



Water Quality in the Brackish Waterbody at Pu'ukoholā Heiau National Historic Site

Summary Report 2007-2011

Natural Resource Data Series NPS/PACN/NRDS—2013/508



ON THE COVER

Mouth of the brackish waterbody at the shoreline of Pu'ukoholā Heiau National Historic Site (PUHE).
Photo courtesy of the National Park Service.

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July 2013

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

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Please cite this publication as:

Raikow, D. F., and A. Farahi. 2013. Data report for water quality in the brackish waterbody at Pu'ukoholā Heiau National Historic Site: summary report 2007-2011. Natural Resource Data Series NPS/PACN/NRDS—2013/508. National Park Service, Fort Collins, Colorado.

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Abstract/Executive Summary

This Natural Resource Data Series Report (NRDS) presents data collected from the brackish waterbody at Pu'ukoholā Heiau National Historic Site (PUHE) on the west coast of the island of Hawai'i, Hawaii. This is a summary or "data report" as described in Water Quality Vital Signs Monitoring Protocol for the Pacific Island Network Version 1.0, Natural Resource Report NPS/PACN/NRR-2011/418. This report is restricted to data presentation and limited description. The data presented in this report will be analyzed for the establishment of expected parameter value ranges and long-term trends in future reports published under the NPS Natural Resource Technical Report (NRTR) series.

The brackish waterbody at PUHE was sampled 17 times from the last quarter of 2007 through 2011. Two unusual events were observed: a likely minor algal bloom in 2009, and a flood event in 2011. Slightly elevated nutrient concentrations were observed prior to and during the bloom. Heavy rains contributed a pulse of freshwater in 2011 that was directly observed at the inland sites F-PUHE-02 and F-PUHE-03. The most coastal site, F-PUHE-01, intermittently displayed conditions that differed from inland sites due to connection to the ocean. Observations made during the freshwater flood event while in progress illustrated that variability in this system is biphasic. Thus future evaluations of limnological parameter ranges should account for both "low-flow" and flood conditions.

Acknowledgments

We thank Daniel Kawaiiea, Superintendent, and the staff of PUHE for their cooperation and on-site logistical support.

List of Units and Acronyms

°C	Degrees Centigrade
$\mu\text{g} \cdot \text{L}^{-1}$	Micrograms per Liter
$\mu\text{gP} \cdot \text{L}^{-1}$	Micrograms of Phosphorus per Liter
$\mu\text{S} \cdot \text{cm}^{-1}$	Micro-Siemens per Centimeter
Chl	Chlorophyll
HAVO	Hawai'i Volcanoes National Park
I&M	Inventory and Monitoring Program of the National Park Service
$\text{mg} \cdot \text{L}^{-1}$	Milligrams per Liter
$\text{mgN} \cdot \text{L}^{-1}$	Milligrams of Nitrogen per Liter
n	Number of measurements or samples
NO_2	Nitrite
NO_3	Nitrate
NPS	National Park Service
NRDS	Natural Resource Data Series Report
NRTR	Natural Resource Technical Report
NTU	Nephelometric Turbidity Units
ODO	Optical Dissolved Oxygen
ODOsat	Optical Dissolved Oxygen in terms of saturation
PACN	Pacific Island Inventory and Monitoring Network
ppt	Parts Per Thousand
PUHE	Pu'ukoholā Heiau National Historic Site
SD	Standard Deviation
SE	Standard Error
SpC	Specific conductivity
TDN	Total Dissolved Nitrogen
TDP	Total Dissolved Phosphorus
Temp	Temperature
TN	Total Nitrogen
TP	Total Phosphorus
Turb	Turbidity
UHH	University of Hawai'i at Hilo

Introduction

Water quality monitoring is widely used as an indicator of aquatic ecosystem condition. The National Park Service (NPS) has designated water quality as a “Vital Sign”, or set of physical, chemical, biological elements and ecosystem processes selected to represent the overall health or condition of natural resources within parks. Water quality is one Vital Sign monitored by the NPS Inventory and Monitoring (I&M) Pacific Island Network (PACN). This report presents data collected under the PACN water quality protocol (Jones et al. 2011) on the brackish waterbody within Pu’ukoholā Heiau National Historic Site (PUHE) on the island of Hawai’i, Hawaii, between 2007-2011.

This report is a Natural Resource Data Series Report (NRDS), defined by the NPS as an annual or periodic data summary report for long-term monitoring projects. NRDSs are intended only for the release of basic data sets and summaries, with minimal interpretation. This report is one part of the I&M reporting process. Data presented in this report will be incorporated into future I&M trend-analysis reports to be published as NPS Natural Resource Technical Reports (NRTR).

The purpose of collecting data on Vital Signs is to provide park managers information on current conditions and temporal trends in ecosystem health. Park managers can use this information to respond to resource conditions and evaluate management actions. The mission of the I&M Program is to provide data to inform management decisions and support the NPS mission of preserving the natural resources of parks unimpaired for the enjoyment of future generations (16 U.S.C. §1).

Methods

Water was collected for nutrient analyses, a sonde was used to measure limnological parameters, and weather conditions were recorded. Data were collected using methods described in version 1.0 of the PACN water quality protocol (Jones et al. 2011).

Sample Sites

The unnamed brackish waterbody at PUHE in Pōhaukole Gultch inshore of Pelekane Bay is the only waterbody in the park (Fig 1). This waterbody has the appearance of a stream channel, but is frequently a stagnant pond, and experiences intermittent overland connection with the ocean. It is not classified as an anchialine pool. Although this waterbody could be classified as “brackish waters” under §11-54-5.1b of the State of Hawai'i Department of Health Water Quality Standards (Hawaii 2012), there are no inland water quality criteria for this type of waterbody. Three sample sites were chosen spanning the length of the channel and were designated F-PUHE-01, F-PUHE-02, and F-PUHE-03 (Table 1), where F means “fixed location”, as opposed to temporary locations designated with a “T” at sample sites in other parks. Data were collected from November 2007 - October 2011 (Table 2).

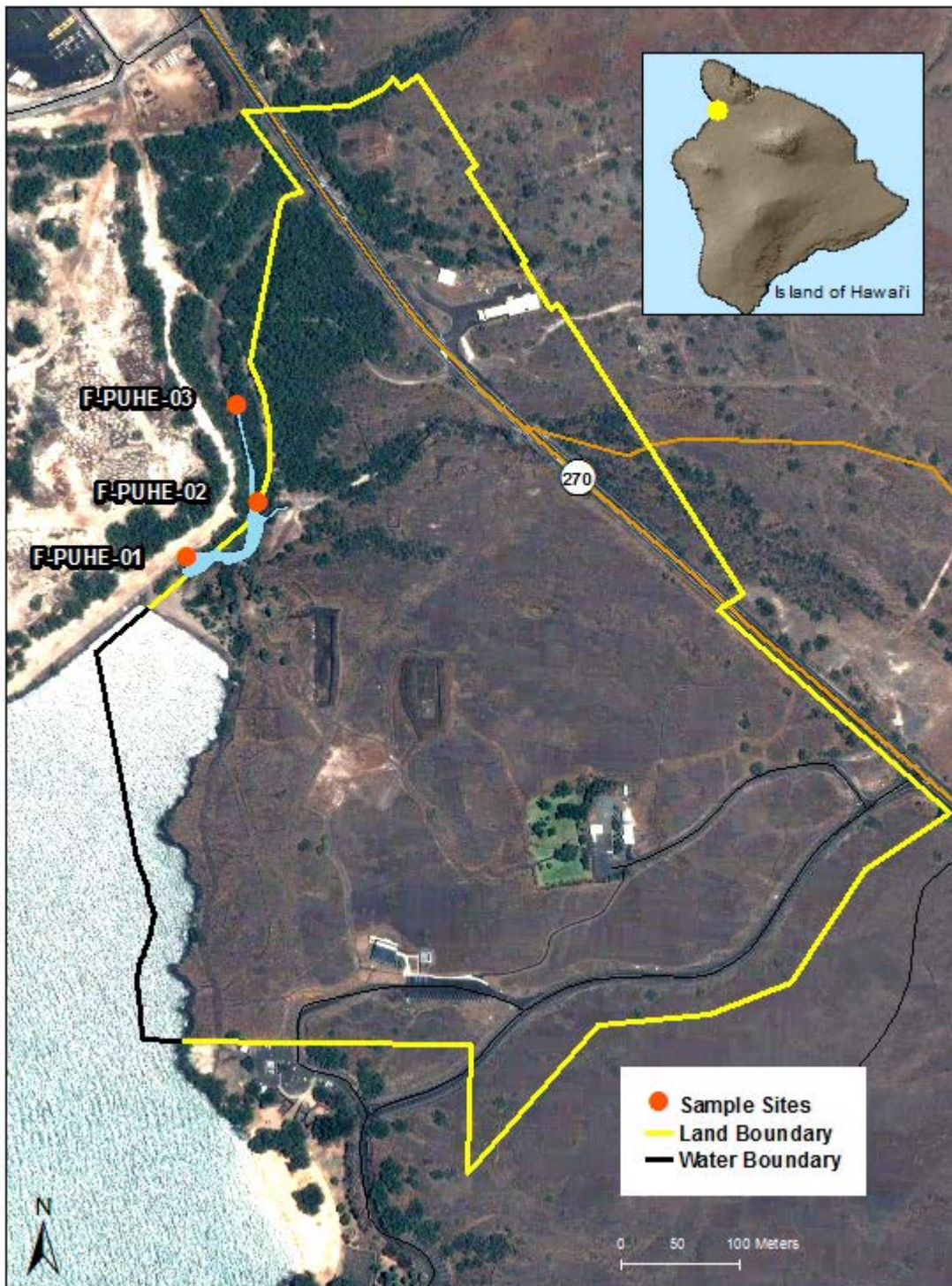


Figure 1. Sample sites in the brackish waterbody at Pu'ukoholā Heiau National Historic Site on the island of Hawai'i.

Table 1. PUHE sample site locations.

Station ID	Notes	Decimal Degrees Latitude	Decimal Degrees Longitude
F-PUHE-01	Terminus near Pelekane Bay.	20.028603	-155.823413
F-PUHE-02	Convergence of two “channels”.	20.029034	-155.822850
F-PUHE-03	Near inland-most terminus.	20.029772	-155.823032

Table 2. PUHE sampling events.

Park	Year	Date	Personnel
PUHE	2007	06-Nov-07	Lindsey Kramer, Tahzay Jones
PUHE	2008	23-Jan-08	Lindsey Kramer, Tahzay Jones
PUHE	2008	20-May-08	Anne Farahi, Lindsey Kramer
PUHE	2008	19-Aug-08	Anne Farahi, Lindsey Kramer
PUHE	2008	13-Nov-08	Anne Farahi, Lindsey Kramer
PUHE	2009	11-Mar-09	Anne Farahi, Lindsey Kramer
PUHE	2009	15-Jun-09	Cassandra Ogura-Yamada, Lindsey Kramer
PUHE	2009	25-Aug-09	Ann Guth, Lindsey Kramer
PUHE	2009	19-Nov-09	Ann Guth, Lindsey Kramer
PUHE	2010	22-Feb-10	Lily Souza, Lindsey Kramer
PUHE	2010	06-May-10	Ann Guth, Lindsey Kramer
PUHE	2010	31-Aug-10	Deona Naboa, Lindsey Kramer
PUHE	2010	30-Nov-10	Ann Guth, Lindsey Kramer
PUHE	2011	04-Feb-11	Lindsey Kramer, M. Jerolaman
PUHE	2011	02-May-11	Asia Addlesberger, M. Jerolaman
PUHE	2011	11-Aug-11	Anne Farahi, Danielle Gross, Tonnie Casey
PUHE	2011	31-Oct-11	Anne Farahi, Danielle Gross

Water Collection

Unfiltered water samples were taken in 2007. In 2008 methodology was changed to collect filtered water using the following procedure. Water was collected using a new or acid-washed 140cc syringe just below the surface to avoid disturbance of sediment or collection of floating material. This water was then discarded away from the collection location to rinse the syringe. Water was again collected using the rinsed syringe. An in-line filter holder and 0.7 μ m filter were then placed on the syringe. Filtered water was then used to rinse each sample bottle three times, for a total of 50ml per bottle, discarding water between each rinse. The filter assembly was then removed, water again was drawn into the syringe, and a filter assembly was again placed onto the syringe. 140ml of water was then filtered into each sample bottle. Three 140ml samples were taken at each sample site. Sample bottles were placed on ice in the field inside an insulated backpack. Samples were transported to Hawai'i Volcanoes National Park (HAVO) on the day of collection and then frozen, or deposited into a freezer on the day of collection and then transported while frozen to HAVO. Samples were then delivered to the EPSCoR Analytical Laboratory at the University of Hawaii at Hilo (UHH) Marine Science Department, 200 W. Kawili St., Hilo, Hawai'i 96720 for chemical analysis. 2007 samples were analyzed for total

phosphorous (TP), total nitrogen (TN) and nitrate + nitrite ($\text{NO}_3 + \text{NO}_2$). Samples collected in beginning in 2008 were analyzed for total dissolved phosphorous (TDP), total dissolved nitrogen (TDN) and nitrate + nitrite ($\text{NO}_3 + \text{NO}_2$).

Limnological Parameters and General Conditions

A YSI 6600 Multiparameter Sonde was calibrated a few days before commencing field sampling. The sonde was used to measure temperature ($^{\circ}\text{C}$), specific conductivity (SpC) in micro Siemens per centimeter ($\mu\text{S} \cdot \text{cm}^{-1}$), salinity in parts per thousand (ppt), pH, dissolved oxygen in percent saturation (% ODOsat) and milligrams per liter ($\text{mg} \cdot \text{L}^{-1}$, ODO), chlorophyll in micrograms per liter ($\mu\text{g} \cdot \text{L}^{-1}$), and turbidity in nephelometric turbidity units (NTU). The sonde was placed under the surface of the water at a sample site for seven to ten minutes, during which readings were taken every 30 seconds. The mean and variance of stable values, excluding initial readings, over this time period is reported. Mean values of chlorophyll and turbidity that were less than zero are reported with a value of zero, i.e. as non-detects. Minimum analytical detection limits were $15.0 \mu\text{gP} \cdot \text{L}^{-1}$ for total dissolved phosphorus (TDP), $0.070 \text{ mgN} \cdot \text{L}^{-1}$ for total dissolved nitrogen (TDN), and $1.0 \mu\text{gN} \cdot \text{L}^{-1}$ for nitrate + nitrite ($\text{NO}_3 + \text{NO}_2$).

Environmental conditions, canopy cover, and water depth were estimated. Average wind speed over three minutes and wind direction were measured using a Kestrel wind speed device. Global positioning system coordinates and site elevation were recorded. Photographs of sample sites were also taken.

Data Analysis, Management, and Quality Control

Environmental parameters, habitat descriptions, and general observations were recorded on datasheets in the field. Datasheets were stored at park offices, scanned, and uploaded to PACN servers. All data including results of laboratory analyses were entered into PACN databases. Data were downloaded from the YSI 650 control unit and uploaded to databases. Accuracy of data entry into databases was verified by comparing database entries to the original datasheets by a person who did not enter the data into databases. Data were then certified by the PACN freshwater program lead at the time, either Tazhay Jones or David Raikow. Data determined to be unreliable were flagged in databases, removed from further consideration, and reported as “no data”. Data were explored visually by plotting time-series and boxplots. Data that deviated from regular temporal patterns were identified. Corroboration between related parameters and field notes was used to identify possible causes of deviation from regular temporal patterns. Statistical analysis of water quality data followed recommendations by the USGS (Helsel and Hirsch 2002) as described in the protocol (Jones et al. 2011).

Measurements from a series of water samples or sonde readings taken at an individual site within minutes of each other were expected to be normally distributed around the true value of the parameter, because the parameter should not change appreciably over the short time required to take multiple samples or readings. Variation in sample values should be most influenced by external factors. Therefore the mean and the standard error are reported for individual sampling events, because the accuracy of the estimate of the mean is of interest (Tables 8-18). Non-normal distributions, however, are generally expected when summarizing limnological conditions over a time period such as a year due to censoring (values cannot drop below zero or have a minimum

analytical detection limit) and positive skewness (having infrequent high values) (Helsel and Hirsch 2002). Therefore the median and standard deviation are reported for annual summaries, because the variance of the parameter over the study period is of interest (Tables 3-7). The median equals the mean in normally-distributed parameters. For the purposes of descriptive statistics, values below detection limits were assigned values equal to one-half of the detection limit. Standard deviation was not calculated for sets of data with $n \leq 2$.

Within boxplots, the upper edge of the box indicates the third quartile (Q_3 , upper quartile, or 75th percentile), and the lower edge indicates the first quartile (Q_1 , lower quartile, or 25th percentile, Fig. 2). Within the box, the white line indicates the median (Q_2 , or 50th percentile). The whiskers extend up or down until the maximum or minimum value within 1.5 IQRs (inter-quartile range, or $Q_3 - Q_1$). Data outside 1.5 IQRs are displayed as dots, and considered outliers. If there are no outliers the whiskers display the entire range of data.

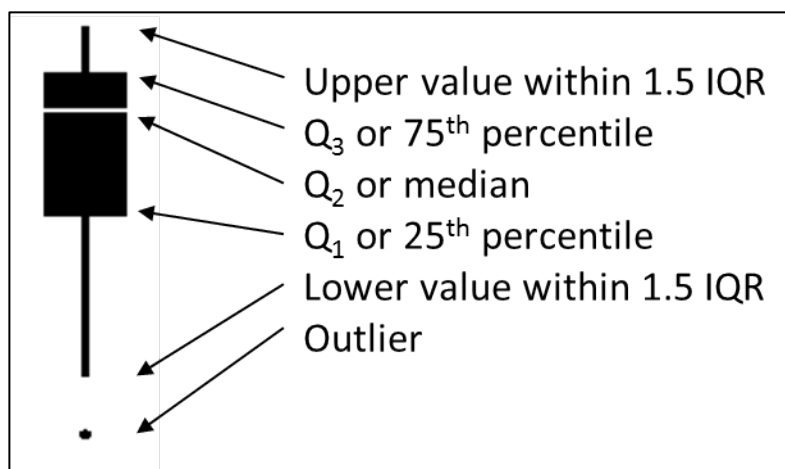


Figure 2. Box plot explanation.

Results

The brackish waterbody was sampled 17 times from 2007 to 2011. The waterbody was connected to the ocean by overland water flow during six sampling events (35%). Results are presented in summaries by year (Tables 3-7, Figs. 3-13) and parameter (Tables 8-18). Annual summaries present the minimum, maximum, median, and variance as standard deviation of all individual measurements at each site across an entire year. Parameter summaries present stable sonde readings and nutrient concentrations from each site and sampling event as mean and standard error of the mean. Box plots display data lumped from all three sample sites by year.

2007

The program started in 2007 with one sampling event (Table 3). The single value for sonde-measured parameters is presented in the “minimum” column. The sonde was not deployed at F-PUHE-02, reported as “no data” (Tables 8-18). Only two water samples were collected.

Table 3. 2007 summary of water quality parameters in the PUHE brackish waterbody.

Parameter	Unit	Site	n	Minimum	Maximum	Median	SD ¹
Total Phosphorus	$\mu\text{gP} \cdot \text{L}^{-1}$	F-PUHE-01	2	<15.0 ²	<15.0 ²	<15.0 ²	
		F-PUHE-02	2	<15.0 ²	<15.0 ²	<15.0 ²	
		F-PUHE-03	2	16.1	24.0	20.1	
Total Nitrogen	$\text{mgN} \cdot \text{L}^{-1}$	F-PUHE-01	2	1.5	2.3	1.9	
		F-PUHE-02	2	1.8	1.9	1.8	
		F-PUHE-03	2	1.7	2.8	2.2	
Nitrate + Nitrite	$\mu\text{gN} \cdot \text{L}^{-1}$	F-PUHE-01	2	65.3	99.4	82.4	
		F-PUHE-02	2	163.4	172.2	167.8	
		F-PUHE-03	2	2.5	13.3	7.9	
Chlorophyll	$\mu\text{g} \cdot \text{L}^{-1}$	F-PUHE-01	1	7.2			
		F-PUHE-03	1	8.1			
Dissolved Oxygen Concentration	$\text{mg} \cdot \text{L}^{-1}$	F-PUHE-01	1	0.9			
		F-PUHE-03	1	0.1			
Dissolved Oxygen Saturation	%	F-PUHE-01	1	12.6			
		F-PUHE-03	1	2.0			
pH	none	F-PUHE-01	1	7.8			
		F-PUHE-03	1	7.5			
Salinity	ppt	F-PUHE-01	1	12.6			
		F-PUHE-03	1	10.9			
Specific Conductance	$\text{mS} \cdot \text{cm}^{-1}$	F-PUHE-01	1	21.2			
		F-PUHE-03	1	18.5			
Temperature	°C	F-PUHE-01	1	28.3			
		F-PUHE-03	1	27.3			
Turbidity	NTU	F-PUHE-01	1	24.2			

¹SD = Standard Deviation; not calculated when $n \leq 2$.

²Non-detection, i.e. less than the analytical detection limit of $15.0 \mu\text{gP} \cdot \text{L}^{-1}$.

2008

Although relatively high concentrations of TDP and $\text{NO}_3 + \text{NO}_2$ were measured, it is too early in the program to determine whether these values fall outside of the expected range of variation (Table 4).

Table 4. 2008 summary of water quality parameters in the PUHE brackish waterbody.

Parameter	Unit	Site	n	Minimum	Maximum	Median	SD ¹
Total Dissolved Phosphorus	$\mu\text{gP} \cdot \text{L}^{-1}$	F-PUHE-01	12	<15.0 ²	81.0	33	29.0
		F-PUHE-02	12	<15.0 ²	158.0	34	58.1
		F-PUHE-03	12	<15.0 ²	203.0	32	62.3
Total Dissolved Nitrogen	$\text{mgN} \cdot \text{L}^{-1}$	F-PUHE-01	12	0.3	0.8	0.5	0.14
		F-PUHE-02	12	0.3	0.7	0.4	0.13
		F-PUHE-03	12	0.3	1.4	0.6	0.37
Nitrate + Nitrite	$\mu\text{gN} \cdot \text{L}^{-1}$	F-PUHE-01	12	60.9	500.0	123.0	134.83
		F-PUHE-02	12	66.0	198.0	98.0	39.11
		F-PUHE-03	12	60.5	567.0	218.5	192.01
Chlorophyll	$\mu\text{g} \cdot \text{L}^{-1}$	F-PUHE-01	4	3.0	22.4	13.1	7.94
		F-PUHE-02	4	10.1	42.3	14.3	17.50
		F-PUHE-03	4	16.3	36.4	18.3	11.07
Dissolved Oxygen Concentration	$\text{mg} \cdot \text{L}^{-1}$	F-PUHE-01	4	4.0	6.8	5.0	1.18
		F-PUHE-02	4	3.3	7.2	5.1	1.60
		F-PUHE-03	4	1.8	7.1	3.7	2.39
Dissolved Oxygen Saturation	%	F-PUHE-01	4	55.9	96.1	64.2	17.90
		F-PUHE-02	4	43.1	102.7	67.8	24.53
		F-PUHE-03	4	23.6	99.1	49.0	34.19
pH	none	F-PUHE-01	4	7.7	7.9	7.9	0.09
		F-PUHE-02	4	7.5	8.0	7.7	0.24
		F-PUHE-03	4	7.4	7.9	7.5	0.22
Salinity	ppt	F-PUHE-01	4	6.6	19.0	8.4	5.81
		F-PUHE-02	4	6.4	20.2	8.7	6.49
		F-PUHE-03	4	4.1	17.9	11.6	5.80
Specific Conductance	$\text{mS} \cdot \text{cm}^{-1}$	F-PUHE-01	4	11.7	30.7	14.5	8.90
		F-PUHE-02	4	11.4	32.5	14.9	9.93
		F-PUHE-03	4	7.5	29.0	19.6	9.07
Temperature	°C	F-PUHE-01	4	25.6	31.6	26.7	2.69
		F-PUHE-02	4	25.1	31.1	27.1	2.51
		F-PUHE-03	4	25.0	30.0	26.0	2.36
Turbidity	NTU	F-PUHE-01	4	4.6	11.9	8.4	3.64
		F-PUHE-02	4	4.9	7.6	7.5	1.53
		F-PUHE-03	4	3.0	11.2	5.3	4.23

¹SD = Standard Deviation.

²Non-detection, i.e. less than the analytical detection limit of $15.0 \mu\text{gP} \cdot \text{L}^{-1}$.

2009

An algal bloom appears to have occurred in 2009 (Table 5). The June, August, and November sampling events recorded relatively high chlorophyll, dissolved oxygen concentrations and saturations, and pH (Tables 11-14, respectively). Reduced acidity (increased pH) is consistent with photosynthetic activity consuming dissolved CO₂ and thus reducing dissolved carbonic acid (Wetzel 2001). Nutrients were also relatively elevated during this time, which would support an algal bloom. Visual observations during this time report relatively turbid water, consistent with turbidity measurements. No surface scums were reported or photographed, therefore the severity of this bloom was most likely minor.

Table 5. 2009 summary of water quality parameters in the PUHE brackish waterbody.

Parameter	Unit	Site	n	Minimum	Maximum	Median	SD ¹
Total Dissolved Phosphorus	$\mu\text{gP} \cdot \text{L}^{-1}$	F-PUHE-01	10	<15.0 ²	86.0	38	33.6
		F-PUHE-02	12	<15.0 ²	102.7	44	33.8
		F-PUHE-03	12	<15.0 ²	65.2	28	22.1
Total Dissolved Nitrogen	$\text{mgN} \cdot \text{L}^{-1}$	F-PUHE-01	10	0.2	1.4	0.5	0.42
		F-PUHE-02	12	0.3	0.9	0.4	0.21
		F-PUHE-03	12	0.1	1.1	0.5	0.27
Nitrate + Nitrite	$\mu\text{gN} \cdot \text{L}^{-1}$	F-PUHE-01	10	<1.0 ³	451.0	52.0	204.80
		F-PUHE-02	12	<1.0 ³	601.0	21.3	249.23
		F-PUHE-03	12	3.3	842.0	108.6	266.46
Chlorophyll	$\mu\text{g} \cdot \text{L}^{-1}$	F-PUHE-01	4	1.0	57.6	25.0	27.89
		F-PUHE-02	4	5.7	74.8	62.9	31.62
		F-PUHE-03	4	5.8	101.6	76.2	42.08
Dissolved Oxygen Concentration	$\text{mg} \cdot \text{L}^{-1}$	F-PUHE-01	4	3.6	11.3	9.7	3.39
		F-PUHE-02	4	2.3	12.2	10.7	4.49
		F-PUHE-03	4	4.5	12.0	9.5	3.24
Dissolved Oxygen Saturation	%	F-PUHE-01	4	54.4	169.4	135.5	49.08
		F-PUHE-02	4	32.4	183.2	147.9	66.02
		F-PUHE-03	4	59.9	174.9	129.7	50.76
pH	none	F-PUHE-01	4	7.4	8.4	8.2	0.45
		F-PUHE-02	4	7.3	8.5	8.3	0.55
		F-PUHE-03	4	7.5	8.3	8.2	0.39
Salinity	ppt	F-PUHE-01	4	3.5	17.1	14.7	6.15
		F-PUHE-02	4	3.5	16.8	15.0	6.11
		F-PUHE-03	4	3.0	16.2	12.6	5.68
Specific Conductance	$\text{mS} \cdot \text{cm}^{-1}$	F-PUHE-01	4	6.5	28.0	24.5	9.80
		F-PUHE-02	4	6.5	27.6	24.9	9.74
		F-PUHE-03	4	5.6	26.6	21.1	9.12
Temperature	°C	F-PUHE-01	4	28.7	33.2	31.8	1.89
		F-PUHE-02	4	27.4	32.3	30.4	2.52
		F-PUHE-03	4	25.9	31.1	28.9	2.59
Turbidity	NTU	F-PUHE-01	3	18.1	24.8	24.1	3.71
		F-PUHE-02	4	12.7	21.0	14.2	3.75
		F-PUHE-03	4	7.2	14.3	10.1	2.96

¹SD = Standard Deviation.

²Non-detection, i.e. less than the analytical detection limit of 15.0 $\mu\text{gP} \cdot \text{L}^{-1}$.

³Non-detection, i.e. less than the analytical detection limit of 1.0 $\mu\text{gN} \cdot \text{L}^{-1}$.

2010

No remarkable conditions or events were observed in 2010 (Table 6).

Table 6. 2010 summary of water quality parameters in the PUHE brackish waterbody.

Parameter	Unit	Site	N	Minimum	Maximum	Median	SD ¹
Total Dissolved Phosphorus	$\mu\text{gP} \cdot \text{L}^{-1}$	F-PUHE-01	12	15.0	111.0	38	29.8
		F-PUHE-02	12	15.0	141.0	36	38.4
		F-PUHE-03	12	15.0	86.0	36	26.1
Total Dissolved Nitrogen	$\text{mgN} \cdot \text{L}^{-1}$	F-PUHE-01	12	0.3	1.0	0.5	0.20
		F-PUHE-02	12	0.3	0.8	0.5	0.15
		F-PUHE-03	12	0.3	1.3	0.6	0.39
Nitrate + Nitrite	$\mu\text{gN} \cdot \text{L}^{-1}$	F-PUHE-01	12	<1.0 ²	561.0	57.0	197.52
		F-PUHE-02	12	<1.0 ²	415.0	65.0	146.59
		F-PUHE-03	12	<1.0 ²	540.0	78.0	176.48
Chlorophyll	$\mu\text{g} \cdot \text{L}^{-1}$	F-PUHE-01	4	8.6	40.3	16.6	15.08
		F-PUHE-02	4	8.6	37.7	24.4	16.11
		F-PUHE-03	4	10.3	37.9	14.8	14.81
Dissolved Oxygen Concentration	$\text{mg} \cdot \text{L}^{-1}$	F-PUHE-01	4	6.1	6.9	6.3	0.33
		F-PUHE-02	4	4.0	7.4	5.4	1.53
		F-PUHE-03	4	2.3	7.3	4.5	2.10
Dissolved Oxygen Saturation	%	F-PUHE-01	4	76.1	99.0	91.2	10.03
		F-PUHE-02	4	57.0	105.2	70.8	21.34
		F-PUHE-03	4	32.9	101.7	57.8	30.18
pH	none	F-PUHE-01	4	7.6	7.9	7.9	0.13
		F-PUHE-02	4	7.7	7.9	7.8	0.09
		F-PUHE-03	4	7.5	7.9	7.6	0.16
Salinity	ppt	F-PUHE-01	4	3.7	23.3	9.3	8.54
		F-PUHE-02	4	4.0	15.1	7.5	5.32
		F-PUHE-03	4	4.2	16.6	7.3	5.88
Specific Conductance	$\text{mS} \cdot \text{cm}^{-1}$	F-PUHE-01	4	6.8	36.9	15.9	13.11
		F-PUHE-02	4	7.4	24.9	13.0	8.49
		F-PUHE-03	4	7.7	27.2	12.8	9.28
Temperature	°C	F-PUHE-01	4	25.1	31.6	30.4	3.01
		F-PUHE-02	4	25.7	30.9	30.3	2.50
		F-PUHE-03	4	24.4	30.1	29.1	2.64
Turbidity	NTU	F-PUHE-01	4	3.9	18.1	13.2	6.58
		F-PUHE-02	4	5.1	15.6	6.4	4.90
		F-PUHE-03	4	4.6	16.9	5.5	6.84

¹SD = Standard Deviation.

²Non-detection, i.e. less than the analytical detection limit of $1.0 \mu\text{gN} \cdot \text{L}^{-1}$.

2011

A flood event was sampled in 2011 with measurements radically different than previously observed (Table 7). Rain and flood conditions were present during the sampling event of 5/2/2011, and the waterbody was connected to the ocean. Site F-PUHE-02 displayed high TDP (Table 8), extremely high TDN and $\text{NO}_2 + \text{NO}_3$ (Tables 9 and 10, respectively), and lower pH (Table 14) than the other sites. Both inland sites, F-PUHE-02 and F-PUHE-03, also displayed decreased salinity and temperature (Tables 15 and 17, respectively) on 5/2/2011, consistent with freshwater inputs. A tsunami washed sediment and other debris into the pond on March 11, 2011.

Table 7. 2011 summary of water quality parameters in the PUHE brackish waterbody.

Parameter	Unit	Site	N	Minimum	Maximum	Median	SD ¹
Total Dissolved Phosphorus	$\mu\text{gP} \cdot \text{L}^{-1}$	F-PUHE-01	6	16.7	31.0	24	5.9
		F-PUHE-02	6	25.0	159.0	35	51.5
		F-PUHE-03	6	16.0	42.3	27	10.0
Total Dissolved Nitrogen	$\text{mgN} \cdot \text{L}^{-1}$	F-PUHE-01	12	0.3	0.6	0.5	0.11
		F-PUHE-02	11	0.4	8.0	0.5	3.07
		F-PUHE-03	12	0.4	0.6	0.5	0.07
Nitrate + Nitrite	$\mu\text{gN} \cdot \text{L}^{-1}$	F-PUHE-01	6	13.7	210.7	49.5	72.84
		F-PUHE-02	6	29.0	2826.5	83.0	1128.51
		F-PUHE-03	6	49.7	236.0	135.5	69.72
Chlorophyll	$\mu\text{g} \cdot \text{L}^{-1}$	F-PUHE-01	4	9.7	37.7	26.8	11.80
		F-PUHE-02	4	12.1	43.2	20.8	13.95
		F-PUHE-03	4	9.6	53.9	16.7	23.79
Dissolved Oxygen Concentration	$\text{mg} \cdot \text{L}^{-1}$	F-PUHE-01	4	5.3	7.7	6.8	1.01
		F-PUHE-02	4	5.1	8.4	6.7	1.43
		F-PUHE-03	4	4.2	8.6	7.0	1.82
Dissolved Oxygen Saturation	%	F-PUHE-01	4	69.8	114.9	100.9	19.11
		F-PUHE-02	4	67.1	104.8	94.9	16.47
		F-PUHE-03	4	54.6	107.4	97.7	23.63
pH	none	F-PUHE-01	4	7.7	8.0	7.8	0.13
		F-PUHE-02	4	7.0	7.8	7.7	0.36
		F-PUHE-03	4	7.7	7.8	7.7	0.06
Salinity	ppt	F-PUHE-01	4	3.7	22.4	19.0	8.58
		F-PUHE-02	4	1.4	22.1	9.5	9.77
		F-PUHE-03	4	0.3	21.2	9.5	9.82
Specific Conductance	$\text{mS} \cdot \text{cm}^{-1}$	F-PUHE-01	4	6.8	35.6	30.8	13.30
		F-PUHE-02	4	2.7	35.2	16.0	15.38
		F-PUHE-03	4	0.5	33.9	16.1	15.63
Temperature	$^{\circ}\text{C}$	F-PUHE-01	4	27.9	32.4	6.8	1.01
		F-PUHE-02	4	22.7	32.5	6.7	1.43
		F-PUHE-03	4	22.5	32.6	7.0	1.82
Turbidity	NTU	F-PUHE-01	4	5.3	26.5	8.7	9.93
		F-PUHE-02	4	6.1	1241.8	13.7	615.32
		F-PUHE-03	4	3.4	1124.3	9.4	558.47

¹SD = Standard Deviation.

Summaries by parameter

Total Dissolved Phosphorus

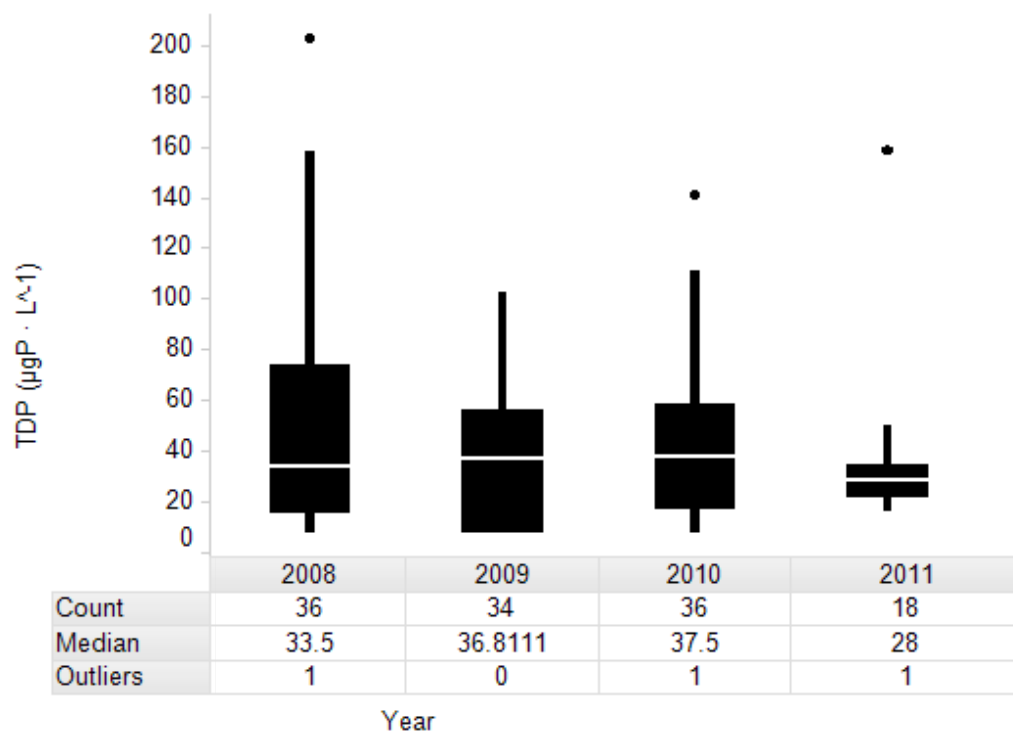


Figure 3. Box plots of Total Dissolved Phosphorus in the PUHE brackish waterbody.

Table 8. Mean Total Dissolved Phosphorus (TDP, $\mu\text{gP} \cdot \text{L}^{-1}$) in the PUHE brackish waterbody.

	F-PUHE-01			F-PUHE-02			F-PUHE-03		
Date	TDP	SE ¹	n	TDP	SE ¹	n	TDP	SE ¹	n
1/23/2008	77.7	2.4	3	149.7	5.6	3	152.0	25.6	3
5/20/2008	<15.0 ²		3	<15.0 ²		3	<15.0 ²		3
8/19/2008	33.7	10.7	3	37.0	9.1	3	19.3	0.7	3
11/13/2008	41.7	12.9	3	44.7	16.9	3	66.3	3.0	3
3/11/2009	79.0	3.6	3	58.7	4.7	3	45.7	5.4	3
6/15/2009	<15.0 ²		1	26.5	6.1	3	19.0	4.0	3
8/25/2009	<15.0 ²		3	<15.0 ²		3	<15.0 ²		3
11/19/2009	50.8	12.6	3	83.5	15.7	3	50.4	10.6	3
2/22/2010	<15.0 ²		3	18.0	3.0	3	18.3	1.8	3
5/6/2010	45.0	7.5	3	96.7	22.3	3	61.3	4.9	3
8/31/2010	69.0	21.1	3	45.0	16.1	3	28.3	12.3	3
11/30/2010	34.7	12.5	3	33.0	2.9	3	52.3	17.9	3
2/4/2011	28.3	1.5	3	37.0	7.2	3	22.3	5.4	3
5/2/2011	17.3		1	159.0		1	31.0		1
8/11/2011	16.7		1	28.0		1	42.3		1
10/31/2011	21.0		1	34.7		1	23.7		1

¹SE = Standard Error

²Non-detection, i.e. less than the analytical detection limit of $15.0 \mu\text{gP} \cdot \text{L}^{-1}$.

Total Dissolved Nitrogen

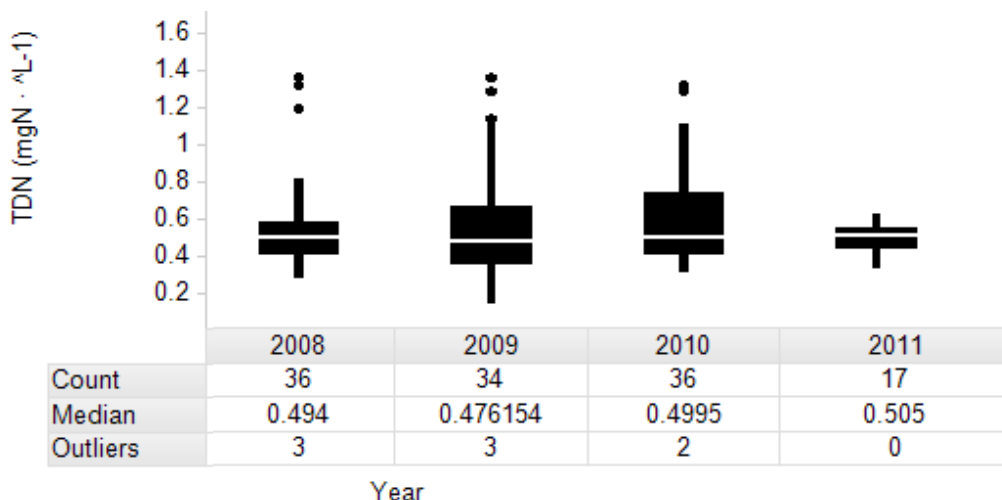


Figure 4. Box plots of Total Dissolved Nitrogen in the PUHE brackish waterbody. An outlier in 2011 at 8.0 mgN · L⁻¹ is not shown (median with outlier = 5.1).

Table 9. Mean Total Dissolved Nitrogen (TDN, mgN · L⁻¹) in the PUHE brackish waterbody.

	F-PUHE-01			F-PUHE-02			F-PUHE-03		
Date	TDN	SE ¹	n	TDN	SE ¹	n	TDN	SE ¹	n
1/23/2008	0.65	0.13	3	0.34	0.03	3	0.62	0.08	3
5/20/2008	0.44	0.06	3	0.34	0.04	3	0.47	0.09	3
8/19/2008	0.39	0.02	3	0.46	0.06	3	0.47	0.01	3
11/13/2008	0.51	0.04	3	0.62	0.03	3	1.29	0.05	3
3/11/2009	1.26	0.06	3	0.81	0.03	3	0.82	0.15	3
6/15/2009	0.37	0.00	1	0.36	0.05	3	0.38	0.05	3
8/25/2009	0.34	0.08	3	0.34	0.05	3	0.19	0.02	3
11/19/2009	0.55	0.01	3	0.52	0.08	3	0.54	0.04	3
2/22/2010	0.34	0.01	3	0.37	0.03	3	0.35	0.02	3
5/6/2010	0.80	0.09	3	0.70	0.05	3	1.06	0.15	3
8/31/2010	0.50	0.02	3	0.45	0.02	3	0.41	0.01	3
11/30/2010	0.59	0.08	3	0.62	0.06	3	1.09	0.11	3
2/4/2011	0.56	0.03	3	0.53	0.04	3	0.54	0.03	3
5/2/2011	0.54	0.02	3	8.00	0.72	2	0.55	0.07	3
8/11/2011	0.33	0.03	3	0.41	0.01	3	0.45	0.03	3
10/31/2011	0.39	0.03	3	0.43	0.02	3	0.42	0.05	3

¹SE = Standard Error

Nitrate + Nitrite

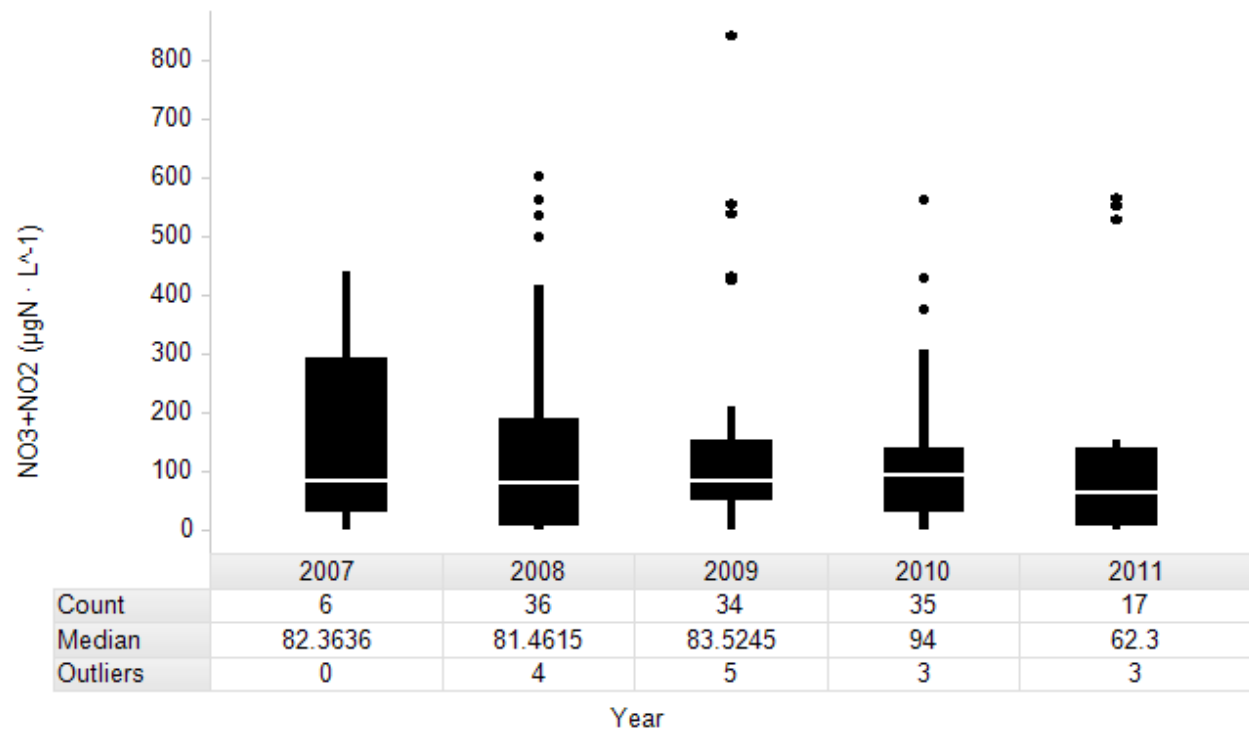


Figure 5. Box plots of nitrate + nitrite in the PUHE brackish waterbody. An outlier in 2010 at 2826 $\mu\text{gN} \cdot \text{L}^{-1}$ is not shown (median with outlier = 95).

Table 10. Mean nitrate + nitrite ($\text{NO}_3 + \text{NO}_2$, $\mu\text{gN} \cdot \text{L}^{-1}$) in the PUHE brackish waterbody.

Date	F-PUHE-01			F-PUHE-02			F-PUHE-03		
	$\text{NO}_2 + \text{NO}_3$	SE^1	n	$\text{NO}_2 + \text{NO}_3$	SE^1	n	$\text{NO}_2 + \text{NO}_3$	SE^1	n
11/6/2007	82.4	17.0	2	167.8	4.4	2	7.9	5.4	2
1/23/2008	351.7	94.9	3	170.7	17.5	3	276.7	24.5	3
5/20/2008	89.7	14.5	3	97.4	11.3	3	82.3	11.2	3
8/19/2008	138.7	2.0	3	85.7	10.2	3	128.3	9.8	3
11/13/2008	83.7	14.0	3	100.7	5.7	3	550.0	10.8	3
3/11/2009	445.3	3.8	3	566.0	19.2	3	609.7	121.5	3
6/15/2009	<1.0 ²		1	<1.0 ²	0.0	3	59.9	23.7	3
8/25/2009	1.0	0.0	3	1.4	0.4	3	4.1	0.5	3
11/19/2009	55.5	5.1	3	52.4	11.6	3	137.9	4.4	3
2/22/2010	3.0	2.0	3	14.0	6.7	3	7.7	6.7	3
5/6/2010	455.0	55.2	3	335.0	54.5	3	424.0	67.9	3
8/31/2010	3.3	2.3	3	12.7	2.4	3	58.3	2.8	3
11/30/2010	143.3	19.2	3	168.3	32.2	3	128.0	19.3	3
2/4/2011	50.0	0.6	3	84.7	1.7	3	140.0	4.6	3
5/2/2011	210.7		1	2826.5		1	236.0		1
8/11/2011	20.3		1	32.0		1	49.7		1
10/31/2011	13.7		1	29.0		1	50.7		1

¹SE = Standard Error

²Non-detection, i.e. less than the analytical detection limit of 1.0 $\mu\text{gN} \cdot \text{L}^{-1}$.

Chlorophyll

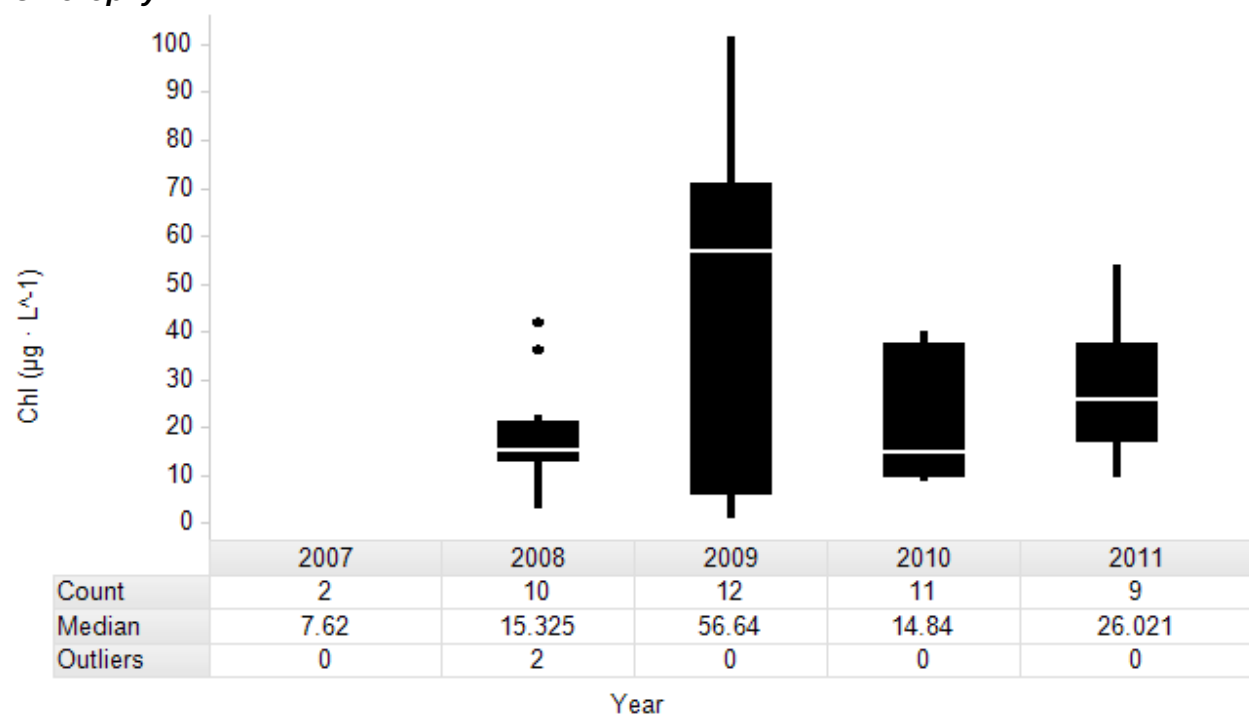


Figure 6. Box plots of chlorophyll in the PUHE brackish waterbody. The range of chlorophyll data in 2007 was too narrow to display as a boxplot beside other years.

Table 11. Mean chlorophyll-a ($\mu\text{g} \cdot \text{L}^{-1}$) in the PUHE brackish waterbody.

	F-PUHE-01			F-PUHE-02			F-PUHE-03		
Date	Chl	SE ¹	n	Chl	SE ¹	n	Chl	SE ¹	n
11/6/2007	7.2	0.18	6	No data			8.1	0.09	13
1/23/2008	3.0	0.16	11	No data			No data		
5/20/2008	13.9	0.11	6	10.1	0.88	7	18.3	0.36	14
8/19/2008	22.4	0.46	11	14.3	0.33	10	16.3	0.27	11
11/13/2008	12.3	0.16	17	42.3	0.16	16	36.4	0.19	12
3/11/2009	1.0	0.15	10	5.7	0.11	17	5.8	0.21	11
6/15/2009	57.6	0.78	11	70.0	0.16	9	86.5	0.52	11
8/25/2009	43.9	0.23	15	55.7	0.45	11	65.9	0.36	9
11/19/2009	6.1	0.42	11	74.8	0.29	15	101.6	0.62	16
2/22/2010	24.3	0.50	13	37.7	0.23	15	No data		
5/6/2010	8.6	0.25	21	11.1	0.14	17	14.8	0.14	16
8/31/2010	40.3	0.14	16	37.7	0.17	19	37.9	0.15	16
11/30/2010	8.9	0.14	18	8.6	0.17	16	10.3	0.46	15
2/4/2011	37.7	0.22	17	43.2	0.20	17	53.9	0.45	12
5/2/2011	23.8	0.38	19	15.6	0.11	18	9.6	0.16	12
8/11/2011	29.8	0.20	14	26.0	0.17	14	No data		
10/31/2011	9.7	0.48	12	12.1	0.55	14	16.7	0.19	15

¹SE = Standard Error

Oxygen Concentration

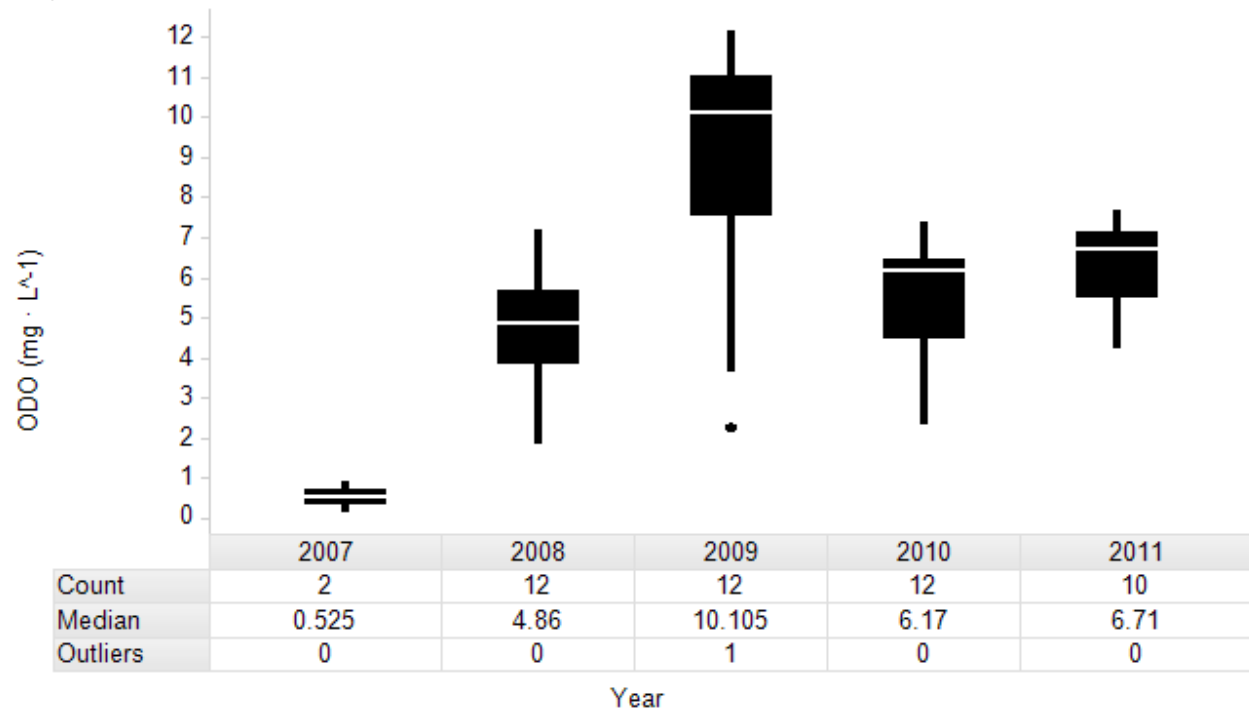


Figure 7. Box plots of oxygen concentration in the PUHE brackish waterbody.

Table 12. Mean oxygen concentration ($\text{mg} \cdot \text{L}^{-1}$) in the PUHE brackish waterbody.

	F-PUHE-01			F-PUHE-02			F-PUHE-03		
Date	ODO	SE ¹	n	ODO	SE ¹	n	ODO	SE ¹	n
11/6/2007	0.9	0.03	6	No data			0.1	0.02	13
1/23/2008	4.0	0.03	11	4.9	0.02	9	4.8	0.02	13
5/20/2008	6.8	0.01	6	7.2	0.03	7	7.1	0.01	14
8/19/2008	5.2	0.01	11	3.3	0.06	10	1.8	0.03	11
11/13/2008	4.7	0.03	17	5.3	0.05	16	2.5	0.04	12
3/11/2009	3.6	0.03	10	2.3	0.03	17	4.5	0.03	11
6/15/2009	11.3	0.03	11	12.2	0.01	9	12.0	0.02	11
8/25/2009	9.5	0.03	15	10.4	0.02	11	10.5	0.01	9
11/19/2009	9.9	0.02	11	11.0	0.03	15	8.6	0.04	16
2/22/2010	6.1	0.06	13	6.2	0.01	15	3.8	0.03	14
5/6/2010	6.2	0.01	21	4.6	0.02	17	5.1	0.05	16
8/31/2010	6.9	0.01	16	7.4	0.01	19	7.3	0.02	16
11/30/2010	6.4	0.02	18	4.0	0.03	16	2.3	0.03	15
2/4/2011	7.1	0.01	17	7.2	0.01	17	6.8	0.03	12
5/2/2011	7.7	0.05	19	8.4	0.02	18	8.6	0.02	12
8/11/2011	6.6	0.01	14	6.1	0.05	14	7.2	0.02	13
10/31/2011	5.3	0.05	12	5.1	0.02	14	4.2	0.01	15

¹SE = Standard Error

Oxygen Saturation

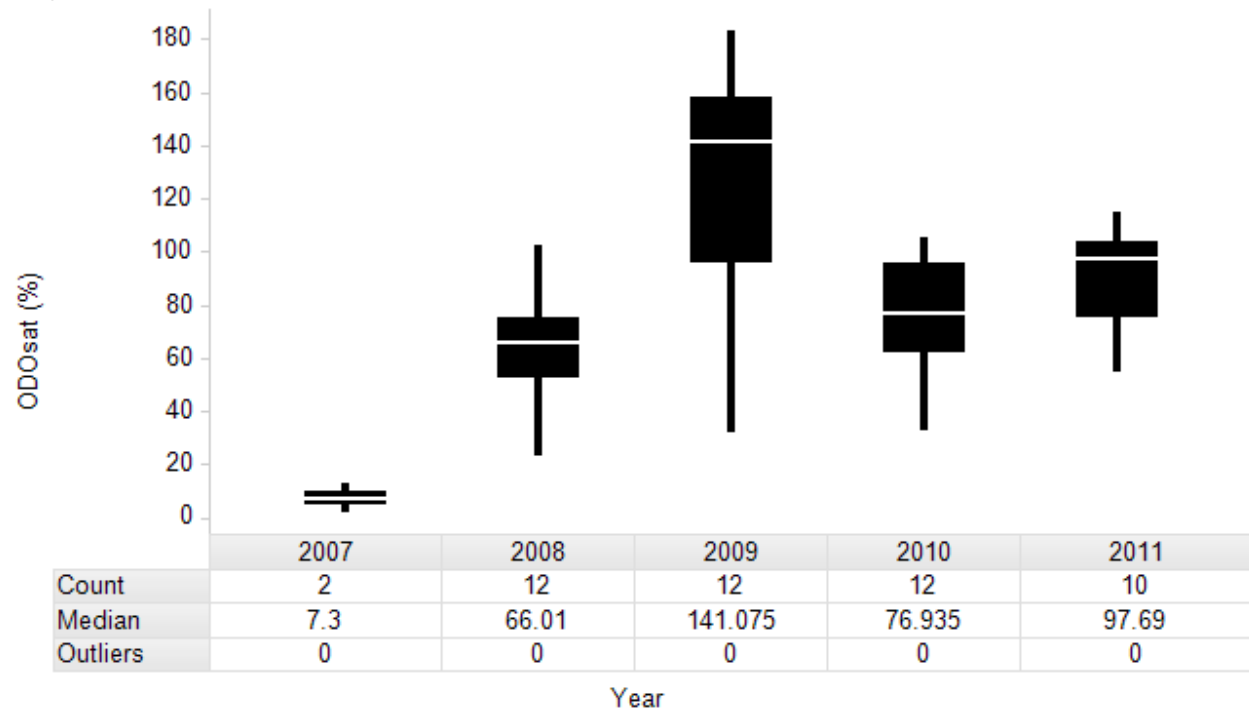


Figure 8. Box plots of oxygen saturation in the PUHE brackish waterbody.

Table 13. Mean oxygen saturation (%) in the PUHE brackish waterbody.

	F-PUHE-01			F-PUHE-02			F-PUHE-03		
Date	ODOsat	SE ¹	n	ODOsat	SE ¹	n	ODOsat	SE ¹	n
11/6/2007	13	0.4	6	No data			2	0.2	13
1/23/2008	56	0.4	11	68	0.4	3	65	0.3	13
5/20/2008	96	0.1	6	103	0.4	7	99	0.2	14
8/19/2008	67	0.1	11	43	0.7	10	24	0.3	11
11/13/2008	61	0.4	17	67	0.7	16	33	0.5	12
3/11/2009	54	0.4	10	32	0.4	17	60	0.5	11
6/15/2009	169	0.5	11	183	0.2	9	175	0.2	11
8/25/2009	141	0.4	15	155	0.4	11	152	0.2	9
11/19/2009	130	0.2	11	141	0.4	15	108	0.6	16
2/22/2010	76	0.7	13	78	0.1	15	46	0.3	14
5/6/2010	88	0.1	21	64	0.2	17	69	0.7	16
8/31/2010	99	0.2	16	105	0.2	19	102	0.3	16
11/30/2010	95	0.3	18	57	0.4	16	33	0.4	15
2/4/2011	102	0.1	17	105	0.2	17	96	0.5	12
5/2/2011	115	0.7	19	98	0.1	18	99	0.1	12
8/11/2011	99	0.2	14	92	0.8	14	107	0.4	13
10/31/2011	70	0.7	12	67	0.2	14	55	0.1	15

¹SE = Standard Error

pH

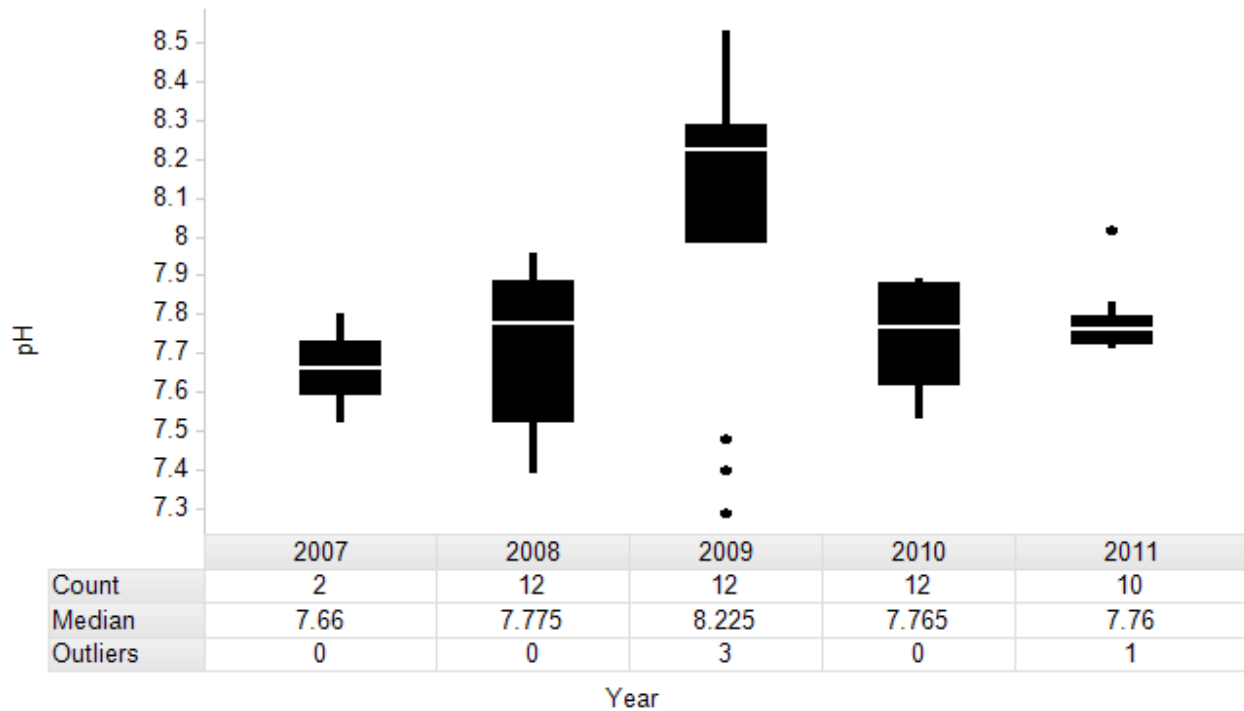


Figure 9. Box plots of pH in the PUHE brackish waterbody.

Table 14. Mean pH in the PUHE brackish waterbody.

	F-PUHE-01			F-PUHE-02			F-PUHE-03		
Date	pH	SE ¹	n	pH	SE ¹	n	pH	SE ¹	n
11/6/2007	7.8	0.00	6	No data			7.5	0.00	13
1/23/2008	7.9	0.01	11	7.5	0.02	9	7.5	0.01	13
5/20/2008	7.9	0.00	6	8.0	0.01	7	7.9	0.00	14
8/19/2008	7.7	0.00	11	7.5	0.01	10	7.4	0.00	11
11/13/2008	7.8	0.00	17	7.9	0.01	16	7.5	0.00	12
3/11/2009	7.4	0.01	10	7.3	0.00	17	7.5	0.01	11
6/15/2009	8.3	0.00	11	8.3	0.00	9	8.3	0.00	11
8/25/2009	8.2	0.00	15	8.2	0.00	11	8.2	0.00	9
11/19/2009	8.4	0.01	11	8.5	0.01	15	8.3	0.01	16
2/22/2010	7.6	0.01	13	7.7	0.01	15	7.5	0.00	14
5/6/2010	7.9	0.00	21	7.7	0.00	17	7.6	0.00	16
8/31/2010	7.9	0.01	16	7.9	0.00	19	7.9	0.00	16
11/30/2010	7.9	0.01	18	7.8	0.01	16	7.6	0.00	15
2/4/2011	7.7	0.00	17	7.7	0.00	17	7.7	0.00	12
5/2/2011	8.0	0.00	19	7.0	0.02	18	7.7	0.02	12
8/11/2011	7.8	0.00	14	7.7	0.00	14	7.8	0.00	13
10/31/2011	7.8	0.00	12	7.8	0.00	14	7.7	0.00	15

¹SE = Standard Error

Salinity

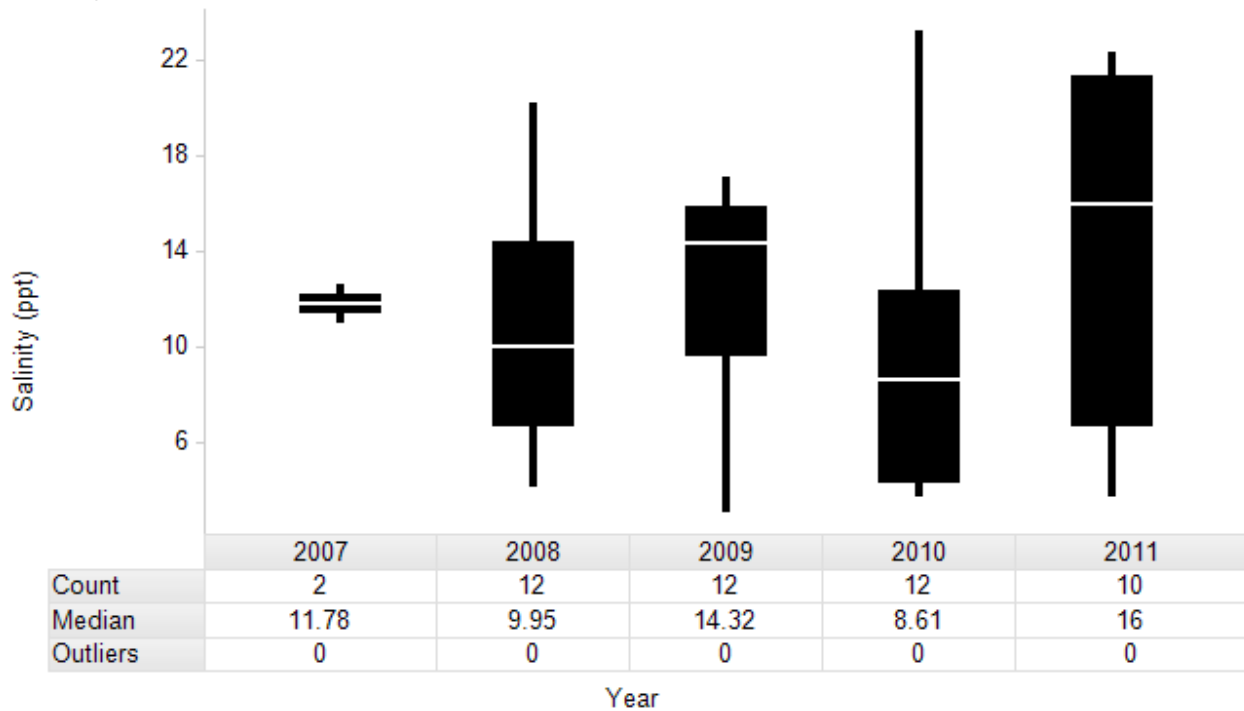


Figure 10. Box plots of salinity in the PUHE brackish waterbody.

Table 15. Mean salinity (ppt) in the PUHE brackish waterbody.

	F-PUHE-01			F-PUHE-02			F-PUHE-03		
Date	Salinity	SE ¹	n	Salinity	SE ¹	n	Salinity	SE ¹	n
11/6/2007	12.6	0.00	6	No data			10.9	0.09	13
1/23/2008	19.0	0.05	11	20.2	0.05	9	17.9	0.03	13
5/20/2008	6.8	0.00	6	10.8	0.01	7	9.9	0.01	14
8/19/2008	6.6	0.00	11	6.4	0.00	10	4.1	0.00	11
11/13/2008	10.0	0.04	17	6.5	0.05	16	13.3	0.05	12
3/11/2009	13.7	0.04	10	15.0	0.04	17	11.6	0.02	11
6/15/2009	17.1	0.01	11	16.8	0.00	9	16.2	0.02	11
8/25/2009	15.8	0.00	15	15.1	0.03	11	13.5	0.00	9
11/19/2009	3.5	0.00	11	3.5	0.00	15	3.0	0.00	16
2/22/2010	3.7	0.06	13	4.3	0.00	15	4.2	0.00	14
5/6/2010	7.0	0.02	21	4.0	0.01	17	4.4	0.00	16
8/31/2010	11.5	0.00	16	10.6	0.00	19	10.2	0.00	16
11/30/2010	23.3	0.02	18	15.1	0.01	16	16.6	0.01	15
2/4/2011	22.4	0.01	17	22.1	0.03	17	21.2	0.01	12
5/2/2011	21.4	0.19	19	1.4	0.11	18	0.3	0.08	12
8/11/2011	16.6	0.00	14	15.3	0.02	14	15.4	0.01	13
10/31/2011	3.7	0.00	12	3.7	0.00	14	3.7	0.00	15

¹SE = Standard Error

Specific Conductance

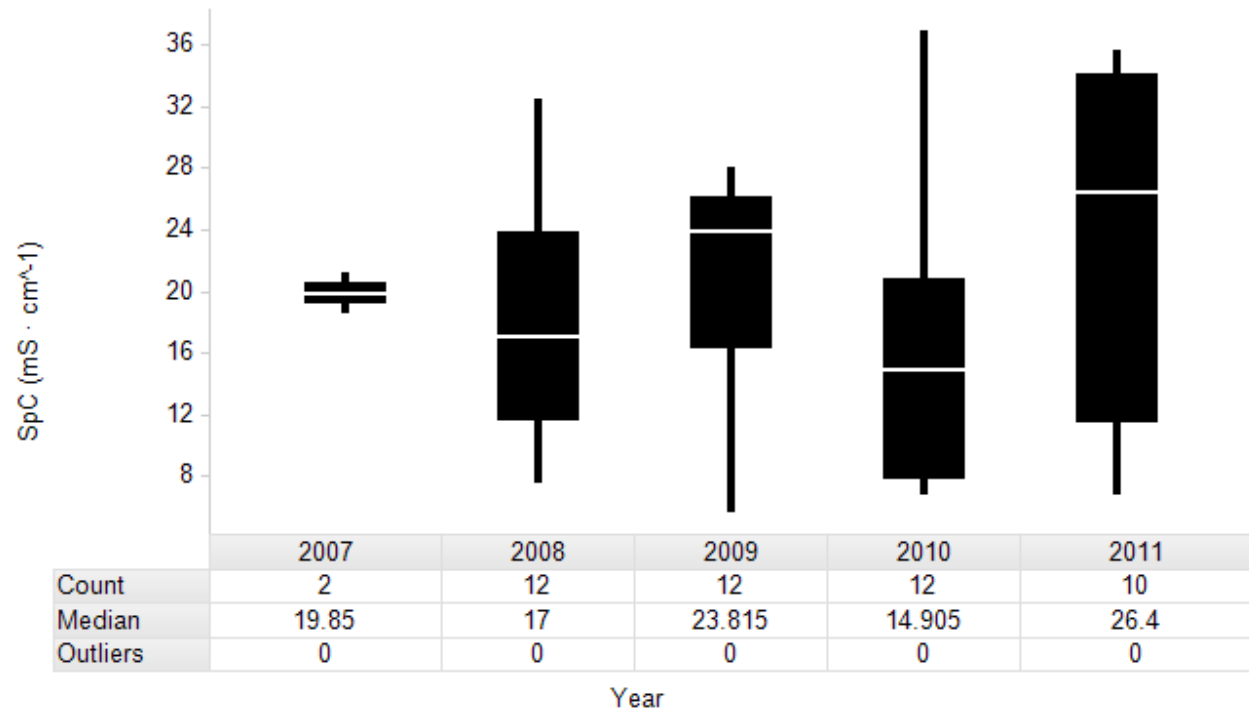


Figure 11. Box plots of specific conductance in the PUHE brackish waterbody.

Table 16. Mean specific conductance ($\mu\text{S} \cdot \text{cm}^{-1}$) in the PUHE brackish waterbody.

	F-PUHE-01			F-PUHE-02			F-PUHE-03		
Date	SpC	SE ¹	n	SpC	SE ¹	n	SpC	SE ¹	n
11/6/2007	21.2	0.00	6	No data			18.5	0.14	13
1/23/2008	30.7	0.08	11	32.5	0.08	9	29.0	0.04	13
5/20/2008	12.0	0.00	6	18.4	0.01	7	17.0	0.02	14
8/19/2008	11.7	0.00	11	11.4	0.01	10	7.5	0.00	11
11/13/2008	17.0	0.07	17	11.5	0.08	16	22.1	0.07	12
3/11/2009	22.9	0.07	10	24.7	0.06	17	19.6	0.04	11
6/15/2009	28.0	0.02	11	27.6	0.00	9	26.6	0.03	11
8/25/2009	26.1	0.00	15	25.1	0.05	11	22.6	0.00	9
11/19/2009	6.5	0.00	11	6.5	0.00	15	5.6	0.00	16
2/22/2010	6.8	0.10	13	7.8	0.00	15	7.7	0.00	14
5/6/2010	12.3	0.03	21	7.4	0.02	17	8.0	0.01	16
8/31/2010	19.5	0.00	16	18.1	0.00	19	17.5	0.01	16
11/30/2010	36.9	0.03	18	24.9	0.02	16	27.2	0.01	15
2/4/2011	35.6	0.01	17	35.2	0.04	17	33.9	0.02	12
5/2/2011	34.3	0.27	19	2.7	0.20	18	0.5	0.17	12
8/11/2011	27.3	0.00	14	25.3	0.04	14	25.5	0.01	13
10/31/2011	6.8	0.00	12	6.7	0.00	14	6.7	0.00	15

¹SE = Standard Error

Temperature

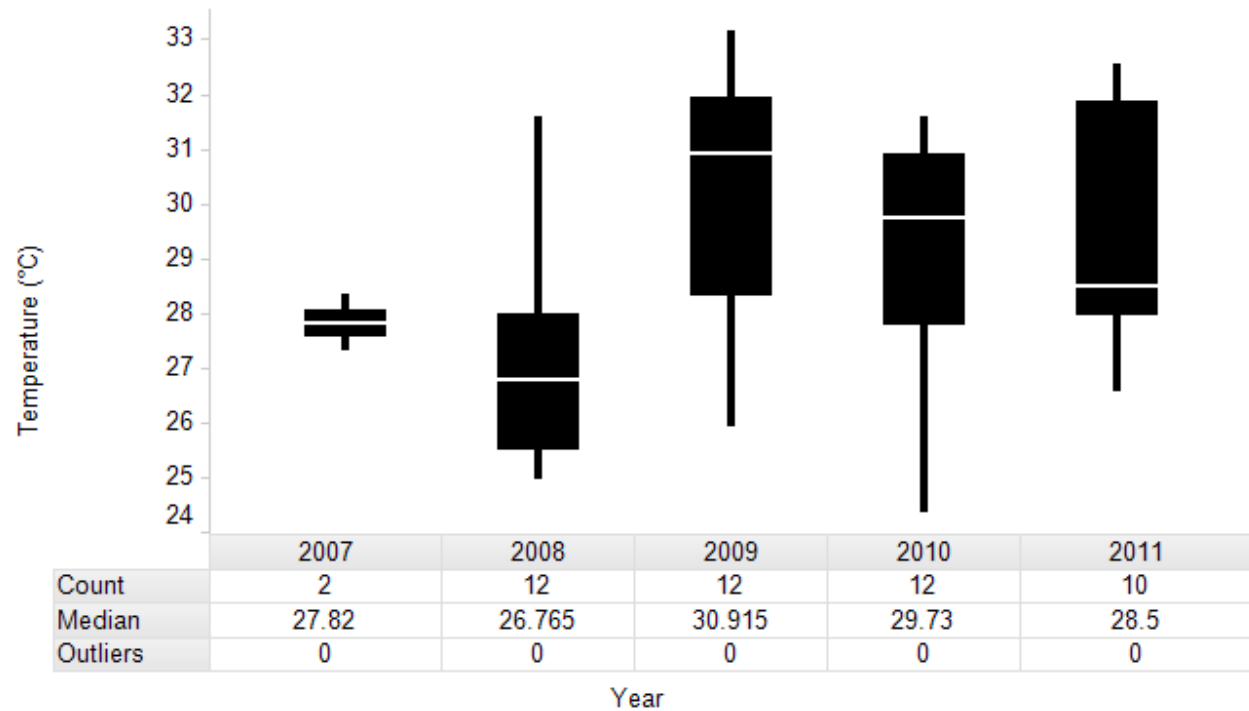


Figure 12. Box plots of temperature in the PUHE brackish waterbody.

Table 17. Mean temperature (°C) in the brackish waterbody at PUHE.

	F-PUHE-01			F-PUHE-02			F-PUHE-03		
Date	Temp	SE ¹	n	Temp	SE ¹	n	Temp	SE ¹	n
11/6/2007	28.3	0.01	6	No data			27.3	0.01	13
1/23/2008	26.6	0.04	11	26.8	0.04	9	25.0	0.01	13
5/20/2008	31.6	0.01	6	31.1	0.00	7	30.0	0.02	14
8/19/2008	26.7	0.01	11	27.3	0.01	10	27.1	0.01	11
11/13/2008	25.6	0.01	17	25.1	0.01	16	25.0	0.00	12
3/11/2009	33.2	0.06	10	28.6	0.02	17	27.1	0.03	11
6/15/2009	31.7	0.02	11	32.3	0.01	9	30.7	0.04	11
8/25/2009	31.9	0.01	15	32.3	0.02	11	31.1	0.01	9
11/19/2009	28.7	0.03	11	27.4	0.01	15	25.9	0.01	16
2/22/2010	25.1	0.03	13	25.7	0.00	15	24.4	0.01	14
5/6/2010	31.6	0.02	21	30.9	0.04	17	29.8	0.01	16
8/31/2010	31.3	0.01	16	30.9	0.01	19	30.1	0.01	16
11/30/2010	29.4	0.01	18	29.7	0.00	16	28.5	0.00	15
2/4/2011	27.9	0.00	17	28.2	0.01	17	26.6	0.01	12
5/2/2011	30.3	0.03	19	22.7	0.07	18	22.5	0.10	12
8/11/2011	32.4	0.00	14	32.5	0.04	14	32.6	0.01	13
10/31/2011	28.4	0.01	12	28.6	0.01	14	27.6	0.01	15

¹SE = Standard Error

Turbidity

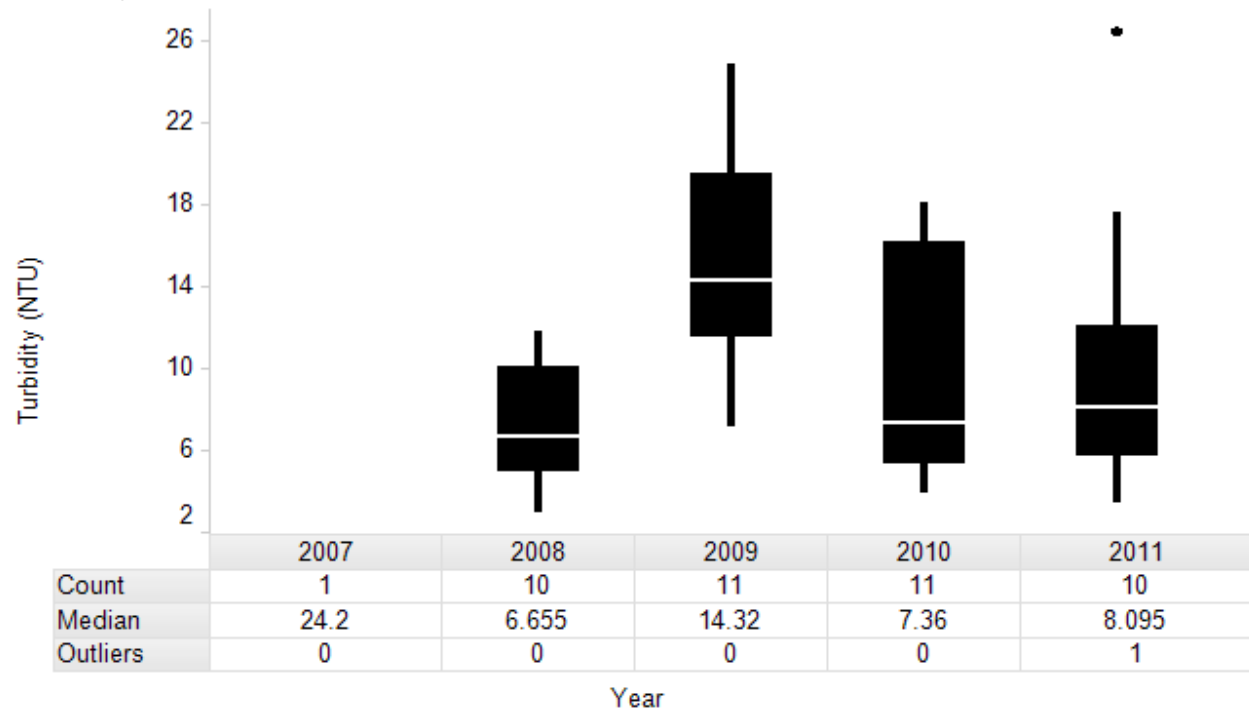


Figure 13. Box plots of turbidity in the PUHE brackish waterbody.

Table 18. Mean turbidity (NTU) in the PUHE brackish waterbody.

	F-PUHE-01			F-PUHE-02			F-PUHE-03		
Date	Turb	SE ¹	n	Turb	SE ¹	n	Turb	SE ¹	n
11/6/2007	24.2	0.31	6	No data			No data		
1/23/2008	5.8	0.43	11	No data			No data		
5/20/2008	11.9	0.08	6	7.6	0.09	7	5.3	0.07	14
8/19/2008	4.6	0.02	11	4.9	0.14	10	3.0	0.08	11
11/13/2008	10.9	0.07	17	7.5	0.49	16	11.2	0.04	12
3/11/2009	No data			21.0	0.27	17	14.3	0.40	11
6/15/2009	24.8	0.20	11	14.5	0.02	9	9.8	0.08	11
8/25/2009	24.1	0.11	15	13.9	0.14	11	7.2	0.14	9
11/19/2009	18.1	0.22	11	12.7	0.23	15	10.5	0.31	16
2/22/2010	9.6	0.18	13	5.1	0.11	15	4.6	0.19	14
5/6/2010	18.1	0.20	21	15.6	0.60	17	16.9	0.18	16
8/31/2010	16.7	1.17	16	7.4	0.67	19	5.5	0.07	16
11/30/2010	3.9	0.23	18	5.5	0.24	16	No data		
2/4/2011	26.5	0.07	17	17.7	0.79	17	12.2	0.13	12
5/2/2011	11.8	4.54	19	>1000 ²			>1000 ²		
8/11/2011	5.3	0.04	14	9.7	0.53	14	6.5	0.07	13
10/31/2011	5.5	0.28	12	6.1	0.44	14	3.4	0.17	15

¹SE = Standard Error

²Exceeded operational range of 0 to 1000 NTU.

Discussion

The brackish waterbody at PUHE was sampled quarterly from the last quarter of 2007 through 2011. During this time two notable events were observed: a likely minor algal bloom in 2009 and a flood event in 2011. Slightly elevated nutrient concentrations were observed prior to and during the bloom. Given the open riparian canopy of the system and abundance of sunlight, nutrient concentrations will likely govern the risk of future blooms. Should a bloom occur in the future, surface scums could form depending on algal species and water temperature. In general, blue-green algae blooms and high ambient temperatures increase the risk of surface scums.

The sampling regime of the program is not designed to target flood events. Typically dry-weather environmental conditions present in the watershed produce limnological conditions analogous to low-flow in streams. Heavy rains contribute a pulse of freshwater that can be directly observed at the inland sites F-PUHE-02 and F-PUHE-03. The most coastal site F-PUHE-01 can display conditions that differ from inland sites, even during freshwater flood events, depending on overland connectivity to the ocean. Data from the observed flood event suggests that relatively large amounts of nutrients, especially nitrogen, are delivered to the waterbody during these events. The relative importance of groundwater versus overland-flow delivery of nutrients during such events is unknown.

Observations made during the freshwater flood event in progress illustrate that variability in this system is biphasic. That is, a natural range of conditions will exist during “low-flow” and these conditions are different than the conditions observed during the freshwater pulses from flood events. Future evaluations of the natural range of conditions, one of the primary goals of the I&M Program, should account for the environmental context of both low-flow and freshwater-pulse conditions.

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