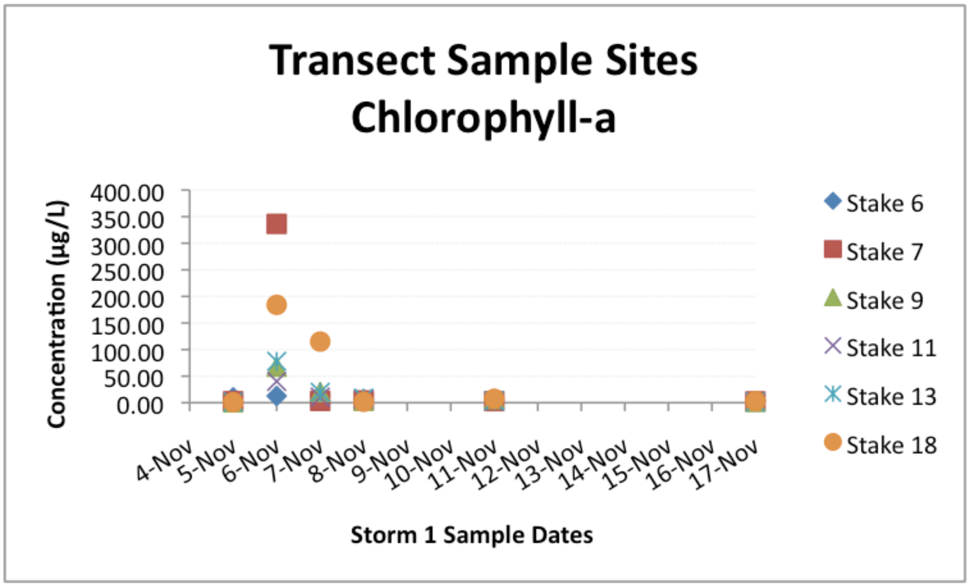
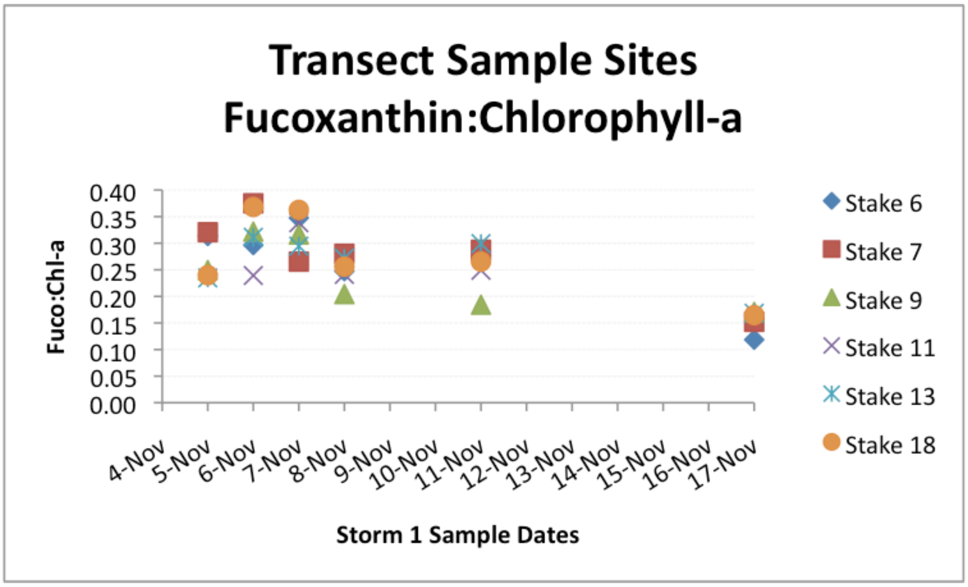


Figure 5.11. Chl-a concentrations for storm event transect sample locations (see Fig. 1.8 for site locations) during the dates associated with the first-flush storm, Storm 1.

A



B

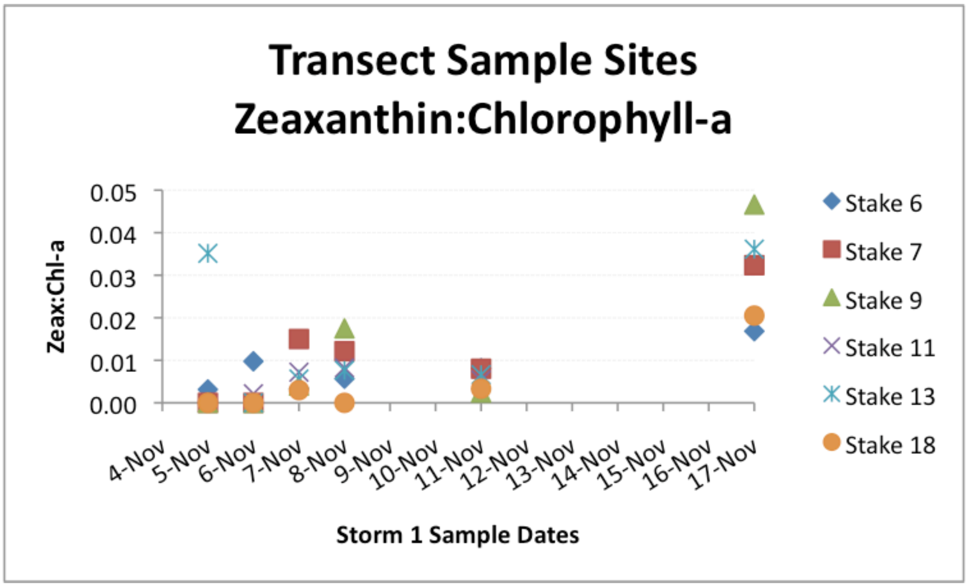


Figure 5.12. (A) Fucoxanthin and (B) Zeaxanthin marker pigments normalized to TChl-a for storm event transect sample locations (see Fig. 1.8 for site locations) during the dates associated with the first-flush storm, Storm 1.

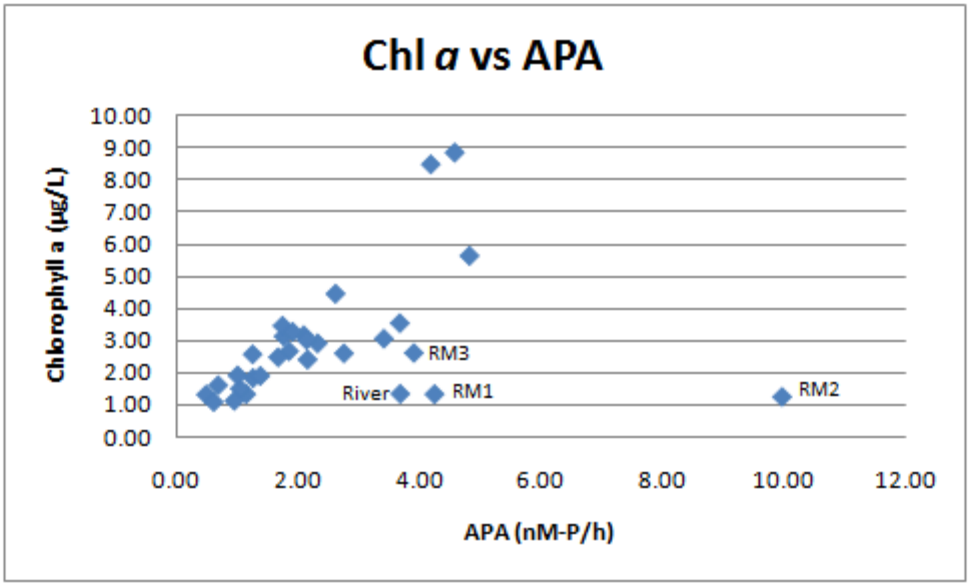


Figure 5.13. Mean annual chlorophyll-a concentration for each sample site shows a linear relationship with APA. A weaker relationship exists for sample sites strongly influenced by freshwater. Figure modified from Hull (2010).

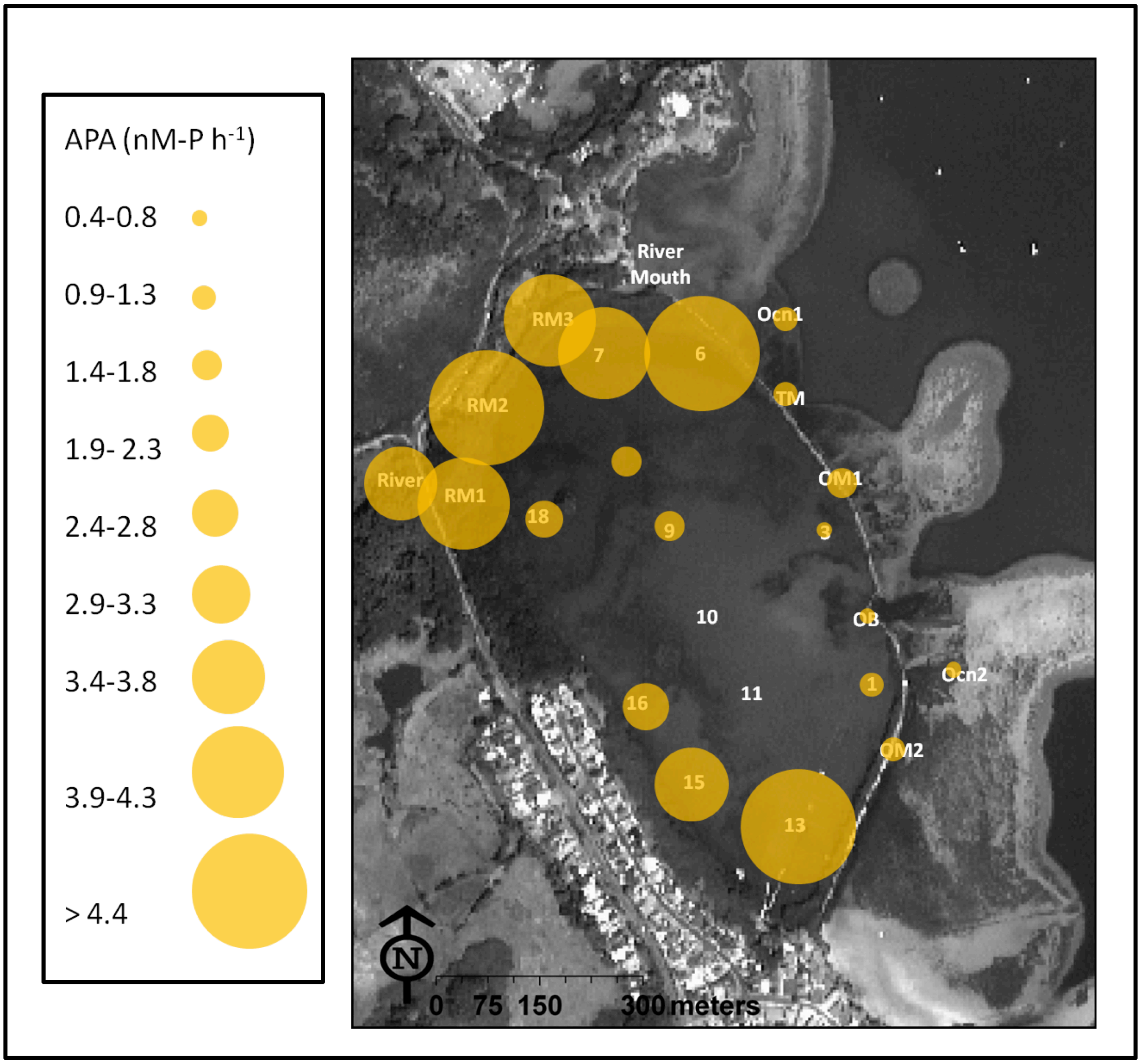


Figure 5.14. Baseline mean alkaline phosphatase activities during the course of this study: Aug 01, 2007-Aug 31, 2008. The size of each yellow circle represents concentration ranges in order to illustrate spatial variability of APA across He‘eia Fishpond. Figure modified from Hull (2010).

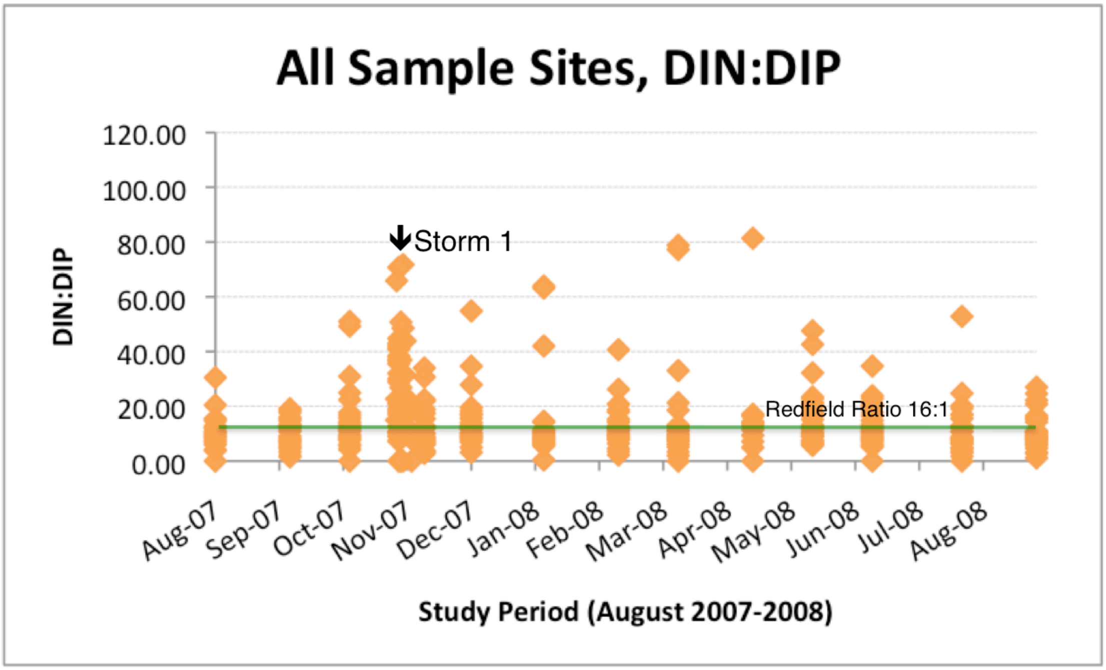


Figure 5.15. DIN:DIP for all sample sites over the course of this study: Aug 01, 2007-Aug 31, 2008. Redfield ratio of 16:1, N:P, is annotated by the green line.

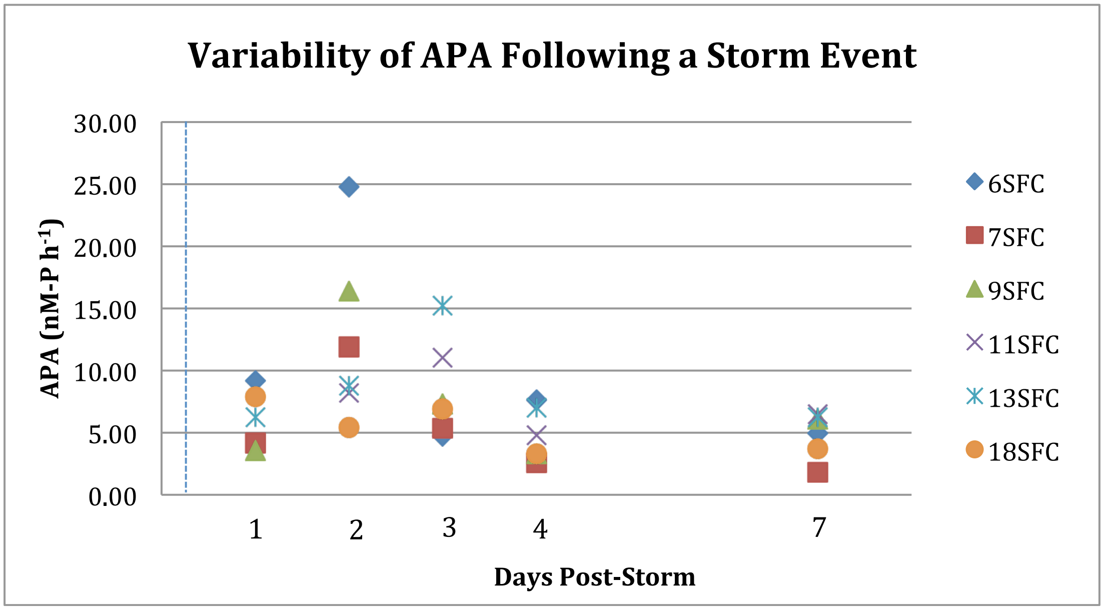


Figure 5.16. Variability in APA concentrations measured during the Storm 1, first-flush, intensive sampling effort: Day 1 = Storm 1 sampling effort (11/05/07) and Days 2-7 = Transects 1-4 (11/06/07-11/11/07) (Table 1.6, Fig. 1.8). The vertical blue dashed line indicates the occurrence of the Storm 1 rain event (11/04/07). Figure modified from Hull (2010).

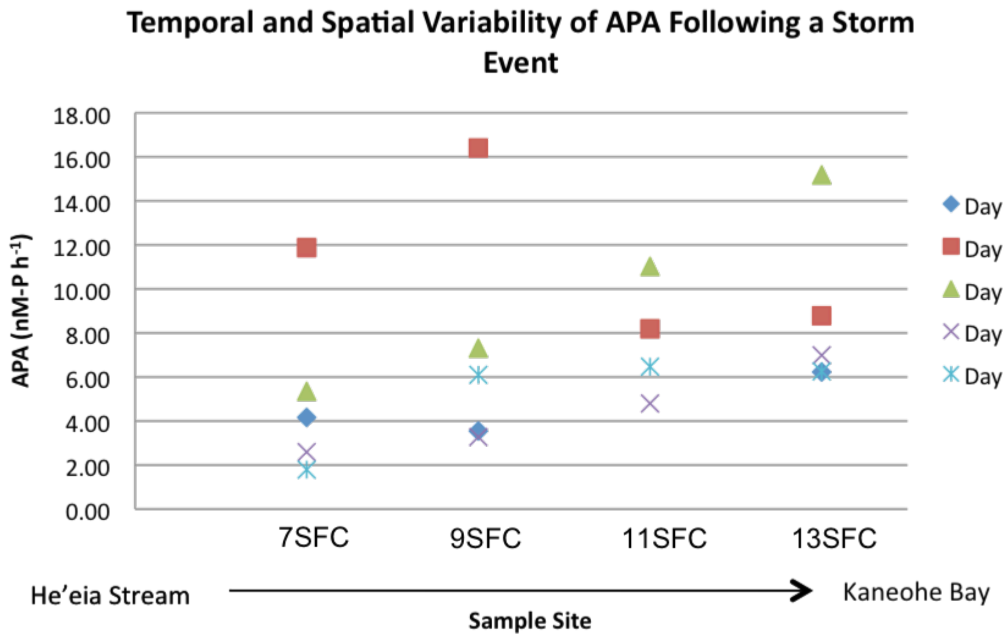


Figure 5.17. APA concentrations measured during the evolution of Storm 1 during the intensive first-flush storm sampling effort: Day 1 = Storm 1 sampling effort (11/05/07) and Days 2-7 = Transects 1-4 (11/06/07-11/11/07) (Table 1.6, Fig. 1.8). Only the sample sites along the primary axis of the storm transect are illustrated, with sites proximal to He‘eia Stream to sites distal to He‘eia Stream listed. Figure modified from Hull (2010).

CHAPTER 6

CONCLUSIONS

He‘eia Fishpond is an ancient Hawaiian fishpond constructed within the Ko‘olaupoko region of O‘ahu along the shoreline of Kane‘ohe Bay. The fishpond is fully surrounded by a kuapā and exchanges freshwater with He‘eia Stream through mākāhā along its northern boarder and saltwater with Kane‘ohe Bay through mākāhā along its eastern border. Proximity to fresh- and saltwater sources allows fishpond managers to manipulate the water quality of the fishpond and promote a healthy environment for their mariculture projects.

For the purposes of the study of biogeochemistry in the coastal ocean, He‘eia Fishpond provides unique and practical advantages. The fact that flow into the fishpond from both freshwater and marine sources occurs through physical gates (mākāhā) in the wall (kuapā) surrounding the fishpond allows these flows to be constrained via *in situ* instrumentation. In any open coastal system, constraint of inputs is essentially an insurmountable obstacle to quantitative assessment of element budgets. We instrumented the mākāhā in order to constrain inputs into the ecosystem, much in the way that constructed mesocosms are designed to constrain inflow and outflow. Thus, by virtue of its constructed physical boundary, He‘eia Fishpond functions as essentially a mesocosm embedded within the natural coastal environment of Kane‘ohe Bay, and has permitted a degree of experimental control for our study that is not achievable in an unconfined coastal system.

He‘eia Fishpond is of cultural importance to the Hawaiian community, as a link to the past and as a model for resource management in the present, and for the future. The fishpond is currently overseen by the nonprofit organization Paepae o He‘eia, who wish to restore the fishpond to its non-impacted ecological state. The research conducted in this study is aimed at identifying and evaluating the forcing mechanisms influencing the present ecology of He‘eia Fishpond, and will contribute to the restoration work being conducted by Paepae o He‘eia.

The fishpond was instrumented with *in situ* current meters, pressure sensors, and temperature sensors to characterize fishpond hydrology and water column stratification. Water flow data combined with nutrient inventories and nutrient ratios are used to assess the relative importance of each of the fishpond mākāhā for nutrient loading. Discrete water column samples were taken on a variety of time scales to constrain water column nutrient inventories, phytoplankton biomass, and nutrient deficiency indicators, allowing us to address the principle objectives of this study: (i) to quantify the nutrient inventories and nutrient ratios in He‘eia Fishpond, (ii) to quantify the external (riverine/marine) nutrient loading so that it can be contrasted to the internal (benthic flux) nutrient loading to the fishpond, and (iii) to evaluate shifts in fishpond phytoplankton community composition as a function of storm event-driven nutrient loading.

Water column data from monthly discrete sampling, and more frequent sampling during storm events, demonstrates the first-flush storm of the wet season can dramatically change the biogeochemistry of He‘eia Fishpond. Variations in nutrient loading, especially after storm events, affect nutrient ratios and often stimulate phytoplankton growth. Changes in algal composition within the fishpond due to storm-induced nutrification can propagate into phytoplankton community shifts. The data presented in this study provide insight into dynamic, yet ephemeral, events occurring within He‘eia Fishpond, in particular on the processes that transfer nutrients from the land to the sea. The quantitative understanding of the processes involved in supplying essential nutrients to the coastal oceans is of great importance to biogeochemists and ecosystem managers alike.

APPENDICES

Overview

Over the course of this 13-month field study, a large data set resulting from measurements aimed at parameterizing water column structure, dissolved nutrient concentrations, and suspended particulates was generated. Within the individual chapters of this thesis, a subset of this data set, in the form of tables and figures, is presented to illustrate major topics under discussion, and to support explanations of and arguments about specific processes observed within He‘eia Fishpond. The full data set collected during this study is summarized in the following appendices.

Appendix 1

Water column temperature and salinity data were measured using a YSI 6600A v2 multi-parameter water quality sonde (Table 1.4) during each water sampling event, for each sample site, and organized into three data sets: mean (integrated) water column values, mean surface water values (upper 25 cm), and mean near-bottom (deep) water values (bottom 25 cm). Each data set is divided by sampling date and organized by sample site.

Appendix 2

Water column % dissolved oxygen and pH data were measured using a YSI 6600A v2 multi-parameter water quality sonde (Table 1.4) during each water sampling event, for each sample site, and organized into three data sets: mean (integrated) water column values, mean surface water values (upper 25 cm), and mean near-bottom (deep) water values (bottom 25 cm). Each data set is divided by sampling date and organized by sample site.

Appendix 3

Monthly and storm sampling effort mean salinity values for surface and near-bottom sample sites were plotted on a geo-referenced map of He‘eia Fishpond.

Appendix 4

Monthly and storm sampling effort mean temperature values for surface and near-bottom sample sites were plotted on a geo-referenced map of He‘eia Fishpond.

Appendix 5

Dissolved inorganic nutrient concentrations for surface and near-bottom water samples are listed in Appendix 5.1. Total and dissolved organic nutrient concentrations for surface and near-bottom water samples are listed in Appendix 5.2. Inorganic and organic nutrient ratios for surface and near-bottom water samples are listed in Appendix 5.3.

Appendix 6

Property-property plots illustrate chemical mixing patterns during non-storm conditions and storm conditions for temperature, % DO, pH, DOC, TDN, NH_4^+, $(NO_3^- + NO_2^-)$, DON, TDP, PO_4^{3-}, DOP, H_4SiO_4, and chl-a.

Appendix 7

Property-property plots illustrate chemical mixing patterns during the first-flush, wet season, storm (Storm 1) and the dry season storm (Storm 4) for temperature, % DO, pH, DOC, TDN, NH_4^+, (NO_3^- + NO_2^-), DON, TDP, PO_4^{3-}, DOP, H_4SiO_4, and chl-a. Note: In cases where less than ½ of the sample sites had DON and DOP data, the available data are shown without a regression line, as it was deemed that the data set did not reflect the analyte dynamics across the fishpond.

Appendix 8

Property-property plots for dissolved organic and inorganic nutrient ratios (DIN:DIP, DOC:DON, DOC:DOP, and DON:DOP) for non-storm and storm conditions, as well as a comparison of Storm 1 vs. Storm 4, when data was available.

Appendix 9

Surface annual mean non-storm and storm salinity, NH_4^+, (NO_3^- + NO_2^-), PO_4^{3-}, and H_4SiO_4 data grouped by similarly trending sample sites. Presenting the data in this manner illustrated spatial trends across He‘eia Fishpond.

Appendix 10

Surface annual mean Storm 1, 2, and 4 salinity, NH_4^+, (NO_3^- + NO_2^-), PO_4^{3-}, and H_4SiO_4 data grouped by similarly trending sample sites. All three storms were defined as “storms” by virtue of crossing the rainfall threshold (see Chapters 2 and 3 for discussion of storm threshold); only Storms 1 and 4 are defined as “storms” by the EOF analysis (See Chapter 3 for discussion of EOF analysis).

Appendix 11

Total Suspended Solids (TSS) data were collected during monthly and storm event water sampling events.

Appendix 12

Photosynthetic pigment (fucoxanthin, zeaxanthin, monovinyl chlorophyll b, 19'-hexanoyloxyfucoxanthin, and peridinin) data were collected during monthly and storm event water sampling events.

Appendix 13

DIN:DIP ratios calculated from measurements found in Appendix 5; APA and $APA_{\text{chl-a normalized}}$ data were collected during monthly and storm event water sampling events.

Appendix 1. Surface (upper 25 cm), near-bottom (bottom 25 cm), and water column (WC) average temperature and salinity data, as measured by a YSI 6600A v2 multi-parameter water quality sonde.

Site	Date	Temp Upper 25cm	Temp Bottom 25cm	Temp WC
OM2	8/11/07	26.80	26.75	26.77
OCN2	8/11/07	27.54	27.54	27.54
OB	8/11/07	27.16	27.16	27.16
OM1	8/11/07	27.53	27.58	27.55
TM	8/11/07	27.96	28.16	28.06
OCN1	8/11/07	27.95	27.95	27.95
RM3	8/11/07	26.34	26.36	26.35
RM2	8/11/07	25.03	25.03	25.03
RM1	8/11/07	28.58	28.58	28.58
River	8/11/07	NaN	NaN	NaN
Stk1sfc	8/11/07	29.76	29.77	29.76
Stk3sfc	8/11/07	28.53	28.36	28.45
Stk6sfc	8/11/07	30.19	29.36	29.77
Stk7sfc	8/11/07	29.77	29.87	29.82
Stk8sfc	8/11/07	29.60	29.40	29.50
Stk9sfc	8/11/07	28.90	28.78	28.84
Stk13sfc	8/11/07	30.46	30.28	30.37
Stk15sfc	8/11/07	29.74	30.02	29.88
Stk16sfc	8/11/07	29.83	29.89	29.86
Stk18sfc	8/11/07	29.49	29.57	29.53

Site	Date	Salinity Upper 25cm	Salinity Bottom 25cm	Salinity WC
OM2	8/11/07	32.74	32.79	32.76
OCN2	8/11/07	33.74	33.74	33.74
OB	8/11/07	32.97	32.96	32.96
OM1	8/11/07	32.59	32.66	32.63
TM	8/11/07	31.93	32.55	32.24
OCN1	8/11/07	31.31	31.31	31.31
RM3	8/11/07	9.69	9.71	9.70
RM2	8/11/07	0.00	0.00	0.00
RM1	8/11/07	24.67	24.67	24.67
River	8/11/07	0.00	0.00	0.00
Stk1sfc	8/11/07	33.73	33.85	33.79
Stk3sfc	8/11/07	34.57	34.69	34.63
Stk6sfc	8/11/07	32.82	33.73	33.28
Stk7sfc	8/11/07	31.45	32.85	32.15
Stk8sfc	8/11/07	32.84	33.44	33.14
Stk9sfc	8/11/07	33.66	33.89	33.78
Stk13sfc	8/11/07	32.59	32.77	32.68
Stk15sfc	8/11/07	32.56	33.20	32.88
Stk16sfc	8/11/07	33.07	33.39	33.23
Stk18sfc	8/11/07	29.39	33.12	31.26

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. “NaN” is defined as “Not a Number” when a parameter was not measured.)

Site	Date	Temp Upper 25cm	Temp Bottom 25cm	Temp WC
OM2	9/15/07	27.19	27.24	27.22
OCN2	9/15/07	27.94	27.90	27.92
OB	9/15/07	28.01	28.01	28.01
OM1	9/15/07	27.87	27.78	27.83
TM	9/15/07	28.31	28.11	28.21
OCN1	9/15/07	28.18	28.19	28.18
RM3	9/15/07	27.67	27.67	27.67
RM2	9/15/07	25.01	25.02	25.02
RM1	9/15/07	26.89	26.89	26.89
River	9/15/07	NaN	NaN	NaN
Stk1sfc	9/15/07	28.82	28.82	28.82
Stk3sfc	9/15/07	28.85	28.86	28.86
Stk6sfc	9/15/07	28.76	28.75	28.75
Stk7sfc	9/15/07	28.42	28.41	28.42
Stk8sfc	9/15/07	28.44	28.43	28.44
Stk9sfc	9/15/07	28.64	28.64	28.64
Stk13sfc	9/15/07	29.28	29.28	29.28
Stk15sfc	9/15/07	28.45	28.46	28.45
Stk16sfc	9/15/07	28.54	28.54	28.54
Stk18sfc	9/15/07	27.65	27.93	27.79

Site	Date	Salinity Upper 25cm	Salinity Bottom 25cm	Salinity WC
OM2	9/15/07	32.85	32.95	32.90
OCN2	9/15/07	33.21	33.16	33.18
OB	9/15/07	34.22	34.22	34.22
OM1	9/15/07	32.74	32.52	32.63
TM	9/15/07	32.71	33.24	32.97
OCN1	9/15/07	32.96	32.97	32.97
RM3	9/15/07	29.67	29.67	29.67
RM2	9/15/07	0.00	0.00	0.00
RM1	9/15/07	22.90	23.48	23.19
River	9/15/07	0.00	0.00	0.00
Stk1sfc	9/15/07	32.89	32.89	32.89
Stk3sfc	9/15/07	33.00	33.02	33.01
Stk6sfc	9/15/07	32.20	32.21	32.21
Stk7sfc	9/15/07	31.61	31.55	31.58
Stk8sfc	9/15/07	32.87	32.86	32.86
Stk9sfc	9/15/07	32.88	32.88	32.88
Stk13sfc	9/15/07	32.81	32.81	32.81
Stk15sfc	9/15/07	32.40	32.40	32.40
Stk16sfc	9/15/07	32.81	32.81	32.81
Stk18sfc	9/15/07	28.19	30.71	29.45

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. "NaN" is defined as "Not a Number" when a parameter was not measured.)

Site	Date	Temp Upper 25cm	Temp Bottom 25cm	Temp WC
OM2	10/13/07	25.03	25.08	25.06
OCN2	10/13/07	25.35	25.51	25.43
OB	10/13/07	25.56	25.56	25.56
OM1	10/13/07	25.77	25.79	25.78
TM	10/13/07	26.04	25.77	25.91
OCN1	10/13/07	25.63	25.49	25.56
RM3	10/13/07	26.34	26.34	26.34
RM2	10/13/07	24.02	24.02	24.02
RM1	10/13/07	25.13	25.13	25.13
River	10/13/07	NaN	NaN	NaN
Stk1sfc	10/13/07	26.57	26.57	26.57
Stk3sfc	10/13/07	27.37	27.37	27.37
Stk6sfc	10/13/07	27.59	27.59	27.59
Stk7sfc	10/13/07	27.26	27.26	27.26
Stk8sfc	10/13/07	26.72	26.80	26.76
Stk9sfc	10/13/07	27.49	27.49	27.49
Stk13sfc	10/13/07	27.42	27.42	27.42
Stk15sfc	10/13/07	26.59	26.67	26.63
Stk16sfc	10/13/07	26.60	26.60	26.60
Stk18sfc	10/13/07	27.07	27.07	27.07

Site	Date	Salinity Upper 25cm	Salinity Bottom 25cm	Salinity WC
OM2	10/13/07	30.70	31.08	30.89
OCN2	10/13/07	32.26	33.28	32.77
OB	10/13/07	32.69	32.69	32.69
OM1	10/13/07	32.53	32.60	32.56
TM	10/13/07	32.80	33.14	32.97
OCN1	10/13/07	32.10	33.98	33.04
RM3	10/13/07	30.12	30.12	30.12
RM2	10/13/07	0.00	0.00	0.00
RM1	10/13/07	24.28	24.28	24.28
River	10/13/07	0.00	0.00	0.00
Stk1sfc	10/13/07	31.29	31.29	31.29
Stk3sfc	10/13/07	31.96	31.96	31.96
Stk6sfc	10/13/07	30.70	30.70	30.70
Stk7sfc	10/13/07	30.87	30.87	30.87
Stk8sfc	10/13/07	30.47	30.62	30.54
Stk9sfc	10/13/07	30.76	30.76	30.76
Stk13sfc	10/13/07	27.60	27.60	27.60
Stk15sfc	10/13/07	28.05	28.09	28.07
Stk16sfc	10/13/07	27.32	27.32	27.32
Stk18sfc	10/13/07	28.34	28.34	28.34

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. “NaN” is defined as “Not a Number” when a parameter was not measured.)

Storm 1

Site	Date	Temp Upper 25cm	Temp Bottom 25cm	Temp WC
OM2	11/5/07	25.13	25.12	25.12
OCN2	11/5/07	25.25	25.25	25.25
OB	11/5/07	25.01	25.04	25.02
OM1	11/5/07	25.22	25.16	25.19
TM	11/5/07	25.39	25.20	25.29
OCN1	11/5/07	25.74	25.67	25.71
RM3	11/5/07	23.29	24.58	23.94
RM2	11/5/07	22.39	22.39	22.39
RM1	11/5/07	22.92	24.60	23.76
River	11/5/07	NaN	NaN	NaN
Stk1sfc	11/5/07	26.97	25.90	26.44
Stk3sfc	11/5/07	27.20	26.47	26.83
Stk6sfc	11/5/07	27.06	26.05	26.56
Stk7sfc	11/5/07	26.91	25.64	26.27
Stk8sfc	11/5/07	26.67	25.76	26.22
Stk9sfc	11/5/07	26.44	25.90	26.17
Stk13sfc	11/5/07	25.83	25.88	25.85
Stk15sfc	11/5/07	25.87	25.68	25.77
Stk16sfc	11/5/07	25.69	25.95	25.82
Stk18sfc	11/5/07	25.58	26.15	25.87

Site	Date	Salinity Upper 25cm	Salinity Bottom 25cm	Salinity WC
OM2	11/5/07	30.31	30.50	30.40
OCN2	11/5/07	29.93	29.94	29.94
OB	11/5/07	29.60	29.62	29.61
OM1	11/5/07	29.62	30.24	29.93
TM	11/5/07	29.99	31.58	30.78
OCN1	11/5/07	29.42	29.73	29.58
RM3	11/5/07	12.71	20.30	16.50
RM2	11/5/07	0.00	0.00	0.00
RM1	11/5/07	2.26	14.54	8.40
River	11/5/07	0.00	0.00	0.00
Stk1sfc	11/5/07	8.54	24.35	16.45
Stk3sfc	11/5/07	5.75	13.16	9.45
Stk6sfc	11/5/07	4.05	20.68	12.37
Stk7sfc	11/5/07	4.71	21.95	13.33
Stk8sfc	11/5/07	4.86	22.25	13.55
Stk9sfc	11/5/07	5.85	17.63	11.74
Stk13sfc	11/5/07	10.57	21.38	15.97
Stk15sfc	11/5/07	6.99	18.11	12.55
Stk16sfc	11/5/07	4.80	22.09	13.44
Stk18sfc	11/5/07	3.99	7.26	5.62

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. “NaN” is defined as “Not a Number” when a parameter was not measured.)

Transects 1-4 Site	Date	Temp Upper 25cm	Temp Bottom 25cm	Temp WC
Stk6sfc	11/6/07	27.17	26.96	27.07
Stk7sfc	11/6/07	27.08	27.85	27.46
Stk9sfc	11/6/07	27.43	26.85	27.14
Stk11sfc	11/6/07	27.87	26.78	27.33
Stk13sfc	11/6/07	28.10	26.97	27.53
Stk18sfc	11/6/07	26.74	26.38	26.56
Stk6sfc	11/7/07	27.63	28.30	27.97
Stk7sfc	11/7/07	27.47	27.62	27.54
Stk9sfc	11/7/07	27.84	27.74	27.79
Stk11sfc	11/7/07	27.37	27.42	27.39
Stk13sfc	11/7/07	27.65	27.40	27.52
Stk18sfc	11/7/07	27.78	27.84	27.81
Stk6sfc	11/8/07	28.19	28.41	28.30
Stk7sfc	11/8/07	27.21	28.69	27.95
Stk9sfc	11/8/07	28.63	28.64	28.64
Stk11sfc	11/8/07	28.83	29.03	28.93
Stk13sfc	11/8/07	29.35	29.20	29.27
Stk18sfc	11/8/07	26.51	27.83	27.17
Stk6sfc	11/11/07	24.91	25.42	25.17
Stk7sfc	11/11/07	24.92	25.36	25.14
Stk9sfc	11/11/07	24.60	25.36	24.98
Stk11sfc	11/11/07	24.46	25.22	24.84
Stk13sfc	11/11/07	24.46	24.47	24.46
Stk18sfc	11/11/07	24.36	24.59	24.48

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. “NaN” is defined as “Not a Number” when a parameter was not measured.)

Transects 1-4 Site	Date	Salinity Upper 25cm	Salinity Bottom 25cm	Salinity WC
Stk6sfc	11/6/07	24.72	27.71	26.22
Stk7sfc	11/6/07	23.39	26.35	24.87
Stk9sfc	11/6/07	19.87	29.15	24.51
Stk11sfc	11/6/07	15.03	27.93	21.48
Stk13sfc	11/6/07	10.87	26.33	18.60
Stk18sfc	11/6/07	7.56	25.73	16.65
Stk6sfc	11/7/07	28.79	29.62	29.21
Stk7sfc	11/7/07	27.90	28.80	28.35
Stk9sfc	11/7/07	28.14	28.53	28.34
Stk11sfc	11/7/07	26.73	27.36	27.05
Stk13sfc	11/7/07	18.55	25.85	22.20
Stk18sfc	11/7/07	25.12	27.88	26.50
Stk6sfc	11/8/07	27.42	28.03	27.73
Stk7sfc	11/8/07	23.03	29.49	26.26
Stk9sfc	11/8/07	30.01	30.02	30.02
Stk11sfc	11/8/07	30.36	30.52	30.44
Stk13sfc	11/8/07	30.57	30.43	30.50
Stk18sfc	11/8/07	16.57	27.96	22.27
Stk6sfc	11/11/07	26.77	28.78	27.78
Stk7sfc	11/11/07	29.57	30.64	30.10
Stk9sfc	11/11/07	27.09	30.58	28.84
Stk11sfc	11/11/07	27.46	31.56	29.51
Stk13sfc	11/11/07	27.28	27.42	27.35
Stk18sfc	11/11/07	24.84	28.78	26.81

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. “NaN” is defined as “Not a Number” when a parameter was not measured.)

Site	Date	Temp Upper 25cm	Temp Bottom 25cm	Temp WC
OM2	11/17/07	24.39	24.27	24.33
OCN2	11/17/07	24.93	24.92	24.92
OB	11/17/07	25.25	25.31	25.28
OM1	11/17/07	25.36	25.43	25.39
TM	11/17/07	25.41	25.59	25.50
OCN1	11/17/07	25.18	25.78	25.48
RM3	11/17/07	24.83	24.94	24.89
RM2	11/17/07	23.15	23.17	23.16
RM1	11/17/07	24.64	24.71	24.68
River	11/17/07	NaN	NaN	NaN
Stk1sfc	11/17/07	26.04	26.08	26.06
Stk3sfc	11/17/07	25.77	26.15	25.96
Stk6sfc	11/17/07	25.22	25.31	25.26
Stk7sfc	11/17/07	25.09	25.15	25.12
Stk8sfc	11/17/07	24.95	25.35	25.15
Stk9sfc	11/17/07	25.23	25.30	25.26
Stk13sfc	11/17/07	25.25	25.31	25.28
Stk15sfc	11/17/07	24.90	24.97	24.93
Stk16sfc	11/17/07	24.85	24.99	24.92
Stk18sfc	11/17/07	25.08	25.17	25.12

Site	Date	Salinity Upper 25cm	Salinity Bottom 25cm	Salinity WC
OM2	11/17/07	33.44	33.22	33.33
OCN2	11/17/07	33.98	33.97	33.98
OB	11/17/07	33.87	33.82	33.84
OM1	11/17/07	33.79	33.64	33.72
TM	11/17/07	32.64	33.48	33.06
OCN1	11/17/07	31.08	32.28	31.68
RM3	11/17/07	27.65	29.13	28.39
RM2	11/17/07	0.00	0.00	0.00
RM1	11/17/07	13.59	23.55	18.57
River	11/17/07	0.00	0.00	0.00
Stk1sfc	11/17/07	34.02	33.98	34.00
Stk3sfc	11/17/07	32.20	33.05	32.62
Stk6sfc	11/17/07	30.75	30.92	30.83
Stk7sfc	11/17/07	30.03	30.46	30.25
Stk8sfc	11/17/07	29.55	31.47	30.51
Stk9sfc	11/17/07	30.31	30.34	30.33
Stk13sfc	11/17/07	31.40	31.39	31.39
Stk15sfc	11/17/07	26.55	29.78	28.16
Stk16sfc	11/17/07	27.11	31.07	29.09
Stk18sfc	11/17/07	25.94	29.76	27.85

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. “NaN” is defined as “Not a Number” when a parameter was not measured.)

Storm 2

Site	Date	Temp Upper 25cm	Temp Bottom 25cm	Temp WC
OM2	12/9/07	24.20	24.10	24.15
OCN2	12/9/07	23.92	23.93	23.93
OB	12/9/07	23.80	24.16	23.98
OM1	12/9/07	24.03	24.20	24.11
TM	12/9/07	24.01	24.04	24.02
OCN1	12/9/07	24.01	24.36	24.18
RM3	12/9/07	24.10	24.10	24.10
RM2	12/9/07	21.93	21.93	21.93
RM1	12/9/07	23.90	24.60	24.25
River	12/9/07	NaN	NaN	NaN
Stk1sfc	12/9/07	24.59	25.15	24.87
Stk3sfc	12/9/07	24.32	24.66	24.49
Stk6sfc	12/9/07	24.90	25.37	25.13
Stk7sfc	12/9/07	25.06	25.40	25.23
Stk8sfc	12/9/07	24.39	24.97	24.68
Stk9sfc	12/9/07	24.64	25.28	24.96
Stk13sfc	12/9/07	24.50	24.99	24.75
Stk15sfc	12/9/07	24.55	25.03	24.79
Stk16sfc	12/9/07	24.59	25.18	24.88
Stk18sfc	12/9/07	24.46	25.00	24.73

Site	Date	Salinity Upper 25cm	Salinity Bottom 25cm	Salinity WC
OM2	12/9/07	30.93	31.29	31.11
OCN2	12/9/07	30.73	31.12	30.93
OB	12/9/07	26.56	30.81	28.68
OM1	12/9/07	27.10	29.72	28.41
TM	12/9/07	28.42	30.27	29.34
OCN1	12/9/07	26.30	31.12	28.71
RM3	12/9/07	25.76	25.76	25.76
RM2	12/9/07	0.00	0.00	0.00
RM1	12/9/07	24.25	30.27	27.26
River	12/9/07	0.00	0.00	0.00
Stk1sfc	12/9/07	28.37	30.96	29.66
Stk3sfc	12/9/07	25.21	29.62	27.41
Stk6sfc	12/9/07	28.16	29.96	29.06
Stk7sfc	12/9/07	29.86	30.71	30.28
Stk8sfc	12/9/07	26.29	31.24	28.76
Stk9sfc	12/9/07	25.47	28.99	27.23
Stk13sfc	12/9/07	14.84	24.59	19.72
Stk15sfc	12/9/07	13.34	30.02	21.78
Stk16sfc	12/9/07	25.60	31.30	28.45
Stk18sfc	12/9/07	26.29	30.73	28.51

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. “NaN” is defined as “Not a Number” when a parameter was not measured.)

Site	Date	Temp Upper 25cm	Temp Bottom 25cm	Temp WC
OM2	1/12/08	22.44	22.72	22.58
OCN2	1/12/08	23.48	23.51	23.49
OB	1/12/08	23.37	23.37	23.37
OM1	1/12/08	23.12	23.23	23.18
TM	1/12/08	23.46	23.52	23.49
OCN1	1/12/08	23.75	23.83	23.79
RM3	1/12/08	23.57	23.57	23.57
RM2	1/12/08	20.31	20.31	20.31
RM1	1/12/08	22.99	22.99	22.99
River	1/12/08	NaN	NaN	NaN
Stk1sfc	1/12/08	23.95	24.14	24.05
Stk3sfc	1/12/08	23.89	23.89	23.89
Stk6sfc	1/12/08	24.38	24.38	24.38
Stk7sfc	1/12/08	24.81	24.81	24.81
Stk8sfc	1/12/08	24.60	24.85	24.73
Stk9sfc	1/12/08	24.73	24.73	24.73
Stk13sfc	1/12/08	24.90	24.89	24.90
Stk15sfc	1/12/08	24.63	24.64	24.64
Stk16sfc	1/12/08	24.33	24.40	24.36
Stk18sfc	1/12/08	24.96	25.07	25.02

Site	Date	Salinity Upper 25cm	Salinity Bottom 25cm	Salinity WC
OM2	1/12/08	26.59	29.46	28.02
OCN2	1/12/08	33.15	33.40	33.27
OB	1/12/08	29.97	29.97	29.97
OM1	1/12/08	27.97	29.34	28.65
TM	1/12/08	25.14	27.09	26.12
OCN1	1/12/08	32.83	33.88	33.35
RM3	1/12/08	26.52	26.52	26.52
RM2	1/12/08	0.00	0.00	0.00
RM1	1/12/08	27.24	27.24	27.24
River	1/12/08	0.00	0.00	0.00
Stk1sfc	1/12/08	25.63	26.77	26.20
Stk3sfc	1/12/08	28.39	28.39	28.39
Stk6sfc	1/12/08	29.84	29.84	29.84
Stk7sfc	1/12/08	29.79	29.79	29.79
Stk8sfc	1/12/08	30.25	30.63	30.44
Stk9sfc	1/12/08	28.40	28.40	28.40
Stk13sfc	1/12/08	22.51	23.23	22.87
Stk15sfc	1/12/08	26.10	28.45	27.27
Stk16sfc	1/12/08	27.19	28.02	27.61
Stk18sfc	1/12/08	29.29	29.61	29.45

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. “NaN” is defined as “Not a Number” when a parameter was not measured.)

Site	Date	Temp Upper 25cm	Temp Bottom 25cm	Temp WC
OM2	2/16/08	23.38	23.43	23.41
OCN2	2/16/08	23.77	23.77	23.77
OB	2/16/08	23.38	23.38	23.38
OM1	2/16/08	23.67	23.70	23.69
TM	2/16/08	24.62	23.99	24.30
OCN1	2/16/08	23.81	23.74	23.78
RM3	2/16/08	25.39	25.39	25.39
RM2	2/16/08	20.08	20.08	20.08
RM1	2/16/08	23.61	23.61	23.61
River	2/16/08	NaN	NaN	NaN
Stk1sfc	2/16/08	25.36	25.36	25.36
Stk3sfc	2/16/08	26.04	26.04	26.04
Stk6sfc	2/16/08	27.20	27.20	27.20
Stk7sfc	2/16/08	26.11	26.11	26.11
Stk8sfc	2/16/08	25.60	25.60	25.60
Stk9sfc	2/16/08	26.18	26.18	26.18
Stk13sfc	2/16/08	25.01	25.01	25.01
Stk15sfc	2/16/08	24.96	24.96	24.96
Stk16sfc	2/16/08	25.18	25.18	25.18
Stk18sfc	2/16/08	25.99	25.99	25.99

Site	Date	Salinity Upper 25cm	Salinity Bottom 25cm	Salinity WC
OM2	2/16/08	32.78	33.01	32.89
OCN2	2/16/08	32.91	32.98	32.95
OB	2/16/08	31.92	31.92	31.92
OM1	2/16/08	31.70	32.88	32.29
TM	2/16/08	33.60	34.00	33.80
OCN1	2/16/08	33.08	33.67	33.38
RM3	2/16/08	32.66	32.66	32.66
RM2	2/16/08	0.00	0.00	0.00
RM1	2/16/08	30.69	30.69	30.69
River	2/16/08	0.00	0.00	0.00
Stk1sfc	2/16/08	32.27	32.27	32.27
Stk3sfc	2/16/08	33.86	33.86	33.86
Stk6sfc	2/16/08	33.49	33.49	33.49
Stk7sfc	2/16/08	33.11	33.11	33.11
Stk8sfc	2/16/08	33.61	33.61	33.61
Stk9sfc	2/16/08	33.59	33.59	33.59
Stk13sfc	2/16/08	26.19	26.19	26.19
Stk15sfc	2/16/08	29.60	29.60	29.60
Stk16sfc	2/16/08	29.42	29.42	29.42
Stk18sfc	2/16/08	32.29	32.29	32.29

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. “NaN” is defined as “Not a Number” when a parameter was not measured.)

Site	Date	Temp Upper 25cm	Temp Bottom 25cm	Temp WC
OM2	3/15/08	23.78	23.79	23.78
OCN2	3/15/08	23.76	23.76	23.76
OB	3/15/08	23.90	23.94	23.92
OM1	3/15/08	24.92	24.73	24.83
TM	3/15/08	25.25	25.10	25.18
OCN1	3/15/08	24.17	25.12	24.65
RM3	3/15/08	NaN	NaN	NaN
RM2	3/15/08	NaN	NaN	NaN
RM1	3/15/08	NaN	NaN	NaN
River	3/15/08	NaN	NaN	NaN
Stk1sfc	3/15/08	NaN	NaN	NaN
Stk3sfc	3/15/08	NaN	NaN	NaN
Stk6sfc	3/15/08	NaN	NaN	NaN
Stk7sfc	3/15/08	NaN	NaN	NaN
Stk8sfc	3/15/08	NaN	NaN	NaN
Stk9sfc	3/15/08	NaN	NaN	NaN
Stk13sfc	3/15/08	NaN	NaN	NaN
Stk15sfc	3/15/08	NaN	NaN	NaN
Stk16sfc	3/15/08	NaN	NaN	NaN
Stk18sfc	3/15/08	NaN	NaN	NaN

Site	Date	Salinity Upper 25cm	Salinity Bottom 25cm	Salinity WC
OM2	3/15/08	34.24	34.26	34.25
OCN2	3/15/08	34.45	34.45	34.45
OB	3/15/08	33.50	33.68	33.59
OM1	3/15/08	33.10	33.16	33.13
TM	3/15/08	32.28	32.60	32.44
OCN1	3/15/08	23.07	32.48	27.77
RM3	3/15/08	NaN	NaN	NaN
RM2	3/15/08	NaN	NaN	NaN
RM1	3/15/08	NaN	NaN	NaN
River	3/15/08	NaN	NaN	NaN
Stk1sfc	3/15/08	NaN	NaN	NaN
Stk3sfc	3/15/08	NaN	NaN	NaN
Stk6sfc	3/15/08	NaN	NaN	NaN
Stk7sfc	3/15/08	NaN	NaN	NaN
Stk8sfc	3/15/08	NaN	NaN	NaN
Stk9sfc	3/15/08	NaN	NaN	NaN
Stk13sfc	3/15/08	NaN	NaN	NaN
Stk15sfc	3/15/08	NaN	NaN	NaN
Stk16sfc	3/15/08	NaN	NaN	NaN
Stk18sfc	3/15/08	NaN	NaN	NaN

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. “NaN” is defined as “Not a Number” when a parameter was not measured.)

Site	Date	Temp Upper 25cm	Temp Bottom 25cm	Temp WC
OM2	4/19/08	25.92	25.88	25.90
OCN2	4/19/08	26.14	26.14	26.14
OB	4/19/08	26.21	26.21	26.21
OM1	4/19/08	26.34	26.26	26.30
TM	4/19/08	26.75	26.37	26.56
OCN1	4/19/08	26.11	25.97	26.04
RM3	4/19/08	25.88	25.88	25.88
RM2	4/19/08	22.75	22.75	22.75
RM1	4/19/08	24.82	24.82	24.82
River	4/19/08	NaN	NaN	NaN
Stk1sfc	4/19/08	28.46	28.46	28.46
Stk3sfc	4/19/08	27.71	27.71	27.71
Stk6sfc	4/19/08	27.75	27.75	27.75
Stk7sfc	4/19/08	27.30	27.86	27.58
Stk8sfc	4/19/08	27.92	27.95	27.94
Stk9sfc	4/19/08	28.64	28.65	28.64
Stk13sfc	4/19/08	29.01	29.01	29.01
Stk15sfc	4/19/08	28.26	28.25	28.25
Stk16sfc	4/19/08	28.16	28.38	28.27
Stk18sfc	4/19/08	26.66	28.32	27.49

Site	Date	Salinity Upper 25cm	Salinity Bottom 25cm	Salinity WC
OM2	4/19/08	32.33	32.35	32.34
OCN2	4/19/08	33.37	33.37	33.37
OB	4/19/08	33.09	33.09	33.09
OM1	4/19/08	32.69	32.98	32.84
TM	4/19/08	32.64	32.00	32.32
OCN1	4/19/08	32.54	32.72	32.63
RM3	4/19/08	23.04	23.04	23.04
RM2	4/19/08	0.00	0.00	0.00
RM1	4/19/08	8.25	8.25	8.25
River	4/19/08	0.00	0.00	0.00
Stk1sfc	4/19/08	32.47	32.47	32.47
Stk3sfc	4/19/08	33.25	33.25	33.25
Stk6sfc	4/19/08	28.60	28.60	28.60
Stk7sfc	4/19/08	24.76	27.11	25.93
Stk8sfc	4/19/08	33.02	33.04	33.03
Stk9sfc	4/19/08	32.89	32.89	32.89
Stk13sfc	4/19/08	32.57	32.58	32.58
Stk15sfc	4/19/08	31.00	31.37	31.18
Stk16sfc	4/19/08	30.86	31.33	31.10
Stk18sfc	4/19/08	23.14	29.48	26.31

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. “NaN” is defined as “Not a Number” when a parameter was not measured.)

Site	Date	Temp Upper 25cm	Temp Bottom 25cm	Temp WC
OM2	5/17/08	26.85	26.85	26.85
OCN2	5/17/08	28.08	28.08	28.08
OB	5/17/08	27.27	27.27	27.27
OM1	5/17/08	26.72	26.68	26.70
TM	5/17/08	26.94	26.81	26.87
OCN1	5/17/08	27.30	27.20	27.25
RM3	5/17/08	27.70	27.70	27.70
RM2	5/17/08	22.84	22.84	22.84
RM1	5/17/08	28.08	28.08	28.08
River	5/17/08	NaN	NaN	NaN
Stk1sfc	5/17/08	28.94	28.94	28.94
Stk3sfc	5/17/08	28.17	28.17	28.17
Stk6sfc	5/17/08	29.94	29.94	29.94
Stk7sfc	5/17/08	30.96	30.96	30.96
Stk8sfc	5/17/08	31.47	31.28	31.37
Stk9sfc	5/17/08	30.08	30.05	30.07
Stk13sfc	5/17/08	30.38	30.35	30.37
Stk15sfc	5/17/08	31.04	31.03	31.03
Stk16sfc	5/17/08	30.75	30.91	30.83
Stk18sfc	5/17/08	31.34	31.31	31.32

Site	Date	Salinity Upper 25cm	Salinity Bottom 25cm	Salinity WC
OM2	5/17/08	32.49	32.49	32.49
OCN2	5/17/08	34.00	34.00	34.00
OB	5/17/08	34.10	34.10	34.10
OM1	5/17/08	33.08	33.79	33.44
TM	5/17/08	33.84	35.08	34.46
OCN1	5/17/08	33.88	34.67	34.27
RM3	5/17/08	24.32	24.32	24.32
RM2	5/17/08	0.00	0.00	0.00
RM1	5/17/08	28.74	28.74	28.74
River	5/17/08	0.00	0.00	0.00
Stk1sfc	5/17/08	33.21	33.21	33.21
Stk3sfc	5/17/08	34.44	34.44	34.44
Stk6sfc	5/17/08	33.28	33.28	33.28
Stk7sfc	5/17/08	33.28	33.28	33.28
Stk8sfc	5/17/08	33.41	33.55	33.48
Stk9sfc	5/17/08	33.86	33.88	33.87
Stk13sfc	5/17/08	33.13	33.15	33.14
Stk15sfc	5/17/08	33.79	33.79	33.79
Stk16sfc	5/17/08	30.14	33.70	31.92
Stk18sfc	5/17/08	30.55	33.11	31.83

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. “NaN” is defined as “Not a Number” when a parameter was not measured.)

Storm 4

Site	Date	Temp Upper 25cm	Temp Bottom 25cm	Temp WC
OM2	6/14/08	25.86	25.97	25.91
OCN2	6/14/08	25.89	26.07	25.98
OB	6/14/08	25.93	25.98	25.96
OM1	6/14/08	26.01	26.76	26.39
TM	6/14/08	26.14	26.35	26.24
OCN1	6/14/08	27.24	28.27	27.76
RM3	6/14/08	26.79	26.79	26.79
RM2	6/14/08	22.99	22.99	22.99
RM1	6/14/08	25.68	25.68	25.68
River	6/14/08	NaN	NaN	NaN
Stk1sfc	6/14/08	27.71	27.99	27.85
Stk3sfc	6/14/08	27.27	27.28	27.28
Stk6sfc	6/14/08	30.02	30.02	30.02
Stk7sfc	6/14/08	28.31	28.56	28.43
Stk8sfc	6/14/08	28.09	29.16	28.63
Stk9sfc	6/14/08	27.43	27.32	27.38
Stk13sfc	6/14/08	26.60	27.51	27.06
Stk15sfc	6/14/08	27.50	28.79	28.14
Stk16sfc	6/14/08	27.36	29.06	28.21
Stk18sfc	6/14/08	27.82	29.36	28.59

Site	Date	Salinity Upper 25cm	Salinity Bottom 25cm	Salinity WC
OM2	6/14/08	20.72	22.71	21.71
OCN2	6/14/08	20.85	22.94	21.89
OB	6/14/08	25.41	26.42	25.92
OM1	6/14/08	24.28	29.95	27.11
TM	6/14/08	25.16	31.20	28.18
OCN1	6/14/08	25.04	30.28	27.66
RM3	6/14/08	12.57	12.57	12.57
RM2	6/14/08	0.00	0.00	0.00
RM1	6/14/08	3.53	3.53	3.53
River	6/14/08	0.00	0.00	0.00
Stk1sfc	6/14/08	24.28	24.86	24.57
Stk3sfc	6/14/08	28.75	28.88	28.82
Stk6sfc	6/14/08	21.54	21.54	21.54
Stk7sfc	6/14/08	18.71	21.31	20.01
Stk8sfc	6/14/08	18.37	25.51	21.94
Stk9sfc	6/14/08	17.56	30.40	23.98
Stk13sfc	6/14/08	12.83	22.70	17.76
Stk15sfc	6/14/08	12.92	26.16	19.54
Stk16sfc	6/14/08	11.47	25.56	18.51
Stk18sfc	6/14/08	14.92	26.39	20.66

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. “NaN” is defined as “Not a Number” when a parameter was not measured.)

Site	Date	Temp Upper 25cm	Temp Bottom 25cm	Temp WC
OM2	7/26/08	25.72	25.78	25.75
OCN2	7/26/08	26.10	26.10	26.10
OB	7/26/08	26.74	26.76	26.75
OM1	7/26/08	26.94	26.92	26.93
TM	7/26/08	26.24	26.30	26.27
OCN1	7/26/08	26.43	26.85	26.64
RM3	7/26/08	25.31	25.44	25.37
RM2	7/26/08	24.75	26.14	25.45
RM1	7/26/08	25.50	26.92	26.21
River	7/26/08	NaN	NaN	NaN
Stk1sfc	7/26/08	27.33	27.34	27.33
Stk3sfc	7/26/08	27.32	27.56	27.44
Stk6sfc	7/26/08	27.08	27.30	27.19
Stk7sfc	7/26/08	27.04	27.16	27.10
Stk8sfc	7/26/08	26.51	27.09	26.80
Stk9sfc	7/26/08	26.94	27.13	27.03
Stk13sfc	7/26/08	27.58	27.57	27.58
Stk15sfc	7/26/08	26.77	27.48	27.12
Stk16sfc	7/26/08	26.58	27.28	26.93
Stk18sfc	7/26/08	26.52	27.12	26.82

Site	Date	Salinity Upper 25cm	Salinity Bottom 25cm	Salinity WC
OM2	7/26/08	34.26	34.45	34.35
OCN2	7/26/08	34.75	34.76	34.75
OB	7/26/08	34.87	34.89	34.88
OM1	7/26/08	35.10	35.09	35.10
TM	7/26/08	32.34	32.76	32.55
OCN1	7/26/08	32.21	33.85	33.03
RM3	7/26/08	27.34	28.32	27.83
RM2	7/26/08	0.00	0.00	0.00
RM1	7/26/08	18.41	29.76	24.08
River	7/26/08	0.00	0.00	0.00
Stk1sfc	7/26/08	34.65	34.66	34.65
Stk3sfc	7/26/08	33.15	34.29	33.72
Stk6sfc	7/26/08	30.12	30.72	30.42
Stk7sfc	7/26/08	29.82	30.73	30.28
Stk8sfc	7/26/08	28.77	31.64	30.20
Stk9sfc	7/26/08	30.24	31.17	30.70
Stk13sfc	7/26/08	33.07	33.08	33.07
Stk15sfc	7/26/08	29.02	32.39	30.71
Stk16sfc	7/26/08	26.14	32.51	29.33
Stk18sfc	7/26/08	24.39	30.64	27.51

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. “NaN” is defined as “Not a Number” when a parameter was not measured.)

Site	Date	Temp Upper 25cm	Temp Bottom 25cm	Temp WC
OM2	8/30/08	27.78	27.78	27.78
OCN2	8/30/08	27.65	27.65	27.65
OB	8/30/08	27.48	27.47	27.48
OM1	8/30/08	26.79	26.79	26.79
TM	8/30/08	27.20	26.95	27.08
OCN1	8/30/08	26.94	27.04	26.99
RM3	8/30/08	26.34	26.34	26.34
RM2	8/30/08	24.29	24.29	24.29
RM1	8/30/08	26.71	26.71	26.71
River	8/30/08	NaN	NaN	NaN
Stk1sfc	8/30/08	28.31	28.31	28.31
Stk3sfc	8/30/08	28.14	28.14	28.14
Stk6sfc	8/30/08	28.26	28.26	28.26
Stk7sfc	8/30/08	27.52	27.69	27.60
Stk8sfc	8/30/08	28.58	28.58	28.58
Stk9sfc	8/30/08	28.85	28.85	28.85
Stk13sfc	8/30/08	28.73	28.72	28.72
Stk15sfc	8/30/08	28.49	28.48	28.49
Stk16sfc	8/30/08	28.43	28.57	28.50
Stk18sfc	8/30/08	27.57	27.68	27.63

Site	Date	Salinity Upper 25cm	Salinity Bottom 25cm	Salinity WC
OM2	8/30/08	33.28	33.26	33.27
OCN2	8/30/08	33.69	33.69	33.69
OB	8/30/08	32.43	32.43	32.43
OM1	8/30/08	32.49	32.49	32.49
TM	8/30/08	32.29	32.92	32.61
OCN1	8/30/08	30.60	32.18	31.39
RM3	8/30/08	23.38	23.38	23.38
RM2	8/30/08	0.00	0.00	0.00
RM1	8/30/08	28.19	28.19	28.19
River	8/30/08	0.00	0.00	0.00
Stk1sfc	8/30/08	33.07	33.07	33.07
Stk3sfc	8/30/08	32.93	32.93	32.93
Stk6sfc	8/30/08	30.86	30.86	30.86
Stk7sfc	8/30/08	29.37	29.83	29.60
Stk8sfc	8/30/08	32.30	32.30	32.30
Stk9sfc	8/30/08	32.56	32.56	32.56
Stk13sfc	8/30/08	32.66	32.66	32.66
Stk15sfc	8/30/08	32.98	32.99	32.99
Stk16sfc	8/30/08	31.53	32.40	31.97
Stk18sfc	8/30/08	29.41	30.62	30.01

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. “NaN” is defined as “Not a Number” when a parameter was not measured.)

Appendix 2. Surface, near-bottom, and water column (WC) average % DO and pH data, as measured by a YSI 6600A v2 multi-parameter water quality sonde.

Site	Date	% DO Upper 25cm	% DO Bottom 25cm	% DO WC
OM2	8/11/07	82.50	82.00	82.25
OCN2	8/11/07	109.72	109.72	109.72
OB	8/11/07	87.16	87.16	87.16
OM1	8/11/07	96.24	103.23	99.73
TM	8/11/07	89.48	93.78	91.63
OCN1	8/11/07	97.87	97.87	97.87
RM3	8/11/07	63.53	63.55	63.54
RM2	8/11/07	48.82	48.82	48.82
RM1	8/11/07	114.20	114.20	114.20
River	8/11/07	NaN	NaN	NaN
Stk1sfc	8/11/07	157.63	159.73	158.68
Stk3sfc	8/11/07	108.86	108.12	108.49
Stk6sfc	8/11/07	134.88	122.18	128.53
Stk7sfc	8/11/07	126.00	128.50	127.25
Stk8sfc	8/11/07	121.73	120.90	121.32
Stk9sfc	8/11/07	113.52	113.25	113.39
Stk13sfc	8/11/07	155.83	154.95	155.39
Stk15sfc	8/11/07	132.62	139.24	135.93
Stk16sfc	8/11/07	127.73	129.80	128.76
Stk18sfc	8/11/07	119.64	121.18	120.41

Site	Date	pH Upper 25cm	pH Bottom 25cm	pH WC
OM2	8/11/07	NaN	NaN	NaN
OCN2	8/11/07	NaN	NaN	NaN
OB	8/11/07	NaN	NaN	NaN
OM1	8/11/07	NaN	NaN	NaN
TM	8/11/07	NaN	NaN	NaN
OCN1	8/11/07	NaN	NaN	NaN
RM3	8/11/07	NaN	NaN	NaN
RM2	8/11/07	NaN	NaN	NaN
RM1	8/11/07	NaN	NaN	NaN
River	8/11/07	NaN	NaN	NaN
Stk1sfc	8/11/07	NaN	NaN	NaN
Stk3sfc	8/11/07	NaN	NaN	NaN
Stk6sfc	8/11/07	NaN	NaN	NaN
Stk7sfc	8/11/07	NaN	NaN	NaN
Stk8sfc	8/11/07	NaN	NaN	NaN
Stk9sfc	8/11/07	NaN	NaN	NaN
Stk13sfc	8/11/07	NaN	NaN	NaN
Stk15sfc	8/11/07	NaN	NaN	NaN
Stk16sfc	8/11/07	NaN	NaN	NaN
Stk18sfc	8/11/07	NaN	NaN	NaN

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. "NaN" is defined as "Not a Number" when a parameter was not measured.)

Site	Date	% DO Upper 25cm	% DO Bottom 25cm	% DO WC
OM2	9/15/07	80.16	81.19	80.68
OCN2	9/15/07	71.80	71.55	71.67
OB	9/15/07	108.92	108.92	108.92
OM1	9/15/07	97.75	93.25	95.50
TM	9/15/07	91.33	109.21	100.27
OCN1	9/15/07	98.88	99.53	99.21
RM3	9/15/07	90.72	90.72	90.72
RM2	9/15/07	52.64	52.61	52.62
RM1	9/15/07	72.76	72.29	72.53
River	9/15/07	NaN	NaN	NaN
Stk1sfc	9/15/07	111.59	111.71	111.65
Stk3sfc	9/15/07	119.05	119.19	119.12
Stk6sfc	9/15/07	118.93	118.43	118.68
Stk7sfc	9/15/07	117.57	117.99	117.78
Stk8sfc	9/15/07	111.77	111.23	111.50
Stk9sfc	9/15/07	126.67	126.58	126.62
Stk13sfc	9/15/07	126.69	126.54	126.62
Stk15sfc	9/15/07	116.16	117.09	116.62
Stk16sfc	9/15/07	144.80	145.32	145.06
Stk18sfc	9/15/07	97.76	99.83	98.80

Site	Date	pH Upper 25cm	pH Bottom 25cm	pH WC
OM2	9/15/07	8.00	8.01	8.01
OCN2	9/15/07	7.90	7.89	7.90
OB	9/15/07	8.11	8.11	8.11
OM1	9/15/07	8.03	8.02	8.03
TM	9/15/07	7.98	8.07	8.03
OCN1	9/15/07	8.02	8.03	8.03
RM3	9/15/07	7.96	7.96	7.96
RM2	9/15/07	7.22	7.21	7.22
RM1	9/15/07	7.71	7.72	7.71
River	9/15/07	NaN	NaN	NaN
Stk1sfc	9/15/07	8.07	8.07	8.07
Stk3sfc	9/15/07	8.11	8.11	8.11
Stk6sfc	9/15/07	8.10	8.09	8.10
Stk7sfc	9/15/07	8.10	8.10	8.10
Stk8sfc	9/15/07	8.08	8.08	8.08
Stk9sfc	9/15/07	8.16	8.16	8.16
Stk13sfc	9/15/07	8.12	8.11	8.11
Stk15sfc	9/15/07	8.12	8.13	8.13
Stk16sfc	9/15/07	8.24	8.24	8.24
Stk18sfc	9/15/07	7.96	8.00	7.98

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. "NaN" is defined as "Not a Number" when a parameter was not measured.)

Site	Date	% DO Upper 25cm	% DO Bottom 25cm	% DO WC
OM2	10/13/07	NaN	NaN	NaN
OCN2	10/13/07	NaN	NaN	NaN
OB	10/13/07	NaN	NaN	NaN
OM1	10/13/07	NaN	NaN	NaN
TM	10/13/07	NaN	NaN	NaN
OCN1	10/13/07	NaN	NaN	NaN
RM3	10/13/07	NaN	NaN	NaN
RM2	10/13/07	NaN	NaN	NaN
RM1	10/13/07	NaN	NaN	NaN
River	10/13/07	NaN	NaN	NaN
Stk1sfc	10/13/07	NaN	NaN	NaN
Stk3sfc	10/13/07	NaN	NaN	NaN
Stk6sfc	10/13/07	NaN	NaN	NaN
Stk7sfc	10/13/07	NaN	NaN	NaN
Stk8sfc	10/13/07	NaN	NaN	NaN
Stk9sfc	10/13/07	NaN	NaN	NaN
Stk13sfc	10/13/07	NaN	NaN	NaN
Stk15sfc	10/13/07	NaN	NaN	NaN
Stk16sfc	10/13/07	NaN	NaN	NaN
Stk18sfc	10/13/07	NaN	NaN	NaN

Site	Date	pH Upper 25cm	pH Bottom 25cm	pH WC
OM2	10/13/07	7.87	7.89	7.88
OCN2	10/13/07	8.01	7.92	7.97
OB	10/13/07	7.97	7.97	7.97
OM1	10/13/07	7.89	7.89	7.89
TM	10/13/07	7.85	7.86	7.85
OCN1	10/13/07	7.77	7.81	7.79
RM3	10/13/07	7.81	7.81	7.81
RM2	10/13/07	7.43	7.43	7.43
RM1	10/13/07	7.51	7.51	7.51
River	10/13/07	NaN	NaN	NaN
Stk1sfc	10/13/07	7.93	7.93	7.93
Stk3sfc	10/13/07	7.93	7.93	7.93
Stk6sfc	10/13/07	7.89	7.89	7.89
Stk7sfc	10/13/07	7.93	7.93	7.93
Stk8sfc	10/13/07	7.97	7.98	7.97
Stk9sfc	10/13/07	8.00	8.00	8.00
Stk13sfc	10/13/07	8.01	8.01	8.01
Stk15sfc	10/13/07	7.90	7.91	7.91
Stk16sfc	10/13/07	7.84	7.84	7.84
Stk18sfc	10/13/07	7.97	7.97	7.97

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. “NaN” is defined as “Not a Number” when a parameter was not measured.)

Storm 1

Site	Date	% DO Upper 25cm	% DO Bottom 25cm	% DO WC
OM2	11/5/07	83.84	83.45	83.64
OCN2	11/5/07	104.61	105.09	104.85
OB	11/5/07	92.71	93.11	92.91
OM1	11/5/07	99.93	106.13	103.03
TM	11/5/07	111.14	113.45	112.29
OCN1	11/5/07	103.33	112.92	108.13
RM3	11/5/07	57.70	63.70	60.70
RM2	11/5/07	51.24	50.73	50.98
RM1	11/5/07	61.18	70.52	65.85
River	11/5/07	NaN	NaN	NaN
Stk1sfc	11/5/07	80.80	72.70	76.75
Stk3sfc	11/5/07	84.29	78.23	81.26
Stk6sfc	11/5/07	80.72	83.79	82.25
Stk7sfc	11/5/07	80.76	70.75	75.75
Stk8sfc	11/5/07	80.49	86.31	83.40
Stk9sfc	11/5/07	79.80	80.35	80.08
Stk13sfc	11/5/07	74.37	74.60	74.49
Stk15sfc	11/5/07	78.96	59.08	69.02
Stk16sfc	11/5/07	76.55	56.17	66.36
Stk18sfc	11/5/07	76.67	59.77	68.22

Site	Date	pH Upper 25cm	pH Bottom 25cm	pH WC
OM2	11/5/07	5.79	5.86	5.82
OCN2	11/5/07	6.44	6.48	6.46
OB	11/5/07	6.95	6.99	6.97
OM1	11/5/07	7.92	7.97	7.95
TM	11/5/07	8.03	8.00	8.02
OCN1	11/5/07	7.89	7.92	7.90
RM3	11/5/07	6.01	6.72	6.36
RM2	11/5/07	6.06	5.98	6.02
RM1	11/5/07	6.14	6.44	6.29
River	11/5/07	NaN	NaN	NaN
Stk1sfc	11/5/07	5.52	5.63	5.58
Stk3sfc	11/5/07	6.12	5.95	6.04
Stk6sfc	11/5/07	6.04	6.35	6.20
Stk7sfc	11/5/07	6.25	6.60	6.43
Stk8sfc	11/5/07	6.35	6.74	6.54
Stk9sfc	11/5/07	6.73	6.97	6.85
Stk13sfc	11/5/07	7.01	7.25	7.13
Stk15sfc	11/5/07	6.94	7.08	7.01
Stk16sfc	11/5/07	6.79	7.38	7.09
Stk18sfc	11/5/07	6.71	6.96	6.83

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. "NaN" is defined as "Not a Number" when a parameter was not measured.)

Transects 1-4 Site	**Date**	**% DO Upper 25cm**	**% DO Bottom 25cm**	**% DO WC**
Stk6sfc	11/6/07	65.88	92.55	79.22
Stk7sfc	11/6/07	64.50	110.28	87.39
Stk9sfc	11/6/07	61.33	94.99	78.16
Stk11sfc	11/6/07	80.94	107.75	94.34
Stk13sfc	11/6/07	85.42	109.82	97.62
Stk18sfc	11/6/07	63.37	63.13	63.25
Stk6sfc	11/7/07	95.78	130.10	112.94
Stk7sfc	11/7/07	75.58	78.98	77.28
Stk9sfc	11/7/07	79.80	79.99	79.90
Stk11sfc	11/7/07	86.87	86.11	86.49
Stk13sfc	11/7/07	89.63	95.53	92.58
Stk18sfc	11/7/07	79.21	78.50	78.86
Stk6sfc	11/8/07	92.40	94.93	93.66
Stk7sfc	11/8/07	84.21	94.59	89.40
Stk9sfc	11/8/07	119.64	119.79	119.71
Stk11sfc	11/8/07	139.93	140.24	140.08
Stk13sfc	11/8/07	150.22	164.68	157.45
Stk18sfc	11/8/07	70.16	82.33	76.24
Stk6sfc	11/11/07	85.88	89.83	87.86
Stk7sfc	11/11/07	81.40	83.88	82.64
Stk9sfc	11/11/07	85.10	98.87	91.98
Stk11sfc	11/11/07	86.39	87.39	86.89
Stk13sfc	11/11/07	87.26	87.63	87.45
Stk18sfc	11/11/07	82.62	84.47	83.54

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. "NaN" is defined as "Not a Number" when a parameter was not measured.)

Transects 1-4 Site	Date	pH Upper 25cm	pH Bottom 25cm	pH WC
Stk6sfc	11/6/07	7.60	7.70	7.65
Stk7sfc	11/6/07	7.43	7.76	7.59
Stk9sfc	11/6/07	7.38	7.79	7.59
Stk11sfc	11/6/07	7.43	7.74	7.58
Stk13sfc	11/6/07	7.30	7.71	7.51
Stk18sfc	11/6/07	6.63	7.12	6.88
Stk6sfc	11/7/07	7.23	7.40	7.31
Stk7sfc	11/7/07	7.00	7.07	7.04
Stk9sfc	11/7/07	7.40	7.38	7.39
Stk11sfc	11/7/07	7.47	7.48	7.47
Stk13sfc	11/7/07	7.55	7.63	7.59
Stk18sfc	11/7/07	6.80	6.98	6.89
Stk6sfc	11/8/07	7.49	7.55	7.52
Stk7sfc	11/8/07	7.15	7.55	7.35
Stk9sfc	11/8/07	7.72	7.72	7.72
Stk11sfc	11/8/07	7.90	7.88	7.89
Stk13sfc	11/8/07	7.89	7.95	7.92
Stk18sfc	11/8/07	6.62	7.27	6.95
Stk6sfc	11/11/07	7.38	7.43	7.40
Stk7sfc	11/11/07	7.47	7.52	7.49
Stk9sfc	11/11/07	7.31	7.45	7.38
Stk11sfc	11/11/07	7.13	7.22	7.17
Stk13sfc	11/11/07	7.19	7.19	7.19
Stk18sfc	11/11/07	7.35	7.44	7.39

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. “NaN” is defined as “Not a Number” when a parameter was not measured.)

Site	Date	% DO Upper 25cm	% DO Bottom 25cm	% DO WC
OM2	11/17/07	NaN	NaN	NaN
OCN2	11/17/07	NaN	NaN	NaN
OB	11/17/07	NaN	NaN	NaN
OM1	11/17/07	NaN	NaN	NaN
TM	11/17/07	NaN	NaN	NaN
OCN1	11/17/07	NaN	NaN	NaN
RM3	11/17/07	NaN	NaN	NaN
RM2	11/17/07	NaN	NaN	NaN
RM1	11/17/07	NaN	NaN	NaN
River	11/17/07	NaN	NaN	NaN
Stk1sfc	11/17/07	NaN	NaN	NaN
Stk3sfc	11/17/07	NaN	NaN	NaN
Stk6sfc	11/17/07	NaN	NaN	NaN
Stk7sfc	11/17/07	NaN	NaN	NaN
Stk8sfc	11/17/07	NaN	NaN	NaN
Stk9sfc	11/17/07	NaN	NaN	NaN
Stk13sfc	11/17/07	NaN	NaN	NaN
Stk15sfc	11/17/07	NaN	NaN	NaN
Stk16sfc	11/17/07	NaN	NaN	NaN
Stk18sfc	11/17/07	NaN	NaN	NaN

Site	Date	pH Upper 25cm	pH Bottom 25cm	pH WC
OM2	11/17/07	7.73	7.68	7.70
OCN2	11/17/07	7.92	7.92	7.92
OB	11/17/07	7.96	7.97	7.97
OM1	11/17/07	7.96	7.97	7.96
TM	11/17/07	7.94	8.07	8.00
OCN1	11/17/07	7.87	7.95	7.91
RM3	11/17/07	7.73	7.76	7.75
RM2	11/17/07	7.16	7.04	7.10
RM1	11/17/07	7.56	7.56	7.56
River	11/17/07	NaN	NaN	NaN
Stk1sfc	11/17/07	7.93	7.93	7.93
Stk3sfc	11/17/07	7.92	7.96	7.94
Stk6sfc	11/17/07	7.81	7.84	7.83
Stk7sfc	11/17/07	7.86	7.86	7.86
Stk8sfc	11/17/07	7.86	7.90	7.88
Stk9sfc	11/17/07	7.87	7.87	7.87
Stk13sfc	11/17/07	7.94	7.95	7.95
Stk15sfc	11/17/07	7.85	7.85	7.85
Stk16sfc	11/17/07	7.78	7.86	7.82
Stk18sfc	11/17/07	7.73	7.85	7.79

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. "NaN" is defined as "Not a Number" when a parameter was not measured.)

Storm 2

Site	Date	% DO Upper 25cm	% DO Bottom 25cm	% DO WC
OM2	12/9/07	90.11	88.53	89.32
OCN2	12/9/07	94.94	93.19	94.06
OB	12/9/07	96.29	93.78	95.04
OM1	12/9/07	97.88	97.18	97.53
TM	12/9/07	96.92	97.22	97.07
OCN1	12/9/07	99.00	101.34	100.17
RM3	12/9/07	79.82	79.82	79.82
RM2	12/9/07	83.88	69.45	76.66
RM1	12/9/07	74.02	79.56	76.79
River	12/9/07	NaN	NaN	NaN
Stk1sfc	12/9/07	111.30	112.28	111.79
Stk3sfc	12/9/07	111.67	109.57	110.62
Stk6sfc	12/9/07	101.08	108.75	104.91
Stk7sfc	12/9/07	94.81	107.65	101.23
Stk8sfc	12/9/07	98.92	104.59	101.75
Stk9sfc	12/9/07	106.23	109.38	107.80
Stk13sfc	12/9/07	107.55	108.63	108.09
Stk15sfc	12/9/07	104.43	101.61	103.02
Stk16sfc	12/9/07	96.65	101.19	98.92
Stk18sfc	12/9/07	96.61	92.02	94.32

Site	Date	pH Upper 25cm	pH Bottom 25cm	pH WC
OM2	12/9/07	8.42	8.40	8.41
OCN2	12/9/07	8.39	8.40	8.40
OB	12/9/07	8.43	8.45	8.44
OM1	12/9/07	8.47	8.50	8.49
TM	12/9/07	8.37	8.45	8.41
OCN1	12/9/07	8.38	8.50	8.44
RM3	12/9/07	8.30	8.30	8.30
RM2	12/9/07	7.70	7.64	7.67
RM1	12/9/07	7.83	8.06	7.95
River	12/9/07	NaN	NaN	NaN
Stk1sfc	12/9/07	8.29	8.35	8.32
Stk3sfc	12/9/07	8.35	8.37	8.36
Stk6sfc	12/9/07	8.43	8.47	8.45
Stk7sfc	12/9/07	8.47	8.54	8.50
Stk8sfc	12/9/07	8.24	8.39	8.31
Stk9sfc	12/9/07	8.41	8.47	8.44
Stk13sfc	12/9/07	8.17	8.24	8.20
Stk15sfc	12/9/07	7.94	8.17	8.06
Stk16sfc	12/9/07	7.92	8.09	8.00
Stk18sfc	12/9/07	7.86	8.12	7.99

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. “NaN” is defined as “Not a Number” when a parameter was not measured.)

Site	Date	% DO Upper 25cm	% DO Bottom 25cm	% DO WC
OM2	1/12/08	79.22	78.14	78.68
OCN2	1/12/08	95.27	95.33	95.30
OB	1/12/08	97.53	97.53	97.53
OM1	1/12/08	87.20	87.20	87.20
TM	1/12/08	87.26	87.69	87.48
OCN1	1/12/08	96.22	97.40	96.81
RM3	1/12/08	82.41	82.41	82.41
RM2	1/12/08	52.36	52.36	52.36
RM1	1/12/08	70.61	70.61	70.61
River	1/12/08	NaN	NaN	NaN
Stk1sfc	1/12/08	89.58	88.14	88.86
Stk3sfc	1/12/08	87.75	87.75	87.75
Stk6sfc	1/12/08	85.19	85.19	85.19
Stk7sfc	1/12/08	97.99	97.99	97.99
Stk8sfc	1/12/08	75.74	75.73	75.74
Stk9sfc	1/12/08	93.63	93.63	93.63
Stk13sfc	1/12/08	91.24	91.10	91.17
Stk15sfc	1/12/08	85.56	84.88	85.22
Stk16sfc	1/12/08	88.39	90.61	89.50
Stk18sfc	1/12/08	70.54	69.96	70.25

Site	Date	pH Upper 25cm	pH Bottom 25cm	pH WC
OM2	1/12/08	7.88	7.86	7.87
OCN2	1/12/08	8.00	8.00	8.00
OB	1/12/08	7.98	7.98	7.98
OM1	1/12/08	7.92	7.92	7.92
TM	1/12/08	7.86	7.88	7.87
OCN1	1/12/08	8.01	8.02	8.01
RM3	1/12/08	7.85	7.85	7.85
RM2	1/12/08	7.41	7.41	7.41
RM1	1/12/08	7.71	7.71	7.71
River	1/12/08	NaN	NaN	NaN
Stk1sfc	1/12/08	7.80	7.81	7.81
Stk3sfc	1/12/08	7.88	7.88	7.88
Stk6sfc	1/12/08	7.92	7.92	7.92
Stk7sfc	1/12/08	7.96	7.96	7.96
Stk8sfc	1/12/08	7.86	7.86	7.86
Stk9sfc	1/12/08	7.88	7.88	7.88
Stk13sfc	1/12/08	7.64	7.65	7.64
Stk15sfc	1/12/08	7.68	7.72	7.70
Stk16sfc	1/12/08	7.76	7.78	7.77
Stk18sfc	1/12/08	7.73	7.73	7.73

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. “NaN” is defined as “Not a Number” when a parameter was not measured.)

Site	Date	% DO Upper 25cm	% DO Bottom 25cm	% DO WC
OM2	2/16/08	89.80	88.98	89.39
OCN2	2/16/08	96.09	95.00	95.55
OB	2/16/08	98.88	98.88	98.88
OM1	2/16/08	93.28	95.78	94.53
TM	2/16/08	97.57	103.84	100.71
OCN1	2/16/08	96.63	99.14	97.89
RM3	2/16/08	74.33	74.33	74.33
RM2	2/16/08	58.51	58.51	58.51
RM1	2/16/08	61.45	61.45	61.45
River	2/16/08	NaN	NaN	NaN
Stk1sfc	2/16/08	66.15	66.15	66.15
Stk3sfc	2/16/08	107.58	107.58	107.58
Stk6sfc	2/16/08	76.79	76.79	76.79
Stk7sfc	2/16/08	90.06	90.06	90.06
Stk8sfc	2/16/08	57.93	57.93	57.93
Stk9sfc	2/16/08	127.83	127.83	127.83
Stk13sfc	2/16/08	100.85	100.85	100.85
Stk15sfc	2/16/08	92.82	92.82	92.82
Stk16sfc	2/16/08	94.30	94.30	94.30
Stk18sfc	2/16/08	113.90	113.90	113.90

Site	Date	pH Upper 25cm	pH Bottom 25cm	pH WC
OM2	2/16/08	7.93	7.93	7.93
OCN2	2/16/08	7.96	7.96	7.96
OB	2/16/08	7.97	7.97	7.97
OM1	2/16/08	7.95	7.96	7.96
TM	2/16/08	7.93	7.97	7.95
OCN1	2/16/08	7.93	7.96	7.94
RM3	2/16/08	7.78	7.78	7.78
RM2	2/16/08	8.17	8.17	8.17
RM1	2/16/08	7.48	7.48	7.48
River	2/16/08	NaN	NaN	NaN
Stk1sfc	2/16/08	7.98	7.98	7.98
Stk3sfc	2/16/08	8.03	8.03	8.03
Stk6sfc	2/16/08	7.85	7.85	7.85
Stk7sfc	2/16/08	7.92	7.92	7.92
Stk8sfc	2/16/08	7.92	7.92	7.92
Stk9sfc	2/16/08	8.04	8.04	8.04
Stk13sfc	2/16/08	7.93	7.93	7.93
Stk15sfc	2/16/08	7.93	7.93	7.93
Stk16sfc	2/16/08	7.94	7.94	7.94
Stk18sfc	2/16/08	7.97	7.97	7.97

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. “NaN” is defined as “Not a Number” when a parameter was not measured.)

Site	Date	% DO Upper 25cm	% DO Bottom 25cm	% DO WC
OM2	3/15/08	77.07	76.40	76.74
OCN2	3/15/08	86.38	86.33	86.35
OB	3/15/08	86.11	86.35	86.23
OM1	3/15/08	72.62	79.37	75.99
TM	3/15/08	73.15	70.94	72.05
OCN1	3/15/08	82.25	90.62	86.44
RM3	3/15/08	NaN	NaN	NaN
RM2	3/15/08	NaN	NaN	NaN
RM1	3/15/08	NaN	NaN	NaN
River	3/15/08	NaN	NaN	NaN
Stk1sfc	3/15/08	NaN	NaN	NaN
Stk3sfc	3/15/08	NaN	NaN	NaN
Stk6sfc	3/15/08	NaN	NaN	NaN
Stk7sfc	3/15/08	NaN	NaN	NaN
Stk8sfc	3/15/08	NaN	NaN	NaN
Stk9sfc	3/15/08	NaN	NaN	NaN
Stk13sfc	3/15/08	NaN	NaN	NaN
Stk15sfc	3/15/08	NaN	NaN	NaN
Stk16sfc	3/15/08	NaN	NaN	NaN
Stk18sfc	3/15/08	NaN	NaN	NaN

Site	Date	pH Upper 25cm	pH Bottom 25cm	pH WC
OM2	3/15/08	8.08	8.08	8.08
OCN2	3/15/08	8.10	8.10	8.10
OB	3/15/08	8.03	8.03	8.03
OM1	3/15/08	7.96	7.98	7.97
TM	3/15/08	7.94	7.96	7.95
OCN1	3/15/08	7.89	8.05	7.97
RM3	3/15/08	NaN	NaN	NaN
RM2	3/15/08	NaN	NaN	NaN
RM1	3/15/08	NaN	NaN	NaN
River	3/15/08	NaN	NaN	NaN
Stk1sfc	3/15/08	NaN	NaN	NaN
Stk3sfc	3/15/08	NaN	NaN	NaN
Stk6sfc	3/15/08	NaN	NaN	NaN
Stk7sfc	3/15/08	NaN	NaN	NaN
Stk8sfc	3/15/08	NaN	NaN	NaN
Stk9sfc	3/15/08	NaN	NaN	NaN
Stk13sfc	3/15/08	NaN	NaN	NaN
Stk15sfc	3/15/08	NaN	NaN	NaN
Stk16sfc	3/15/08	NaN	NaN	NaN
Stk18sfc	3/15/08	NaN	NaN	NaN

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. “NaN” is defined as “Not a Number” when a parameter was not measured.)

Site	Date	% DO Upper 25cm	% DO Bottom 25cm	% DO WC
OM2	4/19/08	123.50	119.76	121.63
OCN2	4/19/08	204.52	204.52	204.52
OB	4/19/08	105.82	105.82	105.82
OM1	4/19/08	107.94	110.24	109.09
TM	4/19/08	121.16	124.24	122.70
OCN1	4/19/08	111.19	111.00	111.09
RM3	4/19/08	93.92	93.92	93.92
RM2	4/19/08	56.34	55.64	55.99
RM1	4/19/08	89.23	89.23	89.23
River	4/19/08	NaN	NaN	NaN
Stk1sfc	4/19/08	154.38	154.57	154.48
Stk3sfc	4/19/08	139.82	139.82	139.82
Stk6sfc	4/19/08	141.47	141.47	141.47
Stk7sfc	4/19/08	132.21	131.73	131.97
Stk8sfc	4/19/08	162.52	164.49	163.50
Stk9sfc	4/19/08	154.60	154.09	154.34
Stk13sfc	4/19/08	161.97	162.34	162.15
Stk15sfc	4/19/08	176.39	176.30	176.35
Stk16sfc	4/19/08	160.36	156.95	158.66
Stk18sfc	4/19/08	99.78	120.79	110.29

Site	Date	pH Upper 25cm	pH Bottom 25cm	pH WC
OM2	4/19/08	7.98	7.98	7.98
OCN2	4/19/08	8.24	8.24	8.24
OB	4/19/08	7.96	7.96	7.96
OM1	4/19/08	7.99	8.01	8.00
TM	4/19/08	8.05	8.08	8.06
OCN1	4/19/08	8.02	8.03	8.03
RM3	4/19/08	7.92	7.92	7.92
RM2	4/19/08	8.00	7.70	7.85
RM1	4/19/08	7.44	7.44	7.44
River	4/19/08	NaN	NaN	NaN
Stk1sfc	4/19/08	8.06	8.06	8.06
Stk3sfc	4/19/08	8.03	8.03	8.03
Stk6sfc	4/19/08	8.02	8.02	8.02
Stk7sfc	4/19/08	7.94	7.96	7.95
Stk8sfc	4/19/08	8.14	8.15	8.15
Stk9sfc	4/19/08	8.26	8.27	8.27
Stk13sfc	4/19/08	8.20	8.20	8.20
Stk15sfc	4/19/08	8.21	8.23	8.22
Stk16sfc	4/19/08	8.21	8.22	8.21
Stk18sfc	4/19/08	7.87	8.04	7.96

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. “NaN” is defined as “Not a Number” when a parameter was not measured.)

Site	Date	% DO Upper 25cm	% DO Bottom 25cm	% DO WC
OM2	5/17/08	NaN	NaN	NaN
OCN2	5/17/08	NaN	NaN	NaN
OB	5/17/08	NaN	NaN	NaN
OM1	5/17/08	NaN	NaN	NaN
TM	5/17/08	NaN	NaN	NaN
OCN1	5/17/08	NaN	NaN	NaN
RM3	5/17/08	NaN	NaN	NaN
RM2	5/17/08	NaN	NaN	NaN
RM1	5/17/08	NaN	NaN	NaN
River	5/17/08	NaN	NaN	NaN
Stk1sfc	5/17/08	NaN	NaN	NaN
Stk3sfc	5/17/08	NaN	NaN	NaN
Stk6sfc	5/17/08	NaN	NaN	NaN
Stk7sfc	5/17/08	NaN	NaN	NaN
Stk8sfc	5/17/08	NaN	NaN	NaN
Stk9sfc	5/17/08	NaN	NaN	NaN
Stk13sfc	5/17/08	NaN	NaN	NaN
Stk15sfc	5/17/08	NaN	NaN	NaN
Stk16sfc	5/17/08	NaN	NaN	NaN
Stk18sfc	5/17/08	NaN	NaN	NaN

Site	Date	pH Upper 25cm	pH Bottom 25cm	pH WC
OM2	5/17/08	7.95	7.95	7.95
OCN2	5/17/08	8.03	8.03	8.03
OB	5/17/08	8.01	8.01	8.01
OM1	5/17/08	7.99	7.99	7.99
TM	5/17/08	8.06	8.10	8.08
OCN1	5/17/08	8.03	8.07	8.05
RM3	5/17/08	7.77	7.77	7.77
RM2	5/17/08	8.19	8.19	8.19
RM1	5/17/08	7.76	7.76	7.76
River	5/17/08	NaN	NaN	NaN
Stk1sfc	5/17/08	8.05	8.05	8.05
Stk3sfc	5/17/08	8.02	8.02	8.02
Stk6sfc	5/17/08	8.07	8.07	8.07
Stk7sfc	5/17/08	7.93	7.93	7.93
Stk8sfc	5/17/08	8.12	8.11	8.11
Stk9sfc	5/17/08	8.14	8.15	8.14
Stk13sfc	5/17/08	8.00	8.01	8.01
Stk15sfc	5/17/08	8.07	8.08	8.08
Stk16sfc	5/17/08	7.93	8.03	7.98
Stk18sfc	5/17/08	7.94	8.10	8.02

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. “NaN” is defined as “Not a Number” when a parameter was not measured.)

Storm 4

Site	Date	% DO Upper 25cm	% DO Bottom 25cm	% DO WC
OM2	6/14/08	NaN	NaN	NaN
OCN2	6/14/08	NaN	NaN	NaN
OB	6/14/08	NaN	NaN	NaN
OM1	6/14/08	NaN	NaN	NaN
TM	6/14/08	NaN	NaN	NaN
OCN1	6/14/08	NaN	NaN	NaN
RM3	6/14/08	NaN	NaN	NaN
RM2	6/14/08	NaN	NaN	NaN
RM1	6/14/08	NaN	NaN	NaN
River	6/14/08	NaN	NaN	NaN
Stk1sfc	6/14/08	NaN	NaN	NaN
Stk3sfc	6/14/08	NaN	NaN	NaN
Stk6sfc	6/14/08	NaN	NaN	NaN
Stk7sfc	6/14/08	NaN	NaN	NaN
Stk8sfc	6/14/08	NaN	NaN	NaN
Stk9sfc	6/14/08	NaN	NaN	NaN
Stk13sfc	6/14/08	NaN	NaN	NaN
Stk15sfc	6/14/08	NaN	NaN	NaN
Stk16sfc	6/14/08	NaN	NaN	NaN
Stk18sfc	6/14/08	NaN	NaN	NaN

Site	Date	pH Upper 25cm	pH Bottom 25cm	pH WC
OM2	6/14/08	8.00	7.96	7.98
OCN2	6/14/08	7.91	7.93	7.92
OB	6/14/08	7.83	7.85	7.84
OM1	6/14/08	7.83	7.96	7.89
TM	6/14/08	7.82	7.98	7.90
OCN1	6/14/08	7.94	8.09	8.01
RM3	6/14/08	7.56	7.56	7.56
RM2	6/14/08	6.86	6.86	6.86
RM1	6/14/08	7.03	7.03	7.03
River	6/14/08	NaN	NaN	NaN
Stk1sfc	6/14/08	7.96	7.96	7.96
Stk3sfc	6/14/08	7.99	8.00	7.99
Stk6sfc	6/14/08	7.79	7.79	7.79
Stk7sfc	6/14/08	7.75	7.78	7.77
Stk8sfc	6/14/08	7.78	7.93	7.85
Stk9sfc	6/14/08	7.88	8.04	7.96
Stk13sfc	6/14/08	7.87	7.91	7.89
Stk15sfc	6/14/08	7.82	8.09	7.96
Stk16sfc	6/14/08	7.89	8.04	7.96
Stk18sfc	6/14/08	7.64	8.05	7.84

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. “NaN” is defined as “Not a Number” when a parameter was not measured.)

Site	Date	% DO Upper 25cm	% DO Bottom 25cm	% DO WC
OM2	7/26/08	87.19	84.84	86.01
OCN2	7/26/08	98.93	99.30	99.12
OB	7/26/08	99.75	99.01	99.38
OM1	7/26/08	108.51	107.98	108.24
TM	7/26/08	89.96	89.27	89.61
OCN1	7/26/08	84.96	88.33	86.64
RM3	7/26/08	81.81	76.45	79.13
RM2	7/26/08	49.12	57.26	53.19
RM1	7/26/08	91.61	81.23	86.42
River	7/26/08	NaN	NaN	NaN
Stk1sfc	7/26/08	122.84	122.68	122.76
Stk3sfc	7/26/08	102.96	108.01	105.49
Stk6sfc	7/26/08	88.87	89.81	89.34
Stk7sfc	7/26/08	81.11	85.33	83.22
Stk8sfc	7/26/08	96.73	99.48	98.10
Stk9sfc	7/26/08	98.23	99.14	98.68
Stk13sfc	7/26/08	123.22	122.64	122.93
Stk15sfc	7/26/08	102.99	140.46	121.73
Stk16sfc	7/26/08	103.73	106.39	105.06
Stk18sfc	7/26/08	100.13	116.17	108.15

Site	Date	pH Upper 25cm	pH Bottom 25cm	pH WC
OM2	7/26/08	7.88	7.89	7.88
OCN2	7/26/08	7.96	7.97	7.96
OB	7/26/08	8.00	8.00	8.00
OM1	7/26/08	8.05	8.05	8.05
TM	7/26/08	7.94	7.95	7.94
OCN1	7/26/08	7.93	7.99	7.96
RM3	7/26/08	7.79	7.77	7.78
RM2	7/26/08	6.91	7.38	7.15
RM1	7/26/08	7.67	7.93	7.80
River	7/26/08	NaN	NaN	NaN
Stk1sfc	7/26/08	8.06	8.06	8.06
Stk3sfc	7/26/08	8.01	8.05	8.03
Stk6sfc	7/26/08	7.95	7.98	7.96
Stk7sfc	7/26/08	7.92	7.97	7.95
Stk8sfc	7/26/08	7.96	8.01	7.98
Stk9sfc	7/26/08	7.98	8.02	8.00
Stk13sfc	7/26/08	8.05	8.06	8.06
Stk15sfc	7/26/08	8.05	8.25	8.15
Stk16sfc	7/26/08	7.98	8.08	8.03
Stk18sfc	7/26/08	7.93	8.16	8.04

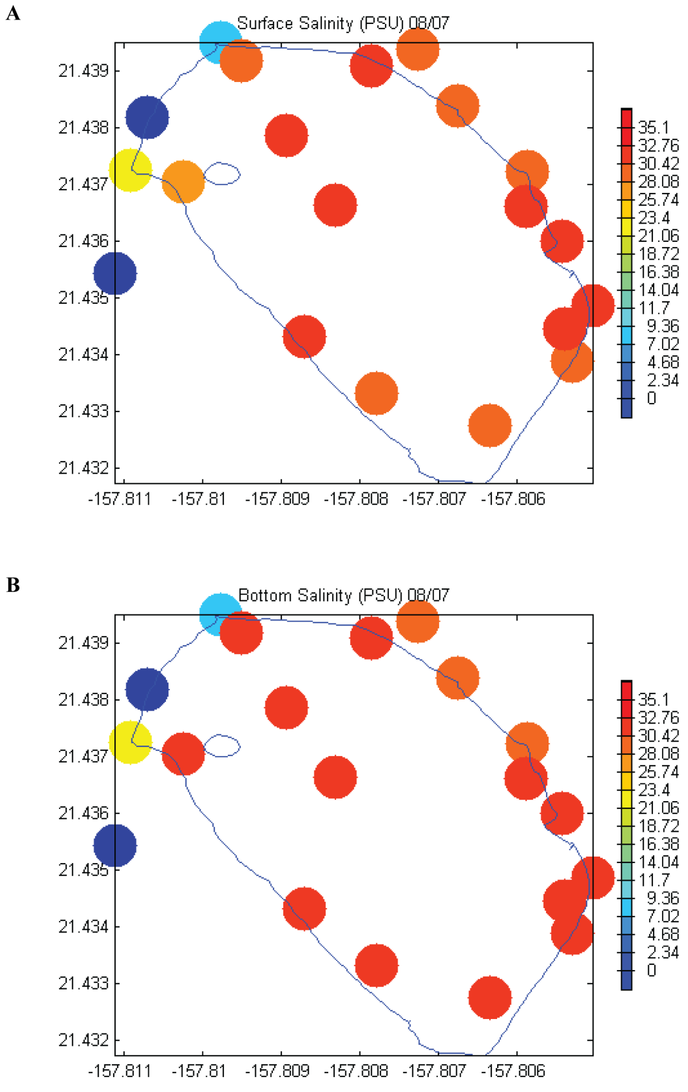
(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. “NaN” is defined as “Not a Number” when a parameter was not measured.)

Site	Date	% DO Upper 25cm	% DO Bottom 25cm	% DO WC
OM2	8/30/08	101.62	101.50	101.56
OCN2	8/30/08	160.49	160.49	160.49
OB	8/30/08	142.67	142.67	142.67
OM1	8/30/08	118.73	118.73	118.73
TM	8/30/08	102.14	101.49	101.81
OCN1	8/30/08	105.08	105.59	105.34
RM3	8/30/08	83.77	83.77	83.77
RM2	8/30/08	55.65	55.75	55.70
RM1	8/30/08	76.49	76.31	76.40
River	8/30/08	NaN	NaN	NaN
Stk1sfc	8/30/08	129.96	129.96	129.96
Stk3sfc	8/30/08	134.53	134.53	134.53
Stk6sfc	8/30/08	114.54	114.54	114.54
Stk7sfc	8/30/08	97.77	97.77	97.77
Stk8sfc	8/30/08	95.52	95.52	95.52
Stk9sfc	8/30/08	136.76	137.54	137.15
Stk13sfc	8/30/08	130.13	131.89	131.01
Stk15sfc	8/30/08	130.19	133.48	131.84
Stk16sfc	8/30/08	166.70	185.29	175.99
Stk18sfc	8/30/08	101.67	108.83	105.25

Site	Date	pH Upper 25cm	pH Bottom 25cm	pH WC
OM2	8/30/08	7.89	7.89	7.89
OCN2	8/30/08	8.05	8.05	8.05
OB	8/30/08	8.01	8.01	8.01
OM1	8/30/08	7.97	7.97	7.97
TM	8/30/08	7.90	7.91	7.91
OCN1	8/30/08	7.84	7.85	7.85
RM3	8/30/08	7.78	7.78	7.78
RM2	8/30/08	8.79	8.79	8.79
RM1	8/30/08	7.63	7.63	7.63
River	8/30/08	NaN	NaN	NaN
Stk1sfc	8/30/08	7.97	7.97	7.97
Stk3sfc	8/30/08	7.98	7.98	7.98
Stk6sfc	8/30/08	7.94	7.94	7.94
Stk7sfc	8/30/08	7.85	7.85	7.85
Stk8sfc	8/30/08	7.91	7.91	7.91
Stk9sfc	8/30/08	8.00	8.00	8.00
Stk13sfc	8/30/08	8.04	8.06	8.05
Stk15sfc	8/30/08	8.05	8.07	8.06
Stk16sfc	8/30/08	8.14	8.16	8.15
Stk18sfc	8/30/08	7.92	7.92	7.92

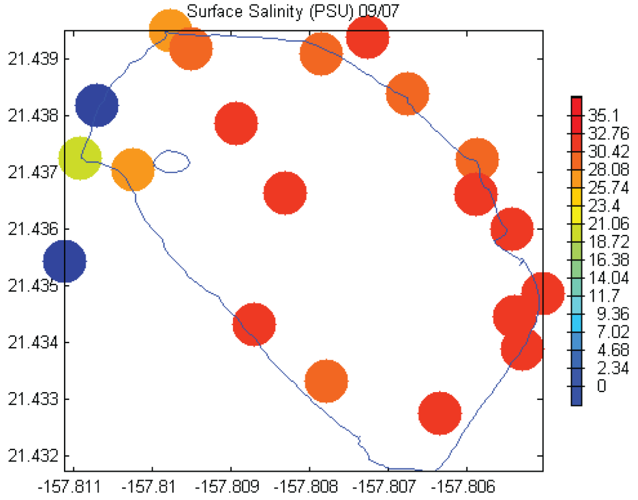
(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. “NaN” is defined as “Not a Number” when a parameter was not measured.)

Appendix 3.1. Sample site mean (A) surface and (B) near-bottom salinity values for the 08/11/07 monthly sampling event. Site locations are geo-referenced to the He‘eia Fishpond perimeter outlined in blue. He‘eia Stream is located to the northwest and Kane‘ohe Bay to the east.

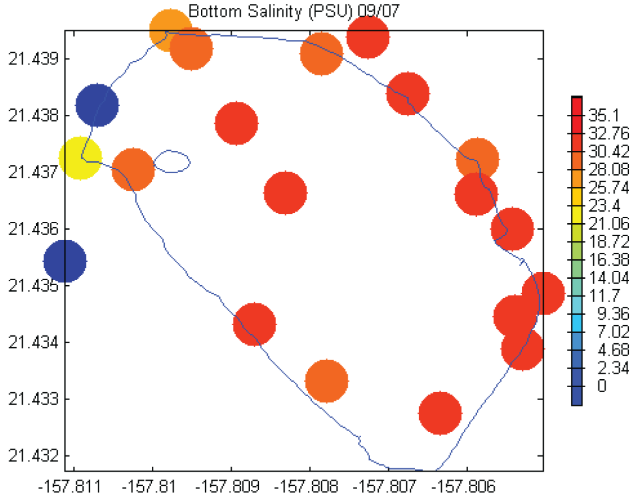


Appendix 3.2. Sample site mean (A) surface and (B) near-bottom salinity values for the 09/15/07 monthly sampling event. Site locations are geo-referenced to the He‘eia Fishpond perimeter outlined in blue. He‘eia Stream is located to the northwest and Kane‘ohe Bay to the east.

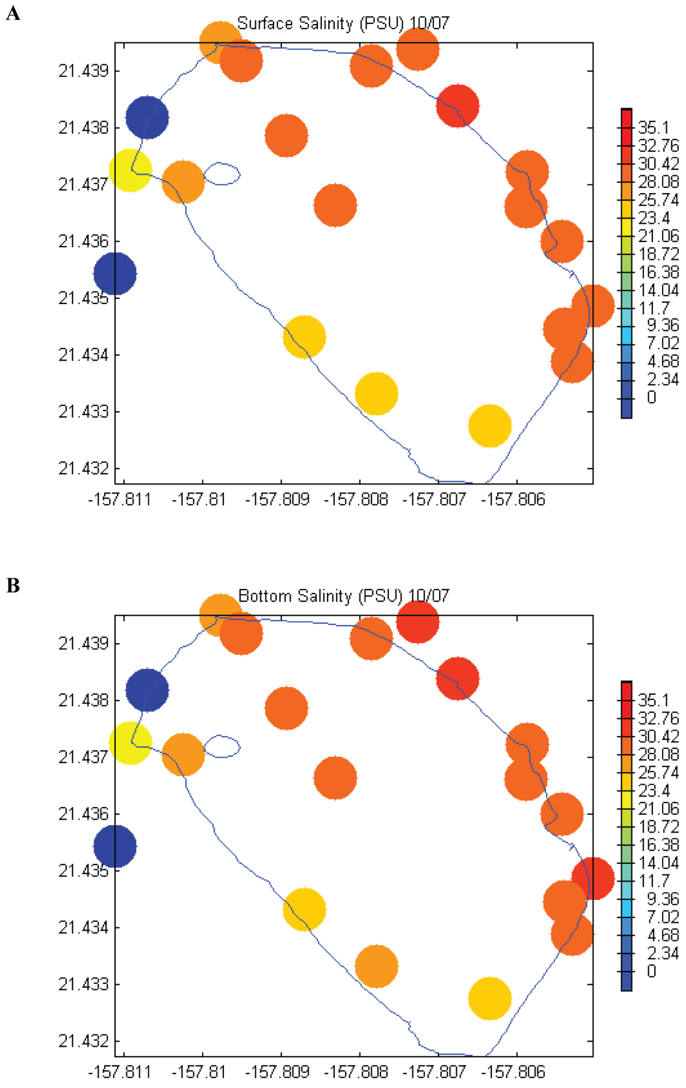
A



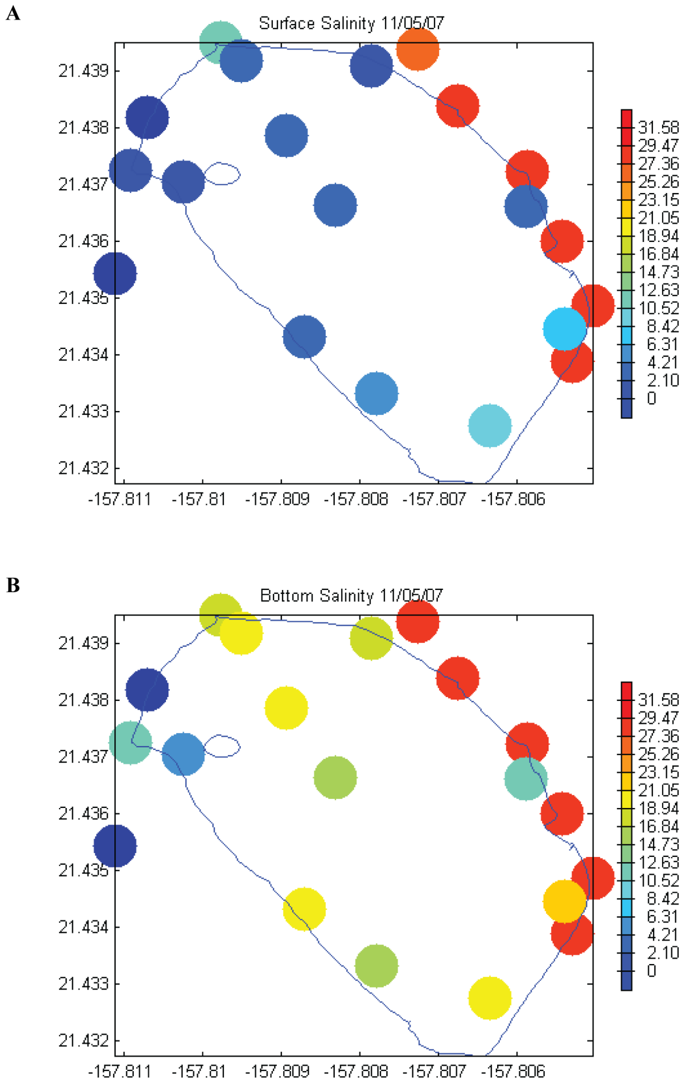
B



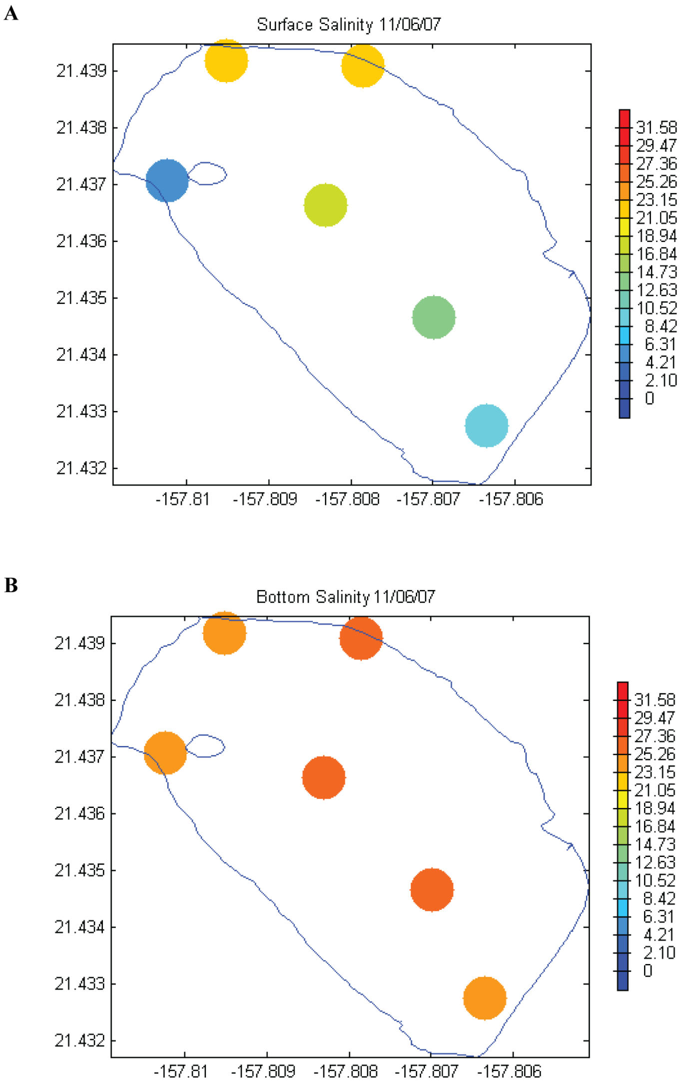
Appendix 3.3. Sample site mean (A) surface and (B) near-bottom salinity values for the 10/13/07 monthly sampling event. Site locations are geo-referenced to the He‘eia Fishpond perimeter outlined in blue. He‘eia Stream is located to the northwest and Kane‘ohe Bay to the east.



Appendix 3.4. Sample site mean (A) surface and (B) near-bottom salinity (PSU) values for the 11/05/07, Storm 1, sampling event. Site locations are geo-referenced to the He‘eia Fishpond perimeter outlined in blue. He‘eia Stream is located to the northwest and Kane‘ohe Bay to the east.

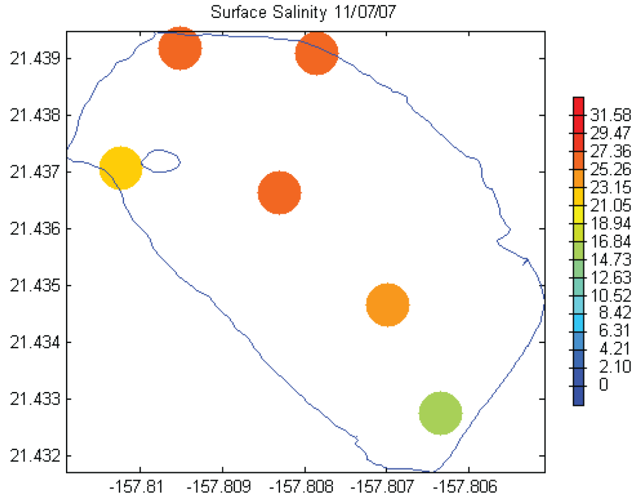


Appendix 3.5. Sample site mean (A) surface and (B) near-bottom salinity (PSU) values for the 11/06/07, Storm 1-Transect 1, sampling event. Site locations are geo-referenced to the He‘eia Fishpond perimeter outlined in blue. He‘eia Stream is located to the northwest and Kane‘ohe Bay to the east.

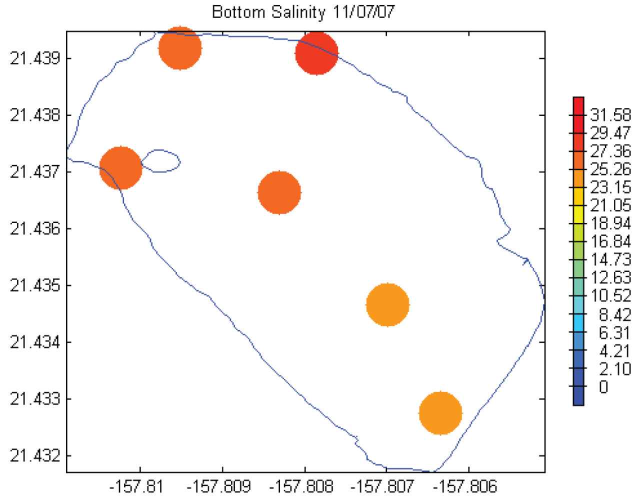


Appendix 3.6. Sample site mean (A) surface and (B) near-bottom salinity (PSU) values for the 11/07/07, Storm 1-Transect 2, sampling event. Site locations are geo-referenced to the He‘eia Fishpond perimeter outlined in blue. He‘eia Stream is located to the northwest and Kane‘ohe Bay to the east.

A

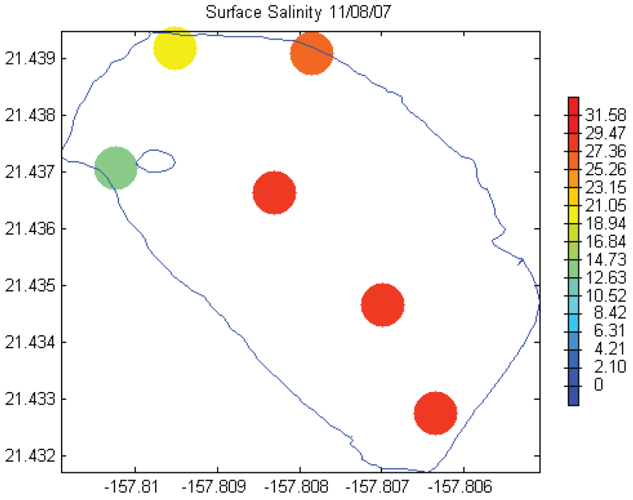


B

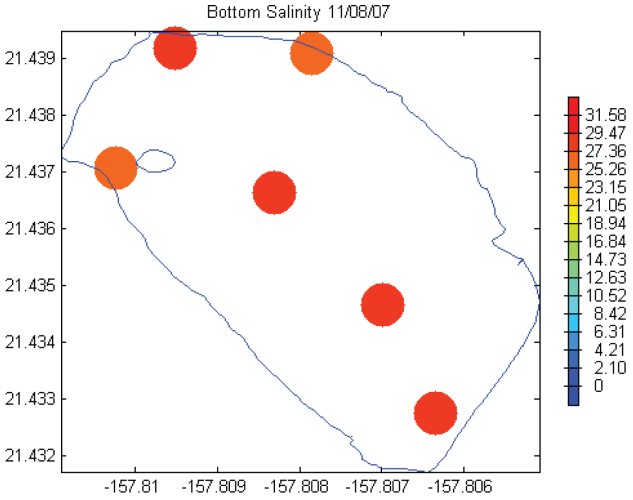


Appendix 3.7. Sample site mean (A) surface and (B) near-bottom salinity (PSU) values for the 11/08/07, Storm 1-Transect 3, sampling event. Site locations are geo-referenced to the He‘eia Fishpond perimeter outlined in blue. He‘eia Stream is located to the northwest and Kane‘ohe Bay to the east.

A

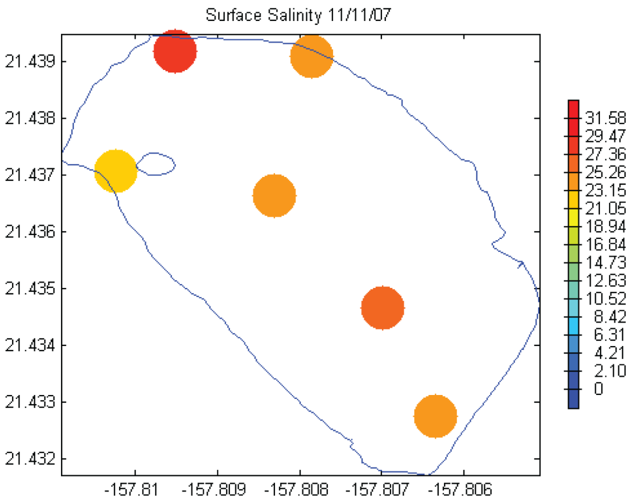


B

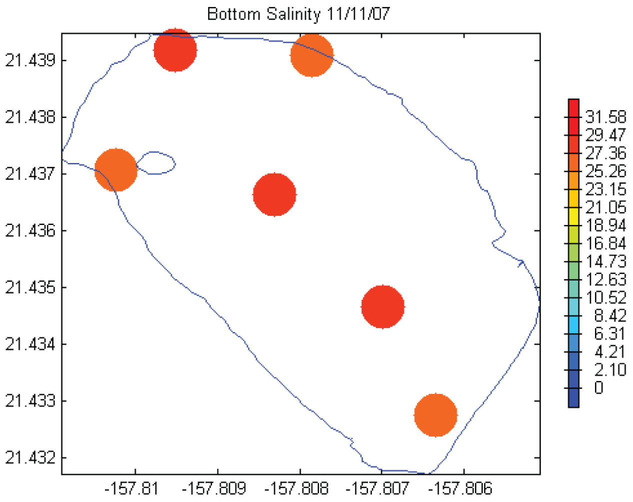


Appendix 3.8. Sample site mean (A) surface and (B) near-bottom salinity (PSU) values for the 11/11/07, Storm 1-Transect 4, sampling event. Site locations are geo-referenced to the He‘eia Fishpond perimeter outlined in blue. He‘eia Stream is located to the northwest and Kane‘ohe Bay to the east.

A

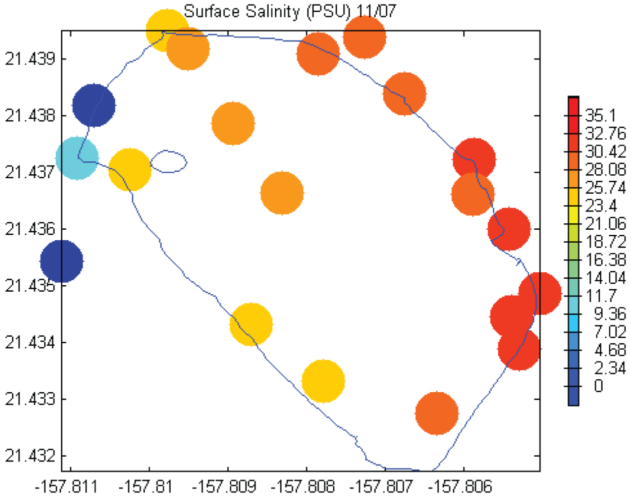


B

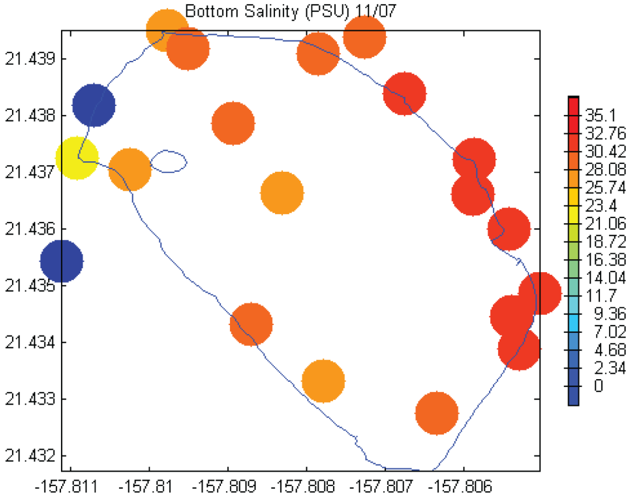


Appendix 3.9. Sample site mean (A) surface and (B) near-bottom salinity values for the 11/17/07 monthly sampling event. Site locations are geo-referenced to the He‘eia Fishpond perimeter outlined in blue. He‘eia Stream is located to the northwest and Kane‘ohe Bay to the east.

A

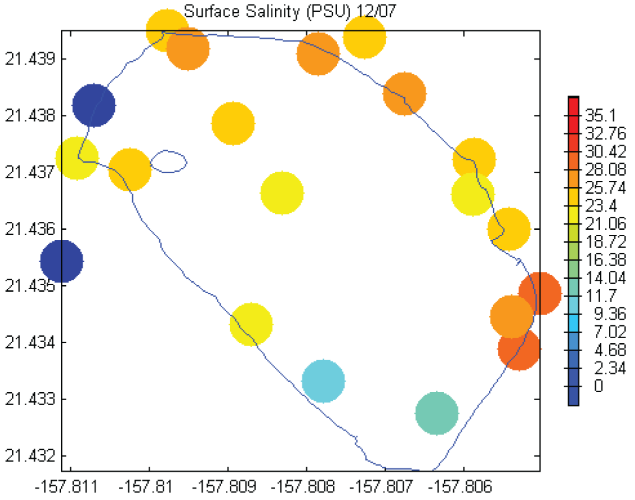


B

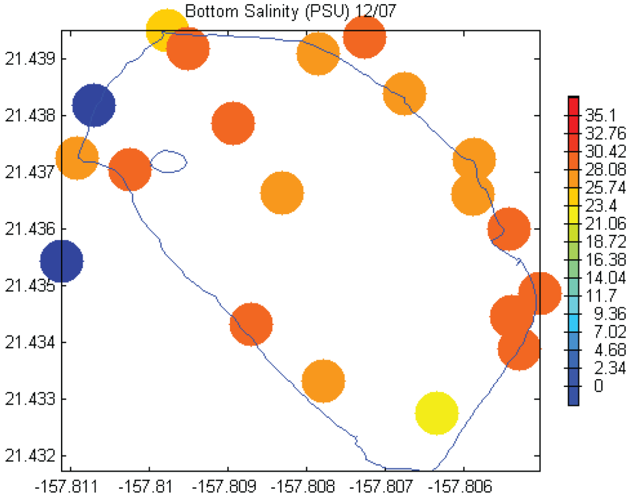


Appendix 3.10. Sample site mean (A) surface and (B) near-bottom salinity values for the 12/09/07 monthly sampling event. Site locations are geo-referenced to the He‘eia Fishpond perimeter outlined in blue. He‘eia Stream is located to the northwest and Kane‘ohe Bay to the east.

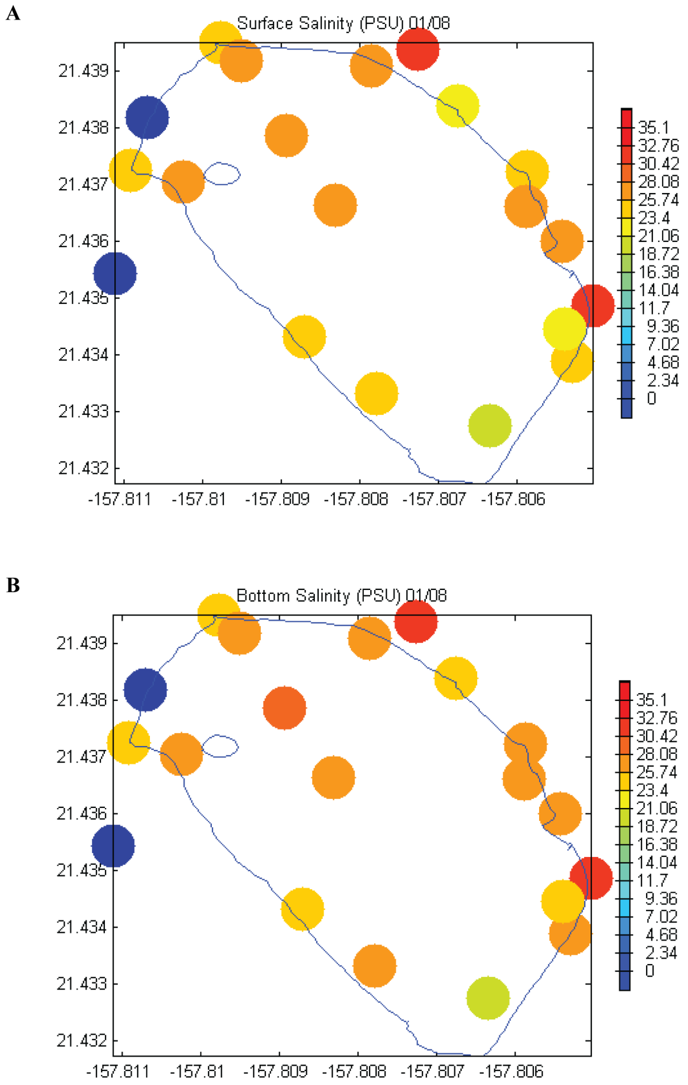
A



B

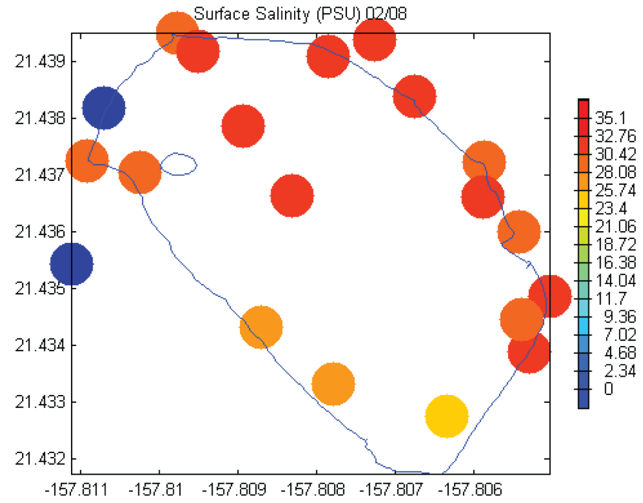


Appendix 3.11. Sample site mean (A) surface and (B) near-bottom salinity values for the 01/12/08 monthly sampling event. Site locations are geo-referenced to the He‘eia Fishpond perimeter outlined in blue. He‘eia Stream is located to the northwest and Kane‘ohe Bay to the east.

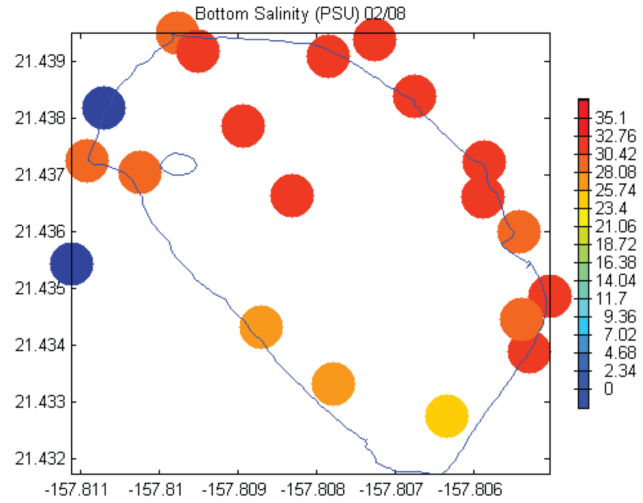


Appendix 3.12. Sample site mean (A) surface and (B) near-bottom salinity values for the 02/16/08 monthly sampling event. Site locations are geo-referenced to the He‘eia Fishpond perimeter outlined in blue. He‘eia Stream is located to the northwest and Kane‘ohe Bay to the east.

A

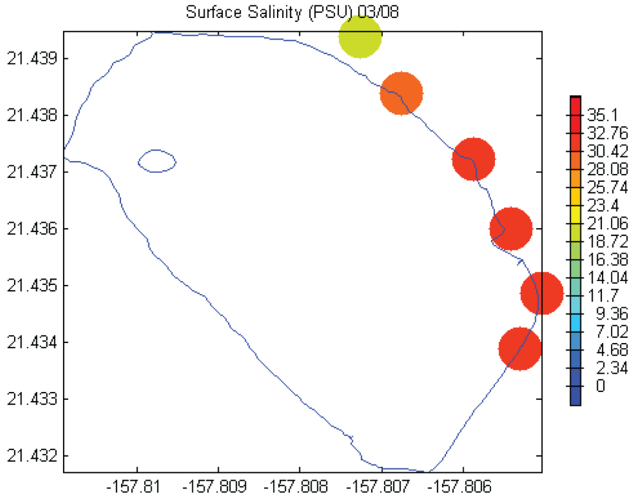


B

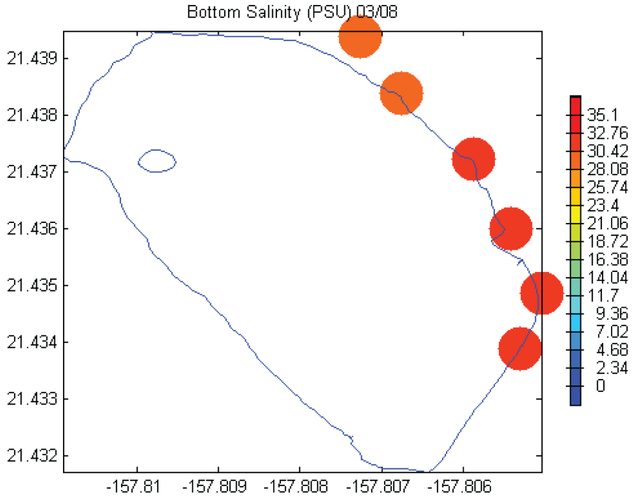


Appendix 3.13. Sample site mean (A) surface and (B) near-bottom salinity values for the 03/15/08 monthly sampling event. Site locations are geo-referenced to the He‘eia Fishpond perimeter outlined in blue. He‘eia Stream is located to the northwest and Kane‘ohe Bay to the east. Not all sample sites measured due to instrument malfunction.

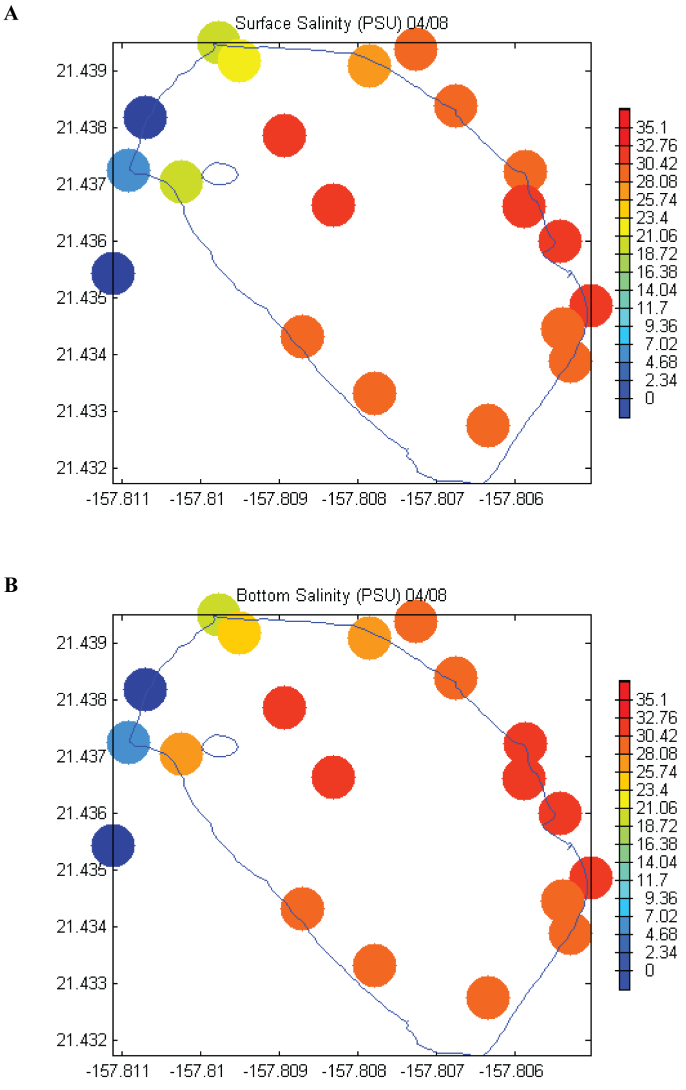
A



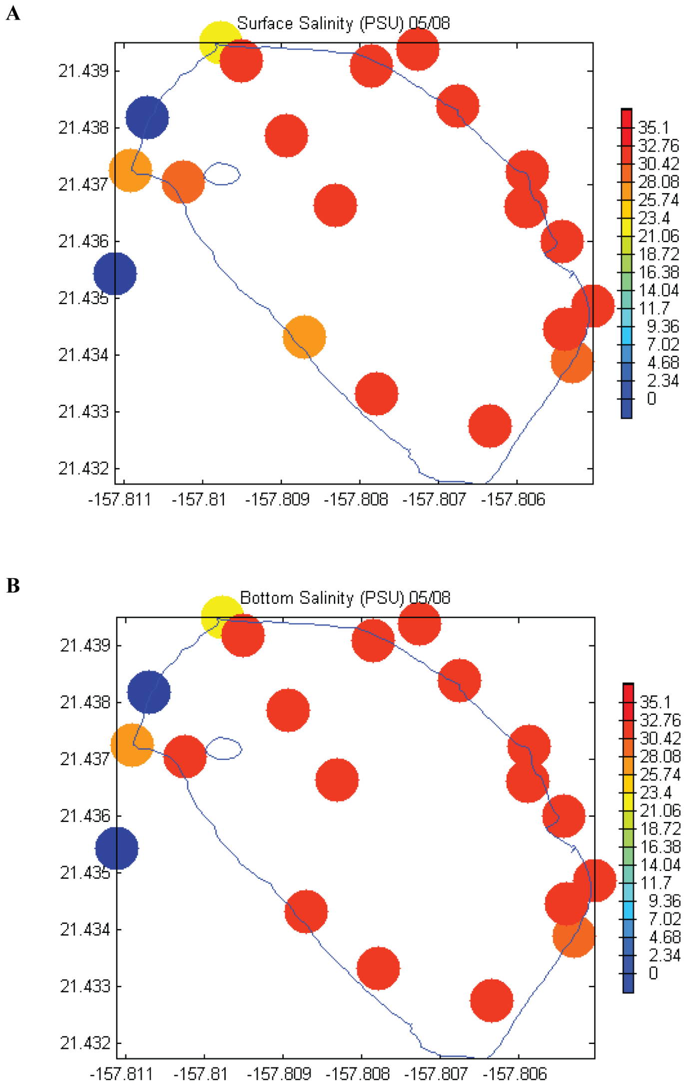
B



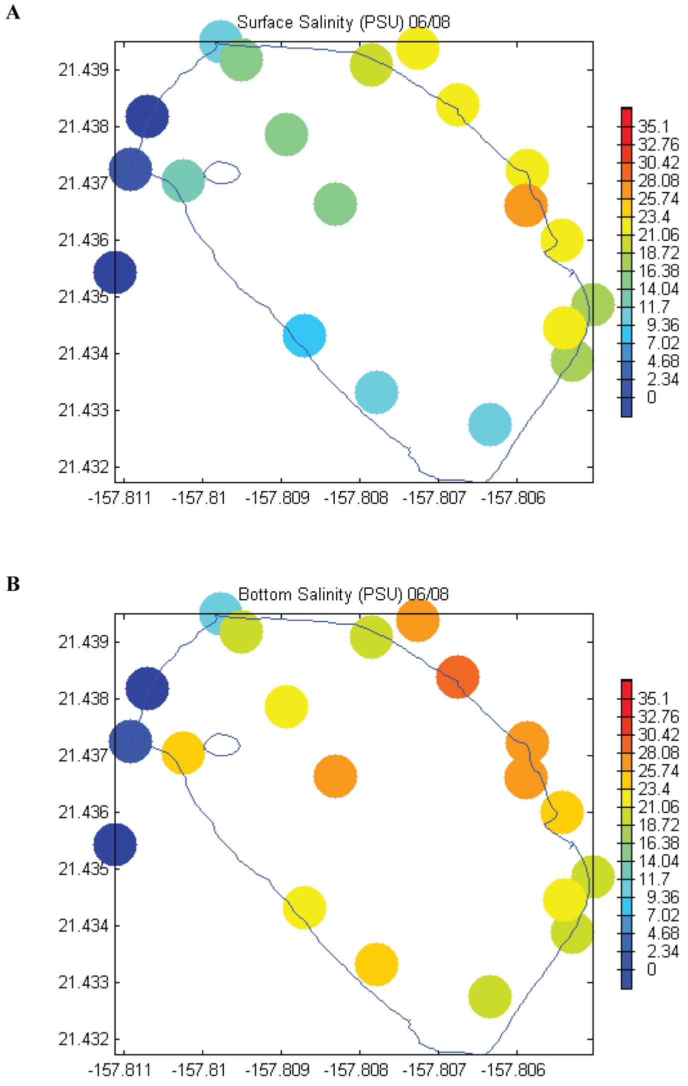
Appendix 3.14. Sample site mean (A) surface and (B) near-bottom salinity values for the 04/19/08 monthly sampling event. Site locations are geo-referenced to the He‘eia Fishpond perimeter outlined in blue. He‘eia Stream is located to the northwest and Kane‘ohe Bay to the east.



Appendix 3.15. Sample site mean (A) surface and (B) near-bottom salinity values for the 05/17/08 monthly sampling event. Site locations are geo-referenced to the He‘eia Fishpond perimeter outlined in blue. He‘eia Stream is located to the northwest and Kane‘ohe Bay to the east.

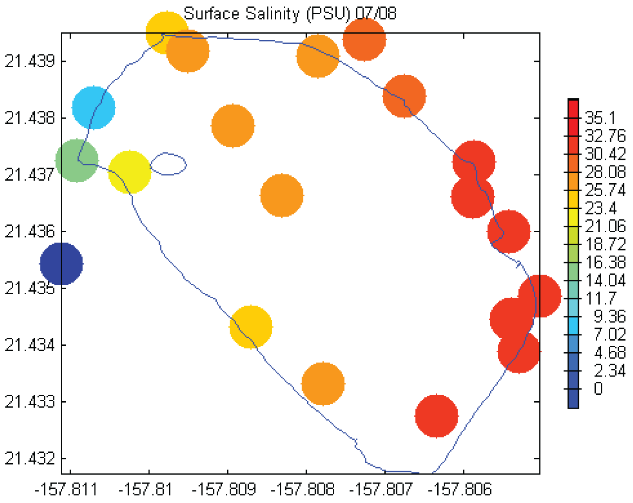


Appendix 3.16. Sample site mean (A) surface and (B) near-bottom salinity values for the 06/14/08 monthly sampling event. Site locations are geo-referenced to the He‘eia Fishpond perimeter outlined in blue. He‘eia Stream is located to the northwest and Kane‘ohe Bay to the east.

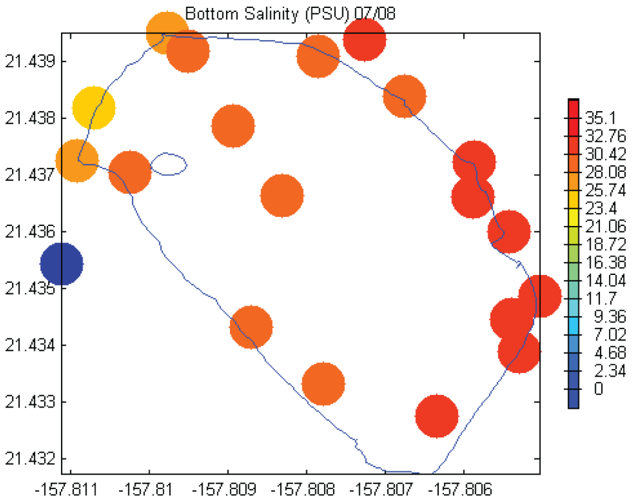


Appendix 3.17. Sample site mean (A) surface and (B) near-bottom salinity values for the 07/26/08 monthly sampling event. Site locations are geo-referenced to the He‘eia Fishpond perimeter outlined in blue. He‘eia Stream is located to the northwest and Kane‘ohe Bay to the east.

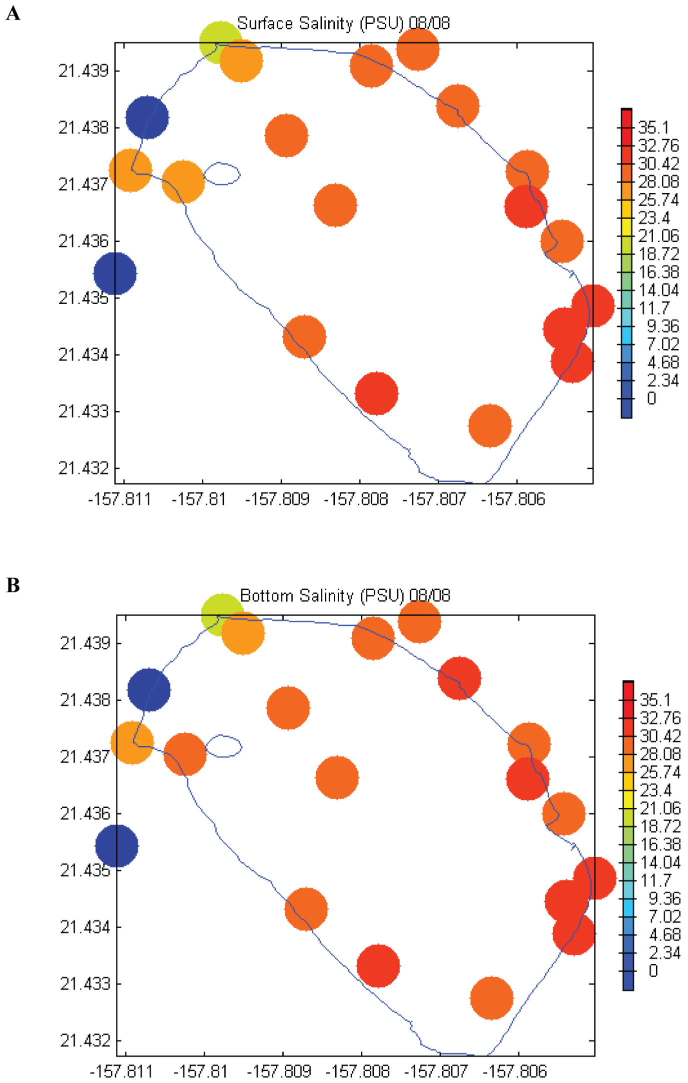
A



B

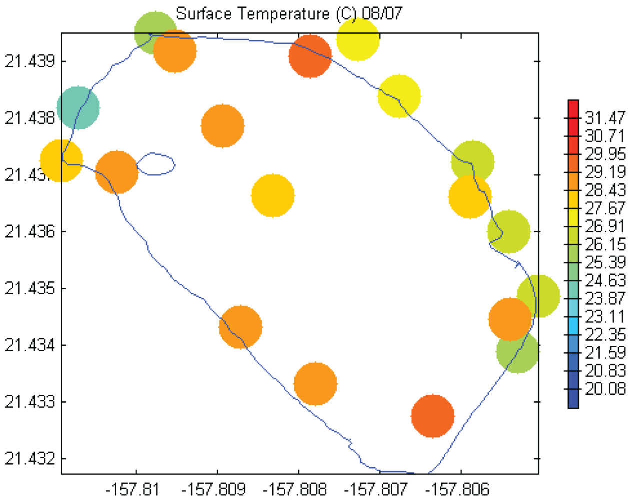


Appendix 3.18. Sample site mean (A) surface and (B) near-bottom salinity values for the 08/30/08 monthly sampling event. Site locations are geo-referenced to the He‘eia Fishpond perimeter outlined in blue. He‘eia Stream is located to the northwest and Kane‘ohe Bay to the east.

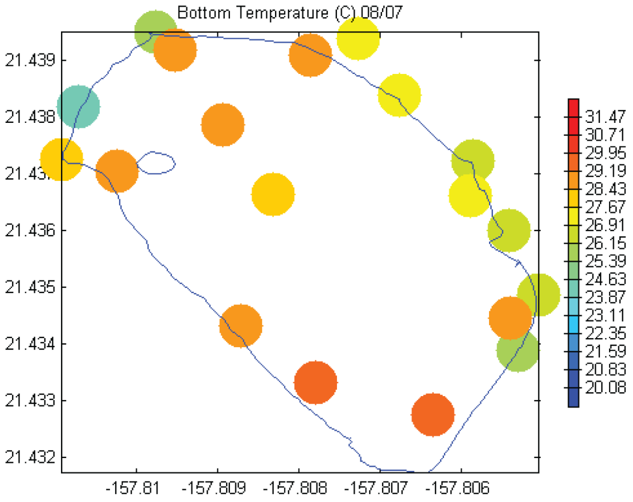


Appendix 4.1. Sample site mean (A) surface and (B) near-bottom temperature values for the 08/11/07 monthly sampling event. Site locations are geo-referenced to the He‘eia Fishpond perimeter outlined in blue. He‘eia Stream is located to the northwest and Kane‘ohe Bay to the east.

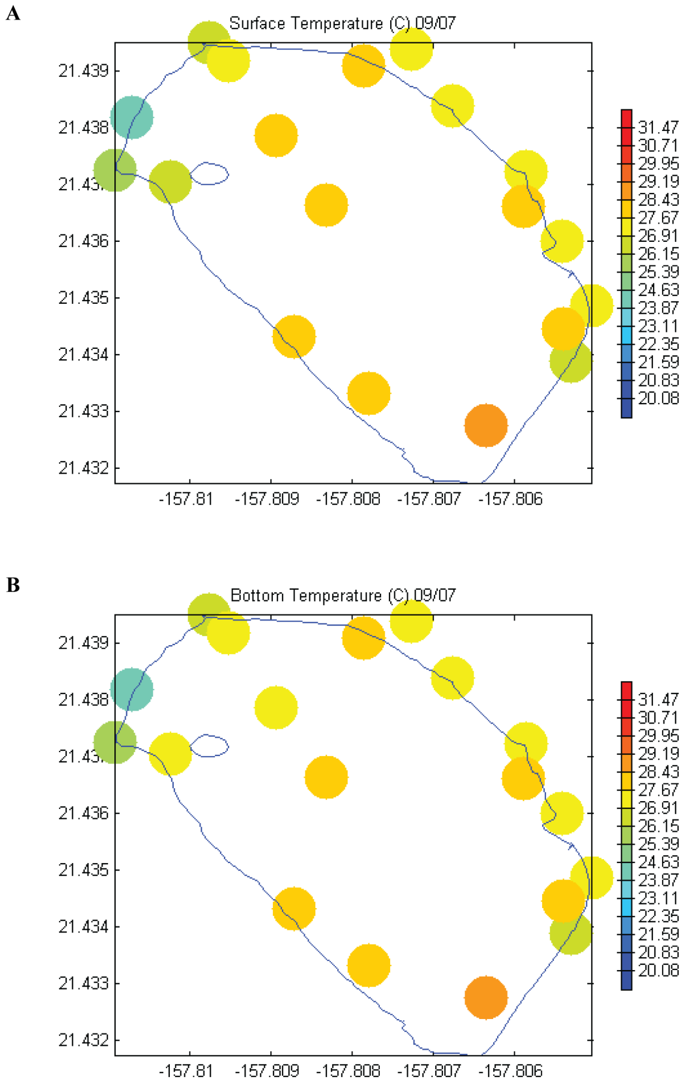
A



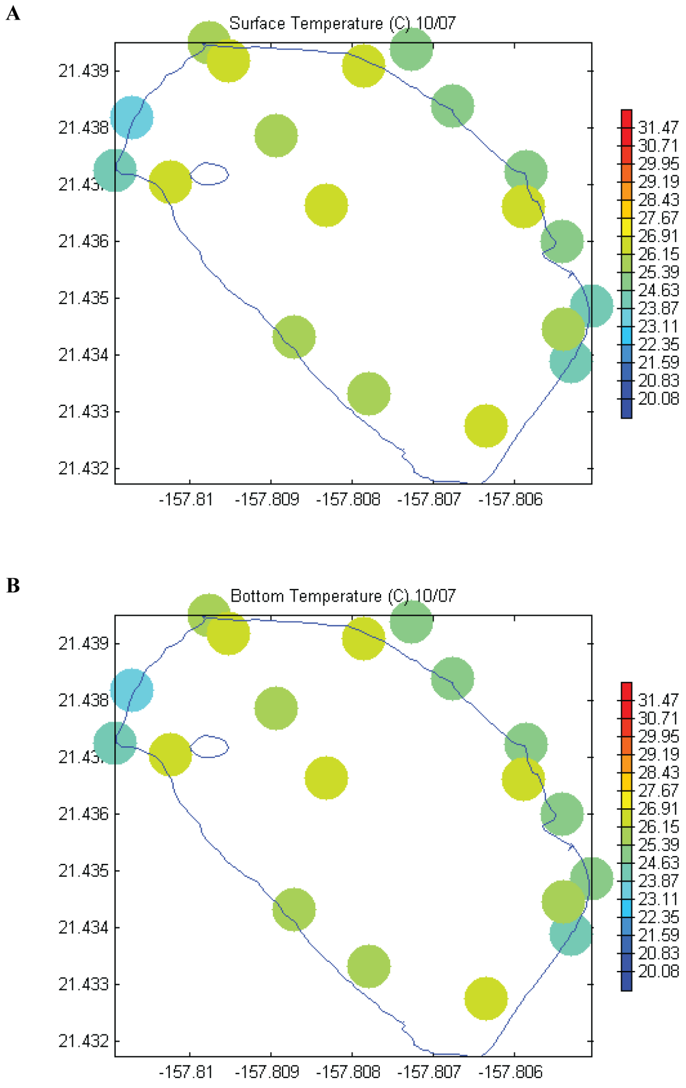
B



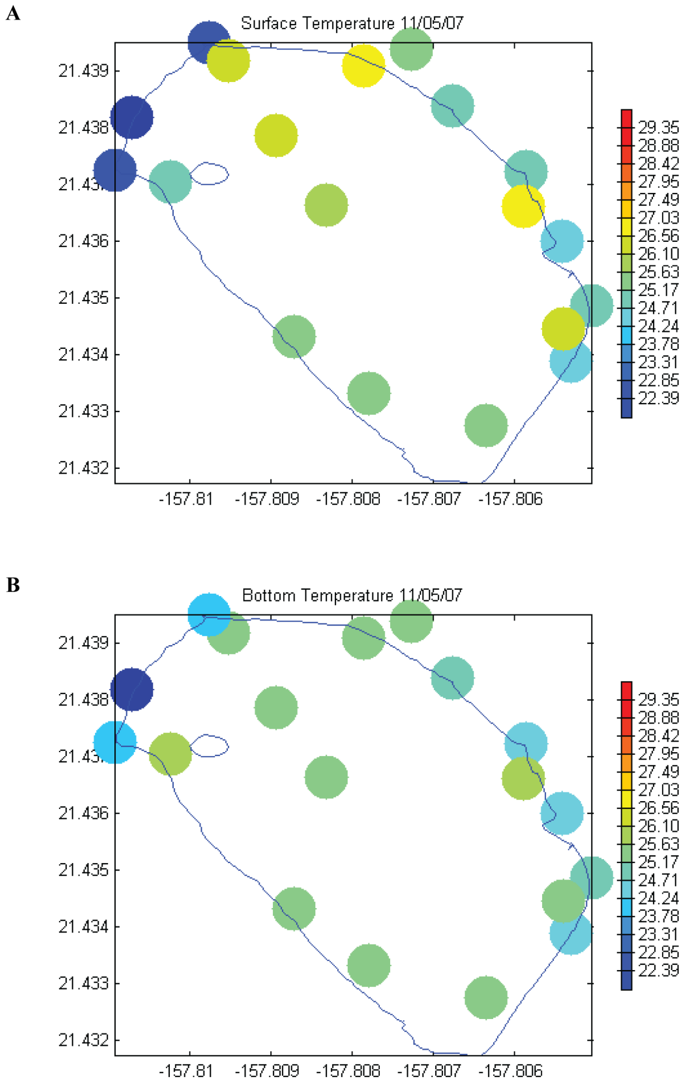
Appendix 4.2. Sample site mean (A) surface and (B) near-bottom temperature values for the 09/15/07 monthly sampling event. Site locations are geo-referenced to the He‘eia Fishpond perimeter outlined in blue. He‘eia Stream is located to the northwest and Kane‘ohe Bay to the east.



Appendix 4.3. Sample site mean (A) surface and (B) near-bottom temperature values for the 10/13/07 monthly sampling event. Site locations are geo-referenced to the He‘eia Fishpond perimeter outlined in blue. He‘eia Stream is located to the northwest and Kane‘ohe Bay to the east.

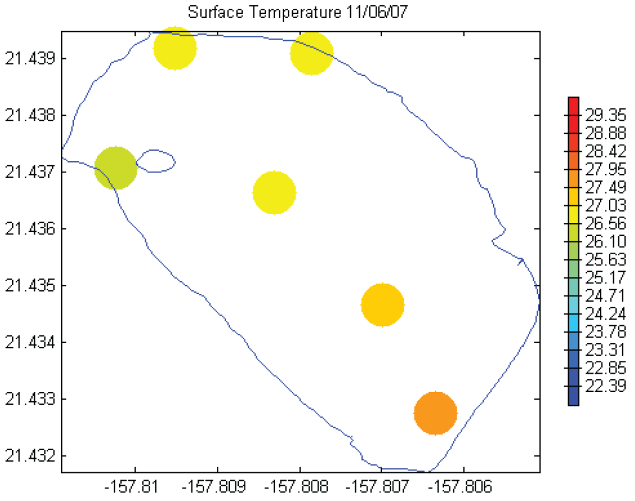


Appendix 4.4. Sample site mean (A) surface and (B) near-bottom temperature values for the 11/05/07, Storm 1, sampling event. Site locations are geo-referenced to the He‘eia Fishpond perimeter outlined in blue. He‘eia Stream is located to the northwest and Kane‘ohe Bay to the east.

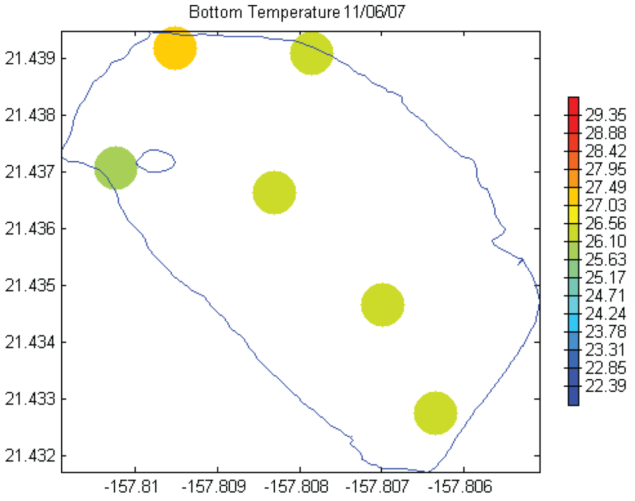


Appendix 4.5. Sample site mean (A) surface and (B) near-bottom temperature values for the 11/06/07, Storm 1-Transect 1, sampling event. Site locations are geo-referenced to the He‘eia Fishpond perimeter outlined in blue. He‘eia Stream is located to the northwest and Kane‘ohe Bay to the east.

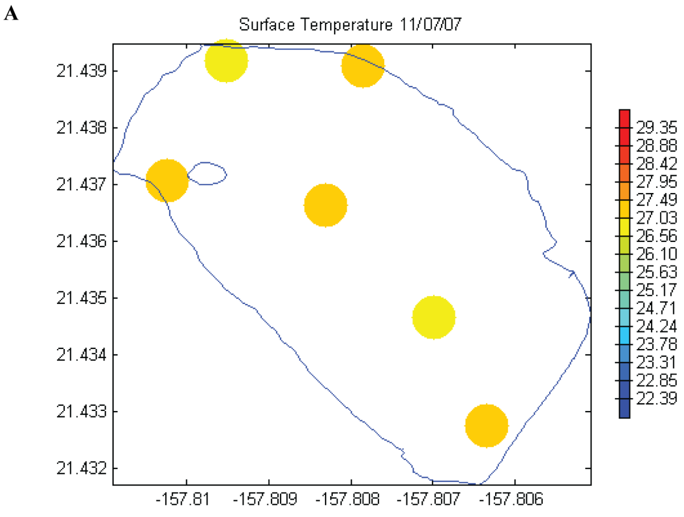
A

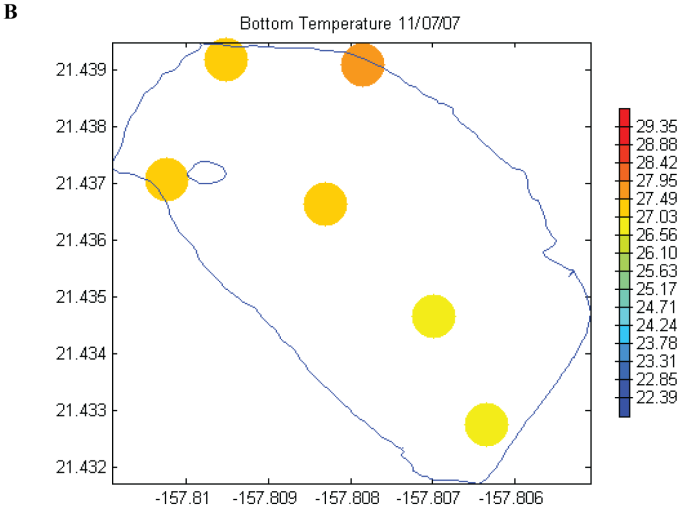


B

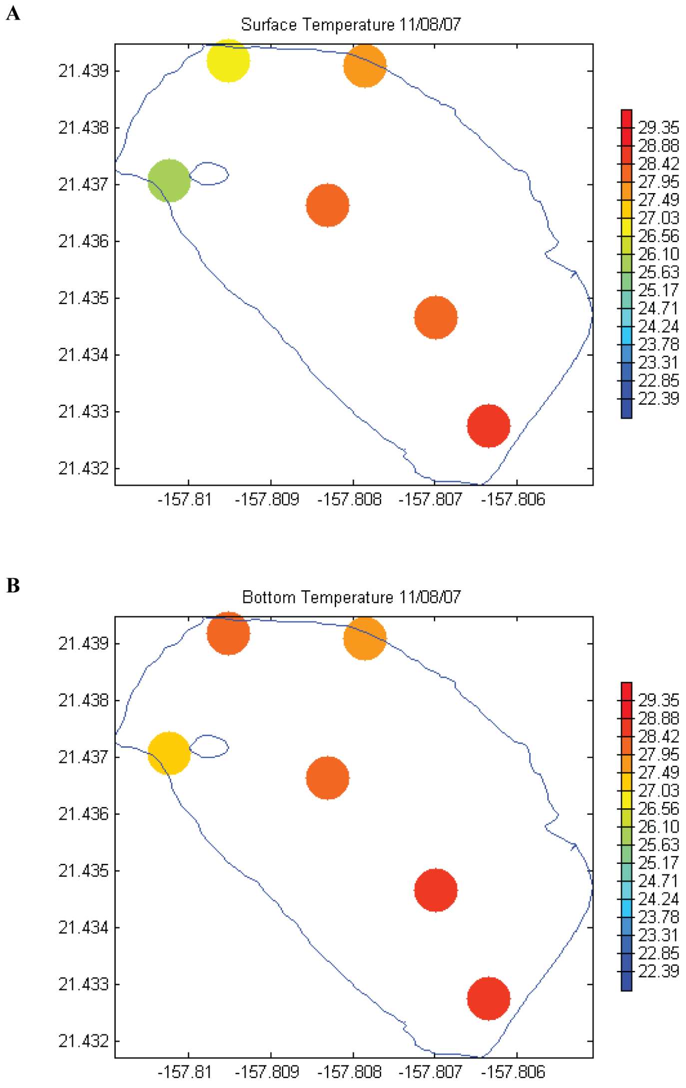


Appendix 4.6. Sample site mean (A) surface and (B) near-bottom temperature values for the 11/07/07, Storm 1-Transect 2, sampling event. Site locations are geo-referenced to the He‘eia Fishpond perimeter outlined in blue. He‘eia Stream is located to the northwest and Kane‘ohe Bay to the east.

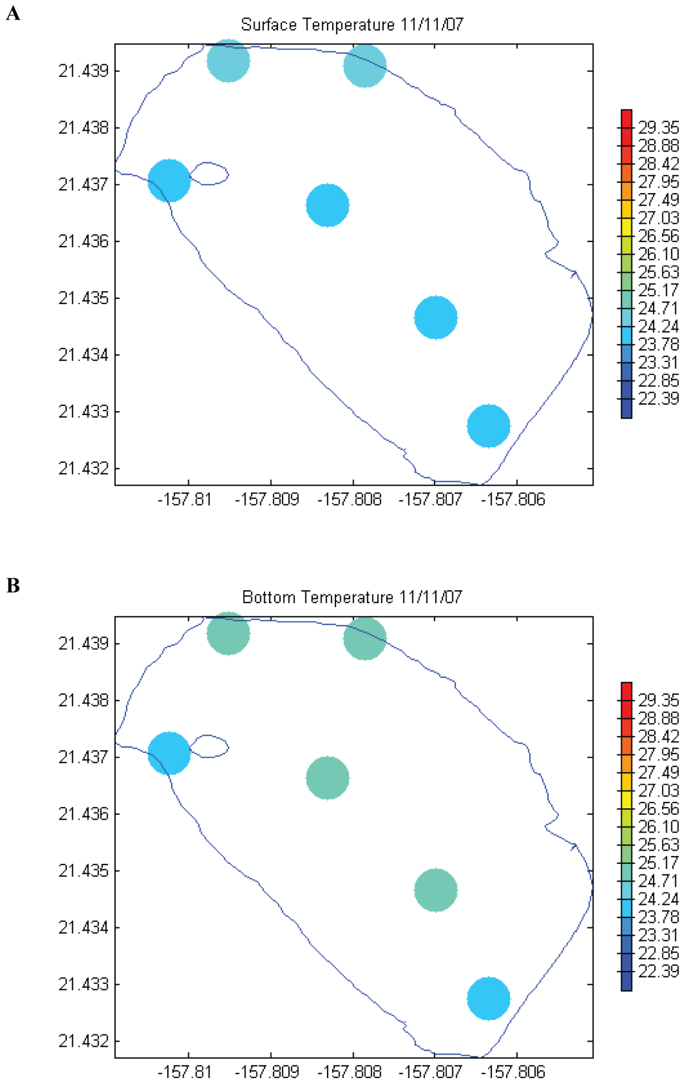




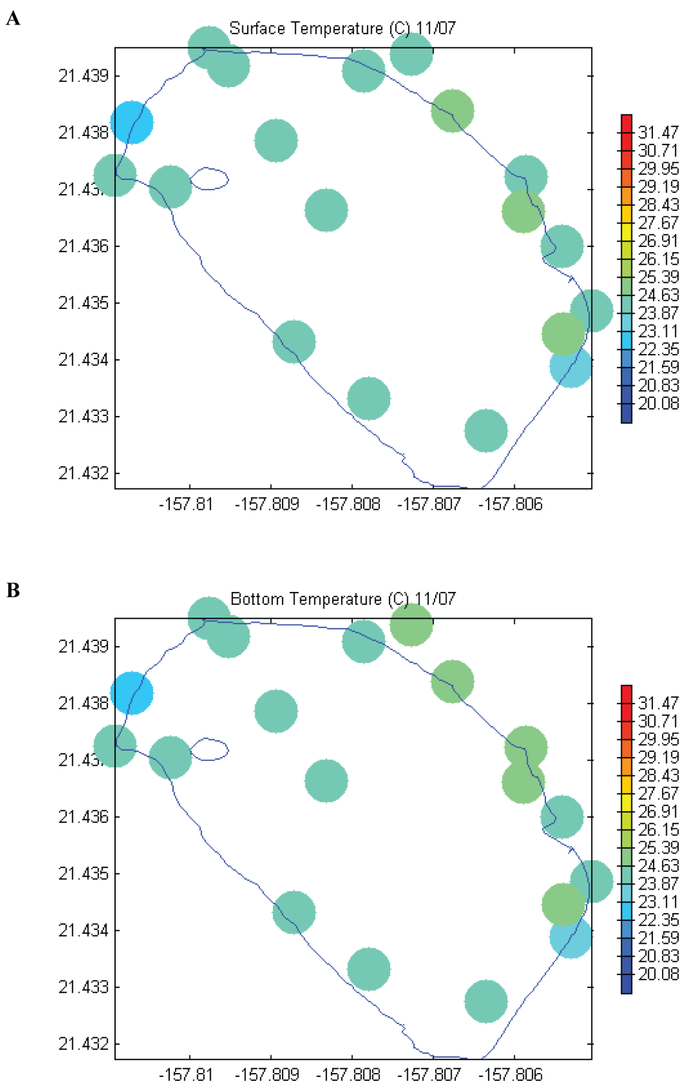
Appendix 4.7. Sample site mean (A) surface and (B) near-bottom temperature values for the 11/08/07, Storm 1-Transect 3, sampling event. Site locations are geo-referenced to the He‘eia Fishpond perimeter outlined in blue. He‘eia Stream is located to the northwest and Kane‘ohe Bay to the east.



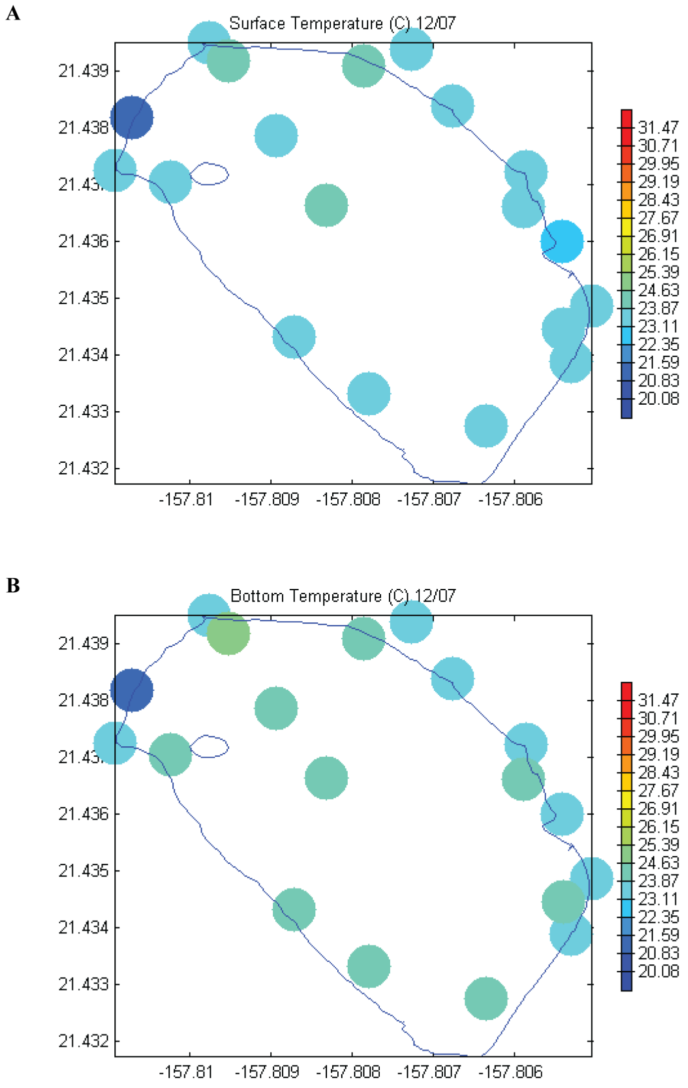
Appendix 4.8. Sample site mean (A) surface and (B) near-bottom temperature values for the 11/11/07, Storm 1-Transect 4, sampling event. Site locations are geo-referenced to the He‘eia Fishpond perimeter outlined in blue. He‘eia Stream is located to the northwest and Kane‘ohe Bay to the east.



Appendix 4.9. Sample site mean (A) surface and (B) near-bottom temperature values for the 11/17/07 monthly sampling event. Site locations are geo-referenced to the He‘eia Fishpond perimeter outlined in blue. He‘eia Stream is located to the northwest and Kane‘ohe Bay to the east.

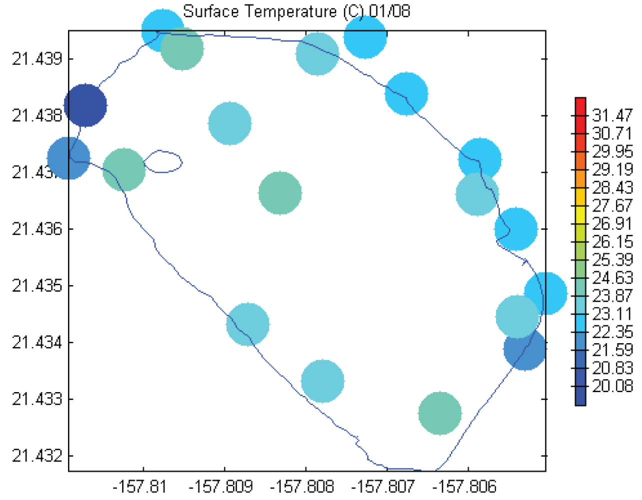


Appendix 4.10. Sample site mean (A) surface and (B) near-bottom temperature values for the 12/09/07 monthly sampling event. Site locations are geo-referenced to the He‘eia Fishpond perimeter outlined in blue. He‘eia Stream is located to the northwest and Kane‘ohe Bay to the east.

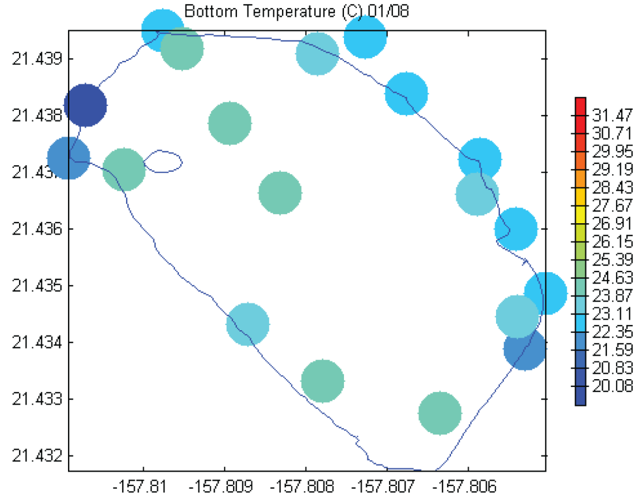


Appendix 4.11. Sample site mean (A) surface and (B) near-bottom temperature values for the 01/12/08 monthly sampling event. Site locations are geo-referenced to the He‘eia Fishpond perimeter outlined in blue. He‘eia Stream is located to the northwest and Kane‘ohe Bay to the east.

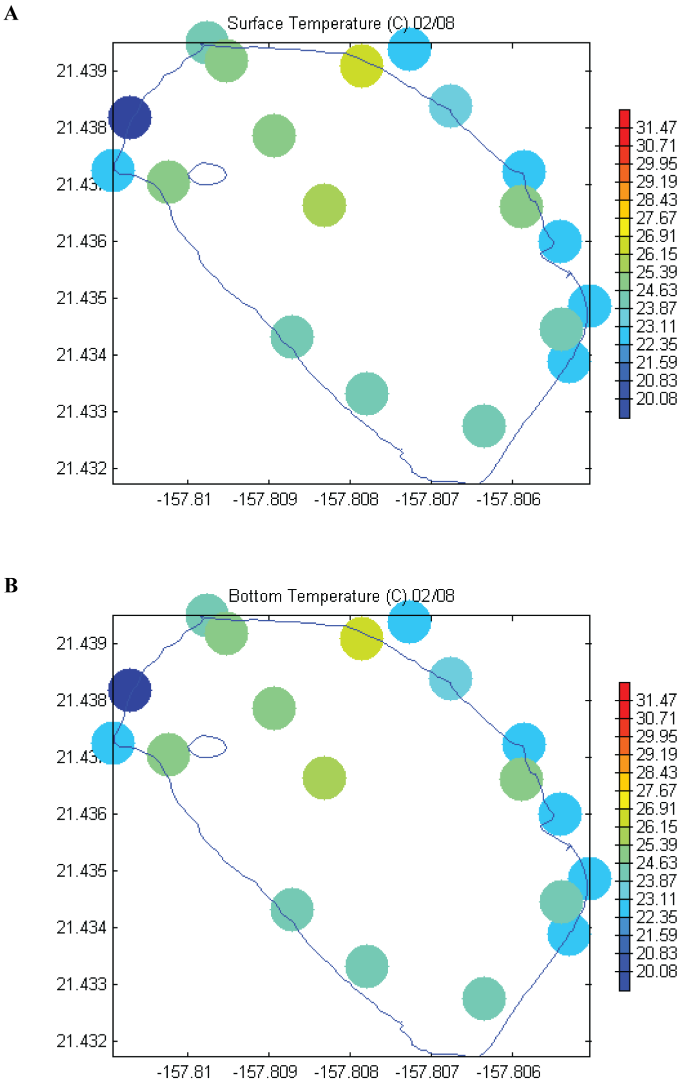
A



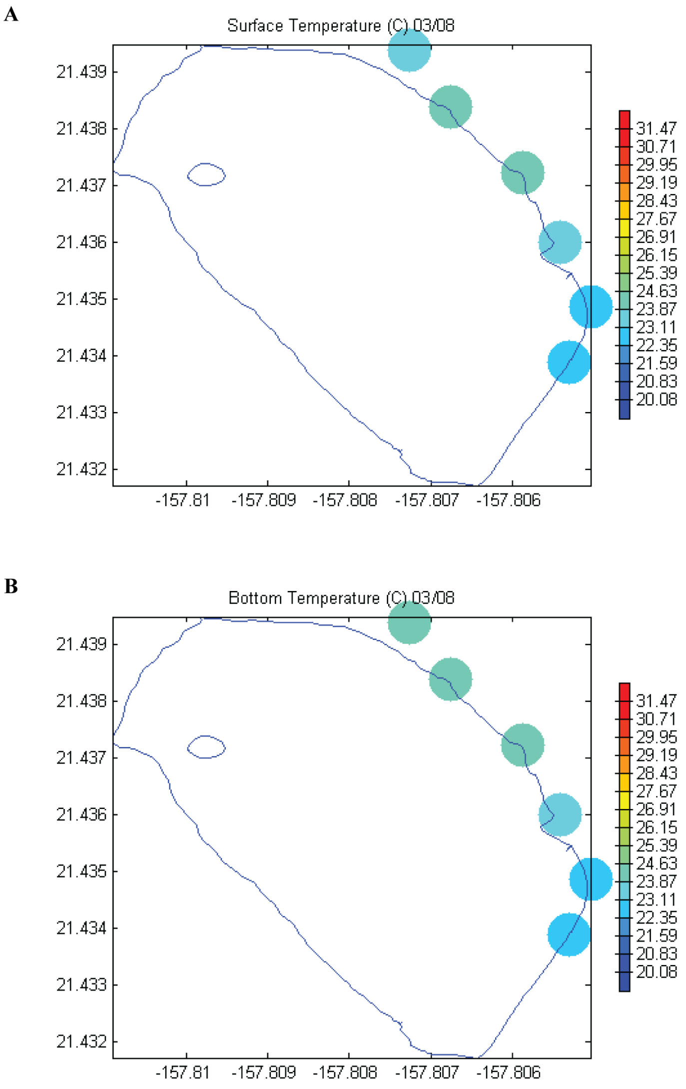
B



Appendix 4.12. Sample site mean (A) surface and (B) near-bottom temperature values for the 02/16/08 monthly sampling event. Site locations are geo-referenced to the He‘eia Fishpond perimeter outlined in blue. He‘eia Stream is located to the northwest and Kane‘ohe Bay to the east.

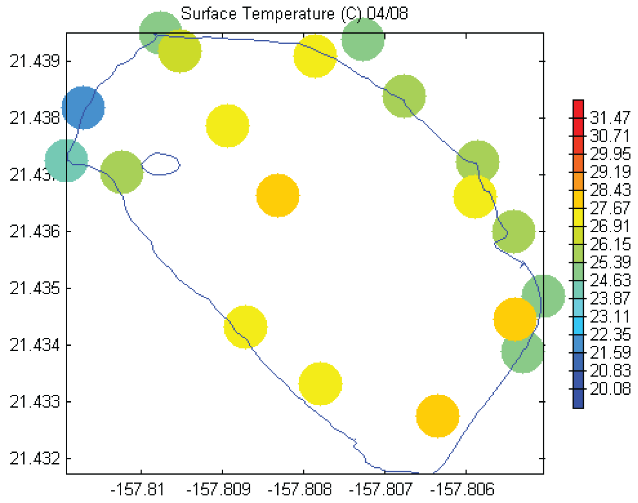


Appendix 4.13. Sample site mean (A) surface and (B) near-bottom temperature values for the 03/15/08 monthly sampling event. Site locations are geo-referenced to the He‘eia Fishpond perimeter outlined in blue. He‘eia Stream is located to the northwest and Kane‘ohe Bay to the east. Not all sample sites measured due to instrument malfunction.

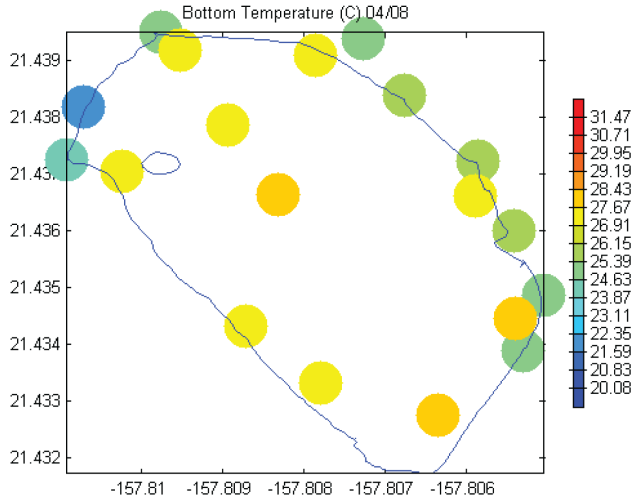


Appendix 4.14. Sample site mean (A) surface and (B) near-bottom temperature values for the 04/19/08 monthly sampling event. Site locations are geo-referenced to the He‘eia Fishpond perimeter outlined in blue. He‘eia Stream is located to the northwest and Kane‘ohe Bay to the east.

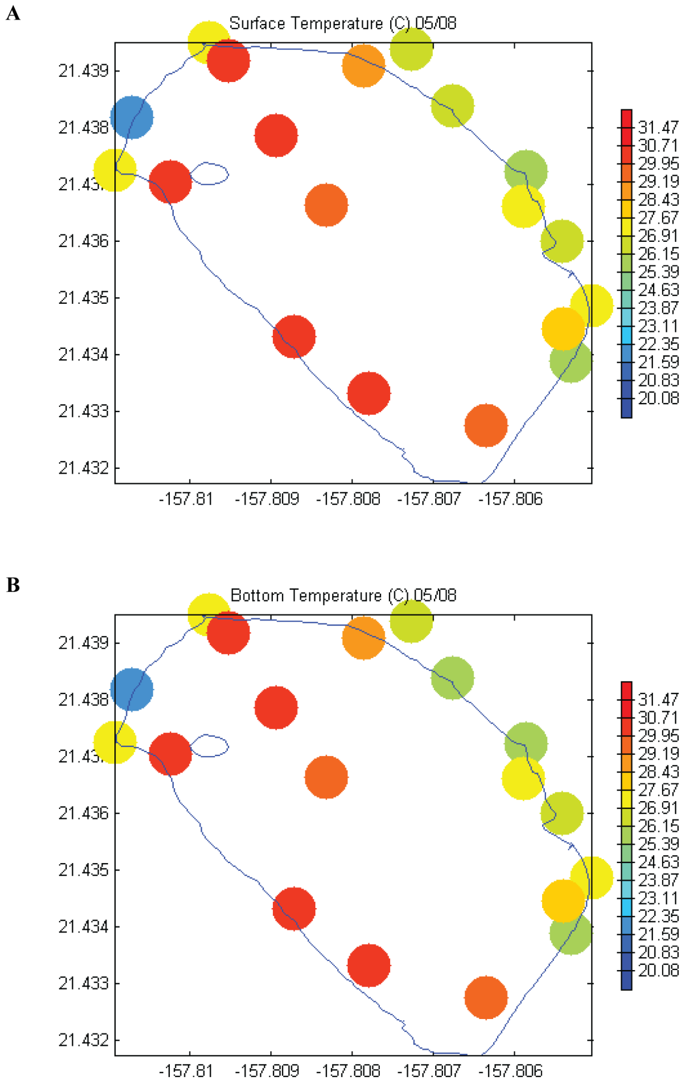
A



B

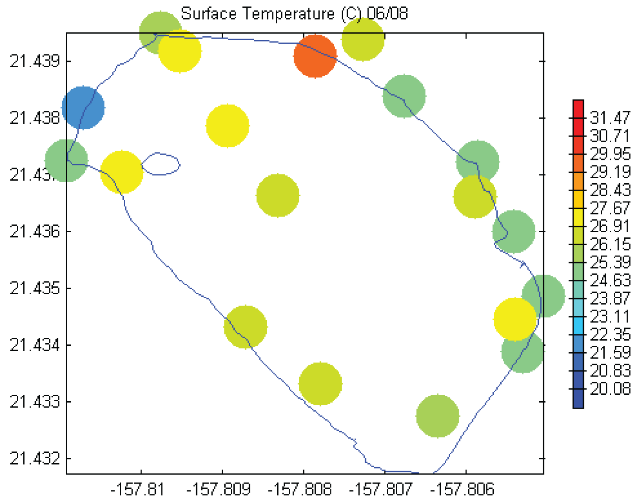


Appendix 4.15. Sample site mean (A) surface and (B) near-bottom temperature values for the 05/17/08 monthly sampling event. Site locations are geo-referenced to the He‘eia Fishpond perimeter outlined in blue. He‘eia Stream is located to the northwest and Kane‘ohe Bay to the east.

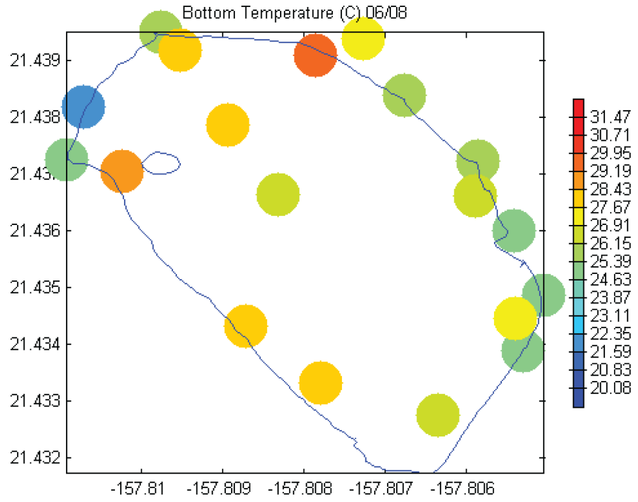


Appendix 4.16. Sample site mean (A) surface and (B) near-bottom temperature values for the 06/14/08 monthly sampling event. Site locations are geo-referenced to the He‘eia Fishpond perimeter outlined in blue. He‘eia Stream is located to the northwest and Kane‘ohe Bay to the east.

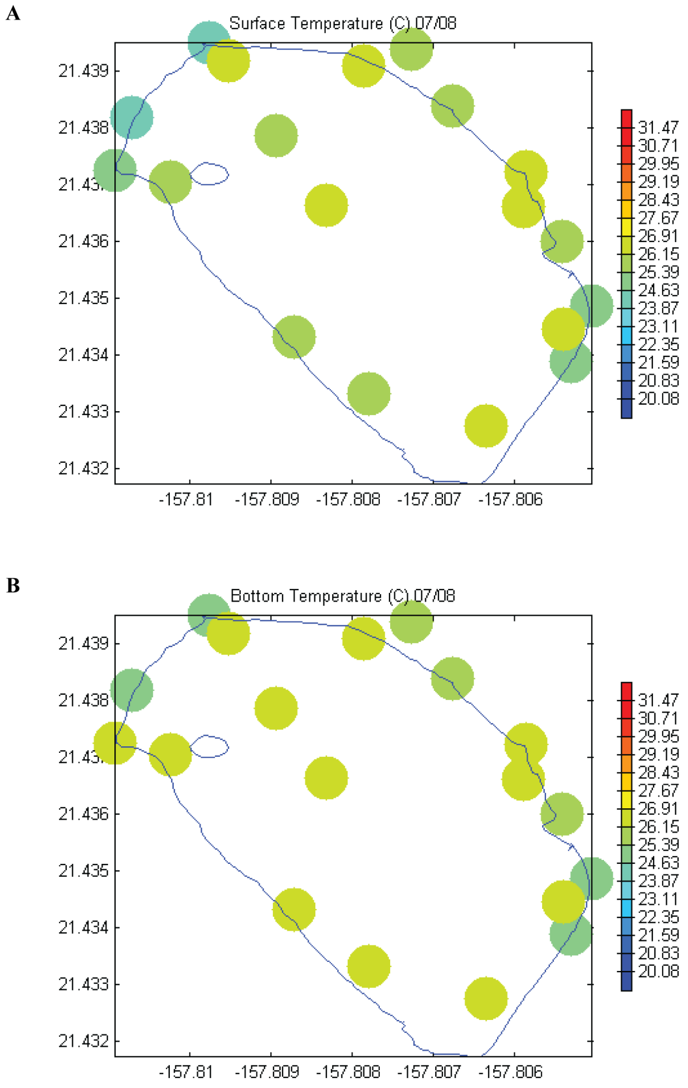
A



B

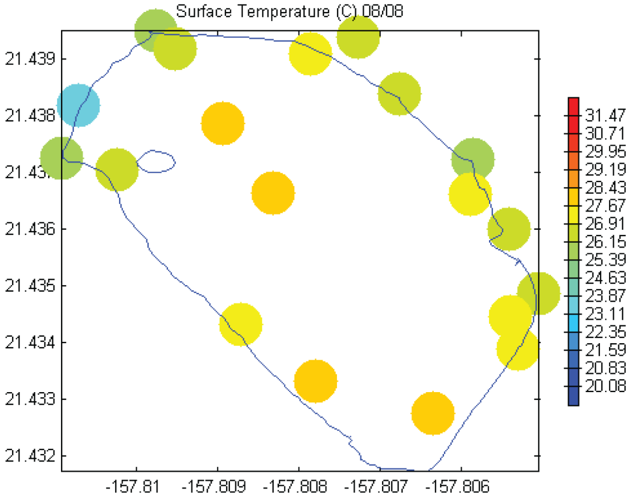


Appendix 4.17. Sample site mean (A) surface and (B) near-bottom temperature values for the 07/26/08 monthly sampling event. Site locations are geo-referenced to the He‘eia Fishpond perimeter outlined in blue. He‘eia Stream is located to the northwest and Kane‘ohe Bay to the east.

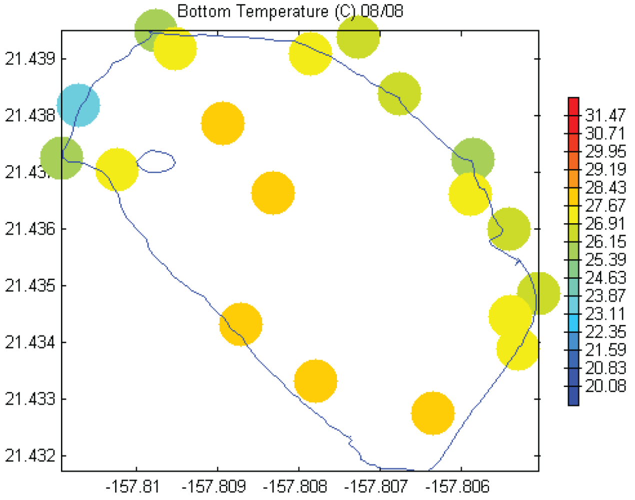


Appendix 4.18. Sample site mean (A) surface and (B) near-bottom temperature values for the 08/30/08 monthly sampling event. Site locations are geo-referenced to the He‘eia Fishpond perimeter outlined in blue. He‘eia Stream is located to the northwest and Kane‘ohe Bay to the east.

A



B



Appendix 5.1. Dissolved inorganic nutrient concentration data for surface and near-bottom water samples. Concentrations are in µM.

Site	Date	NH_4^+	$(NO_3^- + NO_2^-)$	PO_4^{3-}	H_4SiO_4
OM2	8/11/07	3.44	0.20	0.29	25.83
OCN2	8/11/07	0.61	0.17	0.19	16.30
OB	8/11/07	3.78	0.40	0.20	29.11
OM1	8/11/07	1.91	0.16	0.16	22.48
TM	8/11/07	4.45	0.51	0.32	40.48
OCN1	8/11/07	3.16	0.57	0.31	42.72
RM3	8/11/07	25.87	0.24	0.86	299.51
RM2	8/11/07	6.09	0.09	0.88	392.34
RM1	8/11/07	10.01	0.22	0.98	158.71
River	8/11/07	9.89	0.04	0.91	NaN
Stk1sfc	8/11/07	1.06	0.21	0.10	21.10
Stk1deep	8/11/07	1.66	0.23	0.18	19.19
Stk3sfc	8/11/07	1.50	0.36	0.20	10.78
Stk3deep	8/11/07	1.81	0.26	0.17	9.00
Stk6sfc	8/11/07	1.47	0.15	0.16	35.29
Stk6deep	8/11/07	1.34	0.34	0.20	19.06
Stk7sfc	8/11/07	2.04	0.11	0.25	53.36
Stk7deep	8/11/07	0.84	0.24	0.28	34.24
Stk8sfc	8/11/07	2.04	0.18	0.18	32.33
Stk8deep	8/11/07	0.72	0.24	0.16	14.98
Stk9sfc	8/11/07	1.07	0.18	0.08	18.66
Stk9deep	8/11/07	1.11	0.28	0.19	15.58
Stk13sfc	8/11/07	1.82	0.13	0.19	29.11
Stk13deep	8/11/07	1.54	0.21	0.23	25.83
Stk15sfc	8/11/07	1.56	0.17	0.19	38.78
Stk15deep	8/11/07	NaN	NaN	NaN	NaN
Stk16sfc	8/11/07	1.20	0.65	0.22	35.21
Stk16deep	8/11/07	1.19	0.23	0.24	30.23
Stk18sfc	8/11/07	4.59	0.10	0.31	74.46
Stk18deep	8/11/07	NaN	NaN	NaN	NaN

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. “NaN” is defined as “Not a Number” when a parameter was not measured.)

Site	Date	NH_4^+	$(NO_3^- + NO_2^-)$	PO_4^{3-}	H_4SiO_4
OM2	9/15/07	3.23	0.23	0.22	29.92
OCN2	9/15/07	1.35	0.38	0.21	22.70
OB	9/15/07	4.20	0.53	0.30	39.46
OM1	9/15/07	3.41	0.64	0.34	34.95
TM	9/15/07	3.80	0.46	0.33	36.49
OCN1	9/15/07	4.70	0.64	0.40	50.16
RM3	9/15/07	6.37	0.54	0.56	71.14
RM2	9/15/07	6.09	0.20	0.88	406.90
RM1	9/15/07	9.33	0.23	1.06	191.52
River	9/15/07	5.14	0.02	0.91	418.50
Stk1sfc	9/15/07	3.12	0.09	0.22	35.72
Stk1deep	9/15/07	2.02	0.20	0.30	35.40
Stk3sfc	9/15/07	2.32	0.22	0.22	33.85
Stk3deep	9/15/07	1.95	0.19	0.26	29.98
Stk6sfc	9/15/07	2.17	0.14	0.28	42.94
Stk6deep	9/15/07	0.38	0.26	0.33	42.94
Stk7sfc	9/15/07	2.64	0.14	0.26	43.07
Stk7deep	9/15/07	0.90	0.18	0.33	45.00
Stk8sfc	9/15/07	2.82	0.16	0.16	36.75
Stk8deep	9/15/07	0.20	0.24	0.29	35.72
Stk9sfc	9/15/07	3.04	0.28	0.17	36.85
Stk9deep	9/15/07	2.07	0.17	0.29	40.10
Stk13sfc	9/15/07	2.79	0.33	0.23	38.49
Stk13deep	9/15/07	1.86	0.26	0.32	38.69
Stk15sfc	9/15/07	2.76	0.17	0.17	39.33
Stk15deep	9/15/07	0.87	0.19	0.31	37.78
Stk16sfc	9/15/07	1.39	1.13	0.14	36.51
Stk16deep	9/15/07	0.96	0.27	0.26	37.29
Stk18sfc	9/15/07	2.83	0.13	0.58	109.68
Stk18deep	9/15/07	1.50	0.19	0.36	49.55

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. "NaN" is defined as "Not a Number" when a parameter was not measured.)

Site	Date	NH_4^+	$(NO_3^- + NO_2^-)$	PO_4^{3-}	H_4SiO_4
OM2	10/13/07	3.48	0.20	0.00	25.71
OCN2	10/13/07	1.41	0.15	0.12	26.02
OB	10/13/07	6.16	0.37	0.13	25.06
OM1	10/13/07	2.55	0.27	0.17	31.93
TM	10/13/07	3.86	0.28	0.26	32.93
OCN1	10/13/07	4.59	0.25	0.44	90.31
RM3	10/13/07	3.44	0.29	0.31	67.73
RM2	10/13/07	8.26	0.06	0.87	422.49
RM1	10/13/07	8.40	0.19	0.79	206.83
River	10/13/07	7.99	0.09	0.89	430.19
Stk1sfc	10/13/07	4.46	0.11	0.15	39.90
Stk1deep	10/13/07	1.00	0.17	0.28	39.28
Stk3sfc	10/13/07	4.05	0.13	0.08	37.60
Stk3deep	10/13/07	2.12	0.20	0.26	44.94
Stk6sfc	10/13/07	4.18	0.10	0.24	58.14
Stk6deep	10/13/07	3.20	0.23	0.29	36.54
Stk7sfc	10/13/07	5.95	0.11	0.27	51.54
Stk7deep	10/13/07	1.82	0.17	0.26	44.01
Stk8sfc	10/13/07	3.91	0.14	0.28	55.83
Stk8deep	10/13/07	2.94	0.23	0.27	38.97
Stk9sfc	10/13/07	3.78	0.13	0.16	48.49
Stk9deep	10/13/07	2.03	0.31	0.28	48.24
Stk13sfc	10/13/07	5.14	0.04	0.46	67.41
Stk13deep	10/13/07	2.31	0.13	0.45	59.44
Stk15sfc	10/13/07	3.23	0.11	0.43	70.86
Stk15deep	10/13/07	2.45	0.19	0.43	67.36
Stk16sfc	10/13/07	4.73	0.18	0.42	85.06
Stk16deep	10/13/07	2.82	0.24	0.35	65.31
Stk18sfc	10/13/07	5.54	0.22	0.42	NaN
Stk18deep	10/13/07	3.93	0.18	0.34	NaN

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. “NaN” is defined as “Not a Number” when a parameter was not measured.)

Storm 1

Site	Date	NH_4^+	$(NO_3^- + NO_2^-)$	PO_4^{3-}	H_4SiO_4
River	11/4/07	7.45	6.17	0.91	234.72
Stk10sfc	11/4/07	20.76	40.19	0.93	205.33
Stk18sfc	11/4/07	8.80	12.44	0.94	263.63
OM2	11/5/07	4.38	0.26	0.04	13.06
OCN2	11/5/07	3.64	1.15	0.15	18.33
OB	11/5/07	3.26	1.78	0.47	20.19
OM1	11/5/07	4.01	1.83	0.46	19.52
TM	11/5/07	6.42	2.16	0.58	50.42
OCN1	11/5/07	2.75	1.69	0.49	21.67
RM3	11/5/07	9.08	9.03	0.86	324.72
RM2	11/5/07	10.57	6.22	0.88	342.77
RM1	11/5/07	26.98	9.98	0.52	329.54
River	11/5/07	8.13	1.19	0.91	367.09
Stk1sfc	11/5/07	11.52	22.00	0.92	166.58
Stk1deep	11/5/07	17.34	7.61	0.56	68.62
Stk3sfc	11/5/07	16.82	22.49	0.93	238.79
Stk3deep	11/5/07	16.32	9.05	0.88	80.65
Stk6sfc	11/5/07	15.60	19.99	0.93	244.33
Stk6deep	11/5/07	10.09	10.24	1.31	115.80
Stk7sfc	11/5/07	16.55	19.07	0.93	253.96
Stk7deep	11/5/07	18.35	10.72	0.97	129.76
Stk8sfc	11/5/07	NaN	NaN	NaN	242.88
Stk8deep	11/5/07	NaN	NaN	NaN	NaN
Stk9sfc	11/5/07	19.74	18.34	0.92	255.38
Stk9deep	11/5/07	9.92	6.85	0.47	96.15
Stk13sfc	11/5/07	25.37	8.71	0.79	187.78
Stk13deep	11/5/07	10.27	4.03	1.97	114.92
Stk15sfc	11/5/07	18.45	19.21	0.92	NaN
Stk15deep	11/5/07	9.87	9.76	1.15	126.51
Stk16sfc	11/5/07	NaN	NaN	NaN	NaN
Stk16deep	11/5/07	10.04	11.43	1.03	193.88
Stk18sfc	11/5/07	9.21	7.72	0.93	68.68
Stk18deep	11/5/07	20.30	13.70	0.91	245.99

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. “NaN” is defined as “Not a Number” when a parameter was not measured.)

Transects 1-4 Site	Date	NH_4^+	$(NO_3^- + NO_2^-)$	PO_4^{3-}	H_4SiO_4
Stk6sfc	11/6/07	NaN	3.24	0.69	84.63
Stk7sfc	11/6/07	12.64	2.50	0.78	112.07
Stk9sfc	11/6/07	35.22	5.56	0.80	130.19
Stk11sfc	11/6/07	27.36	2.14	0.80	176.25
Stk13sfc	11/6/07	16.01	6.53	0.84	230.64
Stk18sfc	11/6/07	11.25	0.49	0.93	324.22
Stk6sfc	11/7/07	6.90	0.60	0.10	53.27
Stk7sfc	11/7/07	12.20	0.33	0.61	112.56
Stk9sfc	11/7/07	13.70	0.70	0.03	43.47
Stk11sfc	11/7/07	10.84	1.34	0.25	58.17
Stk13sfc	11/7/07	14.38	1.78	0.69	161.06
Stk18sfc	11/7/07	NaN	0.38	0.78	171.84
Stk6sfc	11/8/07	3.64	0.15	0.23	69.93
Stk7sfc	11/8/07	8.67	0.20	0.75	166.45
Stk9sfc	11/8/07	2.55	0.15	0.11	30.24
Stk11sfc	11/8/07	2.11	0.12	0.07	25.83
Stk13sfc	11/8/07	2.10	0.14	0.05	22.89
Stk18sfc	11/8/07	9.21	0.07	0.92	279.14
Stk6sfc	11/11/07	3.10	0.04	0.29	67.97
Stk7sfc	11/11/07	12.61	0.09	0.05	31.71
Stk9sfc	11/11/07	3.23	0.03	0.41	61.11
Stk11sfc	11/11/07	2.96	0.05	0.15	52.29
Stk13sfc	11/11/07	2.69	0.06	0.14	52.29
Stk18sfc	11/11/07	5.14	0.04	0.56	113.54

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. “NaN” is defined as “Not a Number” when a parameter was not measured.)

Site	Date	NH_4^+	$(NO_3^- + NO_2^-)$	PO_4^{3-}	H_4SiO_4
OM2	11/17/07	0.68	0.20	0.11	9.63
OCN2	11/17/07	1.05	0.29	0.20	7.50
OB	11/17/07	1.22	0.25	0.21	4.39
OM1	11/17/07	1.57	0.41	0.27	11.25
TM	11/17/07	2.15	0.39	0.25	21.73
OCN1	11/17/07	1.80	0.27	0.17	28.21
RM3	11/17/07	5.99	0.16	0.97	172.76
RM2	11/17/07	6.36	0.07	0.88	394.05
RM1	11/17/07	12.20	0.09	0.80	263.00
River	11/17/07	10.84	0.09	0.91	421.23
Stk1sfc	11/17/07	2.29	0.10	0.07	8.40
Stk1deep	11/17/07	1.44	0.17	0.13	8.79
Stk3sfc	11/17/07	3.22	0.15	0.15	32.22
Stk3deep	11/17/07	2.03	0.22	0.19	10.73
Stk6sfc	11/17/07	4.45	0.12	0.36	64.58
Stk6deep	11/17/07	2.01	0.17	0.30	34.48
Stk7sfc	11/17/07	6.77	0.05	0.36	90.53
Stk7deep	11/17/07	0.71	0.14	0.30	38.88
Stk8sfc	11/17/07	4.32	0.05	0.25	64.84
Stk8deep	11/17/07	1.71	0.20	0.27	37.40
Stk9sfc	11/17/07	4.44	0.12	0.21	48.07
Stk9deep	11/17/07	0.61	0.16	0.24	34.48
Stk13sfc	11/17/07	3.42	0.17	0.12	27.30
Stk13deep	11/17/07	2.07	0.20	0.19	24.52
Stk15sfc	11/17/07	3.51	0.04	0.51	96.05
Stk15deep	11/17/07	1.37	0.17	0.26	37.46
Stk16sfc	11/17/07	6.49	0.05	0.81	219.23
Stk16deep	11/17/07	3.20	0.20	0.28	34.83
Stk18sfc	11/17/07	7.04	0.07	0.81	201.39
Stk18deep	11/17/07	0.76	0.19	0.25	36.15

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. “NaN” is defined as “Not a Number” when a parameter was not measured.)

Storm 2

Site	Date	NH_4^+	$(NO_3^- + NO_2^-)$	PO_4^{3-}	H_4SiO_4
OM2	12/9/07	4.65	0.65	0.31	28.44
OCN2	12/9/07	3.92	0.42	0.22	33.15
OB	12/9/07	21.77	0.42	0.40	71.44
OM1	12/9/07	11.72	0.50	0.79	95.96
TM	12/9/07	10.33	1.00	1.10	151.68
OCN1	12/9/07	10.85	0.77	0.91	174.14
RM3	12/9/07	15.65	0.35	0.96	112.95
RM2	12/9/07	7.72	0.13	0.87	395.44
RM1	12/9/07	12.86	0.32	1.90	317.18
River	12/9/07	8.94	0.31	0.91	426.75
Stk1sfc	12/9/07	7.45	0.20	0.81	176.51
Stk1deep	12/9/07	3.13	0.29	0.39	48.78
Stk3sfc	12/9/07	8.80	0.23	0.69	125.77
Stk3deep	12/9/07	1.11	0.19	0.41	43.28
Stk6sfc	12/9/07	9.08	0.13	0.73	100.06
Stk6deep	12/9/07	5.35	0.18	0.40	43.55
Stk7sfc	12/9/07	6.63	0.13	0.67	86.95
Stk7deep	12/9/07	3.79	0.16	0.33	37.79
Stk8sfc	12/9/07	9.89	0.15	1.15	76.57
Stk8deep	12/9/07	3.02	0.18	0.28	29.70
Stk9sfc	12/9/07	5.68	0.14	0.74	106.95
Stk9deep	12/9/07	1.17	0.29	0.29	35.47
Stk13sfc	12/9/07	6.77	0.19	0.83	215.97
Stk13deep	12/9/07	3.78	0.14	0.11	47.26
Stk15sfc	12/9/07	7.45	0.21	0.83	279.49
Stk15deep	12/9/07	9.24	0.30	0.34	33.65
Stk16sfc	12/9/07	7.58	0.07	0.92	306.92
Stk16deep	12/9/07	4.22	0.38	0.25	29.80
Stk18sfc	12/9/07	10.71	0.10	0.93	328.57
Stk18deep	12/9/07	4.30	0.26	0.38	37.50

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. “NaN” is defined as “Not a Number” when a parameter was not measured.)

Site	Date	NH_4^+	$(NO_3^- + NO_2^-)$	PO_4^{3-}	H_4SiO_4
OM2	1/12/08	8.54	0.33	1.38	58.25
OCN2	1/12/08	2.79	0.58	0.35	36.15
OB	1/12/08	21.77	0.23	0.35	66.51
OM1	1/12/08	3.37	0.21	0.42	47.95
TM	1/12/08	21.77	0.18	0.34	65.26
OCN1	1/12/08	4.18	0.29	0.73	87.22
RM3	1/12/08	9.21	0.22	0.92	118.93
RM2	1/12/08	9.48	0.26	0.87	425.04
RM1	1/12/08	10.42	0.54	0.26	232.28
River	1/12/08	7.04	0.61	0.90	361.60
Stk1sfc	1/12/08	5.82	0.18	1.06	138.50
Stk1deep	1/12/08	1.14	0.17	0.24	30.05
Stk3sfc	1/12/08	3.23	0.08	0.44	64.15
Stk3deep	1/12/08	0.00	0.10	0.27	28.45
Stk6sfc	1/12/08	4.84	0.08	0.42	46.77
Stk6deep	1/12/08	1.96	0.16	0.26	36.28
Stk7sfc	1/12/08	2.59	0.08	0.37	57.33
Stk7deep	1/12/08	4.39	0.24	0.32	39.23
Stk8sfc	1/12/08	4.71	0.14	0.46	54.77
Stk8deep	1/12/08	3.08	0.15	0.35	42.51
Stk9sfc	1/12/08	3.91	0.11	0.28	65.39
Stk9deep	1/12/08	1.04	0.13	0.21	25.92
Stk13sfc	1/12/08	6.63	0.06	0.82	215.97
Stk13deep	1/12/08	1.75	0.44	0.28	31.23
Stk15sfc	1/12/08	8.67	0.67	0.82	310.95
Stk15deep	1/12/08	1.64	0.16	0.27	37.78
Stk16sfc	1/12/08	8.80	0.54	1.47	277.49
Stk16deep	1/12/08	1.58	0.28	0.30	37.29
Stk18sfc	1/12/08	8.26	0.35	1.06	249.06
Stk18deep	1/12/08	1.88	0.16	0.30	49.55

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. “NaN” is defined as “Not a Number” when a parameter was not measured.)

Site	**Date**	**NH_4^+**	**$(NO_3^- + NO_2^-)$**	**PO_4^{3-}**	**H_4SiO_4**
OM2	2/16/08	5.93	0.19	0.15	16.40
OCN2	2/16/08	4.29	0.39	0.33	21.26
OB	2/16/08	4.54	0.81	0.42	35.34
OM1	2/16/08	5.79	0.28	0.23	24.79
TM	2/16/08	0.38	0.22	0.17	21.61
OCN1	2/16/08	2.21	0.19	0.28	34.39
RM3	2/16/08	5.71	0.29	0.29	35.34
RM2	2/16/08	10.57	0.29	0.87	461.11
RM1	2/16/08	11.26	0.31	1.00	178.85
River	2/16/08	8.67	0.43	0.90	425.59
Stk1sfc	2/16/08	2.85	0.10	0.14	36.48
Stk1deep	2/16/08	1.80	0.25	0.22	23.59
Stk3sfc	2/16/08	2.09	0.09	0.12	14.82
Stk3deep	2/16/08	1.12	0.17	0.13	12.86
Stk6sfc	2/16/08	3.54	0.17	0.21	29.34
Stk6deep	2/16/08	3.45	0.17	0.30	26.94
Stk7sfc	2/16/08	2.72	0.12	0.23	27.89
Stk7deep	2/16/08	0.22	0.19	0.19	25.99
Stk8sfc	2/16/08	3.03	0.15	0.21	22.39
Stk8deep	2/16/08	2.10	0.14	0.23	20.82
Stk9sfc	2/16/08	1.49	0.15	0.11	21.64
Stk9deep	2/16/08	1.01	0.16	0.14	21.01
Stk13sfc	2/16/08	7.04	0.08	0.74	114.40
Stk13deep	2/16/08	1.90	0.21	0.24	25.61
Stk15sfc	2/16/08	3.51	0.10	0.25	63.38
Stk15deep	2/16/08	1.05	0.16	0.19	27.09
Stk16sfc	2/16/08	4.86	0.02	0.44	96.36
Stk16deep	2/16/08	1.38	0.15	0.20	27.31
Stk18sfc	2/16/08	5.09	0.16	0.58	103.05
Stk18deep	2/16/08	0.86	0.18	0.23	29.67

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. “NaN” is defined as “Not a Number” when a parameter was not measured.)

Site	Date	NH_4^+	$(NO_3^- + NO_2^-)$	PO_4^{3-}	H_4SiO_4
OM2	3/15/08	2.40	0.22	0.26	27.58
OCN2	3/15/08	0.17	0.18	0.18	23.84
OB	3/15/08	2.76	0.33	0.35	26.77
OM1	3/15/08	3.23	0.27	0.32	45.92
TM	3/15/08	2.00	0.10	0.26	56.02
OCN1	3/15/08	8.32	0.23	0.93	134.29
RM3	3/15/08	5.54	0.03	0.73	146.55
RM2	3/15/08	9.62	0.33	0.87	354.29
RM1	3/15/08	15.73	0.19	0.86	271.34
River	3/15/08	4.59	0.04	0.90	428.12
Stk1sfc	3/15/08	NaN	NaN	NaN	NaN
Stk1deep	3/15/08	0.41	0.12	0.16	26.71
Stk3sfc	3/15/08	2.15	0.09	0.11	40.93
Stk3deep	3/15/08	2.55	0.07	0.02	37.50
Stk6sfc	3/15/08	NaN	NaN	NaN	NaN
Stk6deep	3/15/08	2.83	0.08	0.22	61.82
Stk7sfc	3/15/08	5.82	0.09	0.82	122.25
Stk7deep	3/15/08	4.59	0.06	0.50	104.61
Stk8sfc	3/15/08	NaN	NaN	NaN	NaN
Stk8deep	3/15/08	1.74	0.04	0.05	49.19
Stk9sfc	3/15/08	NaN	NaN	NaN	NaN
Stk9deep	3/15/08	2.01	0.09	0.01	25.53
Stk13sfc	3/15/08	NaN	NaN	NaN	NaN
Stk13deep	3/15/08	3.91	0.09	0.05	30.02
Stk15sfc	3/15/08	NaN	NaN	NaN	NaN
Stk15deep	3/15/08	2.42	0.05	0.03	31.95
Stk16sfc	3/15/08	NaN	NaN	NaN	NaN
Stk16deep	3/15/08	3.51	0.07	0.28	62.45
Stk18sfc	3/15/08	NaN	NaN	NaN	NaN
Stk18deep	3/15/08	4.32	0.03	0.71	151.32

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. “NaN” is defined as “Not a Number” when a parameter was not measured.)

Site	Date	NH_4^+	$(NO_3^- + NO_2^-)$	PO_4^{3-}	H_4SiO_4
OM2	4/19/08	11.11	0.26	0.14	28.31
OCN2	4/19/08	2.56	0.24	0.22	19.75
OB	4/19/08	2.57	0.65	0.19	24.18
OM1	4/19/08	2.10	0.12	0.19	33.61
TM	4/19/08	3.49	0.22	0.23	34.76
OCN1	4/19/08	2.70	0.14	0.20	36.75
RM3	4/19/08	5.06	0.09	1.05	169.29
RM2	4/19/08	NaN	NaN	NaN	NaN
RM1	4/19/08	NaN	NaN	NaN	NaN
River	4/19/08	6.36	0.03	0.90	420.97
Stk1sfc	4/19/08	NaN	NaN	NaN	NaN
Stk1deep	4/19/08	3.44	0.19	0.26	26.10
Stk3sfc	4/19/08	NaN	NaN	NaN	NaN
Stk3deep	4/19/08	2.34	0.30	0.28	24.63
Stk6sfc	4/19/08	NaN	NaN	NaN	NaN
Stk6deep	4/19/08	NaN	NaN	NaN	NaN
Stk7sfc	4/19/08	NaN	NaN	NaN	NaN
Stk7deep	4/19/08	NaN	NaN	NaN	NaN
Stk8sfc	4/19/08	NaN	NaN	NaN	NaN
Stk8deep	4/19/08	NaN	NaN	NaN	NaN
Stk9sfc	4/19/08	NaN	NaN	NaN	NaN
Stk9deep	4/19/08	NaN	NaN	NaN	NaN
Stk13sfc	4/19/08	NaN	NaN	NaN	NaN
Stk13deep	4/19/08	NaN	NaN	NaN	NaN
Stk15sfc	4/19/08	NaN	NaN	NaN	NaN
Stk15deep	4/19/08	NaN	NaN	NaN	NaN
Stk16sfc	4/19/08	NaN	NaN	NaN	NaN
Stk16deep	4/19/08	NaN	NaN	NaN	NaN
Stk18sfc	4/19/08	NaN	NaN	NaN	NaN
Stk18deep	4/19/08	NaN	NaN	NaN	NaN

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. “NaN” is defined as “Not a Number” when a parameter was not measured.)

Site	Date	NH_4^+	$(NO_3^- + NO_2^-)$	PO_4^{3-}	H_4SiO_4
OM2	5/17/08	5.76	0.33	0.27	47.89
OCN2	5/17/08	3.63	0.51	0.45	36.25
OB	5/17/08	2.82	1.12	0.45	26.65
OM1	5/17/08	3.32	0.47	0.53	64.86
TM	5/17/08	2.97	0.46	0.53	67.75
OCN1	5/17/08	6.03	0.35	0.72	106.74
RM3	5/17/08	11.65	0.26	0.95	144.14
RM2	5/17/08	6.49	0.12	0.88	412.93
RM1	5/17/08	21.55	0.33	1.07	207.76
River	5/17/08	5.00	0.13	0.90	429.70
Stk1sfc	5/17/08	3.11	0.18	0.32	39.80
Stk1deep	5/17/08	5.74	0.19	0.36	40.06
Stk3sfc	5/17/08	3.10	0.57	0.37	21.32
Stk3deep	5/17/08	2.49	0.59	0.27	19.02
Stk6sfc	5/17/08	3.38	0.17	0.15	30.86
Stk6deep	5/17/08	3.29	0.40	0.22	29.67
Stk7sfc	5/17/08	1.31	0.14	0.24	44.34
Stk7deep	5/17/08	4.02	0.19	0.32	44.73
Stk8sfc	5/17/08	5.83	0.22	0.19	38.42
Stk8deep	5/17/08	3.57	0.20	0.32	39.80
Stk9sfc	5/17/08	6.68	0.17	0.14	28.29
Stk9deep	5/17/08	3.51	0.22	0.21	27.31
Stk13sfc	5/17/08	6.18	0.26	0.37	48.15
Stk13deep	5/17/08	6.84	0.32	0.36	45.79
Stk15sfc	5/17/08	4.43	0.21	0.37	36.08
Stk15deep	5/17/08	5.38	0.31	0.27	34.90
Stk16sfc	5/17/08	4.18	0.15	0.28	74.85
Stk16deep	5/17/08	13.19	0.32	0.32	39.10
Stk18sfc	5/17/08	2.56	0.13	0.36	71.86
Stk18deep	5/17/08	2.01	0.20	0.31	44.07

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. “NaN” is defined as “Not a Number” when a parameter was not measured.)

Storm 4

Site	Date	NH_4^+	$(NO_3^- + NO_2^-)$	PO_4^{3-}	H_4SiO_4
OM2	6/14/08	4.71	1.19	0.48	99.75
OCN2	6/14/08	21.77	0.21	0.63	138.85
OB	6/14/08	7.39	0.13	0.79	180.39
OM1	6/14/08	5.66	0.10	0.92	170.50
TM	6/14/08	6.47	0.53	0.81	169.51
OCN1	6/14/08	5.59	0.14	0.79	153.68
RM3	6/14/08	16.53	1.62	0.79	217.84
RM2	6/14/08	NaN	NaN	NaN	394.05
RM1	6/14/08	6.09	1.19	0.86	332.10
River	6/14/08	4.59	0.04	0.90	422.25
Stk1sfc	6/14/08	4.05	0.22	0.39	82.66
Stk1deep	6/14/08	6.68	0.48	0.34	34.83
Stk3sfc	6/14/08	10.84	0.45	0.05	30.17
Stk3deep	6/14/08	7.79	1.41	0.39	24.87
Stk6sfc	6/14/08	8.53	0.95	0.83	220.93
Stk6deep	6/14/08	2.89	1.47	0.53	90.56
Stk7sfc	6/14/08	6.36	0.05	0.82	217.47
Stk7deep	6/14/08	2.08	0.70	0.50	82.27
Stk8sfc	6/14/08	6.36	5.98	0.83	216.48
Stk8deep	6/14/08	2.32	1.00	0.38	62.54
Stk9sfc	6/14/08	5.95	4.31	0.84	189.29
Stk9deep	6/14/08	2.18	0.10	0.22	27.70
Stk13sfc	6/14/08	10.16	4.65	0.84	187.31
Stk13deep	6/14/08	2.83	0.73	0.43	75.26
Stk15sfc	6/14/08	14.10	5.82	0.83	194.73
Stk15deep	6/14/08	3.88	0.93	0.36	57.26
Stk16sfc	6/14/08	7.58	6.14	0.83	189.29
Stk16deep	6/14/08	2.96	1.24	0.33	58.74
Stk18sfc	6/14/08	13.56	4.93	0.92	244.17
Stk18deep	6/14/08	NaN	NaN	NaN	NaN

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. “NaN” is defined as “Not a Number” when a parameter was not measured.)

Site	Date	NH_4^+	$(NO_3^- + NO_2^-)$	PO_4^{3-}	H_4SiO_4
OM2	7/26/08	0.98	0.20	0.11	13.90
OCN2	7/26/08	3.36	0.23	0.19	11.58
OB	7/26/08	0.85	0.23	0.22	8.03
OM1	7/26/08	1.81	0.21	0.26	7.34
TM	7/26/08	2.40	0.21	0.17	28.74
OCN1	7/26/08	3.39	0.28	0.29	37.16
RM3	7/26/08	6.00	0.35	0.59	83.35
RM2	7/26/08	7.04	0.05	0.86	110.08
RM1	7/26/08	6.77	0.03	0.79	88.55
River	7/26/08	7.17	0.11	0.89	116.54
Stk1sfc	7/26/08	3.09	0.16	0.01	11.65
Stk1deep	7/26/08	4.46	0.22	0.09	11.84
Stk3sfc	7/26/08	3.44	0.17	0.15	33.87
Stk3deep	7/26/08	1.76	0.30	0.10	11.32
Stk6sfc	7/26/08	2.94	0.09	0.35	72.65
Stk6deep	7/26/08	0.73	0.18	0.29	41.79
Stk7sfc	7/26/08	3.78	0.16	0.23	60.19
Stk7deep	7/26/08	0.38	0.14	0.30	44.79
Stk8sfc	7/26/08	3.37	0.03	0.28	69.33
Stk8deep	7/26/08	0.67	0.20	0.20	28.35
Stk9sfc	7/26/08	1.86	0.09	0.28	53.01
Stk9deep	7/26/08	1.09	0.18	0.20	26.92
Stk13sfc	7/26/08	2.48	NaN	0.05	20.26
Stk13deep	7/26/08	2.50	0.21	0.22	18.57
Stk15sfc	7/26/08	5.68	0.03	0.33	38.98
Stk15deep	7/26/08	1.16	0.20	0.18	15.83
Stk16sfc	7/26/08	4.73	0.02	0.73	59.08
Stk16deep	7/26/08	0.93	0.17	0.22	18.60
Stk18sfc	7/26/08	5.68	0.03	0.82	75.19
Stk18deep	7/26/08	0.50	0.14	0.19	17.01

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. “NaN” is defined as “Not a Number” when a parameter was not measured.)

Site	Date	NH_4^+	$(NO_3^- + NO_2^-)$	PO_4^{3-}	H_4SiO_4
OM2	8/30/08	2.90	0.18	0.20	28.54
OCN2	8/30/08	0.33	0.11	0.16	19.50
OB	8/30/08	2.81	0.59	0.13	25.25
OM1	8/30/08	3.75	1.02	0.19	37.33
TM	8/30/08	3.46	0.45	0.41	68.75
OCN1	8/30/08	3.25	0.26	0.41	71.84
RM3	8/30/08	9.18	0.26	1.51	136.45
RM2	8/30/08	7.85	0.06	0.87	428.60
RM1	8/30/08	8.41	0.20	0.99	189.66
River	8/30/08	7.17	0.10	0.89	438.10
Stk1sfc	8/30/08	1.93	0.24	0.15	29.36
Stk1deep	8/30/08	2.06	0.27	0.22	29.62
Stk3sfc	8/30/08	2.27	0.17	0.16	25.70
Stk3deep	8/30/08	0.99	0.16	0.15	24.31
Stk6sfc	8/30/08	5.57	0.17	0.37	23.74
Stk6deep	8/30/08	1.83	0.13	0.34	23.74
Stk7sfc	8/30/08	8.40	0.08	0.97	23.23
Stk7deep	8/30/08	0.33	0.11	0.39	23.17
Stk8sfc	8/30/08	7.45	0.12	0.34	25.06
Stk8deep	8/30/08	2.20	0.20	0.32	24.87
Stk9sfc	8/30/08	1.71	0.13	0.19	25.51
Stk9deep	8/30/08	0.61	0.19	0.26	23.17
Stk13sfc	8/30/08	1.92	0.15	0.19	19.31
Stk13deep	8/30/08	1.07	0.14	0.26	21.65
Stk15sfc	8/30/08	1.46	0.73	0.13	22.06
Stk15deep	8/30/08	1.05	0.25	0.20	21.99
Stk16sfc	8/30/08	4.90	0.18	0.48	87.67
Stk16deep	8/30/08	1.75	0.15	0.20	24.53
Stk18sfc	8/30/08	3.78	0.06	0.18	131.63
Stk18deep	8/30/08	2.45	0.18	0.84	49.10

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. “NaN” is defined as “Not a Number” when a parameter was not measured.)

Appendix 5.2. Total and dissolved organic nutrient concentration data for surface and near-bottom water samples. Concentrations are in μM.

Site	Date	DOC	TDN	DON*	TDP	DOP*
OM2	8/11/07	NaN	NaN	NaN	0.61	0.32
OCN2	8/11/07	34.53	6.84	6.06	0.63	0.44
OB	8/11/07	NaN	NaN	NaN	0.63	0.42
OM1	8/11/07	NaN	NaN	NaN	0.62	0.46
TM	8/11/07	NaN	NaN	NaN	0.62	0.30
OCN1	8/11/07	27.95	8.01	4.29	0.62	0.31
RM3	8/11/07	NaN	NaN	NaN	0.60	NaN
RM2	8/11/07	NaN	NaN	NaN	0.62	NaN
RM1	8/11/07	NaN	NaN	NaN	0.60	NaN
River	8/11/07	17.30	3.87	NaN	0.65	NaN
Stk1sfc	8/11/07	NaN	NaN	NaN	0.60	0.50
Stk1deep	8/11/07	NaN	NaN	NaN	0.54	0.36
Stk3sfc	8/11/07	NaN	NaN	NaN	0.59	0.39
Stk3deep	8/11/07	NaN	NaN	NaN	0.65	0.48
Stk6sfc	8/11/07	120.04	9.09	7.46	0.62	0.47
Stk6deep	8/11/07	51.60	7.99	6.31	0.59	0.39
Stk7sfc	8/11/07	44.86	6.01	3.86	0.58	0.33
Stk7deep	8/11/07	32.53	7.11	6.03	0.57	0.29
Stk8sfc	8/11/07	NaN	NaN	NaN	0.56	0.38
Stk8deep	8/11/07	NaN	NaN	NaN	0.58	0.42
Stk9sfc	8/11/07	13.63	5.90	4.65	0.56	0.48
Stk9deep	8/11/07	86.99	9.59	8.19	0.58	0.39
Stk13sfc	8/11/07	60.01	7.84	5.90	0.58	0.39
Stk13deep	8/11/07	59.01	10.11	8.37	0.58	0.35
Stk15sfc	8/11/07	44.27	7.26	5.54	0.57	0.38
Stk15deep	8/11/07	42.11	7.26	NaN	NaN	NaN
Stk16sfc	8/11/07	NaN	NaN	NaN	0.62	0.40
Stk16deep	8/11/07	NaN	NaN	NaN	0.59	0.36
Stk18sfc	8/11/07	59.43	6.83	2.14	0.57	0.26
Stk18deep	8/11/07	27.62	6.60	NaN	NaN	NaN

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. "NaN" is defined as "Not a Number" when a parameter was not measured. "*" indicates concentrations calculated by difference, Total-Inorganic=Organic.)

Site	Date	DOC	TDN	DON*	TDP	DOP*
OM2	9/15/07	NaN	NaN	NaN	NaN	NaN
OCN2	9/15/07	NaN	NaN	NaN	NaN	NaN
OB	9/15/07	NaN	NaN	NaN	NaN	NaN
OM1	9/15/07	NaN	NaN	NaN	NaN	NaN
TM	9/15/07	NaN	NaN	NaN	NaN	NaN
OCN1	9/15/07	NaN	NaN	NaN	NaN	NaN
RM3	9/15/07	NaN	NaN	NaN	NaN	NaN
RM2	9/15/07	NaN	NaN	NaN	NaN	NaN
RM1	9/15/07	NaN	NaN	NaN	NaN	NaN
River	9/15/07	NaN	NaN	NaN	NaN	NaN
Stk1sfc	9/15/07	NaN	NaN	NaN	NaN	NaN
Stk1deep	9/15/07	NaN	NaN	NaN	NaN	NaN
Stk3sfc	9/15/07	NaN	NaN	NaN	NaN	NaN
Stk3deep	9/15/07	NaN	NaN	NaN	NaN	NaN
Stk6sfc	9/15/07	NaN	NaN	NaN	NaN	NaN
Stk6deep	9/15/07	NaN	NaN	NaN	NaN	NaN
Stk7sfc	9/15/07	NaN	NaN	NaN	NaN	NaN
Stk7deep	9/15/07	NaN	NaN	NaN	NaN	NaN
Stk8sfc	9/15/07	NaN	NaN	NaN	NaN	NaN
Stk8deep	9/15/07	NaN	NaN	NaN	NaN	NaN
Stk9sfc	9/15/07	NaN	NaN	NaN	NaN	NaN
Stk9deep	9/15/07	NaN	NaN	NaN	NaN	NaN
Stk13sfc	9/15/07	NaN	NaN	NaN	NaN	NaN
Stk13deep	9/15/07	NaN	NaN	NaN	NaN	NaN
Stk15sfc	9/15/07	NaN	NaN	NaN	NaN	NaN
Stk15deep	9/15/07	NaN	NaN	NaN	NaN	NaN
Stk16sfc	9/15/07	NaN	NaN	NaN	NaN	NaN
Stk16deep	9/15/07	NaN	NaN	NaN	NaN	NaN
Stk18sfc	9/15/07	NaN	NaN	NaN	NaN	NaN
Stk18deep	9/15/07	NaN	NaN	NaN	NaN	NaN

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. “NaN” is defined as “Not a Number” when a parameter was not measured. “*” indicates concentrations calculated by difference, Total-Inorganic=Organic.)

Site	Date	DOC	TDN	DON*	TDP	DOP*
OM2	10/13/07	NaN	NaN	NaN	NaN	NaN
OCN2	10/13/07	17.63	6.06	4.50	NaN	NaN
OB	10/13/07	NaN	NaN	NaN	NaN	NaN
OM1	10/13/07	NaN	NaN	NaN	NaN	NaN
TM	10/13/07	NaN	NaN	NaN	NaN	NaN
OCN1	10/13/07	33.78	7.17	2.33	NaN	NaN
RM3	10/13/07	NaN	NaN	NaN	NaN	NaN
RM2	10/13/07	NaN	NaN	NaN	NaN	NaN
RM1	10/13/07	NaN	NaN	NaN	NaN	NaN
River	10/13/07	41.03	5.49	NaN	NaN	NaN
Stk1sfc	10/13/07	NaN	NaN	NaN	NaN	NaN
Stk1deep	10/13/07	NaN	NaN	NaN	NaN	NaN
Stk3sfc	10/13/07	NaN	NaN	NaN	NaN	NaN
Stk3deep	10/13/07	NaN	NaN	NaN	NaN	NaN
Stk6sfc	10/13/07	36.70	8.26	3.98	NaN	NaN
Stk6deep	10/13/07	23.54	7.18	3.75	NaN	NaN
Stk7sfc	10/13/07	38.19	8.84	2.78	NaN	NaN
Stk7deep	10/13/07	35.86	7.52	5.53	NaN	NaN
Stk8sfc	10/13/07	NaN	NaN	NaN	NaN	NaN
Stk8deep	10/13/07	NaN	NaN	NaN	NaN	NaN
Stk9sfc	10/13/07	36.53	9.32	5.41	NaN	NaN
Stk9deep	10/13/07	31.62	7.02	4.68	NaN	NaN
Stk13sfc	10/13/07	70.00	10.24	5.07	NaN	NaN
Stk13deep	10/13/07	72.08	11.00	8.56	NaN	NaN
Stk15sfc	10/13/07	60.43	8.86	5.52	NaN	NaN
Stk15deep	10/13/07	54.26	10.80	8.16	NaN	NaN
Stk16sfc	10/13/07	NaN	NaN	NaN	NaN	NaN
Stk16deep	10/13/07	NaN	NaN	NaN	NaN	NaN
Stk18sfc	10/13/07	49.60	9.00	3.24	NaN	NaN
Stk18deep	10/13/07	38.69	6.83	2.72	NaN	NaN

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. “NaN” is defined as “Not a Number” when a parameter was not measured. “*” indicates concentrations calculated by difference, Total-Inorganic=Organic.)

Storm 1

Site	Date	DOC	TDN	DON*	TDP	DOP*
River	11/4/07	327.54	23.67	10.05	2.57	1.66
Stk10sfc	11/4/07	583.99	100.79	39.83	2.25	1.32
Stk18sfc	11/4/07	399.14	38.32	17.08	3.10	2.17
OM2	11/5/07	NaN	NaN	NaN	0.34	0.30
OCN2	11/5/07	30.70	8.34	3.55	0.54	0.39
OB	11/5/07	NaN	NaN	NaN	0.62	0.15
OM1	11/5/07	NaN	NaN	NaN	0.64	0.18
TM	11/5/07	NaN	NaN	NaN	0.75	0.17
OCN1	11/5/07	38.36	9.21	4.77	0.64	0.15
RM3	11/5/07	NaN	NaN	NaN	0.75	NaN
RM2	11/5/07	NaN	NaN	NaN	0.75	NaN
RM1	11/5/07	NaN	NaN	NaN	1.12	0.60
River	11/5/07	263.59	17.43	8.12	1.15	0.24
Stk1sfc	11/5/07	NaN	NaN	NaN	1.37	0.46
Stk1deep	11/5/07	NaN	NaN	NaN	0.75	0.19
Stk3sfc	11/5/07	NaN	NaN	NaN	2.45	1.51
Stk3deep	11/5/07	NaN	NaN	NaN	1.06	0.18
Stk6sfc	11/5/07	383.82	57.20	21.61	1.23	0.30
Stk6deep	11/5/07	202.56	33.71	13.37	0.94	NaN
Stk7sfc	11/5/07	424.71	55.67	20.05	1.26	0.33
Stk7deep	11/5/07	219.04	35.14	6.07	0.87	NaN
Stk8sfc	11/5/07	NaN	NaN	NaN	NaN	NaN
Stk8deep	11/5/07	NaN	NaN	NaN	NaN	NaN
Stk9sfc	11/5/07	381.58	50.50	12.42	1.12	0.20
Stk9deep	11/5/07	158.09	25.64	8.86	0.66	0.19
Stk13sfc	11/5/07	313.63	53.80	19.73	1.26	0.47
Stk13deep	11/5/07	204.06	35.09	20.79	0.93	NaN
Stk15sfc	11/5/07	356.85	53.64	15.98	1.32	0.40
Stk15deep	11/5/07	204.72	36.18	16.54	0.89	NaN
Stk16sfc	11/5/07	NaN	NaN	NaN	NaN	NaN
Stk16deep	11/5/07	NaN	NaN	NaN	1.01	NaN
Stk18sfc	11/5/07	342.86	30.31	13.38	0.93	NaN
Stk18deep	11/5/07	335.95	43.16	9.17	1.07	0.16

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. “NaN” is defined as “Not a Number” when a parameter was not measured. “*” indicates concentrations calculated by difference, Total-Inorganic=Organic.)

Transects 1-4 Site	Date	DOC	TDN	DON*	TDP	DOP*
Stk6sfc	11/6/07	119.96	19.43	NaN	0.52	NaN
Stk7sfc	11/6/07	146.77	17.44	2.30	0.63	NaN
Stk9sfc	11/6/07	190.40	28.96	NaN	0.63	NaN
Stk11sfc	11/6/07	246.77	35.06	5.55	0.56	NaN
Stk13sfc	11/6/07	309.88	32.74	10.20	0.70	NaN
Stk18sfc	11/6/07	367.59	18.84	7.10	0.59	NaN
Stk6sfc	11/7/07	54.85	8.88	1.38	0.47	0.36
Stk7sfc	11/7/07	91.23	9.24	NaN	0.52	NaN
Stk9sfc	11/7/07	59.01	9.24	NaN	0.55	0.52
Stk11sfc	11/7/07	79.24	11.66	NaN	0.57	0.32
Stk13sfc	11/7/07	180.99	15.32	NaN	0.62	NaN
Stk18sfc	11/7/07	152.35	10.94	NaN	0.50	NaN
Stk6sfc	11/8/07	56.10	7.60	3.81	0.50	0.27
Stk7sfc	11/8/07	77.25	7.40	NaN	0.52	NaN
Stk9sfc	11/8/07	28.70	6.65	3.95	0.52	0.41
Stk11sfc	11/8/07	31.20	8.09	5.86	0.49	0.42
Stk13sfc	11/8/07	33.53	6.68	4.44	0.55	0.50
Stk18sfc	11/8/07	195.23	12.53	3.25	0.47	NaN
Stk6sfc	11/11/07	59.01	7.30	4.17	0.47	0.18
Stk7sfc	11/11/07	48.44	7.63	NaN	0.52	0.47
Stk9sfc	11/11/07	57.18	7.04	3.78	0.55	0.14
Stk11sfc	11/11/07	65.17	7.81	4.80	0.61	0.46
Stk13sfc	11/11/07	62.42	7.08	4.33	0.61	0.47
Stk18sfc	11/11/07	91.32	8.04	2.86	0.62	0.06

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. “NaN” is defined as “Not a Number” when a parameter was not measured. “*” indicates concentrations calculated by difference, Total-Inorganic=Organic.)

Site	Date	DOC	TDN	DON*	TDP	DOP*
OM2	11/17/07	NaN	NaN	NaN	0.56	0.45
OCN2	11/17/07	22.29	7.77	6.43	0.65	0.45
OB	11/17/07	NaN	NaN	NaN	0.61	0.39
OM1	11/17/07	NaN	NaN	NaN	0.71	0.44
TM	11/17/07	NaN	NaN	NaN	0.64	0.39
OCN1	11/17/07	20.79	6.74	4.67	0.59	0.43
RM3	11/17/07	NaN	NaN	NaN	0.62	NaN
RM2	11/17/07	NaN	NaN	NaN	0.58	NaN
RM1	11/17/07	NaN	NaN	NaN	0.51	NaN
River	11/17/07	66.25	6.30	NaN	0.66	NaN
Stk1sfc	11/17/07	NaN	NaN	NaN	0.63	0.56
Stk1deep	11/17/07	NaN	NaN	NaN	0.55	0.42
Stk3sfc	11/17/07	NaN	NaN	NaN	0.63	0.48
Stk3deep	11/17/07	NaN	NaN	NaN	0.64	0.45
Stk6sfc	11/17/07	58.51	7.01	2.44	0.66	0.30
Stk6deep	11/17/07	32.03	7.24	5.06	0.55	0.25
Stk7sfc	11/17/07	71.58	8.40	1.59	0.54	0.18
Stk7deep	11/17/07	35.78	7.32	6.47	0.61	0.30
Stk8sfc	11/17/07	NaN	NaN	NaN	0.58	0.33
Stk8deep	11/17/07	NaN	NaN	NaN	0.56	0.29
Stk9sfc	11/17/07	49.35	7.84	3.28	0.61	0.41
Stk9deep	11/17/07	36.70	7.12	6.35	0.63	0.39
Stk13sfc	11/17/07	54.85	9.01	5.42	0.59	0.48
Stk13deep	11/17/07	40.28	7.00	4.74	0.60	0.41
Stk15sfc	11/17/07	72.50	8.19	4.64	0.55	0.04
Stk15deep	11/17/07	42.69	8.38	6.84	0.58	0.33
Stk16sfc	11/17/07	NaN	NaN	NaN	0.51	NaN
Stk16deep	11/17/07	NaN	NaN	NaN	0.25	NaN
Stk18sfc	11/17/07	107.97	9.05	1.94	0.15	NaN
Stk18deep	11/17/07	27.87	6.28	5.32	0.25	NaN

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. “NaN” is defined as “Not a Number” when a parameter was not measured. “*” indicates concentrations calculated by difference, Total-Inorganic=Organic.)

Storm 2

Site	Date	DOC	TDN	DON*	TDP	DOP*
OM2	12/9/07	NaN	NaN	NaN	0.93	0.62
OCN2	12/9/07	NaN	NaN	NaN	0.81	0.59
OB	12/9/07	NaN	NaN	NaN	0.84	0.44
OM1	12/9/07	NaN	NaN	NaN	0.74	NaN
TM	12/9/07	NaN	NaN	NaN	0.89	NaN
OCN1	12/9/07	NaN	NaN	NaN	0.91	NaN
RM3	12/9/07	NaN	NaN	NaN	0.91	NaN
RM2	12/9/07	NaN	NaN	NaN	0.96	0.08
RM1	12/9/07	NaN	NaN	NaN	0.83	NaN
River	12/9/07	175.91	10.21	0.95	0.87	NaN
Stk1sfc	12/9/07	NaN	NaN	NaN	NaN	NaN
Stk1deep	12/9/07	NaN	NaN	NaN	0.79	0.40
Stk3sfc	12/9/07	NaN	NaN	NaN	0.91	0.21
Stk3deep	12/9/07	NaN	NaN	NaN	0.73	0.32
Stk6sfc	12/9/07	103.14	9.62	NaN	0.81	NaN
Stk6deep	12/9/07	NaN	NaN	NaN	0.81	0.41
Stk7sfc	12/9/07	89.73	8.13	1.37	0.70	NaN
Stk7deep	12/9/07	NaN	NaN	NaN	0.80	0.47
Stk8sfc	12/9/07	NaN	NaN	NaN	0.79	NaN
Stk8deep	12/9/07	NaN	NaN	NaN	0.65	0.38
Stk9sfc	12/9/07	112.63	8.33	2.51	0.85	NaN
Stk9deep	12/9/07	NaN	NaN	NaN	0.76	0.46
Stk13sfc	12/9/07	207.39	9.69	2.73	0.70	NaN
Stk13deep	12/9/07	NaN	NaN	NaN	0.78	0.67
Stk15sfc	12/9/07	255.68	11.89	4.24	0.84	NaN
Stk15deep	12/9/07	NaN	NaN	NaN	0.87	0.52
Stk16sfc	12/9/07	NaN	NaN	NaN	0.73	NaN
Stk16deep	12/9/07	NaN	NaN	NaN	NaN	NaN
Stk18sfc	12/9/07	282.74	14.64	3.83	0.84	NaN
Stk18deep	12/9/07	NaN	NaN	NaN	0.80	0.42

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. “NaN” is defined as “Not a Number” when a parameter was not measured. “*” indicates concentrations calculated by difference, Total-Inorganic=Organic.)

Site	Date	DOC	TDN	DON*	TDP	DOP*
OM2	1/12/08	NaN	NaN	NaN	NaN	NaN
OCN2	1/12/08	NaN	NaN	NaN	NaN	NaN
OB	1/12/08	NaN	NaN	NaN	NaN	NaN
OM1	1/12/08	NaN	NaN	NaN	NaN	NaN
TM	1/12/08	NaN	NaN	NaN	NaN	NaN
OCN1	1/12/08	NaN	NaN	NaN	NaN	NaN
RM3	1/12/08	NaN	NaN	NaN	NaN	NaN
RM2	1/12/08	NaN	NaN	NaN	NaN	NaN
RM1	1/12/08	NaN	NaN	NaN	NaN	NaN
River	1/12/08	NaN	NaN	NaN	NaN	NaN
Stk1sfc	1/12/08	NaN	NaN	NaN	NaN	NaN
Stk1deep	1/12/08	NaN	NaN	NaN	NaN	NaN
Stk3sfc	1/12/08	NaN	NaN	NaN	NaN	NaN
Stk3deep	1/12/08	NaN	NaN	NaN	NaN	NaN
Stk6sfc	1/12/08	NaN	NaN	NaN	NaN	NaN
Stk6deep	1/12/08	NaN	NaN	NaN	NaN	NaN
Stk7sfc	1/12/08	NaN	NaN	NaN	NaN	NaN
Stk7deep	1/12/08	NaN	NaN	NaN	NaN	NaN
Stk8sfc	1/12/08	NaN	NaN	NaN	NaN	NaN
Stk8deep	1/12/08	NaN	NaN	NaN	NaN	NaN
Stk9sfc	1/12/08	NaN	NaN	NaN	NaN	NaN
Stk9deep	1/12/08	NaN	NaN	NaN	NaN	NaN
Stk13sfc	1/12/08	NaN	NaN	NaN	NaN	NaN
Stk13deep	1/12/08	NaN	NaN	NaN	NaN	NaN
Stk15sfc	1/12/08	NaN	NaN	NaN	NaN	NaN
Stk15deep	1/12/08	NaN	NaN	NaN	NaN	NaN
Stk16sfc	1/12/08	NaN	NaN	NaN	NaN	NaN
Stk16deep	1/12/08	NaN	NaN	NaN	NaN	NaN
Stk18sfc	1/12/08	NaN	NaN	NaN	NaN	NaN
Stk18deep	1/12/08	NaN	NaN	NaN	NaN	NaN

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. "NaN" is defined as "Not a Number" when a parameter was not measured. "*" indicates concentrations calculated by difference, Total-Inorganic=Organic.)

Site	Date	DOC	TDN	DON*	TDP	DOP*
OM2	2/16/08	NaN	NaN	NaN	NaN	NaN
OCN2	2/16/08	NaN	NaN	NaN	NaN	NaN
OB	2/16/08	NaN	NaN	NaN	NaN	NaN
OM1	2/16/08	NaN	NaN	NaN	NaN	NaN
TM	2/16/08	NaN	NaN	NaN	NaN	NaN
OCN1	2/16/08	NaN	NaN	NaN	NaN	NaN
RM3	2/16/08	NaN	NaN	NaN	NaN	NaN
RM2	2/16/08	NaN	NaN	NaN	NaN	NaN
RM1	2/16/08	NaN	NaN	NaN	NaN	NaN
River	2/16/08	NaN	NaN	NaN	NaN	NaN
Stk1sfc	2/16/08	NaN	NaN	NaN	NaN	NaN
Stk1deep	2/16/08	NaN	NaN	NaN	NaN	NaN
Stk3sfc	2/16/08	NaN	NaN	NaN	NaN	NaN
Stk3deep	2/16/08	NaN	NaN	NaN	NaN	NaN
Stk6sfc	2/16/08	NaN	NaN	NaN	NaN	NaN
Stk6deep	2/16/08	NaN	NaN	NaN	NaN	NaN
Stk7sfc	2/16/08	NaN	NaN	NaN	NaN	NaN
Stk7deep	2/16/08	NaN	NaN	NaN	NaN	NaN
Stk8sfc	2/16/08	NaN	NaN	NaN	NaN	NaN
Stk8deep	2/16/08	NaN	NaN	NaN	NaN	NaN
Stk9sfc	2/16/08	NaN	NaN	NaN	NaN	NaN
Stk9deep	2/16/08	NaN	NaN	NaN	NaN	NaN
Stk13sfc	2/16/08	NaN	NaN	NaN	NaN	NaN
Stk13deep	2/16/08	NaN	NaN	NaN	NaN	NaN
Stk15sfc	2/16/08	NaN	NaN	NaN	NaN	NaN
Stk15deep	2/16/08	NaN	NaN	NaN	NaN	NaN
Stk16sfc	2/16/08	NaN	NaN	NaN	NaN	NaN
Stk16deep	2/16/08	NaN	NaN	NaN	NaN	NaN
Stk18sfc	2/16/08	NaN	NaN	NaN	NaN	NaN
Stk18deep	2/16/08	NaN	NaN	NaN	NaN	NaN

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. “NaN” is defined as “Not a Number” when a parameter was not measured. “*” indicates concentrations calculated by difference, Total-Inorganic=Organic.)

Site	Date	DOC	TDN	DON*	TDP	DOP*
OM2	3/15/08	NaN	NaN	NaN	NaN	NaN
OCN2	3/15/08	NaN	NaN	NaN	NaN	NaN
OB	3/15/08	NaN	NaN	NaN	NaN	NaN
OM1	3/15/08	NaN	NaN	NaN	NaN	NaN
TM	3/15/08	NaN	NaN	NaN	NaN	NaN
OCN1	3/15/08	NaN	NaN	NaN	NaN	NaN
RM3	3/15/08	NaN	NaN	NaN	NaN	NaN
RM2	3/15/08	NaN	NaN	NaN	NaN	NaN
RM1	3/15/08	NaN	NaN	NaN	NaN	NaN
River	3/15/08	NaN	NaN	NaN	NaN	NaN
Stk1sfc	3/15/08	NaN	NaN	NaN	NaN	NaN
Stk1deep	3/15/08	NaN	NaN	NaN	NaN	NaN
Stk3sfc	3/15/08	NaN	NaN	NaN	NaN	NaN
Stk3deep	3/15/08	NaN	NaN	NaN	NaN	NaN
Stk6sfc	3/15/08	NaN	NaN	NaN	NaN	NaN
Stk6deep	3/15/08	NaN	NaN	NaN	NaN	NaN
Stk7sfc	3/15/08	NaN	NaN	NaN	NaN	NaN
Stk7deep	3/15/08	NaN	NaN	NaN	NaN	NaN
Stk8sfc	3/15/08	NaN	NaN	NaN	NaN	NaN
Stk8deep	3/15/08	NaN	NaN	NaN	NaN	NaN
Stk9sfc	3/15/08	NaN	NaN	NaN	NaN	NaN
Stk9deep	3/15/08	NaN	NaN	NaN	NaN	NaN
Stk13sfc	3/15/08	NaN	NaN	NaN	NaN	NaN
Stk13deep	3/15/08	NaN	NaN	NaN	NaN	NaN
Stk15sfc	3/15/08	NaN	NaN	NaN	NaN	NaN
Stk15deep	3/15/08	NaN	NaN	NaN	NaN	NaN
Stk16sfc	3/15/08	NaN	NaN	NaN	NaN	NaN
Stk16deep	3/15/08	NaN	NaN	NaN	NaN	NaN
Stk18sfc	3/15/08	NaN	NaN	NaN	NaN	NaN
Stk18deep	3/15/08	NaN	NaN	NaN	NaN	NaN

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. "NaN" is defined as "Not a Number" when a parameter was not measured. "*" indicates concentrations calculated by difference, Total-Inorganic=Organic.)

Site	Date	DOC	TDN	DON*	TDP	DOP*
OM2	4/19/08	NaN	NaN	NaN	NaN	NaN
OCN2	4/19/08	NaN	NaN	NaN	NaN	NaN
OB	4/19/08	NaN	NaN	NaN	NaN	NaN
OM1	4/19/08	NaN	NaN	NaN	NaN	NaN
TM	4/19/08	NaN	NaN	NaN	NaN	NaN
OCN1	4/19/08	NaN	NaN	NaN	NaN	NaN
RM3	4/19/08	NaN	NaN	NaN	NaN	NaN
RM2	4/19/08	NaN	NaN	NaN	NaN	NaN
RM1	4/19/08	NaN	NaN	NaN	NaN	NaN
River	4/19/08	NaN	NaN	NaN	NaN	NaN
Stk1sfc	4/19/08	NaN	NaN	NaN	NaN	NaN
Stk1deep	4/19/08	NaN	NaN	NaN	NaN	NaN
Stk3sfc	4/19/08	NaN	NaN	NaN	NaN	NaN
Stk3deep	4/19/08	NaN	NaN	NaN	NaN	NaN
Stk6sfc	4/19/08	NaN	NaN	NaN	NaN	NaN
Stk6deep	4/19/08	NaN	NaN	NaN	NaN	NaN
Stk7sfc	4/19/08	NaN	NaN	NaN	NaN	NaN
Stk7deep	4/19/08	NaN	NaN	NaN	NaN	NaN
Stk8sfc	4/19/08	NaN	NaN	NaN	NaN	NaN
Stk8deep	4/19/08	NaN	NaN	NaN	NaN	NaN
Stk9sfc	4/19/08	NaN	NaN	NaN	NaN	NaN
Stk9deep	4/19/08	NaN	NaN	NaN	NaN	NaN
Stk13sfc	4/19/08	NaN	NaN	NaN	NaN	NaN
Stk13deep	4/19/08	NaN	NaN	NaN	NaN	NaN
Stk15sfc	4/19/08	NaN	NaN	NaN	NaN	NaN
Stk15deep	4/19/08	NaN	NaN	NaN	NaN	NaN
Stk16sfc	4/19/08	NaN	NaN	NaN	NaN	NaN
Stk16deep	4/19/08	NaN	NaN	NaN	NaN	NaN
Stk18sfc	4/19/08	NaN	NaN	NaN	NaN	NaN
Stk18deep	4/19/08	NaN	NaN	NaN	NaN	NaN

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. “NaN” is defined as “Not a Number” when a parameter was not measured. “*” indicates concentrations calculated by difference, Total-Inorganic=Organic.)

Site	Date	DOC	TDN	DON*	TDP	DOP*
OM2	5/17/08	NaN	NaN	NaN	NaN	NaN
OCN2	5/17/08	NaN	NaN	NaN	NaN	NaN
OB	5/17/08	NaN	NaN	NaN	NaN	NaN
OM1	5/17/08	NaN	NaN	NaN	NaN	NaN
TM	5/17/08	NaN	NaN	NaN	NaN	NaN
OCN1	5/17/08	NaN	NaN	NaN	NaN	NaN
RM3	5/17/08	NaN	NaN	NaN	NaN	NaN
RM2	5/17/08	NaN	NaN	NaN	NaN	NaN
RM1	5/17/08	NaN	NaN	NaN	NaN	NaN
River	5/17/08	NaN	NaN	NaN	NaN	NaN
Stk1sfc	5/17/08	NaN	NaN	NaN	NaN	NaN
Stk1deep	5/17/08	NaN	NaN	NaN	NaN	NaN
Stk3sfc	5/17/08	NaN	NaN	NaN	NaN	NaN
Stk3deep	5/17/08	NaN	NaN	NaN	NaN	NaN
Stk6sfc	5/17/08	NaN	NaN	NaN	NaN	NaN
Stk6deep	5/17/08	NaN	NaN	NaN	NaN	NaN
Stk7sfc	5/17/08	NaN	NaN	NaN	NaN	NaN
Stk7deep	5/17/08	NaN	NaN	NaN	NaN	NaN
Stk8sfc	5/17/08	NaN	NaN	NaN	NaN	NaN
Stk8deep	5/17/08	NaN	NaN	NaN	NaN	NaN
Stk9sfc	5/17/08	NaN	NaN	NaN	NaN	NaN
Stk9deep	5/17/08	NaN	NaN	NaN	NaN	NaN
Stk13sfc	5/17/08	NaN	NaN	NaN	NaN	NaN
Stk13deep	5/17/08	NaN	NaN	NaN	NaN	NaN
Stk15sfc	5/17/08	NaN	NaN	NaN	NaN	NaN
Stk15deep	5/17/08	NaN	NaN	NaN	NaN	NaN
Stk16sfc	5/17/08	NaN	NaN	NaN	NaN	NaN
Stk16deep	5/17/08	NaN	NaN	NaN	NaN	NaN
Stk18sfc	5/17/08	NaN	NaN	NaN	NaN	NaN
Stk18deep	5/17/08	NaN	NaN	NaN	NaN	NaN

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. “NaN” is defined as “Not a Number” when a parameter was not measured. “*” indicates concentrations calculated by difference, Total-Inorganic=Organic.)

Storm 4

Site	Date	DOC	TDN	DON*	TDP	DOP*
OM2	6/14/08	NaN	NaN	NaN	0.33	NaN
OCN2	6/14/08	160.93	7.11	NaN	0.66	NaN
OB	6/14/08	NaN	NaN	NaN	1.01	0.22
OM1	6/14/08	NaN	NaN	NaN	0.97	NaN
TM	6/14/08	NaN	NaN	NaN	0.41	NaN
OCN1	6/14/08	266.59	8.82	3.09	0.86	NaN
RM3	6/14/08	NaN	NaN	NaN	0.38	NaN
RM2	6/14/08	NaN	NaN	NaN	0.25	NaN
RM1	6/14/08	NaN	NaN	NaN	0.29	NaN
River	6/14/08	181.16	5.46	NaN	0.41	NaN
Stk1sfc	6/14/08	NaN	NaN	NaN	0.40	NaN
Stk1deep	6/14/08	NaN	NaN	NaN	0.31	NaN
Stk3sfc	6/14/08	NaN	NaN	NaN	0.35	0.31
Stk3deep	6/14/08	NaN	NaN	NaN	0.34	NaN
Stk6sfc	6/14/08	270.42	16.10	6.62	0.49	NaN
Stk6deep	6/14/08	221.63	9.23	4.87	0.35	NaN
Stk7sfc	6/14/08	280.49	14.01	7.61	NaN	NaN
Stk7deep	6/14/08	333.78	12.41	9.64	0.43	NaN
Stk8sfc	6/14/08	NaN	NaN	NaN	0.57	NaN
Stk8deep	6/14/08	NaN	NaN	NaN	0.35	NaN
Stk9sfc	6/14/08	385.66	22.08	11.82	0.64	NaN
Stk9deep	6/14/08	231.53	5.48	3.20	0.41	0.19
Stk13sfc	6/14/08	233.62	13.90	NaN	0.62	NaN
Stk13deep	6/14/08	271.58	20.15	16.59	0.43	NaN
Stk15sfc	6/14/08	247.77	14.71	NaN	0.75	NaN
Stk15deep	6/14/08	270.33	11.40	6.59	0.40	NaN
Stk16sfc	6/14/08	NaN	NaN	NaN	0.75	NaN
Stk16deep	6/14/08	NaN	NaN	NaN	0.48	0.15
Stk18sfc	6/14/08	NaN	10.25	NaN	0.61	NaN
Stk18deep	6/14/08	204.89	8.88	NaN	NaN	NaN

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. “NaN” is defined as “Not a Number” when a parameter was not measured. “*” indicates concentrations calculated by difference, Total-Inorganic=Organic.)

Site	Date	DOC	TDN	DON*	TDP	DOP*
OM2	7/26/08	NaN	NaN	NaN	NaN	NaN
OCN2	7/26/08	NaN	NaN	NaN	NaN	NaN
OB	7/26/08	NaN	NaN	NaN	NaN	NaN
OM1	7/26/08	NaN	NaN	NaN	NaN	NaN
TM	7/26/08	NaN	NaN	NaN	NaN	NaN
OCN1	7/26/08	NaN	NaN	NaN	NaN	NaN
RM3	7/26/08	NaN	NaN	NaN	NaN	NaN
RM2	7/26/08	NaN	NaN	NaN	NaN	NaN
RM1	7/26/08	NaN	NaN	NaN	NaN	NaN
River	7/26/08	44.61	4.49	NaN	NaN	NaN
Stk1sfc	7/26/08	NaN	NaN	NaN	NaN	NaN
Stk1deep	7/26/08	NaN	NaN	NaN	NaN	NaN
Stk3sfc	7/26/08	NaN	NaN	NaN	NaN	NaN
Stk3deep	7/26/08	NaN	NaN	NaN	NaN	NaN
Stk6sfc	7/26/08	68.09	8.10	5.07	NaN	NaN
Stk6deep	7/26/08	NaN	NaN	NaN	NaN	NaN
Stk7sfc	7/26/08	93.98	10.48	6.55	NaN	NaN
Stk7deep	7/26/08	NaN	NaN	NaN	NaN	NaN
Stk8sfc	7/26/08	NaN	NaN	NaN	NaN	NaN
Stk8deep	7/26/08	NaN	NaN	NaN	NaN	NaN
Stk9sfc	7/26/08	64.01	8.66	6.71	NaN	NaN
Stk9deep	7/26/08	NaN	NaN	NaN	NaN	NaN
Stk13sfc	7/26/08	68.34	9.82	NaN	NaN	NaN
Stk13deep	7/26/08	NaN	NaN	NaN	NaN	NaN
Stk15sfc	7/26/08	119.13	10.04	4.33	NaN	NaN
Stk15deep	7/26/08	NaN	NaN	NaN	NaN	NaN
Stk16sfc	7/26/08	NaN	NaN	NaN	NaN	NaN
Stk16deep	7/26/08	NaN	NaN	NaN	NaN	NaN
Stk18sfc	7/26/08	95.56	7.60	1.89	NaN	NaN
Stk18deep	7/26/08	NaN	NaN	NaN	NaN	NaN

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. "NaN" is defined as "Not a Number" when a parameter was not measured. "*" indicates concentrations calculated by difference, Total-Inorganic=Organic.)

Site	Date	DOC	TDN	DON*	TDP	DOP*
OM2	8/30/08	NaN	NaN	NaN	0.70	0.50
OCN2	8/30/08	42.02	9.20	8.76	0.97	0.81
OB	8/30/08	NaN	NaN	NaN	0.84	0.71
OM1	8/30/08	NaN	NaN	NaN	0.76	0.56
TM	8/30/08	NaN	NaN	NaN	0.70	0.29
OCN1	8/30/08	46.52	7.09	3.58	0.64	0.23
RM3	8/30/08	NaN	NaN	NaN	1.17	NaN
RM2	8/30/08	NaN	NaN	NaN	0.83	NaN
RM1	8/30/08	NaN	NaN	NaN	0.56	NaN
River	8/30/08	48.85	4.01	NaN	0.66	NaN
Stk1sfc	8/30/08	NaN	NaN	NaN	1.17	1.02
Stk1deep	8/30/08	NaN	NaN	NaN	0.84	0.62
Stk3sfc	8/30/08	NaN	NaN	NaN	0.58	0.42
Stk3deep	8/30/08	NaN	NaN	NaN	0.41	0.26
Stk6sfc	8/30/08	122.71	6.17	NaN	0.53	0.15
Stk6deep	8/30/08	48.94	8.00	6.04	0.66	0.32
Stk7sfc	8/30/08	67.59	7.76	NaN	0.50	NaN
Stk7deep	8/30/08	63.09	6.75	6.31	0.55	0.15
Stk8sfc	8/30/08	NaN	NaN	NaN	0.66	0.32
Stk8deep	8/30/08	NaN	NaN	NaN	0.62	0.30
Stk9sfc	8/30/08	41.69	6.95	5.11	0.68	0.49
Stk9deep	8/30/08	48.60	8.23	7.44	0.95	0.69
Stk13sfc	8/30/08	53.68	8.01	5.93	0.50	0.31
Stk13deep	8/30/08	205.64	8.75	7.55	0.69	0.43
Stk15sfc	8/30/08	58.84	9.61	7.42	0.67	0.53
Stk15deep	8/30/08	344.11	7.69	6.38	1.00	0.80
Stk16sfc	8/30/08	NaN	NaN	NaN	0.67	0.20
Stk16deep	8/30/08	NaN	NaN	NaN	0.68	0.48
Stk18sfc	8/30/08	65.01	8.06	4.22	0.71	0.53
Stk18deep	8/30/08	45.11	9.11	6.48	0.90	0.06

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. “NaN” is defined as “Not a Number” when a parameter was not measured. “*” indicates concentrations calculated by difference, Total-Inorganic=Organic.)

Appendix 5.3. Inorganic and organic nutrient ratios for surface and near-bottom water samples.

Site	Date	DIN:DIP	DOC:DON	DOC:DOP	DON:DOP
OM2	8/11/07	12.61	NaN	NaN	NaN
OCN2	8/11/07	4.11	5.70	79.03	13.86
OB	8/11/07	20.44	NaN	NaN	NaN
OM1	8/11/07	12.57	NaN	NaN	NaN
TM	8/11/07	15.49	NaN	NaN	NaN
OCN1	8/11/07	12.17	6.52	89.09	13.67
RM3	8/11/07	30.49	NaN	NaN	NaN
RM2	8/11/07	7.02	NaN	NaN	NaN
RM1	8/11/07	10.39	NaN	NaN	NaN
River	8/11/07	10.87	NaN	NaN	NaN
Stk1sfc	8/11/07	12.72	NaN	NaN	NaN
Stk1deep	8/11/07	10.38	NaN	NaN	NaN
Stk3sfc	8/11/07	9.49	NaN	NaN	NaN
Stk3deep	8/11/07	12.00	NaN	NaN	NaN
Stk6sfc	8/11/07	10.34	16.09	256.54	15.95
Stk6deep	8/11/07	8.60	8.18	130.82	15.99
Stk7sfc	8/11/07	8.73	11.63	136.27	11.72
Stk7deep	8/11/07	3.80	5.39	111.84	20.74
Stk8sfc	8/11/07	12.58	NaN	NaN	NaN
Stk8deep	8/11/07	6.07	NaN	NaN	NaN
Stk9sfc	8/11/07	14.66	2.93	28.51	9.73
Stk9deep	8/11/07	7.44	10.62	221.00	20.82
Stk13sfc	8/11/07	10.15	10.18	153.67	15.10
Stk13deep	8/11/07	7.52	7.05	169.29	24.01
Stk15sfc	8/11/07	8.92	8.00	117.71	14.72
Stk15deep	8/11/07	NaN	NaN	NaN	NaN
Stk16sfc	8/11/07	8.49	NaN	NaN	NaN
Stk16deep	8/11/07	6.01	NaN	NaN	NaN
Stk18sfc	8/11/07	15.17	27.78	227.28	8.18
Stk18deep	8/11/07	NaN	NaN	NaN	NaN

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. “NaN” is defined as “Not a Number” when a parameter was not measured.)

Site	Date	DIN:DIP	DOC:DON	DOC:DOP	DON:DOP
OM2	9/15/07	15.54	NaN	NaN	NaN
OCN2	9/15/07	8.24	NaN	NaN	NaN
OB	9/15/07	15.96	NaN	NaN	NaN
OM1	9/15/07	11.87	NaN	NaN	NaN
TM	9/15/07	12.95	NaN	NaN	NaN
OCN1	9/15/07	13.35	NaN	NaN	NaN
RM3	9/15/07	12.41	NaN	NaN	NaN
RM2	9/15/07	7.16	NaN	NaN	NaN
RM1	9/15/07	9.06	NaN	NaN	NaN
River	9/15/07	5.66	NaN	NaN	NaN
Stk1sfc	9/15/07	14.84	NaN	NaN	NaN
Stk1deep	9/15/07	7.37	NaN	NaN	NaN
Stk3sfc	9/15/07	11.73	NaN	NaN	NaN
Stk3deep	9/15/07	8.28	NaN	NaN	NaN
Stk6sfc	9/15/07	8.27	NaN	NaN	NaN
Stk6deep	9/15/07	1.98	NaN	NaN	NaN
Stk7sfc	9/15/07	10.82	NaN	NaN	NaN
Stk7deep	9/15/07	3.29	NaN	NaN	NaN
Stk8sfc	9/15/07	18.96	NaN	NaN	NaN
Stk8deep	9/15/07	1.52	NaN	NaN	NaN
Stk9sfc	9/15/07	19.09	NaN	NaN	NaN
Stk9deep	9/15/07	7.84	NaN	NaN	NaN
Stk13sfc	9/15/07	13.50	NaN	NaN	NaN
Stk13deep	9/15/07	6.53	NaN	NaN	NaN
Stk15sfc	9/15/07	17.62	NaN	NaN	NaN
Stk15deep	9/15/07	3.46	NaN	NaN	NaN
Stk16sfc	9/15/07	18.53	NaN	NaN	NaN
Stk16deep	9/15/07	4.74	NaN	NaN	NaN
Stk18sfc	9/15/07	5.11	NaN	NaN	NaN
Stk18deep	9/15/07	4.68	NaN	NaN	NaN

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. “NaN” is defined as “Not a Number” when a parameter was not measured.)

Site	Date	DIN:DIP	DOC:DON	DOC:DOP	DON:DOP
OM2	10/13/07	NaN	NaN	NaN	NaN
OCN2	10/13/07	12.98	3.92	NaN	NaN
OB	10/13/07	49.25	NaN	NaN	NaN
OM1	10/13/07	16.59	NaN	NaN	NaN
TM	10/13/07	15.63	NaN	NaN	NaN
OCN1	10/13/07	11.07	14.51	NaN	NaN
RM3	10/13/07	12.06	NaN	NaN	NaN
RM2	10/13/07	9.61	NaN	NaN	NaN
RM1	10/13/07	10.85	NaN	NaN	NaN
River	10/13/07	9.06	NaN	NaN	NaN
Stk1sfc	10/13/07	30.90	NaN	NaN	NaN
Stk1deep	10/13/07	4.23	NaN	NaN	NaN
Stk3sfc	10/13/07	50.97	NaN	NaN	NaN
Stk3deep	10/13/07	8.92	NaN	NaN	NaN
Stk6sfc	10/13/07	17.67	9.22	NaN	NaN
Stk6deep	10/13/07	11.70	6.28	NaN	NaN
Stk7sfc	10/13/07	22.35	13.74	NaN	NaN
Stk7deep	10/13/07	7.67	6.49	NaN	NaN
Stk8sfc	10/13/07	14.22	NaN	NaN	NaN
Stk8deep	10/13/07	11.58	NaN	NaN	NaN
Stk9sfc	10/13/07	24.92	6.75	NaN	NaN
Stk9deep	10/13/07	8.34	6.76	NaN	NaN
Stk13sfc	10/13/07	11.22	13.82	NaN	NaN
Stk13deep	10/13/07	5.43	8.42	NaN	NaN
Stk15sfc	10/13/07	7.69	10.94	NaN	NaN
Stk15deep	10/13/07	6.08	6.65	NaN	NaN
Stk16sfc	10/13/07	11.80	NaN	NaN	NaN
Stk16deep	10/13/07	8.80	NaN	NaN	NaN
Stk18sfc	10/13/07	13.68	15.31	NaN	NaN
Stk18deep	10/13/07	11.97	14.23	NaN	NaN

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. “NaN” is defined as “Not a Number” when a parameter was not measured.)

Storm 1

Site	Date	DIN:DIP	DOC:DON	DOC:DOP	DON:DOP
River	11/4/07	14.96	32.58	197.21	6.05
Stk10sfc	11/4/07	65.85	14.66	442.49	30.18
Stk18sfc	11/4/07	22.68	23.37	184.34	7.89
OM2	11/5/07	NaN	NaN	NaN	NaN
OCN2	11/5/07	32.01	8.64	79.18	9.16
OB	11/5/07	10.79	NaN	NaN	NaN
OM1	11/5/07	12.64	NaN	NaN	NaN
TM	11/5/07	14.86	NaN	NaN	NaN
OCN1	11/5/07	9.01	8.05	253.81	31.55
RM3	11/5/07	21.04	NaN	NaN	NaN
RM2	11/5/07	19.03	NaN	NaN	NaN
RM1	11/5/07	70.72	NaN	NaN	NaN
River	11/5/07	10.25	32.47	1082.44	33.34
Stk1sfc	11/5/07	36.46	NaN	NaN	NaN
Stk1deep	11/5/07	44.73	NaN	NaN	NaN
Stk3sfc	11/5/07	42.10	NaN	NaN	NaN
Stk3deep	11/5/07	28.88	NaN	NaN	NaN
Stk6sfc	11/5/07	38.38	17.76	1283.97	72.29
Stk6deep	11/5/07	15.55	15.15	NaN	NaN
Stk7sfc	11/5/07	38.23	21.18	1296.29	61.19
Stk7deep	11/5/07	29.97	36.08	NaN	NaN
Stk8sfc	11/5/07	NaN	NaN	NaN	NaN
Stk8deep	11/5/07	NaN	NaN	NaN	NaN
Stk9sfc	11/5/07	41.21	30.73	1923.89	62.60
Stk9deep	11/5/07	35.51	17.84	828.90	46.46
Stk13sfc	11/5/07	42.98	15.90	665.73	41.87
Stk13deep	11/5/07	7.27	9.82	NaN	NaN
Stk15sfc	11/5/07	40.82	22.33	893.88	40.04
Stk15deep	11/5/07	17.13	12.37	NaN	NaN
Stk16sfc	11/5/07	NaN	NaN	NaN	NaN
Stk16deep	11/5/07	20.83	NaN	NaN	NaN
Stk18sfc	11/5/07	18.11	25.63	NaN	NaN
Stk18deep	11/5/07	37.16	36.65	2109.85	57.56

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. “NaN” is defined as “Not a Number” when a parameter was not measured.)

Transects 1-4 Site	**Date**	**DIN:DIP**	**DOC:DON**	**DOC:DOP**	**DON:DOP**
Stk6sfc	11/6/07	NaN	NaN	NaN	NaN
Stk7sfc	11/6/07	19.51	63.78	NaN	NaN
Stk9sfc	11/6/07	50.74	NaN	NaN	NaN
Stk11sfc	11/6/07	36.92	44.45	NaN	NaN
Stk13sfc	11/6/07	26.85	30.38	NaN	NaN
Stk18sfc	11/6/07	12.62	51.80	NaN	NaN
Stk6sfc	11/7/07	71.73	39.89	150.58	3.78
Stk7sfc	11/7/07	20.54	NaN	NaN	NaN
Stk9sfc	11/7/07	NaN	NaN	113.12	NaN
Stk11sfc	11/7/07	48.53	NaN	245.04	NaN
Stk13sfc	11/7/07	23.38	NaN	NaN	NaN
Stk18sfc	11/7/07	NaN	NaN	NaN	NaN
Stk6sfc	11/8/07	16.18	14.71	211.55	14.38
Stk7sfc	11/8/07	11.82	NaN	NaN	NaN
Stk9sfc	11/8/07	23.57	7.27	70.54	9.70
Stk11sfc	11/8/07	31.42	5.32	74.88	14.07
Stk13sfc	11/8/07	43.88	7.56	67.02	8.87
Stk18sfc	11/8/07	10.12	60.07	NaN	NaN
Stk6sfc	11/11/07	10.88	14.16	321.25	22.68
Stk7sfc	11/11/07	NaN	NaN	102.27	NaN
Stk9sfc	11/11/07	7.95	15.14	422.79	27.92
Stk11sfc	11/11/07	20.25	13.58	140.95	10.38
Stk13sfc	11/11/07	19.18	14.41	132.58	9.20
Stk18sfc	11/11/07	9.23	31.93	1424.30	44.60

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. “NaN” is defined as “Not a Number” when a parameter was not measured.)

Site	Date	DIN:DIP	DOC:DON	DOC:DOP	DON:DOP
OM2	11/17/07	8.15	NaN	NaN	NaN
OCN2	11/17/07	6.61	3.46	49.64	14.33
OB	11/17/07	6.91	NaN	NaN	NaN
OM1	11/17/07	7.21	NaN	NaN	NaN
TM	11/17/07	10.06	NaN	NaN	NaN
OCN1	11/17/07	12.45	4.45	48.81	10.96
RM3	11/17/07	6.34	NaN	NaN	NaN
RM2	11/17/07	7.33	NaN	NaN	NaN
RM1	11/17/07	15.43	NaN	NaN	NaN
River	11/17/07	12.05	NaN	NaN	NaN
Stk1sfc	11/17/07	33.99	NaN	NaN	NaN
Stk1deep	11/17/07	12.52	NaN	NaN	NaN
Stk3sfc	11/17/07	22.46	NaN	NaN	NaN
Stk3deep	11/17/07	11.93	NaN	NaN	NaN
Stk6sfc	11/17/07	12.75	23.94	193.76	8.09
Stk6deep	11/17/07	7.21	6.33	129.90	20.51
Stk7sfc	11/17/07	18.83	45.12	395.18	8.76
Stk7deep	11/17/07	2.81	5.53	117.35	21.22
Stk8sfc	11/17/07	17.43	NaN	NaN	NaN
Stk8deep	11/17/07	7.09	NaN	NaN	NaN
Stk9sfc	11/17/07	21.94	15.07	121.75	8.08
Stk9deep	11/17/07	3.25	5.78	93.98	16.26
Stk13sfc	11/17/07	30.68	10.11	115.39	11.41
Stk13deep	11/17/07	12.00	8.50	99.02	11.64
Stk15sfc	11/17/07	6.97	15.61	1875.71	120.18
Stk15deep	11/17/07	5.97	6.24	130.80	20.96
Stk16sfc	11/17/07	8.03	NaN	NaN	NaN
Stk16deep	11/17/07	12.07	NaN	NaN	NaN
Stk18sfc	11/17/07	8.76	55.73	NaN	NaN
Stk18deep	11/17/07	3.74	5.24	NaN	NaN

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. “NaN” is defined as “Not a Number” when a parameter was not measured.)

Storm 2

Site	Date	DIN:DIP	DOC:DON	DOC:DOP	DON:DOP
OM2	12/9/07	17.18	NaN	NaN	NaN
OCN2	12/9/07	19.60	NaN	NaN	NaN
OB	12/9/07	54.81	NaN	NaN	NaN
OM1	12/9/07	15.53	NaN	NaN	NaN
TM	12/9/07	10.30	NaN	NaN	NaN
OCN1	12/9/07	12.77	NaN	NaN	NaN
RM3	12/9/07	16.70	NaN	NaN	NaN
RM2	12/9/07	8.97	NaN	NaN	NaN
RM1	12/9/07	6.94	NaN	NaN	NaN
River	12/9/07	10.22	184.46	NaN	NaN
Stk1sfc	12/9/07	9.40	NaN	NaN	NaN
Stk1deep	12/9/07	8.70	NaN	NaN	NaN
Stk3sfc	12/9/07	13.01	NaN	NaN	NaN
Stk3deep	12/9/07	3.15	NaN	NaN	NaN
Stk6sfc	12/9/07	12.61	NaN	NaN	5.42
Stk6deep	12/9/07	13.96	NaN	NaN	NaN
Stk7sfc	12/9/07	10.12	65.61	NaN	42.53
Stk7deep	12/9/07	12.01	NaN	NaN	NaN
Stk8sfc	12/9/07	8.71	NaN	NaN	NaN
Stk8deep	12/9/07	11.53	NaN	NaN	NaN
Stk9sfc	12/9/07	7.90	44.81	NaN	22.16
Stk9deep	12/9/07	4.97	NaN	NaN	NaN
Stk13sfc	12/9/07	8.41	75.84	NaN	NaN
Stk13deep	12/9/07	34.64	NaN	NaN	NaN
Stk15sfc	12/9/07	9.24	60.31	NaN	NaN
Stk15deep	12/9/07	27.84	NaN	NaN	NaN
Stk16sfc	12/9/07	8.34	NaN	NaN	NaN
Stk16deep	12/9/07	18.29	NaN	NaN	NaN
Stk18sfc	12/9/07	11.63	73.76	NaN	NaN
Stk18deep	12/9/07	11.99	NaN	NaN	NaN

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. “NaN” is defined as “Not a Number” when a parameter was not measured.)

Site	Date	DIN:DIP	DOC:DON	DOC:DOP	DON:DOP
OM2	1/12/08	6.42	NaN	NaN	NaN
OCN2	1/12/08	9.57	NaN	NaN	NaN
OB	1/12/08	63.19	NaN	NaN	NaN
OM1	1/12/08	8.51	NaN	NaN	NaN
TM	1/12/08	63.91	NaN	NaN	NaN
OCN1	1/12/08	6.11	NaN	NaN	NaN
RM3	1/12/08	10.29	NaN	NaN	NaN
RM2	1/12/08	11.15	NaN	NaN	NaN
RM1	1/12/08	42.02	NaN	NaN	NaN
River	1/12/08	8.46	NaN	NaN	NaN
Stk1sfc	1/12/08	5.66	NaN	NaN	NaN
Stk1deep	1/12/08	5.58	NaN	NaN	NaN
Stk3sfc	1/12/08	7.56	NaN	NaN	NaN
Stk3deep	1/12/08	0.39	NaN	NaN	NaN
Stk6sfc	1/12/08	11.61	NaN	NaN	NaN
Stk6deep	1/12/08	8.25	NaN	NaN	NaN
Stk7sfc	1/12/08	7.22	NaN	NaN	NaN
Stk7deep	1/12/08	14.54	NaN	NaN	NaN
Stk8sfc	1/12/08	10.65	NaN	NaN	NaN
Stk8deep	1/12/08	9.18	NaN	NaN	NaN
Stk9sfc	1/12/08	14.18	NaN	NaN	NaN
Stk9deep	1/12/08	5.60	NaN	NaN	NaN
Stk13sfc	1/12/08	8.14	NaN	NaN	NaN
Stk13deep	1/12/08	7.93	NaN	NaN	NaN
Stk15sfc	1/12/08	11.39	NaN	NaN	NaN
Stk15deep	1/12/08	6.63	NaN	NaN	NaN
Stk16sfc	1/12/08	6.36	NaN	NaN	NaN
Stk16deep	1/12/08	6.20	NaN	NaN	NaN
Stk18sfc	1/12/08	8.11	NaN	NaN	NaN
Stk18deep	1/12/08	6.75	NaN	NaN	NaN

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. “NaN” is defined as “Not a Number” when a parameter was not measured.)

Site	Date	DIN:DIP	DOC:DON	DOC:DOP	DON:DOP
OM2	2/16/08	40.66	NaN	NaN	NaN
OCN2	2/16/08	14.37	NaN	NaN	NaN
OB	2/16/08	12.70	NaN	NaN	NaN
OM1	2/16/08	26.19	NaN	NaN	NaN
TM	2/16/08	3.51	NaN	NaN	NaN
OCN1	2/16/08	8.50	NaN	NaN	NaN
RM3	2/16/08	20.88	NaN	NaN	NaN
RM2	2/16/08	12.46	NaN	NaN	NaN
RM1	2/16/08	11.61	NaN	NaN	NaN
River	2/16/08	10.08	NaN	NaN	NaN
Stk1sfc	2/16/08	20.66	NaN	NaN	NaN
Stk1deep	2/16/08	9.21	NaN	NaN	NaN
Stk3sfc	2/16/08	18.70	NaN	NaN	NaN
Stk3deep	2/16/08	9.94	NaN	NaN	NaN
Stk6sfc	2/16/08	17.93	NaN	NaN	NaN
Stk6deep	2/16/08	12.11	NaN	NaN	NaN
Stk7sfc	2/16/08	12.10	NaN	NaN	NaN
Stk7deep	2/16/08	2.19	NaN	NaN	NaN
Stk8sfc	2/16/08	15.23	NaN	NaN	NaN
Stk8deep	2/16/08	9.93	NaN	NaN	NaN
Stk9sfc	2/16/08	15.30	NaN	NaN	NaN
Stk9deep	2/16/08	8.12	NaN	NaN	NaN
Stk13sfc	2/16/08	9.62	NaN	NaN	NaN
Stk13deep	2/16/08	8.96	NaN	NaN	NaN
Stk15sfc	2/16/08	14.17	NaN	NaN	NaN
Stk15deep	2/16/08	6.40	NaN	NaN	NaN
Stk16sfc	2/16/08	11.06	NaN	NaN	NaN
Stk16deep	2/16/08	7.74	NaN	NaN	NaN
Stk18sfc	2/16/08	9.08	NaN	NaN	NaN
Stk18deep	2/16/08	4.54	NaN	NaN	NaN

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. “NaN” is defined as “Not a Number” when a parameter was not measured.)

Site	Date	DIN:DIP	DOC:DON	DOC:DOP	DON:DOP
OM2	3/15/08	9.94	NaN	NaN	NaN
OCN2	3/15/08	1.94	NaN	NaN	NaN
OB	3/15/08	8.94	NaN	NaN	NaN
OM1	3/15/08	10.95	NaN	NaN	NaN
TM	3/15/08	8.01	NaN	NaN	NaN
OCN1	3/15/08	9.25	NaN	NaN	NaN
RM3	3/15/08	7.63	NaN	NaN	NaN
RM2	3/15/08	11.44	NaN	NaN	NaN
RM1	3/15/08	18.56	NaN	NaN	NaN
River	3/15/08	5.14	NaN	NaN	NaN
Stk1sfc	3/15/08	NaN	NaN	NaN	NaN
Stk1deep	3/15/08	3.35	NaN	NaN	NaN
Stk3sfc	3/15/08	21.29	NaN	NaN	NaN
Stk3deep	3/15/08	NaN	NaN	NaN	NaN
Stk6sfc	3/15/08	NaN	NaN	NaN	NaN
Stk6deep	3/15/08	13.17	NaN	NaN	NaN
Stk7sfc	3/15/08	7.20	NaN	NaN	NaN
Stk7deep	3/15/08	9.39	NaN	NaN	NaN
Stk8sfc	3/15/08	NaN	NaN	NaN	NaN
Stk8deep	3/15/08	33.03	NaN	NaN	NaN
Stk9sfc	3/15/08	NaN	NaN	NaN	NaN
Stk9deep	3/15/08	151.17	NaN	NaN	NaN
Stk13sfc	3/15/08	NaN	NaN	NaN	NaN
Stk13deep	3/15/08	77.22	NaN	NaN	NaN
Stk15sfc	3/15/08	NaN	NaN	NaN	NaN
Stk15deep	3/15/08	78.81	NaN	NaN	NaN
Stk16sfc	3/15/08	NaN	NaN	NaN	NaN
Stk16deep	3/15/08	12.70	NaN	NaN	NaN
Stk18sfc	3/15/08	NaN	NaN	NaN	NaN
Stk18deep	3/15/08	6.16	NaN	NaN	NaN

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. “NaN” is defined as “Not a Number” when a parameter was not measured.)

Site	Date	DIN:DIP	DOC:DON	DOC:DOP	DON:DOP
OM2	4/19/08	81.37	NaN	NaN	NaN
OCN2	4/19/08	12.92	NaN	NaN	NaN
OB	4/19/08	17.07	NaN	NaN	NaN
OM1	4/19/08	11.45	NaN	NaN	NaN
TM	4/19/08	16.40	NaN	NaN	NaN
OCN1	4/19/08	14.34	NaN	NaN	NaN
RM3	4/19/08	4.92	NaN	NaN	NaN
RM2	4/19/08	NaN	NaN	NaN	NaN
RM1	4/19/08	NaN	NaN	NaN	NaN
River	4/19/08	7.10	NaN	NaN	NaN
Stk1sfc	4/19/08	NaN	NaN	NaN	NaN
Stk1deep	4/19/08	13.82	NaN	NaN	NaN
Stk3sfc	4/19/08	NaN	NaN	NaN	NaN
Stk3deep	4/19/08	9.38	NaN	NaN	NaN
Stk6sfc	4/19/08	NaN	NaN	NaN	NaN
Stk6deep	4/19/08	NaN	NaN	NaN	NaN
Stk7sfc	4/19/08	NaN	NaN	NaN	NaN
Stk7deep	4/19/08	NaN	NaN	NaN	NaN
Stk8sfc	4/19/08	NaN	NaN	NaN	NaN
Stk8deep	4/19/08	NaN	NaN	NaN	NaN
Stk9sfc	4/19/08	NaN	NaN	NaN	NaN
Stk9deep	4/19/08	NaN	NaN	NaN	NaN
Stk13sfc	4/19/08	NaN	NaN	NaN	NaN
Stk13deep	4/19/08	NaN	NaN	NaN	NaN
Stk15sfc	4/19/08	NaN	NaN	NaN	NaN
Stk15deep	4/19/08	NaN	NaN	NaN	NaN
Stk16sfc	4/19/08	NaN	NaN	NaN	NaN
Stk16deep	4/19/08	NaN	NaN	NaN	NaN
Stk18sfc	4/19/08	NaN	NaN	NaN	NaN
Stk18deep	4/19/08	NaN	NaN	NaN	NaN

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. “NaN” is defined as “Not a Number” when a parameter was not measured.)

Site	Date	DIN:DIP	DOC:DON	DOC:DOP	DON:DOP
OM2	5/17/08	22.77	NaN	NaN	NaN
OCN2	5/17/08	9.32	NaN	NaN	NaN
OB	5/17/08	8.80	NaN	NaN	NaN
OM1	5/17/08	7.11	NaN	NaN	NaN
TM	5/17/08	6.41	NaN	NaN	NaN
OCN1	5/17/08	8.86	NaN	NaN	NaN
RM3	5/17/08	12.51	NaN	NaN	NaN
RM2	5/17/08	7.51	NaN	NaN	NaN
RM1	5/17/08	20.48	NaN	NaN	NaN
River	5/17/08	5.72	NaN	NaN	NaN
Stk1sfc	5/17/08	10.27	NaN	NaN	NaN
Stk1deep	5/17/08	16.52	NaN	NaN	NaN
Stk3sfc	5/17/08	9.97	NaN	NaN	NaN
Stk3deep	5/17/08	11.23	NaN	NaN	NaN
Stk6sfc	5/17/08	23.39	NaN	NaN	NaN
Stk6deep	5/17/08	16.97	NaN	NaN	NaN
Stk7sfc	5/17/08	6.07	NaN	NaN	NaN
Stk7deep	5/17/08	13.21	NaN	NaN	NaN
Stk8sfc	5/17/08	32.20	NaN	NaN	NaN
Stk8deep	5/17/08	11.94	NaN	NaN	NaN
Stk9sfc	5/17/08	47.57	NaN	NaN	NaN
Stk9deep	5/17/08	17.84	NaN	NaN	NaN
Stk13sfc	5/17/08	17.51	NaN	NaN	NaN
Stk13deep	5/17/08	19.82	NaN	NaN	NaN
Stk15sfc	5/17/08	12.55	NaN	NaN	NaN
Stk15deep	5/17/08	21.35	NaN	NaN	NaN
Stk16sfc	5/17/08	15.23	NaN	NaN	NaN
Stk16deep	5/17/08	42.60	NaN	NaN	NaN
Stk18sfc	5/17/08	7.51	NaN	NaN	NaN
Stk18deep	5/17/08	7.08	NaN	NaN	NaN

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. “NaN” is defined as “Not a Number” when a parameter was not measured.)

Storm 4

Site	Date	DIN:DIP	DOC:DON	DOC:DOP	DON:DOP
OM2	6/14/08	12.19	NaN	NaN	NaN
OCN2	6/14/08	34.68	NaN	NaN	NaN
OB	6/14/08	9.56	NaN	NaN	NaN
OM1	6/14/08	6.28	NaN	NaN	NaN
TM	6/14/08	8.70	NaN	NaN	NaN
OCN1	6/14/08	7.22	86.26	NaN	NaN
RM3	6/14/08	22.84	NaN	NaN	NaN
RM2	6/14/08	NaN	NaN	NaN	NaN
RM1	6/14/08	8.46	NaN	NaN	NaN
River	6/14/08	5.17	NaN	NaN	NaN
Stk1sfc	6/14/08	10.99	NaN	NaN	NaN
Stk1deep	6/14/08	20.77	NaN	NaN	NaN
Stk3sfc	6/14/08	NaN	NaN	NaN	NaN
Stk3deep	6/14/08	23.78	NaN	NaN	NaN
Stk6sfc	6/14/08	11.40	40.84	NaN	NaN
Stk6deep	6/14/08	8.26	45.52	NaN	NaN
Stk7sfc	6/14/08	7.77	36.86	NaN	NaN
Stk7deep	6/14/08	5.61	34.64	NaN	NaN
Stk8sfc	6/14/08	14.86	NaN	NaN	NaN
Stk8deep	6/14/08	8.76	NaN	NaN	NaN
Stk9sfc	6/14/08	12.20	32.63	NaN	NaN
Stk9deep	6/14/08	10.24	72.31	NaN	16.94
Stk13sfc	6/14/08	17.72	NaN	NaN	NaN
Stk13deep	6/14/08	8.27	16.37	NaN	NaN
Stk15sfc	6/14/08	23.87	NaN	NaN	NaN
Stk15deep	6/14/08	13.51	41.05	NaN	NaN
Stk16sfc	6/14/08	16.47	NaN	NaN	NaN
Stk16deep	6/14/08	12.73	NaN	NaN	NaN
Stk18sfc	6/14/08	20.08	NaN	NaN	NaN
Stk18deep	6/14/08	NaN	NaN	NaN	NaN

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. “NaN” is defined as “Not a Number” when a parameter was not measured.)

Site	Date	DIN:DIP	DOC:DON	DOC:DOP	DON:DOP
OM2	7/26/08	10.67	NaN	NaN	NaN
OCN2	7/26/08	19.19	NaN	NaN	NaN
OB	7/26/08	4.95	NaN	NaN	NaN
OM1	7/26/08	7.83	NaN	NaN	NaN
TM	7/26/08	15.49	NaN	NaN	NaN
OCN1	7/26/08	12.85	NaN	NaN	NaN
RM3	7/26/08	10.79	NaN	NaN	NaN
RM2	7/26/08	8.22	NaN	NaN	NaN
RM1	7/26/08	8.57	NaN	NaN	NaN
River	7/26/08	8.14	NaN	NaN	NaN
Stk1sfc	7/26/08	NaN	NaN	NaN	NaN
Stk1deep	7/26/08	52.81	NaN	NaN	NaN
Stk3sfc	7/26/08	24.71	NaN	NaN	NaN
Stk3deep	7/26/08	20.14	NaN	NaN	NaN
Stk6sfc	7/26/08	8.71	13.44	NaN	NaN
Stk6deep	7/26/08	3.10	NaN	NaN	NaN
Stk7sfc	7/26/08	16.75	14.36	NaN	NaN
Stk7deep	7/26/08	1.72	NaN	NaN	NaN
Stk8sfc	7/26/08	12.27	NaN	NaN	NaN
Stk8deep	7/26/08	4.25	NaN	NaN	NaN
Stk9sfc	7/26/08	6.85	9.55	NaN	NaN
Stk9deep	7/26/08	6.30	NaN	NaN	NaN
Stk13sfc	7/26/08	NaN	NaN	NaN	NaN
Stk13deep	7/26/08	12.14	NaN	NaN	NaN
Stk15sfc	7/26/08	17.06	27.48	NaN	NaN
Stk15deep	7/26/08	7.64	NaN	NaN	NaN
Stk16sfc	7/26/08	6.53	NaN	NaN	NaN
Stk16deep	7/26/08	4.94	NaN	NaN	NaN
Stk18sfc	7/26/08	6.99	50.48	NaN	NaN
Stk18deep	7/26/08	3.31	NaN	NaN	NaN

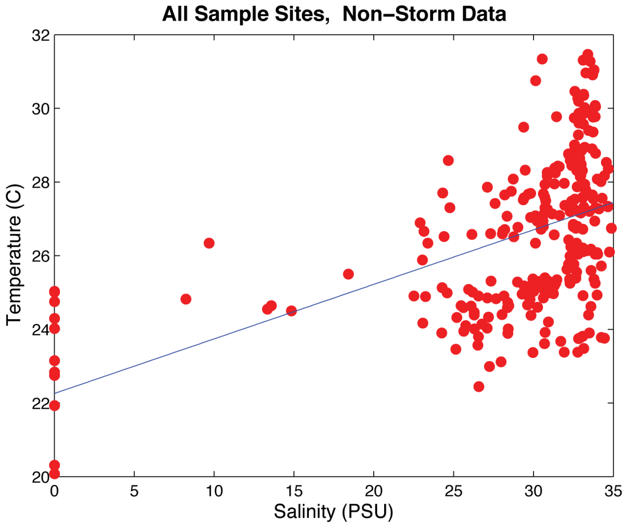
(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. “NaN” is defined as “Not a Number” when a parameter was not measured.)

Site	Date	DIN:DIP	DOC:DON	DOC:DOP	DON:DOP
OM2	8/30/08	15.69	NaN	NaN	NaN
OCN2	8/30/08	2.75	4.80	52.01	10.85
OB	8/30/08	26.98	NaN	NaN	NaN
OM1	8/30/08	24.60	NaN	NaN	NaN
TM	8/30/08	9.52	NaN	NaN	NaN
OCN1	8/30/08	8.61	13.00	202.91	15.60
RM3	8/30/08	6.24	NaN	NaN	NaN
RM2	8/30/08	9.11	NaN	NaN	NaN
RM1	8/30/08	8.73	NaN	NaN	NaN
River	8/30/08	8.14	NaN	NaN	NaN
Stk1sfc	8/30/08	14.30	NaN	NaN	NaN
Stk1deep	8/30/08	10.35	NaN	NaN	NaN
Stk3sfc	8/30/08	15.77	NaN	NaN	NaN
Stk3deep	8/30/08	7.58	NaN	NaN	NaN
Stk6sfc	8/30/08	15.37	NaN	803.78	2.81
Stk6deep	8/30/08	5.78	8.10	152.45	18.81
Stk7sfc	8/30/08	8.78	NaN	NaN	NaN
Stk7deep	8/30/08	1.13	10.00	408.27	40.84
Stk8sfc	8/30/08	22.18	NaN	NaN	NaN
Stk8deep	8/30/08	7.37	NaN	NaN	NaN
Stk9sfc	8/30/08	9.53	8.16	85.33	10.46
Stk9deep	8/30/08	3.07	6.54	70.62	10.81
Stk13sfc	8/30/08	11.03	9.05	173.06	19.13
Stk13deep	8/30/08	4.64	27.25	473.92	17.39
Stk15sfc	8/30/08	16.54	7.93	110.38	13.92
Stk15deep	8/30/08	6.47	53.91	429.34	7.96
Stk16sfc	8/30/08	10.69	NaN	NaN	NaN
Stk16deep	8/30/08	9.51	NaN	NaN	NaN
Stk18sfc	8/30/08	20.81	15.39	123.57	8.03
Stk18deep	8/30/08	3.13	6.96	775.64	111.49

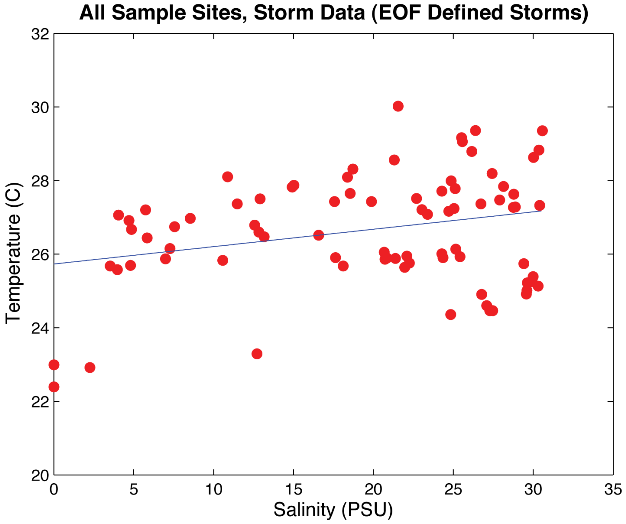
(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. “NaN” is defined as “Not a Number” when a parameter was not measured.)

Appendix 6.1. Water column temperature data for all sample sites during (A) non-storm monthly sampling events (12 months) and (B) storm sampling events (Storm 1, Transects 1-4, and Storm 4).

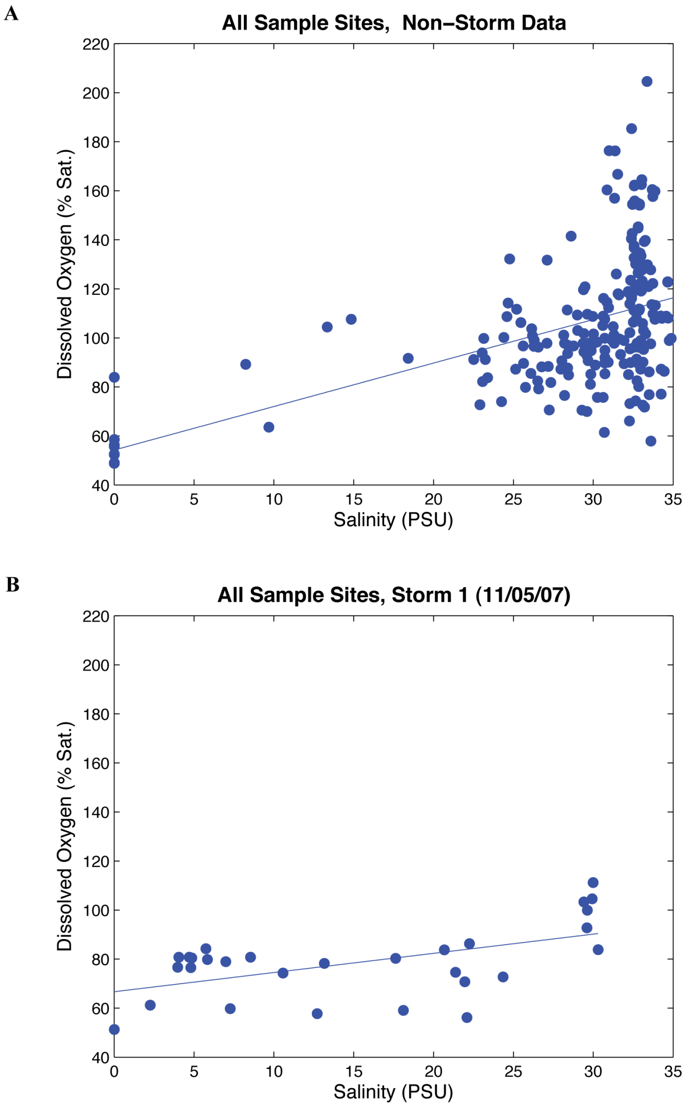
A



B

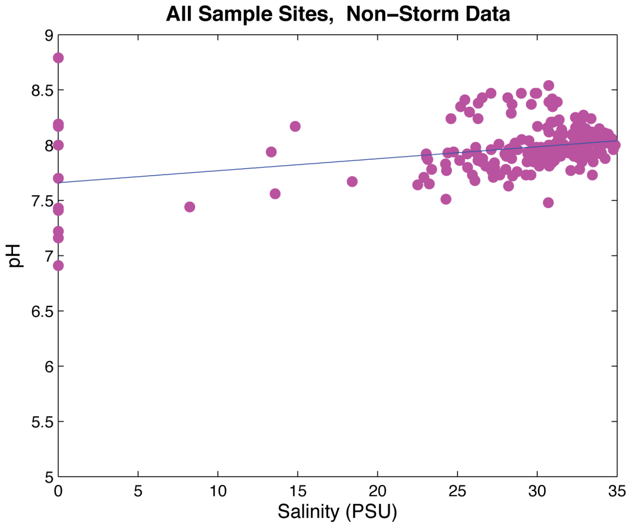


Appendix 6.2. Water column % DO data for all sample sites during (A) non-storm monthly sampling events (12 months) and (B) only Storm 1 (% DO measurements were not taken during Storm 4, so a combined mean storm plot does not exist).

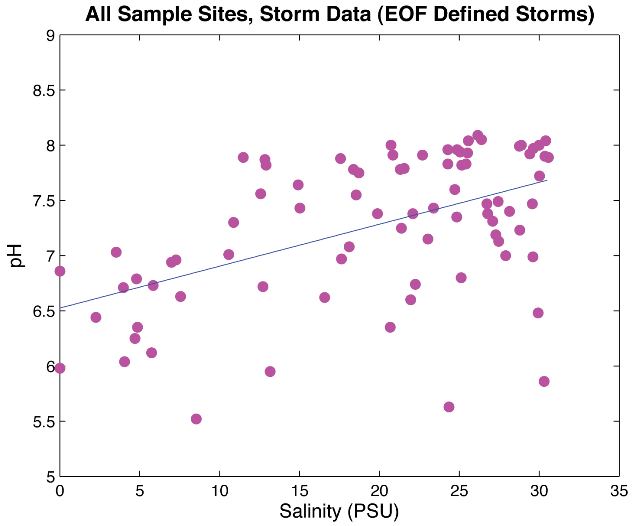


Appendix 6.3. Water column pH data for all sample sites during (A) non-storm monthly sampling events (12 months) and (B) storm sampling events (Storm 1, Transects 1-4, and Storm 4).

A

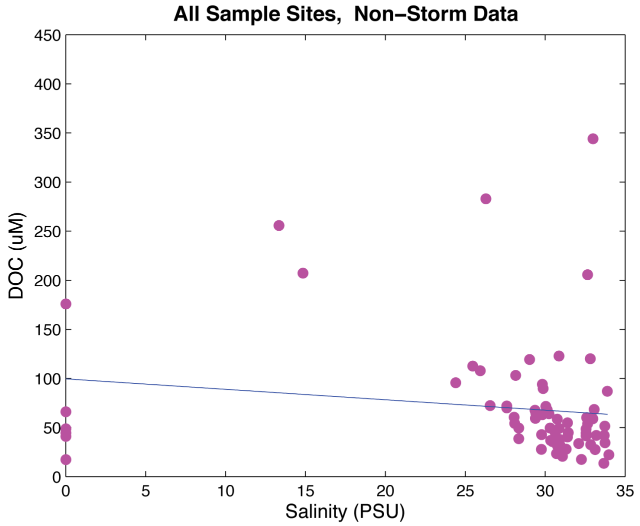


B

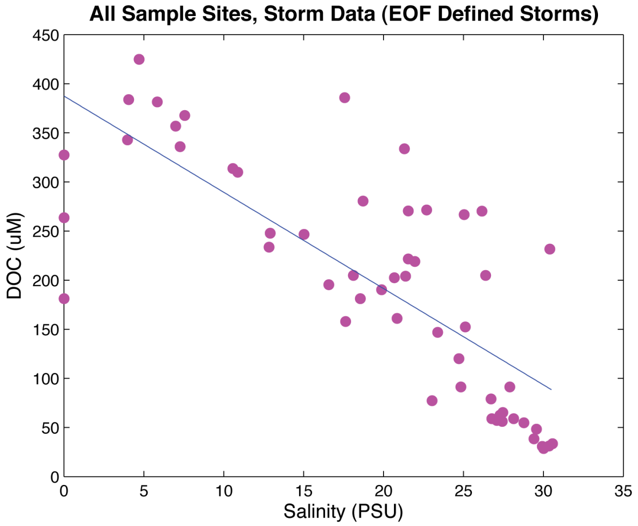


Appendix 6.4. Water column DOC data for all sample sites during (A) non-storm monthly sampling events (12 months) and (B) storm sampling events (Storm 1, Transects 1-4, and Storm 4).

A

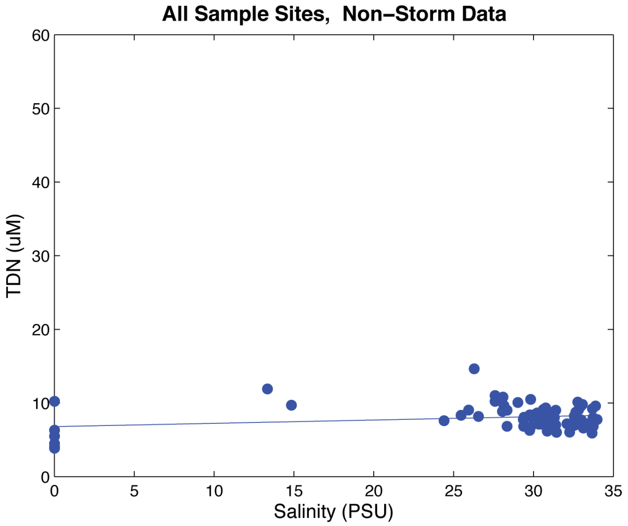


B

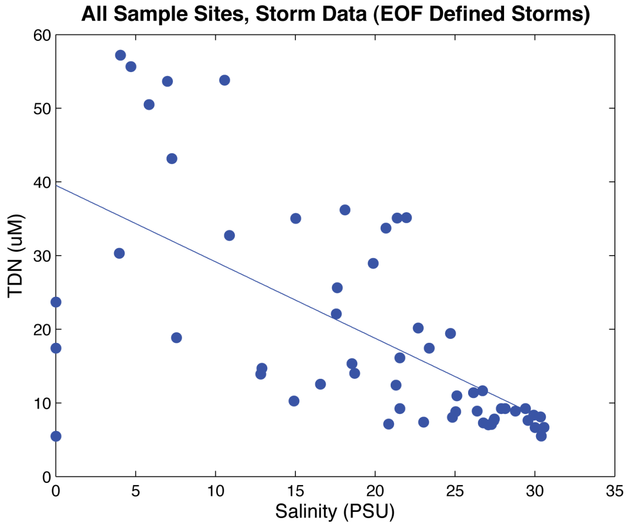


Appendix 6.5. Water column TDN data for all sample sites during (A) non-storm monthly sampling events (12 months) and (B) storm sampling events (Storm 1, Transects 1-4, and Storm 4).

A

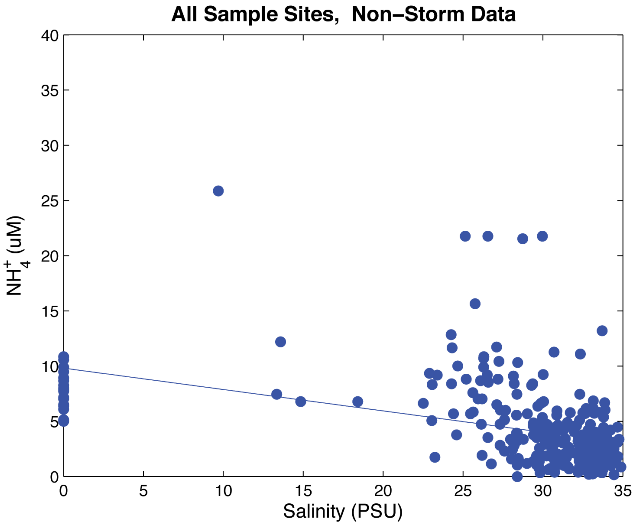


B

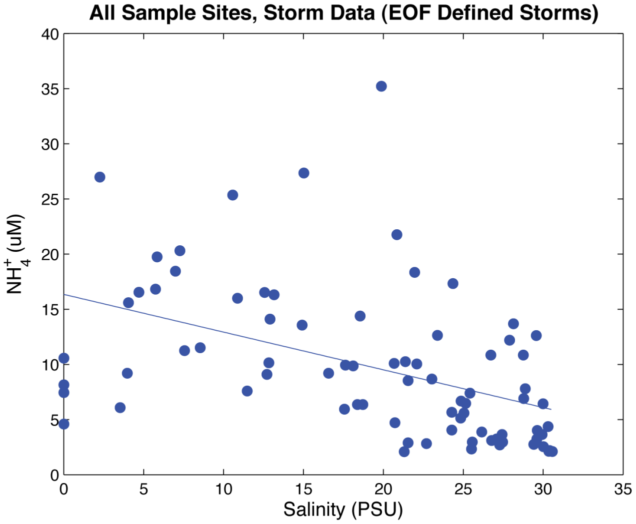


Appendix 6.6. Water column NH_4^+ data for all sample sites during (A) non-storm monthly sampling events (12 months) and (B) storm sampling events (Storm 1, Transects 1-4, and Storm 4).

A

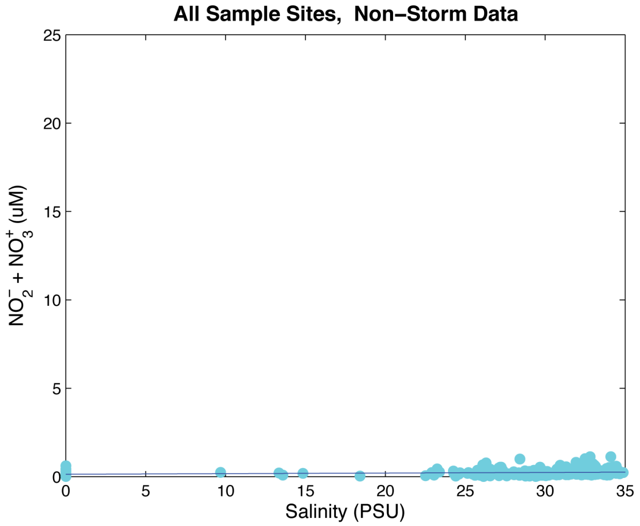


B

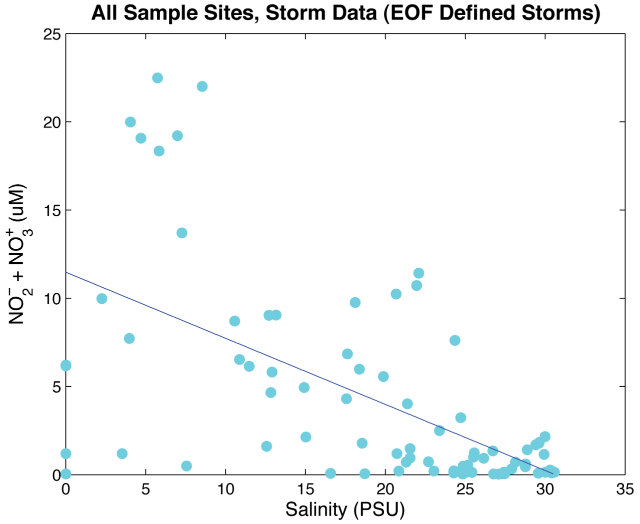


Appendix 6.7a. Water column (NO_3^- + NO_2^-) data for all sample sites during (A) non-storm monthly sampling events (12 months) and (B) storm sampling events (Storm 1, Transects 1-4, and Storm 4).

A

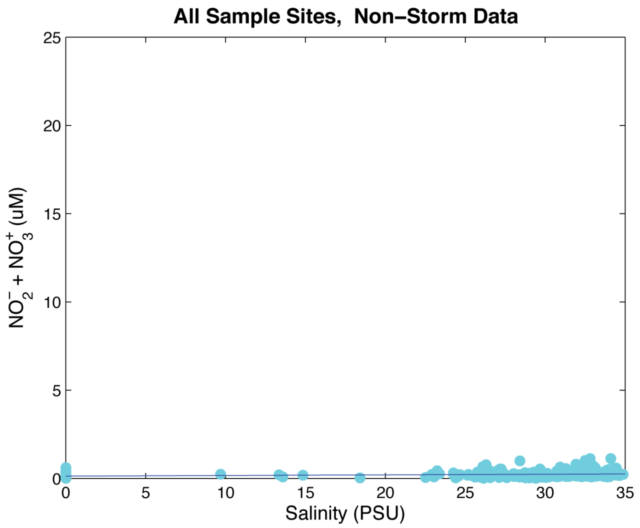


B

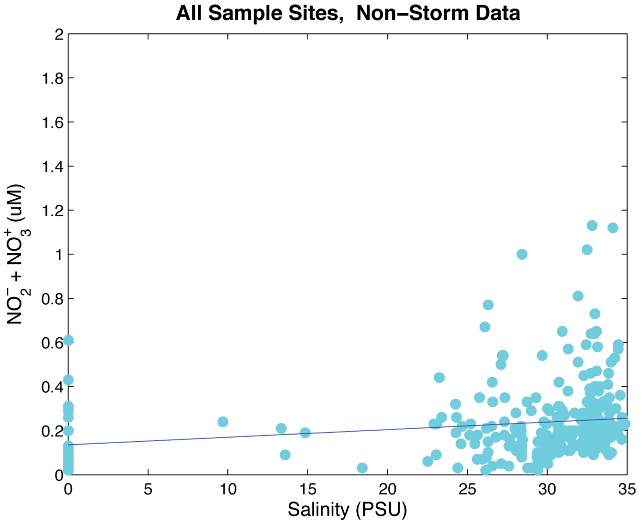


Appendix 6.7b. Expanded water column (NO_3^- + NO_2^-) data for all sample sites during non-storm monthly sampling events (12 months).

A

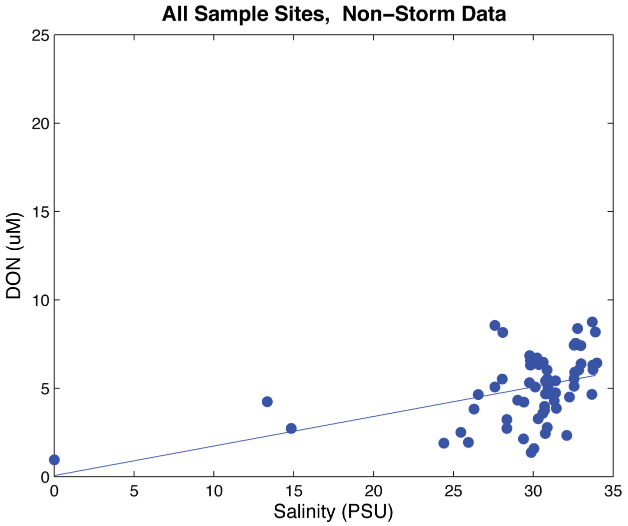


B

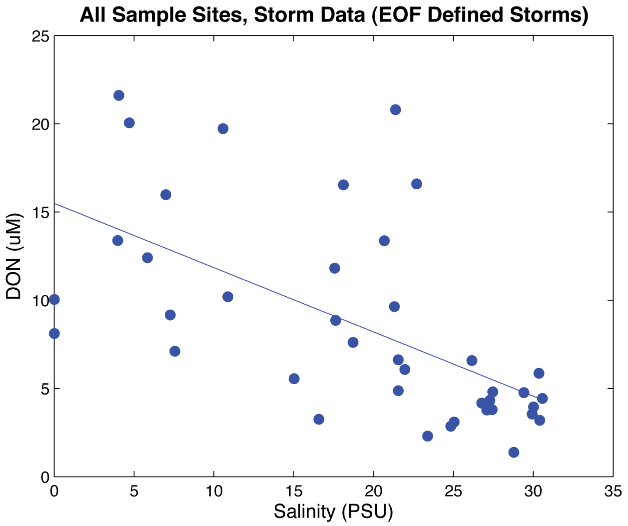


Appendix 6.8. Water column DON data for all sample sites during (A) non-storm monthly sampling events (12 months) and (B) storm sampling events (Storm 1, Transects 1-4, and Storm 4).

A

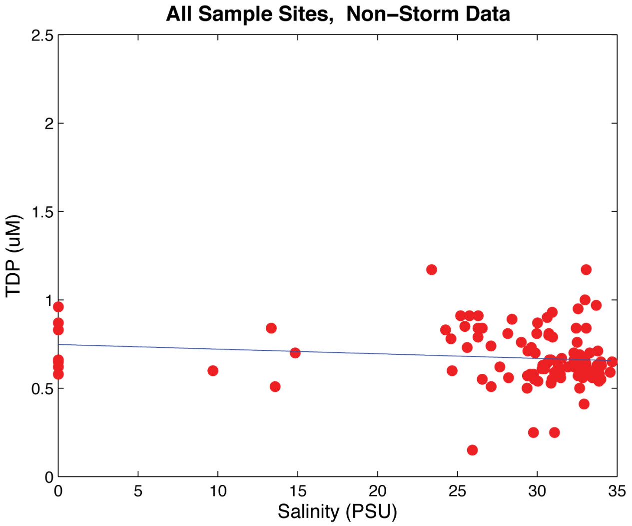


B

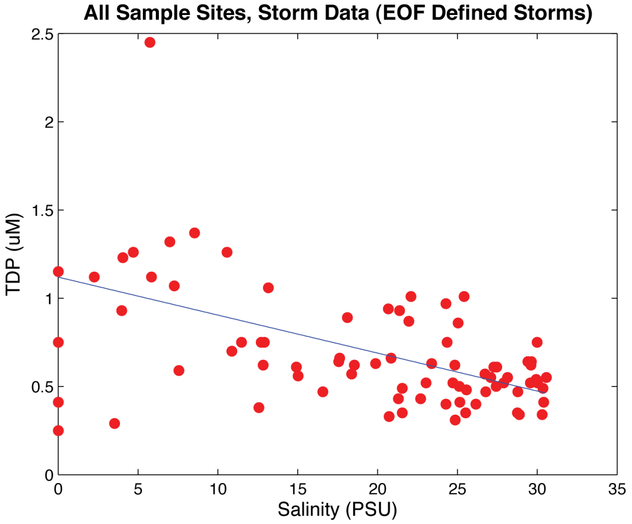


Appendix 6.9. Water column TDP data for all sample sites during (A) non-storm monthly sampling events (12 months) and (B) storm sampling events (Storm 1, Transects 1-4, and Storm 4).

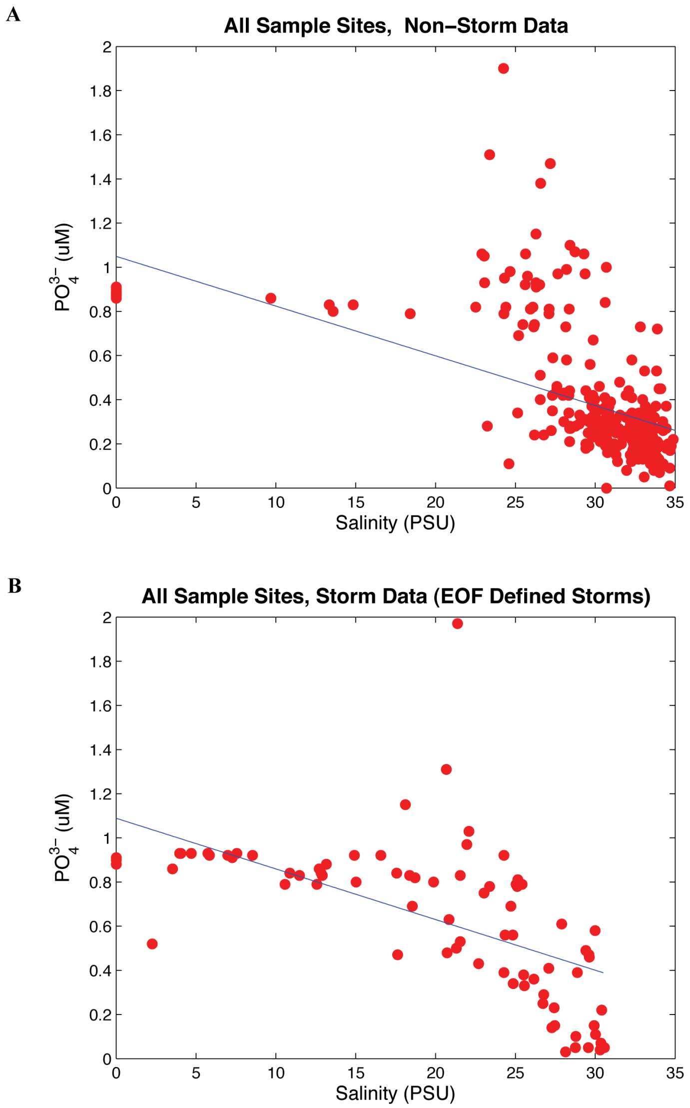
A



B

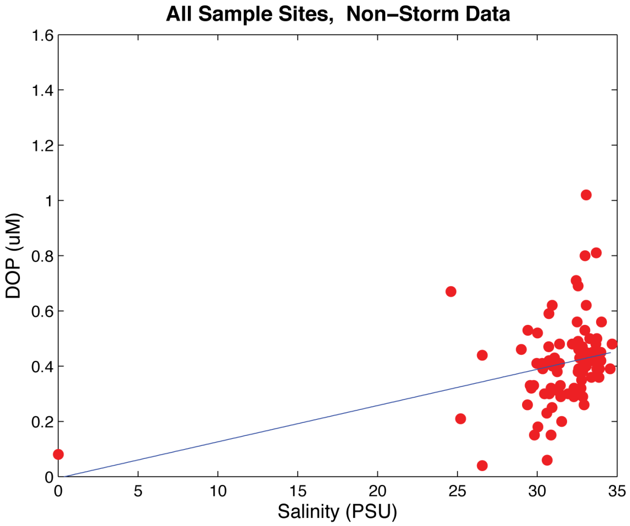


Appendix 6.10. Water column PO_4^{3-} data for all sample sites during (A) non-storm monthly sampling events (12 months) and (B) storm sampling events (Storm 1, Transects 1-4, and Storm 4).

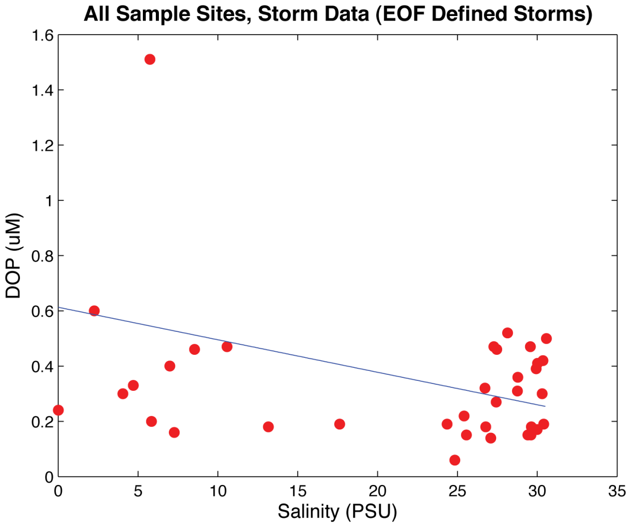


Appendix 6.11. Water column DOP data for all sample sites during (A) non-storm monthly sampling events (12 months) and (B) storm sampling events (Storm 1, Transects 1-4, and Storm 4).

A

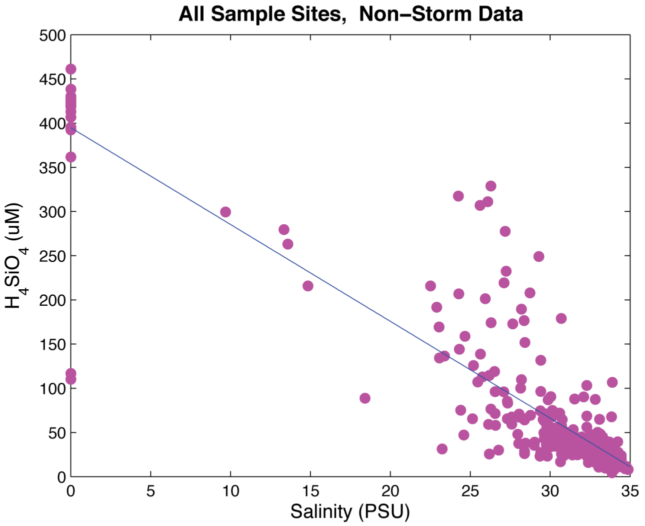


B

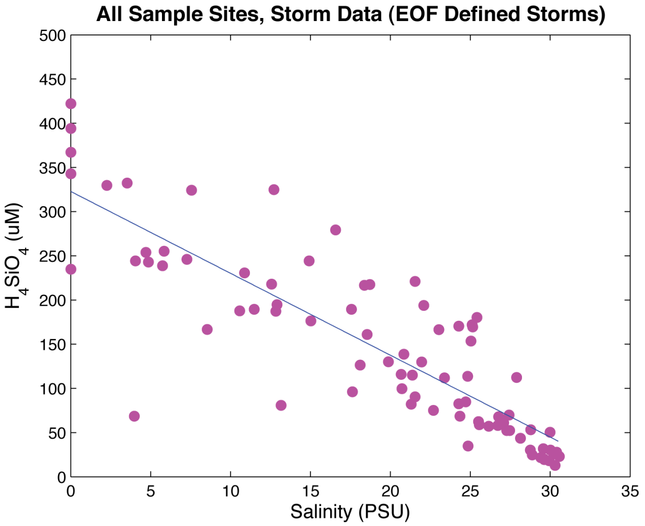


Appendix 6.12. Water column H_4SiO_4 data for all sample sites during (A) non-storm monthly sampling events (12 months) and (B) storm sampling events (Storm 1, Transects 1-4, and Storm 4).

A

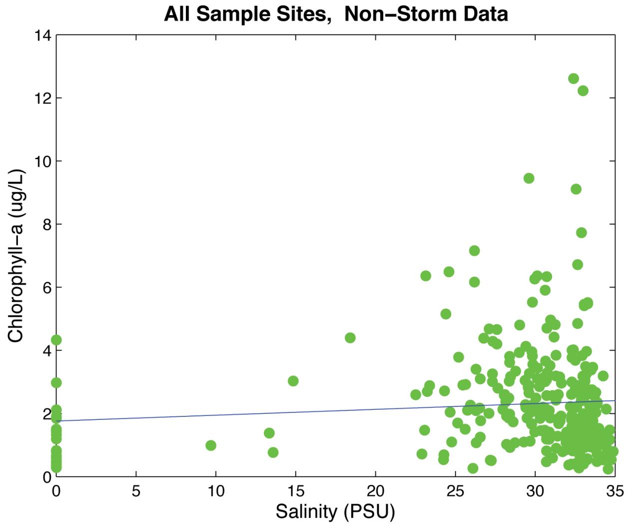


B

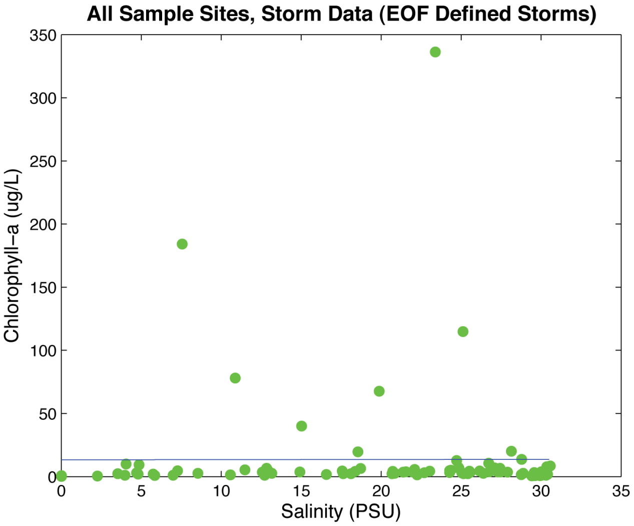


Appendix 6.13. Water column chl-a data for all sample sites during (A) non-storm monthly sampling events (12 months) and (B) storm sampling events (Storm 1, Transects 1-4, and Storm 4).

A

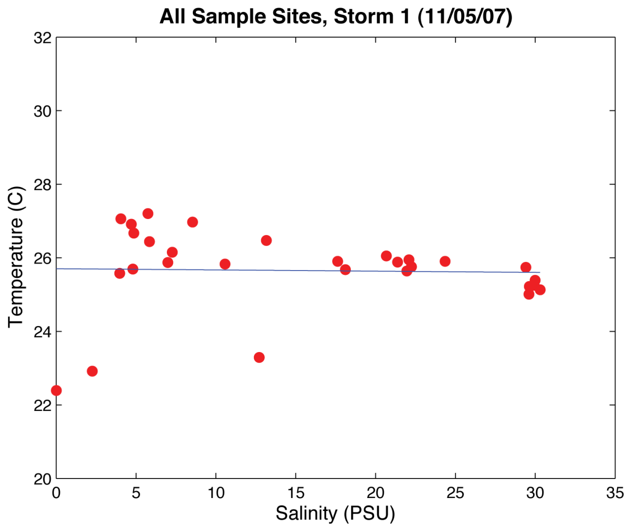


B

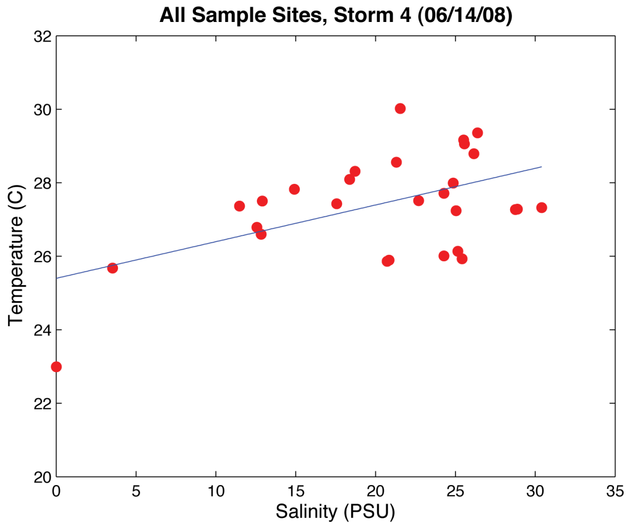


Appendix 7.1. Water column temperature data for all sample sites during a (A) wet season storm (Storm 1) and (B) dry season storm (Storm 4).

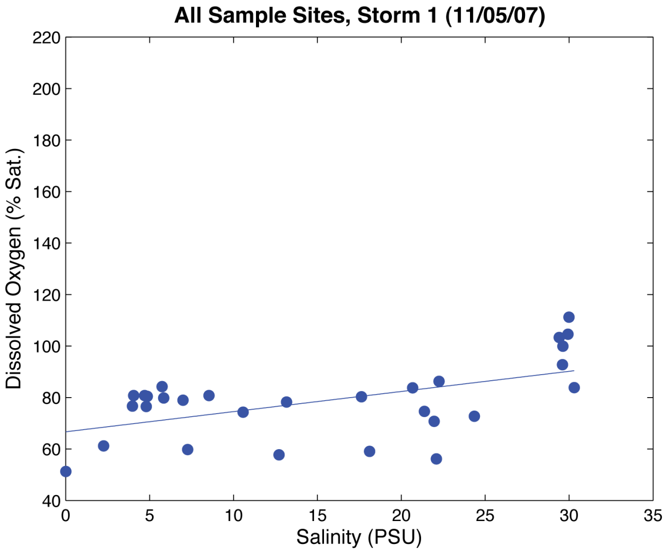
A



B

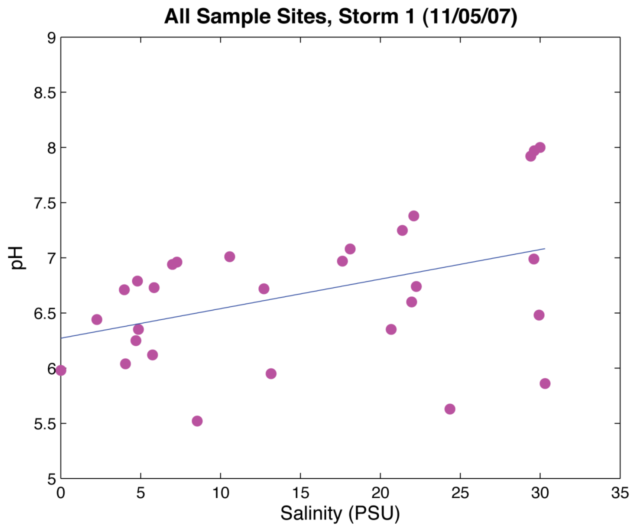


Appendix 7.2. Water column % DO data for all sample sites during a wet season storm (Storm 1) only (% DO measurements were not taken during Storm 4).

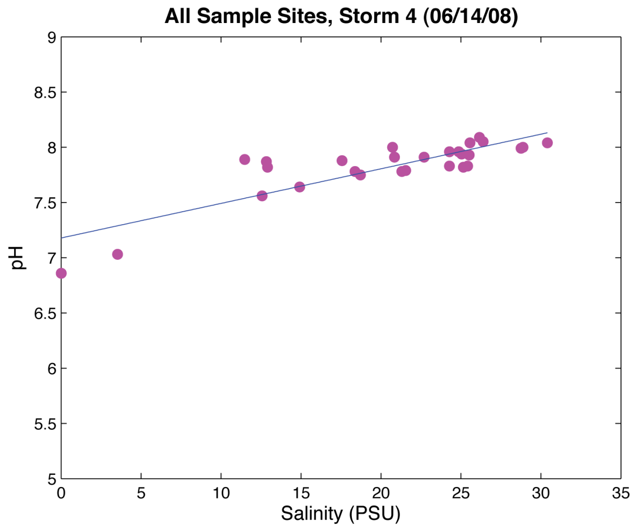


Appendix 7.3. Water column pH data for all sample sites during a (A) wet season storm (Storm 1) and (B) dry season storm (Storm 4).

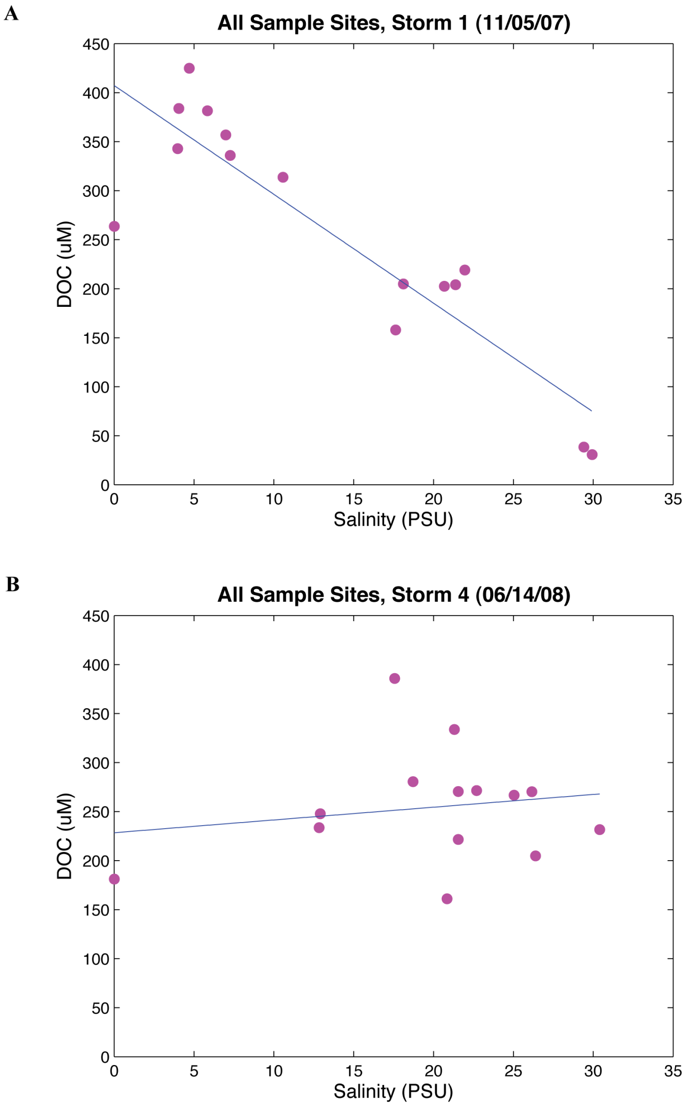
A



B

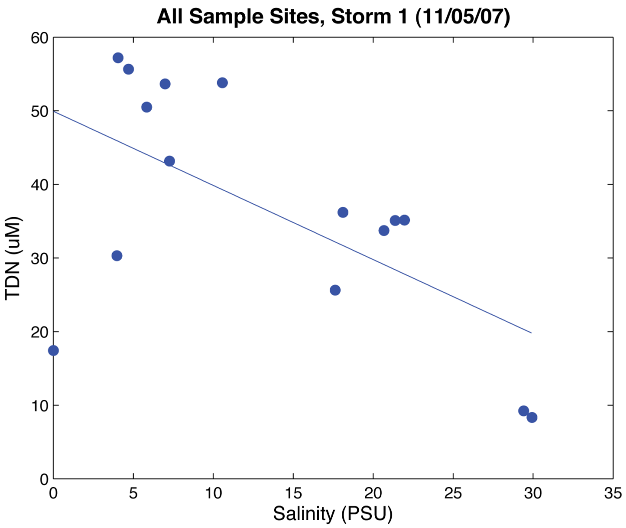


Appendix 7.4. Water column DOC data for all sample sites during a (A) wet season storm (Storm 1) and (B) dry season storm (Storm 4).

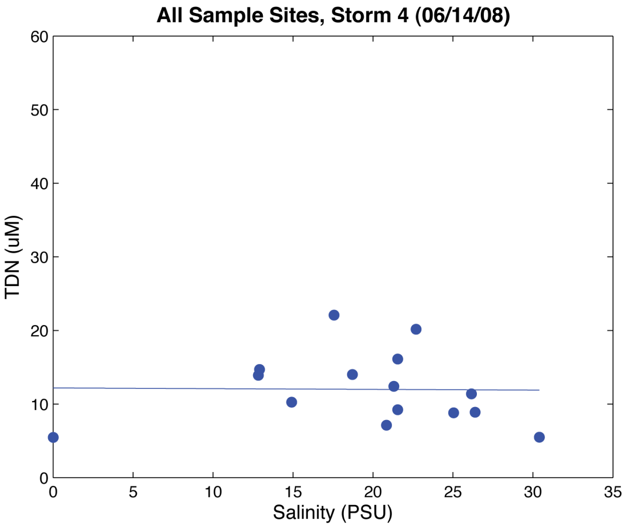


Appendix 7.5. Water column TDN data for all sample sites during a (A) wet season storm (Storm 1) and (B) dry season storm (Storm 4).

A

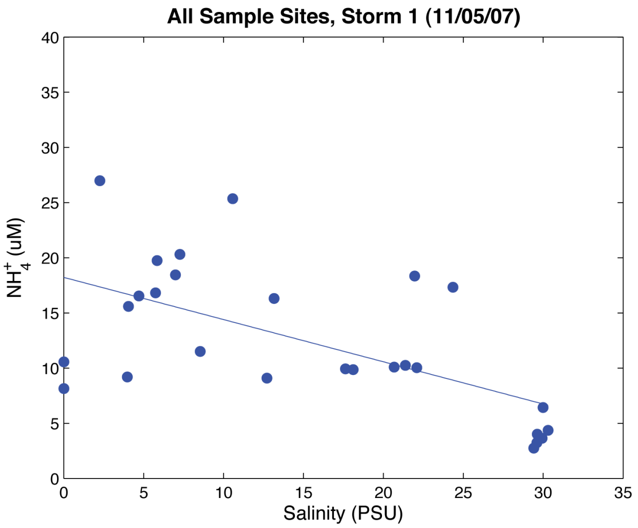


B

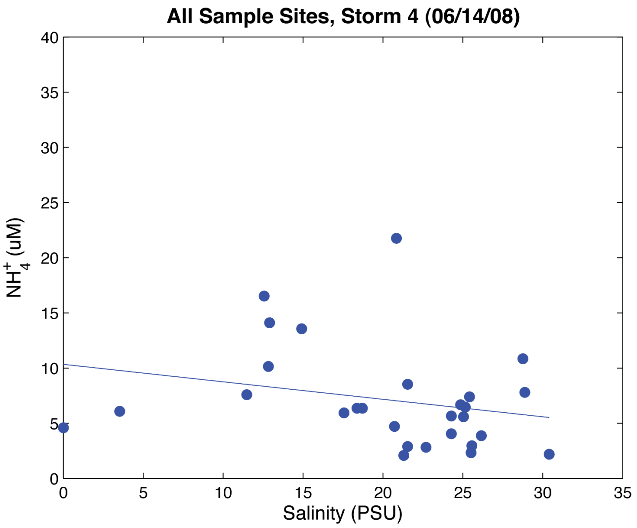


Appendix 7.6. Water column NH_4^+ data for all sample sites during a (A) wet season storm (Storm 1) and (B) dry season storm (Storm 4).

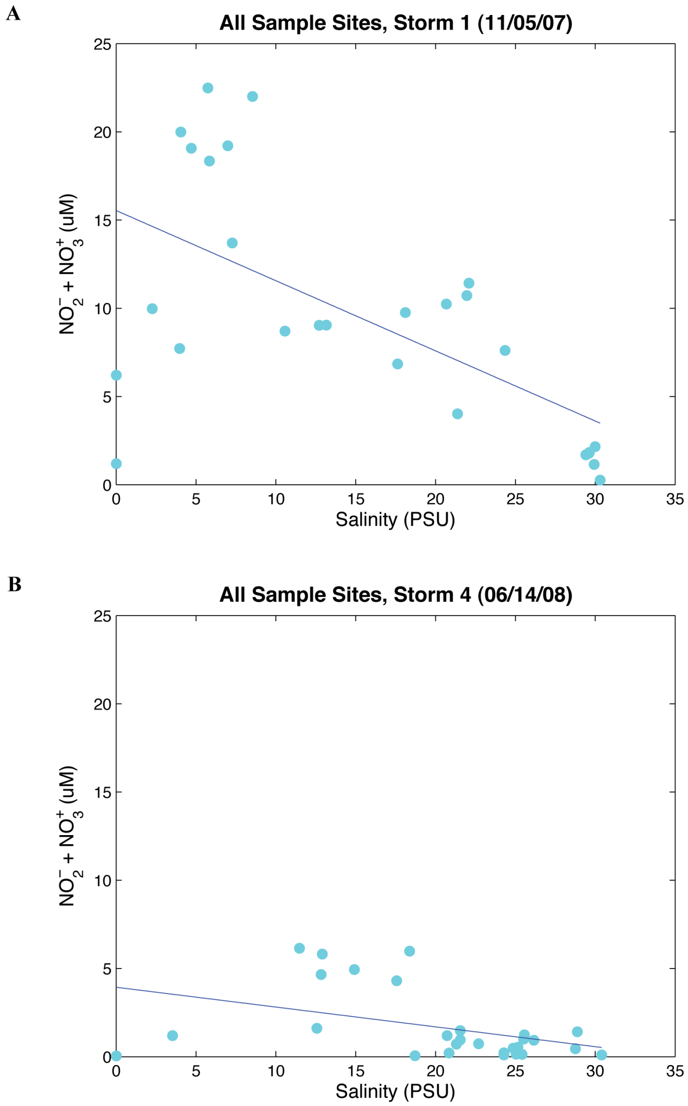
A



B

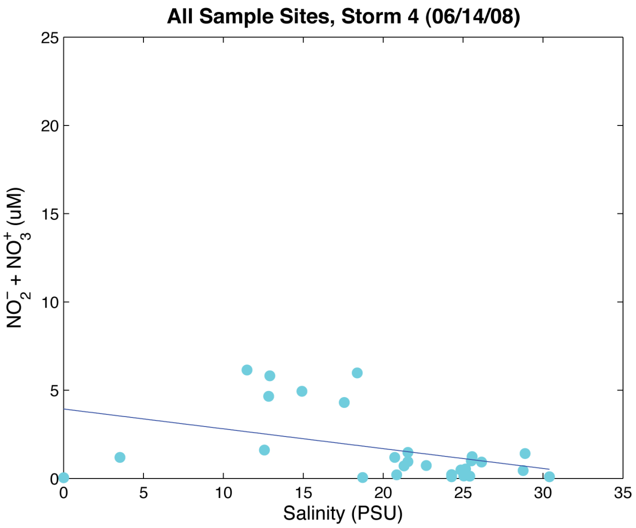


Appendix 7.7a. Water column (NO_3^- + NO_2^-) data for all sample sites during a (A) wet season storm (Storm 1) and (B) dry season storm (Storm 4).

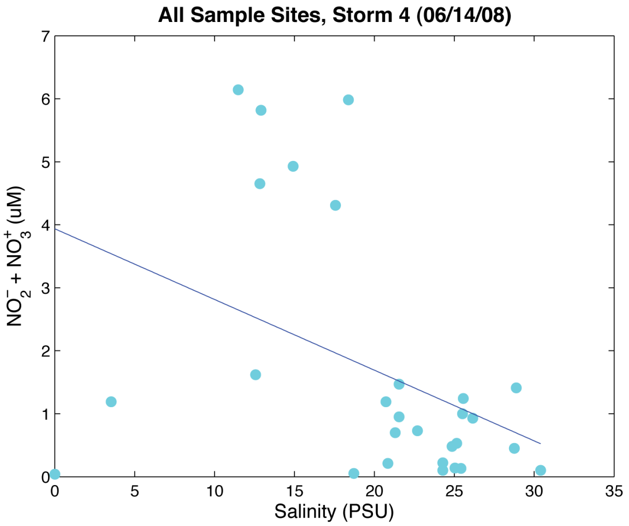


Appendix 7.7b. Expanded water column (NO_3^- + NO_2^-) data for all sample sites during a dry season storm (Storm 4).

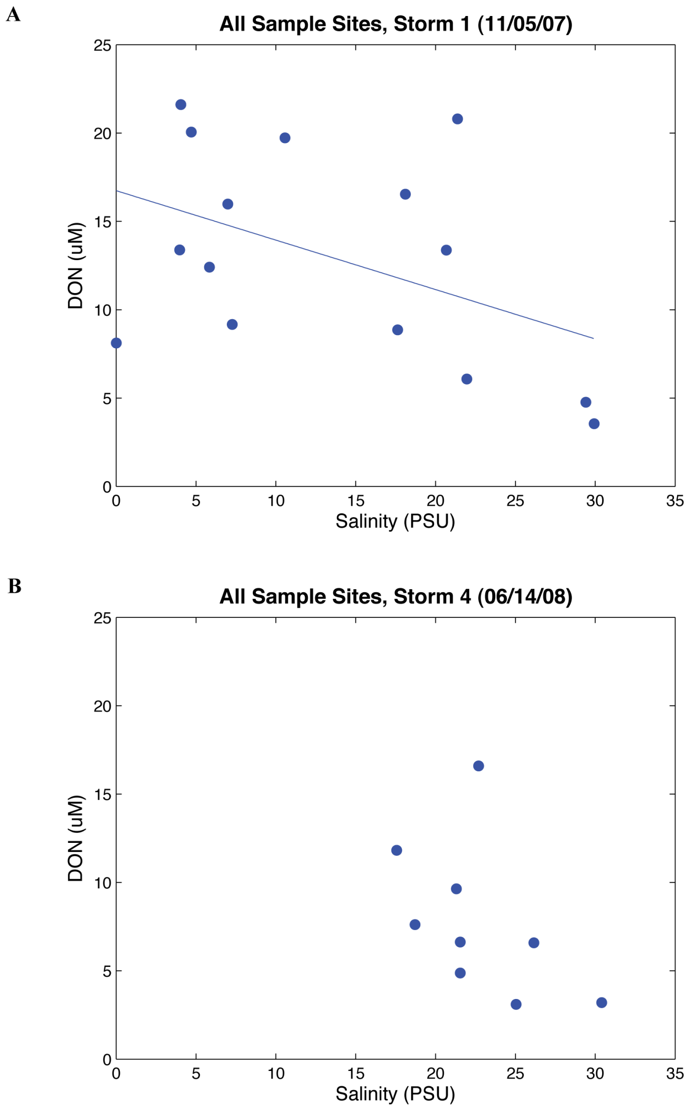
A



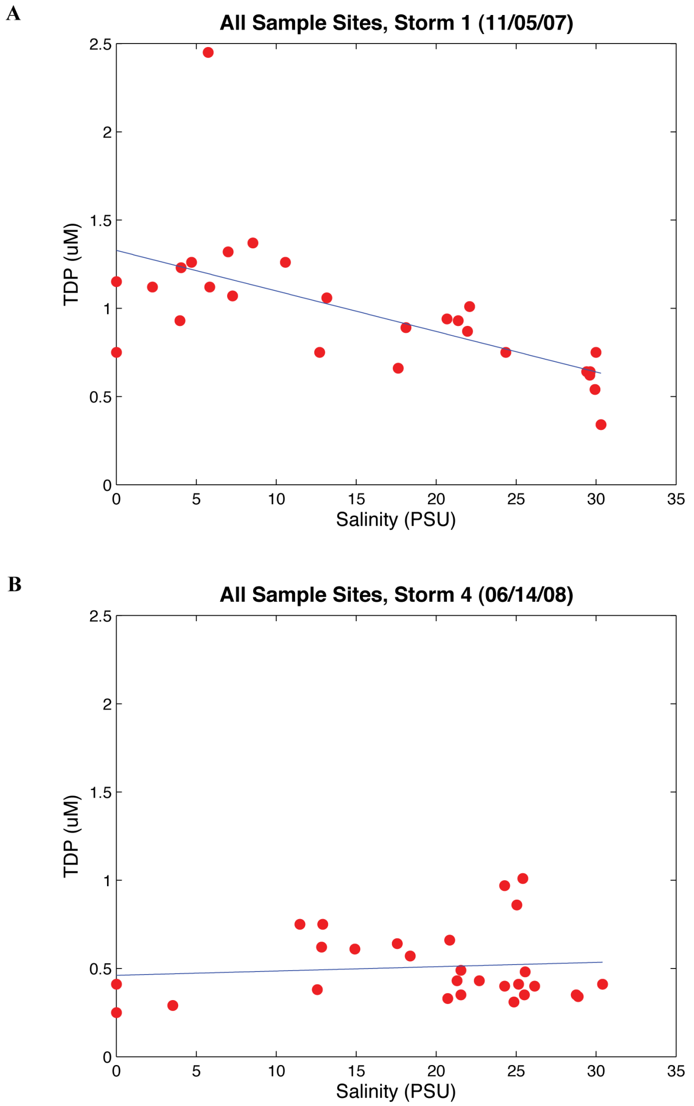
B



Appendix 7.8. Water column DON data for all sample sites during a (A) wet season storm (Storm 1) and (B) dry season storm (Storm 4). No conservative mixing line exists for Storm 4 due to an insufficient data set.

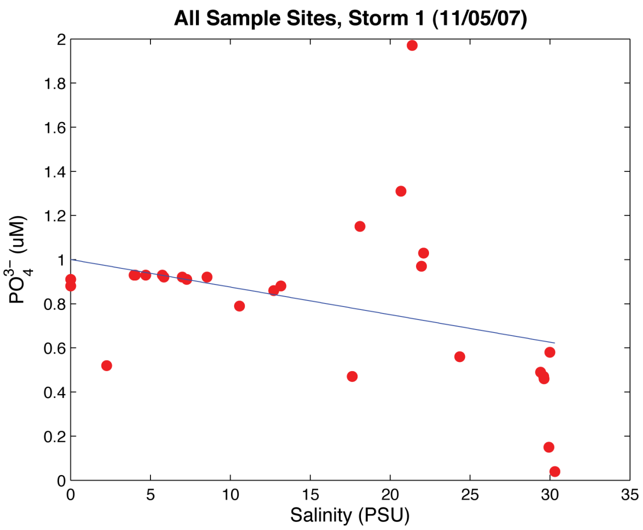


Appendix 7.9. Water column TDP data for all sample sites during a (A) wet season storm (Storm 1) and (B) dry season storm (Storm 4).

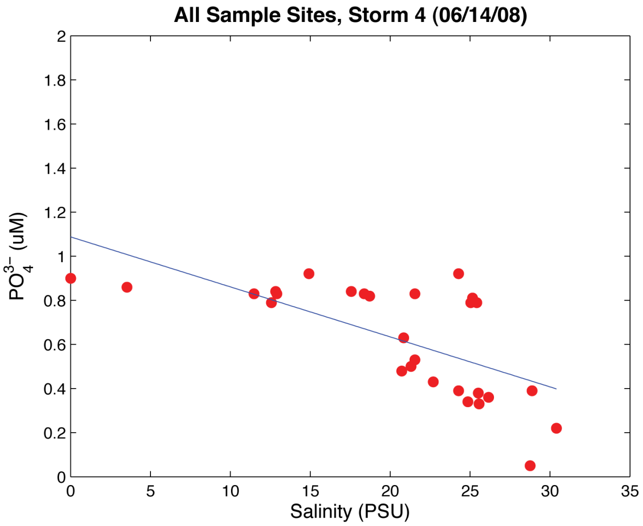


Appendix 7.10. Water column PO_4^{3-} data for all sample sites during a (A) wet season storm (Storm 1) and (B) dry season storm (Storm 4).

A

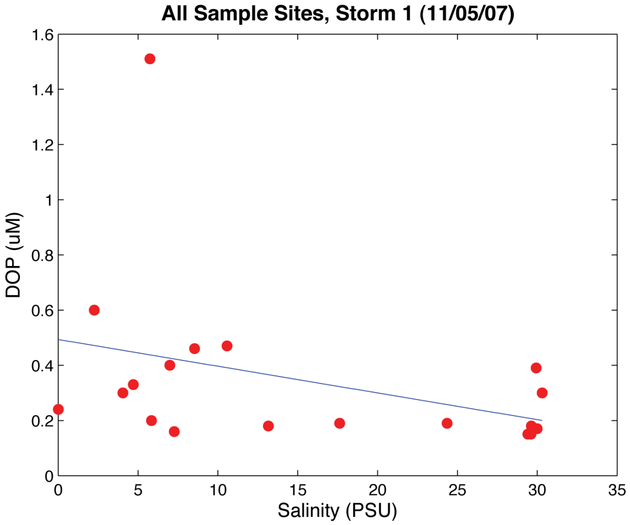


B

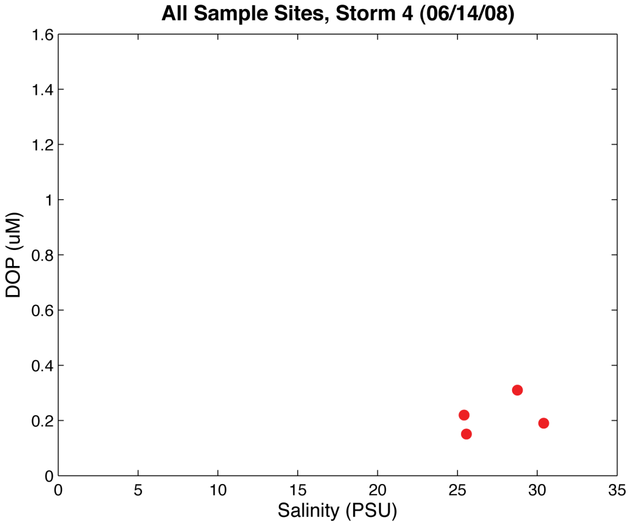


Appendix 7.11. Water column DOP data for all sample sites during a (A) wet season storm (Storm 1) and (B) dry season storm (Storm 4). No conservative mixing line exists for Storm 4 due to an insufficient data set.

A

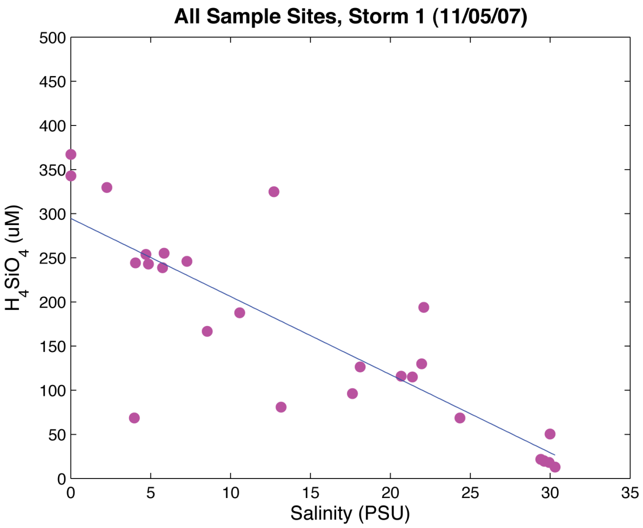


B

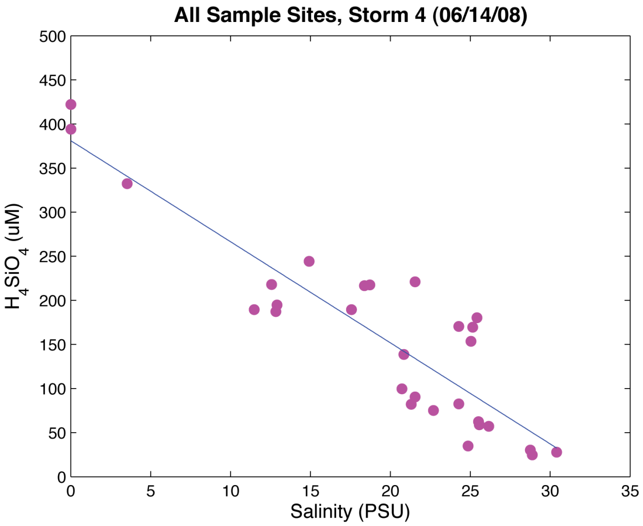


Appendix 7.12. Water column H_4SiO_4 data for all sample sites during a (A) wet season storm (Storm 1) and (B) dry season storm (Storm 4).

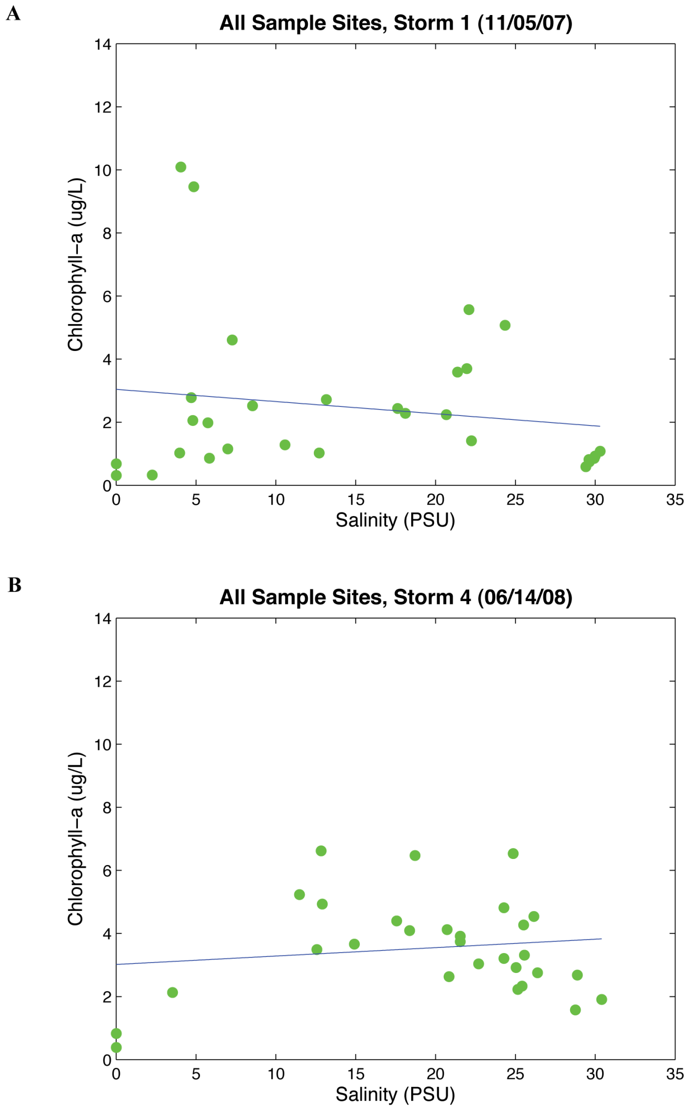
A



B

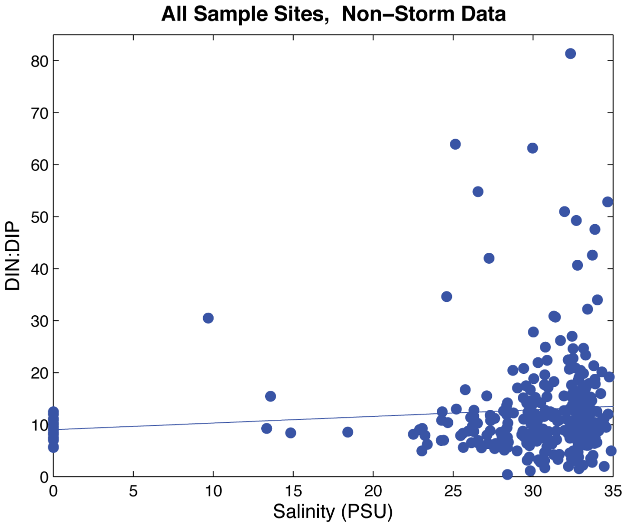


Appendix 7.13. Water column chl-a data for all sample sites during a (A) wet season storm (Storm 1) and (B) dry season storm (Storm 4).

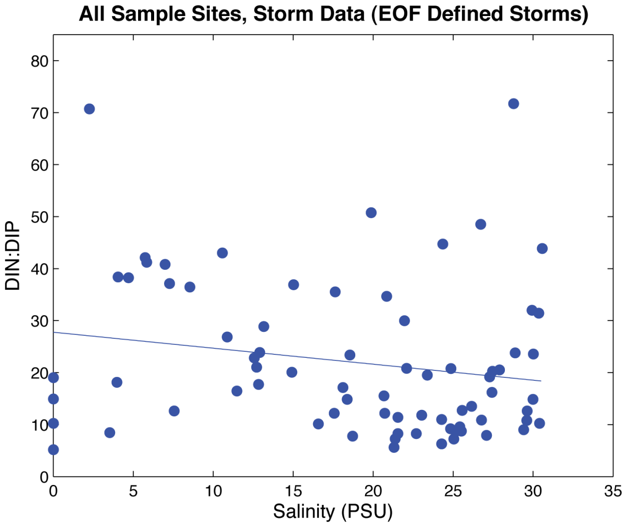


Appendix 8.1a. Water column DIN:DIP ratio data for all sample sites during (A) non-storm monthly sampling events (12 months) and (B) storm sampling events (Storm 1, Transects 1-4, and Storm 4).

A

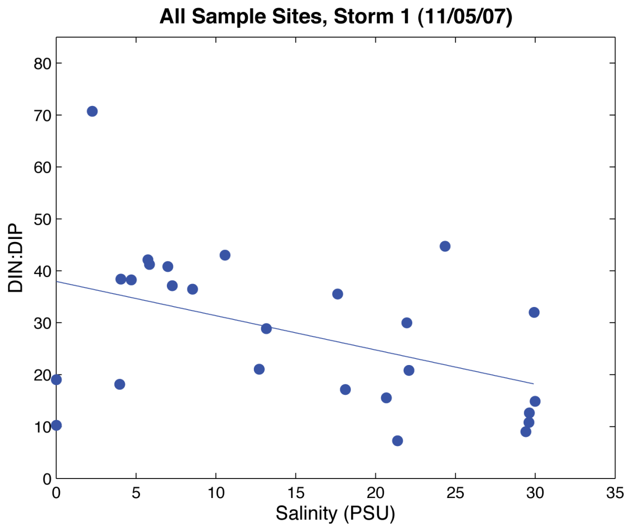


B

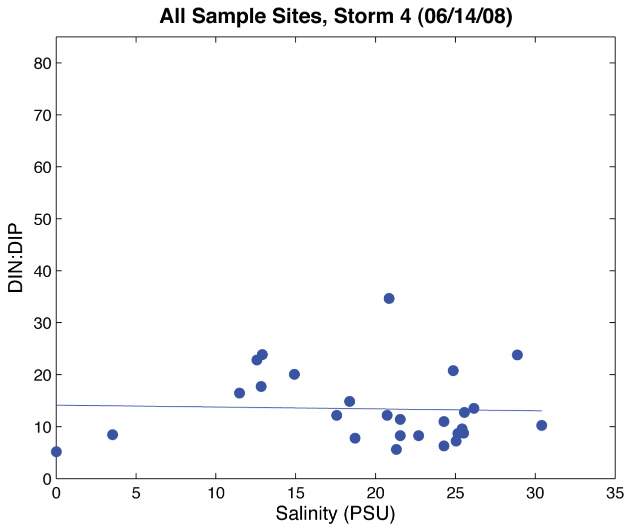


Appendix 8.1b. Water column DIN:DIP ratio data for all sample sites during a (A) wet season storm (Storm 1) and (B) dry season storm (Storm 4).

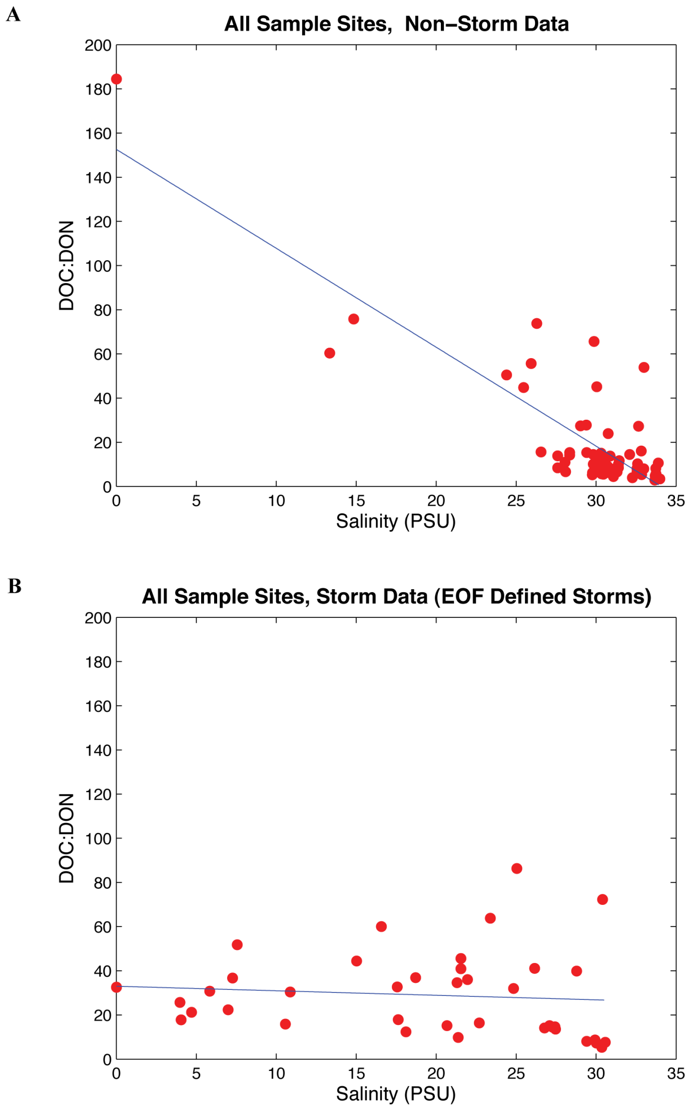
A



B

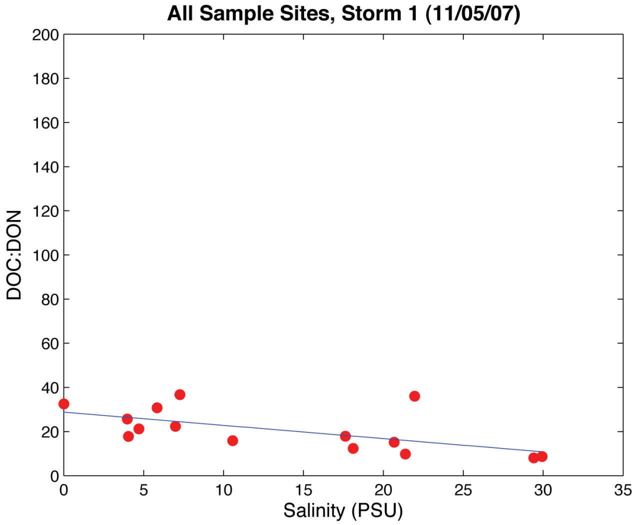


Appendix 8.2a. Water column DOC:DON ratio data for all sample sites during (A) non-storm monthly sampling events (12 months) and (B) storm sampling events (Storm 1, Transects 1-4, and Storm 4).

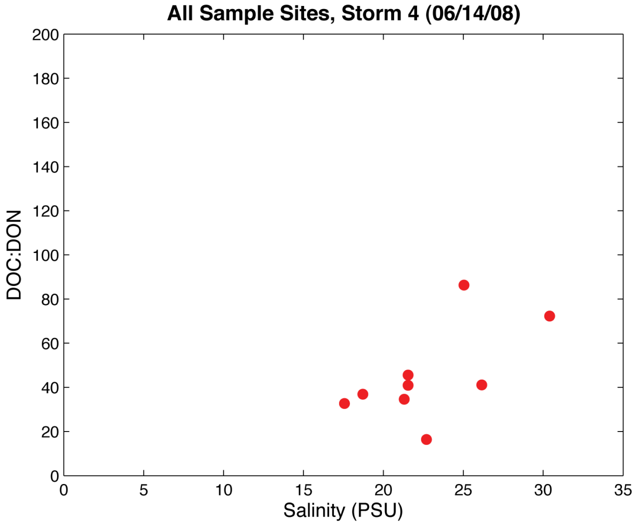


Appendix 8.2b. Water column DOC:DON ratio data for all sample sites during a (A) wet season storm (Storm 1) and (B) dry season storm (Storm 4). No conservative mixing line exists for Storm 4 due to an insufficient data set.

A

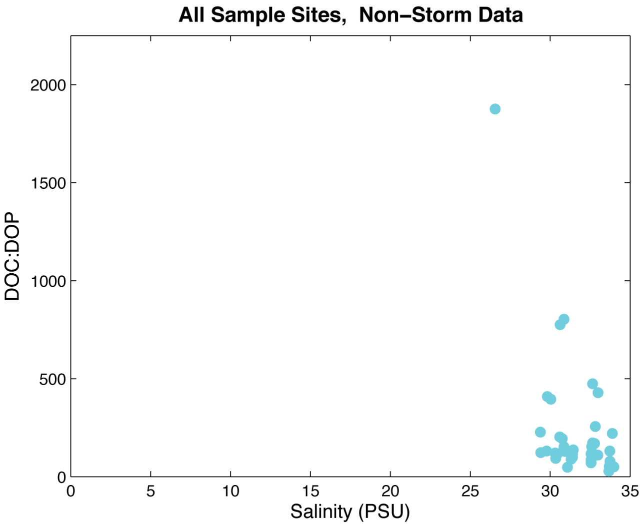


B

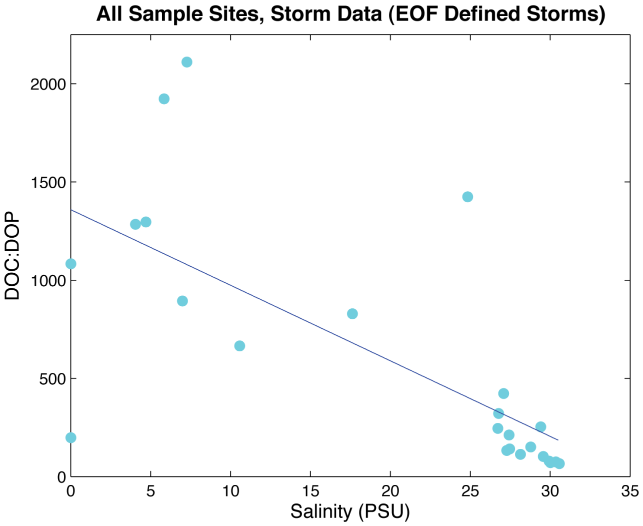


Appendix 8.3a. Water column DOC:DOP ratio data for all sample sites during (A) non-storm monthly sampling events (12 months) and (B) storm sampling events (Storm 1 and Transects 1-4). No conservative mixing line exists for Non-Storm conditions due to an insufficient data set.

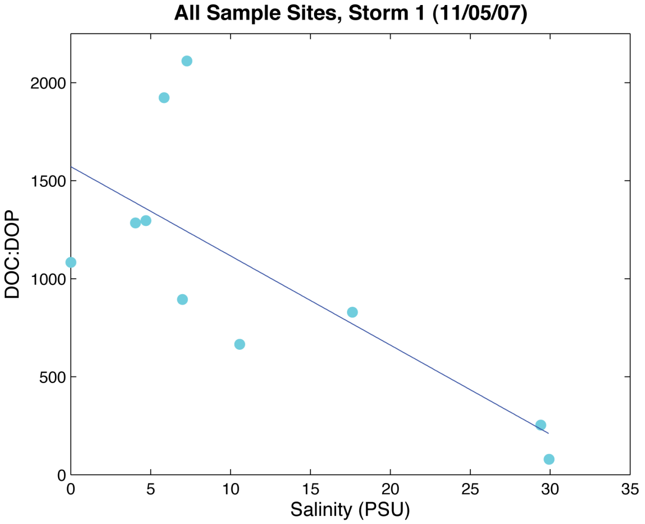
A



B

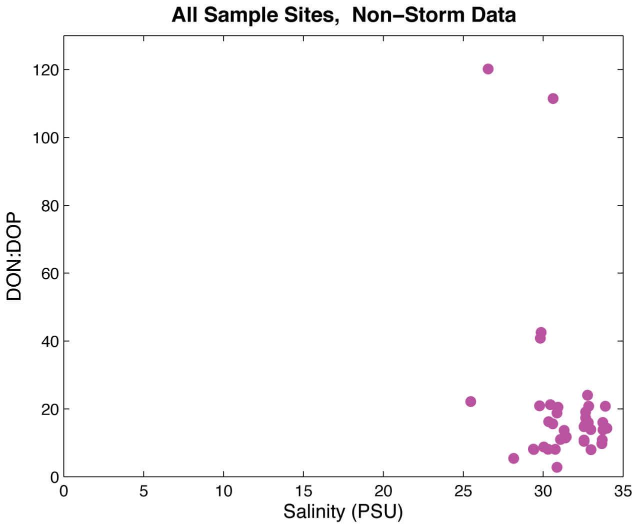


Appendix 8.3b. Water column DOC:DOP ratio data for all sample sites during a wet season storm (Storm 1) only (DOC:DOP ratio data are not available for Storm 4).

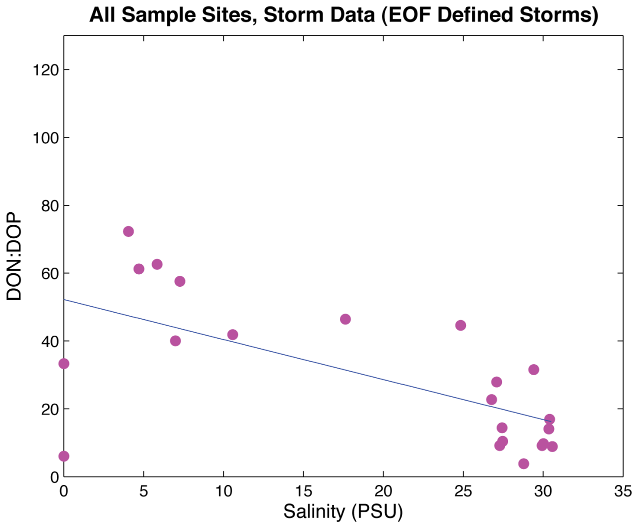


Appendix 8.4a. Water column DON:DOP ratio data for all sample sites during (A) non-storm monthly sampling events (12 months) and (B) storm sampling events (Storm 1 and Transects 1-4). No conservative mixing line exists for Non-Storm conditions due to an insufficient data set.

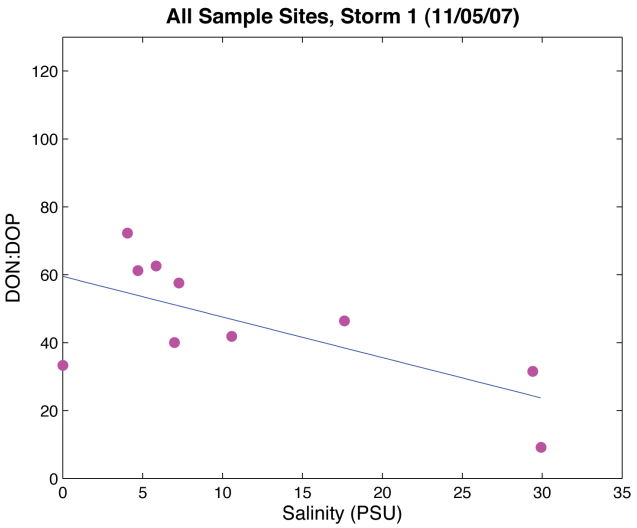
A



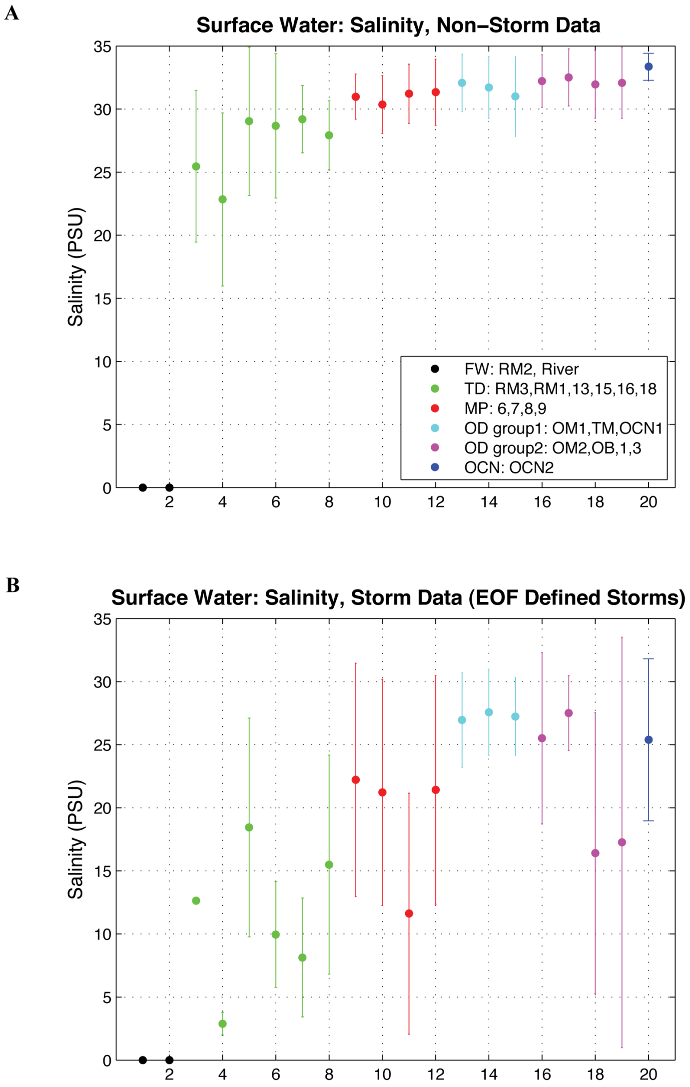
B



Appendix 8.4b. Water column DON:DOP ratio data for all sample sites during a wet season storm (Storm 1) only (DON:DOP ratio data are not available for Storm 4).

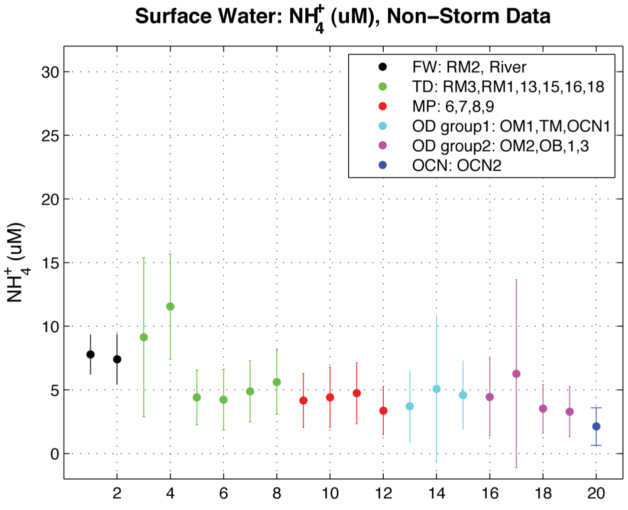


Appendix 9.1. Mean surface water salinity data and standard deviation for each sample site during (A) non-storm monthly sampling events (12 months; n=12) and (B) storm sampling events (Storm 1, Transects 1-4, and Storm 4; n=6). Color bins reflect similar background condition salinity trends. X-axis numbers are assigned to sample site (**1=RM2, 2=River, 3=RM3, 4=RM1, 5=Stk13, 6=Stk15, 7=Stk16, 8=Stk18, 9=Stk6, 10=Stk7, 11=Stk8, 12=Stk9, 13=OM1, 14=TM, 15=OCN1, 16=OM2, 17=OB, 18=Stk1, 19=Stk3, 20=OCN2**).

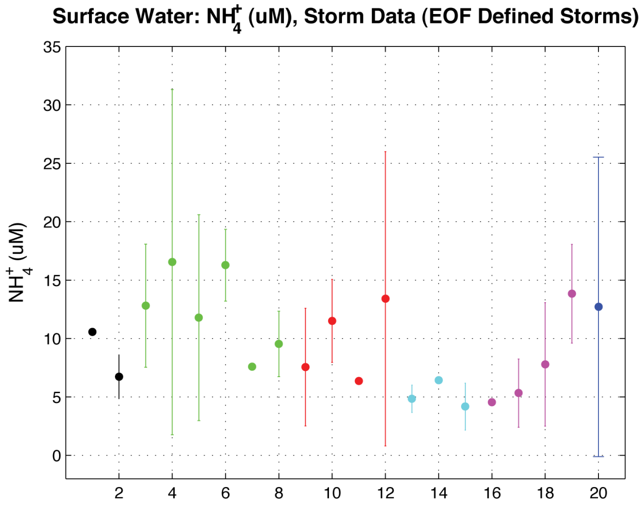


Appendix 9.2. Mean surface water NH_4^+ data and standard deviation for each sample site during (A) non-storm monthly sampling events (12 months; n=12) and (B) storm sampling events (Storm 1, Transects 1-4, and Storm 4; n=6). Color bins reflect similar background condition salinity trends. X-axis numbers are assigned to sample site (**1=RM2**, **2=River**, **3=RM3**, **4=RM1**, **5=Stk13**, **6=Stk15**, **7=Stk16**, **8=Stk18**, **9=Stk6**, **10=Stk7**, **11=Stk8**, **12=Stk9**, **13=OM1**, **14=TM**, **15=OCN1**, **16=OM2**, **17=OB**, **18=Stk1**, **19=Stk3**, **20=OCN2**).

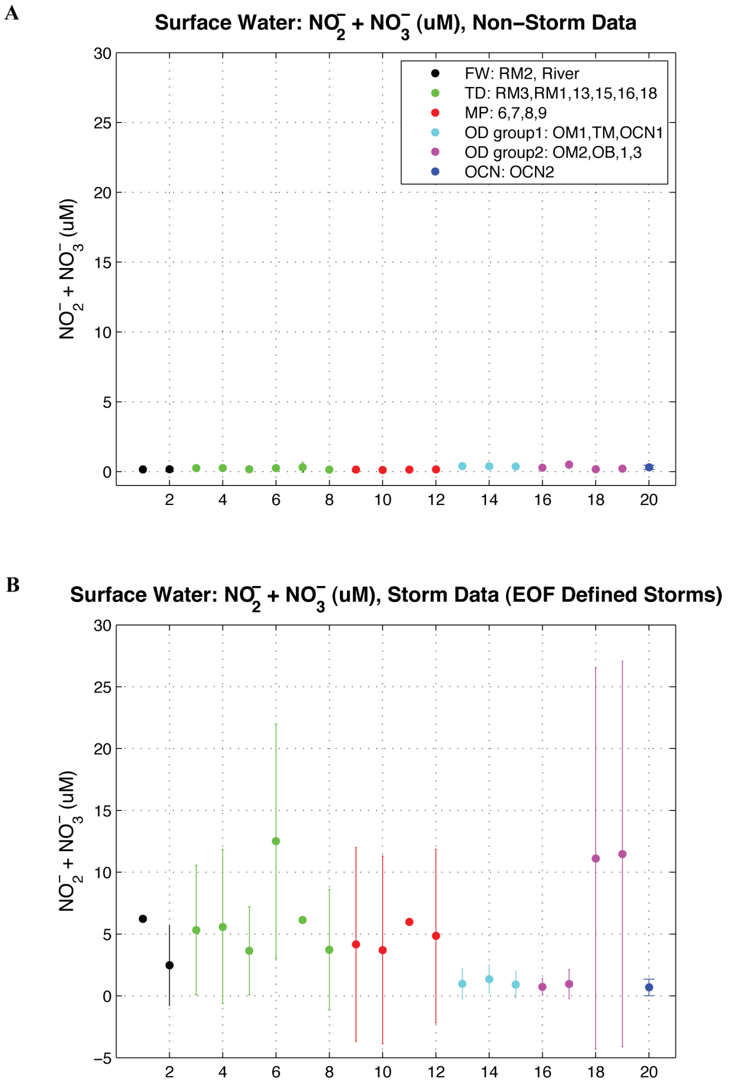
A



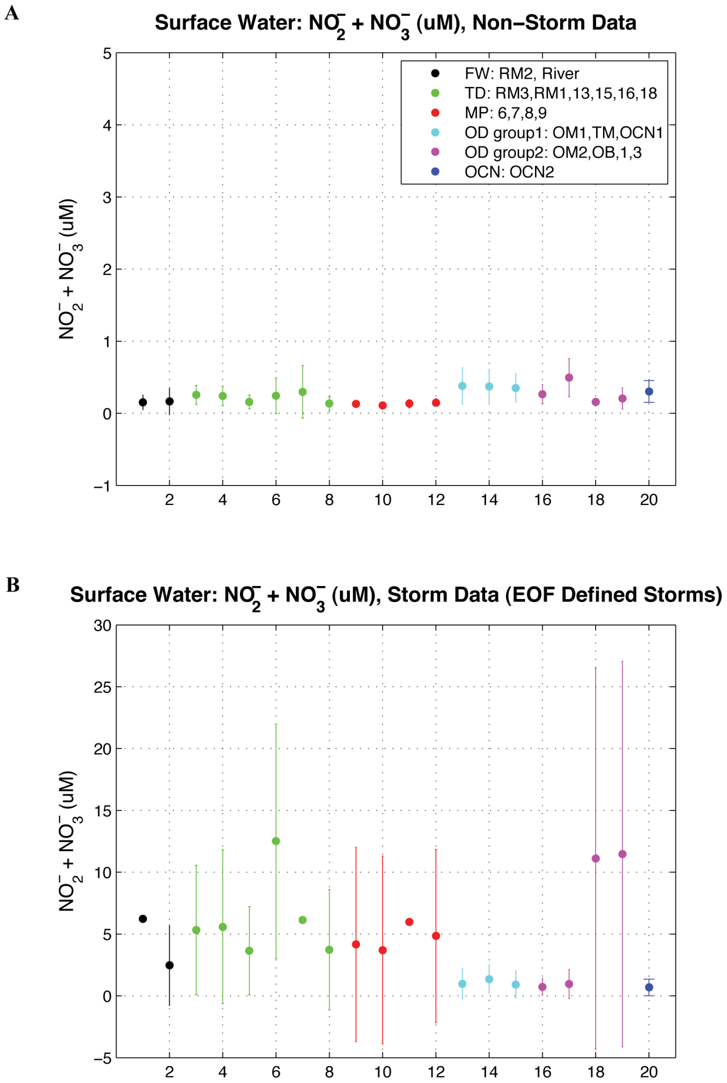
B



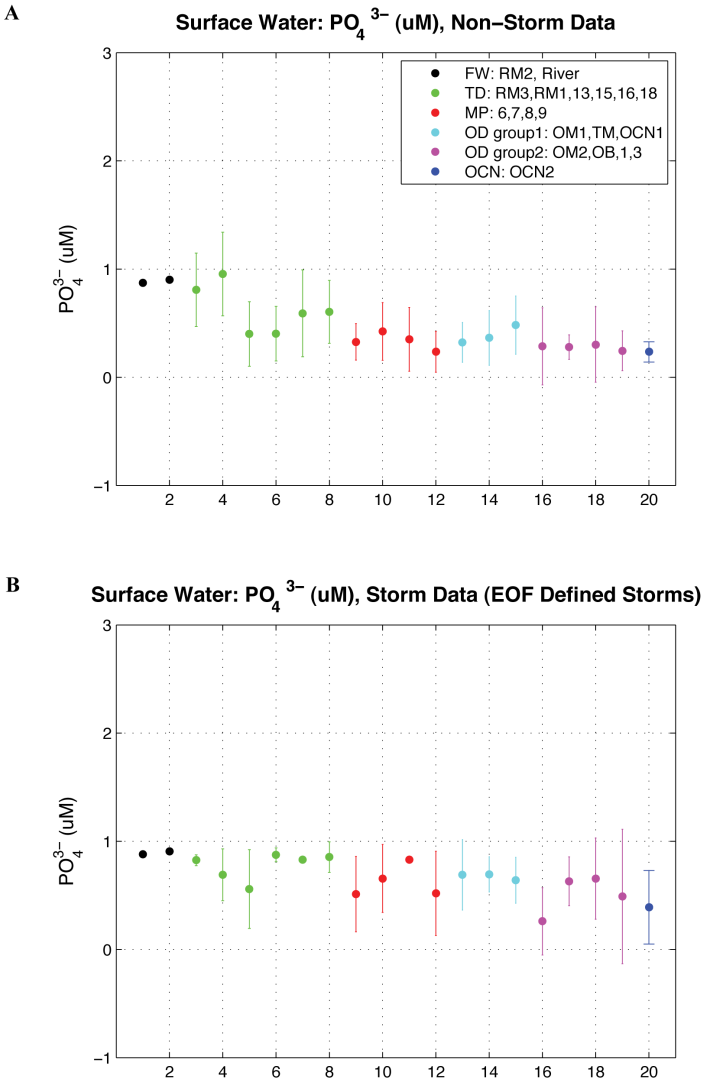
Appendix 9.3a. Mean surface water (NO_3^- + NO_2^-) data and standard deviation for each sample site during (A) non-storm monthly sampling events (12 months; n=12) and (B) storm sampling events (Storm 1, Transects 1-4, and Storm 4; n=6). Color bins reflect similar background condition salinity trends. X-axis numbers are assigned to sample site (**1=RM2**, **2=River**, **3=RM3**, **4=RM1**, **5=Stk13**, **6=Stk15**, **7=Stk16**, **8=Stk18**, **9=Stk6**, **10=Stk7**, **11=Stk8**, **12=Stk9**, **13=OM1**, **14=TM**, **15=OCN1**, **16=OM2**, **17=OB**, **18=Stk1**, **19=Stk3**, **20=OCN2**).



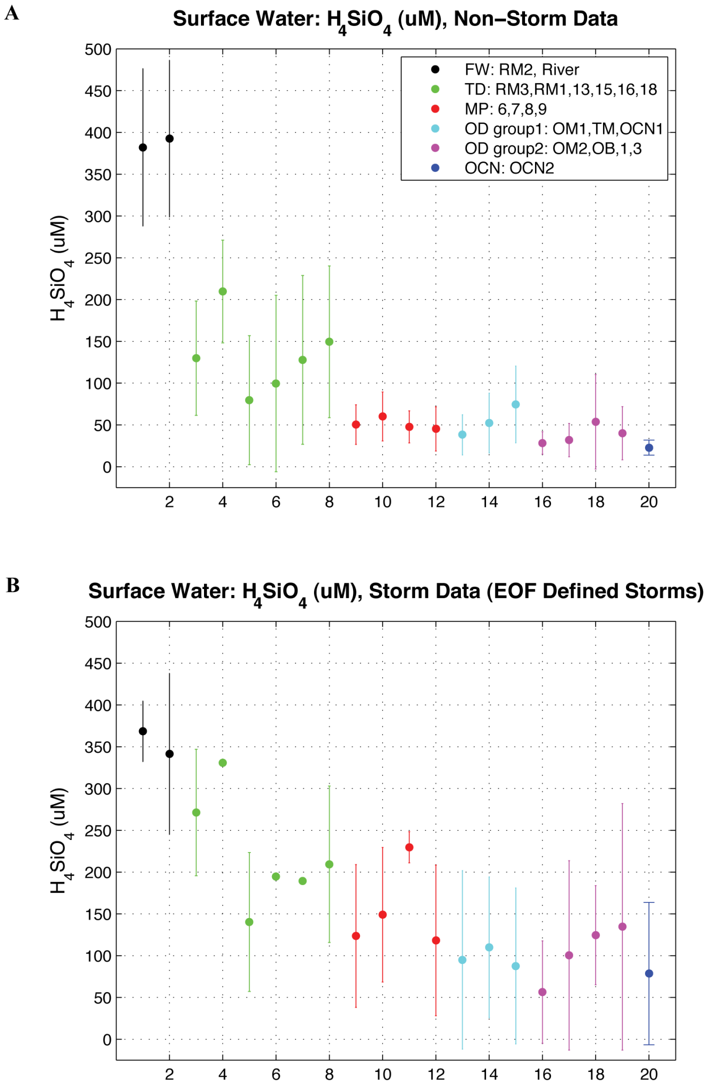
Appendix 9.3b. Expanded mean surface water (NO_3^- + NO_2^-) data and standard deviation for each sample site during (A) non-storm monthly sampling events (12 months; n=12) and (B) storm sampling events (Storm 1, Transects 1-4, and Storm 4; n=6). Color bins reflect similar background condition salinity trends. X-axis numbers are assigned to sample site (**1=RM2, 2=River, 3=RM3, 4=RM1, 5=Stk13, 6=Stk15, 7=Stk16, 8=Stk18, 9=Stk6, 10=Stk7, 11=Stk8, 12=Stk9, 13=OM1, 14=TM, 15=OCN1, 16=OM2, 17=OB, 18=Stk1, 19=Stk3, 20=OCN2**).



Appendix 9.4. Mean surface water PO_4^{3-} data and standard deviation for each sample site during (A) non-storm monthly sampling events (12 months; n=12) and (B) storm sampling events (Storm 1, Transects 1-4, and Storm 4; n=6). Color bins reflect similar background condition salinity trends. X-axis numbers are assigned to sample site (**1=RM2**, **2=River**, **3=RM3**, **4=RM1**, **5=Stk13**, **6=Stk15**, **7=Stk16**, **8=Stk18**, **9=Stk6**, **10=Stk7**, **11=Stk8**, **12=Stk9**, **13=OM1**, **14=TM**, **15=OCN1**, **16=OM2**, **17=OB**, **18=Stk1**, **19=Stk3**, **20=OCN2**).



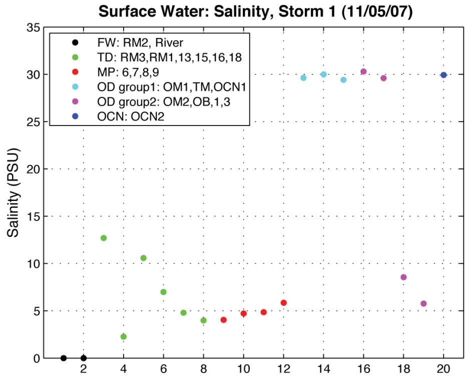
Appendix 9.5. Mean surface water H_4SiO_4 data and standard deviation for each sample site during (A) non-storm monthly sampling events (12 months; n=12) and (B) storm sampling events (Storm 1, Transects 1-4, and Storm 4; n=6). Color bins reflect similar background condition salinity trends. X-axis numbers are assigned to sample site (**1=RM2**, **2=River**, **3=RM3**, **4=RM1**, **5=Stk13**, **6=Stk15**, **7=Stk16**, **8=Stk18**, **9=Stk6**, **10=Stk7**, **11=Stk8**, **12=Stk9**, **13=OM1**, **14=TM**, **15=OCN1**, **16=OM2**, **17=OB**, **18=Stk1**, **19=Stk3**, **20=OCN2**).



Appendix 10.1. Surface water salinity data for all sample sites during the EOF defined storms: (A) wet season storm (Storm 1) and (B) dry season storm (Storm 4). (C) Storm 2 is added for reference and is not an EOF defined storm. Color bins reflect similar baseline salinity trends. X-axis numbers are assigned to sample site (**1=RM2, 2=River**, **3=RM3**, **4=RM1**, **5=Stk13**, **6=Stk15**, **7=Stk16**, **8=Stk18**, **9=Stk6**, **10=Stk7**, **11=Stk8**, **12=Stk9**, 13=OM1, 14=TM, 15=OCN1, **16=OM2**, **17=OB**, **18=Stk1**, **19=Stk3**, **20=OCN2**).

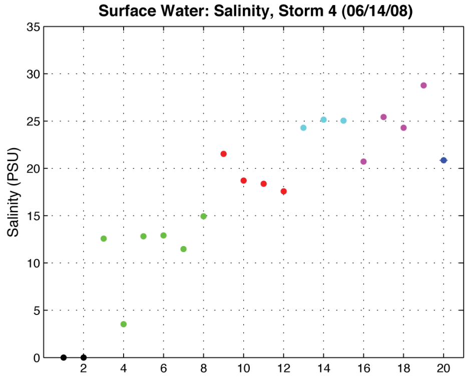
EOF Defined Storm:

A

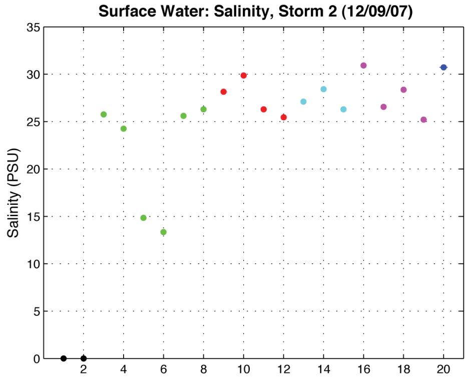


EOF Defined Storm:

B



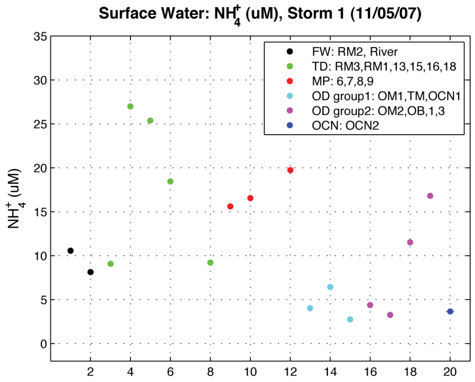
C



Appendix 10.2. Surface water NH_4^+ data for all sample sites during the EOF defined storms: (A) wet season storm (Storm 1) and (B) dry season storm (Storm 4). (C) Storm 2 is added for reference and is not an EOF defined storm. Color bins reflect similar baseline salinity trends. X-axis numbers are assigned to sample site (**1=RM2, 2=River**, **3=RM3**, **4=RM1**, **5=Stk13**, **6=Stk15**, **7=Stk16**, **8=Stk18**, **9=Stk6**, **10=Stk7**, **11=Stk8**, **12=Stk9**, **13=OM1**, **14=TM**, **15=OCN1**, **16=OM2**, **17=OB**, **18=Stk1**, **19=Stk3**, **20=OCN2**).

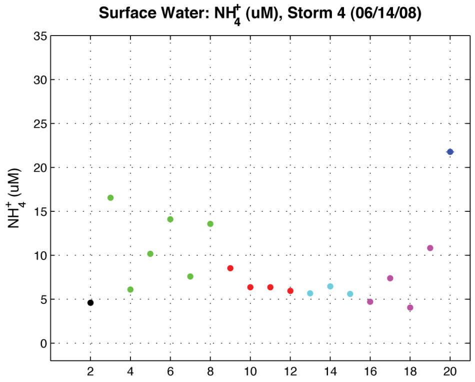
EOF Defined Storm:

A

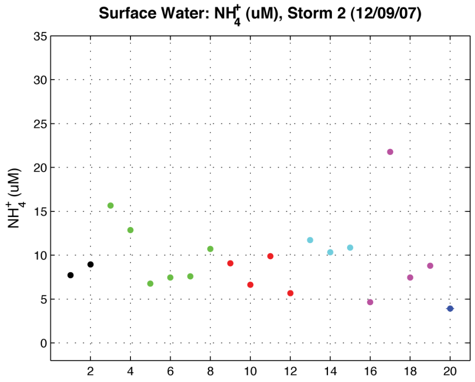


EOF Defined Storm:

B



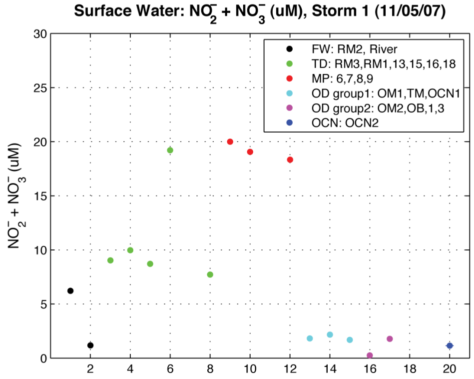
C



Appendix 10.3a. Surface water ($NO_3^- + NO_2^-$) data for all sample sites during the EOF defined storms: (A) wet season storm (Storm 1) and (B) dry season storm (Storm 4). (C) Storm 2 is added for reference and is not an EOF defined storm. Color bins reflect similar baseline salinity trends. X-axis numbers are assigned to sample site (**1=RM2, 2=River, 3=RM3, 4=RM1, 5=Stk13, 6=Stk15, 7=Stk16, 8=Stk18, 9=Stk6, 10=Stk7, 11=Stk8, 12=Stk9, 13=OM1, 14=TM, 15=OCN1, 16=OM2, 17=OB, 18=Stk1, 19=Stk3, 20=OCN2**).

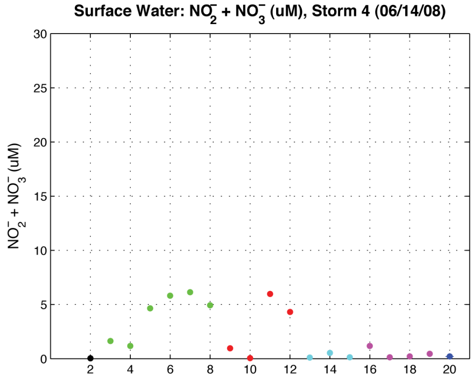
EOF Defined Storm:

A

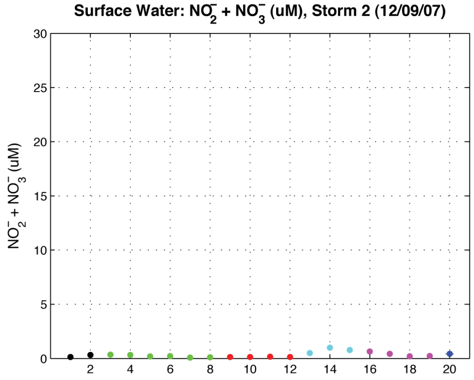


EOF Defined Storm:

B



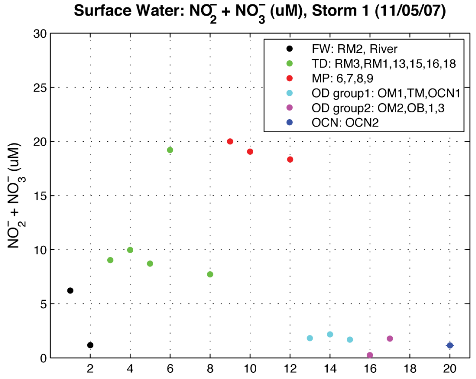
C



Appendix 10.3b. Expanded surface water ($NO_3^- + NO_2^-$) data for all sample sites during the EOF defined storms: (A) wet season storm (Storm 1) and (B) dry season storm (Storm 4). (C) Storm 2 is added for reference and is not an EOF defined storm. Color bins reflect similar baseline salinity trends. X-axis numbers are assigned to sample site (**1=RM2, 2=River, 3=RM3, 4=RM1, 5=Stk13, 6=Stk15, 7=Stk16, 8=Stk18, 9=Stk6, 10=Stk7, 11=Stk8, 12=Stk9, 13=OM1, 14=TM, 15=OCN1, 16=OM2, 17=OB, 18=Stk1, 19=Stk3, 20=OCN2**).

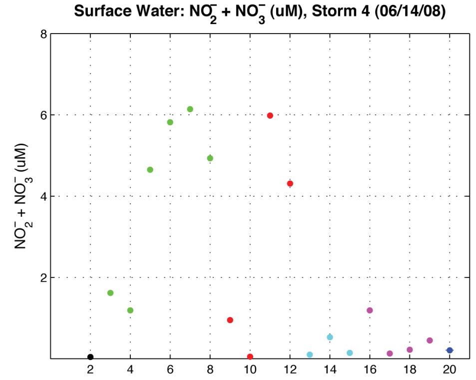
EOF Defined Storm:

A

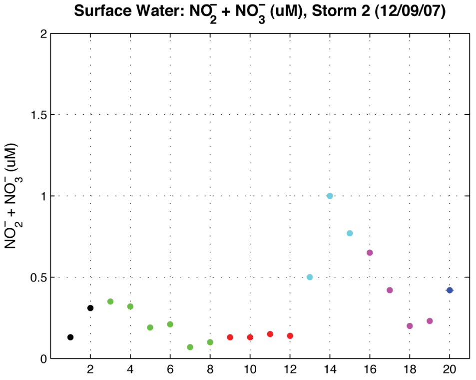


EOF Defined Storm:

B



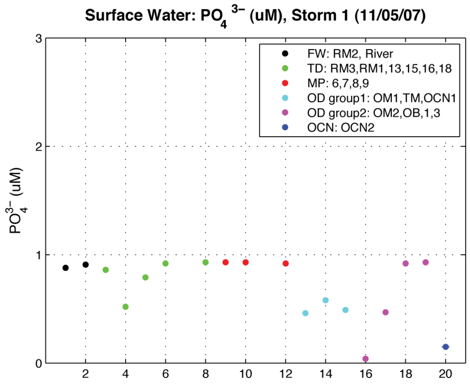
C



Appendix 10.4. Surface water PO_4^{3-} data for all sample sites during the EOF defined storms: (A) wet season storm (Storm 1) and (B) dry season storm (Storm 4). (C) Storm 2 is added for reference and is not an EOF defined storm. Color bins reflect similar baseline salinity trends. X-axis numbers are assigned to sample site (**1=RM2, 2=River**, **3=RM3**, **4=RM1**, **5=Stk13**, **6=Stk15**, **7=Stk16**, **8=Stk18**, **9=Stk6**, **10=Stk7**, **11=Stk8**, **12=Stk9**, **13=OM1**, **14=TM**, **15=OCN1**, **16=OM2**, **17=OB**, **18=Stk1**, **19=Stk3**, **20=OCN2**).

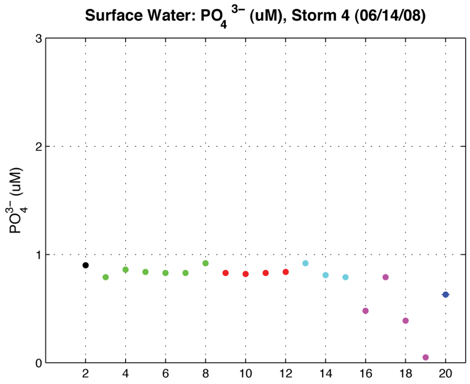
EOF Defined Storm:

A

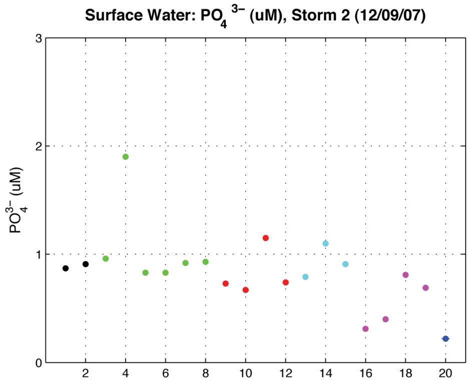


EOF Defined Storm:

B



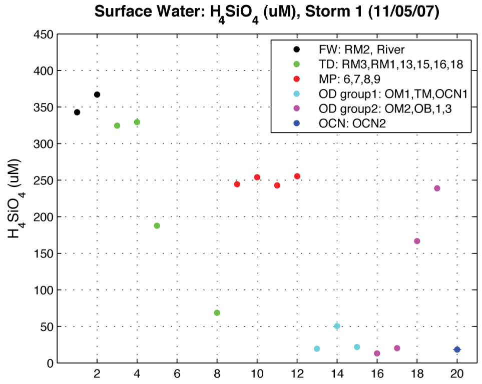
C



Appendix 10.5. Surface water H_4SiO_4 data for all sample sites during the EOF defined storms: (A) wet season storm (Storm 1) and (B) dry season storm (Storm 4). (C) Storm 2 is added for reference and is not an EOF defined storm. Color bins reflect similar baseline salinity trends. X-axis numbers are assigned to sample site (**1=RM2, 2=River, 3=RM3, 4=RM1, 5=Stk13, 6=Stk15, 7=Stk16, 8=Stk18, 9=Stk6, 10=Stk7, 11=Stk8, 12=Stk9, 13=OM1, 14=TM, 15=OCN1, 16=OM2, 17=OB, 18=Stk1, 19=Stk3, 20=OCN2**).

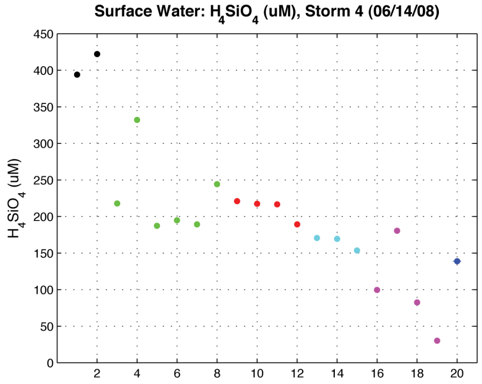
EOF Defined Storm:

A

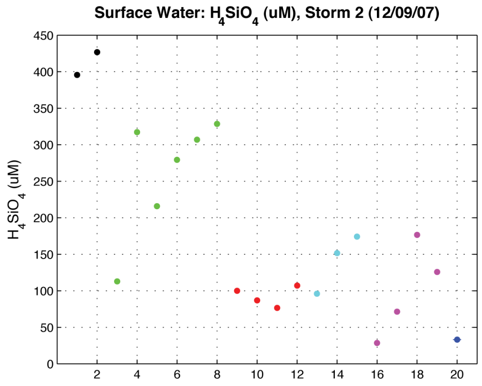

Surface Water: H_4SiO_4 (uM), Storm 1 (11/05/07)

EOF Defined Storm:

B


Surface Water: H_4SiO_4 (uM), Storm 4 (06/14/08)

C


Surface Water: H_4SiO_4 (uM), Storm 2 (12/09/07)

Appendix 11. Total Suspended Solids (TSS) in units of mg/l.

Site	Date	TSS	Date	TSS	Date	TSS
OM2	8/11/07	0.01368	9/15/07	0.00849	10/13/07	0.00992
OCN2	8/11/07	0.01076	9/15/07	0.00692	10/13/07	0.00496
OB	8/11/07	0.01385	9/15/07	0.01077	10/13/07	0.00255
OM1	8/11/07	0.00675	9/15/07	0.00913	10/13/07	0.00848
TM	8/11/07	0.01317	9/15/07	0.01871	10/13/07	0.01380
OCN1	8/11/07	0.01181	9/15/07	0.01167	10/13/07	0.00470
RM3	8/11/07	0.01179	9/15/07	0.01091	10/13/07	0.02061
RM2	8/11/07	0.00822	9/15/07	0.01019	10/13/07	0.00990
RM1	8/11/07	0.01451	9/15/07	0.00999	10/13/07	0.02047
River	8/11/07	0.00353	9/15/07	0.00442	10/13/07	0.00332
Stk1sfc	8/11/07	0.01766	9/15/07	0.01090	10/13/07	0.05271
Stk1deep	8/11/07	0.03429	9/15/07	0.01450	10/13/07	0.03347
Stk3sfc	8/11/07	0.01526	9/15/07	0.01127	10/13/07	0.03588
Stk3deep	8/11/07	0.01581	9/15/07	0.01115	10/13/07	0.02179
Stk6sfc	8/11/07	0.02233	9/15/07	0.02274	10/13/07	0.02348
Stk6deep	8/11/07	0.02338	9/15/07	0.02524	10/13/07	0.03724
Stk7sfc	8/11/07	0.02978	9/15/07	0.01590	10/13/07	0.01281
Stk7deep	8/11/07	0.00877	9/15/07	0.01625	10/13/07	0.04045
Stk8sfc	8/11/07	0.02100	9/15/07	0.02172	10/13/07	0.02405
Stk8deep	8/11/07	0.02153	9/15/07	0.02371	10/13/07	NaN
Stk9sfc	8/11/07	0.00813	9/15/07	0.02192	10/13/07	0.02213
Stk9deep	8/11/07	0.01515	9/15/07	0.00873	10/13/07	0.03627
Stk13sfc	8/11/07	0.01259	9/15/07	0.01651	10/13/07	0.02591
Stk13deep	8/11/07	0.01979	9/15/07	0.01922	10/13/07	0.01971
Stk15sfc	8/11/07	0.01773	9/15/07	0.01294	10/13/07	0.07009
Stk15deep	8/11/07	NaN	9/15/07	0.01175	10/13/07	0.01788
Stk16sfc	8/11/07	0.00368	9/15/07	0.01078	10/13/07	NaN
Stk16deep	8/11/07	0.01521	9/15/07	0.00898	10/13/07	0.00743
Stk18sfc	8/11/07	0.01857	9/15/07	0.01847	10/13/07	0.01711
Stk18deep	8/11/07	NaN	9/15/07	0.01941	10/13/07	0.02148

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. “NaN” is defined as “Not a Number” when a parameter was not measured.)

Storm 1 Site	Date	TSS	Transects 1-4 Site	Date	TSS
River	11/4/07	0.03728	Stk6sfc	11/6/07	0.08647
Stk10sfc	11/4/07	0.03874	Stk7sfc	11/6/07	0.33672
Stk18sfc	11/4/07	0.04243	Stk9sfc	11/6/07	0.11115
OM2	11/5/07	0.00992	Stk11sfc	11/6/07	0.03192
OCN2	11/5/07	0.00496	Stk13sfc	11/6/07	0.03155
OB	11/5/07	0.00255	Stk18sfc	11/6/07	0.55075
OM1	11/5/07	0.00848	Stk6sfc	11/7/07	0.03897
TM	11/5/07	0.01380	Stk7sfc	11/7/07	0.03871
OCN1	11/5/07	0.00470	Stk9sfc	11/7/07	0.04626
RM3	11/5/07	0.02061	Stk11sfc	11/7/07	0.03716
RM2	11/5/07	0.00990	Stk13sfc	11/7/07	0.02803
RM1	11/5/07	0.02047	Stk18sfc	11/7/07	0.10430
River	11/5/07	0.00332	Stk6sfc	11/8/07	0.02255
Stk1sfc	11/5/07	0.05271	Stk7sfc	11/8/07	0.02277
Stk1deep	11/5/07	0.03347	Stk9sfc	11/8/07	0.01483
Stk3sfc	11/5/07	0.03588	Stk11sfc	11/8/07	0.02026
Stk3deep	11/5/07	0.02179	Stk13sfc	11/8/07	0.04155
Stk6sfc	11/5/07	0.02348	Stk18sfc	11/8/07	0.02562
Stk6deep	11/5/07	0.03724	Stk6sfc	11/11/07	0.02253
Stk7sfc	11/5/07	0.01281	Stk7sfc	11/11/07	0.01826
Stk7deep	11/5/07	0.04045	Stk9sfc	11/11/07	0.02692
Stk8sfc	11/5/07	0.02405	Stk11sfc	11/11/07	0.04029
Stk8deep	11/5/07	NaN	Stk13sfc	11/11/07	0.01846
Stk9sfc	11/5/07	0.02213	Stk18sfc	11/11/07	0.02074
Stk9deep	11/5/07	0.03627			
Stk13sfc	11/5/07	0.02591			
Stk13deep	11/5/07	0.01971			
Stk15sfc	11/5/07	0.07009			
Stk15deep	11/5/07	0.01788			
Stk16sfc	11/5/07	NaN			
Stk16deep	11/5/07	0.00743			
Stk18sfc	11/5/07	0.01711			
Stk18deep	11/5/07	0.02148			

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. "NaN" is defined as "Not a Number" when a parameter was not measured.)

Storm 2

Site	Date	TSS	Date	TSS	Date	TSS
OM2	11/17/07	0.00687	12/9/07	0.00827	1/12/08	0.01338
OCN2	11/17/07	0.00728	12/9/07	0.01165	1/12/08	0.01250
OB	11/17/07	0.00756	12/9/07	0.00595	1/12/08	0.01444
OM1	11/17/07	0.01079	12/9/07	0.00762	1/12/08	0.01504
TM	11/17/07	0.00624	12/9/07	0.00639	1/12/08	0.00943
OCN1	11/17/07	0.00654	12/9/07	0.00655	1/12/08	0.00915
RM3	11/17/07	0.00616	12/9/07	0.01370	1/12/08	0.01011
RM2	11/17/07	0.00927	12/9/07	0.00922	1/12/08	0.01393
RM1	11/17/07	0.00614	12/9/07	0.00588	1/12/08	0.01407
River	11/17/07	0.00147	12/9/07	0.00429	1/12/08	0.01307
Stk1sfc	11/17/07	0.01168	12/9/07	0.00667	1/12/08	0.00825
Stk1deep	11/17/07	0.01071	12/9/07	0.01188	1/12/08	0.01339
Stk3sfc	11/17/07	0.00998	12/9/07	0.00651	1/12/08	0.00882
Stk3deep	11/17/07	0.01188	12/9/07	0.01002	1/12/08	0.01213
Stk6sfc	11/17/07	0.01026	12/9/07	0.01015	1/12/08	0.01000
Stk6deep	11/17/07	0.01430	12/9/07	0.01552	1/12/08	0.02044
Stk7sfc	11/17/07	0.01167	12/9/07	0.00770	1/12/08	0.00785
Stk7deep	11/17/07	0.01220	12/9/07	0.01405	1/12/08	0.01685
Stk8sfc	11/17/07	0.00867	12/9/07	0.00806	1/12/08	0.00986
Stk8deep	11/17/07	0.00771	12/9/07	0.01337	1/12/08	0.01444
Stk9sfc	11/17/07	0.00888	12/9/07	0.00504	1/12/08	0.00859
Stk9deep	11/17/07	0.00821	12/9/07	0.01116	1/12/08	0.01183
Stk13sfc	11/17/07	0.00803	12/9/07	0.00673	1/12/08	0.01184
Stk13deep	11/17/07	0.01038	12/9/07	0.01456	1/12/08	0.01207
Stk15sfc	11/17/07	0.00713	12/9/07	0.00510	1/12/08	0.01187
Stk15deep	11/17/07	0.00780	12/9/07	0.01021	1/12/08	0.01147
Stk16sfc	11/17/07	0.00530	12/9/07	0.00743	1/12/08	0.01246
Stk16deep	11/17/07	NaN	12/9/07	0.01165	1/12/08	0.01255
Stk18sfc	11/17/07	0.00630	12/9/07	0.00630	1/12/08	0.00653
Stk18deep	11/17/07	0.01026	12/9/07	0.02573	1/12/08	0.01874

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. “NaN” is defined as “Not a Number” when a parameter was not measured.)

Site	Date	TSS	Date	TSS	Date	TSS
OM2	2/16/08	0.00962	3/15/08	0.01509	4/19/08	NaN
OCN2	2/16/08	0.01244	3/15/08	0.01402	4/19/08	NaN
OB	2/16/08	0.00816	3/15/08	0.00934	4/19/08	NaN
OM1	2/16/08	0.01135	3/15/08	0.01256	4/19/08	0.03154
TM	2/16/08	0.01267	3/15/08	0.01137	4/19/08	NaN
OCN1	2/16/08	0.01036	3/15/08	0.01023	4/19/08	0.03076
RM3	2/16/08	0.02538	3/15/08	0.02478	4/19/08	0.04165
RM2	2/16/08	0.00946	3/15/08	0.00758	4/19/08	NaN
RM1	2/16/08	0.00787	3/15/08	0.00999	4/19/08	NaN
River	2/16/08	0.00289	3/15/08	0.00161	4/19/08	NaN
Stk1sfc	2/16/08	0.00830	3/15/08	0.00905	4/19/08	NaN
Stk1deep	2/16/08	0.01191	3/15/08	0.01645	4/19/08	NaN
Stk3sfc	2/16/08	0.01044	3/15/08	0.01212	4/19/08	NaN
Stk3deep	2/16/08	0.01104	3/15/08	0.01761	4/19/08	0.01265
Stk6sfc	2/16/08	0.02813	3/15/08	NaN	4/19/08	NaN
Stk6deep	2/16/08	0.10471	3/15/08	0.01625	4/19/08	NaN
Stk7sfc	2/16/08	0.02929	3/15/08	0.06327	4/19/08	NaN
Stk7deep	2/16/08	0.02031	3/15/08	0.02289	4/19/08	NaN
Stk8sfc	2/16/08	0.01109	3/15/08	NaN	4/19/08	NaN
Stk8deep	2/16/08	0.01518	3/15/08	0.01490	4/19/08	NaN
Stk9sfc	2/16/08	0.00661	3/15/08	NaN	4/19/08	NaN
Stk9deep	2/16/08	0.03103	3/15/08	0.04990	4/19/08	NaN
Stk13sfc	2/16/08	0.01314	3/15/08	NaN	4/19/08	NaN
Stk13deep	2/16/08	0.00676	3/15/08	0.01181	4/19/08	NaN
Stk15sfc	2/16/08	0.01413	3/15/08	NaN	4/19/08	NaN
Stk15deep	2/16/08	0.02148	3/15/08	0.00778	4/19/08	NaN
Stk16sfc	2/16/08	0.06094	3/15/08	NaN	4/19/08	NaN
Stk16deep	2/16/08	0.03723	3/15/08	0.03800	4/19/08	NaN
Stk18sfc	2/16/08	0.00922	3/15/08	NaN	4/19/08	NaN
Stk18deep	2/16/08	0.04551	3/15/08	0.02221	4/19/08	NaN

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. “NaN” is defined as “Not a Number” when a parameter was not measured.)

Storm 4

Site	Date	TSS	Date	TSS	Date	TSS
OM2	5/17/08	0.00482	6/14/08	0.00854	7/26/08	0.01204
OCN2	5/17/08	0.00586	6/14/08	0.00799	7/26/08	0.01246
OB	5/17/08	0.00349	6/14/08	0.01052	7/26/08	0.01187
OM1	5/17/08	0.00345	6/14/08	0.01175	7/26/08	0.01215
TM	5/17/08	0.00479	6/14/08	0.00919	7/26/08	0.00375
OCN1	5/17/08	0.00378	6/14/08	0.00835	7/26/08	0.01335
RM3	5/17/08	0.00545	6/14/08	0.00962	7/26/08	0.01325
RM2	5/17/08	0.00734	6/14/08	0.00902	7/26/08	0.00698
RM1	5/17/08	0.01211	6/14/08	0.00937	7/26/08	0.00467
River	5/17/08	0.00187	6/14/08	0.00475	7/26/08	0.00088
Stk1sfc	5/17/08	0.00391	6/14/08	0.00814	7/26/08	0.01666
Stk1deep	5/17/08	0.00255	6/14/08	0.01368	7/26/08	0.02083
Stk3sfc	5/17/08	0.00335	6/14/08	0.01244	7/26/08	0.01442
Stk3deep	5/17/08	0.00389	6/14/08	0.01551	7/26/08	0.02354
Stk6sfc	5/17/08	0.00387	6/14/08	0.01221	7/26/08	0.01348
Stk6deep	5/17/08	0.00785	6/14/08	0.01424	7/26/08	0.01633
Stk7sfc	5/17/08	0.00700	6/14/08	0.00963	7/26/08	0.01415
Stk7deep	5/17/08	NaN	6/14/08	0.02473	7/26/08	0.02306
Stk8sfc	5/17/08	0.00950	6/14/08	0.00635	7/26/08	0.01386
Stk8deep	5/17/08	NaN	6/14/08	0.01999	7/26/08	0.02037
Stk9sfc	5/17/08	0.00213	6/14/08	0.00926	7/26/08	0.02507
Stk9deep	5/17/08	0.00374	6/14/08	0.00951	7/26/08	0.01230
Stk13sfc	5/17/08	0.00732	6/14/08	0.01034	7/26/08	0.01357
Stk13deep	5/17/08	0.01165	6/14/08	0.02761	7/26/08	0.01601
Stk15sfc	5/17/08	0.00682	6/14/08	0.00774	7/26/08	0.01851
Stk15deep	5/17/08	0.00487	6/14/08	0.00576	7/26/08	0.02356
Stk16sfc	5/17/08	0.00645	6/14/08	0.00690	7/26/08	0.00015
Stk16deep	5/17/08	0.00448	6/14/08	0.01210	7/26/08	0.00397
Stk18sfc	5/17/08	0.00811	6/14/08	0.00813	7/26/08	0.02177
Stk18deep	5/17/08	0.00489	6/14/08	NaN	7/26/08	0.01324

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. “NaN” is defined as “Not a Number” when a parameter was not measured.)

Site	Date	TSS
OM2	8/30/08	0.01601
OCN2	8/30/08	0.01365
OB	8/30/08	0.01576
OM1	8/30/08	0.01167
TM	8/30/08	NaN
OCN1	8/30/08	0.02215
RM3	8/30/08	NaN
RM2	8/30/08	NaN
RM1	8/30/08	NaN
River	8/30/08	NaN
Stk1sfc	8/30/08	NaN
Stk1deep	8/30/08	NaN
Stk3sfc	8/30/08	NaN
Stk3deep	8/30/08	NaN
Stk6sfc	8/30/08	NaN
Stk6deep	8/30/08	NaN
Stk7sfc	8/30/08	NaN
Stk7deep	8/30/08	NaN
Stk8sfc	8/30/08	NaN
Stk8deep	8/30/08	NaN
Stk9sfc	8/30/08	NaN
Stk9deep	8/30/08	NaN
Stk13sfc	8/30/08	NaN
Stk13deep	8/30/08	NaN
Stk15sfc	8/30/08	NaN
Stk15deep	8/30/08	NaN
Stk16sfc	8/30/08	NaN
Stk16deep	8/30/08	NaN
Stk18sfc	8/30/08	NaN
Stk18deep	8/30/08	NaN

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. “NaN” is defined as “Not a Number” when a parameter was not measured.)

Appendix 12. Photosynthetic pigments in units of μg/l.

Site	Date	TChl a	Fuco	Zeax	Chl b	Hex-fuco	Per
OM2	8/11/07	0.97	NaN	NaN	NaN	NaN	NaN
OCN2	8/11/07	1.15	NaN	NaN	NaN	NaN	NaN
OB	8/11/07	0.51	NaN	NaN	NaN	NaN	NaN
OM1	8/11/07	0.43	NaN	NaN	NaN	NaN	NaN
TM	8/11/07	0.85	NaN	NaN	NaN	NaN	NaN
OCN1	8/11/07	0.90	NaN	NaN	NaN	NaN	NaN
RM3	8/11/07	0.99	NaN	NaN	NaN	NaN	NaN
RM2	8/11/07	0.79	NaN	NaN	NaN	NaN	NaN
RM1	8/11/07	2.04	NaN	NaN	NaN	NaN	NaN
River	8/11/07	0.47	NaN	NaN	NaN	NaN	NaN
Stk1sfc	8/11/07	1.25	NaN	NaN	NaN	NaN	NaN
Stk1deep	8/11/07	0.48	NaN	NaN	NaN	NaN	NaN
Stk3sfc	8/11/07	0.24	NaN	NaN	NaN	NaN	NaN
Stk3deep	8/11/07	0.67	NaN	NaN	NaN	NaN	NaN
Stk6sfc	8/11/07	2.66	NaN	NaN	NaN	NaN	NaN
Stk6deep	8/11/07	2.08	NaN	NaN	NaN	NaN	NaN
Stk7sfc	8/11/07	2.60	NaN	NaN	NaN	NaN	NaN
Stk7deep	8/11/07	2.64	NaN	NaN	NaN	NaN	NaN
Stk8sfc	8/11/07	1.57	NaN	NaN	NaN	NaN	NaN
Stk8deep	8/11/07	1.56	NaN	NaN	NaN	NaN	NaN
Stk9sfc	8/11/07	1.31	NaN	NaN	NaN	NaN	NaN
Stk9deep	8/11/07	2.35	NaN	NaN	NaN	NaN	NaN
Stk13sfc	8/11/07	2.20	NaN	NaN	NaN	NaN	NaN
Stk13deep	8/11/07	1.02	NaN	NaN	NaN	NaN	NaN
Stk15sfc	8/11/07	1.39	NaN	NaN	NaN	NaN	NaN
Stk15deep	8/11/07	1.12	NaN	NaN	NaN	NaN	NaN
Stk16sfc	8/11/07	1.38	NaN	NaN	NaN	NaN	NaN
Stk16deep	8/11/07	1.97	NaN	NaN	NaN	NaN	NaN
Stk18sfc	8/11/07	2.28	NaN	NaN	NaN	NaN	NaN
Stk18deep	8/11/07	2.56	NaN	NaN	NaN	NaN	NaN

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location, Table 5.1 for pigment abbreviation. “NaN” is defined as “Not a Number” when a parameter was not measured.)

Site	Date	TChl a	Fuco	Zeax	Chl b	Hex-fuco	Per
OM2	9/15/07	0.64	NaN	NaN	NaN	NaN	NaN
OCN2	9/15/07	0.56	NaN	NaN	NaN	NaN	NaN
OB	9/15/07	0.64	NaN	NaN	NaN	NaN	NaN
OM1	9/15/07	0.28	NaN	NaN	NaN	NaN	NaN
TM	9/15/07	0.80	NaN	NaN	NaN	NaN	NaN
OCN1	9/15/07	0.56	NaN	NaN	NaN	NaN	NaN
RM3	9/15/07	1.12	NaN	NaN	NaN	NaN	NaN
RM2	9/15/07	1.20	NaN	NaN	NaN	NaN	NaN
RM1	9/15/07	0.72	NaN	NaN	NaN	NaN	NaN
River	9/15/07	4.33	NaN	NaN	NaN	NaN	NaN
Stk1sfc	9/15/07	1.12	NaN	NaN	NaN	NaN	NaN
Stk1deep	9/15/07	0.96	NaN	NaN	NaN	NaN	NaN
Stk3sfc	9/15/07	0.56	NaN	NaN	NaN	NaN	NaN
Stk3deep	9/15/07	0.40	NaN	NaN	NaN	NaN	NaN
Stk6sfc	9/15/07	0.96	NaN	NaN	NaN	NaN	NaN
Stk6deep	9/15/07	1.44	NaN	NaN	NaN	NaN	NaN
Stk7sfc	9/15/07	1.92	NaN	NaN	NaN	NaN	NaN
Stk7deep	9/15/07	1.76	NaN	NaN	NaN	NaN	NaN
Stk8sfc	9/15/07	2.56	NaN	NaN	NaN	NaN	NaN
Stk8deep	9/15/07	2.40	NaN	NaN	NaN	NaN	NaN
Stk9sfc	9/15/07	1.12	NaN	NaN	NaN	NaN	NaN
Stk9deep	9/15/07	1.12	NaN	NaN	NaN	NaN	NaN
Stk13sfc	9/15/07	0.64	NaN	NaN	NaN	NaN	NaN
Stk13deep	9/15/07	0.56	NaN	NaN	NaN	NaN	NaN
Stk15sfc	9/15/07	1.44	NaN	NaN	NaN	NaN	NaN
Stk15deep	9/15/07	1.52	NaN	NaN	NaN	NaN	NaN
Stk16sfc	9/15/07	1.20	NaN	NaN	NaN	NaN	NaN
Stk16deep	9/15/07	2.89	NaN	NaN	NaN	NaN	NaN
Stk18sfc	9/15/07	1.92	NaN	NaN	NaN	NaN	NaN
Stk18deep	9/15/07	1.28	NaN	NaN	NaN	NaN	NaN

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location, Table 5.1 for pigment abbreviation. “NaN” is defined as “Not a Number” when a parameter was not measured.)

Site	Date	TChl a	Fuco	Zeax	Chl b	Hex-fuco	Per
OM2	10/13/07	0.81	NaN	NaN	NaN	NaN	NaN
OCN2	10/13/07	0.40	0.07	0.00	0.00	0.00	0.00
OB	10/13/07	0.75	NaN	NaN	NaN	NaN	NaN
OM1	10/13/07	1.30	NaN	NaN	NaN	NaN	NaN
TM	10/13/07	1.38	NaN	NaN	NaN	NaN	NaN
OCN1	10/13/07	0.37	0.10	0.00	0.00	0.00	0.00
RM3	10/13/07	3.11	NaN	NaN	NaN	NaN	NaN
RM2	10/13/07	1.49	NaN	NaN	NaN	NaN	NaN
RM1	10/13/07	0.69	NaN	NaN	NaN	NaN	NaN
River	10/13/07	2.98	0.30	0.00	0.33	0.00	0.00
Stk1sfc	10/13/07	2.42	NaN	NaN	NaN	NaN	NaN
Stk1deep	10/13/07	3.19	NaN	NaN	NaN	NaN	NaN
Stk3sfc	10/13/07	1.41	NaN	NaN	NaN	NaN	NaN
Stk3deep	10/13/07	1.34	NaN	NaN	NaN	NaN	NaN
Stk6sfc	10/13/07	1.19	0.27	0.00	0.00	0.00	0.05
Stk6deep	10/13/07	3.07	1.10	0.02	0.09	0.00	0.10
Stk7sfc	10/13/07	1.41	0.24	0.00	0.00	0.00	0.11
Stk7deep	10/13/07	2.09	0.51	0.00	0.15	0.00	0.11
Stk8sfc	10/13/07	2.20	NaN	NaN	NaN	NaN	NaN
Stk8deep	10/13/07	2.17	NaN	NaN	NaN	NaN	NaN
Stk9sfc	10/13/07	1.39	0.21	0.03	0.00	0.02	0.07
Stk9deep	10/13/07	1.33	0.21	0.02	0.11	0.00	0.08
Stk13sfc	10/13/07	4.66	0.46	0.04	0.18	0.02	0.54
Stk13deep	10/13/07	4.20	0.46	0.02	0.12	0.00	0.58
Stk15sfc	10/13/07	2.58	0.32	0.02	0.11	0.02	0.23
Stk15deep	10/13/07	2.60	0.37	0.02	0.15	0.03	0.25
Stk16sfc	10/13/07	3.26	NaN	NaN	NaN	NaN	NaN
Stk16deep	10/13/07	3.01	NaN	NaN	NaN	NaN	NaN
Stk18sfc	10/13/07	2.49	0.34	0.00	0.14	0.03	0.14
Stk18deep	10/13/07	1.86	0.38	0.02	0.20	0.00	0.07

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location, Table 5.1 for pigment abbreviation. "NaN" is defined as "Not a Number" when a parameter was not measured.)

Storm 1

Site	Date	TChl a	Fuco	Zeax	Chl b	Hex-fuco	Per
River	11/4/07	0.62	0.06	0.02	0.08	0.00	0.00
Stk10sfc	11/4/07	0.85	0.04	0.03	0.12	0.00	0.00
Stk18sfc	11/4/07	0.42	0.03	0.00	0.05	0.00	0.00
OM2	11/5/07	1.08	NaN	NaN	NaN	NaN	NaN
OCN2	11/5/07	0.85	0.11	0.03	0.06	0.00	0.05
OB	11/5/07	0.81	NaN	NaN	NaN	NaN	NaN
OM1	11/5/07	0.74	NaN	NaN	NaN	NaN	NaN
TM	11/5/07	0.92	NaN	NaN	NaN	NaN	NaN
OCN1	11/5/07	0.59	0.08	0.06	0.00	0.00	0.00
RM3	11/5/07	1.03	NaN	NaN	NaN	NaN	NaN
RM2	11/5/07	0.68	NaN	NaN	NaN	NaN	NaN
RM1	11/5/07	0.32	NaN	NaN	NaN	NaN	NaN
River	11/5/07	0.31	0.04	0.00	0.00	0.00	0.00
Stk1sfc	11/5/07	2.52	NaN	NaN	NaN	NaN	NaN
Stk1deep	11/5/07	5.07	NaN	NaN	NaN	NaN	NaN
Stk3sfc	11/5/07	1.98	NaN	NaN	NaN	NaN	NaN
Stk3deep	11/5/07	2.72	NaN	NaN	NaN	NaN	NaN
Stk6sfc	11/5/07	10.09	3.16	0.03	0.00	0.00	0.00
Stk6deep	11/5/07	2.24	0.67	0.06	0.08	0.00	0.03
Stk7sfc	11/5/07	2.78	0.89	0.00	0.00	0.00	0.00
Stk7deep	11/5/07	3.70	0.66	0.07	0.11	0.00	0.36
Stk8sfc	11/5/07	9.46	NaN	NaN	NaN	NaN	NaN
Stk8deep	11/5/07	1.41	NaN	NaN	NaN	NaN	NaN
Stk9sfc	11/5/07	0.86	0.21	0.00	0.00	0.00	0.00
Stk9deep	11/5/07	2.44	0.42	0.08	0.14	0.00	0.22
Stk13sfc	11/5/07	1.28	0.30	0.05	0.06	0.00	0.00
Stk13deep	11/5/07	3.59	0.57	0.08	0.15	0.00	0.37
Stk15sfc	11/5/07	1.15	0.25	0.03	0.00	0.00	0.00
Stk15deep	11/5/07	2.28	0.31	0.08	0.06	0.00	0.27
Stk16sfc	11/5/07	2.05	NaN	NaN	NaN	NaN	NaN
Stk16deep	11/5/07	5.57	NaN	NaN	NaN	NaN	NaN
Stk18sfc	11/5/07	1.02	0.24	0.00	0.00	0.00	0.00
Stk18deep	11/5/07	4.60	0.46	0.05	0.04	0.00	0.75

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location, Table 5.1 for pigment abbreviation. “NaN” is defined as “Not a Number” when a parameter was not measured.)

Transects 1-4 Site	Date	TChl a	Fuco	Zeax	Chl b	Hex-fuco	Per
Stk6sfc	11/6/07	12.71	3.77	0.12	0.58	0.00	0.00
Stk7sfc	11/6/07	336.33	126.14	0.00	0.00	0.00	0.00
Stk9sfc	11/6/07	67.68	21.78	0.00	0.00	0.00	0.00
Stk11sfc	11/6/07	40.08	9.59	0.09	0.00	0.00	1.79
Stk13sfc	11/6/07	77.95	24.26	0.00	0.00	0.00	0.27
Stk18sfc	11/6/07	184.08	67.76	0.00	0.00	0.00	0.00
Stk6sfc	11/7/07	13.57	4.72	0.04	0.07	0.00	0.00
Stk7sfc	11/7/07	3.51	0.93	0.05	0.14	0.03	0.07
Stk9sfc	11/7/07	20.08	6.35	0.08	0.07	0.00	0.13
Stk11sfc	11/7/07	10.55	3.57	0.08	0.08	0.00	0.11
Stk13sfc	11/7/07	19.64	5.78	0.11	0.43	0.00	0.29
Stk18sfc	11/7/07	114.97	41.70	0.34	0.00	0.00	0.00
Stk6sfc	11/8/07	6.50	1.61	0.04	0.17	0.04	0.10
Stk7sfc	11/8/07	4.27	1.20	0.05	0.13	0.04	0.03
Stk9sfc	11/8/07	3.84	0.78	0.07	0.22	0.05	0.09
Stk11sfc	11/8/07	7.70	1.86	0.06	0.46	0.07	0.17
Stk13sfc	11/8/07	8.48	2.30	0.06	0.36	0.02	0.10
Stk18sfc	11/8/07	1.80	0.46	0.00	0.07	0.00	0.00
Stk6sfc	11/11/07	3.81	1.03	0.03	0.09	0.04	0.02
Stk7sfc	11/11/07	3.12	0.90	0.03	0.06	0.04	0.00
Stk9sfc	11/11/07	6.99	1.29	0.02	0.07	0.03	0.44
Stk11sfc	11/11/07	3.70	0.92	0.02	0.07	0.04	0.03
Stk13sfc	11/11/07	3.71	1.11	0.02	0.14	0.03	0.00
Stk18sfc	11/11/07	7.31	1.94	0.02	0.15	0.03	0.07

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location, Table 5.1 for pigment abbreviation. "NaN" is defined as "Not a Number" when a parameter was not measured.)

Site	Date	TChl a	Fuco	Zeax	Chl b	Hex-fuco	Per
OM2	11/17/07	1.82	NaN	NaN	NaN	NaN	NaN
OCN2	11/17/07	1.53	0.20	0.03	0.00	0.00	0.16
OB	11/17/07	1.03	NaN	NaN	NaN	NaN	NaN
OM1	11/17/07	0.89	NaN	NaN	NaN	NaN	NaN
TM	11/17/07	0.95	NaN	NaN	NaN	NaN	NaN
OCN1	11/17/07	0.60	0.09	0.04	0.00	0.00	0.00
RM3	11/17/07	2.80	NaN	NaN	NaN	NaN	NaN
RM2	11/17/07	1.44	NaN	NaN	NaN	NaN	NaN
RM1	11/17/07	0.77	NaN	NaN	NaN	NaN	NaN
River	11/17/07	2.12	0.25	0.00	0.15	0.00	0.00
Stk1sfc	11/17/07	1.24	NaN	NaN	NaN	NaN	NaN
Stk1deep	11/17/07	1.35	NaN	NaN	NaN	NaN	NaN
Stk3sfc	11/17/07	2.22	NaN	NaN	NaN	NaN	NaN
Stk3deep	11/17/07	1.31	NaN	NaN	NaN	NaN	NaN
Stk6sfc	11/17/07	3.29	0.39	0.06	0.49	0.03	0.03
Stk6deep	11/17/07	3.52	0.58	0.08	0.51	0.02	0.10
Stk7sfc	11/17/07	2.49	0.38	0.08	0.20	0.04	0.04
Stk7deep	11/17/07	2.04	0.41	0.08	0.19	0.00	0.03
Stk8sfc	11/17/07	2.83	NaN	NaN	NaN	NaN	NaN
Stk8deep	11/17/07	1.68	NaN	NaN	NaN	NaN	NaN
Stk9sfc	11/17/07	1.84	0.31	0.09	0.25	0.04	0.02
Stk9deep	11/17/07	1.46	0.30	0.07	0.16	0.00	0.00
Stk13sfc	11/17/07	1.28	0.21	0.05	0.13	0.02	0.00
Stk13deep	11/17/07	1.83	0.31	0.04	0.27	0.00	0.06
Stk15sfc	11/17/07	3.10	0.51	0.06	0.43	0.05	0.04
Stk15deep	11/17/07	1.66	0.33	0.05	0.17	0.02	0.00
Stk16sfc	11/17/07	4.68	NaN	NaN	NaN	NaN	NaN
Stk16deep	11/17/07	2.57	NaN	NaN	NaN	NaN	NaN
Stk18sfc	11/17/07	2.26	0.43	0.04	0.21	0.02	0.00
Stk18deep	11/17/07	1.68	0.37	0.06	0.17	0.03	0.00

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location, Table 5.1 for pigment abbreviation. “NaN” is defined as “Not a Number” when a parameter was not measured.)

Storm 2

Site	Date	TChl a	Fuco	Zeax	Chl b	Hex-fuco	Per
OM2	12/9/07	1.86	NaN	NaN	NaN	NaN	NaN
OCN2	12/9/07	2.11	NaN	NaN	NaN	NaN	NaN
OB	12/9/07	1.25	NaN	NaN	NaN	NaN	NaN
OM1	12/9/07	2.01	NaN	NaN	NaN	NaN	NaN
TM	12/9/07	0.92	NaN	NaN	NaN	NaN	NaN
OCN1	12/9/07	1.07	NaN	NaN	NaN	NaN	NaN
RM3	12/9/07	2.10	NaN	NaN	NaN	NaN	NaN
RM2	12/9/07	0.44	NaN	NaN	NaN	NaN	NaN
RM1	12/9/07	0.54	NaN	NaN	NaN	NaN	NaN
River	12/9/07	0.29	0.05	0.00	0.00	0.00	0.00
Stk1sfc	12/9/07	3.02	NaN	NaN	NaN	NaN	NaN
Stk1deep	12/9/07	4.96	NaN	NaN	NaN	NaN	NaN
Stk3sfc	12/9/07	3.78	NaN	NaN	NaN	NaN	NaN
Stk3deep	12/9/07	3.27	NaN	NaN	NaN	NaN	NaN
Stk6sfc	12/9/07	2.37	0.52	0.17	0.17	0.00	0.00
Stk6deep	12/9/07	6.26	NaN	NaN	NaN	NaN	NaN
Stk7sfc	12/9/07	2.28	0.47	0.17	0.20	0.00	0.00
Stk7deep	12/9/07	6.34	NaN	NaN	NaN	NaN	NaN
Stk8sfc	12/9/07	3.40	NaN	NaN	NaN	NaN	NaN
Stk8deep	12/9/07	4.81	NaN	NaN	NaN	NaN	NaN
Stk9sfc	12/9/07	2.90	0.46	0.18	0.35	0.00	0.00
Stk9deep	12/9/07	3.93	NaN	NaN	NaN	NaN	NaN
Stk13sfc	12/9/07	3.03	0.92	0.09	0.26	0.00	0.12
Stk13deep	12/9/07	6.49	NaN	NaN	NaN	NaN	NaN
Stk15sfc	12/9/07	1.38	0.25	0.05	0.11	0.00	0.06
Stk15deep	12/9/07	3.45	NaN	NaN	NaN	NaN	NaN
Stk16sfc	12/9/07	1.50	NaN	NaN	NaN	NaN	NaN
Stk16deep	12/9/07	3.85	NaN	NaN	NaN	NaN	NaN
Stk18sfc	12/9/07	2.09	0.58	0.00	0.00	0.00	0.00
Stk18deep	12/9/07	NaN	NaN	NaN	NaN	NaN	NaN

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location, Table 5.1 for pigment abbreviation. “NaN” is defined as “Not a Number” when a parameter was not measured.)

Site	Date	TChl a	Fuco	Zeax	Chl b	Hex-fuco	Per
OM2	1/12/08	1.77	NaN	NaN	NaN	NaN	NaN
OCN2	1/12/08	1.25	NaN	NaN	NaN	NaN	NaN
OB	1/12/08	1.42	NaN	NaN	NaN	NaN	NaN
OM1	1/12/08	2.13	NaN	NaN	NaN	NaN	NaN
TM	1/12/08	1.70	NaN	NaN	NaN	NaN	NaN
OCN1	1/12/08	0.91	NaN	NaN	NaN	NaN	NaN
RM3	1/12/08	2.17	NaN	NaN	NaN	NaN	NaN
RM2	1/12/08	0.83	NaN	NaN	NaN	NaN	NaN
RM1	1/12/08	0.51	NaN	NaN	NaN	NaN	NaN
River	1/12/08	0.36	0.05	0.00	0.00	0.00	0.00
Stk1sfc	1/12/08	2.92	NaN	NaN	NaN	NaN	NaN
Stk1deep	1/12/08	4.39	NaN	NaN	NaN	NaN	NaN
Stk3sfc	1/12/08	1.98	NaN	NaN	NaN	NaN	NaN
Stk3deep	1/12/08	3.81	NaN	NaN	NaN	NaN	NaN
Stk6sfc	1/12/08	2.26	0.76	0.04	0.00	0.00	0.00
Stk6deep	1/12/08	3.56	NaN	NaN	NaN	NaN	NaN
Stk7sfc	1/12/08	2.05	0.56	0.03	0.09	0.00	0.00
Stk7deep	1/12/08	3.96	NaN	NaN	NaN	NaN	NaN
Stk8sfc	1/12/08	2.85	NaN	NaN	NaN	NaN	NaN
Stk8deep	1/12/08	5.91	NaN	NaN	NaN	NaN	NaN
Stk9sfc	1/12/08	1.88	0.41	0.02	0.07	0.00	0.00
Stk9deep	1/12/08	3.62	NaN	NaN	NaN	NaN	NaN
Stk13sfc	1/12/08	2.59	0.19	0.00	0.68	0.00	0.04
Stk13deep	1/12/08	2.70	NaN	NaN	NaN	NaN	NaN
Stk15sfc	1/12/08	0.26	0.00	0.00	0.00	0.00	0.00
Stk15deep	1/12/08	3.17	NaN	NaN	NaN	NaN	NaN
Stk16sfc	1/12/08	0.52	NaN	NaN	NaN	NaN	NaN
Stk16deep	1/12/08	NaN	NaN	NaN	NaN	NaN	NaN
Stk18sfc	1/12/08	1.10	0.09	0.00	0.11	0.00	0.00
Stk18deep	1/12/08	9.45	NaN	NaN	NaN	NaN	NaN

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location, Table 5.1 for pigment abbreviation. “NaN” is defined as “Not a Number” when a parameter was not measured.)

Site	Date	TChl a	Fuco	Zeax	Chl b	Hex-fuco	Per
OM2	2/16/08	1.48	NaN	NaN	NaN	NaN	NaN
OCN2	2/16/08	1.00	NaN	NaN	NaN	NaN	NaN
OB	2/16/08	1.08	NaN	NaN	NaN	NaN	NaN
OM1	2/16/08	0.79	NaN	NaN	NaN	NaN	NaN
TM	2/16/08	1.77	NaN	NaN	NaN	NaN	NaN
OCN1	2/16/08	1.25	NaN	NaN	NaN	NaN	NaN
RM3	2/16/08	2.89	NaN	NaN	NaN	NaN	NaN
RM2	2/16/08	1.85	NaN	NaN	NaN	NaN	NaN
RM1	2/16/08	0.47	NaN	NaN	NaN	NaN	NaN
River	2/16/08	0.60	NaN	NaN	NaN	NaN	NaN
Stk1sfc	2/16/08	2.61	NaN	NaN	NaN	NaN	NaN
Stk1deep	2/16/08	1.81	NaN	NaN	NaN	NaN	NaN
Stk3sfc	2/16/08	1.53	NaN	NaN	NaN	NaN	NaN
Stk3deep	2/16/08	2.30	NaN	NaN	NaN	NaN	NaN
Stk6sfc	2/16/08	1.80	NaN	NaN	NaN	NaN	NaN
Stk6deep	2/16/08	3.38	NaN	NaN	NaN	NaN	NaN
Stk7sfc	2/16/08	1.95	NaN	NaN	NaN	NaN	NaN
Stk7deep	2/16/08	3.16	NaN	NaN	NaN	NaN	NaN
Stk8sfc	2/16/08	1.77	NaN	NaN	NaN	NaN	NaN
Stk8deep	2/16/08	1.52	NaN	NaN	NaN	NaN	NaN
Stk9sfc	2/16/08	1.75	NaN	NaN	NaN	NaN	NaN
Stk9deep	2/16/08	3.46	NaN	NaN	NaN	NaN	NaN
Stk13sfc	2/16/08	6.16	NaN	NaN	NaN	NaN	NaN
Stk13deep	2/16/08	7.16	NaN	NaN	NaN	NaN	NaN
Stk15sfc	2/16/08	2.89	NaN	NaN	NaN	NaN	NaN
Stk15deep	2/16/08	2.65	NaN	NaN	NaN	NaN	NaN
Stk16sfc	2/16/08	2.19	NaN	NaN	NaN	NaN	NaN
Stk16deep	2/16/08	2.22	NaN	NaN	NaN	NaN	NaN
Stk18sfc	2/16/08	1.59	NaN	NaN	NaN	NaN	NaN
Stk18deep	2/16/08	1.95	NaN	NaN	NaN	NaN	NaN

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location, Table 5.1 for pigment abbreviation. “NaN” is defined as “Not a Number” when a parameter was not measured.)

Site	Date	TChl a	Fuco	Zeax	Chl b	Hex-fuco	Per
OM2	3/15/08	3.19	NaN	NaN	NaN	NaN	NaN
OCN2	3/15/08	2.14	NaN	NaN	NaN	NaN	NaN
OB	3/15/08	0.94	NaN	NaN	NaN	NaN	NaN
OM1	3/15/08	1.73	NaN	NaN	NaN	NaN	NaN
TM	3/15/08	3.00	NaN	NaN	NaN	NaN	NaN
OCN1	3/15/08	1.47	NaN	NaN	NaN	NaN	NaN
RM3	3/15/08	2.79	NaN	NaN	NaN	NaN	NaN
RM2	3/15/08	1.29	NaN	NaN	NaN	NaN	NaN
RM1	3/15/08	1.56	NaN	NaN	NaN	NaN	NaN
River	3/15/08	1.74	0.17	0.02	0.22	0.00	0.00
Stk1sfc	3/15/08	1.60	NaN	NaN	NaN	NaN	NaN
Stk1deep	3/15/08	2.12	NaN	NaN	NaN	NaN	NaN
Stk3sfc	3/15/08	1.75	NaN	NaN	NaN	NaN	NaN
Stk3deep	3/15/08	2.24	NaN	NaN	NaN	NaN	NaN
Stk6sfc	3/15/08	1.84	0.35	0.10	0.20	0.00	0.00
Stk6deep	3/15/08	2.51	NaN	NaN	NaN	NaN	NaN
Stk7sfc	3/15/08	2.46	0.36	0.11	0.29	0.03	0.07
Stk7deep	3/15/08	2.95	NaN	NaN	NaN	NaN	NaN
Stk8sfc	3/15/08	1.83	NaN	NaN	NaN	NaN	NaN
Stk8deep	3/15/08	5.37	NaN	NaN	NaN	NaN	NaN
Stk9sfc	3/15/08	1.38	0.36	0.08	0.08	0.00	0.06
Stk9deep	3/15/08	1.60	NaN	NaN	NaN	NaN	NaN
Stk13sfc	3/15/08	1.80	0.14	0.09	0.07	0.00	0.16
Stk13deep	3/15/08	3.47	NaN	NaN	NaN	NaN	NaN
Stk15sfc	3/15/08	1.76	0.48	0.05	0.06	0.00	0.06
Stk15deep	3/15/08	2.89	NaN	NaN	NaN	NaN	NaN
Stk16sfc	3/15/08	4.27	NaN	NaN	NaN	NaN	NaN
Stk16deep	3/15/08	4.31	NaN	NaN	NaN	NaN	NaN
Stk18sfc	3/15/08	1.72	0.29	0.08	0.13	0.00	0.03
Stk18deep	3/15/08	3.15	NaN	NaN	NaN	NaN	NaN

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location, Table 5.1 for pigment abbreviation. “NaN” is defined as “Not a Number” when a parameter was not measured.)

Site	Date	TChl a	Fuco	Zeax	Chl b	Hex-fuco	Per
OM2	4/19/08	NaN	NaN	NaN	NaN	NaN	NaN
OCN2	4/19/08	NaN	NaN	NaN	NaN	NaN	NaN
OB	4/19/08	NaN	NaN	NaN	NaN	NaN	NaN
OM1	4/19/08	NaN	NaN	NaN	NaN	NaN	NaN
TM	4/19/08	NaN	NaN	NaN	NaN	NaN	NaN
OCN1	4/19/08	NaN	NaN	NaN	NaN	NaN	NaN
RM3	4/19/08	NaN	NaN	NaN	NaN	NaN	NaN
RM2	4/19/08	NaN	NaN	NaN	NaN	NaN	NaN
RM1	4/19/08	NaN	NaN	NaN	NaN	NaN	NaN
River	4/19/08	NaN	NaN	NaN	NaN	NaN	NaN
Stk1sfc	4/19/08	NaN	NaN	NaN	NaN	NaN	NaN
Stk1deep	4/19/08	NaN	NaN	NaN	NaN	NaN	NaN
Stk3sfc	4/19/08	0.57	NaN	NaN	NaN	NaN	NaN
Stk3deep	4/19/08	0.54	NaN	NaN	NaN	NaN	NaN
Stk6sfc	4/19/08	1.74	NaN	NaN	NaN	NaN	NaN
Stk6deep	4/19/08	NaN	NaN	NaN	NaN	NaN	NaN
Stk7sfc	4/19/08	1.10	NaN	NaN	NaN	NaN	NaN
Stk7deep	4/19/08	NaN	NaN	NaN	NaN	NaN	NaN
Stk8sfc	4/19/08	1.99	NaN	NaN	NaN	NaN	NaN
Stk8deep	4/19/08	1.54	NaN	NaN	NaN	NaN	NaN
Stk9sfc	4/19/08	NaN	NaN	NaN	NaN	NaN	NaN
Stk9deep	4/19/08	7.73	NaN	NaN	NaN	NaN	NaN
Stk13sfc	4/19/08	NaN	NaN	NaN	NaN	NaN	NaN
Stk13deep	4/19/08	2.75	NaN	NaN	NaN	NaN	NaN
Stk15sfc	4/19/08	NaN	NaN	NaN	NaN	NaN	NaN
Stk15deep	4/19/08	NaN	NaN	NaN	NaN	NaN	NaN
Stk16sfc	4/19/08	1.18	NaN	NaN	NaN	NaN	NaN
Stk16deep	4/19/08	NaN	NaN	NaN	NaN	NaN	NaN
Stk18sfc	4/19/08	6.36	NaN	NaN	NaN	NaN	NaN
Stk18deep	4/19/08	1.86	NaN	NaN	NaN	NaN	NaN

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location, Table 5.1 for pigment abbreviation. “NaN” is defined as “Not a Number” when a parameter was not measured.)

Site	Date	TChl a	Fuco	Zeax	Chl b	Hex-fuco	Per
OM2	5/17/08	2.76	NaN	NaN	NaN	NaN	NaN
OCN2	5/17/08	1.40	NaN	NaN	NaN	NaN	NaN
OB	5/17/08	1.06	NaN	NaN	NaN	NaN	NaN
OM1	5/17/08	0.93	NaN	NaN	NaN	NaN	NaN
TM	5/17/08	1.35	NaN	NaN	NaN	NaN	NaN
OCN1	5/17/08	0.97	NaN	NaN	NaN	NaN	NaN
RM3	5/17/08	2.72	NaN	NaN	NaN	NaN	NaN
RM2	5/17/08	1.91	NaN	NaN	NaN	NaN	NaN
RM1	5/17/08	1.07	NaN	NaN	NaN	NaN	NaN
River	5/17/08	0.63	0.07	0.00	0.09	0.00	0.00
Stk1sfc	5/17/08	3.27	NaN	NaN	NaN	NaN	NaN
Stk1deep	5/17/08	3.97	NaN	NaN	NaN	NaN	NaN
Stk3sfc	5/17/08	0.94	NaN	NaN	NaN	NaN	NaN
Stk3deep	5/17/08	1.37	NaN	NaN	NaN	NaN	NaN
Stk6sfc	5/17/08	2.71	0.84	0.09	0.19	0.00	0.00
Stk6deep	5/17/08	5.48	NaN	NaN	NaN	NaN	NaN
Stk7sfc	5/17/08	2.00	0.44	0.11	0.17	0.00	0.00
Stk7deep	5/17/08	5.51	NaN	NaN	NaN	NaN	NaN
Stk8sfc	5/17/08	2.25	NaN	NaN	NaN	NaN	NaN
Stk8deep	5/17/08	2.75	NaN	NaN	NaN	NaN	NaN
Stk9sfc	5/17/08	0.73	0.12	0.05	0.06	0.00	0.00
Stk9deep	5/17/08	0.96	NaN	NaN	NaN	NaN	NaN
Stk13sfc	5/17/08	2.82	0.52	0.07	0.12	0.00	0.07
Stk13deep	5/17/08	3.49	NaN	NaN	NaN	NaN	NaN
Stk15sfc	5/17/08	2.03	0.17	0.05	0.14	0.00	0.16
Stk15deep	5/17/08	2.67	NaN	NaN	NaN	NaN	NaN
Stk16sfc	5/17/08	3.44	NaN	NaN	NaN	NaN	NaN
Stk16deep	5/17/08	2.56	NaN	NaN	NaN	NaN	NaN
Stk18sfc	5/17/08	3.15	0.72	0.11	0.20	0.00	0.00
Stk18deep	5/17/08	3.03	NaN	NaN	NaN	NaN	NaN

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location, Table 5.1 for pigment abbreviation. “NaN” is defined as “Not a Number” when a parameter was not measured.)

Storm 4

Site	Date	TChl a	Fuco	Zeax	Chl b	Hex-fuco	Per
OM2	6/14/08	4.12	NaN	NaN	NaN	NaN	NaN
OCN2	6/14/08	2.63	NaN	NaN	NaN	NaN	NaN
OB	6/14/08	2.33	NaN	NaN	NaN	NaN	NaN
OM1	6/14/08	3.21	NaN	NaN	NaN	NaN	NaN
TM	6/14/08	2.23	NaN	NaN	NaN	NaN	NaN
OCN1	6/14/08	2.92	NaN	NaN	NaN	NaN	NaN
RM3	6/14/08	3.49	NaN	NaN	NaN	NaN	NaN
RM2	6/14/08	0.83	NaN	NaN	NaN	NaN	NaN
RM1	6/14/08	2.13	NaN	NaN	NaN	NaN	NaN
River	6/14/08	0.39	NaN	NaN	NaN	NaN	NaN
Stk1sfc	6/14/08	4.81	NaN	NaN	NaN	NaN	NaN
Stk1deep	6/14/08	6.53	NaN	NaN	NaN	NaN	NaN
Stk3sfc	6/14/08	1.58	NaN	NaN	NaN	NaN	NaN
Stk3deep	6/14/08	2.68	NaN	NaN	NaN	NaN	NaN
Stk6sfc	6/14/08	3.91	NaN	NaN	NaN	NaN	NaN
Stk6deep	6/14/08	3.74	NaN	NaN	NaN	NaN	NaN
Stk7sfc	6/14/08	6.47	NaN	NaN	NaN	NaN	NaN
Stk7deep	6/14/08	NaN	NaN	NaN	NaN	NaN	NaN
Stk8sfc	6/14/08	4.09	NaN	NaN	NaN	NaN	NaN
Stk8deep	6/14/08	4.27	NaN	NaN	NaN	NaN	NaN
Stk9sfc	6/14/08	4.40	NaN	NaN	NaN	NaN	NaN
Stk9deep	6/14/08	1.91	NaN	NaN	NaN	NaN	NaN
Stk13sfc	6/14/08	6.62	NaN	NaN	NaN	NaN	NaN
Stk13deep	6/14/08	3.04	NaN	NaN	NaN	NaN	NaN
Stk15sfc	6/14/08	4.93	NaN	NaN	NaN	NaN	NaN
Stk15deep	6/14/08	4.54	NaN	NaN	NaN	NaN	NaN
Stk16sfc	6/14/08	5.23	NaN	NaN	NaN	NaN	NaN
Stk16deep	6/14/08	3.31	NaN	NaN	NaN	NaN	NaN
Stk18sfc	6/14/08	3.66	NaN	NaN	NaN	NaN	NaN
Stk18deep	6/14/08	2.75	NaN	NaN	NaN	NaN	NaN

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location, Table 5.1 for pigment abbreviation. “NaN” is defined as “Not a Number” when a parameter was not measured.)

Site	Date	TChl a	Fuco	Zeax	Chl b	Hex-fuco	Per
OM2	7/26/08	0.53	NaN	NaN	NaN	NaN	NaN
OCN2	7/26/08	0.54	NaN	NaN	NaN	NaN	NaN
OB	7/26/08	0.80	NaN	NaN	NaN	NaN	NaN
OM1	7/26/08	1.06	NaN	NaN	NaN	NaN	NaN
TM	7/26/08	0.82	NaN	NaN	NaN	NaN	NaN
OCN1	7/26/08	0.92	NaN	NaN	NaN	NaN	NaN
RM3	7/26/08	4.29	NaN	NaN	NaN	NaN	NaN
RM2	7/26/08	1.50	NaN	NaN	NaN	NaN	NaN
RM1	7/26/08	4.40	NaN	NaN	NaN	NaN	NaN
River	7/26/08	0.66	0.08	0.00	0.06	0.00	0.00
Stk1sfc	7/26/08	1.17	NaN	NaN	NaN	NaN	NaN
Stk1deep	7/26/08	1.48	NaN	NaN	NaN	NaN	NaN
Stk3sfc	7/26/08	2.64	NaN	NaN	NaN	NaN	NaN
Stk3deep	7/26/08	1.09	NaN	NaN	NaN	NaN	NaN
Stk6sfc	7/26/08	6.36	1.56	0.07	0.19	0.00	0.00
Stk6deep	7/26/08	2.57	NaN	NaN	NaN	NaN	NaN
Stk7sfc	7/26/08	3.82	1.02	0.05	0.06	0.00	0.00
Stk7deep	7/26/08	4.71	NaN	NaN	NaN	NaN	NaN
Stk8sfc	7/26/08	3.34	NaN	NaN	NaN	NaN	NaN
Stk8deep	7/26/08	2.96	NaN	NaN	NaN	NaN	NaN
Stk9sfc	7/26/08	2.07	0.46	0.06	0.08	0.00	0.00
Stk9deep	7/26/08	4.42	NaN	NaN	NaN	NaN	NaN
Stk13sfc	7/26/08	1.38	0.28	0.03	0.04	0.00	0.05
Stk13deep	7/26/08	1.91	NaN	NaN	NaN	NaN	NaN
Stk15sfc	7/26/08	4.80	1.33	0.02	0.05	0.00	0.02
Stk15deep	7/26/08	4.02	NaN	NaN	NaN	NaN	NaN
Stk16sfc	7/26/08	NaN	NaN	NaN	NaN	NaN	NaN
Stk16deep	7/26/08	3.69	NaN	NaN	NaN	NaN	NaN
Stk18sfc	7/26/08	5.15	1.43	0.03	0.04	0.00	0.00
Stk18deep	7/26/08	3.66	NaN	NaN	NaN	NaN	NaN

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location, Table 5.1 for pigment abbreviation. “NaN” is defined as “Not a Number” when a parameter was not measured.)

Site	Date	TChl a	Fuco	Zeax	Chl b	Hex-fuco	Per
OM2	8/30/08	1.99	NaN	NaN	NaN	NaN	NaN
OCN2	8/30/08	1.07	0.11	0.10	0.13	0.00	0.09
OB	8/30/08	1.17	NaN	NaN	NaN	NaN	NaN
OM1	8/30/08	1.14	NaN	NaN	NaN	NaN	NaN
TM	8/30/08	2.21	NaN	NaN	NaN	NaN	NaN
OCN1	8/30/08	1.47	0.15	0.34	0.19	0.00	0.02
RM3	8/30/08	2.88	NaN	NaN	NaN	NaN	NaN
RM2	8/30/08	1.33	NaN	NaN	NaN	NaN	NaN
RM1	8/30/08	1.02	NaN	NaN	NaN	NaN	NaN
River	8/30/08	0.50	0.08	0.00	0.10	0.00	0.00
Stk1sfc	8/30/08	5.42	NaN	NaN	NaN	NaN	NaN
Stk1deep	8/30/08	5.46	NaN	NaN	NaN	NaN	NaN
Stk3sfc	8/30/08	1.69	NaN	NaN	NaN	NaN	NaN
Stk3deep	8/30/08	3.83	NaN	NaN	NaN	NaN	NaN
Stk6sfc	8/30/08	2.08	0.20	0.53	0.31	0.00	0.02
Stk6deep	8/30/08	NaN	5.25	0.64	0.35	0.00	3.63
Stk7sfc	8/30/08	3.05	0.29	0.58	0.30	0.00	0.18
Stk7deep	8/30/08	5.52	1.06	0.57	0.28	0.00	0.28
Stk8sfc	8/30/08	4.00	NaN	NaN	NaN	NaN	NaN
Stk8deep	8/30/08	3.77	NaN	NaN	NaN	NaN	NaN
Stk9sfc	8/30/08	1.83	0.14	0.33	0.18	0.00	0.14
Stk9deep	8/30/08	9.11	0.35	0.27	0.14	0.00	1.64
Stk13sfc	8/30/08	4.85	0.19	0.43	0.28	0.00	0.62
Stk13deep	8/30/08	6.72	0.24	0.38	0.24	0.00	1.07
Stk15sfc	8/30/08	3.18	0.34	0.41	0.22	0.00	0.19
Stk15deep	8/30/08	12.22	1.29	0.41	0.25	0.00	1.90
Stk16sfc	8/30/08	3.16	NaN	NaN	NaN	NaN	NaN
Stk16deep	8/30/08	12.61	NaN	NaN	NaN	NaN	NaN
Stk18sfc	8/30/08	4.13	0.47	0.54	0.49	0.00	0.16
Stk18deep	8/30/08	3.01	0.26	0.52	0.27	0.00	0.19

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location, Table 5.1 for pigment abbreviation. “NaN” is defined as “Not a Number” when a parameter was not measured.)

Appendix 13. DIN:DIP ratios calculated from measurements found in Appendix 5. APA in units of nM-P/h. $\text{APA}_{\text{chl-a normalized}}$ in units of nM-P/µg-chla/h.

Site	Date	DIN:DIP	APA	$\text{APA}_{\text{chl-a norm.}}$
OM2	8/11/07	12.61	1.86	1.92
OCN2	8/11/07	4.11	0.76	0.66
OB	8/11/07	20.44	0.90	1.76
OM1	8/11/07	12.57	0.88	2.07
TM	8/11/07	15.49	1.61	1.89
OCN1	8/11/07	12.17	1.50	1.66
RM3	8/11/07	30.49	3.36	3.40
RM2	8/11/07	7.02	7.81	9.93
RM1	8/11/07	10.39	2.58	1.26
River	8/11/07	10.87	5.47	11.66
Stk1sfc	8/11/07	12.72	1.78	1.43
Stk1deep	8/11/07	10.38	1.06	2.20
Stk3sfc	8/11/07	9.49	0.64	2.66
Stk3deep	8/11/07	12.00	0.58	0.87
Stk6sfc	8/11/07	10.34	2.46	0.92
Stk6deep	8/11/07	8.60	1.85	0.89
Stk7sfc	8/11/07	8.73	7.33	2.81
Stk7deep	8/11/07	3.80	3.18	1.20
Stk8sfc	8/11/07	12.58	3.25	2.08
Stk8deep	8/11/07	6.07	1.12	0.72
Stk9sfc	8/11/07	14.66	1.72	1.31
Stk9deep	8/11/07	7.44	4.46	1.90
Stk13sfc	8/11/07	10.15	3.97	1.81
Stk13deep	8/11/07	7.52	3.31	3.25
Stk15sfc	8/11/07	8.92	2.86	2.06
Stk15deep	8/11/07	NaN	2.92	2.61
Stk16sfc	8/11/07	8.49	1.90	1.37
Stk16deep	8/11/07	6.01	2.11	1.07
Stk18sfc	8/11/07	15.17	8.95	3.93
Stk18deep	8/11/07	NaN	2.89	1.13

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. “NaN” is defined as “Not a Number” when a parameter was not measured.)

Site	Date	DIN:DIP	APA	$APA_{chl\text{-}a\ norm.}$
OM2	9/15/07	15.54	2.88	4.49
OCN2	9/15/07	8.24	0.55	0.98
OB	9/15/07	15.96	1.91	2.98
OM1	9/15/07	11.87	2.51	8.93
TM	9/15/07	12.95	1.57	1.96
OCN1	9/15/07	13.35	4.57	8.14
RM3	9/15/07	12.41	5.36	4.78
RM2	9/15/07	7.16	7.82	6.51
RM1	9/15/07	9.06	1.90	2.63
River	9/15/07	5.66	8.12	1.88
Stk1sfc	9/15/07	14.84	2.32	2.07
Stk1deep	9/15/07	7.37	1.74	1.81
Stk3sfc	9/15/07	11.73	1.05	1.87
Stk3deep	9/15/07	8.28	0.95	2.37
Stk6sfc	9/15/07	8.27	3.42	3.56
Stk6deep	9/15/07	1.98	2.73	1.89
Stk7sfc	9/15/07	10.82	2.02	1.05
Stk7deep	9/15/07	3.29	2.19	1.24
Stk8sfc	9/15/07	18.96	2.00	0.78
Stk8deep	9/15/07	1.52	2.57	1.07
Stk9sfc	9/15/07	19.09	2.22	1.98
Stk9deep	9/15/07	7.84	2.57	2.29
Stk13sfc	9/15/07	13.50	2.88	4.49
Stk13deep	9/15/07	6.53	4.34	7.74
Stk15sfc	9/15/07	17.62	5.99	4.15
Stk15deep	9/15/07	3.46	3.83	2.52
Stk16sfc	9/15/07	18.53	3.91	3.26
Stk16deep	9/15/07	4.74	4.04	1.40
Stk18sfc	9/15/07	5.11	2.40	1.25
Stk18deep	9/15/07	4.68	2.44	1.90

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. “NaN” is defined as “Not a Number” when a parameter was not measured.)

Site	Date	DIN:DIP	APA	APA$_{\text{chl-a norm.}}$
OM2	10/13/07	NaN	0.62	0.76
OCN2	10/13/07	12.98	0.73	1.85
OB	10/13/07	49.25	0.62	0.83
OM1	10/13/07	16.59	1.49	1.15
TM	10/13/07	15.63	2.01	1.46
OCN1	10/13/07	11.07	1.07	2.90
RM3	10/13/07	12.06	1.91	0.61
RM2	10/13/07	9.61	7.53	5.04
RM1	10/13/07	10.85	1.78	2.58
River	10/13/07	9.06	4.97	1.66
Stk1sfc	10/13/07	30.90	1.02	0.42
Stk1deep	10/13/07	4.23	3.27	1.03
Stk3sfc	10/13/07	50.97	1.36	0.97
Stk3deep	10/13/07	8.92	1.48	1.11
Stk6sfc	10/13/07	17.67	1.09	0.92
Stk6deep	10/13/07	11.70	3.33	1.08
Stk7sfc	10/13/07	22.35	1.43	1.01
Stk7deep	10/13/07	7.67	1.71	0.82
Stk8sfc	10/13/07	14.22	1.18	0.54
Stk8deep	10/13/07	11.58	2.73	1.26
Stk9sfc	10/13/07	24.92	2.22	1.60
Stk9deep	10/13/07	8.34	3.34	2.52
Stk13sfc	10/13/07	11.22	5.88	1.26
Stk13deep	10/13/07	5.43	10.82	2.58
Stk15sfc	10/13/07	7.69	2.40	0.93
Stk15deep	10/13/07	6.08	1.40	0.54
Stk16sfc	10/13/07	11.80	3.33	1.02
Stk16deep	10/13/07	8.80	1.47	0.49
Stk18sfc	10/13/07	13.68	1.56	0.63
Stk18deep	10/13/07	11.97	2.18	1.18

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. “NaN” is defined as “Not a Number” when a parameter was not measured.)

Storm 1 Site	Date	DIN:DIP	APA	$APA_{chl\text{-}a\ norm.}$
River	11/4/07	14.96	13.36	21.44
Stk10sfc	11/4/07	65.85	14.24	16.78
Stk18sfc	11/4/07	22.68	13.16	31.12
OM2	11/5/07	110.65	0.30	0.28
OCN2	11/5/07	32.01	0.56	0.65
OB	11/5/07	10.79	0.53	0.65
OM1	11/5/07	12.64	0.17	0.24
TM	11/5/07	14.86	0.23	0.26
OCN1	11/5/07	9.01	0.42	0.71
RM3	11/5/07	21.04	3.75	3.64
RM2	11/5/07	19.03	6.66	9.79
RM1	11/5/07	70.72	2.50	7.93
River	11/5/07	10.25	3.30	10.82
Stk1sfc	11/5/07	36.46	5.89	2.34
Stk1deep	11/5/07	44.73	3.14	0.62
Stk3sfc	11/5/07	42.10	10.18	5.14
Stk3deep	11/5/07	28.88	2.15	0.79
Stk6sfc	11/5/07	38.38	9.16	0.91
Stk6deep	11/5/07	15.55	2.58	1.15
Stk7sfc	11/5/07	38.23	4.16	1.50
Stk7deep	11/5/07	29.97	4.49	1.21
Stk8sfc	11/5/07	NaN	4.69	0.50
Stk8deep	11/5/07	NaN	2.38	1.69
Stk9sfc	11/5/07	41.21	3.54	4.13
Stk9deep	11/5/07	35.51	4.95	2.03
Stk13sfc	11/5/07	42.98	6.22	4.85
Stk13deep	11/5/07	7.27	5.18	1.44
Stk15sfc	11/5/07	40.82	4.43	3.85
Stk15deep	11/5/07	17.13	3.91	1.71
Stk16sfc	11/5/07	NaN	3.92	1.91
Stk16deep	11/5/07	20.83	4.11	0.74
Stk18sfc	11/5/07	18.11	7.87	7.73
Stk18deep	11/5/07	37.16	6.65	1.45

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. "NaN" is defined as "Not a Number" when a parameter was not measured.)

Transects 1-4 Site	Date	DIN:DIP	APA	$APA_{chl-a\ norm.}$
Stk6sfc	11/6/07	NaN	24.78	1.95
Stk7sfc	11/6/07	19.51	11.87	0.04
Stk9sfc	11/6/07	50.74	16.40	0.24
Stk11sfc	11/6/07	36.92	8.19	0.20
Stk13sfc	11/6/07	26.85	8.78	0.11
Stk18sfc	11/6/07	12.62	5.40	0.03
Stk6sfc	11/7/07	71.73	4.72	0.35
Stk7sfc	11/7/07	20.54	5.35	1.52
Stk9sfc	11/7/07	546.63	7.31	0.36
Stk11sfc	11/7/07	48.53	11.02	1.05
Stk13sfc	11/7/07	23.38	15.18	0.77
Stk18sfc	11/7/07	NaN	6.89	0.06
Stk6sfc	11/8/07	16.18	7.64	1.18
Stk7sfc	11/8/07	11.82	2.59	0.61
Stk9sfc	11/8/07	23.57	3.27	0.85
Stk11sfc	11/8/07	31.42	4.79	0.62
Stk13sfc	11/8/07	43.88	6.98	0.82
Stk18sfc	11/8/07	10.12	3.29	1.83
Stk6sfc	11/11/07	10.88	4.92	1.29
Stk7sfc	11/11/07	264.51	1.79	0.57
Stk9sfc	11/11/07	7.95	6.09	0.87
Stk11sfc	11/11/07	20.25	6.46	1.75
Stk13sfc	11/11/07	19.18	6.25	1.69
Stk18sfc	11/11/07	9.23	3.71	0.51

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. “NaN” is defined as “Not a Number” when a parameter was not measured.)

Site	**Date**	**DIN:DIP**	**APA**	**APA$_{\text{chl-a norm.}}$**
OM2	11/17/07	8.15	0.00	0.00
OCN2	11/17/07	6.61	0.00	0.00
OB	11/17/07	6.91	0.00	0.00
OM1	11/17/07	7.21	1.16	1.30
TM	11/17/07	10.06	0.48	0.51
OCN1	11/17/07	12.45	0.14	0.23
RM3	11/17/07	6.34	4.15	1.48
RM2	11/17/07	7.33	30.68	21.30
RM1	11/17/07	15.43	0.88	1.15
River	11/17/07	12.05	1.16	0.55
Stk1sfc	11/17/07	33.99	0.00	0.00
Stk1deep	11/17/07	12.52	0.00	0.00
Stk3sfc	11/17/07	22.46	0.00	0.00
Stk3deep	11/17/07	11.93	0.00	0.00
Stk6sfc	11/17/07	12.75	0.44	0.13
Stk6deep	11/17/07	7.21	0.16	0.05
Stk7sfc	11/17/07	18.83	0.36	0.14
Stk7deep	11/17/07	2.81	0.20	0.10
Stk8sfc	11/17/07	17.43	0.52	0.18
Stk8deep	11/17/07	7.09	0.17	0.10
Stk9sfc	11/17/07	21.94	0.20	0.11
Stk9deep	11/17/07	3.25	0.08	0.05
Stk13sfc	11/17/07	30.68	0.35	0.27
Stk13deep	11/17/07	12.00	2.10	1.15
Stk15sfc	11/17/07	6.97	0.62	0.20
Stk15deep	11/17/07	5.97	0.00	0.00
Stk16sfc	11/17/07	8.03	0.81	0.17
Stk16deep	11/17/07	12.07	0.08	0.03
Stk18sfc	11/17/07	8.76	0.43	0.19
Stk18deep	11/17/07	3.74	0.00	0.00

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. "NaN" is defined as "Not a Number" when a parameter was not measured.)

Storm 2 Site	Date	DIN:DIP	APA	$APA_{chl\text{-}a\ norm.}$
OM2	12/9/07	17.18	0.00	0.00
OCN2	12/9/07	19.60	0.47	0.22
OB	12/9/07	54.81	0.16	0.13
OM1	12/9/07	15.53	0.20	0.10
TM	12/9/07	10.30	0.66	0.72
OCN1	12/9/07	12.77	0.49	0.46
RM3	12/9/07	16.70	1.00	0.48
RM2	12/9/07	8.97	5.71	12.97
RM1	12/9/07	6.94	0.36	0.66
River	12/9/07	10.22	1.75	6.00
Stk1sfc	12/9/07	9.40	0.14	0.05
Stk1deep	12/9/07	8.70	0.00	0.00
Stk3sfc	12/9/07	13.01	0.20	0.05
Stk3deep	12/9/07	3.15	0.03	0.01
Stk6sfc	12/9/07	12.61	0.04	0.02
Stk6deep	12/9/07	13.96	3.67	0.59
Stk7sfc	12/9/07	10.12	0.63	0.28
Stk7deep	12/9/07	12.01	1.58	0.25
Stk8sfc	12/9/07	8.71	0.21	0.06
Stk8deep	12/9/07	11.53	3.72	0.77
Stk9sfc	12/9/07	7.90	0.45	0.16
Stk9deep	12/9/07	4.97	0.62	0.16
Stk13sfc	12/9/07	8.41	0.00	0.00
Stk13deep	12/9/07	34.64	1.68	0.26
Stk15sfc	12/9/07	9.24	0.69	0.50
Stk15deep	12/9/07	27.84	2.03	0.59
Stk16sfc	12/9/07	8.34	0.83	0.56
Stk16deep	12/9/07	18.29	11.19	2.91
Stk18sfc	12/9/07	11.63	1.30	0.63
Stk18deep	12/9/07	11.99	0.81	NaN

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. “NaN” is defined as “Not a Number” when a parameter was not measured.)

Site	**Date**	**DIN:DIP**	**APA**	**APA$_{\textbf{chl-a norm.}}$**
OM2	1/12/08	6.42	1.43	0.81
OCN2	1/12/08	9.57	0.82	0.66
OB	1/12/08	63.19	1.05	0.74
OM1	1/12/08	8.51	1.60	0.75
TM	1/12/08	63.91	1.42	0.84
OCN1	1/12/08	6.11	1.28	1.41
RM3	1/12/08	10.29	1.76	0.81
RM2	1/12/08	11.15	10.94	13.18
RM1	1/12/08	42.02	2.52	4.99
River	1/12/08	8.46	6.05	16.78
Stk1sfc	1/12/08	5.66	1.69	0.58
Stk1deep	1/12/08	5.58	1.52	0.35
Stk3sfc	1/12/08	7.56	0.59	0.30
Stk3deep	1/12/08	0.39	1.40	0.37
Stk6sfc	1/12/08	11.61	0.53	0.23
Stk6deep	1/12/08	8.25	1.38	0.39
Stk7sfc	1/12/08	7.22	0.31	0.15
Stk7deep	1/12/08	14.54	0.05	0.01
Stk8sfc	1/12/08	10.65	0.02	0.01
Stk8deep	1/12/08	9.18	0.05	0.01
Stk9sfc	1/12/08	14.18	0.01	0.01
Stk9deep	1/12/08	5.60	0.09	0.03
Stk13sfc	1/12/08	8.14	0.08	0.03
Stk13deep	1/12/08	7.93	0.02	0.01
Stk15sfc	1/12/08	11.39	1.15	4.34
Stk15deep	1/12/08	6.63	2.76	0.87
Stk16sfc	1/12/08	6.36	5.29	10.18
Stk16deep	1/12/08	6.20	NaN	NaN
Stk18sfc	1/12/08	8.11	NaN	NaN
Stk18deep	1/12/08	6.75	4.17	0.44

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. “NaN” is defined as “Not a Number” when a parameter was not measured.)

Site	**Date**	**DIN:DIP**	**APA**	**$\mathrm{APA}_{\text{chl-a norm.}}$**
OM2	2/16/08	40.66	0.01	0.01
OCN2	2/16/08	14.37	0.06	0.06
OB	2/16/08	12.70	0.04	0.04
OM1	2/16/08	26.19	0.56	0.70
TM	2/16/08	3.51	0.28	0.16
OCN1	2/16/08	8.50	0.19	0.15
RM3	2/16/08	20.88	1.87	0.65
RM2	2/16/08	12.46	9.76	5.26
RM1	2/16/08	11.61	0.80	1.72
River	2/16/08	10.08	2.16	3.59
Stk1sfc	2/16/08	20.66	0.27	0.10
Stk1deep	2/16/08	9.21	0.24	0.13
Stk3sfc	2/16/08	18.70	0.29	0.19
Stk3deep	2/16/08	9.94	0.26	0.11
Stk6sfc	2/16/08	17.93	0.92	0.51
Stk6deep	2/16/08	12.11	2.04	0.60
Stk7sfc	2/16/08	12.10	0.38	0.19
Stk7deep	2/16/08	2.19	0.51	0.16
Stk8sfc	2/16/08	15.23	0.12	0.07
Stk8deep	2/16/08	9.93	0.29	0.19
Stk9sfc	2/16/08	15.30	0.41	0.23
Stk9deep	2/16/08	8.12	0.64	0.19
Stk13sfc	2/16/08	9.62	0.49	0.08
Stk13deep	2/16/08	8.96	16.39	2.29
Stk15sfc	2/16/08	14.17	0.14	0.05
Stk15deep	2/16/08	6.40	1.14	0.43
Stk16sfc	2/16/08	11.06	0.19	0.09
Stk16deep	2/16/08	7.74	1.24	0.56
Stk18sfc	2/16/08	9.08	0.42	0.27
Stk18deep	2/16/08	4.54	2.21	1.13

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. “NaN” is defined as “Not a Number” when a parameter was not measured.)

Site	Date	DIN:DIP	APA	$APA_{chl\text{-}a\ norm.}$
OM2	3/15/08	9.94	1.30	0.41
OCN2	3/15/08	1.94	0.00	0.00
OB	3/15/08	8.94	0.01	0.01
OM1	3/15/08	10.95	1.24	0.72
TM	3/15/08	8.01	0.91	0.30
OCN1	3/15/08	9.25	0.13	0.09
RM3	3/15/08	7.63	4.14	1.49
RM2	3/15/08	11.44	11.14	8.66
RM1	3/15/08	18.56	1.57	1.01
River	3/15/08	5.14	2.33	1.34
Stk1sfc	3/15/08	NaN	0.88	0.55
Stk1deep	3/15/08	3.35	0.49	0.23
Stk3sfc	3/15/08	21.29	0.32	0.18
Stk3deep	3/15/08	143.46	3.56	1.59
Stk6sfc	3/15/08	NaN	NaN	NaN
Stk6deep	3/15/08	13.17	0.25	0.10
Stk7sfc	3/15/08	7.20	NaN	NaN
Stk7deep	3/15/08	9.39	4.00	1.36
Stk8sfc	3/15/08	NaN	NaN	NaN
Stk8deep	3/15/08	33.03	0.06	0.01
Stk9sfc	3/15/08	NaN	NaN	NaN
Stk9deep	3/15/08	151.17	0.42	0.26
Stk13sfc	3/15/08	NaN	NaN	NaN
Stk13deep	3/15/08	77.22	5.12	1.48
Stk15sfc	3/15/08	NaN	NaN	NaN
Stk15deep	3/15/08	78.81	24.59	8.50
Stk16sfc	3/15/08	NaN	NaN	NaN
Stk16deep	3/15/08	12.70	NaN	NaN
Stk18sfc	3/15/08	NaN	NaN	NaN
Stk18deep	3/15/08	6.16	2.67	0.85

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. "NaN" is defined as "Not a Number" when a parameter was not measured.)

Site	Date	DIN:DIP	APA	APA$_{\text{chl-a norm.}}$
OM2	4/19/08	81.37	0.24	NaN
OCN2	4/19/08	12.92	0.00	NaN
OB	4/19/08	17.07	0.19	NaN
OM1	4/19/08	11.45	0.95	NaN
TM	4/19/08	16.40	0.79	NaN
OCN1	4/19/08	14.34	0.00	NaN
RM3	4/19/08	4.92	4.85	NaN
RM2	4/19/08	NaN	5.59	NaN
RM1	4/19/08	NaN	2.82	NaN
River	4/19/08	7.10	2.57	NaN
Stk1sfc	4/19/08	NaN	0.52	NaN
Stk1deep	4/19/08	13.82	18.99	NaN
Stk3sfc	4/19/08	NaN	0.57	1.00
Stk3deep	4/19/08	9.38	0.40	0.75
Stk6sfc	4/19/08	NaN	0.86	0.49
Stk6deep	4/19/08	NaN	0.80	NaN
Stk7sfc	4/19/08	NaN	1.13	1.03
Stk7deep	4/19/08	NaN	0.71	NaN
Stk8sfc	4/19/08	NaN	1.05	0.53
Stk8deep	4/19/08	NaN	1.18	0.77
Stk9sfc	4/19/08	NaN	1.73	NaN
Stk9deep	4/19/08	NaN	0.61	0.08
Stk13sfc	4/19/08	NaN	1.93	NaN
Stk13deep	4/19/08	NaN	3.23	1.17
Stk15sfc	4/19/08	NaN	1.14	NaN
Stk15deep	4/19/08	NaN	2.11	NaN
Stk16sfc	4/19/08	NaN	0.54	0.46
Stk16deep	4/19/08	NaN	0.47	NaN
Stk18sfc	4/19/08	NaN	1.40	0.22
Stk18deep	4/19/08	NaN	2.96	1.59

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. “NaN” is defined as “Not a Number” when a parameter was not measured.)

Site	Date	DIN:DIP	APA	APA$_{\text{chl-a norm.}}$
OM2	5/17/08	22.77	3.46	1.25
OCN2	5/17/08	9.32	0.00	0.00
OB	5/17/08	8.80	0.00	0.00
OM1	5/17/08	7.11	0.00	0.00
TM	5/17/08	6.41	0.02	0.02
OCN1	5/17/08	8.86	0.02	0.02
RM3	5/17/08	12.51	3.57	1.31
RM2	5/17/08	7.51	14.83	7.76
RM1	5/17/08	20.48	0.44	0.41
River	5/17/08	5.72	3.06	4.89
Stk1sfc	5/17/08	10.27	0.20	0.06
Stk1deep	5/17/08	16.52	2.73	0.69
Stk3sfc	5/17/08	9.97	0.00	0.00
Stk3deep	5/17/08	11.23	0.00	0.00
Stk6sfc	5/17/08	23.39	2.38	0.88
Stk6deep	5/17/08	16.97	23.09	4.21
Stk7sfc	5/17/08	6.07	2.11	1.06
Stk7deep	5/17/08	13.21	0.71	0.13
Stk8sfc	5/17/08	32.20	1.20	0.53
Stk8deep	5/17/08	11.94	1.08	0.39
Stk9sfc	5/17/08	47.57	0.38	0.52
Stk9deep	5/17/08	17.84	3.09	3.22
Stk13sfc	5/17/08	17.51	2.14	0.76
Stk13deep	5/17/08	19.82	1.83	0.53
Stk15sfc	5/17/08	12.55	0.19	0.09
Stk15deep	5/17/08	21.35	0.10	0.04
Stk16sfc	5/17/08	15.23	0.02	0.00
Stk16deep	5/17/08	42.60	1.16	0.45
Stk18sfc	5/17/08	7.51	0.55	0.18
Stk18deep	5/17/08	7.08	0.00	0.00

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. “NaN” is defined as “Not a Number” when a parameter was not measured.)

Storm 4 **Site**	**Date**	**DIN:DIP**	**APA**	**$APA_{chl\text{-}a\ norm.}$**
OM2	6/14/08	12.19	2.41	0.58
OCN2	6/14/08	34.68	1.44	0.55
OB	6/14/08	9.56	2.06	0.88
OM1	6/14/08	6.28	2.75	0.86
TM	6/14/08	8.70	2.45	1.10
OCN1	6/14/08	7.22	1.21	0.42
RM3	6/14/08	22.84	4.03	1.15
RM2	6/14/08	NaN	8.95	10.83
RM1	6/14/08	8.46	3.40	1.59
River	6/14/08	5.17	2.01	5.22
Stk1sfc	6/14/08	10.99	1.02	0.21
Stk1deep	6/14/08	20.77	3.76	0.58
Stk3sfc	6/14/08	246.34	1.17	0.74
Stk3deep	6/14/08	23.78	0.51	0.19
Stk6sfc	6/14/08	11.40	2.43	0.62
Stk6deep	6/14/08	8.26	NaN	NaN
Stk7sfc	6/14/08	7.77	2.78	0.43
Stk7deep	6/14/08	5.61	NaN	NaN
Stk8sfc	6/14/08	14.86	2.71	0.66
Stk8deep	6/14/08	8.76	3.00	0.70
Stk9sfc	6/14/08	12.20	2.55	0.58
Stk9deep	6/14/08	10.24	0.63	0.33
Stk13sfc	6/14/08	17.72	2.32	0.35
Stk13deep	6/14/08	8.27	0.84	0.28
Stk15sfc	6/14/08	23.87	1.99	0.40
Stk15deep	6/14/08	13.51	1.70	0.38
Stk16sfc	6/14/08	16.47	2.21	0.42
Stk16deep	6/14/08	12.73	1.32	0.40
Stk18sfc	6/14/08	20.08	2.01	0.55
Stk18deep	6/14/08	NaN	1.13	0.41

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. “NaN” is defined as “Not a Number” when a parameter was not measured.)

Site	Date	DIN:DIP	APA	$\text{APA}_{\text{chl-a norm.}}$
OM2	7/26/08	10.67	1.13	2.13
OCN2	7/26/08	19.19	1.15	2.13
OB	7/26/08	4.95	0.74	0.92
OM1	7/26/08	7.83	1.20	1.13
TM	7/26/08	15.49	1.28	1.57
OCN1	7/26/08	12.85	1.33	1.44
RM3	7/26/08	10.79	10.93	2.55
RM2	7/26/08	8.22	2.21	1.47
RM1	7/26/08	8.57	22.45	5.10
River	7/26/08	8.14	4.59	6.95
Stk1sfc	7/26/08	241.83	4.01	3.42
Stk1deep	7/26/08	52.81	5.87	3.97
Stk3sfc	7/26/08	24.71	1.96	0.74
Stk3deep	7/26/08	20.14	1.63	1.50
Stk6sfc	7/26/08	8.71	9.07	1.43
Stk6deep	7/26/08	3.10	4.68	1.82
Stk7sfc	7/26/08	16.75	10.46	2.74
Stk7deep	7/26/08	1.72	5.55	1.18
Stk8sfc	7/26/08	12.27	5.94	1.78
Stk8deep	7/26/08	4.25	3.40	1.15
Stk9sfc	7/26/08	6.85	NaN	NaN
Stk9deep	7/26/08	6.30	NaN	NaN
Stk13sfc	7/26/08	326.42	NaN	NaN
Stk13deep	7/26/08	12.14	NaN	NaN
Stk15sfc	7/26/08	17.06	NaN	NaN
Stk15deep	7/26/08	7.64	NaN	NaN
Stk16sfc	7/26/08	6.53	NaN	NaN
Stk16deep	7/26/08	4.94	NaN	NaN
Stk18sfc	7/26/08	6.99	NaN	NaN
Stk18deep	7/26/08	3.31	NaN	NaN

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. "NaN" is defined as "Not a Number" when a parameter was not measured.)

Site	Date	DIN:DIP	APA	APA$_{\text{chl-a norm.}}$
OM2	8/30/08	15.69	1.08	0.54
OCN2	8/30/08	2.75	0.41	0.38
OB	8/30/08	26.98	0.31	0.27
OM1	8/30/08	24.60	0.40	0.36
TM	8/30/08	9.52	0.14	0.06
OCN1	8/30/08	8.61	0.53	0.36
RM3	8/30/08	6.24	3.95	1.37
RM2	8/30/08	9.11	6.81	5.12
RM1	8/30/08	8.73	13.81	13.61
River	8/30/08	8.14	3.74	7.48
Stk1sfc	8/30/08	14.30	2.50	0.46
Stk1deep	8/30/08	10.35	4.79	0.88
Stk3sfc	8/30/08	15.77	0.82	0.49
Stk3deep	8/30/08	7.58	2.31	0.60
Stk6sfc	8/30/08	15.37	2.30	1.11
Stk6deep	8/30/08	5.78	NaN	NaN
Stk7sfc	8/30/08	8.78	4.21	1.38
Stk7deep	8/30/08	1.13	8.39	1.52
Stk8sfc	8/30/08	22.18	4.07	1.02
Stk8deep	8/30/08	7.37	3.59	0.95
Stk9sfc	8/30/08	9.53	3.34	1.83
Stk9deep	8/30/08	3.07	4.44	0.49
Stk13sfc	8/30/08	11.03	3.06	0.63
Stk13deep	8/30/08	4.64	5.37	0.80
Stk15sfc	8/30/08	16.54	1.27	0.40
Stk15deep	8/30/08	6.47	1.60	0.13
Stk16sfc	8/30/08	10.69	2.05	0.65
Stk16deep	8/30/08	9.51	2.07	0.16
Stk18sfc	8/30/08	20.81	4.23	1.02
Stk18deep	8/30/08	3.13	4.30	1.43

(See Table 1.2 for site abbreviation, Figure 1.7 and 1.9 for site location. “NaN” is defined as “Not a Number” when a parameter was not measured.)

BIBLIOGRAPHY

Acha, E. M. and others 2008. An overview of physical and ecological processes in the Rio de la Plata Estuary. Cont. Shelf Res. **28:** 1579-1588.

Apple, R., and W. Kikuchi. 1975. *Ancient Hawaii Shore Zone Fishponds: An Evaluation of Survivors for Historical Preservation*. National Park Service, Dept. of Interior. Honolulu, HI.

Arhonditsis, G., G. Tsirtsis, M. O. Angelidis, and M. Karydis. 2000. Quantification of the effects of nonpoint nutrient sources to coastal marine eutrophication: applications to a semi-enclosed gulf in the Mediterranean Sea. Ecological Modelling **129:** 209-227.

Arrigo, K. R. 2005. Marine Microorganisms and Global Nutrient Cycles. Nature **437:** 349-355.

Bathen, K. H. 1968. A Descriptive Study of the Physical Oceanography of Kaneohe Bay, Oahu, Hawaii. University of Hawaii at Manoa.

Berman, T. 1970. Alkaline Phosphatases and Phosphorus Availability in Lake Kinneret. Limnology and Oceanography **15:** 663-674.

Berner, K. B., and R. A. Berner. 1996. *Global Environment: Water, Air, and Geochemical Cycles*, 1st ed. Prentice Hall.

Bidigare, R. R., L. V. Heukelem, and C. C. Trees. 2005. Analysis of Algal Pigments by High-Performance Liquid Chromatography, p. 565. Algal Culturing Techniques. Elsevier Academic Press.

Bostater, C., and R. Biggs. 1985. River Input as a Principal Cause of Nutrient Distribution in the Patuxent Estuary. Estuaries **8:** A55-A55.

Boyle, E., R. Collier, A. T. Dengler, J. M. Edmond, A. C. Ng, and R. F. Stallard. 1974. On the Chemical Mass-balance in Estuaries. Geochimica et Cosmochimica Acta **38:** 1719–1728.

Burd, A., and G. Jackson. 2002. An analysis of water column distributions in Florida Bay. Estuaries and Coasts **25:** 570-585.

Carter, J. M., and D. G. Driscoll. 2006. Estimating Recharge Using Relations Between Precipitation and Yield in a Mountainous Area with Large Variability in Precipitation. Journal of Hydrology **316:** 71-83.

Cembella, A. D., N. J. Antia, and P. J. Harrison. 1984. The Utilization of Inorganic and Organic Phosphorus-Compounds as Nutrients by Eukaryotic Microalgae - A Multidisciplinary Perspective.1. Crc Critical Reviews in Microbiology **10:** 317-391.

Chanton, J., and G. F. Lewis. 2002. Examination of Coupling between Primary and Secondary Production in a River-Dominated Estuary: Apalachicola Bay, Florida, U.S.A. Limnology and Oceanography **47:** 683-697.

Chróst, R. J., and J. Overbeck. 1987. Kinetics of Alkaline Phosphatase Activity and Phosphorus Availability for Phytoplankton and Bacterioplankton in Lake Plußsee (North German Eutrophic Lake). Microbial Ecology **13:** 229-248.

Costa-Pierce, B. A. 1987. Aquaculture in Ancient Hawaii. BioScience **37:** 320-330.

Cox, E. F., M. Ribes, and R. A. Kinzie. 2006. Temporal and spatial scaling of planktonic responses to nutrient inputs into a subtropical embayment. Marine Ecology Progress Series **324:** 19-35.

De Carlo, E. H., D. H. Hoover, C. W. Young, R. S. Hoover, and F. M. Mackenzie. 2007. Impact of storm runoff from tropical watersheds on coastal water quality and productivity. Applied Geochemistry **22:** 1777-1797.

Drupp, P., E. H. De Carlo, F. Mackenzie, P. Bienfang, and C. L. Sabine. 2011. Nutrient Inputs, Phytoplankton Response, and CO2 Variations in a Semi-Enclosed Subtropical Embayment, Kaneohe Bay, Hawaii. Aquatic Geochemistry **DOI: 10.1007/s10498-010-9115-y**.

Dyhrman, S. T., and B. Palenik. 2003. Characterization of Ectoenzyme Activity and Phosphate-Regulated Proteins in the Coccolithophorid Emiliania huxleyi. J. Plankton Res. **25:** 1215-1225.

Dyhrman, S. T., and K. C. Ruttenberg. 2006. Presence and Regulation of Alkaline Phosphatase Activity in Eukaryotic Phytoplankton from the Coastal Ocean: Implications for Dissolved Organic Phosphorus Remineralization. Limnology and Oceanography **51:** 1381-1390.

Emery, W. J., and R. E. Thomson. 1998. *Data Analysis Methods in Physical Oceanography*, 1st ed. Pergamon.

Ertekin, R. C., H. Sundararaghavan, and A. T. F. M. Van Stiphout. 1996. Molokai Fishpond Tidal Circulation Study, p. 1-92. University of Hawaii Sea Grant College Program.

Eyre, B. 1995. A First-Order Nutrient Budget for the Tropical Moresby Estuary and Catchment, North Queensland, Australia. Journal of Coastal Research **11:** 717-732.

Eyre, B., and P. Balls. 1999. A comparative study of nutrient behavior along the salinity gradient of tropical and temperate estuaries. Estuaries **22:** 313-326.

Eyre, B., and C. Twigg. 1997. Nutrient Behaviour During Post-flood Recovery of the Richmond River Estuary, Northern NSW, Australia. Estuarine, Coastal and Shelf Science **44:** 311-326.

Fisher, T. R. and others 1999. Spatial and temporal variation of resource limitation in Chesapeake Bay. Marine Biology **133:** 763-778.

Fisher, T. R., L. W. Harding, D. W. Stanley, and L. G. Ward. 1988. Phytoplankton, nutrients, and turbidity in the Chesapeake, Delaware, and Hudson estuaries. Estuarine, Coastal and Shelf Science **27:** 61-93.

Fisher, T. R., K. Y. Lee, H. Berndt, J. A. Benitez, and M. M. Norton. 1998. Hydrology and Chemistry of the Choptank River Basin. Water, Air, & Soil Pollution **105:** 387-397.

Fox, L. E., S. L. Sager, and S. C. Wofsy. 1985. Factors Controlling the Concentrations of Soluble Phosphorus in the Mississippi Estuary. Limnology and Oceanography **30:** 826-832.

Fox, L. E., S. L. Sager, and S. C. Wofsy. 1986. The Chemical Control of Soluble Phosphorus in the Amazon Estuary. Geochimica et Cosmochimica Acta **50:** 783-794.

Froelich, P. N. 1988. Kinetic Control of Dissolved Phosphate in Natural Rivers and Estuaries: A Primer on the Phosphate Buffer Mechanism. Limnology and Oceanography **33:** 649-668.

Froelich, P. N., M. L. Bender, N. A. Luedtke, G. R. Heath, and T. Devries. 1982. The Marine Phosphorus Cycle. American Journal of Science **282:** 474-511.

Gameiro, C., and V. Brotas. 2010. Patterns of Phytoplankton Variability in the Tagus Estuary (Portugal). Estuaries and Coasts **33:** 311-323.

Grasshoff, K., M. Ehrhardt, L. Anderson, K. Kremling, and T. Almgren. 1999. *Methods of Seawater Analysis*, 3rd ed. Wiley-VCH.

Healey, F. P., and L. L. Hendzel. 1980. Physiological Indicators of Nutrient Deficiency in Lake Phytoplankton. Can. J. Fish. Aquat. Sci. **37:** 442-453.

Hecky, R. E., and P. Kilham. 1988. Nutrient Limitation of Phytoplankton in Fresh-water and Marine Environments - A Review of Recent Evidence on the Effect of Enrichment. Limnology and Oceanography **33:** 796-822.

Henry, L. B. 1975. An Inventory and Status of Recognizable Fishponds Along the Kaneohe Bay Shoreline. University of Hawaii Urban and Regional Planning Program**:** 1-12.

---. 1993. *He'eia Fishpond (Loko I'a O He'eia): An Interpretive Guide for the He'eia State Park Visitor*. The State Foundation on Culture and the Arts and Ke'Alohi Press.

Hoover, D., and F. Mackenzie. 2009. Fluvial Fluxes of Water, Suspended Particulate Matter, and Nutrients and Potential Impacts on Tropical Coastal Water Biogeochemistry: Oahu, Hawai‘i. Aquatic Geochemistry **15:** 547-570.

Hoover, D. J. 2002. Fluvial Nitrogen and Phosphorus in Hawaii: Storm Runoff, Land Use, and Impacts on Coastal Waters. University of Hawaii at Manoa.

Hoover, R. S., D. Hoover, M. Miller, M. R. Landry, E. H. De Carlo, and F. M. Mackenzie. 2006. Zooplankton response to storm runoff in a tropical estuary: bottom-up and top-down controls. Marine Ecology Progress Series **318:** 187-201.

Howarth, R. W. 1988. Nutrient Limitation of Net Primary Production in Marine Ecosystems. Annual Review of Ecology and Systematics **19:** 89-110.

Hubertz, E., and L. Cahoon. 1999. Short-term variability of water quality parameters in two shallow estuaries of North Carolina. Estuaries and Coasts **22:** 814-823.

Jansson, M., H. Olsson, and K. Pettersson. 1988. Phosphatases; Origin, Characteristics and Function in Lakes. Hydrobiologia **170:** 157-175.

Jeffery, S. W., and M. Vesk. 1997. *Introduction to Marine Phytoplankton and their Pigment Signatures*. UNESCO Publishing.

Jensen, H. S., and B. Thamdrup. 1993. Iron-bound Phosphorus in Marine Sediments as Measured by Bicarbonate-dithionite Extraction. Hydrobiologia **253:** 47-59.

Justic, D., N. N. Rabalais, R. E. Turner, and Q. Dortch. 1995. Changes in nutrient structure of river-dominated coastal waters: stoichiometric nutrient balance and its consequences. Estuarine, Coastal and Shelf Science **40:** 339-356.

Kaul, L. W., and P. N. Froelich. 1984. Modeling Estuarine Nutrient Geochemistry in a Simple System. Geochimica Et Cosmochimica Acta **48:** 1417-1433.

Kelly, M. 1975. *Loko I'a o He'eia*, Second ed. Bernice Pauahi Bishop Estate.

Kikuchi, W. 1976. Prehistoric Hawaiian Fishponds. Science **193:** 295-299.

Knee, K. L., J. H. Street, E. E. Grossman, A. B. Boehm, and A. Paytan. 2010. Nutrient inputs to the coastal ocean from submarine groundwater discharge in a groundwater-dominated system: Relation to land use (Kona coast, Hawaii, USA). Limnology and Oceanography **55:** 1105-1122.

Koch, M. S., D. C. Kletou, and R. Tursi. 2009. Alkaline Phosphatase Activity of Water Column Fractions and Seagrass in a Tropical Carbonate Estuary, Florida Bay. Estuar. Coast. Shelf Sci. **83:** 403-413.

Krom, M. D., and R. A. Berner. 1981. The Diagenesis of Phosphorus in a Nearshore Marine Environment. Geochimica et Cosmochimica **45:** 207-216.

Laws, E. A., and C. B. Allen. 1996. Water Quality in a Subtropical Embayment More Than a Decade after Diversion of Sewage Discharges. Pacific Science **50:** 194-210.

Liss, P. S. 1976. *Conservative and Non-Conservative Behavior of Dissolved Constituents During Estuarine Mixing*. Academic Press.

Mantoura, R. F. C., and C. A. Llewellyn. 1983. The Rapid Determination of Algal Chlorophyll and Carotenoid Pigments and their Breakdown Products in Natural Waters by Reverse-Phase High-Performance Liquid Chromatography. Analytica Chimica Acta **151:** 297-314.

Meade, R. H., T. Dunne, J. E. Richey, U. D. M. S. Santos, and E. Salati. 1985. Storage and Remobilization of Suspended Sediment in the Lower Amazon River of Brazil. Science **228:** 488-490.

Meybeck, M. H. 2001. Global Alteration of Riverine Geochemistry Under Human Pressure, p. 97-113. *In* E. E. Kraft [ed.], Understanding the Earth System: Compartments, Processes and Interactions. Springer.

Milliman, J. D., and R. H. Meade. 1983. World-Wide Delivery of River Sediment to the Oceans. The Journal of Geology **91:** 1-21.

Milliman, J. D., and J. P. M. Syvitski. 1992. Geomorphic/Tectonic Control of Sediment Discharge to the Ocean: The Importance of Small Mountainous Rivers. The Journal of Geology **100:** 525-544.

Monaghan, E. J., and K. C. Ruttenberg. 1999. Dissolved organic phosphorus in the coastal ocean: Reassessment of available methods and seasonal phosphorus profiles from the Eel River Shelf. Limnology and Oceanography **44:** 1702-1714.

Monbet, Y. 1992. Control of Phytoplankton Biomass in Estuaries: A Comparative Analysis of Microtidal and Macrotidal Estuaries. Estuaries **15:** 563-571.

Morris, A. W., J. I. Allen, R. J. M. Howland, and R. G. Wood. 1995. The Estuary Plume Zone: Source or Sink for Land-derived Nutrient Discharges? Estuarine, Coastal and Shelf Science **40:** 387-402.

Nausch, M., G. Nausch, and N. Wasmund. 2004. Phosphorus Dynamics During the Transition from Nitrogen to Phosphate Limitation in the Central Baltic Sea. Marine Ecology Progress Series **266:** 15-25.

Ostrander, C. E., M. A. Mc Manus, E. H. De Carlo, and F. T. Mackenzie. 2008. Temporal and Spatial Variability of Freshwater Plumes in a Semienclosed Estuarine-bay System. Estuaries and Coasts **31:** 192-203.

Pawlowicz, R., B. Beardsley, and S. Lentz. 2002. Classical tidal harmonic analysis including error estimates in MATLAB using T_TIDE. Computers & Geosciences **28:** 929-937.

Perez, B. C., J. W. Day, D. Justic, R. R. Lane, and R. R. Twilley. 2011. Nutrient Stoichiometry, Freshwater Residence Time, and Nutrient Retention in a River-Dominated Estuary in the Mississippi Delta. Hydrobiologia **658:** 41-54.

Pomeroy, L. R., E. E. Smith, and C. M. Grant. 1965. The Exchange of Phosphate Between Estuarine Water and Sediments. Limnology and Oceanography **10:** 167-172.

Poulton, S. W., and D. E. Canfield. 2005. Development of a sequential extraction procedure for iron: implications for iron partitioning in continentally derived particulates. Chemical Geology **214:** 209-221.

Preisendorfer, R. W. 1988. *Principal Component Analysis in Meteorology and Oceanography*. Elsevier.

Rabalais, N. N., N. Atilla, C. Normandeau, and R. E. Turner. 2004. Ecosystem History of Mississippi River-Influenced Continental Shelf Revealed Through Preserved Phytoplankton Pigments. Marine Pollution Bulletin **49:** 537-547.

Rabalais, N. N., R. E. Turner, R. J. D√≠Az, and D. Justiƒá. 2009. Global change and eutrophication of coastal waters. ICES Journal of Marine Science: Journal du Conseil **66:** 1528-1537.

Rao, S. S. 2005. *The Finite Element Method in Engineering*, Fourth ed. Elsevier Butterworth-Heinemann.

Redfield, A. C., B. H. Ketchum, and F. A. Richards. 1963. *The Influence of Organisms on the Composition of Seawater* John Wiley, New York.

Reichardt, W., J. Overbeck, and L. Steubing. 1967. Free Dissolved Enzymes in Lake Waters. Nature **216:** 1345.

Ringuet, S., and F. M. Mackenzie. 2005. Controls on nutrient and phytoplankton dynamics during normal flow and storm runoff conditions, southern Kaneohe Bay, Hawaii. Estuaries **28:** 327-337.

Rodhe, A., and N. Bockgard. 2006. Groundwater recharge in a hard rock aquifer: A conceptual model including surface-loading effects. Journal of Hydrology **330:** 389-401.

Rose, C., and R. P. Axler. 1997. Uses of Alkaline Phosphatase Activity in Evaluating Phytoplankton Community Phosphorus Deficiency. Hydrobiologia **361:** 145-156.

Ruttenberg, K. C. 1992. Development of a Sequential Extraction Method for Different Forms of Phosphorus in Marine-Sediments. Limnology and Oceanography **37:** 1460-1482.

---. 2003. The Global Phosphorus Cycle, p. 585-643. *In* H. D. Holland and K. K. Turekian [eds.], *Treatise on Geochemistry*. Elsevier Science.

Ruttenberg, K. C., and S. T. Dyhrman. 2005. Temporal and spatial variability of dissolved organic and inorganic phosphorus, and metrics of phosphorus bioavailability in an upwelling-dominated coastal system. J. Geophys. Res. **110:** C10S13.

Ruttenberg, K. C., and D. J. Sulak. 2011. Sorption and Desorption of Dissolved Organic Phosphorus onto Iron (oxyhydro) oxides in Seawater. Geochimica Et Cosmochimica Acta **in press**.

Sarin, M. M., and T. M. Church. 1994. Behavior of Uranium During Mixing in the Delaware and Chesapeake Estuaries. Estuar. Coast. Shelf Sci. **39:** 619-631.

Schlesinger, W. H. 1997. *Biogeochemistry: An Analysis of Global Change*, 2nd ed. Academic Press.

Sebastian, M., J. Aristegui, M. F. Montero, and F. X. Niell. 2004. Kinetics of Alkaline Phosphatase Activity, and Effect of Phosphate Enrichment: A Case Study in the NW African Upwelling Region. Mar. Ecol.-Prog. Ser. **270:** 1-13.

Shan, Y., I. D. Mckelvie, and B. T. Hart. 1994. Determination of Alkaline Phosphatase-Hydrolyzable Phosphorus in Natural Water Systems by Enzymatic Flow Injection. Limnology and Oceanography **39:** 1993-2000.

Shimadzu. 2004. PC-Controlled Total Organic Carbon Analyzer User Manual, p. 394. Shimadzu Corporation Analytical and Measuring Instruments Division.

Smith, S. V., R. M. Chambers, and J. T. Hollibaugh. 1996. Dissolved and Particulate Nutrient Transport Through a Coastal Watershed-Estuary System. Journal of Hydrology **176:** 181-203.

Smith, S. V., W. J. Kimmerer, E. A. Laws, R. E. Brock, and T. W. Walsh. 1981. Kaneohe Bay Sewage Diversion Experiment: Perspectives on Ecosystem Responses to Nutritional Perturbation. Pacific Science **35:** 279-395.

Sposito, G. 1989. *The Chemistry of Soils*, 2nd ed. Oxford University Press.

Staver, L. W., K. W. Staver, and J. C. Stevenson. 1996. Nutrient inputs to the Choptank River estuary: Implications for watershed management. Estuaries **19:** 342-358.

Strickland, J. D. H., and T. R. Parsons. 1972. *A Practical Handbook of Seawater Analysis*. Fisheries Research Board of Canada.

Sundby, B., C. Gobeil, N. Silverberg, and A. Mucci. 1992. The Phosphorus Cycle in Coastal Marine Sediments. Limnology and Oceanography **37:** 1129-1145.

Tomlinson, M. S., and E. H. De Carlo. 2003. The need for high resolution time series data to characterize Hawaiian streams. J. Am. Water Resour. Assoc. **39:** 113-123.

Turner, R. E. and others 1998. Fluctuating silicate:nitrate ratios and coastal plankton food webs. Proceedings of the National Academy of Sciences (USA) **95:** 13048-13051.

Uncles, R. J., P. E. Frickers, and C. Harris. 2003. Dissolved Nutrients in the Tweed Estuary, UK: Inputs, Distributions and Effects of Residence Time. The Science of The Total Environment **314-316:** 727-736.

Wang, X. L. and others 2008. Nutrient composition and distributions in coastal waters impacted by the Changjiang plume. Acta Oceanol. Sin. **27:** 111-125.

Wetz, M. S. 2006. Riverine Input of Macronutrients, Iron, and Organic Matter to the Coastal Ocean off Oregon, U.S.A., During the Winter. Limnology and Oceanography **51:** 2221–2231.

Wetz, M. S., and P. A. Wheeler. 2003. Production and Partitioning of Organic Matter during Simulated Phytoplankton Blooms. Limnology and Oceanography **48:** 1808-1817.

White, A. F., and A. E. Blum. 1995. Effects of Climate on Chemical Weathering in Watersheds. Geochimica Et Cosmochimica Acta **59:** 1729-1747.

Wollheim, W. M., C. J. Vorosmarty, B. J. Peterson, S. P. Seitzinger, and C. S. Hopkinson. 2006. Relationship between river size and nutrient removal. Geophys. Res. Lett. **33:** L06410.

Wright, S. W. and others 1991. Improved HPLC Method for the Analysis of Chlorphylls and Carotenoids from Marine-Phytoplankton. Mar. Ecol.-Prog. Ser. **77:** 183-196.

Yamada, H., and M. Kayama. 1987. Distribution and Dissolution of Several Forms of Phosphorus in Coastal Marine Sediments. Oceanologica Acta **10:** 311-321.

Yang, L. 2000. A Circulation Study of Hawaiian Fishponds. University of Hawaii at Manoa.