March 2003

Environmental Technology Verification Report

GENERAL OCEANICS, INC.
OCEAN SEVEN 316 MULTI-PARAMETER WATER QUALITY PROBE/SONDE

Prepared by
Battelle

Battelle
. . . Putting Technology To Work

In cooperation with the
National Oceanic and Atmospheric Administration

Under a cooperative agreement with

U.S. Environmental Protection Agency

ETV ETV ETV

March 2003

Environmental Technology Verification Report

ETV Advanced Monitoring Systems Center

General Oceanics, Inc.
Ocean Seven 316 Multi-Parameter Water Quality Probe/Sonde

by
Jeffrey Myers
Amy Dindal
Zachary Willenberg
Karen Riggs

Battelle
Columbus, Ohio 43201

and

Paul Pennington
Michael Fulton
Geoffrey Scott

NOAA CCEHBR

Notice

The U.S. Environmental Protection Agency (EPA), through its Office of Research and Development, has financially supported and collaborated in the extramural program described here. This document has been peer reviewed by the Agency and recommended for public release. Mention of trade names or commercial products does not constitute endorsement or recommendation by the EPA for use.

The National Oceanic and Atmospheric Administration (NOAA) does not approve, recommend, or endorse any proprietary product or material mentioned in this publication. No reference shall be made to NOAA in any advertising or sales promotion which would indicate or imply that NOAA approves, recommends, or endorses any proprietary product or proprietary material mentioned herein.

Foreword

The U.S. Environmental Protection Agency (EPA) is charged by Congress with protecting the nation's air, water, and land resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, the EPA's Office of Research and Development provides data and science support that can be used to solve environmental problems and to build the scientific knowledge base needed to manage our ecological resources wisely, to understand how pollutants affect our health, and to prevent or reduce environmental risks.

The Environmental Technology Verification (ETV) Program has been established by the EPA to verify the performance characteristics of innovative environmental technology across all media and to report this objective information to permitters, buyers, and users of the technology, thus substantially accelerating the entrance of new environmental technologies into the marketplace. Verification organizations oversee and report verification activities based on testing and quality assurance protocols developed with input from major stakeholders and customer groups associated with the technology area. ETV consists of seven environmental technology centers. Information about each of these centers can be found on the Internet at http://www.epa.gov/etv/.

Effective verifications of monitoring technologies are needed to assess environmental quality and to supply cost and performance data to select the most appropriate technology for that assessment. In 1997, through a competitive cooperative agreement, Battelle was awarded EPA funding and support to plan, coordinate, and conduct such verification tests for "Advanced Monitoring Systems for Air, Water, and Soil" and report the results to the community at large. Information concerning this specific environmental technology area can be found on the Internet at http://www.epa.gov/etv/centers/center1.html.

Acknowledgments

The authors wish to acknowledge the support of all those who helped plan and conduct the verification test, analyze the data, and prepare this report. We would like to thank the National Oceanic and Atmospheric Administration's (NOAA's) National Ocean Service, National Centers for Coastal Ocean Science staff at the Center for Coastal Environmental Health and Biomolecular Research. In particular, we recognize Paul Pennington and Jennifer Tobias for their outstanding efforts. In addition, NOAA's Coastal Service Center is acknowledged for providing access to dock facilities on the Cooper River for the saltwater testing portion of this study. We also acknowledge the assistance of the ETV Advanced Monitoring Systems Center stakeholders Vito Minei, Christine Kolbe, and John Carlton.

Contents

Page

Figures

Tables

List of Abbreviations

AMS	Advanced Monitoring Systems
CCEHBR	Center for Coastal Environmental Health and Biomolecular Research
cm	centimeter
DAS	data acquisition system
DO	dissolved oxygen
EPA	U.S. Environmental Protection Agency
ETV	Environmental Technology Verification
L	liter
mg	milligram
mm	millimeter
ms	millisecond
mS	millisiemen
NIST	National Institute of Standards and Technology
NOAA	National Oceanic and Atmospheric Administration
NTU	nephelometric turbidity unit
PE	performance evaluation
QA	quality assurance
QA/QC	quality assurance/quality control
QMP	Quality Management Plan
RSD	relative standard deviation
s	second
TSA	technical systems audit

Chapter 1
Background

The U.S. Environmental Protection Agency (EPA) has created the Environmental Technology Verification (ETV) Program to facilitate the deployment of innovative environmental technologies through performance verification and dissemination of information. The goal of the ETV Program is to further environmental protection by substantially accelerating the acceptance and use of improved and cost-effective technologies. ETV seeks to achieve this goal by providing high-quality, peer-reviewed data on technology performance to those involved in the design, distribution, financing, permitting, purchase, and use of environmental technologies.

ETV works in partnership with recognized testing organizations; with stakeholder groups consisting of buyers, vendor organizations, and permitters; and with the full participation of individual technology developers. The program evaluates the performance of innovative technologies by developing test plans that are responsive to the needs of stakeholders, conducting field or laboratory tests (as appropriate), collecting and analyzing data, and preparing peer-reviewed reports. All evaluations are conducted in accordance with rigorous quality assurance (QA) protocols to ensure that data of known and adequate quality are generated and that the results are defensible.

The EPA's National Exposure Research Laboratory and its verification organization partner, Battelle, operate the Advanced Monitoring Systems (AMS) Center under ETV. The AMS Center recently evaluated the performance of the General Oceanics, Inc., Ocean Seven 316 water probe.

Chapter 2
Technology Description

The objective of the ETV AMS Center is to verify the performance characteristics of environmental monitoring technologies for air, water, and soil. This verification report provides results for the verification testing of the Ocean Seven 316 water probe by General Oceanics, Inc. Following is a description of the Ocean Seven 316, based on information provided by the vendor. The information provided below was not verified in this test.

The 16-bit, multi-parameter Ocean Seven 316 is available with two diameters: 100 millimeter (mm) and 75 mm. The measurement sensors have time constants of 50 milliseconds (ms) for physical parameters and 3 seconds (s) for chemical parameters. A high-precision resistor acts as a reference for the accuracy of the sensor electronic amplifiers. This resistor has a thermal drift of 1 part per million/°C and is temperature-compensated.

The Ocean Seven 316 is microprocessor-controlled and can measure, store, and transmit sensor data. For real-time data acquisition, the Ocean Seven 316 operates unattended, and data are uploaded at the end of the measuring cycle. An automatic power management procedure switches the Ocean Seven 316 off between the data acquisitions. The internal battery package consists of 10 batteries that allow the Ocean Seven 316 to operate continuously for about 20 hours. The Ocean Seven 316 can be equipped with an external battery package that greatly extends operation time. The Ocean Seven 316 stores up to 32,000 data sets.

Figure 2-1. General Oceanics, Inc., Ocean Seven 316 Water Probe

The Ocean Seven 316 is equipped with sensors to measure pressure, temperature, conductivity, salinity, oxygen, pH, and oxidation-reduction potential. Salinity is automatically calculated from conductivity, temperature, and pressure values. The sensor specifications for the parameters tested are as follows:

Parameter	Range	Accuracy	Resolution	Time Constant
Dissolved Oxygen (DO)	0 to 50 milligrams/ liter (mg/L)	0.1 mg/L	0.01 mg/L	3 s[a]
	0 to 500% sat.	1% sat.	0.1% sat.	3 s
Conductivity	0 to 64 millisiemen/ centimeter (mS/cm)	0.003 mS/cm	0.001 mS/cm	50 ms[b]
Temperature	-3 to +50°C	0.003°C	0.0005°C	50 ms
pH	0 to 14	0.01	0.001	3 s

[a] In air
[b] At 1 m/sec flow rate

Chapter 3
Test Design and Procedures

3.1 Introduction

This verification test was conducted according to procedures specified in the *Test/QA Plan for Long-Term Deployment of Multi-Parameter Water Quality Probes/Sondes*.[1] The purpose of the verification test was to evaluate the performance of the Ocean Seven 316 under realistic operating conditions. The Ocean Seven 316s were evaluated by comparing pre- and post-calibration results and their measurements with standard reference measurements and handheld calibrated probes. Two Ocean Seven 316s were deployed in saltwater, freshwater, and laboratory environments near Charleston, South Carolina, during a 2 ½-month verification test. Water quality parameters were measured by both the Ocean Seven 316s and by reference measurements consisting of both field portable instrumentation and water analyses of collected samples. During each phase, performance was assessed in terms of pre- and post-calibration results, relative bias, precision, linearity, and inter-unit reproducibility for each Ocean Seven 316.

The Ocean Seven 316s were verified in terms of its performance on the following parameters:

- DO
- Conductivity
- Temperature
- pH
- Turbidity.

3.2 Test Site Characteristics

The three test sites used for this verification were selected in an attempt to expose the Ocean Seven 316 to the widest possible range of conditions while conducting an efficient test. The three sites included one saltwater, one freshwater, and one controlled location. Approximate ranges for the target parameters at each of the test sites as determined by reference measurements are given in Table 3-1.

Table 3-1. Water Characteristics at the Test Sites

	Saltwater		Freshwater		Mesocosm	
Parameter	**Low**	**High**	**Low**	**High**	**Low**	**High**
DO	3 mg/L	7.3 mg/L	1.2 mg/L	13.4 mg/L	3.7 mg/L	7.3 mg/L
Conductivity	20 mS/cm	40 mS/cm	0.2 mS/cm	0.45 mS/cm	0.5 mS/cm	38 mS/cm
Temperature	28°C	32°C	20°C	35°C	24°C	31°C
pH	7	8	6	9	7.3	8.5
Turbidity	3 NTU	11 NTU	0.1 NTU	20 NTU	0.1 NTU	130 NTU

3.3 Test Design

The verification test was designed to assess the performance of multi-parameter water probes and was closely coordinated with the National Oceanic and Atmospheric Administration (NOAA) through the CCEHBR. The test was conducted in three phases at a saltwater site in the Cooper River; a freshwater site at Lake Edmunds, approximately one mile from the Center for Coastal Environmental Health and Biomolecular Research (CCEHBR), and a controlled site at the CCEHBR mesocosm facility in Charleston, South Carolina. The first phase of the test was conducted at the saltwater site and lasted 31 days. The CCEHBR campus has access to the Charleston Harbor Estuary, which is a predominantly tidal body of water that receives some riverine input; its salinities range from 20 to 35 parts per thousand. Figure 3-1 shows the saltwater site at the Cooper River. The second phase of the test was conducted at the freshwater site and lasted 24 days. The freshwater site was at a five-acre pond, named Lake Edmunds, approximately one mile from the CCEHBR facility. Figure 3-2 shows the freshwater site. The third phase was conducted over seven days at the CCEHBR's mesocosm facility. This facility contains modular mesocosms that can be classified as "tidal" or "estuarine." Figure 3-3 shows one of the modular mesocosms. At each test site, two Ocean Seven 316s were deployed as close to each other as possible to assess inter-unit reproducibility.

Figure 3-1. Saltwater Site

The schedule for the various testing activities is given in Table 3-2. The saltwater tests began in a small tidal creek tributary of the Charleston Harbor near the CCEHBR facilities. Testing at this location lasted approximately two weeks, but had to be discontinued due to a structural failure of the pier. A new site at NOAA Pier Romeo on the Cooper River was selected to complete the testing. This site is approximately 10 miles from the CCEHBR facility and is operated by NOAA's Coastal Services Center.

Figure 3-2. Freshwater Site

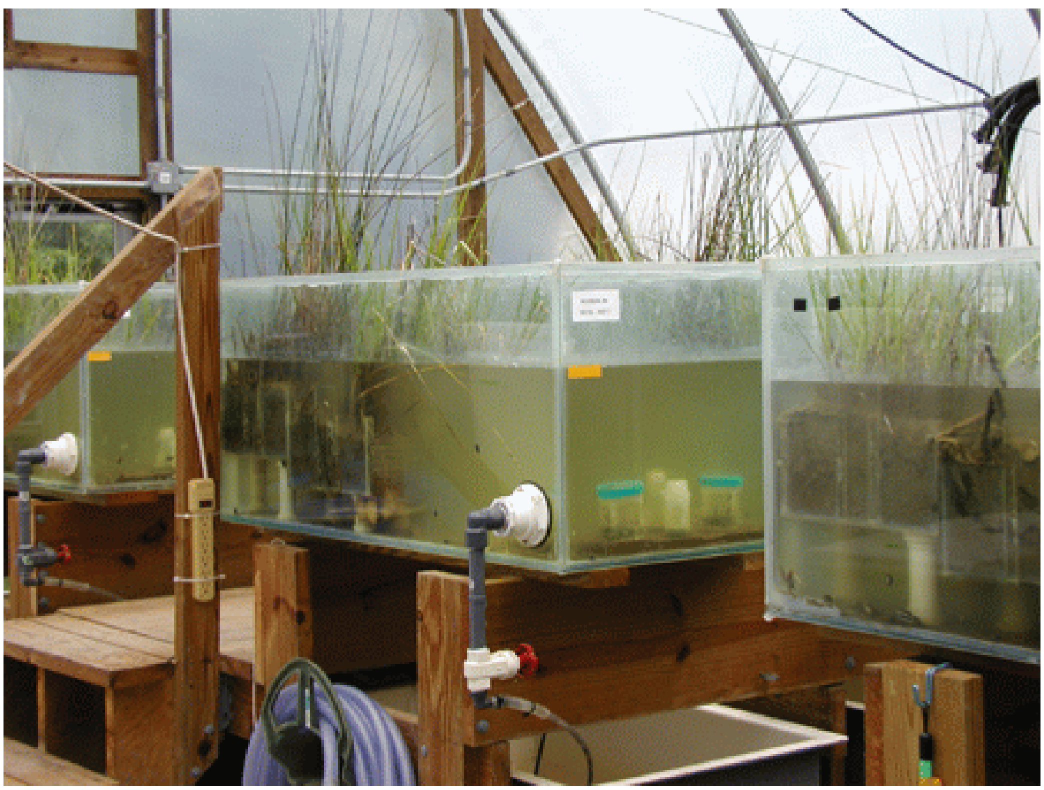

Figure 3-3. Mesocosm Tanks

Table 3-2. Schedule for the Ocean Seven 316 Verification Test

Activity	Date
Vendor setup	June 10
Begin saltwater test at CCEHBR small tidal creek	June 17
End saltwater test at CCEHBR small tidal creek due to structural failure	July 9
Setup at Cooper River (Pier Romeo)	July 11
Begin saltwater test	July 15
End saltwater test	August 14
Set up freshwater test at Lake Edmunds	August 19
Begin freshwater test	August 21
End freshwater test	September 13
Vendor setup for mesocosm test at CCEHBR	September 16
Begin mesocosm test	September 19
End mesocosm test	September 25
Vendor removal of equipment	September 30

3.3.1 Saltwater Testing

Saltwater testing was conducted at two locations. The planned location was in the Charleston River near the NOAA CCEHBR facility. However, due to structural problems at that site, the probes were redeployed in the Charleston Harbor to NOAA Pier Romeo. Pre- and post-calibration data obtained at the first location are presented in Section 6.1 of this report; however, no additional data from that location are available.

The saltwater test lasted for 31 days, during which time the Ocean Seven 316s monitored the naturally occurring range of the target parameters 24 hours a day, while dockside reference measurements were made, and reference samples for turbidity were collected. The Ocean Seven 316s were mounted on iron posts that were driven into the river bed. The instruments were approximately 0.5 meters apart (Figure 3-4) in the shallows of the Cooper River. Samples were collected in rotation during the morning, afternoon, and evening hours throughout the test. More intense sampling occurred at the beginning (Days 1 and 2) and the end (Days 29 and 30) of the sampling period, when samples were taken at 15-minute intervals for eight hours, except on Day 29, when only four hours of sampling occurred because of weather conditions. For the duration of the test, the Ocean Seven 316s were deployed at depths between approximately three and 10 feet, varying according to the tide. Table 3-3 shows the times and numbers of samples taken throughout the saltwater test period. Aside from the initial setup days (July 11 through 14), the Ocean Seven 316s were deployed and collecting data approximately every 15 minutes on the days indicated in Table 3-3.

Table 3-3. Schedule for Saltwater Sample Collection

Test Day	Day of Week	Date	# Reference Samples	# Field Blanks	# Duplicate Samples	Location
	Thu	11-Jul-02				Pier Romeo
	Fri	12-Jul-02				Pier Romeo
	Sat	13-Jul-02				Pier Romeo
	Sun	14-Jul-02				Pier Romeo
1	Mon	15-Jul-02	16			Pier Romeo
2	Tue	16-Jul-02	16			Pier Romeo
3	Wed	17-Jul-02	3	1	1	Pier Romeo
4	Thu	18-Jul-02				Laboratory
5	Fri	19-Jul-02				Laboratory
6	Sat	20-Jul-02				Pier Romeo
7	Sun	21-Jul-02				Pier Romeo
8	Mon	22-Jul-02	2			Pier Romeo
9	Tue	23-Jul-02				Pier Romeo
10	Wed	24-Jul-02	3	1	1	Pier Romeo
11	Thu	25-July-02	2	1		Pier Romeo
12	Fri	26-Jul-02				Laboratory
13	Sat	27-Jul-02				Laboratory
14	Sun	28-Jul-02				Laboratory
15	Mon	29-Jul-02				Laboratory
16	Tue	30-Jul-02				Laboratory
17	Wed	31-Jul-02				Laboratory
18	Thu	01-Aug-02				Laboratory
19	Fri	02-Aug-02		1	1	Pier Romeo
20	Sat	03-Aug-02				Pier Romeo
21	Sun	04-Aug-02				Pier Romeo
22	Mon	05-Aug-02		1	1	Pier Romeo
23	Tue	06-Aug-02	2	2	1	Pier Romeo
24	Wed	07-Aug-02	3	1	1	Pier Romeo
25	Thu	08-Aug-02				Pier Romeo
26	Fri	09-Aug-02				Pier Romeo
27	Sat	10-Aug-02				Pier Romeo
28	Sun	11-Aug-02				Pier Romeo
29	Mon	12-Aug-02	7			Pier Romeo
30	Tue	13-Aug-02	16			Pier Romeo
31	Wed	14-Aug-02				Pier Romeo

Figure 3-4. Saltwater Deployment

3.3.2 Freshwater Testing

Freshwater testing was conducted at Lake Edmunds. Because this site is shallower than Charleston Harbor, samples were taken at only one depth (approximately 0.3 meters). As in the saltwater portion of the verification test, the Ocean Seven 316s monitored the naturally occurring target parameters 24 hours a day, while reference measurements were made and turbidity reference samples collected, again rotating among collection times. More intense sampling occurred at the beginning (Day 3) and the end (Day 23) of the sampling period, when samples were taken at 15- to 30-minute intervals for periods ranging between six and eight hours, as weather permitted. Table 3-4 shows the sampling times and number of samples collected throughout the freshwater test period. The Ocean Seven 316s were tethered with cable ties to large posts driven into the bottom of the lake.

Table 3-4. Schedule for Freshwater Sample Collection

Test Day	Day of Week	Date	# Reference Samples	# Field Blanks	# Duplicate Samples	Location
	Mon	19-Aug-02				Laboratory
	Tue	20-Aug-02				Laboratory
1	Wed	21-Aug-02				Lake Edmunds
2	Thu	22-Aug-02				Lake Edmunds
3	Fri	23-Aug-02	16			Lake Edmunds
4	Sat	24-Aug-02				Lake Edmunds
5	Sun	25-Aug-02				Lake Edmunds
6	Mon	26-Aug-02	4			Lake Edmunds
7	Tue	27-Aug-02				Lake Edmunds
8	Wed	28-Aug-02	2	1	1	Lake Edmunds
9	Thu	29-Aug-02				Laboratory
10	Fri	30-Aug-02				Laboratory
11	Sat	31-Aug-02				Lake Edmunds
12	Sun	01-Sep-02				Lake Edmunds
13	Mon	02-Sep-02				Lake Edmunds
14	Tue	03-Sep-02				Lake Edmunds
15	Wed	04-Sep-02		1	1	Lake Edmunds
16	Thu	05-Sep-02	2	1	1	Laboratory
17	Fri	06-Sep-02				Laboratory
18	Sat	07-Sep-02				Lake Edmunds
19	Sun	08-Sep-02				Lake Edmunds
20	Mon	09-Sep-02	3		1	Lake Edmunds
21	Tue	10-Sep-02	3	1		Lake Edmunds
22	Wed	11-Sep-02				Lake Edmunds
23	Thu	12-Sep-02	12			Lake Edmunds
24	Fri	13-Sep-02				Laboratory

3.3.3 Mesocosm Testing

Mesocosm testing was performed according to the schedule shown in Table 3-5. The mesocosm tanks were filled with water and drained twice daily, simulating a semi-diurnal tidal cycle. Reference measurements were made and water samples were collected during each test day throughout the normal operating hours of the facility (nominally 6 a.m. to 6 p.m.). During this period, the mesocosm was manipulated to introduce variations in the measured parameters. The turbidity of the system was varied by operating a pump near the sediment trays to suspend additional solids in the water. Conductivity was varied by adding freshwater to the saltwater during one of the fill-and-drain cycles.

Variations in temperature, pH, and DO were driven by natural forces and the changes in the other test parameters. Parameters over the ranges specified in Table 3-1 were monitored by the Ocean Seven 316. Each collected sample was analyzed using a reference method for comparison.

Table 3-5. Schedule for Mesocosm Sample Collection

Test Day	Day of Week	Date	# Reference Samples	# Field Blanks	# Duplicate Samples	Location
	Mon	16-Sep-02				Laboratory
	Tue	17-Sep-02				Laboratory
	Wed	18-Sep-02				Laboratory
1	Thu	19-Sep-02	2			Mesocosm
2	Fri	20-Sep-02	5[a]			Mesocosm
3	Sat	21-Sep-02				Mesocosm
4	Sun	22-Sep-02				Mesocosm
5	Mon	23-Sep-02	6[b]			Mesocosm
6	Tue	24-Sep-02	6[c,d]			Mesocosm
7	Wed	25-Sep-02	1	1	1	Mesocosm
	Thu	26-Sep-02				Laboratory
	Fri	27-Sep-02				Laboratory

[a] Stir sediment.
[b] Turn off aeration pump.
[c] Turn on aeration pump.
[d] Add freshwater.

3.4 Materials and Equipment

The reference equipment used in this verification test was selected for the specific parameters, as follows:

- DO—National Institute of Standards and Technology (NIST)-traceable, commercially available probe (Orion 830A)
- Conductivity—NIST-traceable, handheld conductivity meter (Oakton 35631-00)
- Temperature—NIST-traceable, handheld thermocouple and readout (Orion 830A)
- pH—NIST-traceable, handheld pH meter (Oakton 35631-00)
- Turbidity—Hach Ratio XR turbidity meter (Hach 43900).

Reagents were distilled deionized water (for field blanks) and a Hach Ratio XR turbidity standard from Advanced Polymer Systems. Sampling equipment consisted of 0.5- to 1.0-L glass bottles, a Niskin sampling device provided by CCEHBR, and provisions for sample storage. The maximum sample holding times are given in Table 3-6. All sample holding time requirements were met.

Table 3-6. Maximum Sample Holding Times

Parameter	Holding Time
DO	none[a]
Conductivity	none
Temperature	none
pH	none
Turbidity	24 hours

[a] "None" indicates that the sample analysis must be performed immediately after sample collection or in the water column at the site.

Chapter 4
Quality Assurance/Quality Control

Quality assurance/quality control (QA/QC) procedures were performed in accordance with the quality management plan (QMP) for the AMS Center[2] and the test/QA plan for this verification test.[1]

4.1 Instrument Calibration

Both the portable and laboratory reference instruments were calibrated by CCEHBR according to the procedures and schedules in place at the test facility, and documentation was provided to Battelle.

4.2 Field Quality Control

Field blanks and laboratory duplicate samples were taken at the times shown in Tables 3-3 through 3-5. The field blank was a container of deionized water taken to the field and then brought back to the laboratory. It was analyzed in the same manner as the collected samples. The laboratory replicate samples were collected once each week during a regular sampling period. These replicate samples were the field sample split in the field into two separate samples (containers) and analyzed by the same methods. The results from the replicate analysis were within the expected values shown in Table 4-1. The results for the field blanks were within the expected tolerances.

4.3 Sample Custody

Samples collected at the saltwater and freshwater sites were transported to the laboratory in an ice-filled cooler.

Table 4-1. Replicate Analysis Results

Parameter	Anticipated Interval of Results
DO	±5%
Conductivity	±5%
Temperature	±1°C
pH	±0.1
Turbidity	±5 NTU

4.4 Audits

4.4.1 Performance Evaluation Audit

A performance evaluation (PE) audit was conducted by the Battelle Verification Test Coordinator once during the verification test to assess the quality of the reference measurements. For the PE audit, an independent standard was used. Table 4-2 shows the procedures used for the PE audit and associated results.

Table 4-2. Summary of Performance Evaluation Audits

Audited Parameter	Audit Procedure	Acceptable Tolerance	Actual Difference	Passed Audit
DO	Independent monitor	±5%	6.7%	No[a]
Conductivity	Independent monitor	±5%	0.6%	Yes
Temperature	Independent monitor	±1°C	0.2°C	Yes
pH	Independent monitor	±0.1 pH	0.04 pH	Yes
Turbidity	Independent turbidity standard	±10%	0.4%	Yes

[a] Although the measurement recorded during the PE audit was outside the acceptable tolerance, this measurement was repeated 111 times during the verification test. The average agreement during the verification test was 0.2%; therefore, no corrective action was taken.

The DO measurement made by the Orion 830A was compared with that from a handheld DO monitor made by Hanna (94130M). Agreement within 6.7% was achieved. Although this measurement was outside the acceptable tolerance, the measurement was, in fact, repeated 111 times during the verification test, with an average difference of 0.2%, indicating acceptable performance of the reference monitor. A handheld conductivity meter made by Hanna (H19835) was used to perform the conductivity audit. Agreement within 0.6% between the results of the Hanna meter and those of the Oakton reference meter was seen. A NIST-traceable mercury-in-glass thermometer was used for the temperature performance audit. The comparison was made with a sample of collected water, and agreement was within 0.2°C. The handheld pH reference meter from Oakton was compared with a handheld pH meter made by Hanna (991301).

A pH tolerance of 0.04% was recorded. The Hach turbidity meter measurements were compared with an independent turbidity standard. Agreement within 0.4% was observed.

4.4.2 Technical Systems Audit

The Battelle Quality Manager conducted a technical systems audit (TSA) on August 28, 2002, to ensure that the verification test was performed in accordance with the test/QA plan[1] and the AMS Center QMP.[2] As part of the audit, the Battelle Quality Manager reviewed the reference methods used, compared actual test procedures to those specified in the test/QA plan, and reviewed data acquisition and handling procedures. Observations and findings from this audit were documented and submitted to the Battelle Verification Test Coordinator for response. No findings were documented that required any corrective action. The records concerning the TSA are permanently stored with the Battelle Quality Manager.

During the verification test, three deviations from the test/QA plan were necessary. The first was because the manufacturer's instructions required a different calibration frequency than the test/QA plan for pH, conductivity, and turbidity measurements. Because the calibrations were within the specified range during each calibration, it was determined that there was no impact on the verification test. The second and third deviations were that the sampling frequency and total number of samples were different than stated in the test/QA plan. Samples were taken at 15- instead of 30-minute intervals because, in some cases, sampling went faster than anticipated; and weather and environmental conditions required ending the deployment sooner than specified by the test/QA plan, resulting in fewer samples.

4.4.3 Audit of Data Quality

At least 10% of the data acquired during the verification test were audited. Battelle's Quality Manager traced the data from the initial acquisition, through reduction and statistical analysis, to final reporting, to ensure the integrity of the reported results. All calculations performed on the data undergoing the audit were checked.

4.5 QA/QC Reporting

Each assessment and audit was documented in accordance with Sections 3.3.4 and 3.3.5 of the QMP for the ETV AMS Center.[2] Once the assessment report was prepared, the Verification Test Coordinator ensured that a response was provided for each adverse finding or potential problem and implemented any necessary follow-up corrective action. The Battelle Quality Manager ensured that follow-up corrective action was taken. The results of the TSA were sent to the EPA.

4.6 Data Review

Records generated in the verification test were reviewed within two weeks of generation before these records were used to calculate, evaluate, or report verification results. Table 4-3 summarizes the types of data recorded. The review was performed by a technical staff member involved in the verification test, but not the staff member who originally generated the record. The person performing the review added his/her initials and the date to a hard copy of the record being reviewed.

Table 4-3. Summary of Data Recording Process

Data to be Recorded	Responsible Party	Where Recorded	How Often Recorded	Disposition of Data
Dates, times of test events	CCEHBR	Laboratory record books/data sheets	Start/end of test; at each change of a test parameter; at sample collection	Used to organize/ check test results; manually incorporated data into spreadsheets - stored in study binder
Test parameters	Battelle/ CCEHBR	Laboratory record books/ data sheets	Each sample collection	Used to organize/ check test results; manually incorporated data into spreadsheets - stored in study binder
Ocean Seven 316 data				
- digital display	CCEHBR	Data sheets	Continuous fifteen-minute sampling; data downloaded to PC	Used to organize/ check test results; incorporated data into electronic spread-sheets - stored in study binder
- electronic output	CCEHBR	Probe data acquisition system (DAS); data stored on probe downloaded to PC		
Reference monitor readings/reference analytical results	CCEHBR	Laboratory record book/data sheets or data management system, as appropriate	After each batch sample collection; data recorded after reference method performed	Used to organize/ check test results; manually incorporated data into spreadsheets - stored in study binder
Reference calibration data	CCEHBR	Laboratory record books/ data sheets/DAS	Whenever zero and calibration checks are done	Documented correct performance of reference methods
PE audit results	Battelle	Laboratory record books/ data sheets/DAS	At times of PE audits	Test reference methods with independent standards/ measurements

Chapter 5
Statistical Methods

The statistical methods presented in this chapter were used to verify the performance parameters listed in Section 3.1.

5.1 Pre- and Post-Calibration Results

Pre- and post-calibration of the Ocean Seven 316s was done for each measured parameter according to that vendor's instruction manual. The results from the calibration checks were summarized, and accuracy was determined each time the calibration check was conducted. Calibration check accuracy (*A*) is reported as a percentage, calculated using the following equation:

$$A = 1 - (C_s - C_p)/C_s \times 100 \qquad (1)$$

Where C_s is the value of the reference standard, and C_p is the value measured by the vendor's probe.

5.2 Relative Bias

Water samples were analyzed by both the reference method and the Ocean Seven 316, and the results were compared. The results for each sample were recorded, and the accuracy was expressed in terms of the average relative bias (*B*), as calculated from the following equation:

$$B = \frac{C_s - C_p}{C_s} \times 100 \qquad (2)$$

where C_P is a measurement taken from the Ocean Seven 316 being verified at the same time as the reference measurement was taken, and C_S is the reference measurement. This calculation was performed for each reference sample analysis for each of the five target water parameters. Readings of pH were converted to H^+ concentration, and temperature readings were converted to absolute units (i.e., Kelvin) prior to making this calculation. Relative bias was assessed independently for each Ocean Seven 316 to determine inter-unit reproducibility.

5.3 Precision

The standard deviation (S) of the measurements made during a period of stable operation at the mesocosm was calculated and used as a measure of probe precision:

$$S = \left[\frac{1}{n-1} \sum_{k=1}^{n} (C_k - \overline{C})^2 \right]^{1/2} \quad (3)$$

where n is the number of replicate measurements, C_k is the concentration reported for the k^{th} measurement, and $\overline{C}$ is the average concentration of the replicate measurements.

Precision was calculated for each of the five target water parameters. Probe precision was reported in terms of the percent relative standard deviation (RSD) of the series of measurements:

$$\%RSD = \frac{S}{\overline{C}} * 100 \quad (4)$$

5.4 Linearity

For target water parameters with a wide range of variation, linearity was assessed by linear regression, with the analyte concentration measured by the reference method as an independent variable and the reading from the analyzer verified as a dependent variable. Linearity is expressed in terms of the slope, intercept, and coefficient of determination (r^2). Linearity for pH was assessed by converting pH results to H^+ concentration before comparison. Linearity was assessed separately for each Ocean Seven 316 and for the data generated at each of the saltwater, freshwater, and mesocosm test sites.

5.5 Inter-Unit Reproducibility

The results obtained from the two Ocean Seven 316s were compiled independently for each analyzer and compared to assess inter-unit reproducibility. Inter-unit reproducibility was determined by calculating the average absolute difference between the two Ocean Seven 316s. In addition, the two Ocean Seven 316s were compared by evaluating the relative bias of each.

Chapter 6
Test Results

The results of the verification of the two Ocean Seven 316s (identified as GO 204 and GO 205 in this report) are presented in this section. The Ocean Seven 316 data were recorded at 15-minute intervals throughout the verification test. Figures 6-1a through e show plots of nearly 6,000 data points that were collected by the Ocean Seven 316s during this verification test and data points for the 132 reference samples that were collected and analyzed. (Figures 6-4 through 6-8 show parameter-specific data for each of the three tests, so much of the same data is presented as in Figure 6-1a through e, but over a shorter period and with better time resolution).

Reference sample results and corresponding Ocean Seven 316 readings are provided in Appendix A.

The entire data set is presented in a graphical format in Figures 6-1a through 6-1e to allow several non-quantitative observations. First, a comparison of GO 204 and 205 and the reference measurements shows that, for each condition and parameter, the Ocean Seven 316s generally follow the trend of the reference measurements. A visual inspection of the GO 204 and GO 205 data for DO, conductivity, temperature, pH, and turbidity suggests that the GO 204 and 205 data generally agree with each other and the reference measurements.

The DO measurements (Figure 6-1a) show tidal and daily fluctuations, with the freshwater deployment showing the largest magnitude fluctuations. The conductivity measurements (Figure 6-1b) show that Ocean Seven 316s again track daily fluctuations from the saltwater environment, to the freshwater environment, and back to the mesocosm environment. Figure 6-1b also shows that the mesocosm conductivity measured in the saltwater environment closely agrees with the reference measurement during the transition from saltwater to freshwater on September 24, 2002, and back to saltwater. The temperature (Figure 6-1c) and pH (Figure 6-1d) measurements from the GO 204 and 205 are overlaid on their respective charts, and their close agreement makes it difficult to see the individual values. Finally, the turbidity measurements (Figure 6-1e) made by the GO 204 and 205 follow the general trends of the reference measurements and generally agree with each other. It can be seen that on September 21, 2002, a spike in turbidity corresponded with the activation of the pump in the mesocosm. This increased level in turbidity was captured by both the GO 204 and 205, as well as the reference measurements. This report attempts to quantify the extent of agreement using the various statistical methods described in Chapter 5.

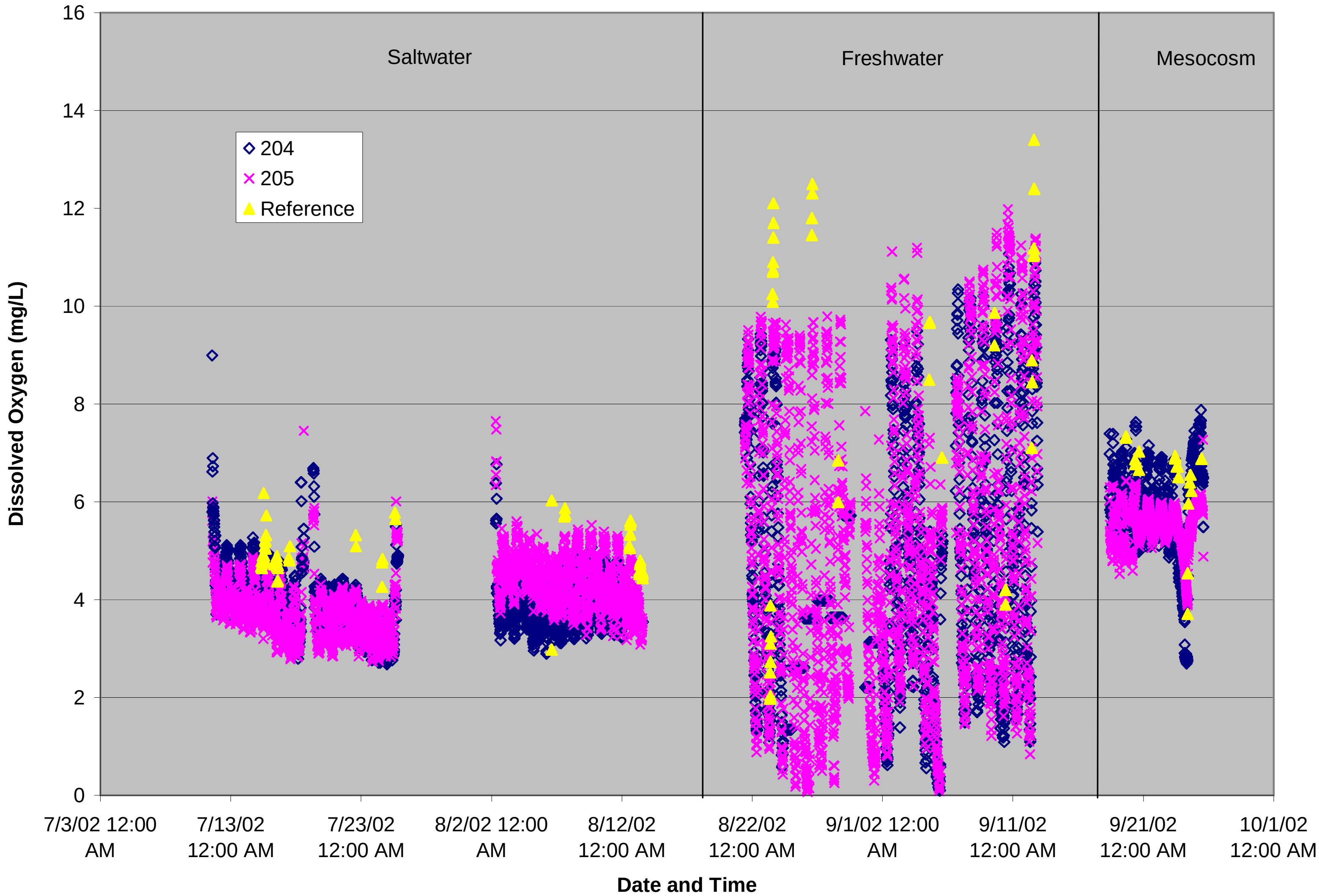

Figure 6-1a. Dissolved Oxygen Data Collected from GO 204 and GO 205 During the Verification Test

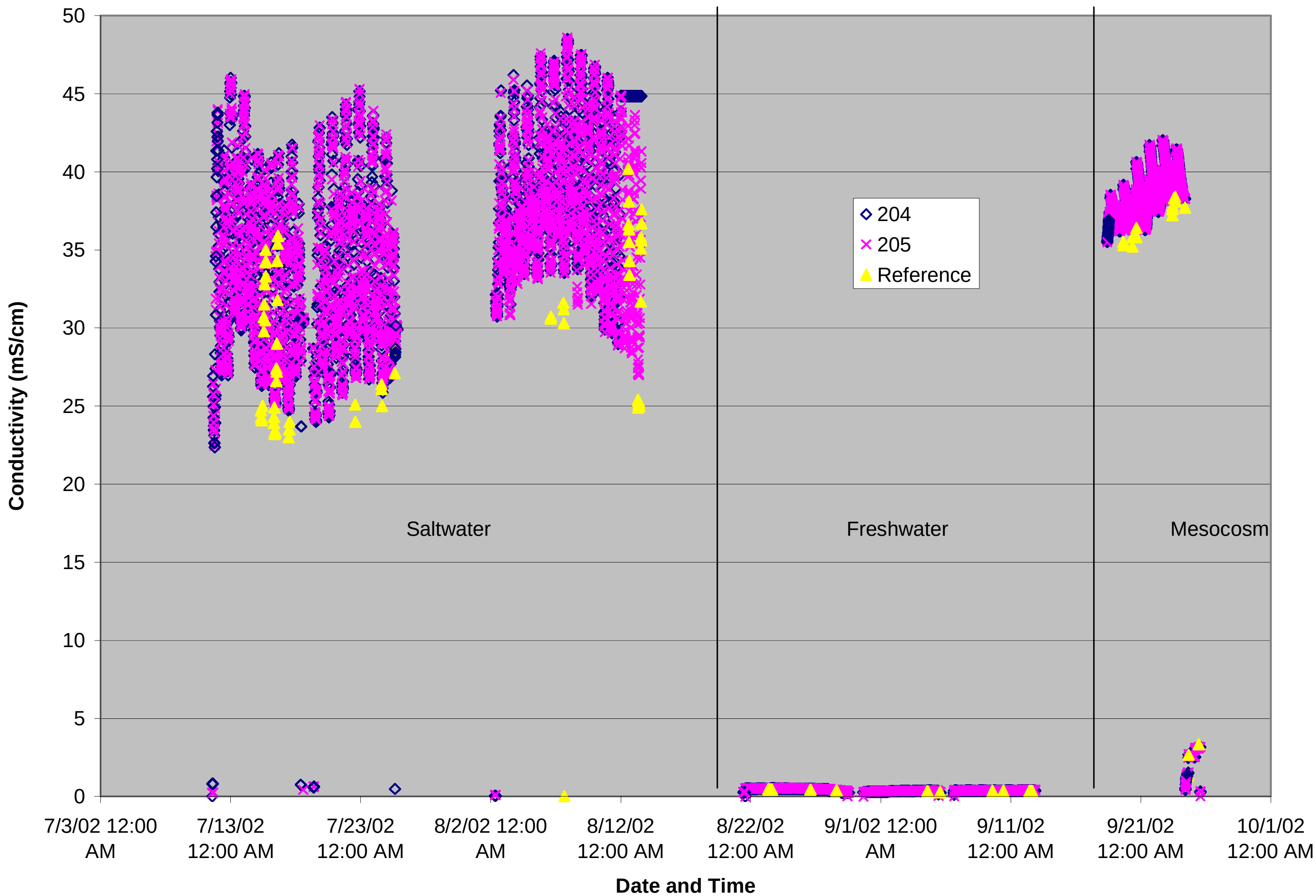

Figure 6-1b. Conductivity Data Collected from GO 204 and GO 205 During the Verification Test

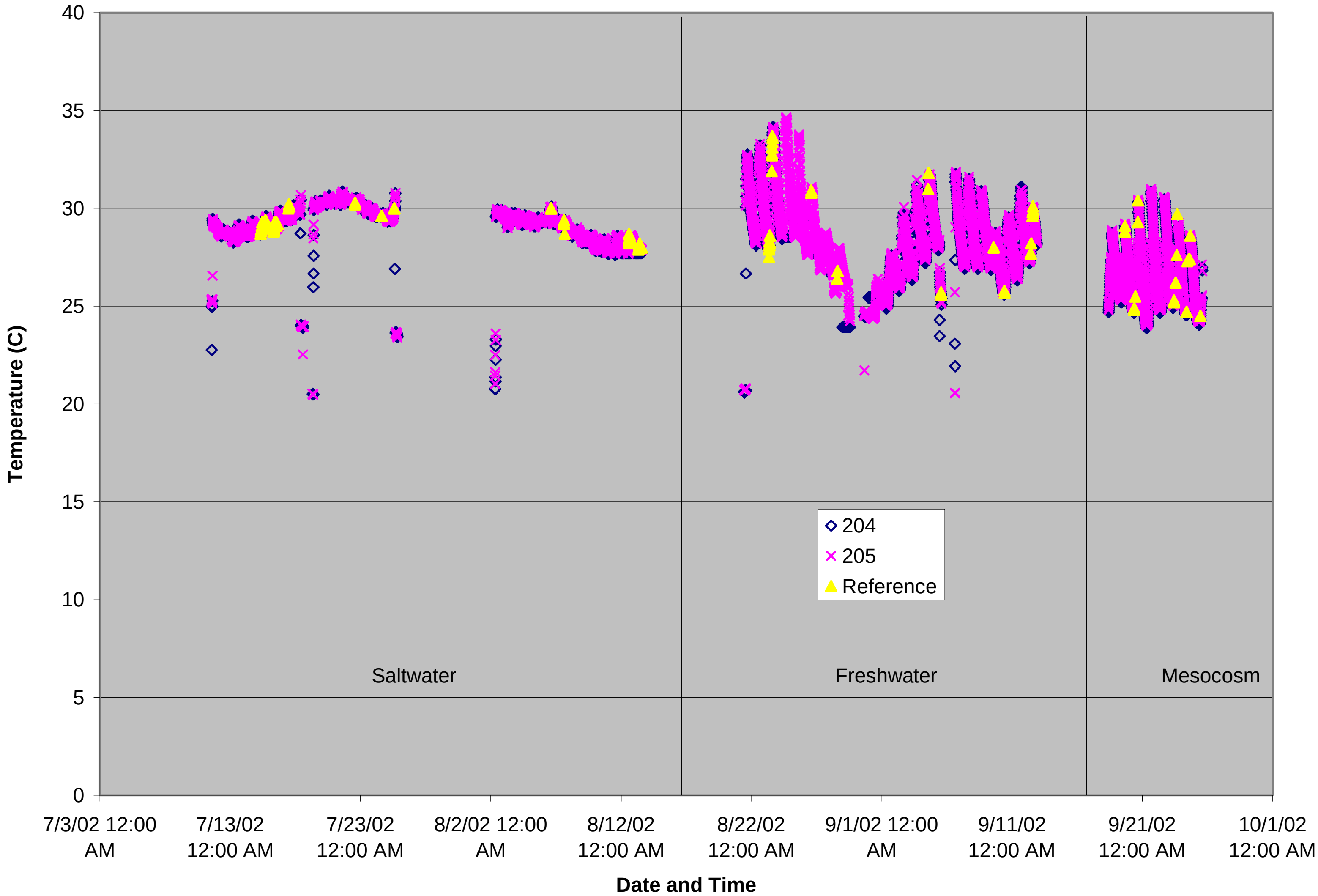

Figure 6-1c. Temperature Data Collected from GO 204 and GO 205 During the Verification Test

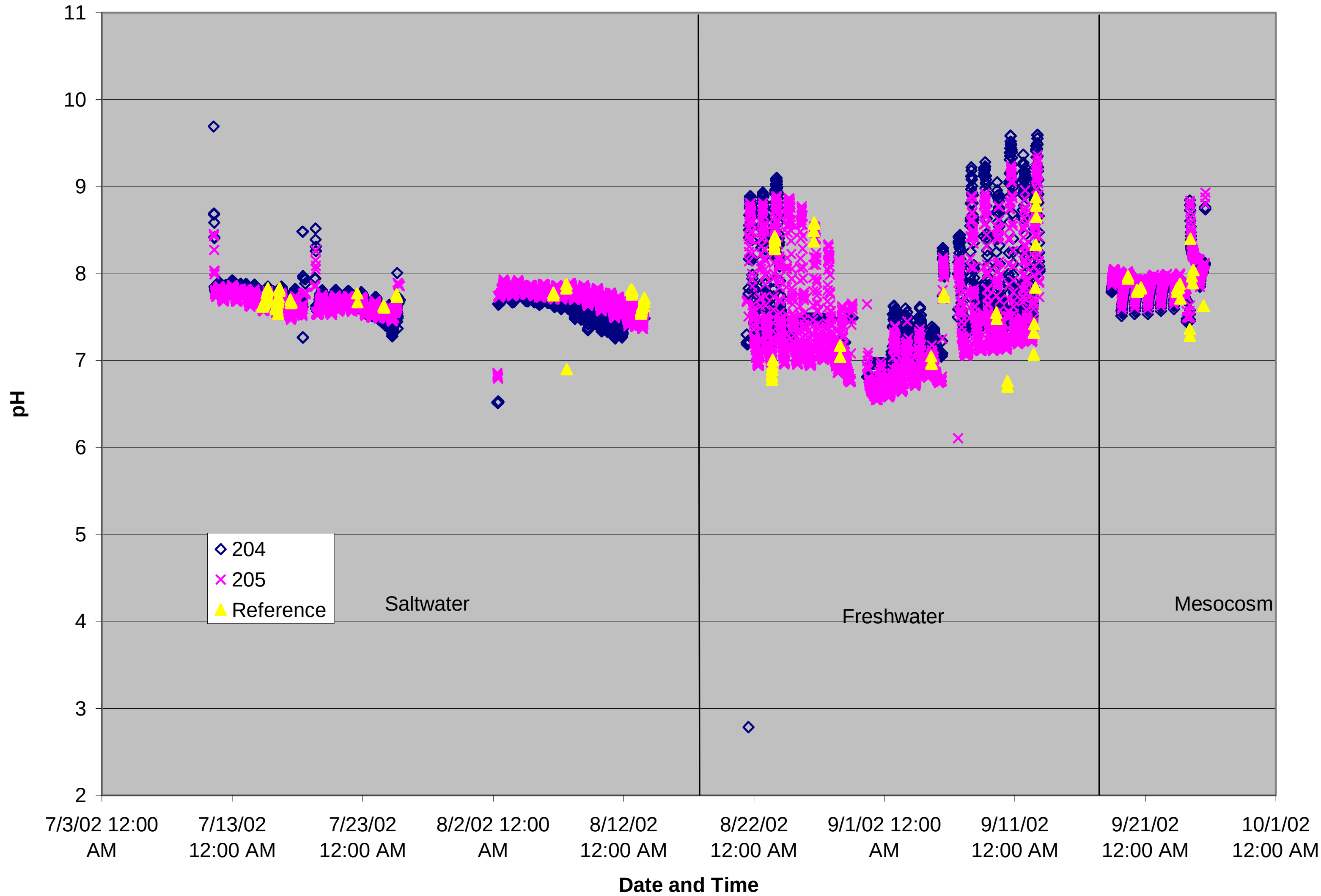

Figure 6-1d. pH Data Collected from GO 204 and GO 205 During the Verification Test

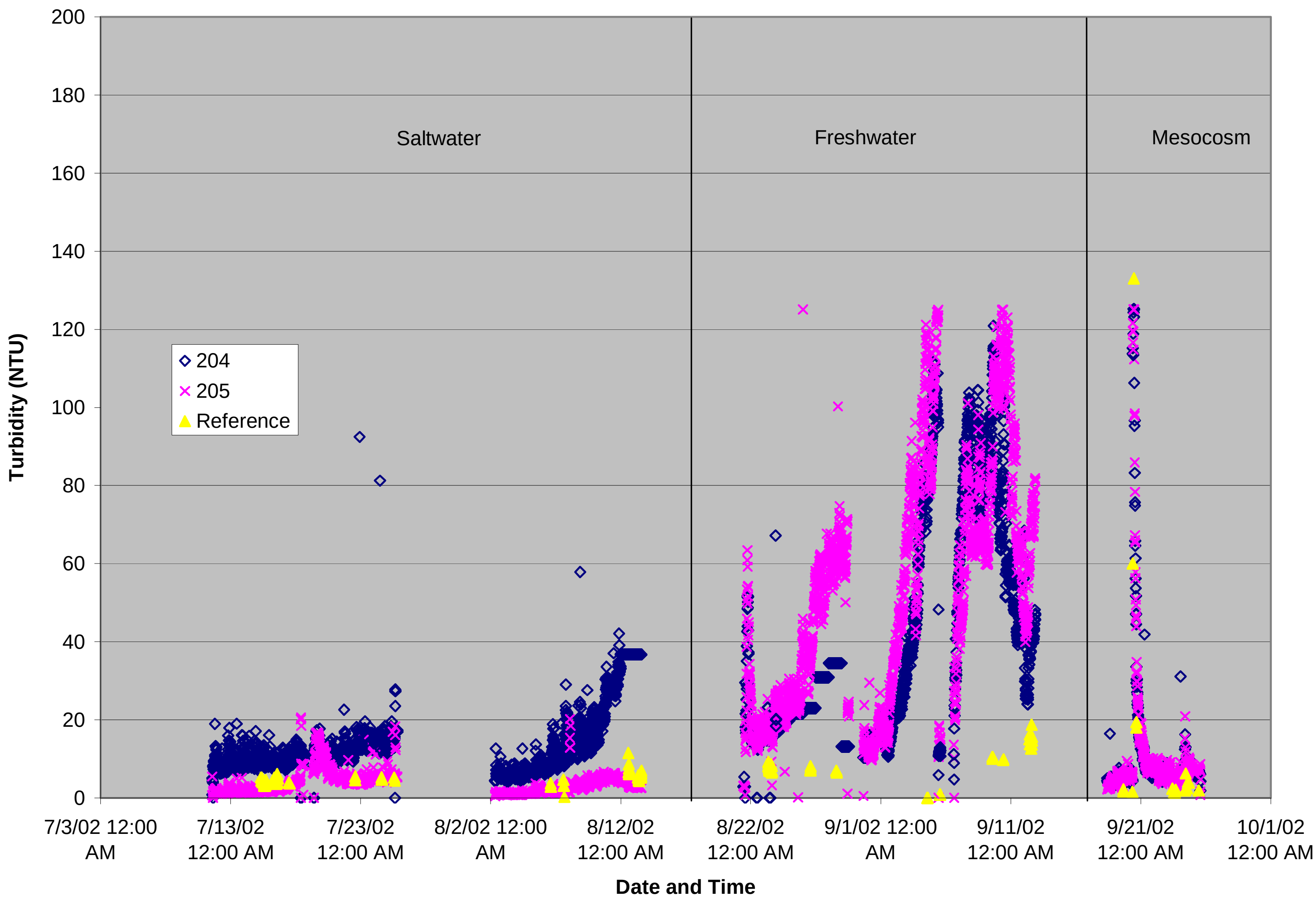

Figure 6-1e. Turbidity Data Collected from GO 204 and GO 205 During the Verification Test

6.1 Pre- and Post-Calibration Results

The Ocean Seven 316s were calibrated at the beginning and end of each deployment period (noted as "in Laboratory" in Tables 3-3, 3-4, and 3-5). The only exception to this was on July 29, 2002, when battery problems prevented a calibration check from being performed on the GO 205. The calibration was checked periodically throughout the deployments to monitor how well the probes held the original calibrations. This operation was performed for pH, conductivity, and DO since only those parameters are adjusted during the calibration. The calibration check levels were selected based on the manufacturer's instructions. Tables 6-1a, b, and c show the results from these calibration checks for the saltwater, freshwater, and mesocosm tests. Figure 6-2 is a graphical representation of these calibration results. The "Reference Standard" column refers to the listed concentration of the standards used in the calibrations, the "GO 204 and GO 205 Readings" columns give the Ocean Seven 316 results during the calibration checks, and the "GO 204 and GO 205 % Accuracy" columns show the calibration check accuracy using the calculations given in Section 5.1. The accuracy for the pH tests ranged from 99% to 108%, for the conductivity tests from 94% to 104%, and for the DO tests from 82% to 105%.

Table 6-1a. Results from the Pre- and Post-Calibration Tests for GO 204 and GO 205 in Saltwater[a]

	Reference Standard			GO 204 Readings			GO 205 Readings			GO 204 % Accuracy			GO 205 % Accuracy		
Date	pH[b]	Con-ductivity (mS/cm)	DO (%)	pH	Con-ductivity (mS/cm)	DO (%)	pH	Con-ductivity (mS/cm)	DO (%)	pH	Conductivity	DO	pH	Con-ductivity	DO
6/25/2002	7.00	10.00	100	7.065	9.934	104.5	6.99	10.02	91.4	101	99	105	100	100	91
6/25/2002	10.00			10.1			10.02			101			100		
7/11/2002	7.00	10.00	100	7.086	9.917	100.5	7.03	10.04	90.7	101	99	101	100	100	91
7/19/2002	7.00	10.04	100	7.145	9.7	96.5	7.11	9.82	95.7	102	97	97	102	98	96
7/19/2002	10.00	--	--	10.09	--	--	10.03	--	--	101	--	--	100	--	--
7/29/2002	7.00	12.88	100	7.061	13.42	98	NA	NA	NA	101	104	98	NA	NA	NA
7/29/2002	10.00	--	--	10.02	--	--	NA	--	--	100	--	--	NA	--	--
8/1/2002	7.00	10.00	100	7.00	10.00	100	7.00	10.00	100	100	100	100	100	100	100
8/1/2002	10.00	--	--	10.00	--	--	10.00	--	--	100	--	--	100	--	--
8/20/2002	7.00	12.88	100	6.933	12.52	99.6	7.11	12.56	103.3	99	97	100	102	98	103

[a] Shaded section is from first saltwater deployment.
[b] The pH calibration checks were performed at two levels, using two separate solutions, while conductivity and DO were checked at one level.
NA= No calibration check was performed because of battery problems.

Table 6-1b. Results from the Pre- and Post-Calibration Tests for GO 204 and GO 205 in Freshwater

	Reference Standard			GO 204 Results			GO 205 Results			GO 204 % Accuracy			GO 205 % Accuracy		
Date	pH	Con-ductivity (mS/cm)	DO (%)	pH	Con-ductivity (mS/cm)	DO (%)	pH	Con-ductivity (mS/cm)	DO (%)	pH	Con-ductivity	DO	pH	Con-ductivity	DO
8/19/2002	7.00	12.88	100	7	12.88	100	7.00	12.88	100	100	100	100	100	100	100
8/19/2002	10.00	--	--	10	--	--	10	--	100	100	--	--	100	--	--
8/29/2002	7.00	1.41	100	7.22	1.34	87.7	7.01	1.33	103.3	103	95	88	100	94	103
8/29/2002	10.00	--	--	10.18	--	--	10.00	--	--	102	--	--	100	--	--
9/6/2002	7.00	1.41	100	7.38	1.41	90.8	7.151	1.4	98.1	105	100	91	102	99	98
9/6/2002	10.00	--	--	10.3	--	--	10.09	--	--	103	--	--	101	--	--
9/17/2002	7.01	1.411	100	7.59	1.41	82	--	--	--	108	100	82	--	--	--
9/18/2002	7.01	1.41	100	--	--	--	7.32	1.37	102.5	--	--	--	104	97	103

Table 6-1c. Results from the Pre- and Post-Calibration Tests for GO 204 and GO 205 in Mesocosm

	Reference Standard			GO 204 Results			GO 205 Results			GO 204 % Accuracy			GO 205 % Accuracy		
Date	pH	Con-ductivity (mS/cm)	DO (%)	pH	Con-ductivity (mS/cm)	DO (%)	pH	Con-ductivity (mS/cm)	DO (%)	pH	Con-ductivity	DO	pH	Con-ductivity	DO
9/25/2002	7.00	1.41	100	7.11	1.42	105	7.17	1.42	97.4	102	101	105	103	100	97
9/25/2002	10.00	--	--	9.99	--	--	10.04	--	--	100	--	--	100	--	--

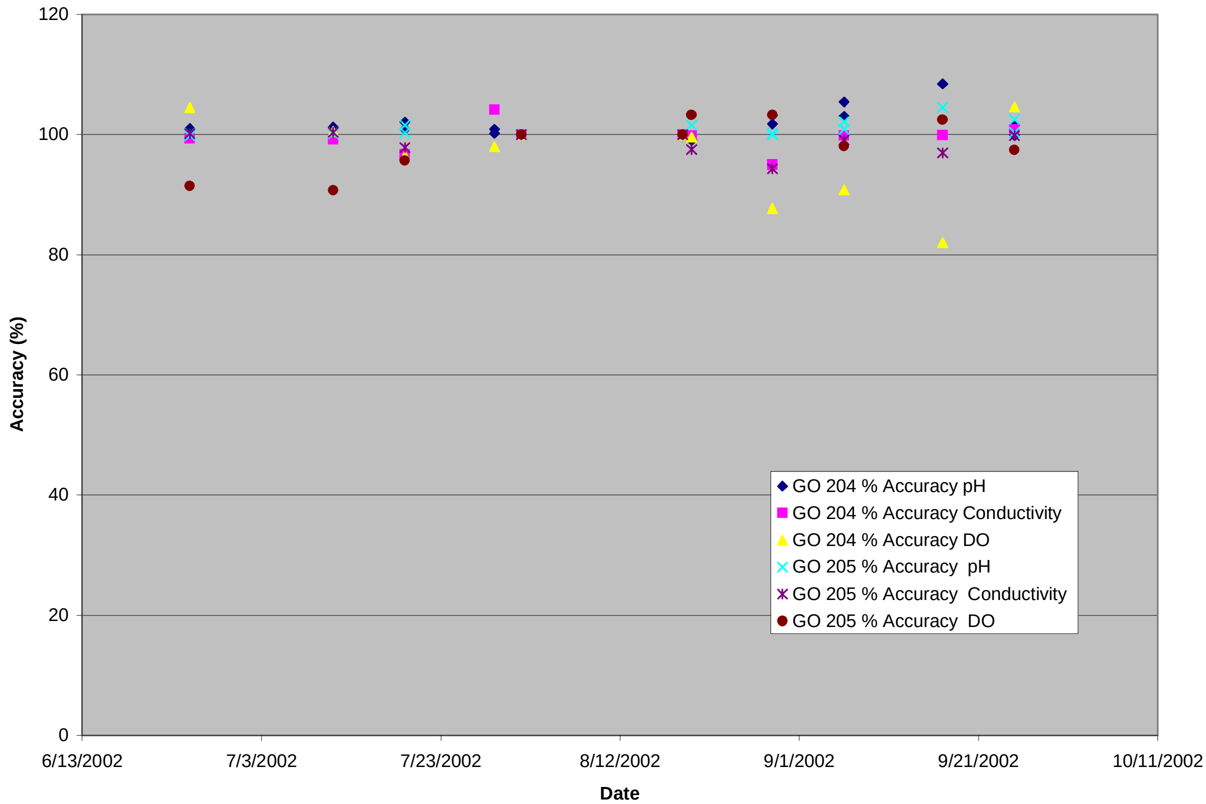

Figure 6-2. Percent Accuracy of GO 204 and GO 205 During Calibration Checks

6.2 Relative Bias

Relative bias was assessed by comparing the reference measurements with the GO 204 and GO 205 readings. The reading that correlated most closely in time to the reference sample was used. Plots of the GO 204 and GO 205 data, along with the corresponding reference measurements that were used for the relative bias calculations, are shown in Figures 6-3a through e.

The relative bias is summarized in Table 6-2. The temperature biases were less than or equal to 0.11% for all deployment settings. Conductivity, pH (reported as H^+ concentration), and DO biases were between approximately 2 and 36% for both units for all deployment settings. The conductivity bias was consistently positive, indicating that generally, the Ocean Seven 316s reported a higher conductivity than the handheld reference probe. The DO bias was consistently negative for each deployment setting. The bias for turbidity ranged between approximately -44% and 420%. From Figure 6-3e it can be seen that the turbidity measurements follow the trends of the reference measurements for the saltwater and mesocosm tests. The probes, in fact, capture the spike that occurred in the mesocosm test during a period of high turbidity. Inter-unit reproducibility was assessed by comparing the direction and size of the relative biases of the Ocean Seven 316s. In general, the Ocean Seven 316s exhibited close agreement for temperature, conductivity, and DO.

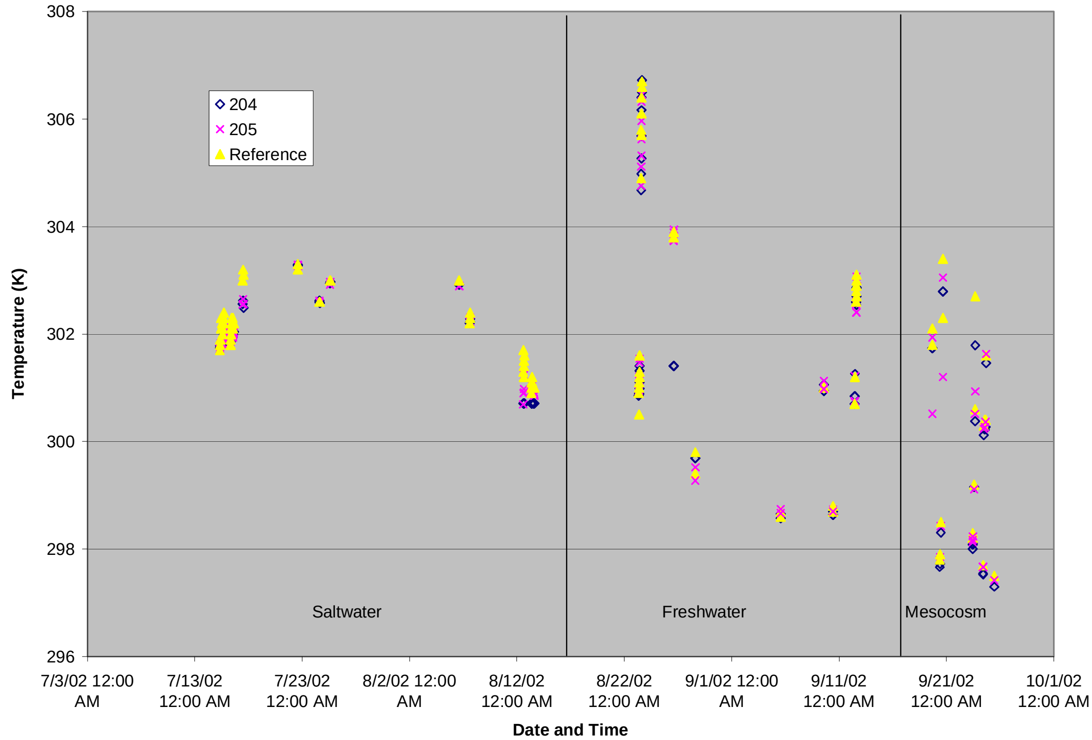

Figure 6-3a. Relative Bias Data for Temperature

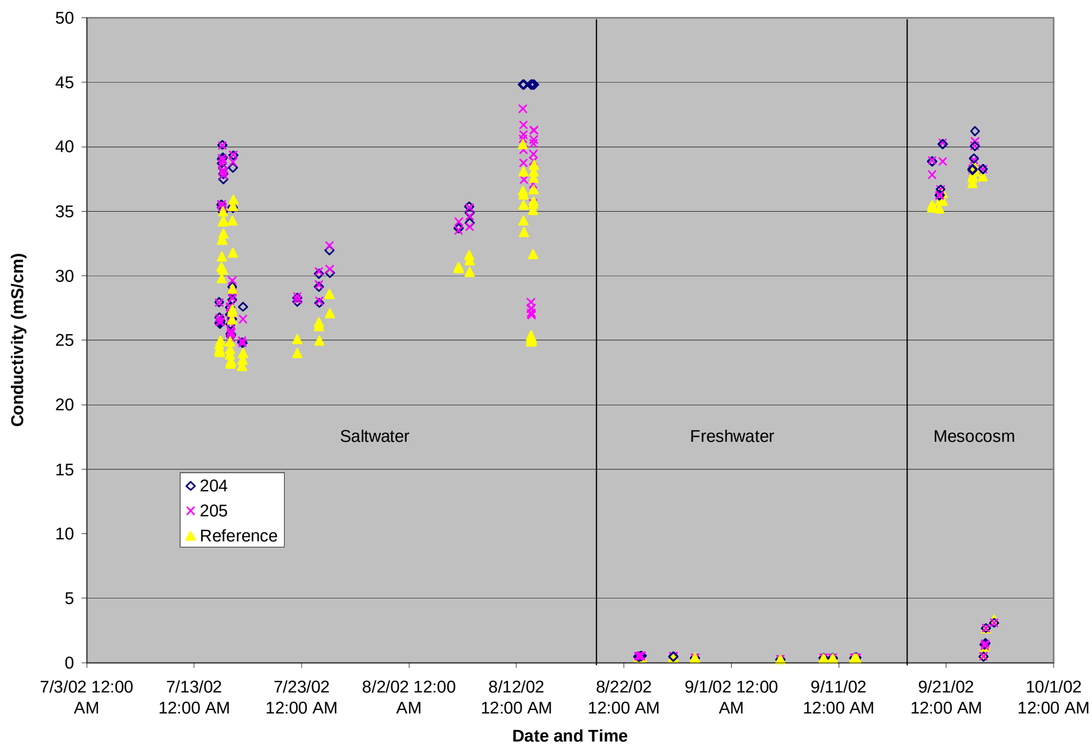

Figure 6-3b. Relative Bias Data for Conductivity

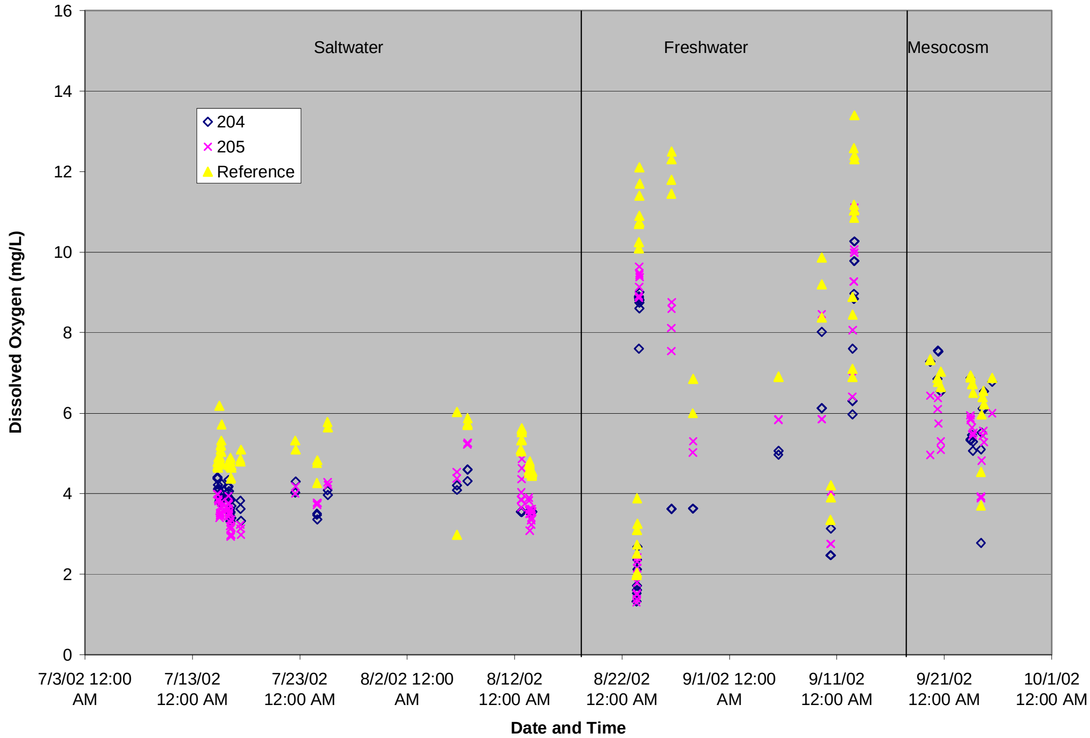

Figure 6-3c. Relative Bias Data Test for Dissolved Oxygen

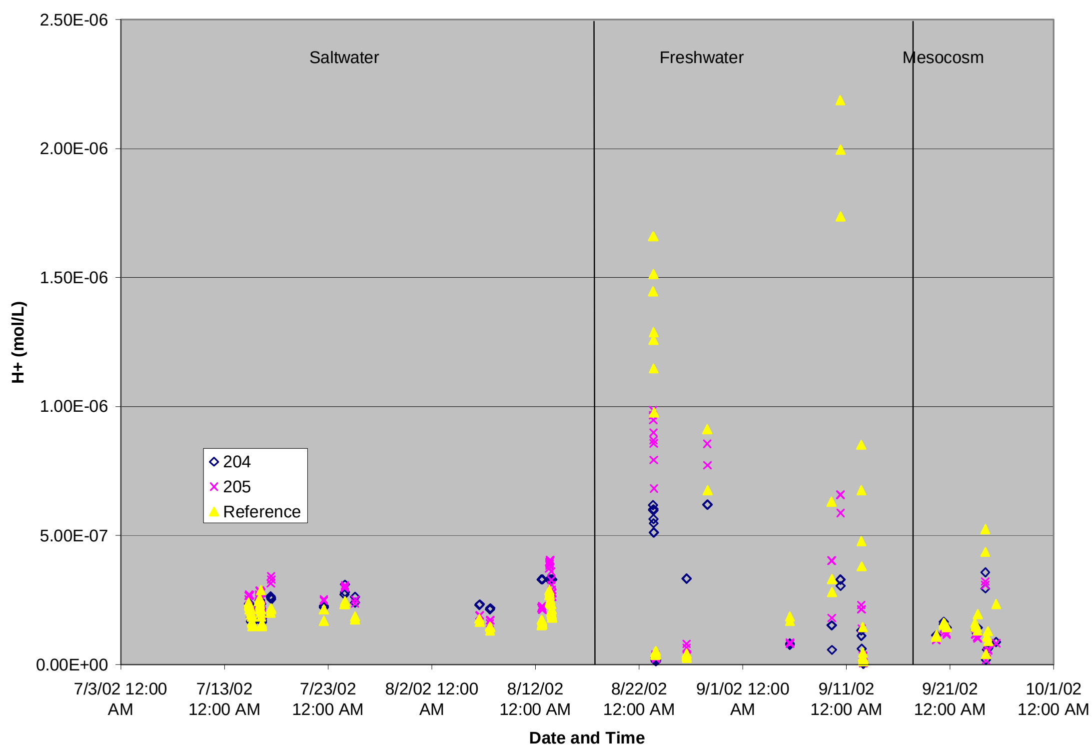

Figure 6-3d. Relative Bias Data for pH

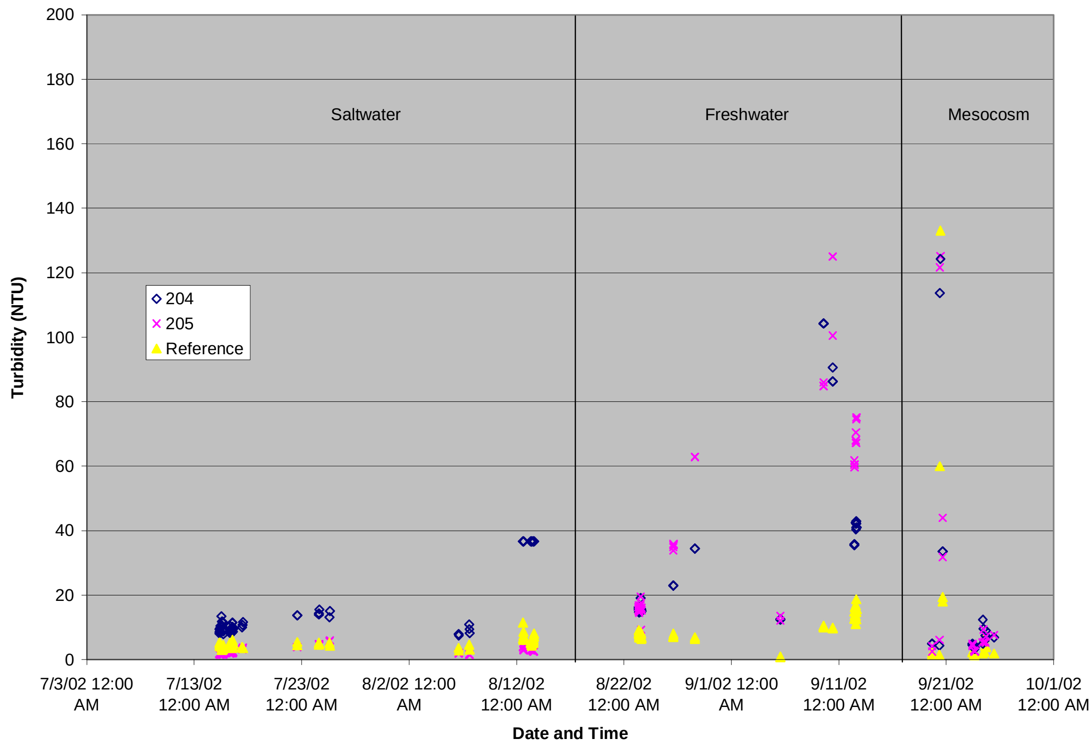

Figure 6-3e. Relative Bias Data for Turbidity

Table 6-2. Average Relative Bias Results for GO 204 and GO 205

		Saltwater		Freshwater		Mesocosm	
Parameter	**Units**	**% Rel. Bias 204**	**% Rel. Bias 205**	**% Rel. Bias 204**	**% Rel. Bias 205**	**% Rel. Bias 204**	**% Rel. Bias 205**
Temperature	K	-0.09	-0.06	-0.11	-0.03	-0.07	-0.09
Conductivity	mS/cm	21.5	10.6	9.21	15.1	2.62	1.96
DO	mg/L	-21.9	-24.8	-28.6	-20.4	-6.19	-15.3
H+	mol/L	28.2	28.8	35.5	-23.9	-20.3	-31.2
Turbidity	NTU	269	-43.9	318	420	146	111

6.3 Precision

Precision, expressed as %RSD, was calculated during periods of stable operation in the mesocosm tank. Periods of stable operation typically corresponded to times during the mesocosm test when the pump was not operating, periods when the freshwater replaced the saltwater, or other periods during which the parameter in question showed no visible change in Ocean Seven 316 measurements. Table 6-3 shows the results of these calculations and the period over which the calculations were made. No %RSD was determined for DO or turbidity because data from a period of stable operation were not available for analysis.

Table 6-3. Percent Relative Standard Deviation for GO 204 and GO 205 During Periods of Stable Operation

Parameter	Stable Time Period Start	Stable Time Period Stop	Number of Measurements	%RSD 204	%RSD 205
Temperature	9/24/02 2:30 PM	9/24/02 3:45 PM	6	0.05	0.04
Conductivity	9/24/02 4:30 PM	9/24/02 11:00 PM	27	1.08	1.07
DO	NA	NA	NA	NA	NA
pH	9/24/02 5:15 AM	9/24/02 8:45 AM	15	0.07	0.02
Turbidity	NA	NA	NA	NA	NA

The pH and temperature had the lowest %RSD, ranging between 0.02%RSD and 0.07%RSD, and conductivity was 1.08%RSD and 1.07%RSD for the two probes.

6.4 Linearity

Linearity was assessed by comparing probe readings against the reference values for each of the parameters at each deployment location. Table 6-4 gives the results of this comparison by showing the slope, intercept, and coefficient of determination (r^2) at each condition. Linear response was highest for conductivity and temperature, with slopes between 0.85 and 1.23 and r^2 values above 0.85. Correlation coefficient results during the mesocosm deployment were above 0.84 except for DO, which had r^2 values of 0.56 and 0.66.

6.5 Inter-Unit Reproducibility

Inter-unit reproducibility was assessed by comparing the relative bias of the two Ocean Seven 316s (Section 6.2), as well as by comparing the average differences between the two probe readings for each parameter at each deployment location. Figures 6-4 through 6-8 show the data used for these calculations. In terms of relative bias, the two Ocean Seven 316s exhibited close agreement for temperature, conductivity, and DO; but showed larger differences for pH (freshwater only) and turbidity (see Table 6-2). The results of average difference comparisons between the two Ocean Seven 316s are shown in Table 6-5.

The average difference in temperature readings was 0.08°C over a range of 24 to 34°C. The difference in conductivity averaged 0.04 mS/cm over a range of 0.3 to 49 mS/cm (Figures 6-5a-c). The DO difference averaged 0.55 mg/L, while the actual Ocean Seven 316 DO readings varied from 0 to 12 mg/L (Figures 6-6a-c). The average difference in pH readings was 0.12 over a range of 6.6 to 9.6 (Figures 6-7a-c). The average difference in turbidity readings was 8.96 NTU, while the actual turbidity measurement ranged from 0 to 125 NTU (Figures 6-8a-c).

The magnitude of the inter-unit reproducibility results was affected by spatial and temporal changes in the sampling environment. For example, the Ocean Seven 316s were sampling in an environment that was changing 8°C over a 24-hour period. Because they were not sampling

Table 6-4. Results of Linearity Analysis for GO 204 and GO 205

		Saltwater			Freshwater			Mesocosm		
GO	Parameter	Slope	Intercept	Coefficient of Determination	Slope	Intercept	Coefficient of Determination	Slope	Intercept	Coefficient of Determination
204	Temp	0.93	20.49	0.85	0.96	10.92	0.99	0.97	9.35	0.98
205	Temp	0.94	18.47	0.86	0.91	28.11	0.91	0.85	45.84	0.95
204	Cond	1.17	-1.59	0.92	1.23	-0.05	0.93	1.05	-0.08	0.99
205	Cond	1.17	-1.55	0.92	1.19	-0.01	0.93	1.04	-0.09	1.00
204	DO	0.16	3.15	0.06	0.67	0.33	0.66	0.97	-0.22	0.56
205	DO	0.36	1.95	0.12	0.82	-0.10	0.92	0.63	1.39	0.66
204	pH	0.94	0.00	0.55	0.26	0.00	0.53	0.62	0.00	0.88
205	pH	0.94	0.00	0.55	0.48	0.00	0.78	0.62	0.00	0.84
204	Turb	0.63	7.67	0.05	2.64	10.18	0.14	1.05	5.88	0.88
205	Turb	0.49	0.43	0.12	4.86	0.21	0.32	1.09	5.42	0.85

Table 6-5. Average Difference in GO 204 and GO 205 Readings for Each Parameter at Each Deployment Location

	Average Difference between GO 204 and GO 205				
Location	Temperature C	Conductivity (mS/cm)	DO (mg/L)	pH	Turbidity (NTU)
Saltwater	0.01	0.10	0.34	0.07	8.18
Freshwater	0.11	0.02	0.60	0.24	17.67
Mesocosm	0.13	0.01	0.71	0.06	1.02
Average	0.08	0.04	0.55	0.12	8.96

in exactly the same location, differences in temperature, caused by the 24-hour fluctuations, resulted in some differences in measurement by the Ocean Seven 316s. Similar behavior occurs in any location that experiences dynamic changes in the environment.

6.6 Other Factors

6.6.1 Ease of Use

The Ocean Seven 316s were set up to collect data with minimal difficulty, and data were downloaded without incident using the provided data cable and a PC. The Ocean Seven 316 operators during this verification test included individuals with and without a college education, all of whom had some experience working with monitoring equipment. The monitors were transported to and from the testing sites in a five-gallon bucket, wrapped in wet towels. Battery replacement was necessary every time the Ocean Seven 316s were brought to the lab for the calibration check interval despite the fact that the Ocean Seven 316s were operating in sleep mode between samples to conserve power.

6.6.2 Costs

At the time of testing, the Ocean Seven 316, as verified, cost $15,000 per unit.

6.6.3 Data Completeness

All portions of the verification test were completed; however, because one period of low battery power resulted in no data being collected on one probe, one day out of a total of 62 sampling days resulted in no data collection. Therefore, data completeness was approximately 98%.

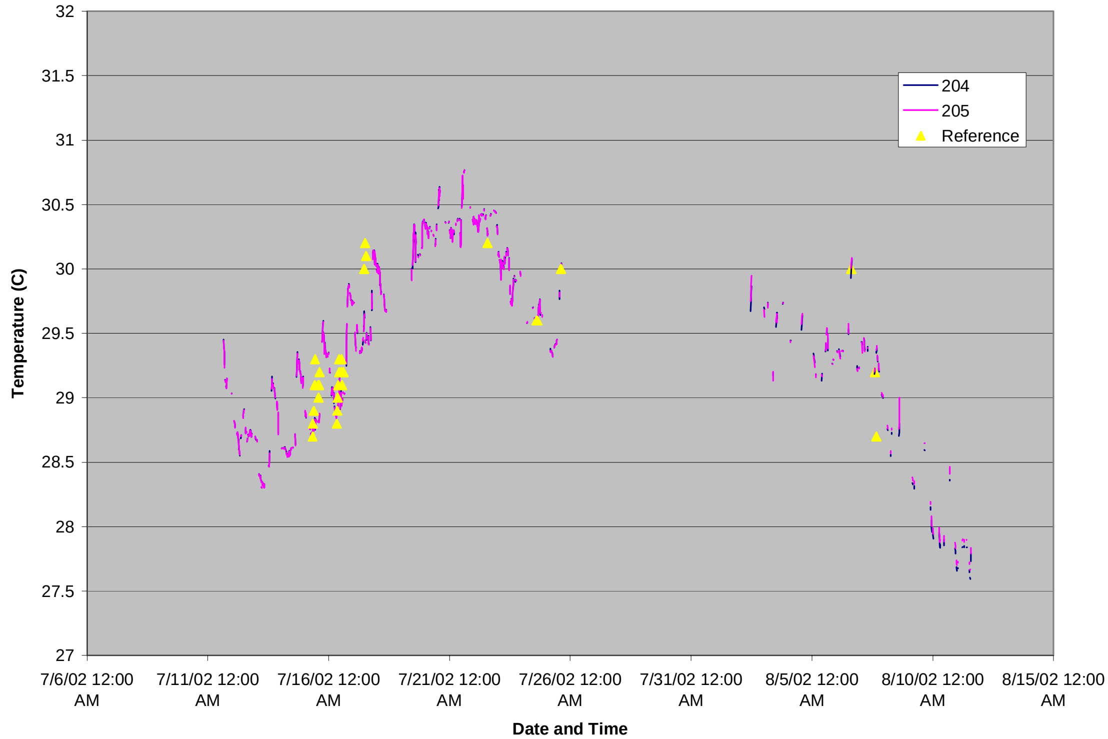

Figure 6-4a. Inter-Unit Reproducibility Data for Temperature During Saltwater Tests

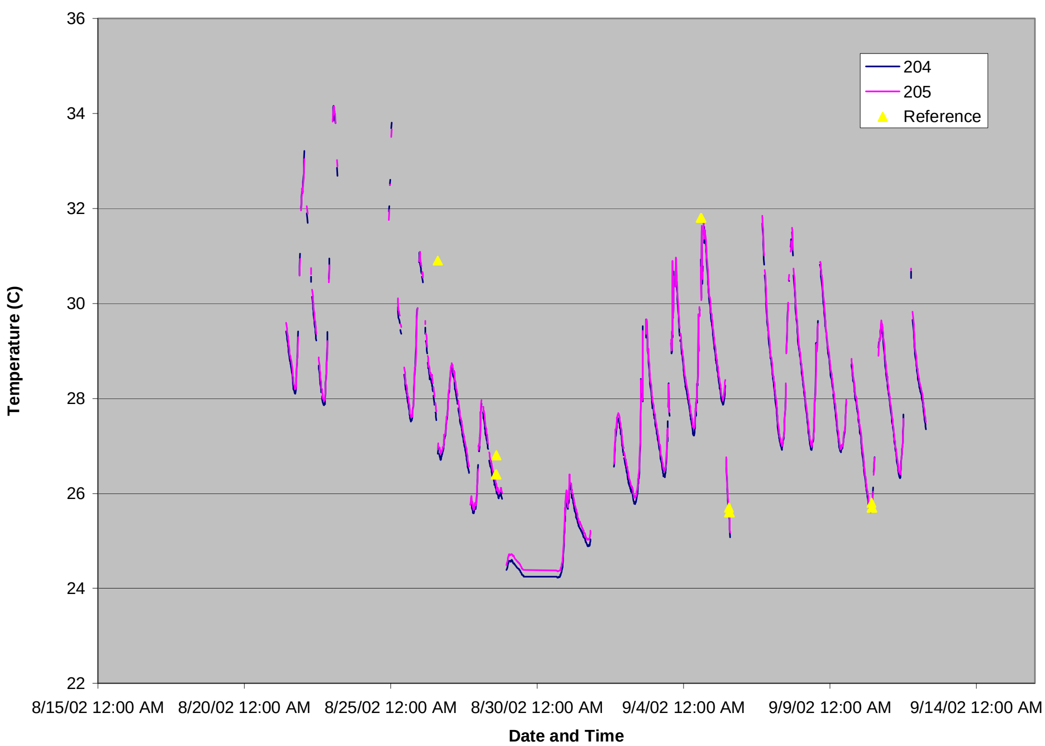

Figure 6-4b. Inter-Unit Reproducibility Data for Temperature During Freshwater Tests

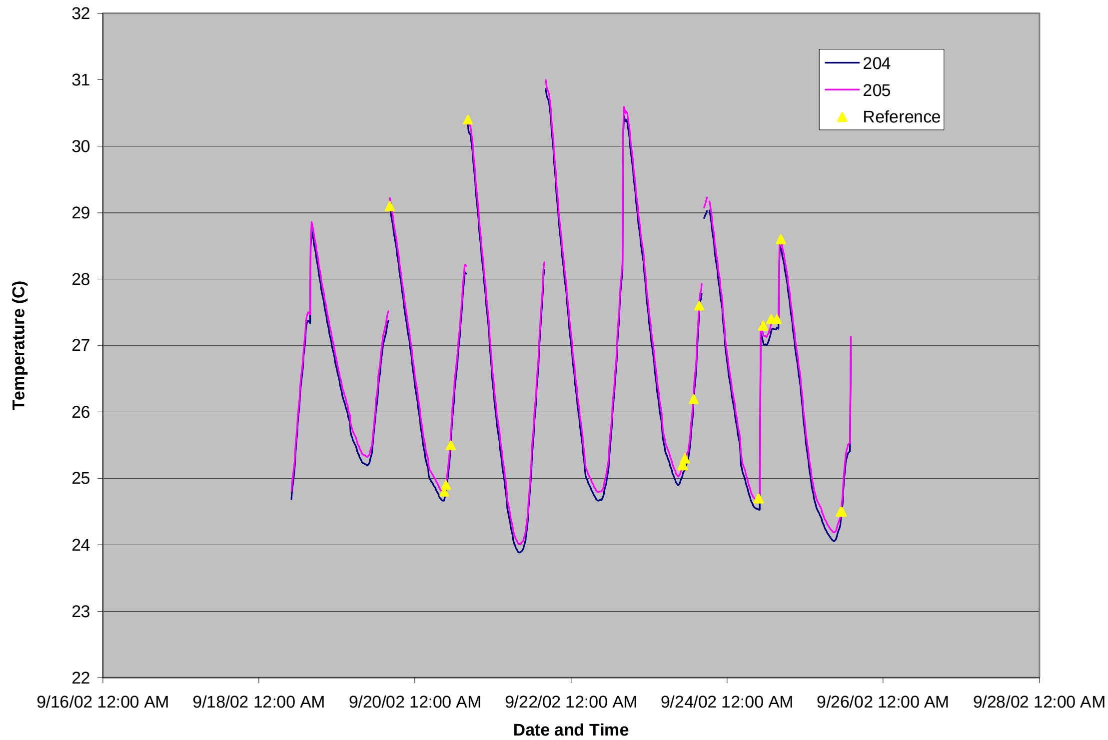

Figure 6-4c. Inter-Unit Reproducibility Data for Temperature During Mesocosm Tests

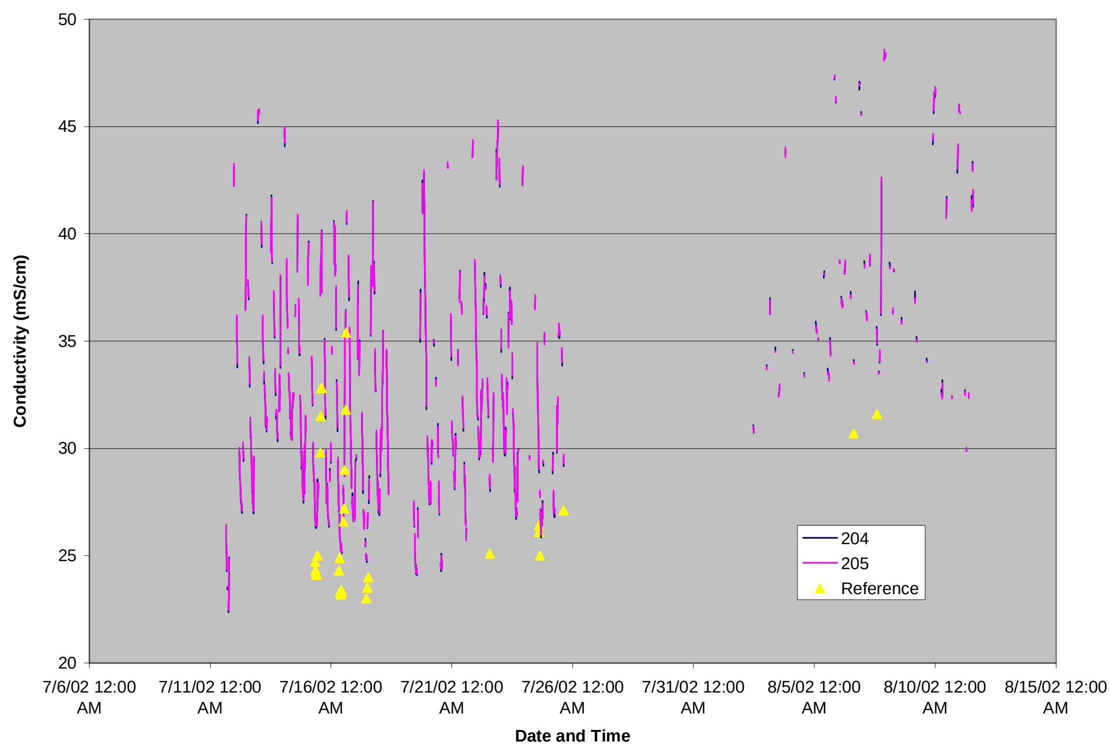

Figure 6-5a. Inter-Unit Reproducibility Data for Conductivity During Saltwater Tests

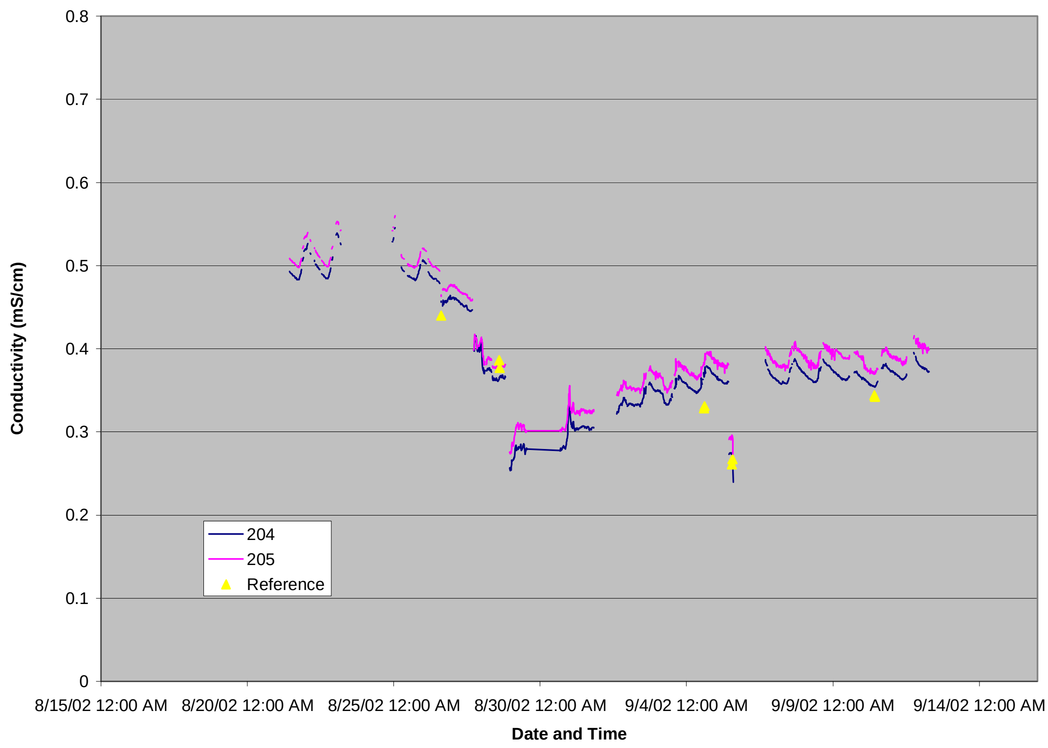

Figure 6-5b. Inter-Unit Reproducibility Data for Conductivity During Freshwater Tests

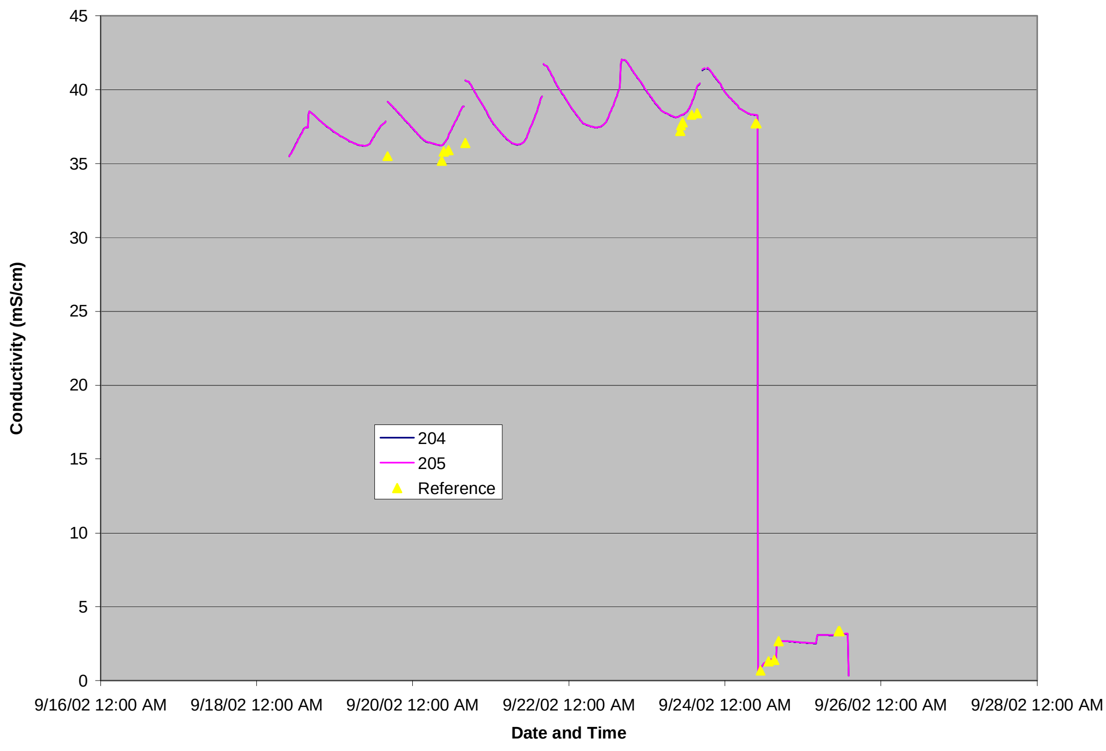

Figure 6-5c. Inter-Unit Reproducibility Data for Conductivity During Mesocosm Tests

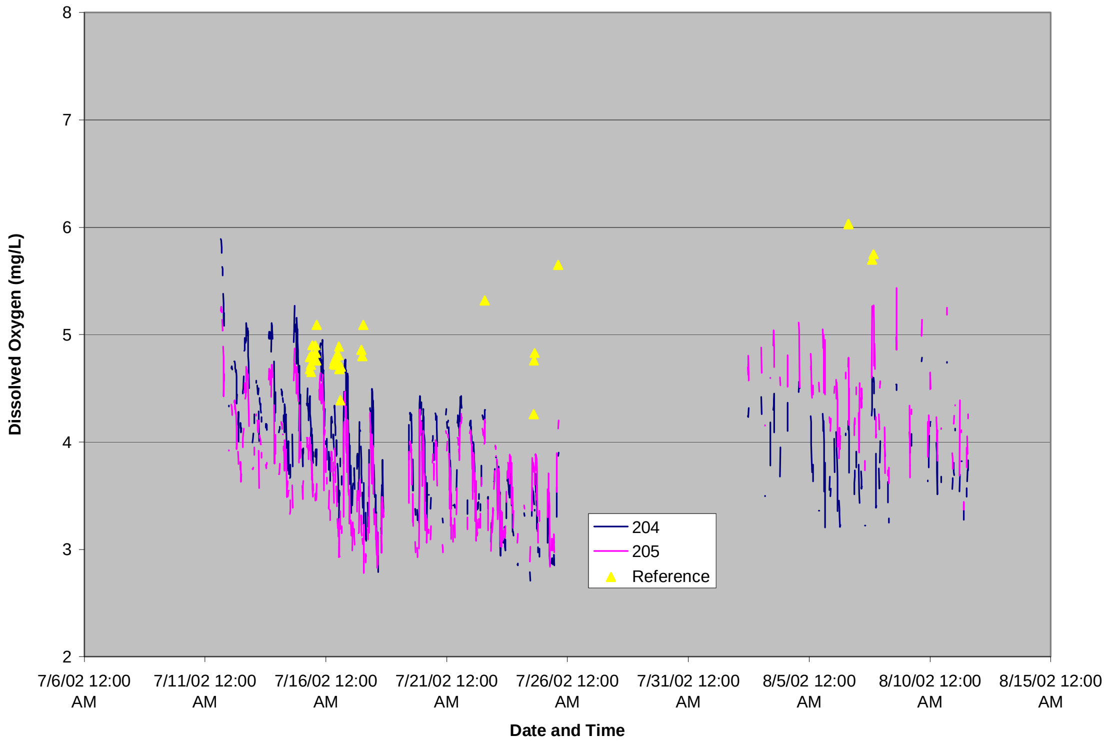

Figure 6-6a. Inter-Unit Reproducibility Data for Dissolved Oxygen During Saltwater Tests

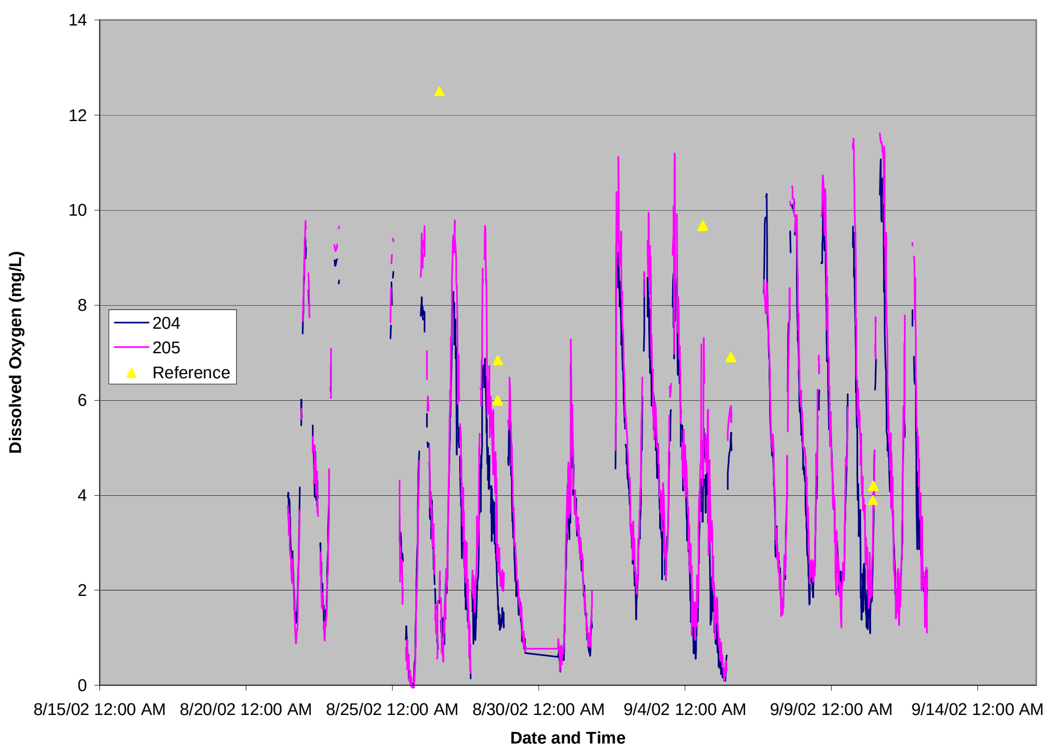

Figure 6-6b. Inter-Unit Reproducibility Data for Dissolved Oxygen During Freshwater Tests

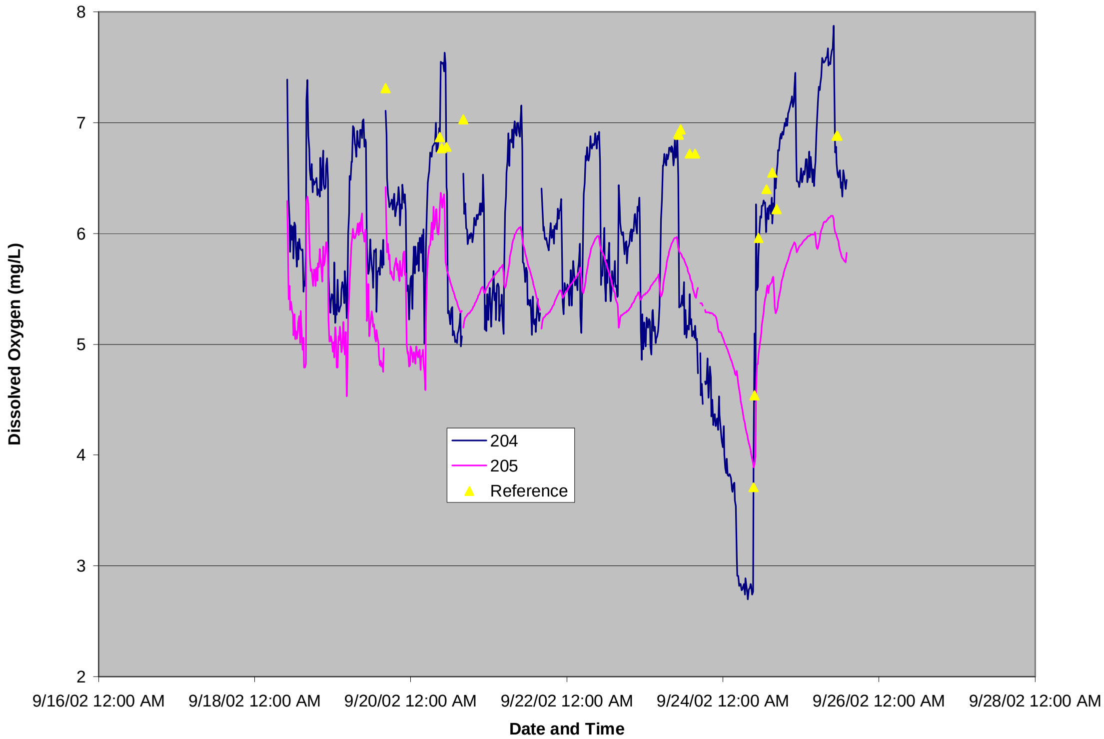

Figure 6-6c. Inter-Unit Reproducibility Data for Dissolved Oxygen During Mesocosm Tests

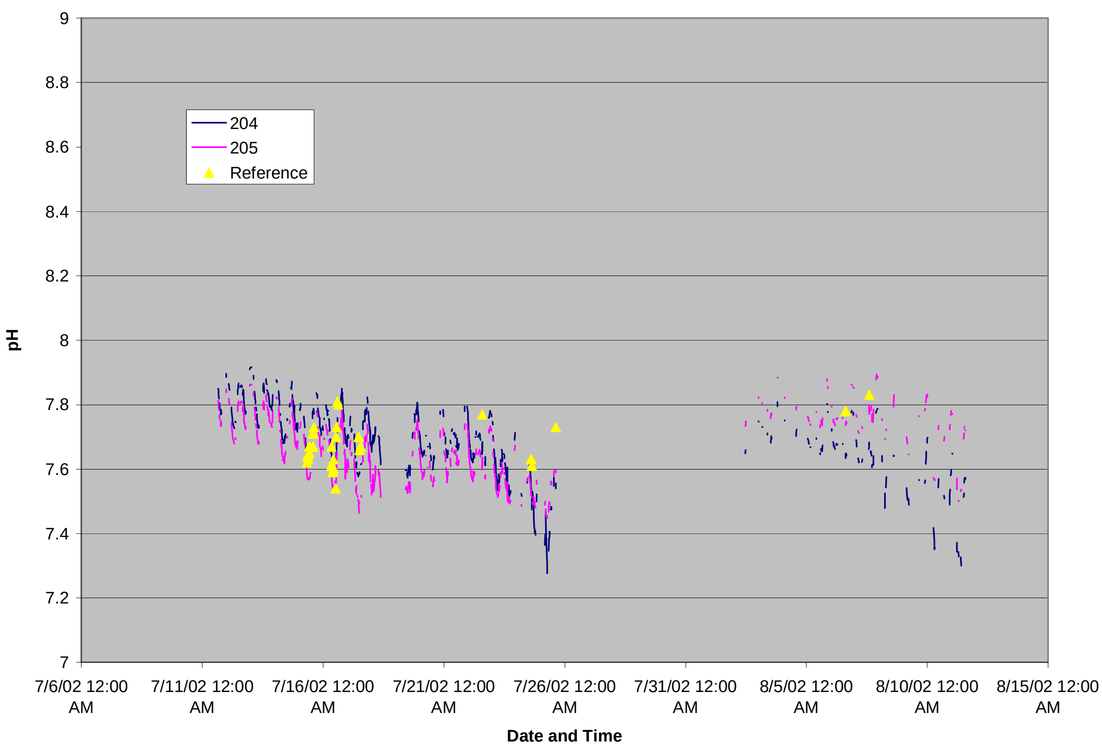

Figure 6-7a. Inter-Unit Reproducibility Data for pH During Saltwater Tests

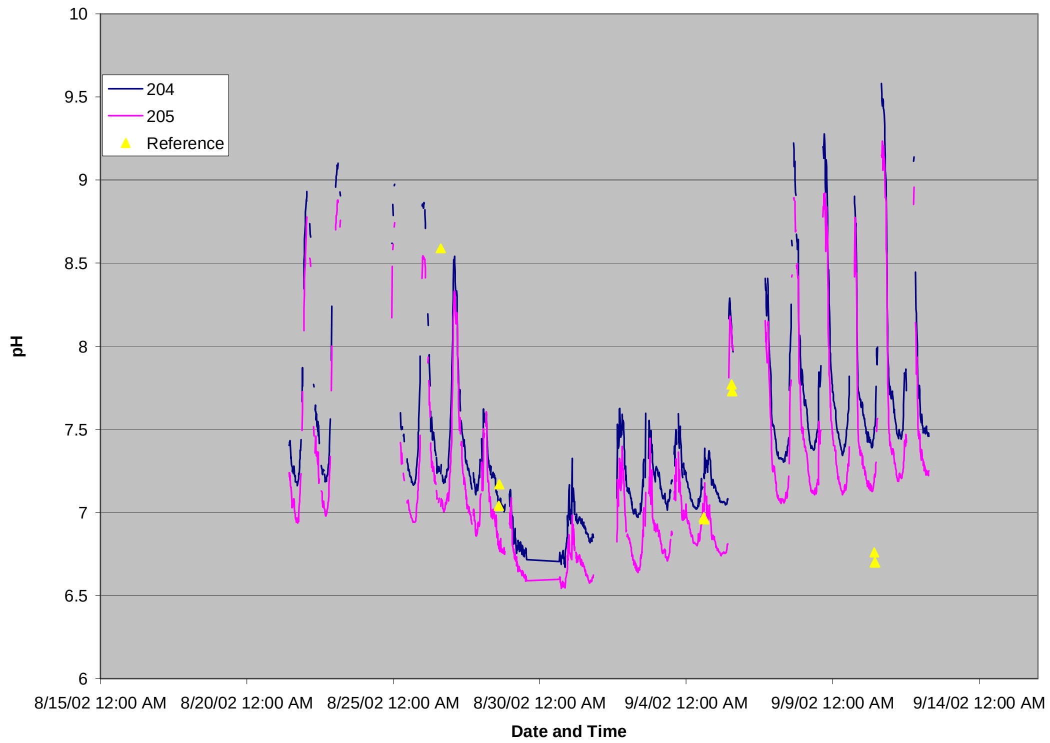

Figure 6-7b. Inter-Unit Reproducibility Data for pH During Freshwater Tests

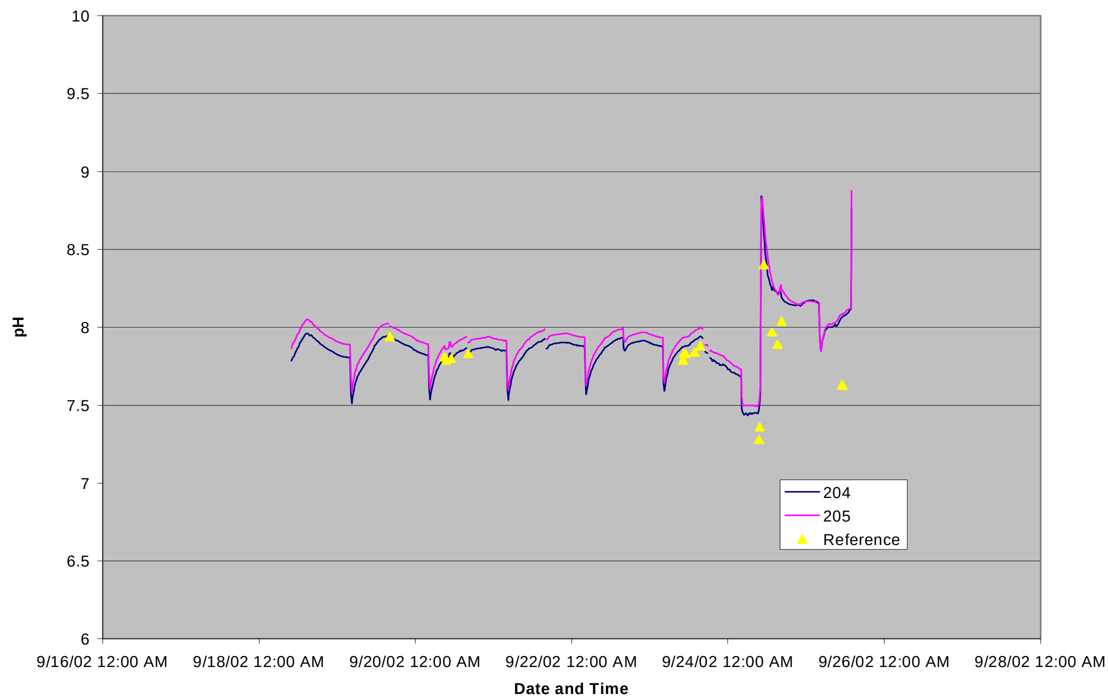

Figure 6-7c. Inter-Unit Reproducibility Data for pH During Mesocosm Tests

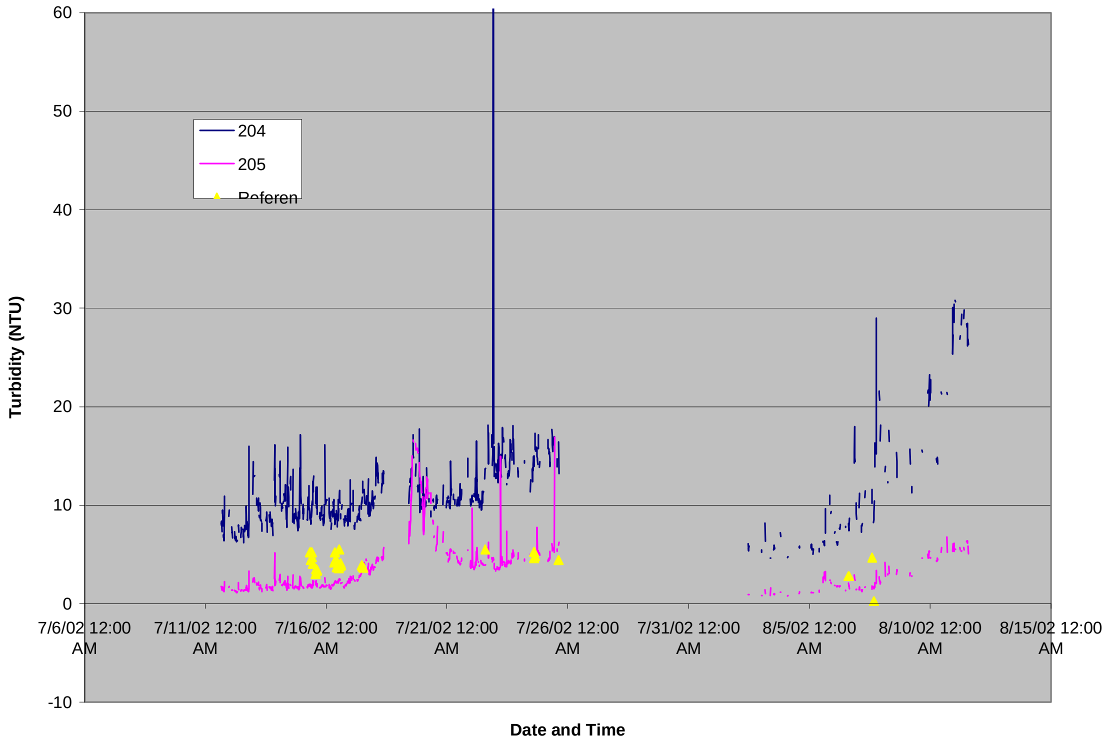

Figure 6-8a. Inter-Unit Reproducibility Data for Turbidity During Saltwater Tests

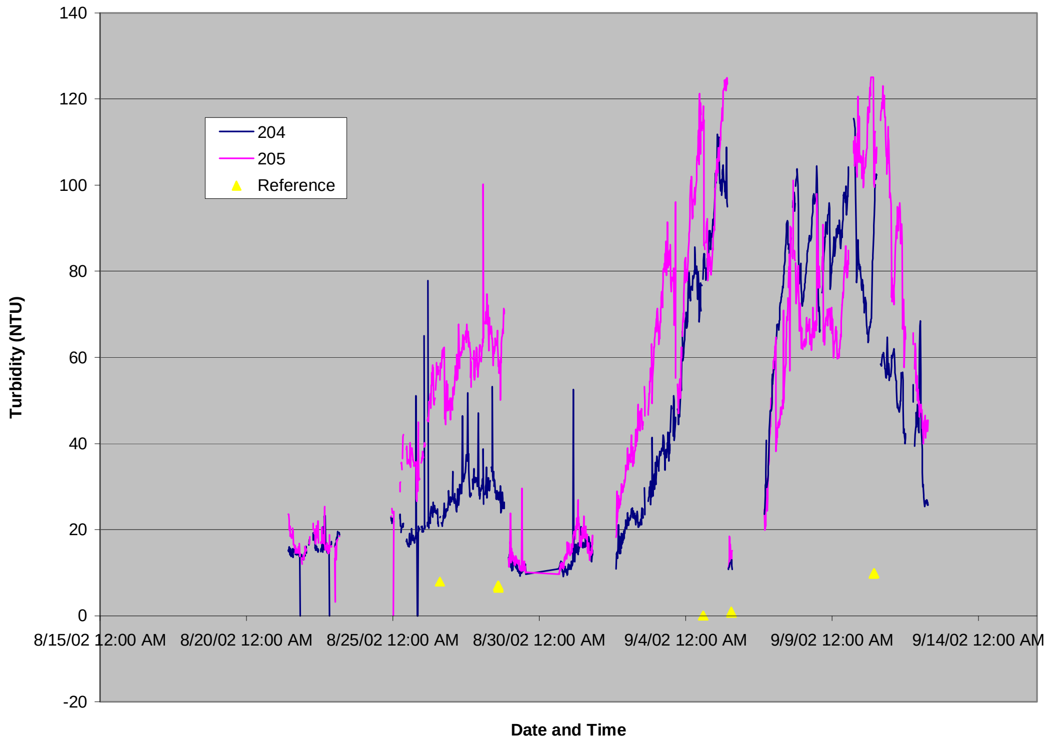

Figure 6-8b. Inter-Unit Reproducibility Data for Turbidity During Freshwater Tests

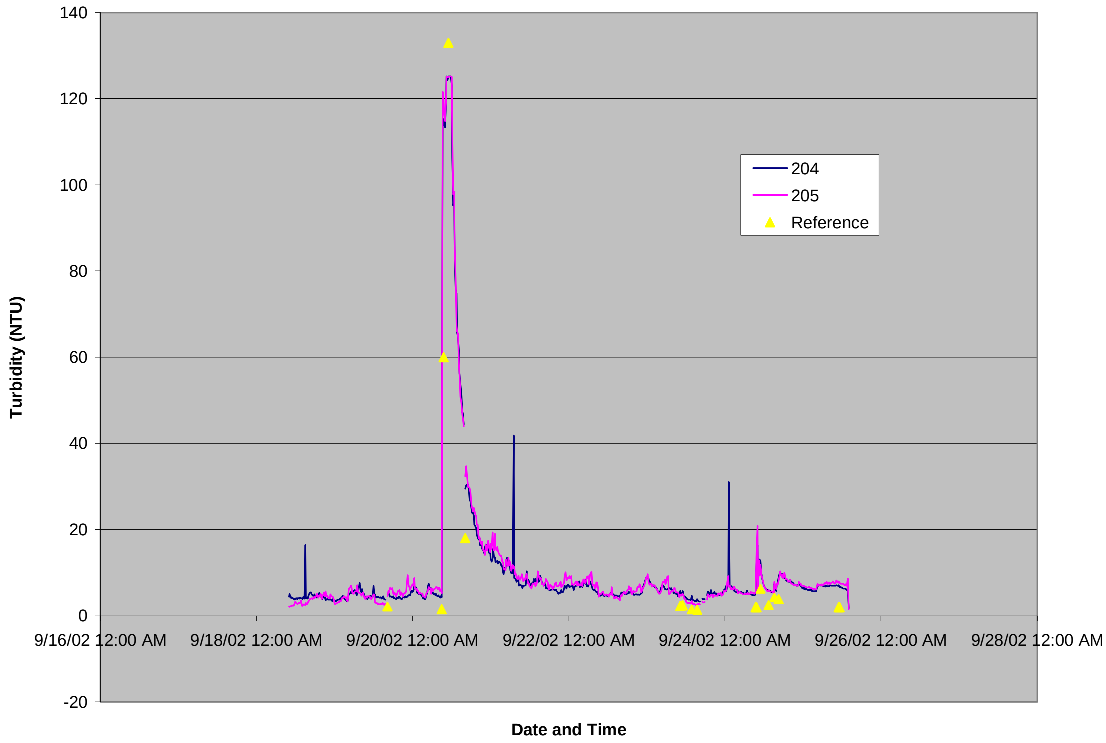

Figure 6-8c. Inter-Unit Reproducibility Data for Turbidity During Mesocosm Tests

Chapter 7
Performance Summary

Pre-and post-calibration tests showed that pH measurement values were accurate within a range of 99 to 108% of the true values. Except for the first result of 73%, the remaining DO measurement values were accurate within a range of 82 to 105% of the true values. Conductivity measurement values were accurate within a range of 94 to 104% of the true values. No modifications were made to the probes (calibration adjustments, maintenance, etc.) during the testing.

The temperature biases were less than or equal to 0.11% for all deployment settings. Conductivity, pH (reported as H+ concentration), and DO biases were between approximately 2 and 36% for both units under all deployment settings. The conductivity bias was consistently positive, indicating that generally, the Ocean Seven 316 probes reported a higher conductivity than the handheld reference probe. The DO bias was consistently negative for each deployment setting. The bias for turbidity ranged between approximately -44% and 420%.

Percent RSD was lowest for the pH and temperature, ranging between 0.02%RSD and 0.07%RSD. Precision for conductivity was 1.08%RSD and 1.07%RSD for the two Ocean Seven 316s. DO and turbidity precision estimates were not determined.

The linear response for the Ocean Seven 316, expressed in terms of slope, intercept, and coefficient of determination at each condition, was highest for conductivity and temperature.

Analysis of inter-unit reproducibility, relative bias of the Ocean Seven 316s exhibited close agreement for temperature, conductivity, and DO; but showed larger differences for pH (freshwater only) and turbidity. The average difference in temperature readings between the two Ocean Seven 316s was 0.08°C over a range of 24 to 34°C. The difference in conductivity averaged 0.04 mS/cm over a range of 0.3 to 49 mS/cm. The average difference in readings for DO was 0.55 mg/L, while the actual Ocean Seven 316 DO readings varied from 0 to 12 mg/L. The average difference in pH readings was 0.12 over a range of 6.6 to 9.6. The average difference in turbidity readings was 8.96 NTU, while the actual turbidity measurement ranged from 0 to 125 NTU.

The magnitude of the inter-unit reproducibility results was affected by spatial and temporal changes in the sampling environment. For example, the Ocean Seven 316s were sampling in an environment that was changing 8°C over a 24-hour period. Because the Ocean Seven 316s were not sampling in exactly the same location, differences in temperature, caused by the 24-hour fluctuations, resulted in some difference in measurement by the Ocean Seven 316s. Similar behavior occurs in any location that experiences dynamic changes in the environment.

The probes were set up to collect data with minimal difficulty, and data were downloaded without incident using the provided data cable and a Windows-based PC. Battery replacement was necessary every time the probes were brought to the lab for the calibration check interval despite the fact that the probes were operating in sleep mode between samples to conserve power. The Ocean Seven 316 verified in this test cost $15,000 per unit.

Chapter 8
References

1. *Test/QA Plan for Long-Term Deployment of Multi-Parameter Water Quality Probes/Sondes*, Battelle, Columbus, Ohio, Version 2.0, May 2002.

2. *Quality Management Plan (QMP) for the ETV Advanced Monitoring Systems Center*, Version 3.0, U.S. EPA Environmental Technology Verification Program, Battelle, Columbus, Ohio, December 2001.

Appendix A
Reference Sample and Probe Readings

m/d/y hh:mm	GO 204 Temp C	GO 204 Cond. mS/cm	GO 204 DO mg/L	GO 204 pH	GO 204 Turb. NTU	GO 205 Temp C	GO 205 Cond. mS/cm	GO 205 DO mg/L	GO 205 pH	GO 205 Turb. NTU	Reference Temp C	Reference Cond. mS/cm	Reference DO mg/L	Reference pH	Reference Turb. NTU
7/15/02 8:00 AM	28.583	27.97	4.41	7.65	9.35	28.574	27.94	3.99	7.60	1.9	28.550	24.7	4.68	7.62	5.2
7/15/02 8:30 AM	28.598	26.77	4.37	7.63	8.48	28.594	26.72	3.99	7.57	1.85	28.650	24.3	4.79	7.64	5.2
7/15/02 9:00 AM	28.631	26.34	4.22	7.63	8.08	28.617	26.45	3.98	7.57	1.7	28.750	24.2	4.72	7.63	4.4
7/15/02 9:30 AM	28.664	26.29	4.11	7.63	8.78	28.638	26.42	3.86	7.57	1.58	28.750	24.1	4.65	7.64	5.2
7/15/02 10:00 AM	28.673	26.37	4.13	7.63	9.73	28.67	26.43	3.83	7.57	1.6	28.950	24.1	4.81	7.67	4.7
7/15/02 10:30 AM	28.697	26.5	4.07	7.63	10.4	28.686	26.43	3.81	7.57	1.6	29.150	25	4.9	7.65	4
7/15/02 1:00 PM	28.672	35.53	3.81	7.73	13.6	28.678	35.49	3.4	7.68	2.75	29.050	30.7	6.18	7.69	4
7/15/02 1:30 PM	28.671	35.32	3.86	7.74	10.2	28.673	35.56	3.45	7.68	1.75	28.950	29.8	4.9	7.71	3
7/15/02 2:00 PM	28.663	38.74	3.9	7.78	11.8	28.662	38.7	3.52	7.72	2.33	28.850	31.5	4.83	7.67	3.5
7/15/02 2:30 PM	28.669	39.07	3.88	7.79	10.7	28.671	39.13	3.48	7.73	1.85	28.950	32.8	4.76	7.71	3.3
7/15/02 3:00 PM	28.663	40.16	3.78	7.79	11.8	28.658	40.1	3.46	7.73	2.03	29.050	32.8	5.09	7.73	3.4
7/15/02 3:30 PM	28.874	34.95	4.03	7.76	11.5	28.874	35.32	3.62	7.71	1.58	29.150	30.5	5.22	7.78	3.1
7/15/02 4:00 PM	28.731	39.17	3.9	7.77	9.28	28.741	38.94	3.53	7.72	1.8	29.150	34.2	5.19	7.78	3.4
7/15/02 4:30 PM	28.832	38.32	3.91	7.78	8.83	28.87	38.06	3.68	7.72	1.58	29.050	35	5.04	7.8	4.5
7/15/02 5:00 PM	28.926	37.89	4	7.78	7.88	28.9	38.17	3.68	7.72	1.65	29.250	34.3	5.32	7.73	4.4
7/15/02 5:15 PM	28.967	37.5	4.24	7.79	8.83	28.97	37.81	3.8	7.73	1.63	29.250	33.3	5.72	7.83	3.8
7/16/02 8:00 AM	28.701	27.55	4.02	7.66	9.35	28.694	27.6	3.64	7.59	1.9	28.650	24.3	4.73	7.61	4.2
7/16/02 8:15 AM	28.729	27.01	3.93	7.65	8.65	28.722	27.11	3.43	7.58	2.13	28.650	23.9	4.78	7.6	4.1
7/16/02 8:30 AM	28.738	26.98	4.16	7.66	10.5	28.74	27.53	3.77	7.61	2.98	28.750	24.9	4.76	7.67	5.2
7/16/02 9:00 AM	28.755	26.25	4.34	7.63	8.03	28.746	26.35	3.94	7.57	2.15	28.850	23.3	4.75	7.61	4.4
7/16/02 9:30 AM	28.778	25.5	4.18	7.6	8.63	28.77	25.46	3.73	7.55	2.35	28.950	23.2	4.72	7.59	4.5
7/16/02 10:00 AM	28.819	25.32	4.07	7.6	8.53	28.837	25.21	3.62	7.55	2.13	28.950	23.4	4.8	7.64	4.4
7/16/02 10:15 AM	28.805	25.47	3.86	7.6	9.55	28.8	25.71	3.49	7.54	2.33	29.050	23.4	4.8	7.63	4.4
7/16/02 10:30 AM	28.858	25.4	3.87	7.61	9.45	28.852	25.6	3.54	7.55	2.1	29.150	23.3	4.76	7.6	3.7
7/16/02 12:30 PM	28.916	26.66	3.62	7.62	8.43	28.894	26.61	3.19	7.55	2.1	29.050	26.6	4.81	7.54	3.6
7/16/02 12:45 PM	28.800	28.16	3.44	7.63	9.65	28.798	28.26	3.12	7.56	2.43	29.050	27.4	4.81	7.67	5.1
7/16/02 1:00 PM	28.784	29.15	3.31	7.63	11.4	28.783	29.64	2.97	7.56	2.7	29.150	27.2	4.89	7.7	5.5
7/16/02 1:30 PM	28.845	28.7	3.55	7.67	11.5	28.845	28.71	3.29	7.60	2.5	28.950	29	4.68	7.73	3.8
7/16/02 2:00 PM	28.841	35.32	3.53	7.73	10.2	28.841	35.38	2.93	7.65	2.43	29.050	34.3	4.37	7.82	6.1

	GO 204					GO 205					Reference				
m/d/y hh:mm	Temp C	Cond. mS/cm	DO mg/L	pH	Turb. NTU	Temp C	Cond. mS/cm	DO mg/L	pH	Turb. NTU	Temp C	Cond. mS/cm	DO mg/L	pH	Turb. NTU
7/17/02 11:15 AM	29.411	24.85	3.83	7.58	9.98	29.399	24.96	3.23	7.50	3.2	29.850	23	4.86	7.7	3.9
7/17/02 12:00 PM	29.473	24.8	3.62	7.59	10.8	29.499	24.81	3.13	7.47	3.4	30.050	23.5	4.8	7.66	3.75
7/17/02 1:00 PM	29.335	27.61	3.33	7.6	11.6	29.409	26.64	2.98	7.48	3.75	29.950	24	5.09	7.67	3.65
7/22/02 2:00 PM	30.141	28.31	4.03	7.65	13.7	30.138	28.38	4	7.60	3.9	30.050	25.1	5.32	7.77	5.49
7/22/02 2:30 PM	30.123	28	4.3	7.66	13.7	30.121	28.14	4.18	7.61	3.95	30.150	24	5.09	7.67	4.54
7/24/02 2:30 PM	29.474	30.16	3.5	7.57	14	29.471	30.34	3.78	7.53	4.7	29.450	26.4	4.26	7.63	5.27
7/24/02 2:45 PM	29.447	29.14	3.47	7.55	14.4	29.448	29.31	3.73	7.52	4.85	29.450	26.1	4.76	7.63	4.62
7/24/02 3:30 PM	29.431	27.9	3.36	7.51	15.6	29.433	28.05	3.77	7.51	4.33	29.450	25	4.83	7.61	4.8
7/25/02 2:15 PM	29.795	31.98	4.08	7.62	13.2	29.771	32.35	4.28	7.63	5.75	29.850	28.6	5.78	7.76	5.21
7/25/02 3:00 PM	29.821	30.21	3.96	7.58	15.1	29.818	30.51	4.21	7.60	6	29.850	27.1	5.65	7.73	4.43
8/6/02 2:45 PM	29.761	33.7	4.21	7.64	7.98	29.745	33.53	4.54	7.72	1.85	29.850	30.6	2.98	7.75	3.72
8/6/02 3:00 PM	29.768	33.71	4.09	7.63	7.5	29.744	34.2	4.38	7.72	2.15	29.850	30.7	6.03	7.78	2.8
8/7/02 2:30 PM	29.052	35.36	4.31	7.67	10.9	29.08	35.29	5.22	7.80	1.7	29.050	31.6	5.7	7.83	4.67
8/7/02 3:00 PM	29.076	34.88	4.6	7.67	9.53	29.084	34.63	5.26	7.77	1.55	29.150	31.2	5.74	7.88	3.14
8/7/02 3:30 PM	29.131	34.11	4.6	7.66	8.15	29.156	33.81	5.26	7.76	1.45	29.250	30.3	5.87	7.84	3.11
8/12/02 2:00 PM	27.561	44.84	3.55	7.48	36.7	27.538	42.96	3.85	7.66	4.03	28.150	40.2	5.1	7.82	11.5
8/12/02 2:30 PM	27.561	44.84	3.55	7.48	36.7	27.744	40.61	4.03	7.65	3.85	28.550	36.6	5.33	7.76	6.6
8/12/02 3:15 PM	27.561	44.84	3.55	7.48	36.7	27.76	41.69	3.66	7.65	3.88	28.050	38.1	5.05	7.77	8.7
8/12/02 3:30 PM	27.561	44.84	3.55	7.48	36.7	27.831	40.94	3.85	7.66	3.2	28.250	36.3	5.34	7.8	6.1
8/12/02 3:45 PM	27.561	44.84	3.55	7.48	36.7	28.086	39.77	4.36	7.66	2.85	28.350	35.5	5.53	7.8	7.5
8/12/02 4:00 PM	27.561	44.84	3.55	7.48	36.7	28.224	38.76	4.63	7.67	3.05	28.350	34.3	5.62	7.81	6.9
8/12/02 4:15 PM	27.561	44.84	3.55	7.48	36.7	28.345	37.46	4.86	7.67	3.03	28.450	33.4	5.59	7.8	6.7
8/13/02 8:00 AM	27.561	44.84	3.55	7.48	36.7	27.78	27.97	3.9	7.43	2.8	27.750	25.4	4.52	7.57	5.31
8/13/02 8:15 AM	27.561	44.84	3.55	7.48	36.7	27.782	27.43	3.83	7.42	2.8	27.750	24.9	4.57	7.57	5.14
8/13/02 8:30 AM	27.561	44.84	3.55	7.48	36.7	27.784	27.14	3.59	7.40	2.8	27.850	24.9	4.58	7.54	5.23
8/13/02 8:45 AM	27.561	44.84	3.55	7.48	36.7	27.792	27.04	3.5	7.41	2.9	27.850	25.1	4.58	7.55	5.81
8/13/02 9:15 AM	27.561	44.84	3.55	7.48	36.7	27.766	27.49	3.61	7.40	3	27.950	25.3	4.76	7.57	4.47

	GO 204					GO 205					Reference				
m/d/y hh:mm	Temp C	Cond. mS/cm	DO mg/L	pH	Turb. NTU	Temp C	Cond. mS/cm	DO mg/L	pH	Turb. NTU	Temp C	Cond. mS/cm	DO mg/L	pH	Turb. NTU
8/13/02 1:00 PM	27.561	44.84	3.55	7.48	36.7	27.778	35.64	3.34	7.44	2.8	27.850	31.7	4.54	7.63	5.1
8/13/02 1:15 PM	27.561	44.84	3.55	7.48	36.7	27.771	37.1	3.41	7.49	2.6	27.850	35.1	4.52	7.69	6.6
8/13/02 1:30 PM	27.561	44.84	3.55	7.48	36.7	27.745	39.45	3.23	7.51	2.6	27.850	35.8	4.56	7.71	6
8/13/02 1:45 PM	27.561	44.84	3.55	7.48	36.7	27.755	38.9	3.62	7.54	2.6	27.850	35.6	4.58	7.71	6.3
8/13/02 2:15 PM	27.561	44.84	3.55	7.48	36.7	27.728	40.26	3.55	7.55	2.53	27.850	36.7	4.52	7.67	7
8/13/02 2:30 PM	27.561	44.84	3.55	7.48	36.7	27.721	40.56	3.52	7.56	2.6	27.850	37.6	4.44	7.72	5.5
8/13/02 2:45 PM	27.561	44.84	3.55	7.48	36.7	27.706	41.3	3.56	7.58	2.6	27.850	38.1	4.48	7.74	8.1
8/13/02 3:00 PM	27.561	44.84	3.55	7.48	36.7	27.706	41.3	3.56	7.58	2.6	27.850	38.6	4.55	7.74	7.25
8/23/02 8:30 AM	27.700	0.485	1.32	7.21	15.8	27.794	0.499	1.3	7.01	16.3	27.750	0.456	1.97	6.84	8.02
8/23/02 8:45 AM	27.744	0.484	1.59	7.22	16.2	27.819	0.499	1.38	7.02	15.5	27.350	0.453	1.98	6.78	9.2
8/23/02 9:00 AM	27.740	0.484	1.53	7.22	15.4	27.828	0.499	1.5	7.02	16.9	27.850	0.456	2.51	6.82	8.19
8/23/02 9:15 AM	27.726	0.485	1.61	7.22	14.8	27.907	0.5	1.52	7.05	15.6	27.950	0.449	2.04	6.78	8.45
8/23/02 9:30 AM	27.833	0.486	1.72	7.25	14.8	27.979	0.501	1.79	7.06	15	28.150	0.454	3.1	6.9	8.54
8/23/02 9:45 AM	27.955	0.487	2.12	7.26	14.6	28.054	0.501	2.15	7.07	15.1	28.050	0.451	2.73	6.89	7.59
8/23/02 10:00 AM	28.166	0.489	2.36	7.29	15.5	28.317	0.503	2.31	7.10	14.6	28.450	0.453	3.88	6.94	7.17
8/23/02 10:15 AM	28.257	0.49	2.68	7.29	14.8	28.389	0.505	2.41	7.17	16.2	28.450	0.452	3.25	7.01	6.9
8/23/02 1:30 PM	31.529	0.515	7.6	8.55	19.1	31.61	0.53	8.87	8.40	19.6	31.750	0.449	10.3	8.33	7.1
8/23/02 1:45 PM	31.831	0.517	8.87	8.64	15.2	31.964	0.532	8.91	8.50	16.9	32.650	0.447	10.1	8.41	8.63
8/23/02 2:00 PM	32.118	0.519	8.9	8.73	14.9	32.167	0.534	8.87	8.50	16.1	32.550	0.448	10.7	8.3	6.66
8/23/02 2:15 PM	32.538	0.523	8.74	8.74	14.9	32.476	0.537	9.13	8.48	9.33	32.950	0.447	10.7	8.43	6.88
8/23/02 2:30 PM	33.017	0.528	8.8	8.73	15.5	32.814	0.54	9.64	8.51	17.6	32.950	0.447	10.9	8.28	7.13
8/23/02 2:45 PM	33.253	0.532	8.6	8.77	15.7	33.173	0.545	9.48	8.54	15.3	33.250	0.446	11.4	8.39	6.48
8/23/02 3:00 PM	33.349	0.533	8.82	8.82	15.6	33.305	0.546	9.43	8.59	15.3	33.550	0.449	12.1	8.38	8.11
8/23/02 3:15 PM	33.570	0.534	9	8.92	15.1	33.42	0.548	9.38	8.65	16.1	33.450	0.448	11.7	8.42	6.78
8/26/02 2:00 PM	28.257	0.484	3.62	7.48	23	30.576	0.521	7.54	8.10	33.9	30.650	0.44	11.5	8.49	7
8/26/02 2:15 PM	28.257	0.484	3.62	7.48	23	30.597	0.521	8.12	8.19	34.9	30.650	0.447	11.8	8.37	7.3
8/26/02 2:30 PM	28.257	0.484	3.62	7.48	23	30.735	0.521	8.59	8.41	35.5	30.750	0.442	12.3	8.57	8.1

	GO 204					GO 205					Reference				
	Temp	**Cond.**	**DO**		**Turb.**	**Temp**	**Cond.**	**DO**		**Turb.**	**Temp**	**Cond.**	**DO**		**Turb.**
m/d/y hh:mm	**C**	**mS/cm**	**mg/L**	**pH**	**NTU**	**C**	**mS/cm**	**mg/L**	**pH**	**NTU**	**C**	**mS/cm**	**mg/L**	**pH**	**NTU**
9/5/02 1:15 PM	25.503	0.273	4.97	8.12	12.5	25.596	0.292	5.83	8.10	13.6	25.550	0.261	6.91	7.77	0.95
9/5/02 1:30 PM	25.420	0.273	5.06	8.08	12.6	25.516	0.296	5.84	8.07	12.1	25.450	0.267	6.9	7.73	0.77
9/9/02 1:45 PM	27.787	0.366	6.12	7.82	104	27.829	0.392	5.85	7.40	84.8	27.850	0.341	8.37	7.2	10.5
9/9/02 2:00 PM	27.787	0.366	6.12	7.82	104	27.829	0.392	5.85	7.40	84.8	27.850	0.341	9.2	7.55	10
9/9/02 2:15 PM	27.909	0.368	8.02	8.25	104	27.977	0.393	8.46	7.75	86	27.850	0.342	9.86	7.48	10.5
9/10/02 10:00 AM	25.481	0.355	2.47	7.48	86.3	25.545	0.371	2.75	7.18	125	25.550	0.343	3.35	6.66	9.8
9/10/02 10:15 AM	25.481	0.355	2.47	7.48	86.3	25.545	0.371	2.75	7.18	125	25.650	0.344	3.9	6.76	9.7
9/10/02 10:30 AM	25.546	0.354	3.13	7.52	90.6	25.578	0.371	4.05	7.23	100	25.550	0.342	4.2	6.7	9.85
9/12/02 10:30 AM	27.547	0.373	5.97	7.88	35.5	27.582	0.402	6.41	7.64	61.8	27.550	0.349	7.1	7.07	15
9/12/02 10:45 AM	27.688	0.374	6.3	7.96	35.8	27.601	0.401	6.9	7.67	60.5	27.550	0.348	6.9	7.17	12.7
9/12/02 11:00 AM	27.688	0.374	6.3	7.96	35.8	27.601	0.401	6.9	7.67	60.5	28.050	0.348	8.89	7.32	13.7
9/12/02 11:15 AM	28.109	0.378	7.6	8.22	35.6	28.064	0.404	8.06	7.86	59.6	28.050	0.351	8.45	7.42	16.2
9/12/02 1:45 PM	29.442	0.388	8.84	8.91	42.5	29.41	0.414	9.27	8.45	68	29.750	0.349	12.6	8.53	11
9/12/02 2:00 PM	29.442	0.388	8.84	8.91	42.5	29.41	0.414	9.27	8.45	68	29.450	0.35	11	7.84	12.6
9/12/02 2:15 PM	29.391	0.387	8.97	9.04	40.5	29.45	0.414	10.1	8.75	70.4	29.650	0.349	11.2	8.33	13.7
9/12/02 2:30 PM	29.555	0.388	9.78	9.22	42.2	29.253	0.413	9.98	8.51	67.3	29.450	0.349	10.9	8.62	16.9
9/12/02 2:45 PM	29.555	0.388	9.78	9.22	42.2	29.253	0.413	9.98	8.51	67.3	29.950	0.346	13.4	8.88	18.8
9/12/02 3:00 PM	29.707	0.388	10.3	9.43	43	29.921	0.415	11	9.21	74.5	29.750	0.348	12.4	8.78	14.7
9/12/02 3:15 PM	29.712	0.389	10.3	9.41	41	29.736	0.411	11.1	9.18	75.1	29.850	0.347	12.3	8.75	12.6
9/12/02 3:30 PM	29.712	0.389	10.3	9.41	41	29.736	0.411	11.1	9.18	75.1	29.550	0.348	11.1	8.65	15.6
9/19/02 4:00 PM	28.585	38.86	7.28	7.94	5.05	27.364	37.85	4.96	8.03	2.5	28.650	35.3	7.34	7.97	1.59
9/19/02 4:15 PM	28.585	38.86	7.28	7.94	5.05	28.789	38.94	6.43	8.02	4.23	28.950	35.5	7.31	7.94	2.13
9/20/02 9:00 AM	24.515	36.24	6.85	7.81	4.33	24.641	36.24	6.1	7.87	6.15	24.650	35.2	6.87	7.81	1.51
9/20/02 9:30 AM	24.576	36.28	7.55	7.78	114	24.7	36.28	6.37	7.86	122	24.750	35.8	6.77	7.79	60
9/20/02 11:00 AM	25.153	36.7	7.53	7.83	124	25.275	36.7	5.74	7.91	125	25.350	35.9	6.78	7.8	133
9/20/02 4:00 PM	29.641	40.2	6.54	7.85	33.6	28.048	38.86	5.3	7.94	44	29.150	35.8	6.65	7.84	19.4

	GO 204					GO 205					Reference				
	Temp	Cond.	DO		Turb.	Temp	Cond.	DO		Turb.	Temp	Cond.	DO		Turb.
m/d/y hh:mm	C	mS/cm	mg/L	pH	NTU	C	mS/cm	mg/L	pH	NTU	C	mS/cm	mg/L	pH	NTU
9/23/02 11:00 AM	24.958	38.28	5.35	7.88	4.8	25.084	38.29	5.83	7.94	4.6	25.150	37.8	6.94	7.83	2.4
9/23/02 1:45 PM	26.005	39.09	5.45	7.92	4.6	25.959	38.97	5.64	7.97	2.8	26.050	38.3	6.72	7.84	1.45
9/23/02 3:30 PM	27.224	40.05	5.06	7.94	3.3	27.361	40.07	5.45	8.00	2.5	27.450	38.4	6.72	7.88	1.35
9/23/02 4:30 PM	28.642	41.22	5.29	7.85	3.9	27.778	40.43	5.51	7.99	2.6	29.550	38.1	6.5	7.71	2.05
9/24/02 9:30 AM	24.393	38.28	2.77	7.45	4.9	24.513	38.29	3.93	7.49	5.3	24.550	37.7	3.71	7.28	1.9
9/24/02 9:45 AM	24.376	38.27	5.1	7.53	12.5	24.515	38.29	3.89	7.51	5.43	24.550	37.7	4.54	7.36	1.9
9/24/02 11:00 AM	26.967	0.493	5.52	8.72	9.63	27.085	0.511	4.82	8.78	9.4	27.150	0.68	5.96	8.4	6.25
9/24/02 1:30 PM	27.069	1.397	6.11	8.24	5.9	27.116	1.321	5.44	8.33	5.7	27.250	1.304	6.4	7.97	2.46
9/24/02 3:15 PM	27.123	1.516	6.09	8.22	7.4	27.215	1.483	5.56	8.23	5.2	27.250	1.406	6.55	7.89	4.22
9/24/02 4:30 PM	28.311	2.682	6.55	8.19	8.98	28.479	2.691	5.28	8.27	7.23	28.450	2.67	6.22	8.04	3.87
9/25/02 11:00 AM	24.147	3.093	6.78	8.06	6.9	24.265	3.105	6	8.08	7.65	24.350	3.35	6.88	7.63	1.91