Lower Charles River Demonstration Project

Gunderboom® Beach Protection System™

2002

New England Interstate Water Pollution Control Commission

Environmental Protection Agency New England

Gunderboom, Inc.

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Introduction

The U.S. Environmental Protection Agency's (EPA) *Clean Charles 2005* Initiative seeks to restore the Lower Charles River (from the Watertown Dam to Boston Harbor) to fishable and swimmable conditions by Earth Day 2005. Progress toward this goal is already evident; according to a Charles River Watershed Association (CRWA) Monthly Water Quality Sampling Data Report, the Lower Charles River met swimming standards for bacteria approximately 75% of the time in 1999, up from just 19% in 1995.

To explore means for improving swimming beach water quality, the New England Interstate Water Pollution Control Commission (NEIWPCC) received a grant from EPA New England to conduct a preliminary evaluation of the Gunderboom® Beach Protection System (BPS™) during the summer of 2000, as well as a follow-up study during the summer of 2002. The 2000 project was conducted over two, three-day periods in the Lower Charles River, near Magazine Beach in Cambridge. The results were generally encouraging and highlighted the potential for the BPS™ technology to be effective for Charles River swimming beach applications; however, some results were less conclusive and even counterintuitive to the simple physics of filtering particulates out of water.

In order to confirm the ability of the BPS™ technology to provide a safe swimming area in the Lower Charles River, a follow-up study was conducted in 2002. In an attempt to address the potential sources of anomalous results seen in the 2000 study, the 2002 project was modified and a new, re-designed BPS™ test system and approach were developed. This report focuses on the 2002 study with a discussion of the results with respect to data collected in 2000, as well as at other BPS™ test sites. Results from the 2002 study demonstrate the potential for the BPS™ technology to improve water clarity and other water quality conditions in the Lower Charles River.

Water Quality in the Lower Charles River

Lower Charles River Basin

The Lower Charles River Basin, defined as the river segment between the Watertown Dam and the new Charles River Dam, provides an ideal setting for a variety of recreational activities, including rowing, sailing, concerts, running, and numerous sporting activities on the adjacent parklands. Due to longstanding and pervasive water quality problems (high bacteria levels and poor aesthetic quality) in the basin, contact recreational activities (e.g., kayaking, sailboarding, swimming, etc.) have been limited. However, contact recreational activities are occurring with increased frequency as a result of intensive efforts during the past five years to reduce the discharge of pollutants from combined sewer overflows (CSOs) and illicit sanitary sewage discharge. Despite continued improvements in bacterial water quality, designated recreational and aquatic life uses are still not fully supported within the basin.

Water Quality Trends

In 1998 the EPA New England Regional Laboratory initiated the Lower Charles River Core Monitoring Program, which is conducted annually during the summer months when peak recreational uses occur in the basin. The monitoring program is designed to assess water quality conditions and track water quality improvements in the river, as well as to identify the need for further pollution reduction actions. The Core Monitoring Program includes both dry and wet weather surveys at ten stations within the Lower Charles River Basin; water quality samples are analyzed for numerous parameters including nutrients, chlorophyll *a*, bacteria, metals, dissolved oxygen, temperature, salinity, transparency, and turbidity. All data are collected in accordance with an approved Quality Assurance Project Plan (QAPP). Other groups such as the CRWA and the Massachusetts Water Resource Authority (MWRA) also routinely sample in the river. For the purpose of this project, only data from EPA's Core Monitoring Program are used for comparison purposes (Table 1).

Table 1. Water Quality Data from EPA's Lower Charles River Core Monitoring Program (1998-2002).

Location	1998	1999	2000	2001	2002
	low -high (mean)	low -high (mean)	low -high (mean)	low -high (mean)	low -high (mean)
Chlorophyll *a* (ug/l)					
Longfellow Bridge	7 – 52 (23)	11 – 116 (45)	9 – 51 (36)	8 – 53 (28)	2 – 65 (23)
BU Bridge-Harvard Bridge	7 – 78 (29)	13 – 77 (44)	15 – 73 (49)	7 – 56 (33)	2 – 59 (35)
Mid to upper Basin	4 – 21 (10)	9 – 50 (25)	3 – 95 (23)	2 – 49 (13)	2 – 49 (16)
Total Phosphorus (ug/l)					
Longfellow Bridge	8 – 200 (120)	25 – 20 (60)	25 – 74 (60)	40 – 120 (70)	28 – 91 (53)
BU Bridge-Harvard Bridge	80 – 140 (110)	25 – 110 (70)	25 – 180 (100)	50 – 110 (80)	20 – 94 (58)
Mid to upper Basin	100 – 330 (150)	25 – 100 (60)	25 – 160 (80)	40 – 100 (60)	35 – 87 (66)
Total Nitrogen (ug/l)					
Longfellow Bridge	**N/A**	**N/A**	**N/A**	**N/A**	670 – 1860 (1078)
BU Bridge-Harvard Bridge	**N/A**	**N/A**	**N/A**	**N/A**	20 – 94 (58)
Mid to upper Basin	**N/A**	**N/A**	**N/A**	**N/A**	35 – 87 (66)
Secchi Depth (meters)					
Longfellow Bridge	0.6 – 1.5 (1.1)	0.9 – 1.8 (1.4)	1.0 – 1.7 (1.3)	0.8 – 1.8 (1.3)	1.1 – 2.2 (1.5)
BU Bridge-Harvard Bridge	0.6 – 1.2 (0.8)	0.7 – 1.7 (1.1)	1.0 – 1.7 (1.3)	0.6 – 1.4 (0.9)	0.9 – 2.2 (1.4)
Mid to upper Basin	0.6 – 1.3 (0.9)	0.7 – 1.3 (1.2)	0.8 – 1.5 (1.1)	1.1 – 1.4 (1.2)	0.8 – 1.4 (1.0)

Note: For 1998-2001, Longfellow Bridge values represent data from EPA core monitoring stations 09, 10, and 11; BU Bridge to Harvard Bridge values represent data from EPA core monitoring stations 05, 06, and 07; and Mid to Upper Basin values represent data from EPA core monitoring stations 02, 03 and 04. For 2002, Longfellow Bridge values represent data from EPA core monitoring stations 09, 10, and 11, and TMDL stations 25, 26, and 28; BU Bridge to Harvard Bridge values represent data from EPA core monitoring stations 05, 06, and 07 and TMDL stations 21, 22, and 23; and Mid to Upper Basin values represent data from EPA core monitoring stations 02, 03 and 04.

Water Clarity Impairments

Secchi depths measured in the basin frequently do not attain the Massachusetts State water clarity standard. Although the clarity standard is in narrative form, the state uses a four foot depth (as measured by a Secchi disk) to assess for attainment with the primary contact recreation use standard. Based on a review of Secchi depth data collected at EPA sampling stations CRBL06 (downstream of the BU Bridge), CRBL07 (downstream of the Harvard Bridge) and CRBL11 (between the Longfellow Bridge and the Museum of Science), only 25%, 53%, and 76% of the observations for 2002, respectively, attained the four-foot criteria. Algae suspended in the water column are partially responsible for the poor water clarity due to both absorption and scattering of light entering the water. Controlling algae growth and preventing particulates from being discharged may enhance the clarity of the water and help achieve the bathing beach visibility standard for the Lower Charles River.

Excessive Algae Impairments

Chlorophyll *a*, total phosphorus, total nitrogen, and Secchi depth are commonly used to classify the trophic status of fresh water lakes and impounded river systems. While oligotrophic water bodies are typically viewed as having excellent water quality, eutrophic waters are often associated with a number of water quality problems related to excessive algae growth. Elevated chlorophyll *a* and nutrient levels, as well as low Secchi depths, observed during the past five years indicate that the Lower Charles River Basin is eutrophic and undergoing eutrophication as a result of excessive pollutant loading. Excessive levels of algae in the river have resulted in reduced water clarity, unappealing coloration, and poor aesthetic quality.

Clean Charles 2005 Initiative

In 1995, EPA New England established the *Clean Charles 2005 Initiative* with the goal to improve water quality in the Lower Charles River and fully restore recreational (i.e., swimmable) and aquatic life (e.g., fishable) uses. Efforts resulting from the initiative are already leading to water quality improvements in the river. However, with room to improve, wet-weather bacteria and pollutant spikes are still threats to the full restoration of the recreational (e.g., swimmable) and aquatic life (e.g., fishable) uses of the Lower Charles River Basin by 2005.

2000 Demonstration Project

The 2000 project was conducted over two, three-day periods in the Lower Charles River near Magazine Beach in Cambridge; the results were encouraging. During deployment, water was pumped out of the boom (an area enclosed by a 150-foot, custom-designed, temporarily-deployed filter curtain); as water was drawn in through the filter fabric, replacing water that was pumped out, significant water quality improvements were observed inside the boom. Unfortunately, results for some parameters were less conclusive and even counterintuitive to the simple physics of filtering particulates out of water; trends in water quality improvement were also inconsistent at times. Test system design, deployment difficulties, and test conditions in the river are thought to have contributed to the inconsistencies; these included an incomplete bottom seal of the temporary filter barrier curtain, re-suspension of settled materials within the boom (associated with boat wakes and river level fluctuation), and a difference in distance from the shore for sampling within and outside the boom. The results of this initial test highlighted the potential for the technology to be effective for Charles River swimming beach applications, but also identified the need for further study and re-design of the test system to optimize performance.

2002 Demonstration Project

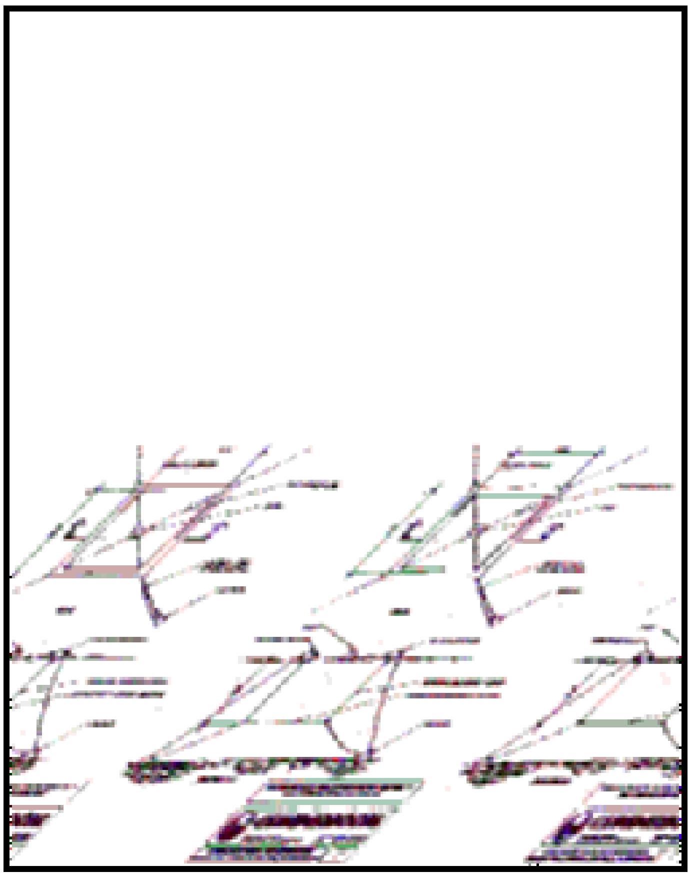
Based on the positive results of the preliminary evaluation in 2000, NEIWPCC received another grant from EPA to conduct a follow-up study of the Gunderboom® BPS™ technology in 2002, in order to confirm the ability of the technology to provide a safe swimming area in the Lower Charles River. NEIWPCC contracted with Gunderboom, Inc. to design a Gunderboom® test system for the Lower Charles River; a senior engineer with Peratovich, Nottingham & Drage, Inc., also contributed to the design of the Gunderboom® test system. The EPA New England Regional Water Quality Laboratory collected and analyzed water quality samples for the study, as well as covered the costs for sample collection and analysis. For the 2002 study, the test system was modified in order to address the potential sources of anomalous results seen in the 2000 study; a new, re-designed test system and approach were developed to further evaluate the potential for successful applications of the BPS™ in the Lower Charles River. In particular, the new, re-designed test system was fully enclosed to minimize chance of exposure from river bottom sediments.

Gunderboom® BPS™ Design

The BPS™ is a patented, "aquatic filter barrier" technology, designed to control migration of particulates and associated microbes. Generally, a BPS™ is comprised of a non-woven fiber material, suspended in the water column, with an integral floatation system, a chain to weight it, and an anchoring system to hold it in place. Gunderboom, Inc. has also developed "AirBurst™" technology to remove sediment buildup on the material for high-flow and/or long-term applications. The Gunderboom® BPS™, Reservoir Protection System™ (RPS™), and Particulate Control System™ (PCS™) have each been shown to significantly reduce suspended solid, turbidity, and coliform concentrations, which often derive from wet weather flows containing high levels of these parameters.

The BPS™ test system used for this project was a PVC-framed, floating filter "pool," designed to prevent interaction with sediments on, or kicked up from, the river bottom, regardless of water level changes or boat wakes (Figure 1). The square test system was 12ft x 12ft and extended a little over 5 feet deep when deployed, having a volume of approximately 5400 gallons. The unit was comprised of a single-layer of filter fabric on all four sides, reinforced anchor points at the top and bottom outside corners, a polyester-reinforced vinyl hood with polystyrene floatation billets, an impermeable rubberized bottom panel, and was open in the middle for pumping and sampling activities. The PVC frame inside of the test system was designed to hold the shape of the system against the force of water being drawn through the filter fabric. The dimensions of the test unit were chosen to minimize the effects of shading on Secchi disk readings, with the sample platform location placed with consideration of this effect, as well. Given the short duration of the test, the boom did not incorporate an AirBurst™ cleaning system.

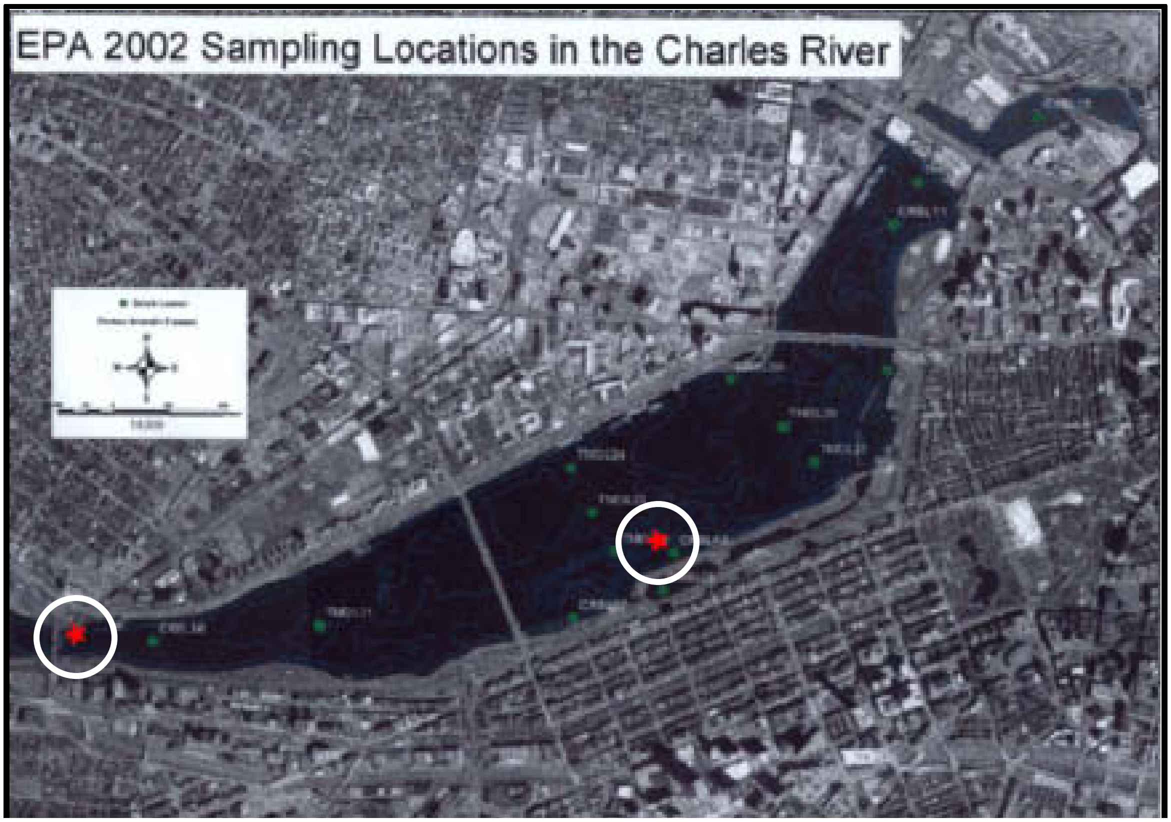
Figure 1. Design of the BPS™ test system used for the Charles River testing effort 2002.



Site Selection

Project coordinators determined that the sampling sites should allow for optimal data collection, enable boom deployment, and be in proximity to a potential site for future use of the Gunderboom® BPS™. The selected sites for this program were in the vicinity of EPA water quality sampling sites CRBLA8, adjacent to the lagoons and site CRBL06, downstream of the BU Bridge and near Magazine Beach (Figure 2). The two sampling locations were selected for their unique water quality characteristics.

Figure 2. Gunderboom® Beach Protection System Sample Locations in the Lower Charles River



Gunderboom® BPS™ Deployment

The test system was set up and deployed from the Metropolitan District Commission (MDC) dock on the lagoon adjacent to the Hatch Shell on the Boston side of the Charles River. Set-up included inserting the system floatation billets into the hood, assembly and placement of the PVC frame inside the test system, and reefing the filter fabric to the floatation to place the test system in its towing configuration. When ready, the test system was pushed off the dock into the water and towed to the first sampling location in the vicinity of site CRBLA8 (Figure 3).

Concurrent with test system set up 4, 40-pound Danforth anchors, complete with marker buoys, anchor chain, and line, were deployed and set. Once the test system was towed into position, the anchor lines were attached to the top anchor points. When all anchor lines were secured, the reefing lines on the test system were released and the PVC frame pushed down to stretch the system to a six-foot depth, to complete the deployment of the system (Figure 4).

Deployment of the system by submerging the frame forced water to be drawn through the filter fabric faster than during testing and sampling. Given the relatively high flow-through fabric velocities during set-up, particulates that would be filtered by the system at lower flow-through rates may have been forced through the fabric, into the test chamber. This resulted in an increase in water quality inside the boom at the start of testing but not to the levels expected to be seen with controlled pumping during the sampling efforts described below.

Figure 3. Reefed test system with exposed PVC frame being towed into position.

Figure 4. Deployed BPS™ test system with PVC fame submerged.

Water Quality Sampling Design

Prior to deploying the Gunderboom® test system, researchers developed a sampling plan that would best characterize the boom's ability to improve water clarity and substantially reduce suspended solids, turbidity and bacterial concentrations within an enclosed area on the Charles River. The area enclosed within the boom would bring the water into full compliance with Massachusetts State swimming standards and provide swimming areas with a safety shield during wet weather events. A new clarity standard is being proposed by the state; however, since the new standard had not yet been issued at the time of the study, the Massachusetts State Bathing Beach standard for water clarity was approximated at four-feet of visibility (based on Secchi disk depth measurements) for the purposes of this project.

For this test, only one boom deployment was possible, taking place during the summer of 2002, on July 15, 16, and 17. The 2002 test system was deployed in two locations. The first, near the Lagoons, was close to EPA water quality sampling site CRBLA8 for the first two days; the second, closer to Magazine Beach and downstream of the Boston University (BU) Bridge, was upstream of EPA water quality sampling site CRBL06 for the final day of pumping and sampling. Two sampling stations were established at each location; one located outside of the boomed area (Station GBOUT) and the other inside the boomed area (Station GBIN). All samples were collected approximately six inches below the water's surface. Water samples were collected for laboratory assessment of total suspended solids (TSS), fecal coliform, *Escherichia coli* (*E. coli*), chlorophyll *a*, true color, apparent color, turbidity, and total phosphorous. In addition, on-site measurements were taken for turbidity, temperature, pH, dissolved oxygen, conductivity, transmissivity, and Secchi depth. EPA New England Water Quality Laboratory staff conducted all sampling in accordance with EPA protocols and an approved QAPP.

Testing

A portable, 3" gas-powered centrifugal pump was used to pump water continuously from inside to outside of the test system at a known and controlled rate. This pumping action increases the hydraulic head outside the boom, causing water to flow through the filter fabric and into the boom, replacing the water being pumped out. The pump could be throttled through a range of approximately 237 gallons per minute (gpm) to 55 gpm. Given the filter fabric area of the test system (approximately 240 ft^2), through-fabric flow rates ranged from 0.99 gpm/ft^2 to 0.23 gpm/ft^2. Most sampling was done at a flow rate of approximately 116 gpm, giving a through-fabric flow rate of 48 gpm/ft^2. At this flow rate, a volume of water (~5400 gallons) was cleared from the test chamber in approximately 47 minutes; this flow-through rate is equivalent to what would likely be targeted for a full scale BPS™ installation.

At location CRBLA8 and near the Lagoons, testing was conducted over two days (7/15/02 and 7/16/02). Two sample rounds were conducted on 7/15/02, while the pump ran for two hours at a rate of approximately 230 GPM (full-throttle). Four sample rounds were conducted on 7/16/02, while the pump ran for four hours at a rate of approximately 116 GPM (mid-throttle). Exact sampling intervals can be seen on the raw data sheet (Appendix 1).

Following the conclusion of testing at CRBLA8 on 7/16/02, the test system was reefed up into its towing configuration and towed up the river to the second sampling location, upstream of site CRBL06 and downstream of the "BU" bridge, near Magazine Beach. The test system was anchored in position on 7/16/02 and remained in the reefed position overnight.

On the morning of 7/17/02, the third and final day of testing, the test system was un-reefed and the PVC frame pushed to its six-foot depth to begin testing. Four sample rounds were conducted, while the pump ran for four hours at a rate of approximately 116 GPM (mid-throttle). Exact sampling intervals can be seen on the raw data sheet (Appendix 1). Upon the conclusion of testing on 7/17/02, the boom was reefed and towed to Magazine Beach where the test system was pulled on shore, inspected for any signs of failure, and broken down for transport.

Results

Observations

The test system designed and fabricated for use in the 2002 Lower Charles River project effectively filtered Charles River water without problems associated with the bottom seal or re-suspension of shallow water sediments, as was experienced with the 2000 study. The deployment, towing, and retrieval of the test system went smoothly and as planned. A post-deployment, onshore inspection of the test system indicated that there had been no failures of seams or fabric integrity.

There was one occurrence that raised an issue regarding the effectiveness of the test system and sampling protocol for direct application of results to future full-scale applications. On the final day of testing, initial improvements in water quality were reversed immediately following the passage of a commercial tour boat in close proximity to the system creating a substantial wake, twice, within a five minute period. Researchers conjectured that over the three days of testing, a substantial amount of fine sediment had settled out, inside the test chamber, coating the PVC frame and bottom of the system; the sediment was re-suspended by the passing boat wake. Additionally, the amount of sediment inside the boom was most likely elevated as a result of towing the boom on 7/16/02, as the floatation was frequently breached and water filtered from inside out, leaving particulates inside the test system (Figure 5).

Figure 5. Towing of reefed boom between sites; note splash over on leading edge of boom.

Initially, researchers believed that the decrease of water quality might be due to a damaged portion of the boom. However, as described above, the post-deployment, onshore inspection of the test system indicated no system failures. This same onshore inspection confirmed a high level of sedimentation on the inside of the test chamber.

Meteorological Considerations

The three days of testing were characterized by sunny skies, light winds, and temperatures ranging from 70 – 90^{o}F. Precipitation during the study period was limited to a significant overnight down-pour in the testing vicinity between the first (7/15/02) and second (7/16/02) day of sampling. Boston Water and Sewer Commission measured the storm as 0.35 inches of rain at Malden Street, South End in a 2-hour period, a wet weather event typical of summer conditions in the Charles River Basin. In fact, runoff following the storm resulted in a small algae bloom in the river, as indicated by the rise in Chlorophyll *a* levels on 7/16/02. The results of this round of testing are considered representative of results that can be expected during other wet weather events with a full scale BPS™ application.

Sampling Data

There were a total of three days of testing, at two separate locations. The first day of testing produced limited results; and as such, its presentation is limited to indicating that all parameters monitored remained consistent with, or were slightly improved over, the sampling period from outside to inside the test system. The data for the two extended sampling periods on day 2 and day 3 are presented in Figures 6 – 27; the entire raw data set for the full 3 days of the test system can be found in Appendix 1. All field and laboratory data passed Quality Assurance and Quality Control (QA/QC) procedures and were processed within the required holding times.

The presentation of data adheres to the following conventions to standardize the data presented. In instances where “Not Detected” (ND) was indicated, the data associated with the lowest accurate level of detection was used. Instances in which both original and duplicate data are available, both are presented. Unfortunately, the limited sample size of the data does not allow for the establishment of strong statistical correlations; therefore, there may be a large margin for sampling error.

The data analysis focuses primarily on comparing results for data obtained from outside of the boom to data obtained from inside the boom. No discernible differences were detected for temperature, dissolved oxygen, specific conductivity or salinity, in either of the two extended sample sets at the two locations; therefore, graphical summaries are not presented for these parameters.

Secchi Depth (meters)

The Secchi depth is a measure of transparency or water clarity for a given water body. It is called the Secchi depth because it is measured by lowering a flat black and white “Secchi disk” below the water surface. The Secchi depth is the water depth at which the disk cannot be seen any more; this is the greatest depth to which light can penetrate under water. The Secchi depth of eutrophic lakes, estuaries, and large rivers ranges from 0 to 2 meters, but in oligotrophic lakes or blue-water oceans, it can be as great as 40 meters. The clarity of a water body varies with season due to algae blooms or suspended sediment and these changes are well demonstrated by Secchi depth measurements for the Lower Charles River.

In all instances, Secchi depth measurements for this project show greater visibility within the Gunderboom® system (Figures 6 and 7). After two hours of pumping at station CRBL06 (7/17/02), Secchi depth was “maxed out,” and the measurement was taken on the bottom of the Gunderboom® system.

Note: data are presented in meters of visibility from the water surface (top of graph); higher numbers indicate greater water clarity.

Transmissivity (%)

Transmissivity is another measure of water clarity; it is a measurement of the percent of ambient light transmitted through a water column. Secchi depth is a *subjective* measurement of water clarity, while transmissivity is an *objective* measurement. A historical comparison of Secchi depth and transmissivity in the Charles River is provided in Appendix 2.

Consistent with Secchi depth results for this project, measurements of transmissivity show greater visibility with the Gunderboom® system in all instances (Figures 8 and 9). After three hours of pumping at station CRBL06 (7/17/02), percent transmissivity decreased to near ambient levels (measurements outside the boom); however, measurements at the fourth and final hour of testing show an increase in transmissivity. Note: data are presented in percent, where higher numbers indicate greater water clarity.

Turbidity (NTU)

Turbidity is a unit of measurement quantifying the degree to which light traveling through a water column is scattered by the suspended organic (including algae) and inorganic particles; the scattering of light increases with a greater suspended load. Turbidity is often largely due to suspended sediment in the water column, which reduces light penetration, thereby suppressing photosynthetic activity of phytoplankton, algae, and macrophytes, especially those farther from the water surface. If turbidity is largely due to algae, light will not penetrate very far into the water, and primary production will be limited to the uppermost layers of water. If turbidity is largely due to organic particles, dissolved oxygen depletion may occur in the water body.

For this test, turbidity was measured in Nephelometric Turbidity Units (NTU). Results for turbidity show a substantial decrease in measurements inside the Gunderboom® system at both station (Figures 10 and 11). The most significant difference between inside and outside (of the Gunderboom® system) was seen after one hour of pumping at station CRBL06 (7/17/02). Note: a duplicate sample was taken inside the Gunderboom® system.

Total Suspended Solids (mg/L)

Total Suspended Solids (TSS) are the solids in water that can be trapped by a filter. TSS can include a wide variety of material, such as silt, decaying plant and animal matter, industrial wastes, and sewage. High concentrations of TSS can block light from reaching submerged vegetation. As the amount of light passing through the water is reduced, photosynthesis slows down, which often results in a decrease in the amount of dissolved oxygen released into the water by plants and potentially leads to dissolved oxygen depletion in the water body. High TSS can also cause an increase in surface water temperature, because the suspended particles absorb heat from sunlight. In some cases, high TSS can be a potential indicator of high concentrations of bacteria, nutrients, pesticides, and/or metals in the water body; these pollutants can attach to sediment particles on the land and be carried in water bodies with stormwater.

TSS measurements for this project show a substantial decrease in measurements inside the Gunderboom® system at both stations (Figures 12 and 13). The most significant difference between inside and outside (of the Gunderboom® system) was seen after one hour of pumping at station CRBL06 (7/17/02). The detection limit for TSS was 10 mg/L; values falling below 10 mg/L are estimates associated with the lowest accurate level of detection.

Volatile Solids (mg/L)

Measurements of volatile solids provide an estimate of the amount of organic matter in a water body. Measurements of volatile solids for this project show a decrease across the entire sample set, with the exception of a sample taken at station CRBL06 (7/17/02) after the third hour of pumping (Figures 14 and 15); however, measurements at the fourth and final hour of testing show a decrease in volatile solids.

Apparent Color

The apparent color of a water body refers to color due to both substances in solution and suspended matter; apparent color is obtained without filtering the sample. The apparent color depends on the interaction between the wavelengths that are scattered back to the eye and the absorption of these wavelengths in the water between the depth of the scattering and the surface. Changes in daily and seasonal spectral distribution of incident radiation, cloud cover, reflection of vegetation, and hills around the water body can affect the apparent color of a water body. In all instances, the Gunderboom® system decreased the apparent color of the water in the Charles River (Figures 16 and 17).

True Color

The true color of a water body is the color of the water and its contents as measured by a spectrophotometer. True color is distinguished from apparent color by filtering the sample (removing turbidity). The most common source of true color is decaying organic matter. Similar to apparent color, the Gunderboom® system decreased the true color of the water in the Charles River in all instances (Figures 18 and 19).

Chlorophyll a (mg/m^3)

Chlorophyll *a* reflects the concentration of the principal pigment in green plants responsible for photosynthesis. As such, this parameter is a surrogate indicator of phytoplankton biomass, the amount of unattached single-celled algae present in the water. In all instances, the levels of Chlorophyll *a* in the Charles River were lower in the water contained in the Gunderboom® system (Figures 20 and 21).

Total Phosphorous (mg/L)

Phosphorus is one of the key elements necessary for the growth of plants. Rainfall can cause varying amounts of phosphorus to wash into nearby water bodies, which in turn will stimulate the growth of plankton and aquatic macrophytes. During the summer, phosphorus can combine with low flows, warm temperatures, and long hours of daylight to promote algae growth. If an excess amount of phosphorus enters the water, algae and aquatic plants will grow wildly and use up large amounts of dissolved oxygen when they die and decompose; this condition is often referred to as eutrophication or over-fertilization.

On an annual basis, most of the phosphorus load in the Lower Charles River comes from above the Watertown Dam during dry weather. Over time, phosphorus loads may present a greater environmental concern to the Lower Charles River than that presented by bacteria. As bacteria enter the Lower Charles River, they are diluted and eventually die off; phosphorus, however, tends to accumulate in the river's bottom sediments.

In all instances, the concentrations of total phosphorus in the Charles River were lower in the water contained in the Gunderboom® system (Figures 22 and 23). The most significant difference between inside and outside (of the Gunderboom® system) was seen after one hour of pumping at station CRBL06 (7/17/02).

Fecal Coliform (cfu/100ml)

Fecal coliforms are used as the primary indicator for determining whether or not water is contaminated by animal or human waste; fecal coliforms are found in the intestines or feces of warm blooded animals. Although fecal coliforms do not normally cause illness in humans, their presence suggests the potential presence of other dangerous pathogens. A standard of less than 200 colonies per 100 mL has been established for contact recreation (i.e., swimming) is the state.

Fecal coliforms measured inside the Gunderboom® system were lower than or equal to measurements outside the boom in all instances but one (Figures 24 and 25). After 2 hours of pumping at station CRBL06 (7/17/02), fecal coliform levels inside the boom measured higher than ambient levels. However, this anomalous data point is followed and preceded by lower fecal coliform counts inside the boom (as compared to outside the boom).

E.coli (cfu/100ml)

Similar to fecal coliforms, *E. coli* (short for *Escherichia coli*) is also a species of bacteria used as an indicator for determining whether or not water is contaminated by animal or human waste; fecal coliforms are naturally present in the intestines or feces of warm blooded animals. Although usually harmless, *E. coli* can potentially cause illnesses such as meningitis, septicemia, urinary tract, and intestinal infections.

For this project, the results obtained for *E. coli* bacteria samples are mixed (Figures 26 and 27). Each test period began and ended with *E. coli* levels lower inside the test system as compared to levels outside the test system. However, *E. coli* levels proceeded to fluctuate between higher and lower than levels outside of the boom for the remainder of the tests.

Figure 6. Secchi Depth at CRBLA8 (7/16/02)

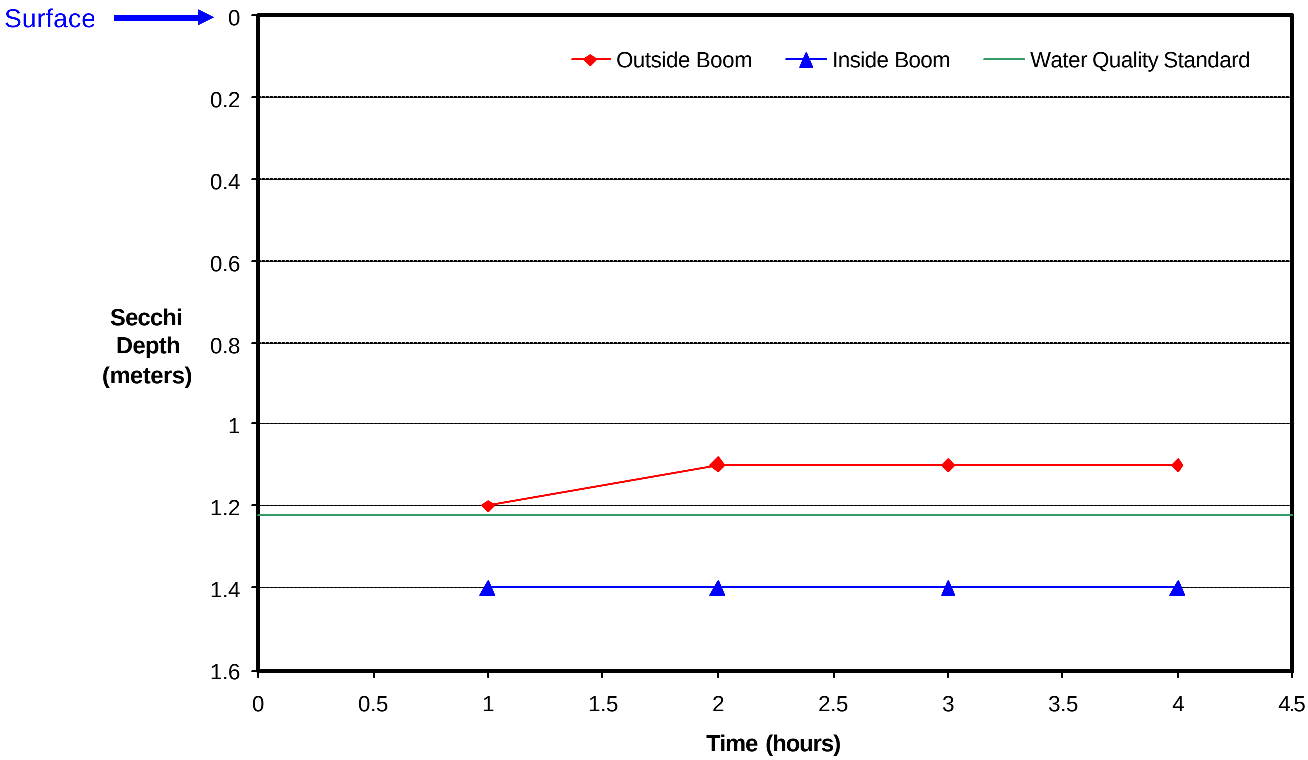


Figure 7. Secchi Depth at CRBL06 (7/17/02)

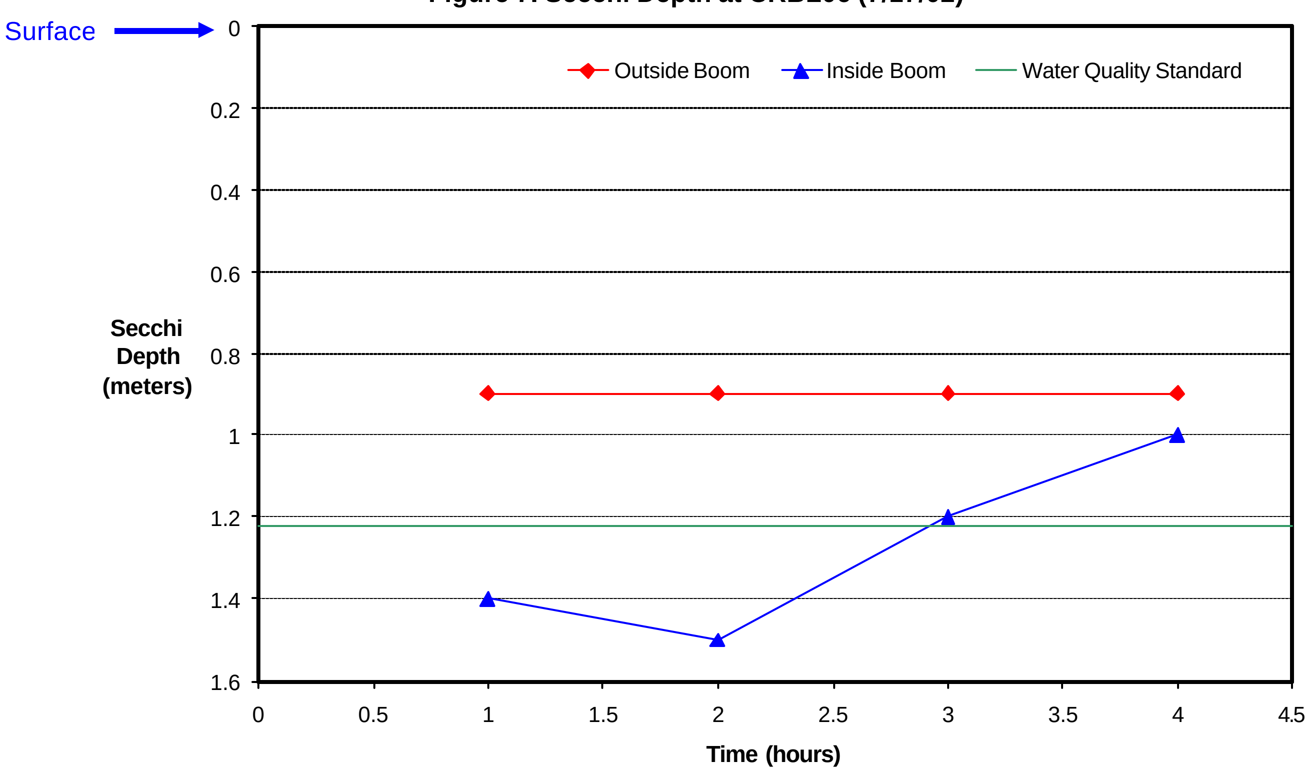


Figure 8. Transmissivity at CRBLA8 (7/16/02)

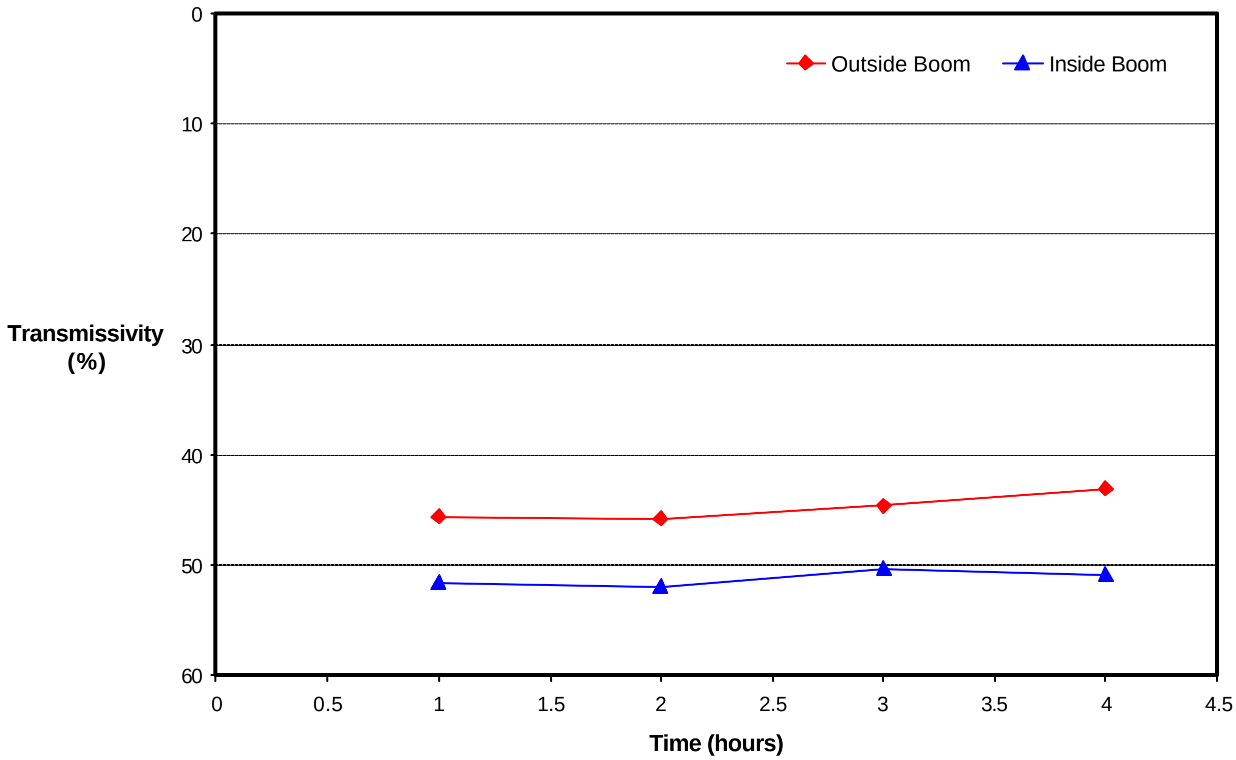


Figure 9. Transmissivity at CRBL06 (7/17/02)

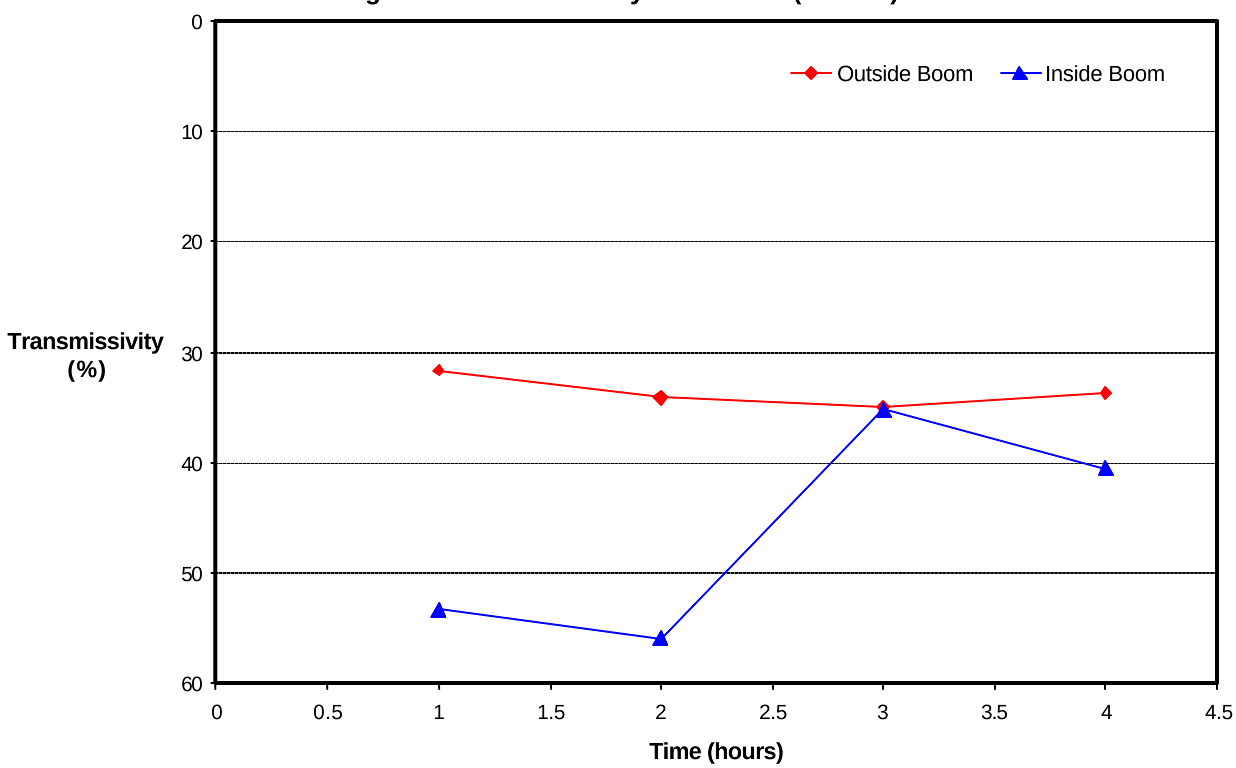


Figure 10. Turbidity at CRBLA8 (7/16/02)

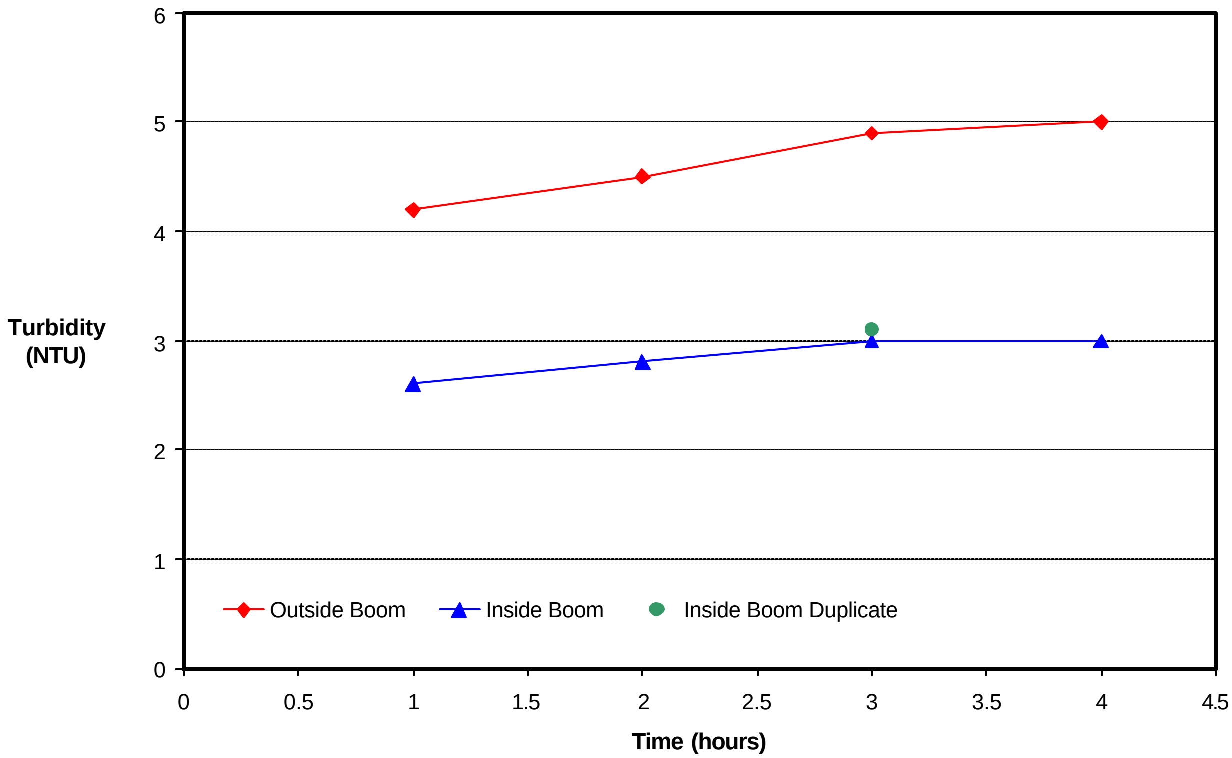


Figure 11. Turbidity at CRBL06 (7/17/02)

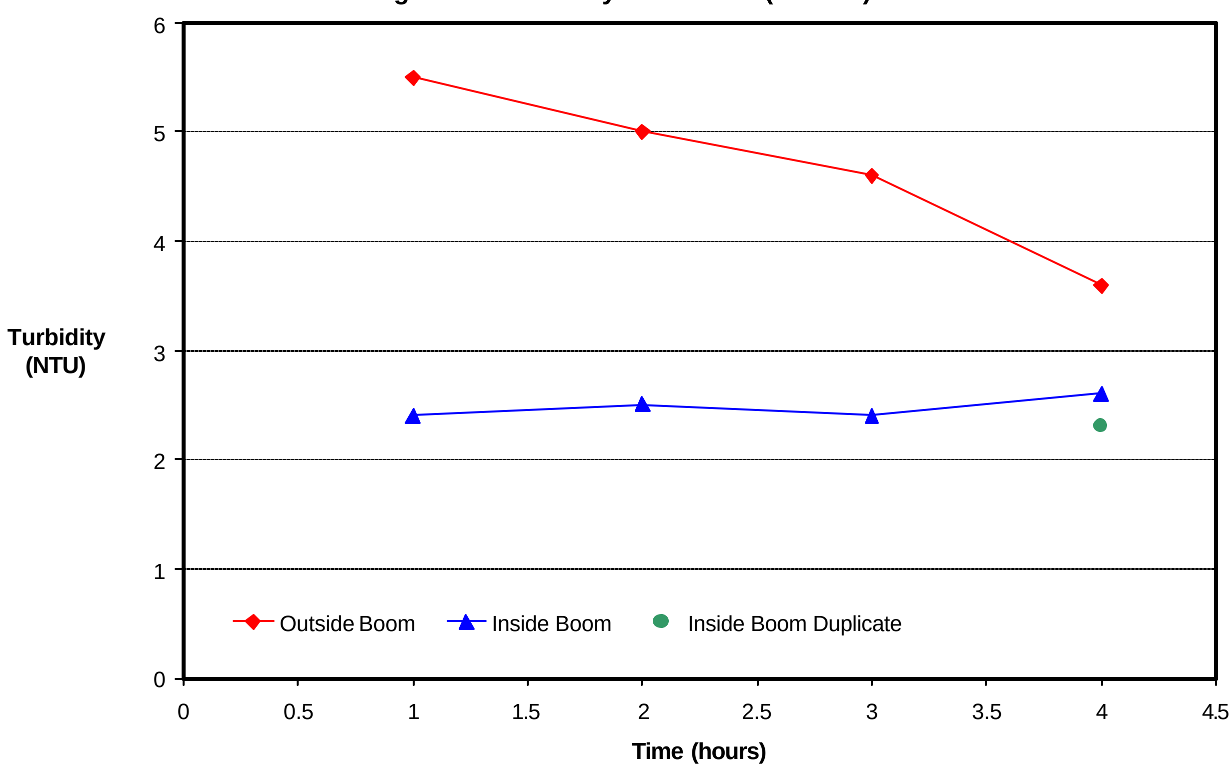


Figure 12. Total Suspended Solids at CRBLA8 (7/16/02)

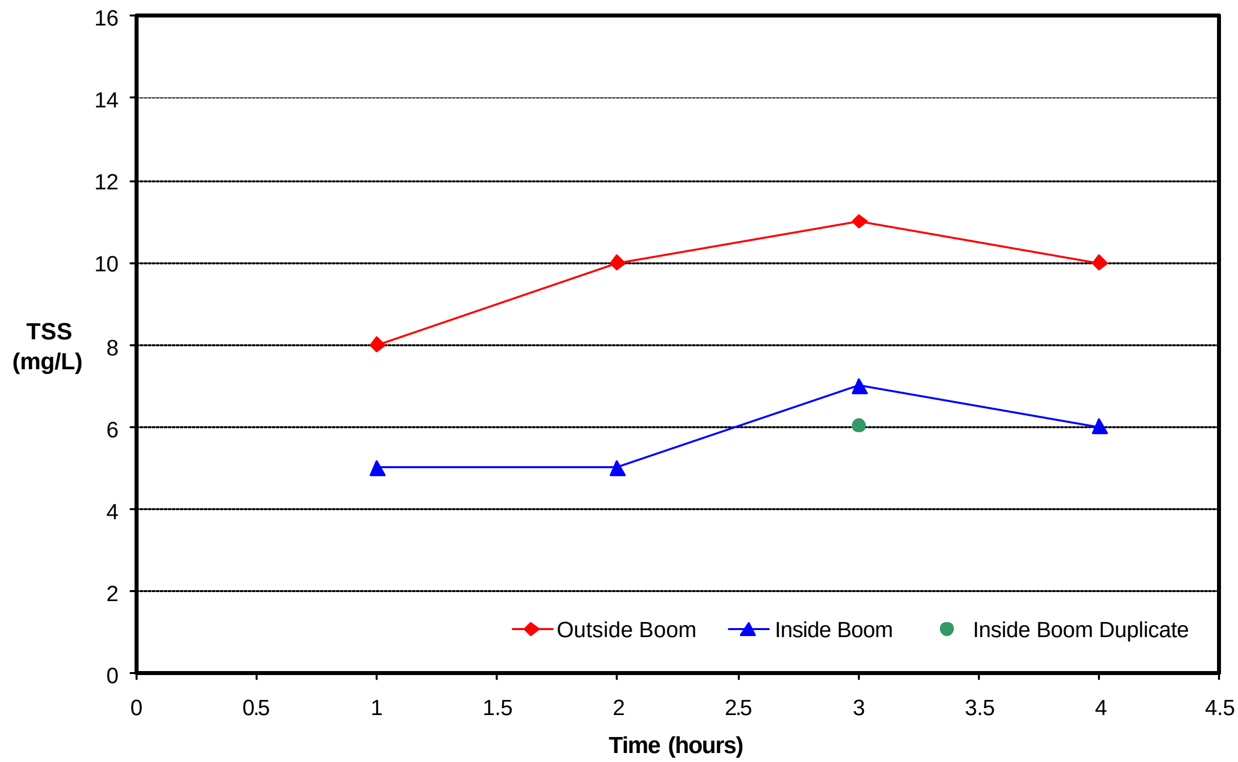


Figure 13. Total Suspended Solids at CRBL06 (7/17/02)

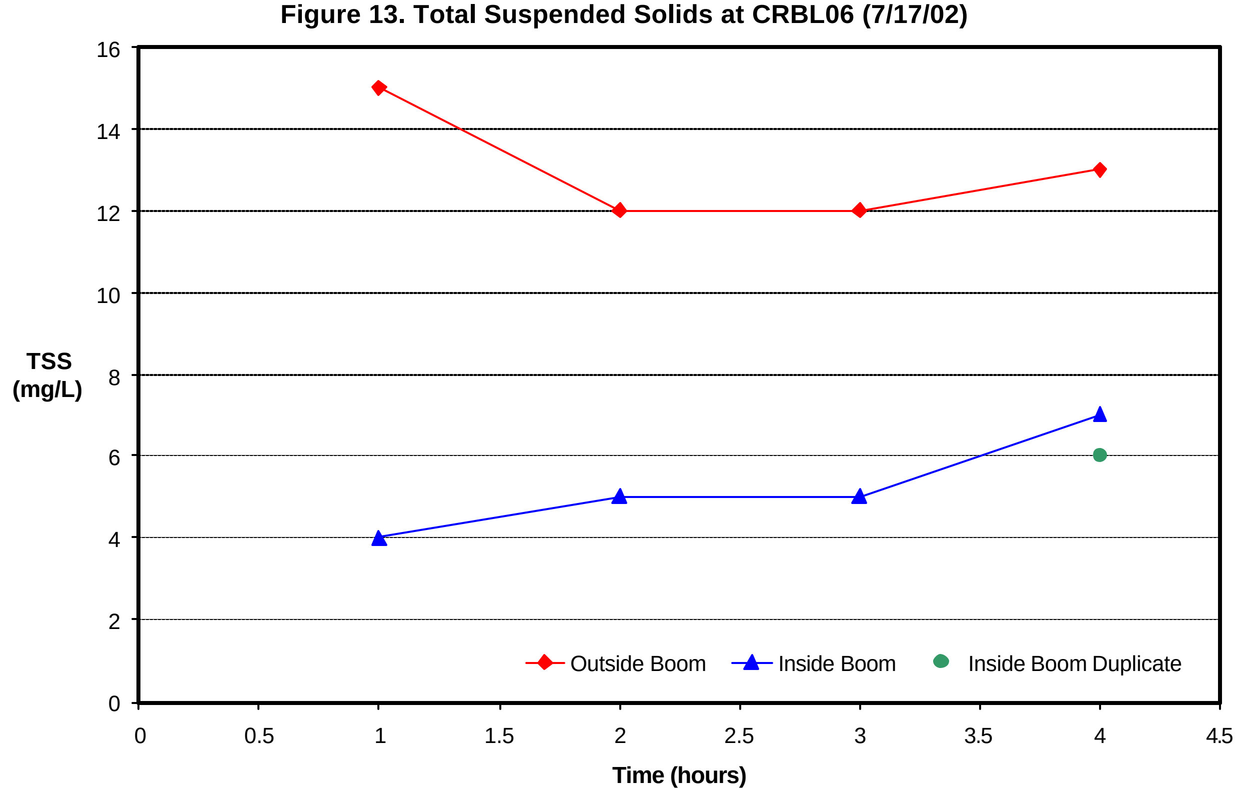


Figure 14. Volatile Solids at CRBLA8 (7/16/02)

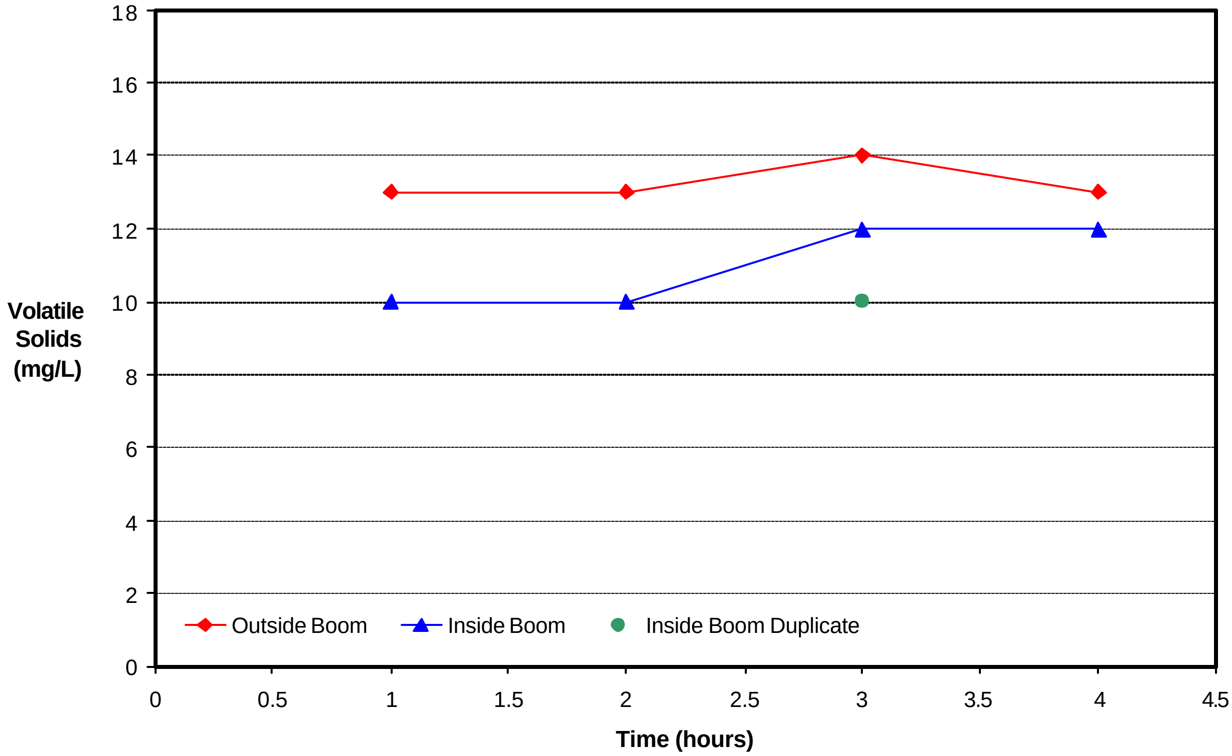


Figure 15. Volatile Solids at CRBL06 (7/17/02)

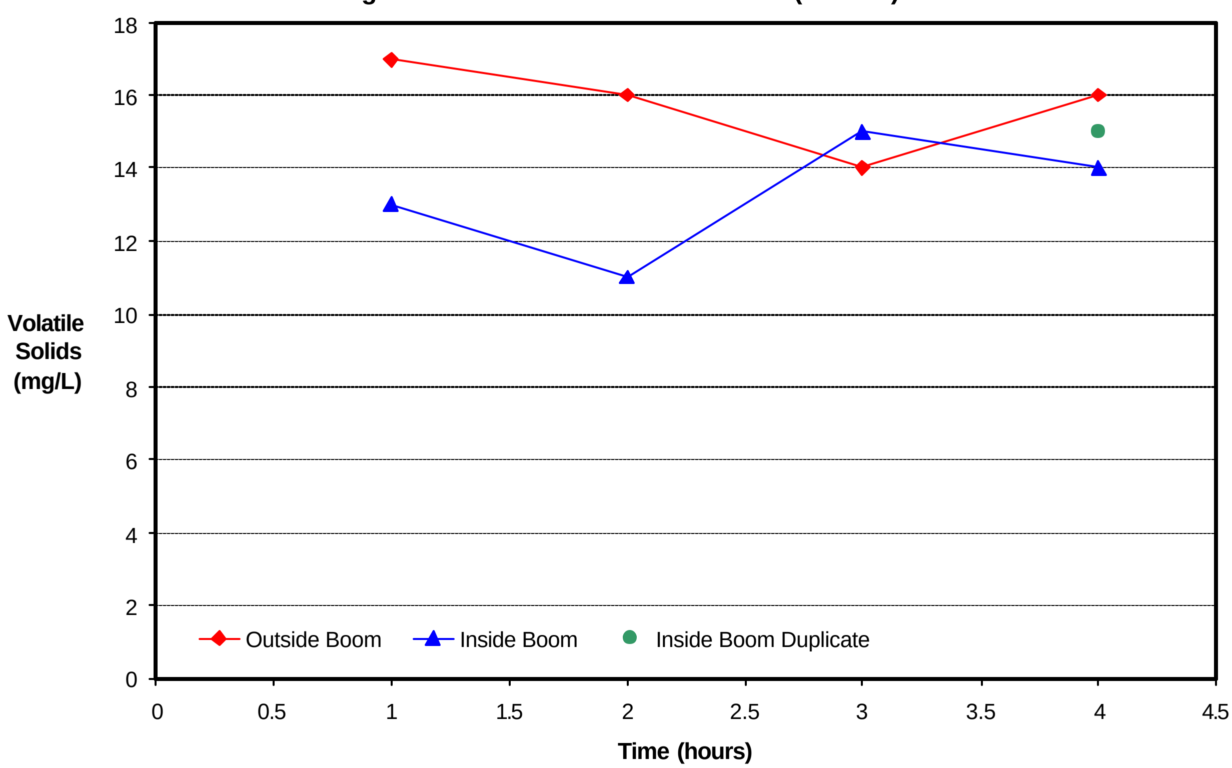


Figure 16. Apparent Color at CRBLA8 (7/16/02)

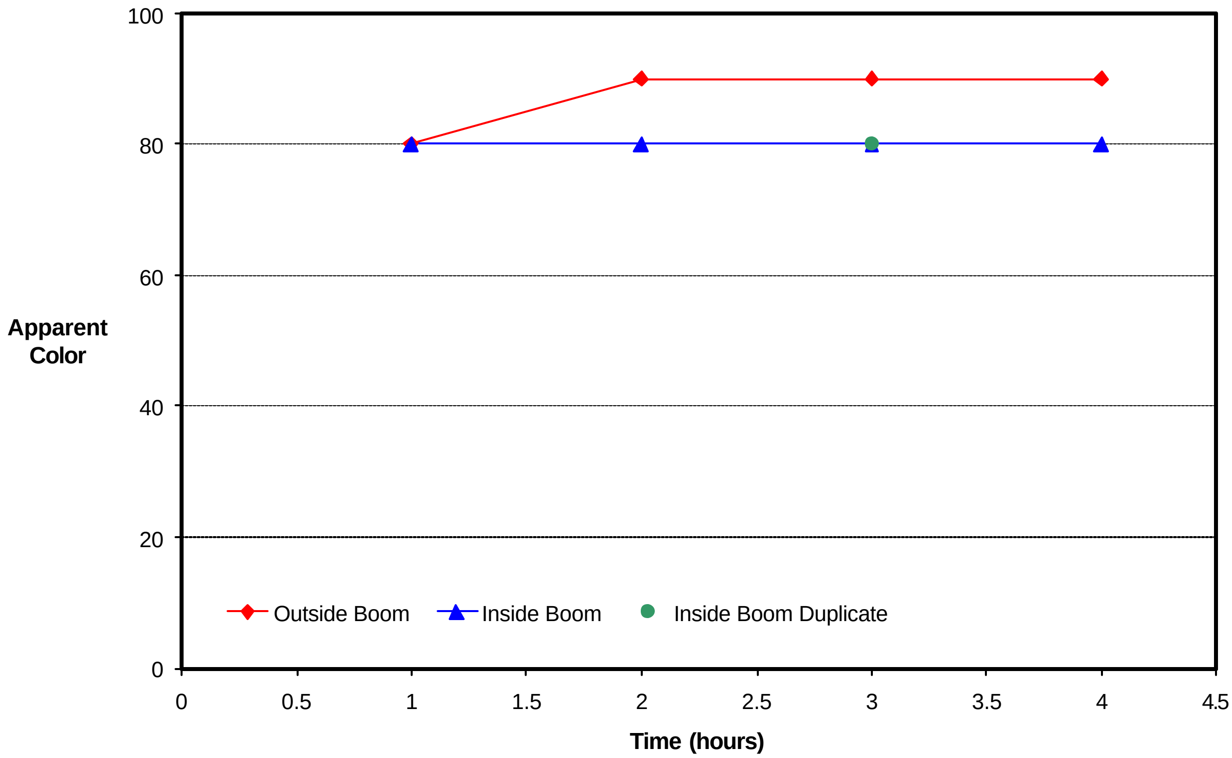


Figure 17. Apparent Color at CRBL06 (7/17/02)

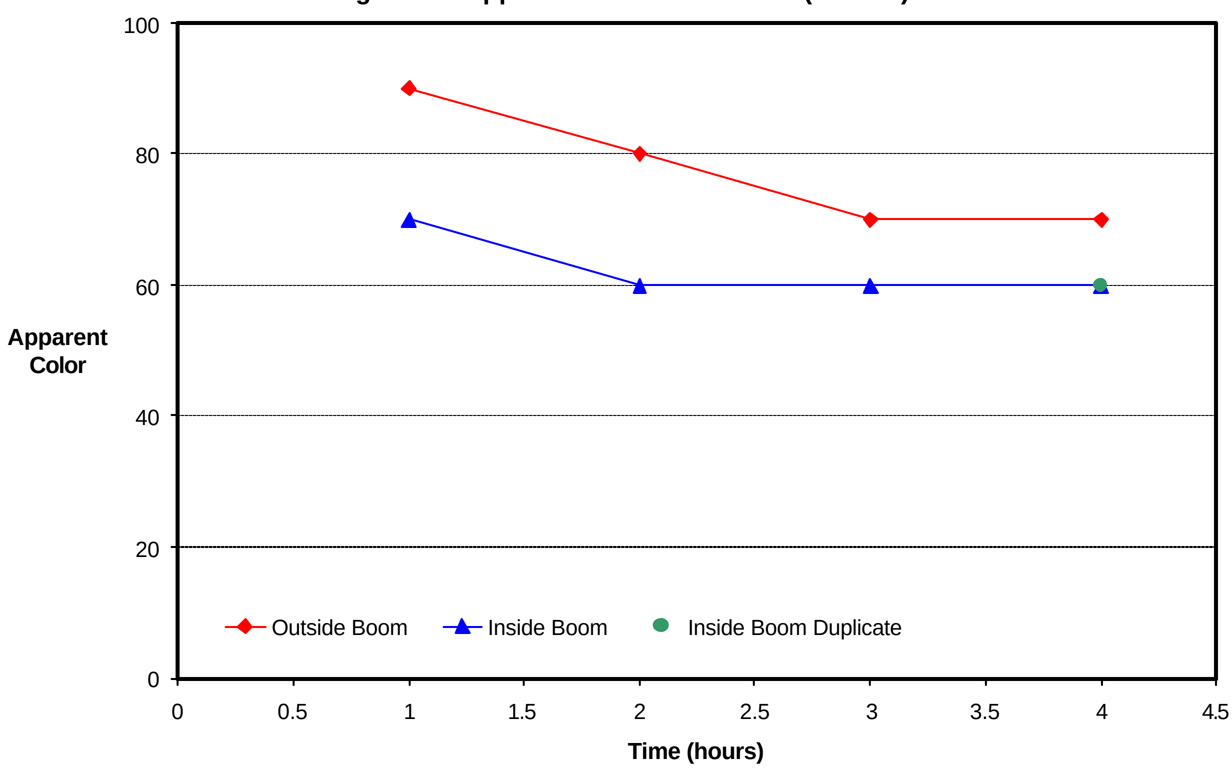


Figure 18. True Color at CRBLA8 (7/16/02)

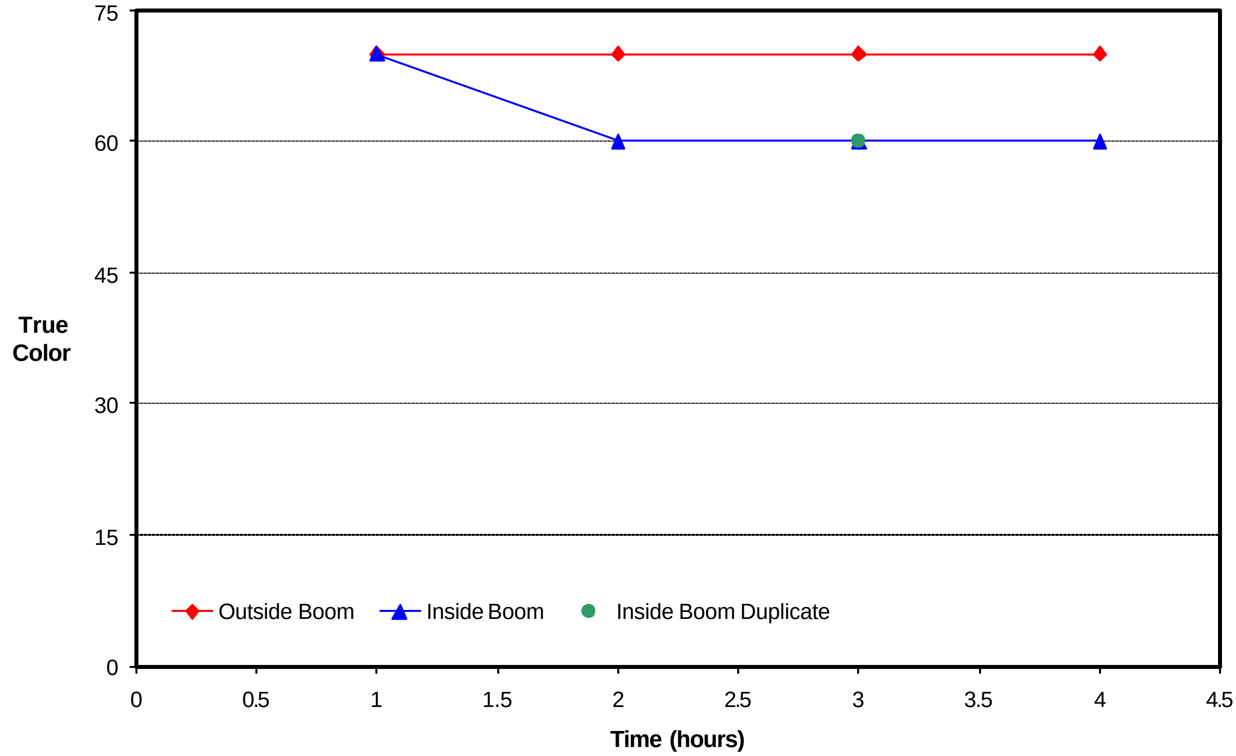


Figure 19. True Color at CRBL06 (7/17/02)

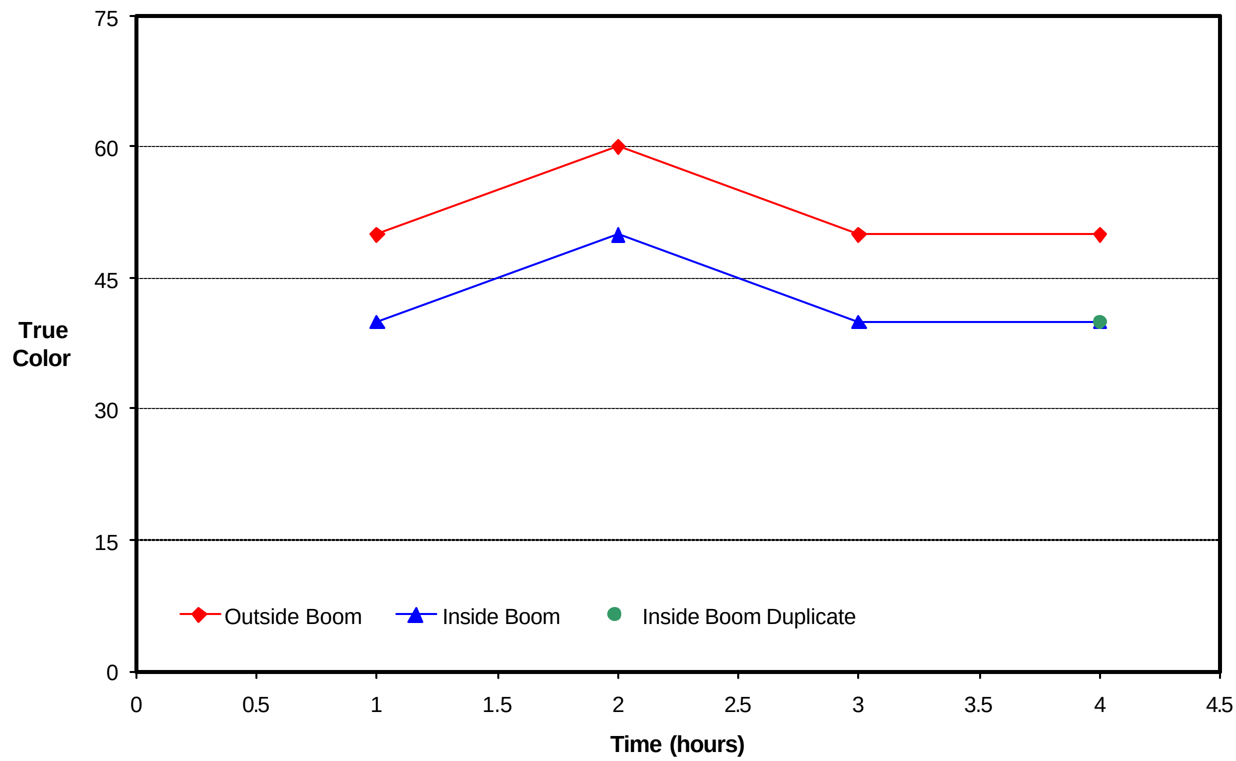


Figure 20. Chlorophyll *a* at CRBLA8 (7/16/02)

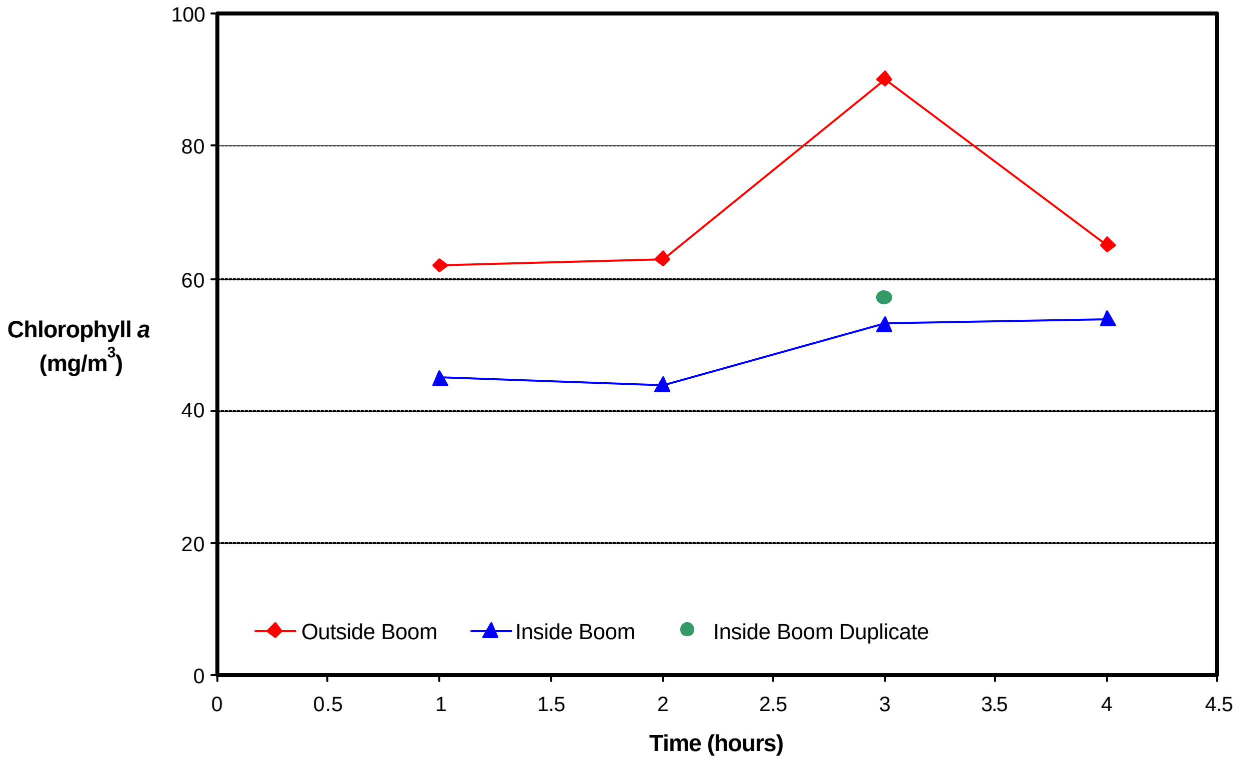


Figure 21. Chlorophyll *a* at CRBL06 (7/17/02)

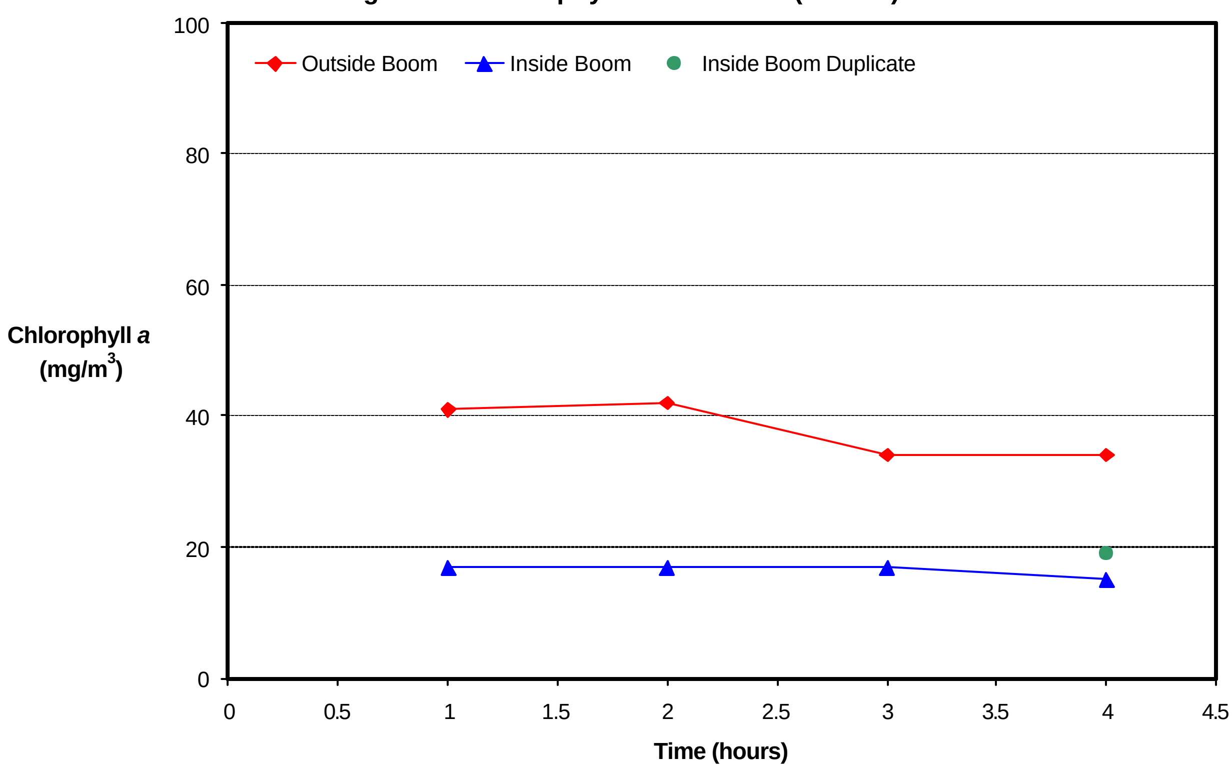


Figure 22. Total Phosphorus at CRBLA8 (7/16/02)

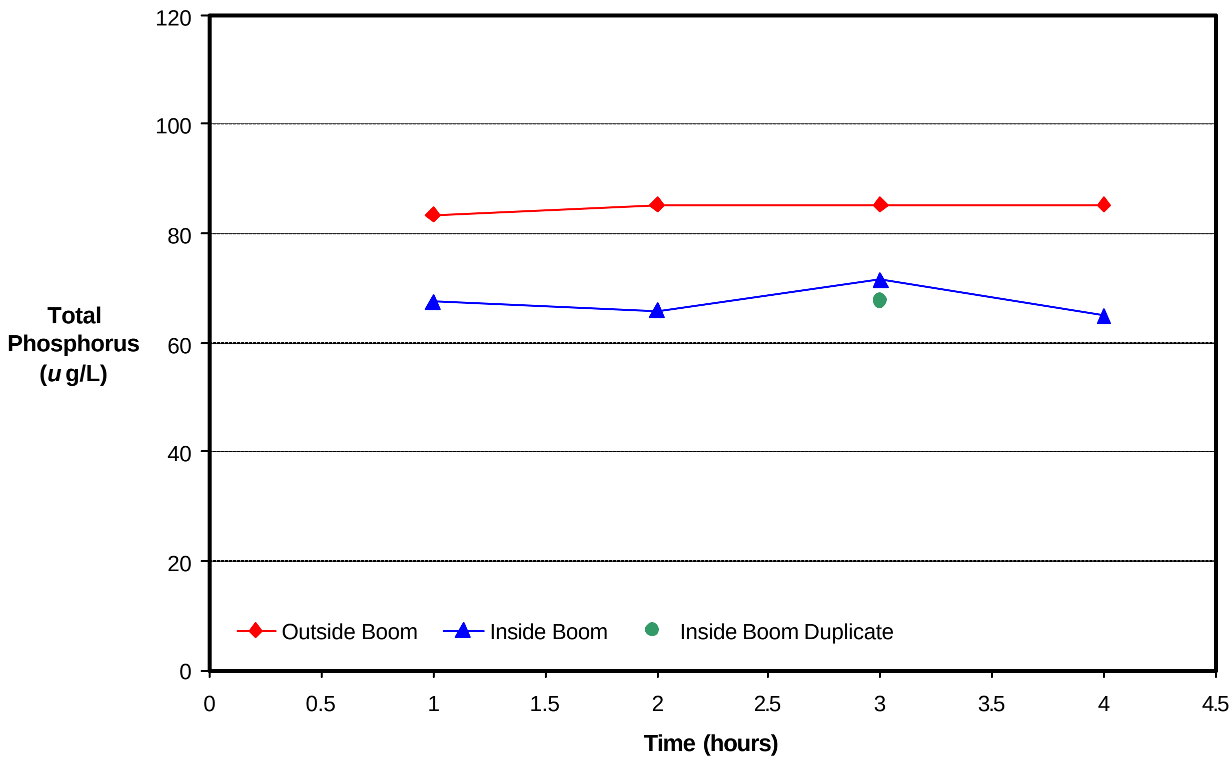
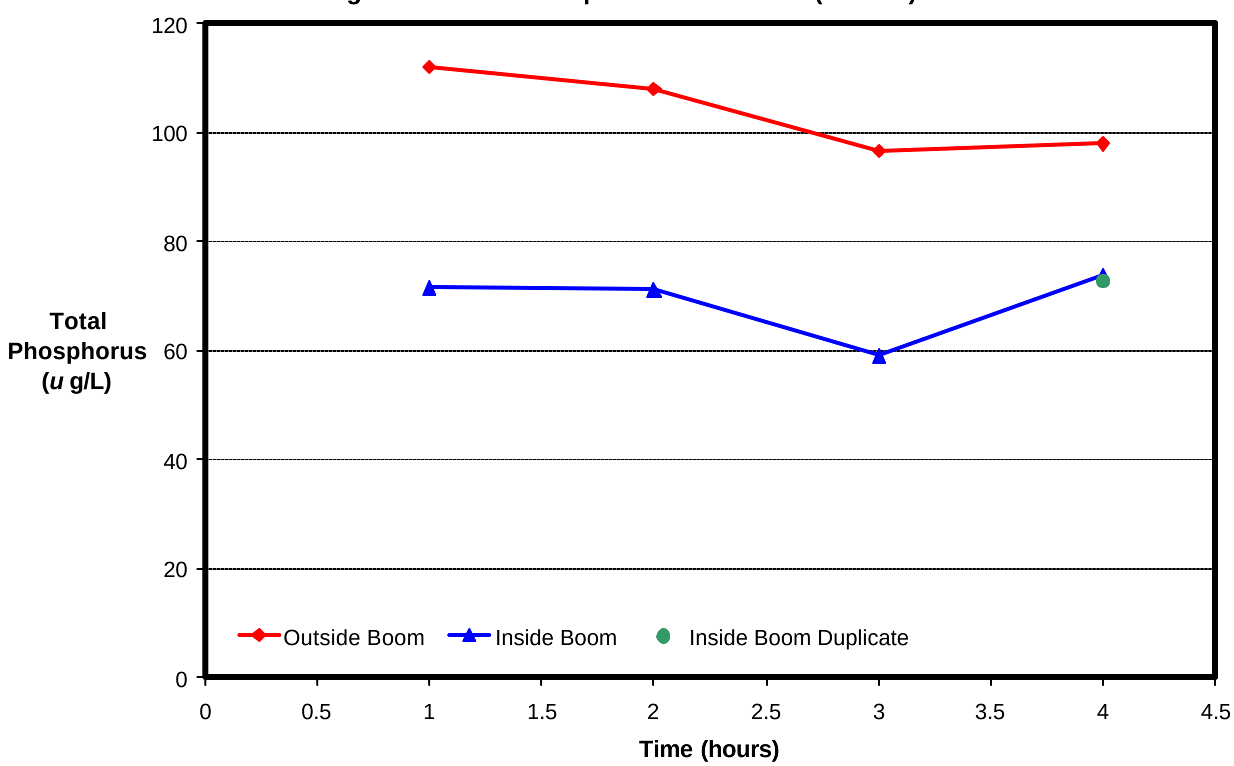


Figure 23. Total Phosphorus at CRBL06 (7/17/02)



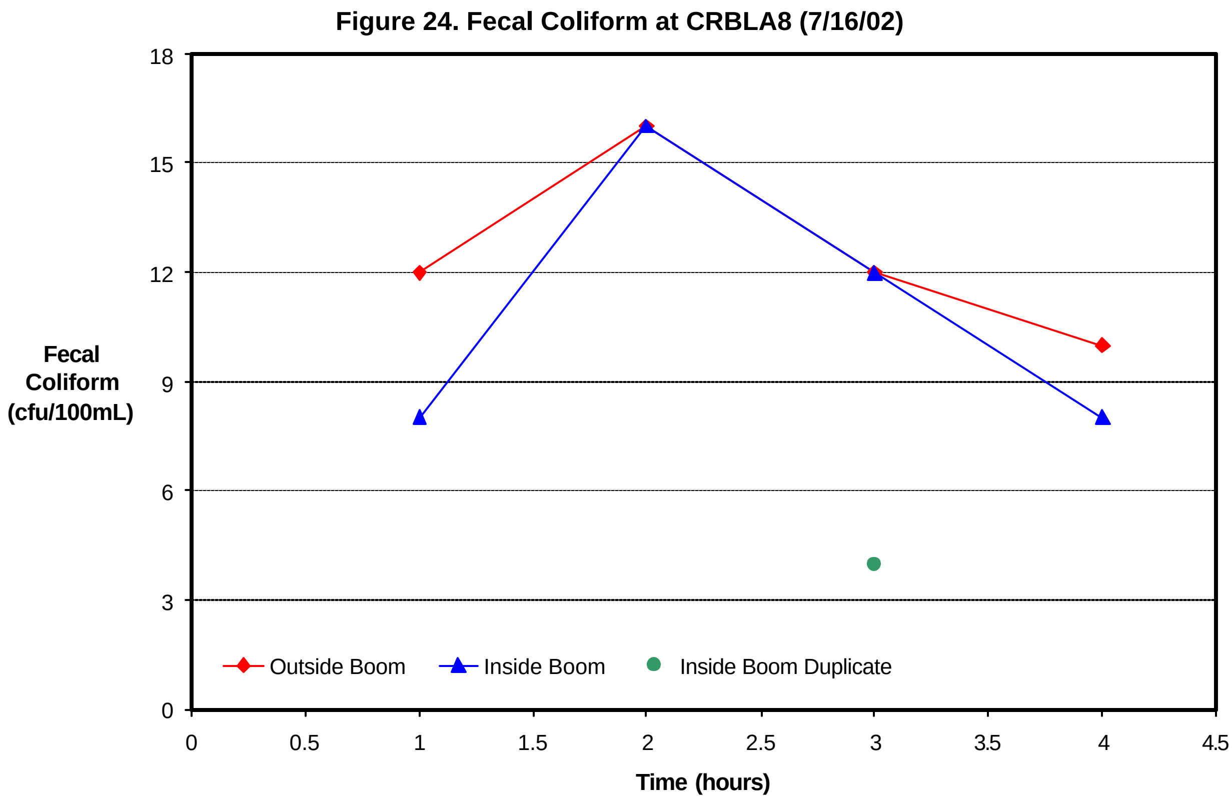


Figure 24. Fecal Coliform at CRBLA8 (7/16/02)
Fecal Coliform (cfu/100mL)
0
3
6
9
12
15
18
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
Time (hours)
Outside Boom
Inside Boom
Inside Boom Duplicate

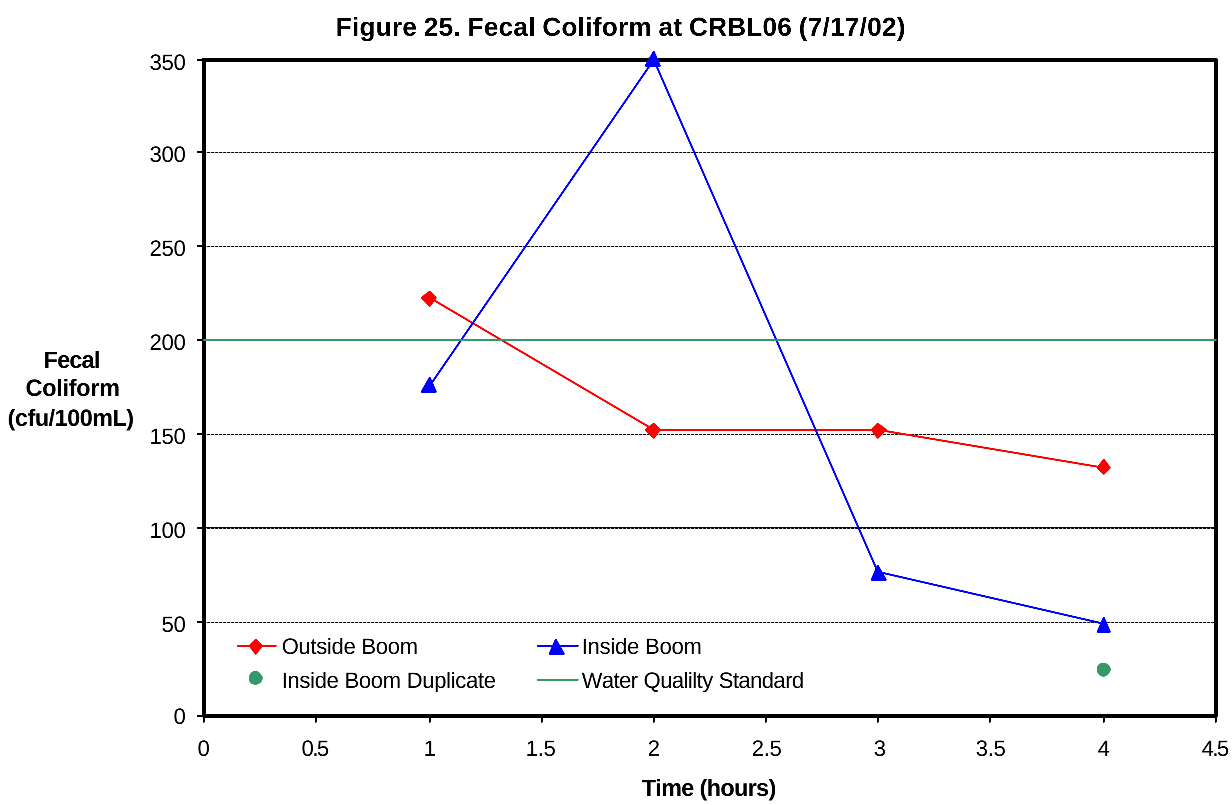


Figure 25. Fecal Coliform at CRBL06 (7/17/02)
Fecal Coliform (cfu/100mL)
0
50
100
150
200
250
300
350
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
Time (hours)
Outside Boom
Inside Boom
Inside Boom Duplicate
Water Qualilty Standard

Figure 26. *E. coli* at CRBLA8 (7/16/02)

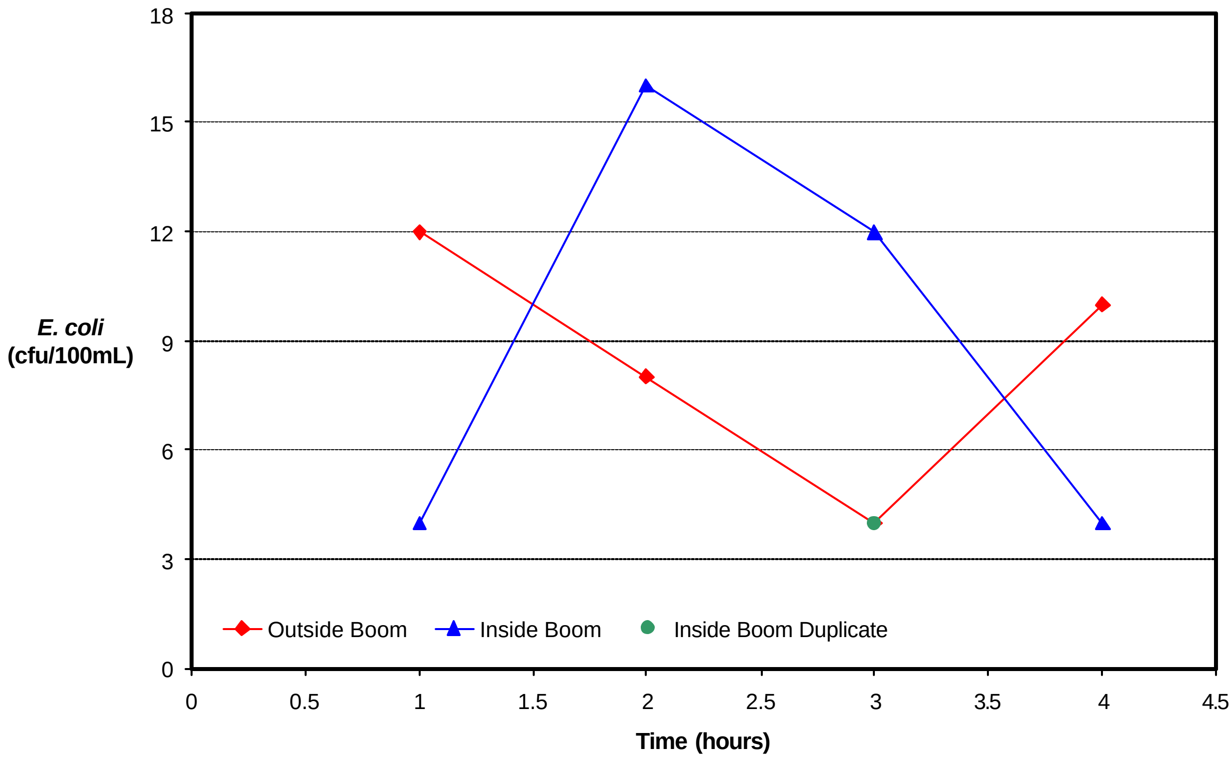
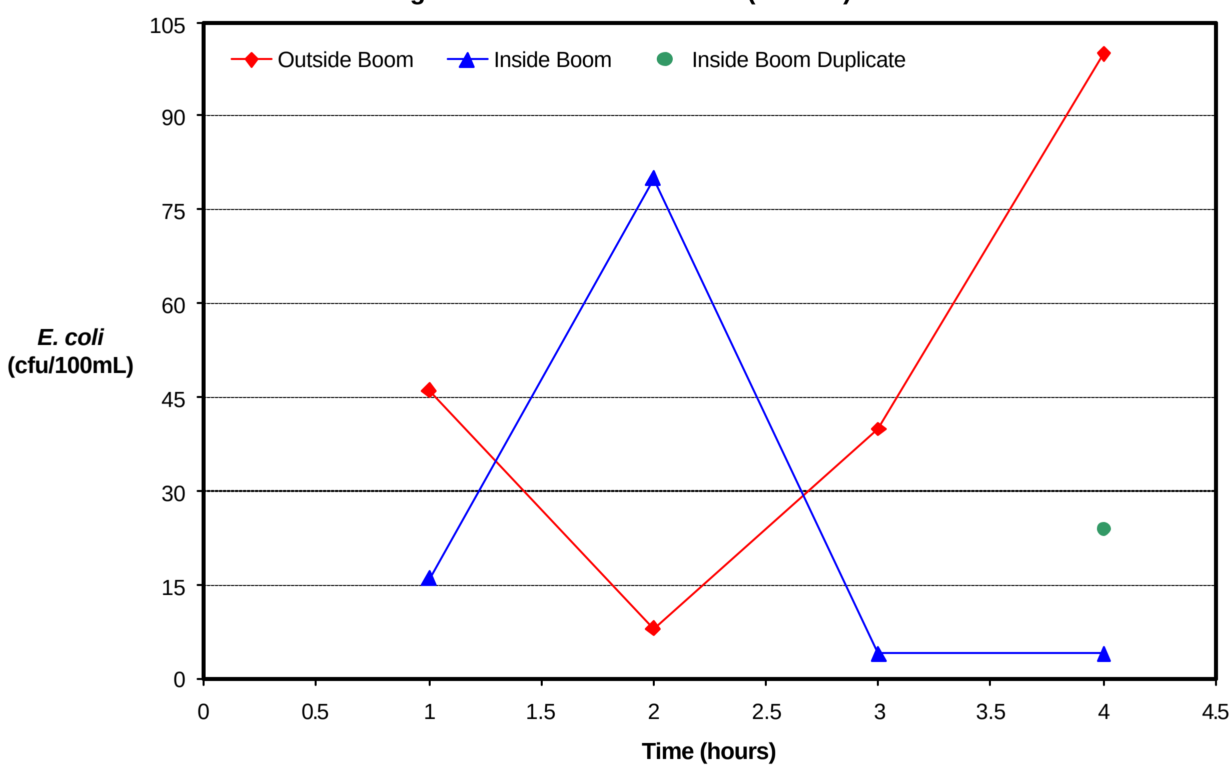


Figure 27. *E. coli* at CRBL06 (7/17/02)



Results

Test Station CRBLA8 (7/15/02)

The first day of testing (7/15/02) was primarily reserved for system set up and was limited to two sampling events. The pump was operated at full-throttle (~239 gpm) for 120 minutes with samples taken after approximately 0.5 and 1.33 hours of pumping. The total volume of water in the test system was approximately 5400 gallons, representing a removal and replacement of approximately 1.3 volumes and 3.5 volumes, for the two sampling events, respectively. While the results were favorable, the short duration of testing does not accurately reflect the nature of a BPS™ deployment; as such, its discussion is limited to this paragraph, with the raw data presented in Appendix 1.

Test Station CRBLA8 (7/16/02)

The second day of testing took place over four hours and produced a full data set reflective of BPS™ system performance. For this test, the pump was run for 4 hours at mid-throttle (~116 gpm), with samples taken after the first hour of pumping and each hour thereafter. Thus, the sampling events reflected volumes pumped of 1.3, 2.6, 3.9 and 5.2 times the volume of water in the test apparatus. The pump rate was decreased from the first day after consulting Gunderboom, Inc. engineers to better approximate the conditions of a fully-deployed BPS™ and minimize the possibility of drawing particulates through the boom fabric itself. The rate of pumping (116 gpm) represented a fabric through-flow rate of approximately 0.5 gpm per ft^2. Overall, the data from the second day of testing station CRBLA8 (7/16/02) are indicative of the system's ability to enhance water quality in the Charles River. Maximum percentage improvements over this sample period are summarized in Table 3.

Table 3. Maximum percentage improvements at station CRBLA8 (7/16/02).

Parameter (units)	**Outside**	**Inside**	**Improvement**
Secchi Depth (meters)	1.1	1.4	**27%**
Transmissivity (%)	43.0	50.8	**18%**
Turbidity (NTU)	5	3	**40%**
Total Suspended Solids (mg/L)	10	5	**50%**
Volatile Solids (mg/L)	14	10 (Dup.)	**29%**
Apparent Color	90	80	**11%**
True Color	70	60	**14%**
Chlorophyll *a* (mg/m^3)	90	53	**41%**
Total Phosphorous (*u*g/L)	85.3	64.9	**24%**
Fecal Coliform (cfu/100ml)	12	4 (Dup.)	**67%**
E.coli (cfu/100ml)	12	4	**67%**

As can be seen in figures 24 through 27, the results of the bacteria testing were erratic, especially for *E. coli*. This may due to the low ambient *E. coli* levels, which make small variations in the data "significant," providing a large margin for error; with baseline levels so low, it is difficult to rely on the data. Complementing this explanation are the results of the duplicate tests run for both fecal coliform and *E. coli* after 3 hours of testing. The ambient fecal coliform level at CRBLA8 at the third hour of testing was 12 cfu/100mL. The initial fecal coliform level inside the boom was equal to ambient levels at 12 cfu/100ml. The duplicate fecal coliform level for this sample period was 4 cfu/100ml, far below the ambient level. The similar pattern was repeated for *E. coli*, where an ambient level after 3 hours of pumping was 4 cfu/100ml. The initial *E. coli* sample was measured at 12 cfu/100ml with the duplicate test at 4 cfu/100ml, equal to ambient levels. This pattern, when applied to the *E. coli* data inside the boom after 2 hours of pumping on 7/16/02, presents the possibility that the inside level may have been abnormally high, and would have been corrected if a duplicate sample had been taken.

Test Station CRBL06 (7/17/02)

The third day of testing (7/17/02) took place over four hours and again produced a full data set reflective of BPS™ system performance. For this series of samples, the pump was run for four hours at mid-throttle (~116gpm), with samples taken after the first hour of pumping and each hour thereafter. The results from station CRBL06 (7/17/02) follow a similar pattern to those from station CRBLA8 (7/16/02), relative to the change in sample location and therefore change in ambient water quality conditions. Maximum percentage improvements over this sample period are summarized in Table 4.

Table 4. Maximum percentage improvements at station CBLA06 (7/17/02).

Parameter (units)	**Outside**	**Inside**	**Improvement**
Secchi Disk (meters)	0.9	1.5 (Maximum)	**67%**
Transmissivity (%)	31.6	53.3	**69%**
Turbidity (NTU)	5.5	2.4	**56%**
Total Suspended Solids (mg/L)	15	4	**73%**
Volatile Solids (mg/L)	16	11	**31%**
Apparent Color	80	60	**25%**
True Color	50	40	**20%**
Chlorophyll *a* (mg/m^3)	42	17	**60%**
Total Phosphorous (*u*g/L)	96.5	59	**39%**
Fecal Coliform (cfu/100ml)	132	24 (Duplicate)	**82%**
E.coli (cfu/100ml)	100	ND (4)	**96%**

The third day of testing again provided data supporting the ability of the technology to improve water quality in the Charles River. During testing, anomalous data were collected for volatile solids, fecal coliform, and *E. coli*, warranting further discussion. The volatile solids reading inside the boom (15 mg/L) after 3 hours of pumping on the third day were greater than ambient levels (14 mg/L). This difference of 1 mg/L is due to a combination of an increase in the inside levels and a decrease in ambient sample level. Regardless, the pattern seen in the duplicate run for the final sample of the day indicates a potential for a difference of 1 mg/L between two samples. Therefore, in the case of volatile solids after 3 hours of sampling on 7/17/02, the inside and outside values may have been equal if a duplicate was taken. Regardless, the difference was partially regained after the fourth hour of sampling.

On the third day of testing, the levels of both fecal coliform and *E. coli* showed substantial decreases in each case, except for after two hours of pumping. At the time of the anomalous data, Secchi depth readings were at their greatest, transmissivity at its highest, turbidity near its lowest, and TSS far below ambient levels. There does not appear to be any correlation that would explain why bacterial counts suddenly increased. Upon inspection of the duplicate samples for these tests, it is difficult to draw any definitive conclusions as to the nature of the data. It appears that these two bacterial spikes are anomalous data that, due to the small sample size, weigh heavily on the data set.

Discussion

Results from the 2002 testing of the Gunderboom® BPS™ test system in the Lower Charles River indicate that the technology has the capacity to significantly improve water quality in the river with respect to Secchi depth, transmissivity, turbidity, TSS, apparent color, true color, chlorophyll *a*, and total phosphorus. The data also show that the BPS™ has the potential to substantially reduce volatile solids and fecal coliform and *E. coli* bacteria levels in the Lower Charles River. These results were accomplished with negligible effect on the baseline water quality parameters of temperature, dissolved oxygen, pH, specific conductivity, and salinity. Varying environmental conditions played no role in the consistency of data; however, changes in sampling location did change the ambient water quality.

Water Clarity

Overall, the BPS™ was able to improve the average water clarity (as measured by Secchi depth) inside the system at both sampling locations and bring the water into compliance with the 4-foot (1.22 meters) water clarity standard. The average Secchi depth measurement within the BPS™ improved by an average of 25% at station CRBLA8, near the lagoons, and by an average of 42% at station CRBL06, near BU Bridge. The maximum Secchi depth measurement (5 feet or 1.5 meters) was taken inside the test system at station CRBL06. This measurement was limited by the bottom of the test chamber, and may have been greater if the test system was designed with greater depth. In all instances, Secchi depth measurements showed non-compliance with the water clarity standards for water outside of the BPS™. However, the water enclosed within the BPS™ was in compliance with water clarity standards 100% of the time at station CRBLA8 (7/16/02) and 75% of the time at station CRBL06 (7/17/02).

Using historical data for stations CRBLA8 (collected by EPA in 2002) and CRBL06 (collected by EPA from 1998 through 2002), cumulative frequency distributions were developed for Secchi depth. The historical data for station CRBLA8 are in compliance with water clarity standards approximately 88% of the time (Figure 28). When the average percent improvement in Secchi depth (25%) associated with BPS™ technology is applied to the historical data for this location, results show the potential for 100% compliance with water clarity standards. The historical data for station CRBL06 are in compliance with water clarity standards approximately 31% of the time (Figure 29). When the average percent improvement in Secchi depth (42%) associated with BPS™ technology is applied to the historical data for this location, results show the potential for 76% compliance with water clarity standards.

Bacteria

Overall, the BPS™ was able to decrease bacterial levels inside the system at both sampling locations. *E. coli* bacteria levels inside the test system were, conservatively, equal to or below ambient outside levels for 70% of the samples taken. Fecal coliform bacteria levels within the BPS™ improved by an average of 24% at station CRBLA8, near the lagoons, and by an average of 54% at station CRBL06, near BU Bridge. These results are comparable to results seen with other Gunderboom® systems, which have clearly demonstrated an ability to reduce bacterial counts in other applications, including harbors and surface waters used for drinking water supplies.

Fecal coliforms measured within the BPS™ were in compliance with bacteria standards in all instances but one. After 2 hours of pumping at station CRBL06 (7/17/02), fecal coliform (and *E. coli*) levels inside the boom measured higher than those outside of the boom. However, this anomalous data is followed and preceded by lower bacteria levels inside the boom (as compared to outside the boom). At the time of the anomalous data, Secchi depth measurements were at their greatest, transmissivity was at its highest, and TSS and turbidity were near their lowest measurements. There does not appear to be any correlation that would explain why bacterial counts suddenly increased. Upon inspection of the duplicate samples of these tests, it is difficult to draw any definitive conclusions as to the nature of the data. It appears that these two bacterial spikes are anomalous data that, due to the small sample size, weigh heavily on the data set.

Using historical data for stations CRBLA8 (collected by EPA in 2002) and CRBL06 (collected by EPA from 1998 through 2002), cumulative frequency distributions were developed for fecal coliform bacteria. The historical data for station CRBLA8 are in compliance with water quality standards approximately 85%

of the time. When the average percent improvement in fecal coliform bacteria levels (24%) associated with BPS™ technology is applied to the historical data for this location, results show the potential for 92% compliance in water quality standards (Figure 30). The historical data for station CRBL06 are in compliance with water quality standards approximately 37% of the time. When the average percent improvement in fecal coliform bacteria levels (54%) associated with BPS™ technology is applied to the historical data for this location, results show the potential for 63% compliance with water quality standards (Figure 31).

Figure 28. Secchi Depth Measurements at CRBLA8 (Lagoons)
Historical (data for 2002) Vs. Projected

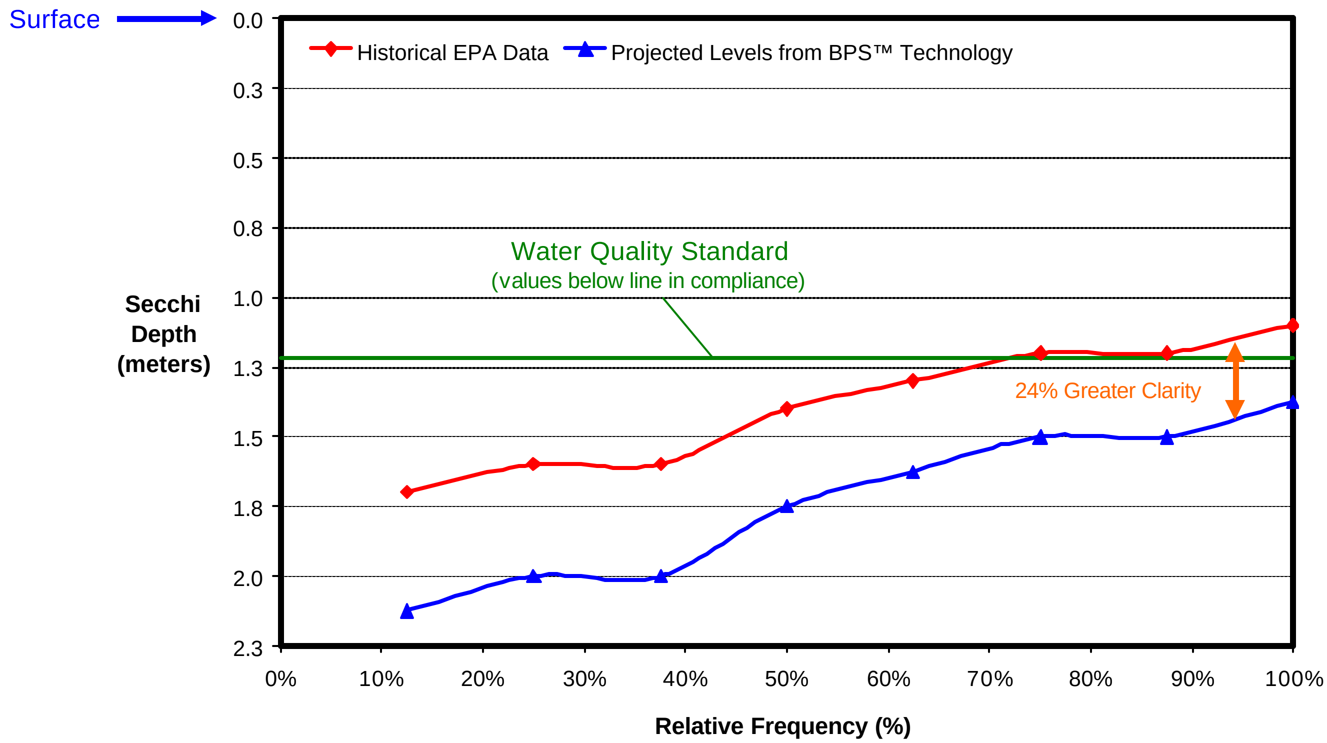


Figure 29. Secchi Depth Measurements at CRBL06 (BU Bridge)
Historical (data for 1998-2000) Vs. Projected

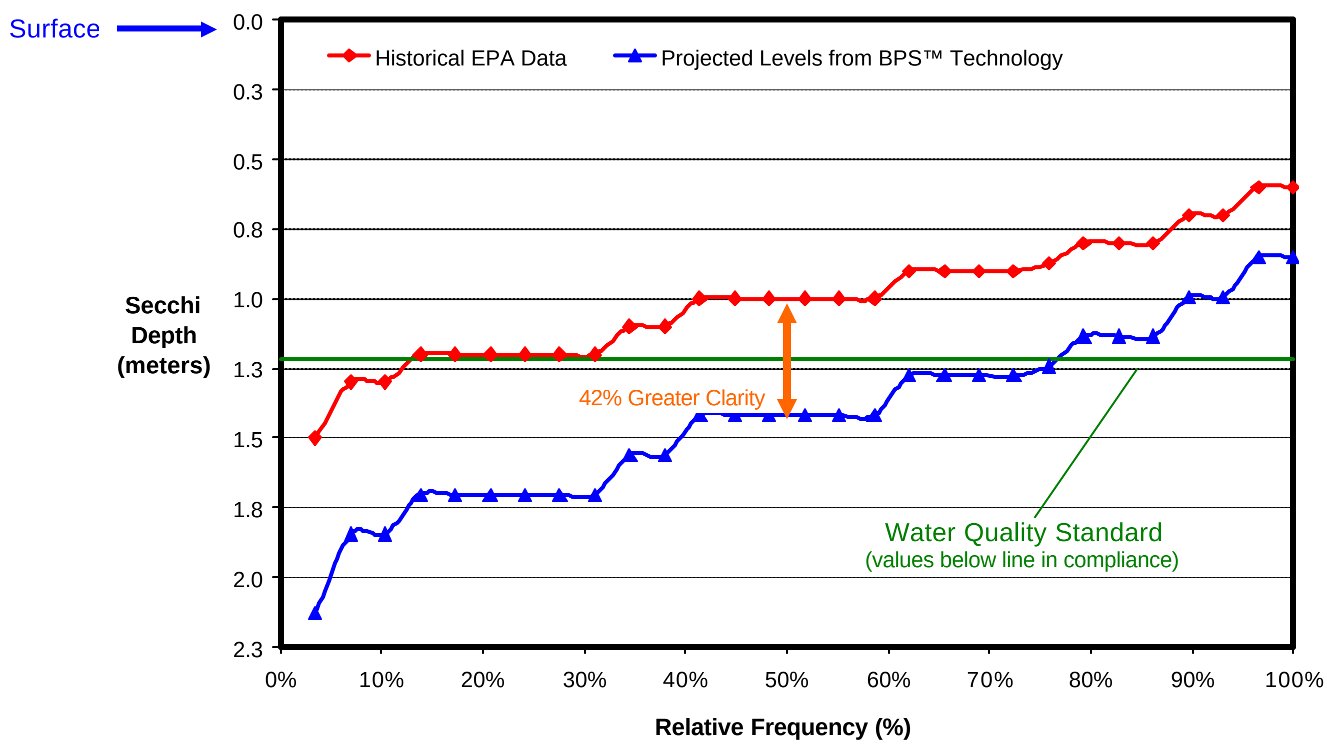


Figure 30. Fecal Coliform Bacteria at CRBLA8 (Lagoons)
Historical (data for 2002) Vs. Projected

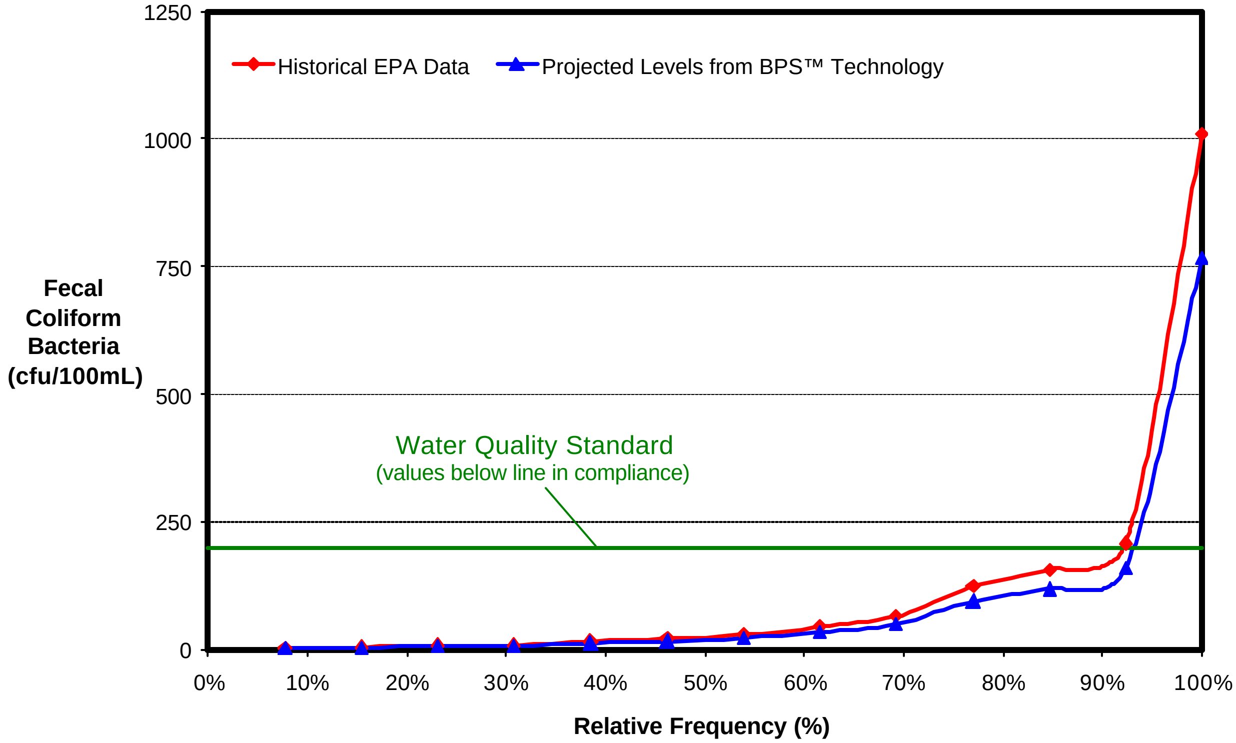
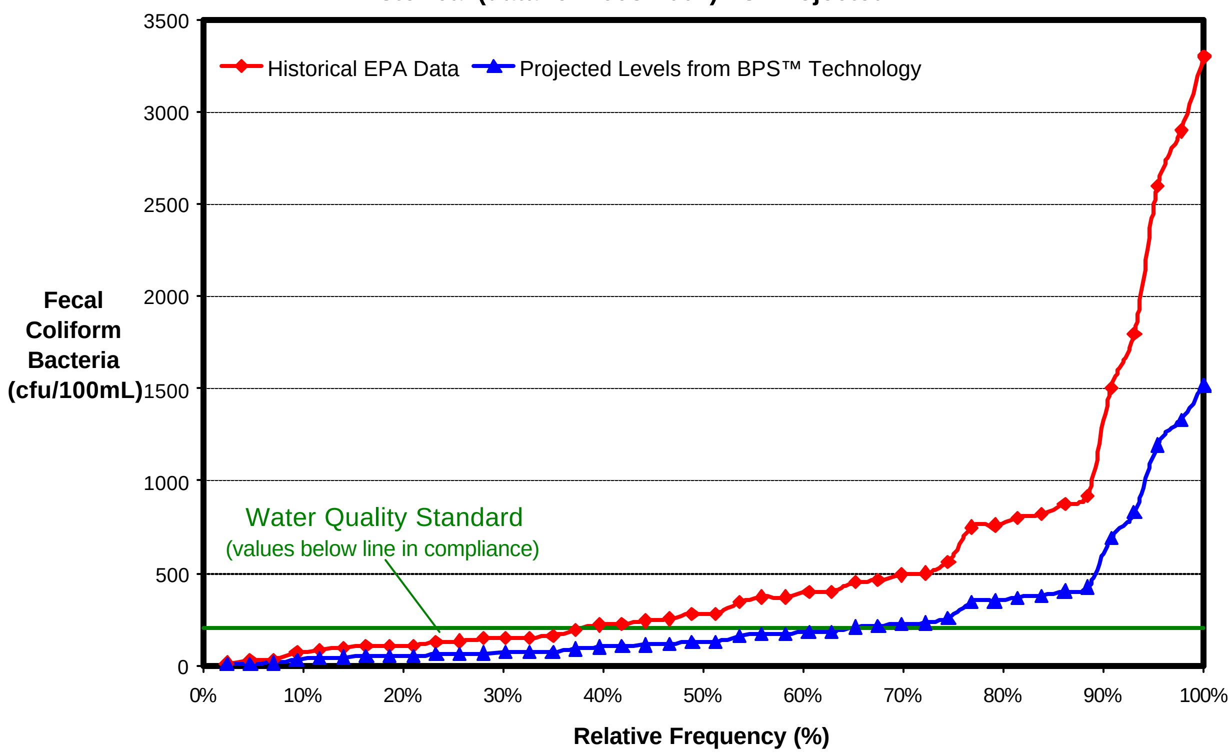


Figure 31. Fecal Coliform Bacteria at CRBL06 (BU Bridge)
Historical (data for 1998-2002) Vs. Projected



Comparison to Other BPS™ Applications

The results associated with the Lower Charles River BPS™ test system are consistent with applications of other Gunderboom® systems that have clearly demonstrated an ability to reduce bacterial counts and improve overall water quality, including harbors and surface waters used for drinking water supplies; three examples are presented.

Rye Lake/Kensico Reservoir Protection System (RPS™) in Westchester County, NY

Representative reductions are described (below) for testing conducted by the Westchester Joint Water Works for a 650-foot RPS™ in Rye Lake/Kensico Reservoir (Westchester County, NY). In this case, the goal of the system was to contain the contents of a polluted tributary, therefore the values for the "contained area" would be equivalent to the ambient conditions of the Charles River, and "outside boom" equivalent to the area inside the Charles River BPS™.

	Contained area	Outside boom
Total suspended solids (mg/L)	20.0	1.1
Turbidity (NTU)	11.0	0.7
Fecal Coliform (MPN)	>2400	22

Wachusett Reservoir Protection System™ (RPM™) in central Massachusetts

During extensive testing of the performance of a 350-foot Gunderboom® system, conducted as part of an EPA-sponsored demonstration project, in the Wachusett Reservoir in central Massachusetts, statistically-significant reductions were found over a season of stormwater flow sampling. Other than some sampling events containing unexplainable anomalous results, the data sets showed results as follows:

	Percentage Reduction	Alpha level[1]
Turbidity (NTU)	33% - 84%	0.001
Fecal Coliform (MPN)	78% - 98%	0.001

[1]Matched Pair – Sign Test

Harbor Island Beach Protection System (BPS™) in Mamaroneck, NY

Based on testing by the Westchester County, New York, Department of Health (WCDH) for a beach enclosed by a Gunderboom® system in Mamaroneck Harbor, WCDH staff reported the following results in a paper published in the Journal of Envi ronmental Health (Guido, et al., 1994):

	Percentage Reduction from Ambient	NY DOH 30-day Standards	Overall Inside Mean Percentage Below Standard
Total Coliforms (MPN)	62%	2400	
Fecal Coliform (MPN)	52%	200	69% below

The most recent and applicable full scale BPS™ application to date is the Harbor Island deployment at Mamaroneck, New York, deployed in the late summer of 2002 (Figure 32). A replacement for the successful Mamaroneck Harbor Island Beach BPS™ described above, this system incorporated many additional design updates from the original, including an enhanced anchoring system and updated structural materials. The initial data were collected and analyzed by the town to determine the effectiveness of the system at providing a safe swimming area (Table 5). Data from 9/16/02 was taken closely following the deployment of the boom. One week later, 9/24/02, the BPS™ brought the water quality at the beach into full compliance with the New York State Standards for safe swimming (2400 MPN Total Coliforms, 200 MPN Fecal Coliform).

Figure 32. The successful Harbor Island BPS™ at Mamaroneck, NY

Table 5. Results of bacteriological testing for the Harbor Island Beach BPS™ in Mamaroneck, New York.

Location	9/16/02**		9/24/2002		10/1/2002		10/8/2002	
	Total Coliforms	Fecal Coliform	Total Coliforms	Fecal Coliform	Total Coliforms	Fecal Coliform	Total Coliforms	Fecal Coliform
Outside boom left	>24,000	>24,000	2,400	2,400	3,500	50	790	270
Outside boom right	>24,000	16,000	3,500	330	1,300	80	330	80
Outside boom center	>24,000	16,000	n/a	n/a	2,400	220	220	110
Inside boom left	>24,000	>24,000	20	20	20	20	<20	<20
Inside boom right	>24,000	>24,000	170	170	<20	<20	20	20
Inside boom center	>24,000	3,500	n/a	n/a	20	<20	20	<20
** Rain Event								

Conclusion

In comparison to data collected from the previous Charles River BPS™ test in 2000, the 2002 effort confirms the test system's ability to bring Charles River water quality within the Massachusetts State swimming standards. As planned, the 2002 deployment, which utilized a refined test system, demonstrated the ability of the BPS™ to decrease both fecal coliform and *E. coli* bacteria levels within the contained area. Combined, the data sets support the ability of the technology to enhance the water quality of the Charles River and provide a safe swimming area on the Charles River that can meet Massachusetts State swimming standards.

Full Scale Application

Based on the combined results of testing in 2000 and 2002, Gunderboom, Inc. is prepared to develop systems that can be designed, installed, and operated on the Charles River in order to provide a safe swimming area for bathers. The BPS™ system is a potentially useful means to restoring sections of the Lower Charles River to "swimmable" conditions by Earth Day 2005, a goal established as part of the EPA *Clean Charles 2005 Initiative*.

The Charles River BPS™ would be designed using the technology and techniques employed for the successful Mamaroneck BPS™ system described above. Given the encouraging nature of the 2002 Charles River test results, and the proven success of other large scale applications, namely Mamaroneck Harbor, there is potential for the Charles River BPS™ to be very successful. The next step pursuant to the installation of a BPS™ on the Charles River would involve the development a preliminary design plan for consideration and feedback from stakeholders. Gunderboom, Inc. utilizes a phased approach to project development to ensure project success and approval. This approach would result in the successful operation of a full scale Gunderboom® BPS™ installation.

A full scale BPS™ deployment in the Charles River may take many shapes. It could provide a safe swimming area in the body of the river off the existing shoreline, be part of an onshore swimming pavilion and/or act as a filtration unit for a pool-like structure. Gunderboom, Inc. scientists and engineers are capable of designing an efficient and effective solution for any need presented. Regardless of the final system design, the Charles River BPS™ would incorporate the same, or equivalent, filter material used in the successful test and Mamaroneck Harbor Island systems to improve the water clarity and quality of the Charles River. Through-fabric flow rates would be equivalent to that used for testing at approximately 0.5 gpm/ft^2 of material and produced by pumping water from inside to outside the enclosed area. This could be accomplished at "off-peak" hours, and intermittently, to mimic a tidal cycle, such as is present at Harbor Island Mamaroneck, where pumping is not necessary. Pumping not only brings in fresh, filtered water through the fabric boom, but expels the water inside the boom which has had contact with bathers and others potential sources of contaminants.

One potential orientation of the Charles River BPS™ is similar to the one seen in figure 32, which displays the successful application of the Harbor Island BPS™ in Mamaroneck, New York. This boom extends from shore to shore in a semicircular orientation and is approximately 800 feet long, providing over 500 feet of protected shoreline and enclosing approximately 4.5 acres of safe swimming area.

Further development of the project would best be undertaken in the traditional, phased approach that is common to other Gunderboom, Inc. projects. This allows for feedback and project goals to be met in an efficient manner. The potential for further scale testing in the Charles River exists, including further, more rigorous bacteriological sampling to enhance the anomalous data collected in 2002. This small (2'x2'x2') dock-side Gunderboom® test system could be deployed anywhere and operate with minimal supervision. The focus would be on bacteria sampling with frequent tests at first and becoming less frequently as the system settles into a long term pattern. A test like this could be done with a minimum of effort by all parties involved and may provide valuable data to be considered in the decision process.

Appendix 1. Charles River Gunderboom Sample Results (2002)

Charles River Gunderboom Sampling Results

Samples and measurements were collected 0.2 meters below the water's surface.

Station	Sample Number	Time (hours)	Temp (deg C)	DO (mg/L)	DO (%)	pH	Sp Cond (mS/cm)	Salinity (ppt)	Secchi (meters)	Transmissivity (%)	Turbidity (lab test)	TSS (mg/L)	Volatile Solids (mg/L)	Apparent Color	True Color	Chlorophyll a (mg/m3))	Total Phosphorus ug/l	Fecal Coliform (cfu/100mL)	E. Coli (cfu/100mL)
Table 1: Results from 7/15/02 sampling (location: at CRBLA8 - near Esplanade)																			
Pumping began at 12:42																			
Results after approximately 30 minutes of pumping																			
GBOUT1	14923	13:25	25.9	9.9	121.9	8.2	1.43	0.72	1.2	44.2	4.7	10	14	70	60	51	83.2	16	4
GBIN02	14924	13:12	25.7	9.4	115.5	7.9	1.44	0.72	1.2	47.8	3.5	8	15	70	60	45	75.7	ND(4)	ND(4)
Results after approximately 1 hour 20 minutes of pumping																			
GBOUT1	14927	14:05	25.6	9.2	112.8	7.8	1.39	0.69	1.2	45.8	4.9	11	14	60	70	47	84.9	ND(4)	ND(4)
GBIN02	14928	14:00	25.8	9.6	117.8	8.0	1.45	0.72	NA	49.5	4.5	8	14	60	60	50	65.9	10	10
GBIN02(dup)	14929	NA	NA	NA	NA	NA	NA	NA	NA	NA	4.4	6	15	70	60	41	76.9	4	ND(4)
Table 2: Results from 7/16/02 sampling (location: at CRBLA8 - near Esplande)																			
Pumping began at 7:54																			
Results after approximately 1 hour of pumping																			
GBOUT1	20706	8:45	24.8	NA	NA	7.8	1.53	0.77	1.2	45.6	4.2	8*	13	80	70	62	83.4	12	12
GBIN02	20705	8:55	24.6	NA	NA	7.5	1.46	0.73	1.4	51.8	2.6	5*	ND(10)	80	70	45	67.3	8	4
Results after approximately 2 hours of pumping																			
GBOUT1	20708	9:45	25.0	NA	NA	8.0	1.55	0.78	1.1	45.8	4.5	10	13	90	70	63	85.1	16	8
GBIN02	14902	9:55	24.9	NA	NA	7.9	1.52	0.76	1.4	51.9	2.8	5*	10	80	60	44	66	16	16
Results after approximately 3 hours of pumping																			
GBOUT1	14903	10:45	25.5	NA	NA	8.5	1.63	0.82	1.1	44.6	4.9	11	14	90	70	90	85.1	12	4
GBIN02	14904	10:55	25.3	NA	NA	8.4	1.59	0.8	1.4	50.3	3.0	7*	12	80	60	53	71.3	12	12
GBIN02(dup)	20709	NA	NA	NA	NA	NA	NA	NA	NA	NA	3.1	6*	10	80	60	57	67.6	4	4
Results after approximately 4 hours of pumping																			
GBOUT1	14901	11:45	25.6	NA	NA	8.6	1.64	0.83	1.1	43	5.0	10	13	90	70	65	85.3	10	10
GBIN02	20707	11:55	25.6	NA	NA	8.6	1.63	0.82	1.4	50.8	3.0	6*	12	80	60	54	64.9	8	4
Table 3: Results from 7/17/02 sampling (location: Downstream of Boston University Bridge)																			
Pumping began at 7:23																			
Results after approximately 1 hour of pumping																			
GBOUT3	20712	8:20	24.1	5.4	64.7	7.0	1.06	0.53	0.9	31.6	5.5	15	17	90	50	41	112	222	46
GBIN04	20711	8:35	24.0	5.7	67.9	7.0	1.06	0.52	1.4	53.3	2.4	4*	13	70	40	17	71.5	176	16
Results after approximately 2 hours of pumping																			
GBOUT3	20714	9:20	24.2	6.0	71.9	7.1	1.00	0.49	0.9	34.1	5.0	12	16	80	60	42	108	152	8
GBIN04	20713	9:35	24.3	5.6	67	7.1	1.06	0.52	(on bottom) 1.5	55.9	2.4	5*	11	60	50	17	71.1	350	80
Results after approximately 3 hours of pumping																			
GBOUT3	20716	10:20	24.9	6.7	81.5	7.2	0.99	0.49	0.9	35	4.6	12	14	70	50	34	96.5	152	40
GBIN04	20715	10:35	24.9	6.2	74.8	7.0	1.04	0.51	1.2	35.2	2.4	5*	15	60	40	17	59	76	4
Results after approximately 4 hours of pumping																			
GBOUT3	20718	11:20	25.5	7.3	89.5	7.2	0.96	0.47	0.9	33.7	3.6	13	16	70	50	34	97.9	132	100
GBIN04	20717	11:35	25.3	6.7	82	7.1	1.00	0.49	1	40.5	2.6	7*	14	60	40	15	73.8	48	ND(4)
GBIN04(dup)	20719		NA	NA	NA	NA	NA	NA	NA	NA	2.3	6*	15	60	40	19	72.7	24	24

Note:

NA = not available

ND = not detected above the associate detection limit

* = indicates estimated values below the reporting limit

GBOUT01 and GBOUT03 were located outside the Boom. GBIN02 and GBIN04 were located inside the Boom.

All field data Qa QAEd by TF met holding times, no limitations and recchecked data entry

Appendix 2. Secchi depth vs. transmissivity in the Charles River as presented by EPA, using data collected at multiple locations and dates