Halifax Harbour
Water Quality Monitoring Program
Final Summary Report

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EXECUTIVE SUMMARY

The Halifax Harbour Water Quality Monitoring Program (HHWQMP) has been an integral part of the Halifax Harbour Solutions Project (HHSP). Prior to the development of the Halifax Harbour Solutions Project two sewage treatment plants had been operating at Mill Cove in Bedford Basin and in Eastern Passage. However about 80% of Halifax Harbour sewershed still entered Halifax Harbour untreated. In 1989 the Halifax Harbour Task Force (HHTF) was commissioned to develop environmental quality guidelines and objectives for uses of Halifax Harbour. The Halifax Regional Municipality (HRM) proposed a regional approach to treat raw sewage before discharge in the Harbour which encompassed three wastewater treatment facilities (WWTFs) with UV disinfection to be located in Halifax, Dartmouth and Herring Cove, a sewage collection system, combined sewage overflows (CSOs), three outfalls and diffusers, and a sewage sludge (biosolids) management facility. The HHSP was designed to meet the water quality objectives set by the HHTF. A condition of Environmental Assessment approval included the following requirement under the heading **3.6 Follow-up**:

"*Under the CEAA, a follow-up program:*
• *verifies the accuracy of the assessment; and*
• *determines the effectiveness of any mitigation measures that have been implemented.*

The primary objective of the project is to meet the water quality objectives for Halifax Harbour as set by the Halifax Harbour Task Force (HHTF 1990) based on intended end use. Upon completion of the project, the proponent will verify that these water quality objectives have been attained."

The above-noted condition of approval and requirement for project follow-up has therefore stipulated the objectives and framework for the Halifax Harbour Water Quality Monitoring Program.

Water quality monitoring commenced in June 2004, before any of the three proposed sewage treatment facilities were constructed, and ended several months after the re-commissioning of the Halifax Wastewater Treatment Facility in 2010. The monitoring program was based on water quality surveys that include over 30 sites distributed from the Bedford Basin to the Outer Halifax Harbour. Water samples taken at 1-m and 10-m depths below the water surface were analyzed for a set of water quality parameters. In addition, continuous vertical profiles with depth of basic hydrographic properties (salinity, temperature and depth), dissolved oxygen and fluorescence were collected. From June 2004 to June 2006 the surveys were conducted weekly and from July 2006 onward, slightly modified surveys were conducted biweekly. Regular sampling stopped in June 2009 with the Halifax plant out of commission, with two additional surveys in the fall of that year. Six additional surveys were conducted between May and September 2010 following re-commissioning of the Halifax plant.

The primary indicator of water quality and the one with the highest potential impact for human health is fecal coliform bacteria concentration, with the amounts measured in

CFU (coliform forming units) per 100 mL of volume. The guideline is expressed in terms of the geometric mean of at least 5 samples taken within 30 days in a given location. Two limits were considered in the analysis: the recreational or swimming limit of 200 CFU/100 mL, and the shellfish harvesting limit of 14 CFU/100 mL. The shellfish harvesting limit applies to the Outer Harbour, while the swimming limit applies to the Middle Harbour and Bedford Basin. The Inner Harbour was classified as an area intended for industrial use, therefore no guidelines apply to that area. During the baseline period before the WWTFs began operating (June 2004 to July 2007), there were frequent exceedances of the guidelines at individual sites, with the highest mean levels in the fall and winter seasons, and the lowest values in the spring and summer. The Inner Harbour was the most polluted area, with mean levels consistently above all guidelines. Measurements in the Middle Harbour and Bedford Basin routinely exceeded the applicable swimming guideline year-round at individual sites, and the mean levels for both sections were high with exceedances of the swimming limit in the fall and winter months. The Outer Harbour mean levels were relatively lower, but consistently above the applicable shellfishing guideline during all seasons in the baseline period.

The year 2008 represents a transitional period when the WWTFs gradually came online. Full effluent treatment began in Halifax in March, in Dartmouth in August, and in the Herring Cove WWTF in December 2008. Significant improvements were measured during this transitional period in all areas of the harbour, except for the Outer Harbour where no apparent effect was observed as the Herring Cove plant was not functional for most of 2008. The Dingle Park and Black Rock beaches were opened for public swimming in August 2008, for the first time in decades. In January 2009 the Halifax WWTF experienced a failure, resulting in elevated bacteria levels, but not to the baseline levels seen before the cleanup began. Full operation of the Halifax WWTF was restored in June 2010. The surveys conducted between June and September 2010 after all three WWTFs were operating in full capacity have shown vast improvements in all areas of the Harbour, on average meeting or exceeding the goals set by HHTF. The mean fecal coliform levels were below all applicable guidelines in all areas of the Harbour. Compared to the baseline fecal coliform concentrations, the levels in Bedford Basin were reduced by 87.5%; in the Inner Harbour where the baseline concentrations were highest, the mean levels were reduced by 97%; in the Middle Harbour by 90.5%; and in the Outer Harbour where the baseline concentrations were lowest, there was a reduction of 85%. There were a few localized guideline exceedances at individual sites, likely related to storm events that can cause overflows in the combined sewage overflow system, resulting in temporary untreated effluent discharges into the harbour.

The analysis of chemistry data shows that the guidelines for metals concentrations have been met on average, however intermittent exceedances of copper and mercury guidelines still occur. The spatial and temporal distribution of these exceedances does not allow for the identification of a single source of contamination.

The analysis of ammonia nitrogen levels shows an increase in the mean levels in 2010, up to twice the baseline values in the Inner Harbour area. This is not unexpected, as the effluent outfalls in 2010 were consolidated to the Inner Harbour area, while they were more widely dispersed through the harbour during the baseline period. Furthermore, the primary treatment process is not expected to diminish the ammonia nitrogen levels in the treated effluent. There are no guidelines set by HHTF for ammonia nitrogen, however there is the potential that elevated values may create the conditions for more frequent algal blooms in the Harbour, which may temporarily and locally reduce dissolved oxygen levels below the applicable guidelines. The measured dissolved oxygen levels in 2010 have been high and satisfying all applicable criteria in all areas of the Harbour, with local exceptions likely related to the observed elevated phytoplankton activity. The Bedford Basin deep water is prone to natural depression of dissolved oxygen, as it represents a deep fjord with a shallow sill that prevents intrusions of oxygenated continental shelf water through most of the year.

The mean levels of total suspended solids in the Harbour have been reduced to approximately 60% of the baseline levels, with a tendency for higher values in the Inner Harbour where the outfalls of the Halifax and Dartmouth WWTFs are located. This is an expected effect of the concentration of the TSS sources in the Inner Harbour by the placement of the Halifax and Dartmouth WWTF outfalls in this area. Due to the fact that the ambient TSS level is not explicitly defined, it is unclear whether the current TSS levels meet the HHTF guideline of 10% above ambient level. Furthermore, the available data for Halifax Harbour do not allow for the estimation of the purely anthropogenic contribution toward the observed TSS concentrations. Given the fact that the values are relatively low above the detection limit and natural plankton activity in the Harbour can contribute significantly, there is no indication that the current levels are abnormal or that they can be reduced further.

ACKNOWLEDGMENT

The authors would like to acknowledge the significant expert contribution of Stephen E. Hurlbut, (3 Sept 1949 – 9 Oct 2010) to the Halifax Harbour Water Quality Monitoring Program. Steve served the role of a Senior Ocean Engineer with Coastal Ocean Associates (COA, later AMEC Earth and Environmental), and was largely responsible for the design and continuous improvements of the methods employed in the monitoring program. He had conducted the oceanographic measurements and observations during most surveys in the program, and was the main author of all the published Survey Reports, Quarterly Reports and Annual Summaries.

Steve held a B.Sc. (1972) in Mechanical Engineering from the University of Vermont and a M.Sc. in Ocean Engineering (1978) from the University of Rhode Island. Steve was familiar with all aspects of marine disposal, including regulatory and technical issues. He was involved in projects related to municipal sewage and industrial waste disposal, oil spills, discharges associated with offshore oil development and production, thermal power plant cooling water discharges and dredged waste disposal. He was particularly experienced with water quality management and the optimisation of marine diffusers. Steve had been involved at a senior level in nearly all major contracted water quality studies in Halifax and the Harbour since 1984. His opinions and insights were highly-regarded by peers and associates in private, public and academic circles.

Steve's traits included a spirit of inquiry, the drive and ability to understand things thoroughly, a passion for the outdoors, a natural teaching ability, an ability to be a very humble role model for many, and a model citizen of the Earth.

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List of Abbreviations Used

BBPMP	Bedford Basin Plankton Monitoring Program
BOD	Biochemical Oxygen Demand
CBOD	Carbonaceous Biochemical Oxygen Demand
CEAA	Canadian Environmental Assessment Act
CFU	Colony Forming Units (equivalent to MPN)
CHS	Canadian Hydrographic Service
COA	Coastal Ocean Associates
CTD	Conductivity Temperature Depth
DC	Dartmouth Cove
DO	Dissolved Oxygen
EA	Environmental Assessment
EQL	Estimated Quantification Limit
FC	Fecal Coliform
HHCI	Halifax Harbour Cleanup Inc.
HHSP	Halifax Harbour Solutions Project
HHTF	Halifax Harbour Task Force
HHWQMP	Halifax Harbour Water Quality Monitoring Program
HRM	Halifax Regional Municipality
JWEL	Jacques Whitford Environmental Limited
MPN	Most Probable Number (equivalent to CFU)
LOBO	Land/Ocean Biogeochemical Observatory
NSDEL	Nova Scotia Department of Environment and Labour
PSU	Practical Salinity Unit
RDL	Reportable Detection Limit
SS	Suspended Solids
TOG	Total Oil and Grease
TSS	Total Suspended Solids
UV	Ultraviolet
WWTF	Wastewater Treatment Facility

1 Program Description

The following report summarizes the findings and conclusions from the Halifax Harbour Water Quality Monitoring Program (HHWQMP), designed to establish baseline levels of water quality parameters in Halifax Harbour since 2004 and to monitor the progress of the Halifax Harbour Solutions Project (HHSP) in terms of the resulting effects on water quality after the wastewater treatment facilities (WWTF) in Halifax, Dartmouth and Herring Cove were put into operation. This first section presents the history of the project, the scientific background and engineering decisions behind the Harbour Solutions Project, as well as the goals set for a variety of water quality indicators by the Halifax Harbour Task Force (HHTF). An overview of the methods employed in the monitoring program is also provided. In Section 2 the oceanographic properties of Halifax Harbour are briefly summarized, and the general seasonal trends of the main water quality parameters are described in the context of seasonal oceanographic and meteorological parameters, as well as in reflection of the levels of effluent treatment at the three WWTFs. Based on this preliminary analysis, the data were grouped into three periods based on the milestones in operation of the WWTFs: a baseline period from June 2004 to July 2007 when raw, untreated effluent was released in the harbour; a transition period in 2008 when the three WWTFs gradually started operations; an after-treatment period in 2010 when all three WWTFs were in full operation. The resulting statistics and conclusions from the 2010 period are compared in more detail to the baseline and 2008 statistics in Section 3.

1.1 Historical Background of the Halifax Harbour Solutions Project

Prior to the development of the Halifax Harbour Solutions Project two sewage treatment plants had been operating at Mill Cove in Bedford Basin and in Eastern Passage. However about 80% of Halifax Harbour sewershed still entered Halifax Harbour untreated (JWEL, 2001).

In 1989 the Halifax Harbour Task Force (HHTF) was commissioned to develop environmental quality guidelines and objectives for uses of Halifax Harbour (JWEL, 2001). The principles and guidelines set by the HHTF for a regional approach to the development of sewage collection, treatment and disposal in Halifax Harbour were reported in HHTF (1990).

In 1993, the Halifax Harbour Cleanup Inc. (HHCI), a Crown Corporation, developed a project to meet the water quality objectives set by the HHTF with a single primary treatment plant on an artificial island just north of McNabs Island. After a joint federal-provincial environmental assessment review, the project was given conditional approval in 1993 (Minister of the Environment for Canada and Minister of the Environment for the Province of Nova Scotia, Halifax Harbour Cleanup Project. 1993). Due to lack of funding, the project was not implemented (JWEL, 2001).

As a result of strong public and stakeholder support for efforts to improve Halifax Harbour water quality, the Halifax Regional Municipality (HRM) proposed a regional approach to treat raw sewage before discharge in the Harbour. This regional approach encompassed three wastewater treatment facilities (WWTFs) to be located in Halifax, Dartmouth and Herring Cove, a sewage collection system, combined sewage overflows (CSOs), three outfalls and diffusers, and a sewage sludge (biosolids) management facility (JWEL, 2001). The design of the HHSP was meant to meet the water quality objectives set by the HHTF and represented an improvement to the HHCI project with three outfalls providing more dispersion than one single outfall and UV disinfection instead of the use of chlorine.

The Halifax Harbour Solutions Symposium was organized by HRM in 1996 (Halifax Harbour Solutions Symposium. 1996). The Halifax Harbour Solutions Advisory Committee was formed to address technical issues not fully addressed during the Symposium. The Committee presented its report (Halifax Harbour Solutions Advisory Committee. 1998) to HRM Council which adopted it in 1998 the report's recommendations and framework for HHSP (JWEL, 2001) and which were included in the Concept Plan presented by HHSP (Halifax Harbour Solutions Project Team, 1998).

The Canadian Environmental Assessment Agency advised HRM that a federal screening level Environmental Assessment (EA) was required for the Halifax Harbour Solutions Project under the *Canadian Environmental Assessment Act* (*CEAA*). The EA undertaken in 2001 incorporated information from the extensive HHCI environmental assessment baseline studies and was presented in JWEL (2001, 2002a, 2002b, 2002c and 2002d). Public Works and Government Services Canada prepared the Screening Report (Public Works and Government Services Canada. 2003) which received approval in 2003. A condition of EA approval included the following requirement under the heading **3.6 Follow-up**:

"*Under the CEAA, a follow-up program:*
• *verifies the accuracy of the assessment; and*
• *determines the effectiveness of any mitigation measures that have been implemented.*

The primary objective of the project is to meet the water quality objectives for Halifax Harbour as set by the Halifax Harbour Task Force (HHTF 1990) based on intended end use. Upon completion of the project, the proponent will verify that these water quality objectives have been attained."

The above-noted condition of approval and requirement for project follow-up has therefore stipulated the objectives and framework for the Halifax Harbour Water Quality Monitoring Program.

1.1.1 Water Quality Objectives

The HHTF set water quality objectives for the various areas of Halifax Harbour based on their desired uses (HHTF 1990), as illustrated in Figure 1.1. The Narrows and the Inner Harbour (to a line between Point Pleasant Park - McNabs Island) were assigned the lowest water quality SC classification fit for industrial use, and also including water quality criteria providing for safe boating and other secondary contact recreational activities, industrial cooling, as well as good aesthetic value and fish and wildlife habitat. Bedford Basin, the Middle Harbour and the Northwest Arm (recommendation of upgrade from SC level by the Halifax Harbour Solutions Advisory Committee, 1998) were assigned the higher water quality SB classification allowing for bathing and other primary contact recreational activities, shellfish harvesting for human consumption after depuration and fish and wildlife habitat. The Outer Harbour, south of McNabs Island, was to be maintained relatively pristine and assigned the highest water quality SA classification providing for bathing and contact recreation, shellfish harvesting for immediate human consumption, and fish and wildlife habitat (COA, 2001; Public Works and Government Services Canada, 2003).

Because of the designation of Bedford Basin and the Middle Harbour (including the Northwest Arm) for swimming, the upper limit for fecal coliforms (FC) in these areas is 200/100 mL. Furthermore, shellfish harvesting for immediate human consumption in the Outer Harbour imposes a limit for FC of 14/100 mL. The laboratory analysis used in the monitoring program measured the concentrations in terms of CFU (colony forming units) or MPN (most probable number), depending on the laboratory method used. These units are considered equivalent and as such they are directly used as a measure of fecal coliform concentration and application of the applicable guidelines.

For dissolved oxygen (DO), the required levels are 8 mg/L, 7 mg/L and 6 mg/L respectively for SA, SB and SC classifications, which can be interpreted as Biochemical Oxygen Demand (BOD) resulting in virtually no oxygen debt for SA classification and a maximum debt of 1 mg/L and 2 mg/L for SB and SC classifications, respectively. The monitoring program included measurements of the Carbonaceous Biochemical Oxygen Demand (CBOD), considered equivalent to BOD.

For suspended solids (SS), the HHTF set the limit at 10% of background, which means a 10:1 dilution of the sewage suspended solids in the receiving environment (as opposed to a dilution in the receiving water). This criterion ensures the same limit on the ratio of sediment of sewage origin to the natural sediment. Because the SS measurements available for the Harbour (Petrie and Yeats, 1990) were generally considered relatively low for a coastal environment, potential exceedance of the SS guideline was acknowledged during the EA. Throughout the monitoring program, the concentrations of suspended solids were reported as total suspended solids (TSS).

As the monitoring program evolved, the methods of analysis were progressively improved. The sampled parameters with their limits of detection in their final state are summarized in Table 1.1.

Figure 1.1 Classification of areas in Halifax Harbour based on intended use. (Source: Halifax Harbour Solutions Project).

	Reportable Detection Limit		Harbour Task Force Guideline	Water Use Category	Sampling Stations	Sampling frequency
	value	units				
Profile Data					All	biweekly
Salinity	n/a	PSU	n/a	n/a		
Temperature	n/a	°C	n/a	n/a		
Chlorophyll *a*	n/a	µg/L	n/a	n/a		
Dissolved Oxygen	n/a	mg/L	8 7 6	SA SB SC		
Secchi depth	n/a	M	n/a	n/a		
Bacteria Samples					Bacteria + Chemical	biweekly
Fecal Coliform	1	CFU/ 100mL	14 200 none	SA SB SC		
Chemical Samples						
CBOD	5	mg/L	none		Supplemental sites	unscheduled
Ammonia Nitrogen	0.05	mg/L	none		Chemical sites	bi-weekly
Total Suspended Solids	0.5	mg/L	<10% background	all	Chemical sites	bi-weekly
Total Oil and Grease	5	mg/L	10	all	Supplemental sites	unscheduled
Metal scan						bi-weekly
Cadmium	0.1	µg/L	9.3	all	Chemical sites	
Copper	0.1	µg/L	2.9	all	Chemical sites	
Lead	0.1	µg/L	5.6	all	Chemical sites	
Manganese	1	µg/L	100	all	Chemical sites	
Nickel	0.5	µg/L	8.3	all	Chemical sites	
Zinc	1	µg/L	86	all	Chemical sites	
Mercury	0.01	µg/L	0.025	all	Chemical sites	
Cobalt	0.1	µg/L	none		Chemical sites	
Iron	1	µg/L	none		Chemical sites	

Table 1.1 Summary of measured parameters.

1.1.2 Effluent Quality Requirements

During the EA screening process, the Nova Scotia Department of Environment and Labour (NSDEL), Environment Canada, Halifax Regional Municipality (HRM) and its consultants advised that the following guidelines for treated effluent were acceptable, could be achieved by advanced primary treatment at three proposed plants and would meet the water quality objectives established by the HHTF if proper design, including outfall siting, and operational maintenance takes place (Public Works and Government Services Canada. 2003):

- Fecal coliforms of less than 5000/100 mL;
- BOD_5 of less than 50 mg/L;
- Suspended solids of less than 40 mg/L.

This represents a small variance from the NSDEL "open coastal" designation guidelines that would have a 30 mg/L limit for both BOD_5 and suspended solids. Such variance is permitted to accommodate efficiencies of removal of the type of treatment proposed, provided that a site-specific analysis shows that the oceanic processes in the receiving water achieve enough dilution to compensate for the deviation (COA, 2001).

1.1.3 Outfall Siting

The HHTF endorsed a principle of "containment", that is that the outfall should be located such that any potential effluent-related contamination would be "contained" in a previously contaminated area. This conforms to the philosophy of not exporting environmental impacts to areas not currently impacted, but it is contrary to the usual approach of maximizing dispersion in order to minimize contamination. It should be noted that the "containment" principle cannot be applied absolutely, as the basic requirement of the design of a diffuser in an inlet or estuary is an assessment to ensure that there is sufficient exchange between the inlet and the surrounding ocean to maintain the design dilution of the diffuser. However, any outfall will cause an area of measurable contamination, though not necessarily high contamination, so that it is reasonable to attempt to keep it in an area of lower quality expectations (ASA, 1991). The selection of the sites for the outfall was therefore a compromise between principles and requirements accounting for the level of sewage treatment, water quality objectives, the Harbour assimilative capacity and flushing, as well as cost.

Based on a review of the oceanography and the sedimentology of the Harbour, the water quality objectives, and public and stakeholder input, the Inner Harbour was identified as the most appropriate for marine outfalls (JWEL, 2001). The Inner Harbour is already an area of high contamination from the past and is classified SC for water quality objectives. The Narrows were excluded in order to protect the sensitive area of Bedford Basin relative to algal blooms and oxygen depletion. The Northwest Arm was excluded because of the higher water quality objectives of an SB classified area. Finally, economic considerations resulted in acknowledging the necessity of a wastewater treatment facility in the Herring Cove area with a nearby outfall.

Other factors were involved in the selection of outfall sites. The sites should offer optimum conditions for a marine outfall such as sufficient depth (>20 m) to achieve good initial diffusion and currents sufficiently strong to promote dispersion. Distance from specific areas such as anchorages, beaches and aesthetically important areas were also considered. The Halifax Harbour Port Authority reviewed the Inner Harbour sites for potential conflict with shipping and anchorage. The suitability of the sites was assessed by detailed oceanographic modeling to determine the assimilative capacity of receiving waters (JWEL, 2001).

1.1.4 Outfall and Diffuser Design

Four steps were necessary to validate the concept developed by HHSP and finalize the design of the diffusers in order to ensure that the water quality objectives set by the HHTF would be met:

1. Estimate bulk flushing of Halifax Harbour using a 'box' model. This is the first step in assessing the compatibility of the assimilative capacity of Halifax Harbour with the treated effluent loads and discharge locations of the project. Each area of the Harbour was represented by one 'box" and exchange of water between boxes was estimated from observations of salinity in the harbour, estimates of freshwater input, and the principles of conservation of water mass and salt (COA, 2001). The Study focused on copper as the key metal tracer as it was the one which had the highest concentration in the effluent compared to the water quality guidelines (2.9 µg/L) proposed by the Harbour Task Force (HHTF,1990) and required the most overall dilution in the Harbour. Results showed that for projected 2041 sewage flow rates bulk flushing keeps average copper concentrations in all areas at about one third of that of the HHTF environmental guideline, even assuming no metal removal during sewage treatment.

2. Estimate the length of the diffusers required to achieve the initial diffusion target. High initial levels of dilution guarantee that metals or other contaminants remaining in the treated effluent can be diluted to receiving water environmental quality guidelines. In the case of suspended solids lower initial concentrations reduces flocculation and therefore minimizes sedimentation in the immediate vicinity of the outfall and allows for further dispersion of fine particles. The HHTF (1990) recommended that design of the diffuser target a 50:1 dilution. This target was then reduced to 20:1 for the Halifax and Dartmouth diffusers (but maintained at 50:1 for Herring Cove) and the project received regulatory environmental approval (Public Works and Government Services Canada. 2003). HRM later reconsidered and adopted the initial target of 50:1 for the Halifax outfall in 2004 and for the Dartmouth outfall in 2005. This preliminary analysis

concluded that a dilution of 50:1 could be achieved by diffusers with an approximate length of 150 m.

3. Estimate water quality parameters in Halifax Harbour by implementing far-field dispersion modelling. Simulations of fecal coliform (FC) dispersion (with die-off) assumed a load of 5000 FC/100 mL in the treated effluent. The FC count was predicted not to exceed 30 FC/100 mL anywhere in the Harbour. Except for parts of the Narrows and the Inner Harbour and the immediate vicinity of the Herring Cove outfall, FC levels were predicted to be below the 14 FC/100 mL limit for shellfish harvesting for immediate human consumption. Overall the other water quality parameters were also found to meet the objectives.

4. Final design of the three diffusers involved two phases: optimization of the hydraulics and dilution simulation. Overall the hydraulics computations showed that the three outfalls presented a design satisfactory not only for the average conditions, but also for the broader range of conditions they will encounter. Dilution simulations indicate that a dilution of 50:1 is exceeded under most conditions.

Results from the four steps of modeling summarized above show that the design and siting of the outfalls and diffusers effectively achieve the water quality objectives established by the HHTF with treated effluent meeting the requirements stated above.

1.2 HHWQMP Sampling and Reporting Schedule

Survey sampling was conducted on a weekly basis between July 2004 and July 2006 and on a biweekly basis between July 2006 and July 2009. Regular sampling stopped in June 2009 with the Halifax WWTF out of commission, with two additional surveys in August and November of that year. Six additional surveys were conducted on a monthly basis between May and September 2010 following re-commissioning of the Halifax plant. The results of the individual surveys have been published as weekly and biweekly Survey Reports with accompanying data spreadsheets. The weekly data sets have been reviewed on a quarterly basis (approximately every 13 weeks), and the results published as Quarterly Reports. A total of 20 Quarterly Reports have been published, spanning the period between June 2004 and June 2009. Every fourth Quarterly Report in the series contains an annual summary of water quality trends. The documents have been made publicly available online (http://www.halifax.ca/harboursol/waterqualitydata.html).

Survey sampling was conducted from one of several vessels, operated by Connors Diving Services Ltd., based at the Armdale Yacht Club. The surveys covered 34 regular sampling sites that are shown on the map in Figure 1.2. These sites are a combination of historically sampled transects (Jordan, 1972), some project-specific sites, and identified recreational (yacht club/beach) sites. Sampling involved the collection of continuous conductivity, temperature and depth (CTD) profile data, as well as discrete water samples at 1 m and 10 m water depths. The level of analysis varied from site to site as depicted in Figure 1.2: CTD only; CTD and coliform bacteria (coliform stations); or CTD, bacteria, and additional parameter analysis (chemistry stations). In addition to the regular sites, Figure 1.2 shows a sampling site in Dartmouth Cove (DC) that was established in response to public concern. At this site, a 1-m water sample and profile data were obtained on a monthly basis during the summer months. The schedule also permitted for supplemental samples to be taken on an exploratory basis when visible water quality features were encountered in the Harbour during the survey.

Occasionally survey sites were not sampled, primarily due to severe weather conditions. The survey details, including missed stations and any additional samples, have been thoroughly documented in the Survey Reports and the Quarterly Reports.

1.2.1 Sampling Order

Throughout the program, sampling generally occurred on Tuesday, with Wednesday and Thursday as contingency days. The order in which the sites were sampled was varied each survey in order to minimize biasing the collected data with respect to known diurnal variations in sewage load and sunlight. Thus, a variable circuit was used that resulted in quasi-random sampling, subject to certain operational constraints. Since wind, waves and visibility can limit operations in the Outer Harbour, a primary and an alternate sampling route were generated for each survey. If the primary route had the Outer Harbour sampled early in the day, the alternate route would have it sampled late in the day. The decision on which route to take was made between the field team and the boat operator considering the weather forecast for the day.

1.2.2 Time of Day

Sewage flows have significant regular diurnal variations that can affect the water quality in the Harbour on short timescales. In residential areas there are generally two flow peaks a day, the largest occurring in the morning, and the second in the evening. In systems with relatively short flow distances these generally occur around 08:00-09:00 and 21:00. In commercial areas the flows are much more uniform during the day and low at night. In addition to variations in sewage load, the most obvious diurnal variation is in sunlight. Sunlight is perhaps the major contributor to the die-off of bacteria, and can have effects on other parameters, particularly chlorophyll (measured via proxy as fluorescence) and dissolved oxygen. The short term variation in sewage load is primarily an issue in the Inner Harbour, relatively close to the outfalls, however sunlight affects the entire Harbour. In Halifax there is also a significant diurnal tidal component affecting water levels.

Figure 1.3 shows the sampling time at each site since the start of the program in June 2004. The data from the six surveys in 2010 are shown in red. In this figure the sampling sites are generally sorted from north to south and grouped into sections representing the areas for which water quality guidelines have been set by the HHTF (1990). Thus, the Bedford Basin and Middle Harbour sections are classified as SB class areas, the Inner Harbour section (including the Narrows) is classified as an SC class area, and the Outer Harbour area is classified as an SA class area.

There are a few general patterns that emerge that have been documented previously. The stations at the north end of Bedford Basin have a smaller range of sampling times. This is because logistics dictated that the surveys never start or end in the Basin. In general, the range of sampling times increases with distance south, a function of travel time from the Armdale Yacht club in the Northwest Arm. Even if a site is sampled first, it still takes time to travel there. Given that sampling began at the same time every survey, these effects were unavoidable. Since each survey either began or ended in the Northwest Arm, there is a built-in early morning/late afternoon bias in the AYC, RNSYS and PC stations of Middle Harbour. The procedure for selecting routes based on weather conditions has resulted in a morning/afternoon bias in the Outer Harbour. Bedford Basin and Inner Harbour have been relatively uniformly sampled.

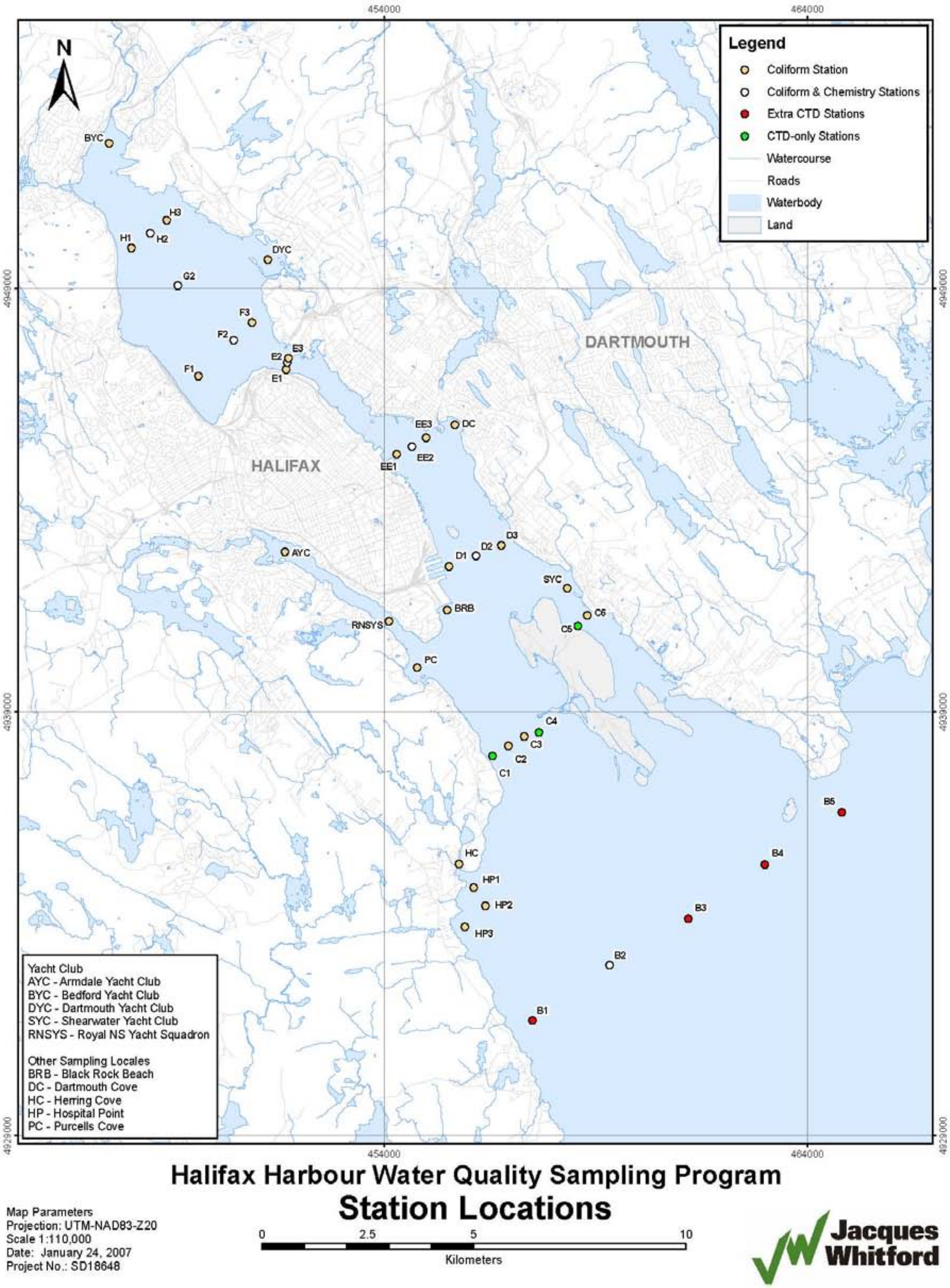

Figure 1.2 Halifax Harbour sampling locations.

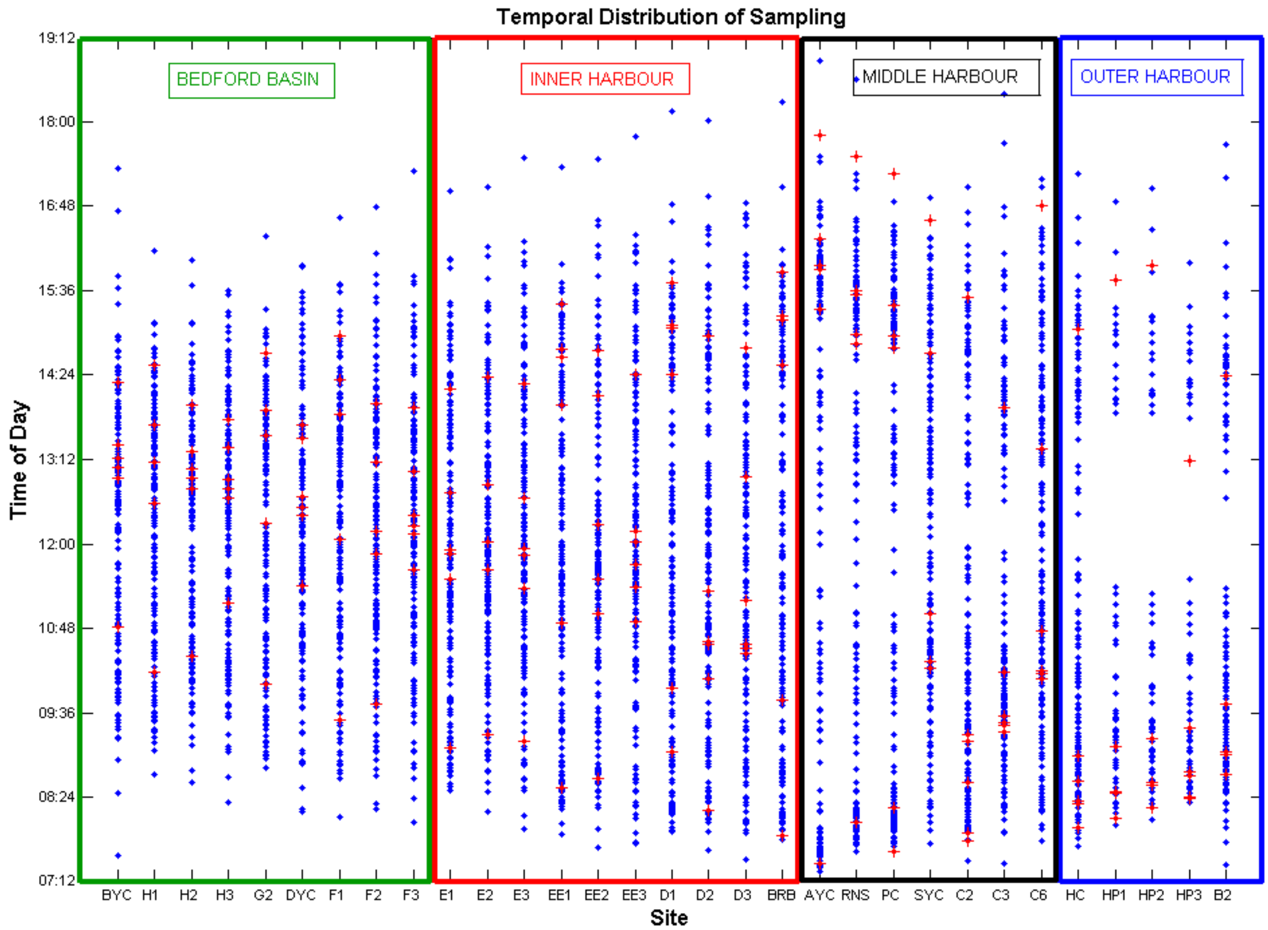

Figure 1.3 Temporal sampling distribution by site over the entire monitoring program (2004-2010). Red markers denote points from the six surveys between 26 May and 28 September 2010.

2 Water Quality Trends and Significant Events

2.1 Oceanographic Trends and Events

The interpretation of the measured water quality parameters requires knowledge of the dynamic state of the harbour at the time of each survey, as well as the seasonal processes and trends that could contribute toward the water quality observations. The CTD probe used in this program measured continuous vertical profiles of temperature, salinity, fluorescence and dissolved oxygen as a function of depth. Throughout the monitoring program, the profile data from station G2 have been compared to the data published by the Bedford Basin Plankton Monitoring Program (BBPMP, DFO 2011) from the centre of Bedford Basin. Additionally, profile data taken in the Northwest Arm have been compared to the archived data from the LOBO buoy (Land/Ocean Biogeochemical Observatory, lobo.satlantic.com). The comparisons allowed for a confirmation and validation of the ranges and quality of the CTD data.

The following subsections outline the general trends and significant events observed in the oceanographic parameters throughout the period of June 2004 to June 2009. All available profile data from station G2 in the Bedford Basin for this period has been plotted in the four colour plots in Figure 2.1. The white vertical sections in the plots represent missing data due to weather conditions or instrument/sensor unavailability. The G2 station represents the deepest station sampled as part of the survey and the profile data recorded there is particularly illustrative of the oceanographic events and processes in Halifax Harbour, as it reflects not only the near surface (upper 20 m) response to meteorological forcing, but also the effects of the periodic intrusion of dense shelf bottom water into Bedford Basin. Oceanographic trends and events from the follow-up surveys in 2010 are summarized in Section 3.

2.1.1 Salinity and Temperature

The temperature and salinity profile data (first two plots in Figure 2.1) reflect the dynamic state of the harbour and therefore represent a base from which to interpret the water quality data. The data is useful in characterizing changes in the state of the Harbour on meteorological and seasonal timescales. To some extent the temperature and salinity, and the resultant density stratification in Halifax Harbour, vary predictably on seasonal timescales.

The surface water generally warms in spring and summer, reaching a maximum in late August or early September, and cools in fall and winter. The temperature minimum is reached approximately in late February to early March. In spring, the surface salinity is low due to the spring freshet from the Sackville River and other tributaries. On top of the seasonal signal is a large amount of variability, mostly on a meteorological timescale (days to weeks).

Meteorological events, precipitation, temperature and wind measurements from Environment Canada have been taken into account in the interpretation of results on a meteorological timescale in the published Quarterly Reports. In general large rainfall events cause freshening of the Harbour similar in magnitude to the freshet anytime throughout the year. Wind forcing directly on the Harbour can push surface water either up or down the Harbour for several days at a time, resulting in local upwelling or downwelling and enhanced vertical mixing. On a larger scale, the passage of weather systems and storms on the continental shelf can cause larger scale upwelling or downwelling events along the coast. Upwelling pushes colder, saltier bottom water into the Harbour, thus forcing the warmer fresher harbour water out of the Harbour in a surface layer. Downwelling acts in the reverse order. These two layer events are very effective in exchanging harbour water and can result in rapid changes in water properties.

The most oceanographically interesting feature of the Halifax Harbour is Bedford Basin. The Basin is a fjord. The near-surface water (down to 20-30 m) exchanges freely with the remainder of the harbour and to a large extent reflects conditions there. The deep water (up to 70 m) is relatively isolated by a sill (20-25 m) in the Narrows and is only renewed periodically by the upwelling of dense continental shelf bottom water over the sill. This water displaces and/or mixes with the existing bottom water. As a result of this mechanism, the bottom water in the Basin is normally denser than any water in the remainder of the Harbour, reflecting its origins in deeper continental shelf water. These renewals can be seen in the salinity and temperature data as abrupt increases in salinity and decreases in temperature in the lower part of the water column, accompanied by a sharp rise in dissolved oxygen levels near the bottom.

Notable intrusion events can be observed in the plots at the end of March and in September 2005; in May and October 2006; in March 2007 and February-March 2008. Between intrusions, the vertical diffusion slowly decreases the bottom water density by mixing it with less dense overlying water.

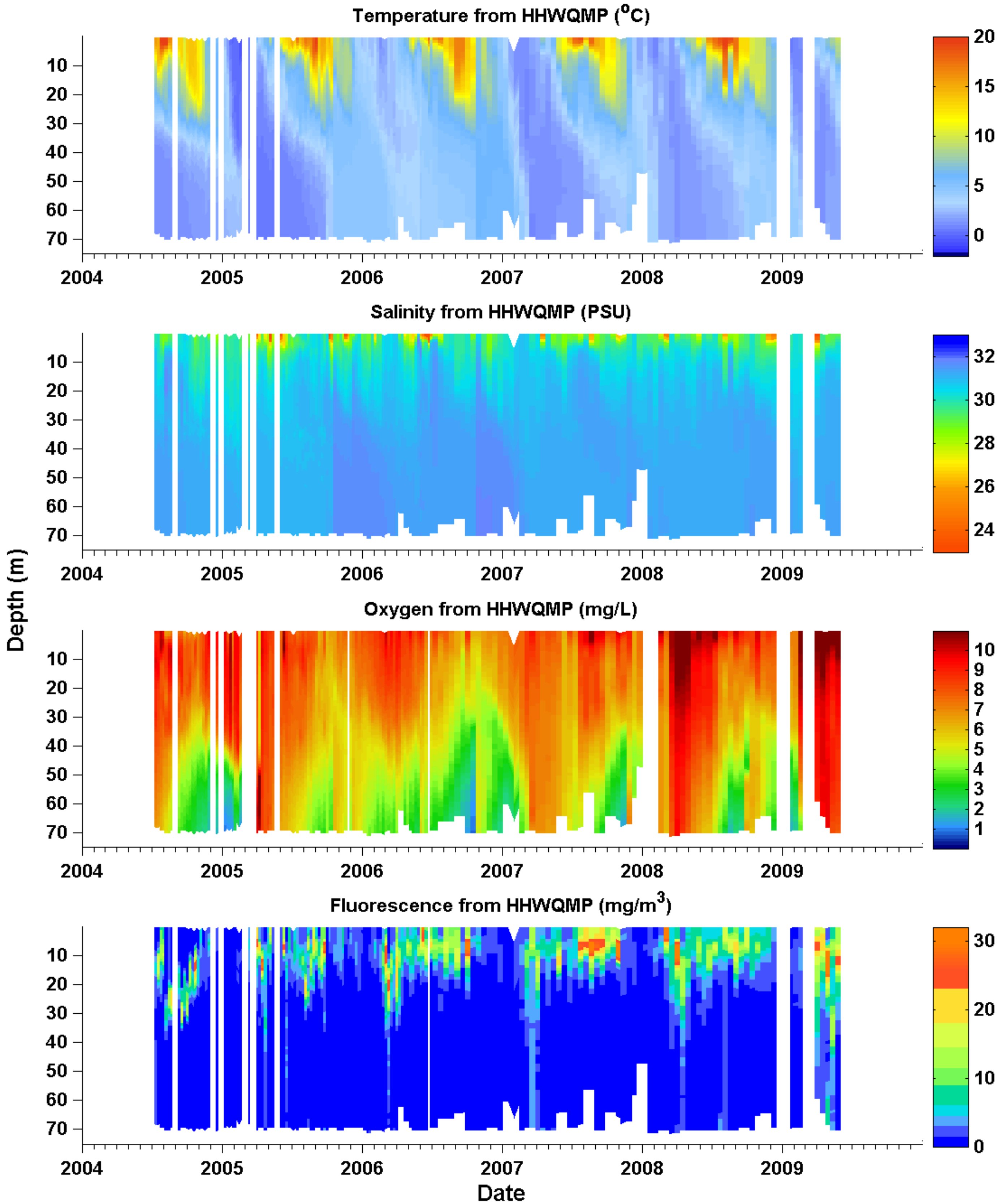

Figure 2.1 Oceanographic data from the HHWQMP at site G2, the deepest station in Bedford Basin (June 2004 to June 2009).

2.1.2 Dissolved Oxygen

Throughout the monitoring program, the dissolved oxygen (DO) levels have been relatively high in surface waters, and chronically low in the deep water of Bedford Basin (third panel, Figure 2.1). This is consistent with the description of Bedford Basin as a fjord, in which depressed DO levels in bottom water are typical. The Harbour Task Force Class SA, SB and SC water use classifications have guidelines for DO of 8.0, 7.0 and 6.0 mg/L respectively. Class SA pertains to the Outer Harbour, Class SC pertains to the Inner Harbour, while the Bedford Basin and the Middle Harbour are classified as class SB. Dissolved oxygen is often the most telling signature of dense bottom water intrusions into the Bedford Basin. Under normal conditions, the DO level in the deep waters of the Basin drops as oxygen is consumed by decomposing organic matter, present in the sediments and "raining" down from the surface water. With time, the DO can become very low. The water in an intrusion is generally well oxygenated and dramatically increases the DO levels. The DO therefore tends to reflect the time since the previous renewal of the bottom water. The DO levels have generally been within the applicable guidelines in all areas. There have been intermittent local depressions of oxygen levels, mostly associated with low rate of flushing of the Harbour and the presence of plankton blooms.

The dissolved oxygen sensor on the CTD probe is inherently prone to decreased sensitivity with time, and rapid decreases of sensitivity when the sensor comes in contact with contaminants during sampling. Comparisons with data from the BBPMP and the LOBO buoy have indicated a generally good agreement of DO trends and values, with some discrepancies in the total levels during individual surveys. To further ground-truth the DO data, starting with survey 151 (11 March 2008) near surface measurements have been conducted using a handheld, easily calibrated, YSI DO meter. This data set, combined with the available data from the BBPMP and the LOBO buoy have been used to calculate a scaling factor for the CTD data. The YSI data and the scaling factor computation have been included in the Survey Reports.

2.1.3 Fluorescence

The fluorescence data collected by the CTD probe is a proxy for chlorophyll, however the HHWQMP values reported for Chlorophyll *a* are un-calibrated and generated using default values provided with the Seabird instrument software. As such, though the measurements are expressed in units of (mg/m^3), they should be considered as a relative indicator of primary productivity, rather than a true measure of the mass concentration of phytoplankton. The conversion to biomass is highly dependent on many factors, including species and condition of plankton present, and is approximate even when fully calibrated with water samples. However, the un-calibrated fluorescence values can be useful when considered on a relative basis. As such, this comparison is more valid within a survey, where conditions are more likely to be consistent over the Harbour, than between surveys which occur under different conditions. The more separated in time and space, the more uncertain the comparison. Nonetheless, due to the large variability in natural plankton concentrations, the data provide useful information on the relative spatial and temporal variability of phytoplankton activity.

In general, phytoplankton blooms tend to start in Bedford Basin and migrate outward to the rest of the Harbour. The profile maximum values generally decrease in magnitude and occur lower in the water column further out of the Harbour. The data in the Basin, as seen in the last plot in Figure 2.1, generally represents the maximum concentrations observed and is representative of the timing of phytoplankton activity in the remainder of the Harbour. The color scale of the plot is limited at 30 mg/m^3, as higher values are only measured during limited periods of time at the peaks of spring blooms. It should be noted though, that the maximum values do not always occur at the G2 site, as the forcing of the wind can displace the maximum values to one side of the Basin or the other.

The phytoplankton in Halifax Harbour generally exhibit more or less typical estuarine behavior in the winter. That is, low productivity (<5 mg/m^3) during the winter followed by the strongest bloom of the year (40-80 mg/m^3) as sunlight returns in the spring (typically March). After the spring bloom, when light is plentiful, the behavior seems to be affected by anthropogenic nutrient input. There are sporadic phytoplankton blooms throughout the summer and into the fall. These blooms can be close to the spring bloom in magnitude (30-40 mg/m^3) and occur until the drop in light levels in late fall and winter.

2.2 Bacteria Levels

The Halifax Harbour Task Force fecal coliform guidelines (HHTF, 1990) are interpreted using the methodology for swimming areas, presented in the Guidelines for Canadian Recreational Water Quality (Health and Welfare Canada, 1992). The guidelines evaluate the compliance with bacterial water quality criteria based on the geometric mean. The geometric mean, G, of n values is defined as:

$$G(x_1, x_2, x_3, \ldots, x_n) = (x_1 \cdot x_2 \cdot x_3 \cdot \ldots \cdot x_n)^{1/n}$$

The geometric mean is always equal to or smaller than the arithmetic mean for a given set of values, and is particularly useful for data values that span several orders of magnitude, such as bacterial concentrations, as it tends to diminish the biasing effect of a single extremely high or extremely low value. To compute the geometric mean, some adjustments to the data are required. Zeros are not valid in the calculation, so ones (1’s) are substituted for all zero values. The result of this is that there will be no zero counts reported at any site. An appropriate interpretation of a reported mean value of one, then, is that it is equivalent to “less than or equal to” one.

The laboratory analysis can resolve 0-10,000 CFU at resolutions of per mL, per 10mL or per 100mL. At the beginning of the monitoring program (first 25 surveys), the laboratory used the standard resolution of CFU/mL, which provided a relatively higher upper limit of detection (1,000,000 CFU/100mL), but it under-resolved the 0-200 CFU/100mL range necessary to evaluate water quality. This was because the results could only be represented as 0, 1 or 2 CFU/mL, the equivalent of 0,100 or 200 CFU/100mL, with no values in between. To alleviate this issue, a variable resolution analysis was adopted for the remainder of the program, with the goal of minimizing out-of-range values while adequately resolving the lower range of values. With the variable analysis, some sites in the Inner Harbour were analyzed at the CFU/10mL resolution (upper limit of 100,000 CFU/100mL), while all the other samples were analyzed at the higher CFU/100mL resolution (upper limit 10,000 CFU/100mL). For the purpose of the current analysis, all values have been converted to CFU/100mL levels. Out of range values have been set to the upper limit of the corresponding analysis at each resolution.

The recreational guidelines specify that in swimming areas, the geometric mean of at least five fecal coliform values taken within 30 days should not exceed 200 CFU/100 mL, and any sample with values >400 CFU/100 mL should trigger re-sampling. This strictly applies only to areas classified SB (recreational) by the Task Force (i.e. the Bedford Basin and Middle Harbour areas). The Inner Harbour, including the Narrows (Figure 1.1), is classified as an SC class area, therefore there are no Task Force limits on bacteria in this area. The Outer Harbour is the only region classified SA. This area has a lower fecal coliform guideline of 14 CFU/100 mL for shellfish harvestable waters compared to the recreational guideline of 200 CFU/100 mL. The sites within the Task Force “Outer Harbour” boundaries are B2, HC and the HP section (refer to Figure 1.2).

At the beginning of the program, the weekly sampling regimen resulted in five samples within 30 days and allowed for a rigorous application of the guidelines for each site. The change to biweekly sampling in the ninth quarter meant that the individual site data did not meet the criteria of at least five samples within 30 days. The analysis in the Quarterly Reports was continued using a three-sample floating average that fit within the 30 day window but sacrificed the five sample criteria for individual sites and depth levels. In 2010 the surveys occurred approximately once per month, thus yielding even fewer samples within 30 days. Thus the criteria could not be strictly applied to individual sites and depth levels, but to groups of sites within different areas of the Harbour, as explained in the next subsection.

The fecal coliform raw data and geometric means spanning from June 2004 to December 2008 have been presented in time series format by Dr. Bill Li (DFO, 2011). The following subsection gives an overview of the full HHWQMP fecal coliform time series, organized by Halifax Harbour Task Force sections.

2.2.1 Time Series of Fecal Coliform Levels

In order to assess the background bacteria levels before the establishment of the sewage treatment plants, as well as to investigate the effects that treatment has had on water quality in the Harbour, time series of fecal coliform concentration data have been compiled for the two water depth levels (1 m and 10 m) at all regularly sampled sites. Additionally, the sites have been grouped into four sections delineated by the HHTF and the fecal coliform geometric mean has been calculated for each section for comparison to the HHTF guidelines.

The plots of the geometric mean calculated at every one of the regular sampling sites are provided in Appendix A. The geometric mean was calculated by using a 30-day sliding window, with a minimum of 3 samples within each window. When fewer than 3 samples were available within this period, no geometric mean was calculated. Thus, the geometric mean calculated in these plots only loosely follows the sampling criteria after July 2006 when biweekly sampling began. The raw data points are also shown to illustrate the variability and limit exceedances of individual measurements. The geometric mean over the Halifax Harbour sections was calculated by including all sites within the given area in the 30-day sliding window. The grouping of multiple neighbouring sites provided the necessary minimum number of 5 measurements within 30 days for most of the program. This allowed for the HHTF criteria to be applied rigorously and provided a unified view of the degree to which the bacteria concentration guidelines were met in each area of the Harbour.

The results for the four main harbour areas are plotted in Figure 2.2, while the values for the Northwest Arm and Eastern Passage are plotted separately in Figure 2.3. The sites from these two areas are included in the Middle Harbour section, however it is instructive to display them separately as they represent relatively detached areas of the Harbour. The plots feature three solid lines, one each for the 1-m and 10-m water depth levels, as well as the total geometric mean that includes both depth levels. All the raw data points are also plotted to illustrate the distribution of values in each section.

A pattern of seasonal variability of bacteria levels is evident in most areas of the Harbour. These variations are due to interactions of meteorological and oceanographic factors affecting source strength, effluent trajectory and mixing, and bacteria die-off on seasonal, weekly and daily timescales. The concentrations are generally lowest in the summer and spring, and higher in fall and winter. Increased harbour flushing, due to high freshwater input (spring freshet and storms) or upwelling and downwelling events along the coast can also result in lower concentrations.

2.2.1.1 Milestones in Wastewater Treatment Facilities Operations

There were several significant milestones in the operation of the Wastewater Treatment Facilities (WWTFs) that need to be taken into account in the analysis of the time series. These milestones are marked with colored timestamps in the time series plots in Figure 2.2 and Figure 2.3 and in the Appendices. The Halifax plant commissioning commenced in July 2007, when the plant first accepted sewage flows and began partial treatment (first yellow timestamp). The period from the beginning of the monitoring program in June 2004 to July 2007 therefore represents the pre-treatment period, from which a baseline can be established to be compared with the period when the sewage was treated prior to release in the Harbour. The Halifax WWTF reached full operational status in March 2008 (first square green timestamp). In August 2008 Harbour beaches (Dingle Park and Black Rock) were opened (first cyan timestamp) for public swimming for the first time in decades. The Dartmouth WWTF became fully operational at the end of the same month (triangular green timestamp). Due to the fact that some, but not all WWTFs were operating in 2008, this year represents a transitional period when the effects of the cleanup effort are evident for the first time. In December 2008 the Herring Cove WWTF started full treatment (circular green timestamp). The Halifax WWTF failed in January 2009 (red timestamp). It started partially treating sewage again in September 2009 (second yellow timestamp), and became fully operational again in June 2010 (second square green timestamp). The beaches re-opened in July 2010 (second cyan timestamp). In 2010 there were a total of six surveys, with the surveys between 25 June and 28 September being conducted after all three WWTFs were fully operational. Note that a survey was conducted on 26 May 2010 that is not considered as part of the after-treatment period.

These milestones form the basis for three comparison periods:

1. the baseline period before any treatment (June 2004 – July 2007);
2. the transition period in 2008 when the WWTFs gradually came online for the first time;
3. the period after full treatment had resumed at all three WWTFs (June – September 2010);

A closer look at the main water quality parameters for the after-treatment period and a comparison of these three periods are presented in Section 3.

2.2.1.2 Bedford Basin (Class SB, Swimming Limit)

The geometric mean time series for fecal coliforms for Bedford Basin exhibit strong seasonal variation, with the highest values generally occurring in late fall and through the winter, when precipitation and runoff levels are higher, sunlight is less abundant and the die-off rate of bacteria due to exposure to ultraviolet (UV) light is diminished. The 10-m fecal coliform concentrations are generally higher than the 1-m concentrations through most of the monitoring program, a trend that is the reverse of what is observed in the rest of the Harbour. The geometric mean fecal coliform values for the Basin are typically below the swimming limit, but the raw data show frequent exceedances at individual sites in the pre-treatment period. The time series of individual sites in Appendix A show that exceedances above the swimming limit most frequently occur in the southern part of the Basin (sites F1, F2 and F3).

In the spring of 2008 when the Halifax WWTF first came online, there is a drop in the fecal coliform geometric mean values to levels below the shellfish limit, consistent with lower bacteria levels in the spring of previous years. Unlike previous years, these low levels persist until November, when there is again a sharp increase consistent with high seasonal values in fall and winter. There is also a noticeable drop in mean levels at the Dartmouth WWTF milestone in August 2008. During 2008 there is a drastic drop in the number of swimming limit exceedances as seen in the raw data points. After the failure of the Halifax WWTF in January 2009 the geometric means return to the baseline levels below the swimming limit. In the period after full treatment is established in 2010, the mean levels are below all limits, with a few raw data points above the shellfish limit. The applicable recreational guideline for this area of the Harbour is therefore met in 2010.

2.2.1.3 Inner Harbour (Class SC, No Limit)

The baseline for fecal coliform for the Inner Harbour is mostly above the swimming limit, with 1-m bacteria levels consistently higher than the 10-m concentration levels. Furthermore, some of the raw data points are at the upper limit of detection in the period before March 2008 (first green marker), indicating that the fecal coliform concentrations were sometimes higher than the limit, and the geometric mean levels during this period are slightly underestimated. The fact that the Inner Harbour is where two of the highest-output sewage outfalls are located likely explains the observation that the baseline mean levels are relatively flat, with significantly less seasonal variability than is seen in the other Harbour areas.

The mean fecal coliform levels drop below the swimming limit for the first time with the start of full operations at the Halifax WWTF in early 2008, a trend that is also seen in the distribution of raw data points. The Dartmouth WWTF milestone seems to be reflected by a measurable drop in mean levels at the end of August 2008. Even after the failure of the Halifax WWTF in January 2009, the levels are elevated, but not as high as they were before treatment began. This can be at least partially explained by the fact that both the Dartmouth and the Herring Cove WWTFs were operating by that time.

The fecal coliform levels in the after-treatment period in 2010 are the lowest measured since the beginning of the monitoring program. The geometric mean fell below the shellfish limit, and all raw data points are below the swimming limit. This represents a tremendous improvement over historic bacteria levels. Since the Inner Harbour is classified as SC class area with no guideline for bacteria concentration, the achieved water quality in 2010 exceeds the goals set by the HHTF for this area.

2.2.1.4 Middle Harbour (Class SB, Swimming limit)

The Middle Harbour exhibits the largest amount of seasonal variability in mean bacteria levels. During the baseline period, the fecal coliform geometric mean exceeds the swimming limit during late fall and winter, while in spring the levels fall below the swimming limit, and during periods in the summer also below the shellfish limit. A vast number of the raw data points are above the swimming limit, indicating that individual sites frequently exceeded the guidelines year-round. These trends are similar between the Northwest Arm and the Eastern Passage areas.

There is a drastic improvement in 2008 with full operation of the Halifax and later on the remaining WWTFs, with mean levels below the shellfish limit for much of the year, and few raw data points (mainly in Eastern Passage) exceeding the swimming limit. It is notable that in the winter of 2009 the mean levels increased when the Halifax WWTF failed, but remained lower than the baseline period and still below the swimming limit for the first time since the beginning of the monitoring program, likely an effect of the operation of the Dartmouth and Herring Cove WWTFs.

The mean fecal coliform levels in the after-treatment period of 2010 are below the shellfish limit, with few raw data points above the swimming limit. Overall, this represents an improvement that meets or exceeds the goals set by the HHTF.

2.2.1.5 Outer Harbour (Class SA, Shellfish limit)

The Outer Harbour has the strictest fecal coliform limit and guideline of 14 CFU/100 mL set by the HHTF. The baseline data show that before treatment, the mean levels were below the swimming limit, but above the shellfish guideline almost year-round, except for brief periods in the spring months. Interestingly, the bacteria levels did not seem to be significantly improved during 2008 when the WWTFs began operating at partial or full capacity, likely due to the fact that the Herring Cove facility, located in this area, became operational only in December 2008.

The fecal coliform mean levels were drastically lowered below the shellfishing limit after all WWTFs began fully operating in 2010, thus meeting the criteria set by the HHTF.

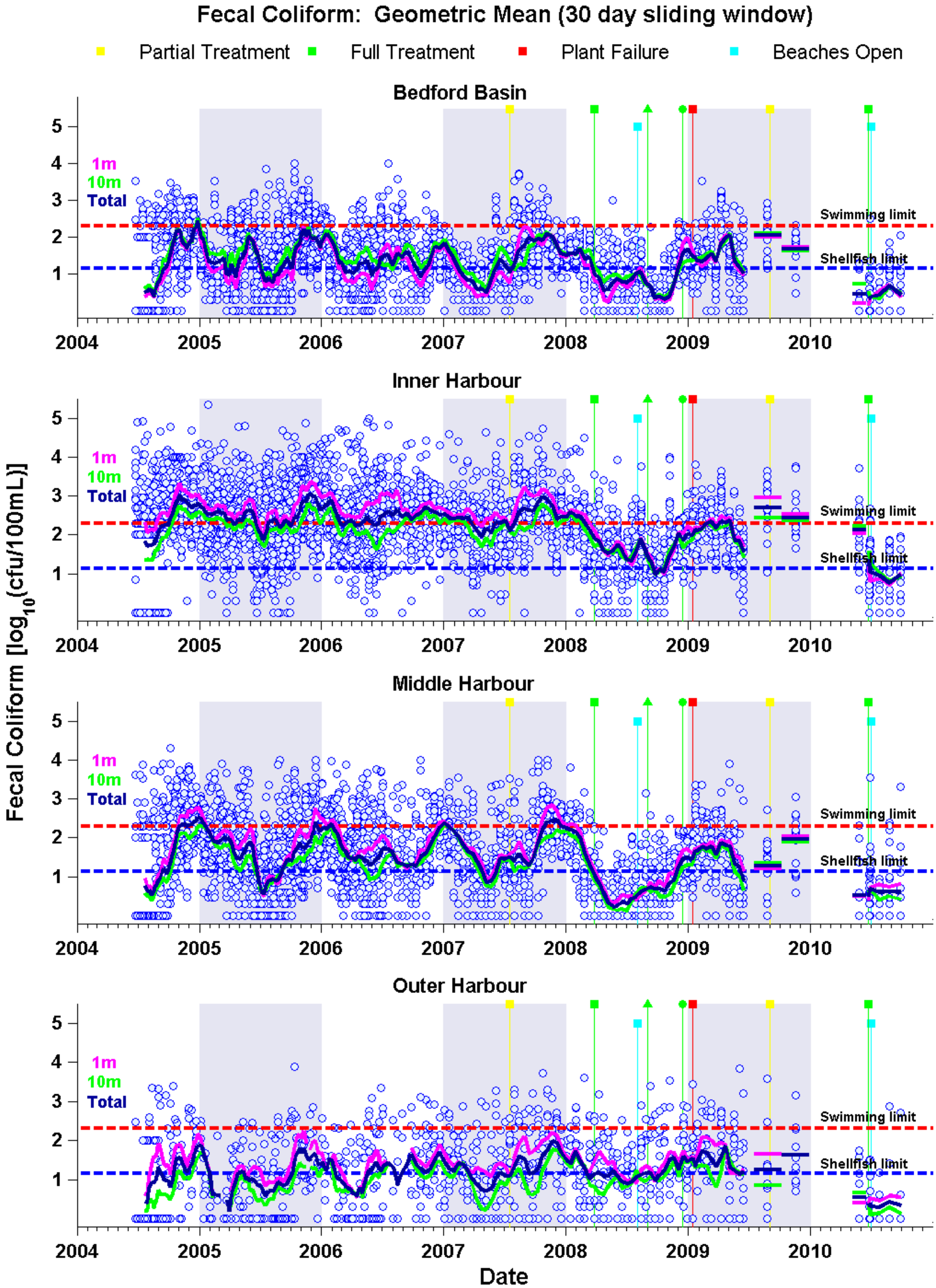

Figure 2.2 Time series of the geometric mean of Fecal Coliform measurements in the sections of Halifax Harbour outlined by HHTF (1990). Raw data points are also shown in background. Note the green timestamps for full treatment at Halifax (square), Dartmouth (triangle) and Herring Cove (circle) WWTFs.

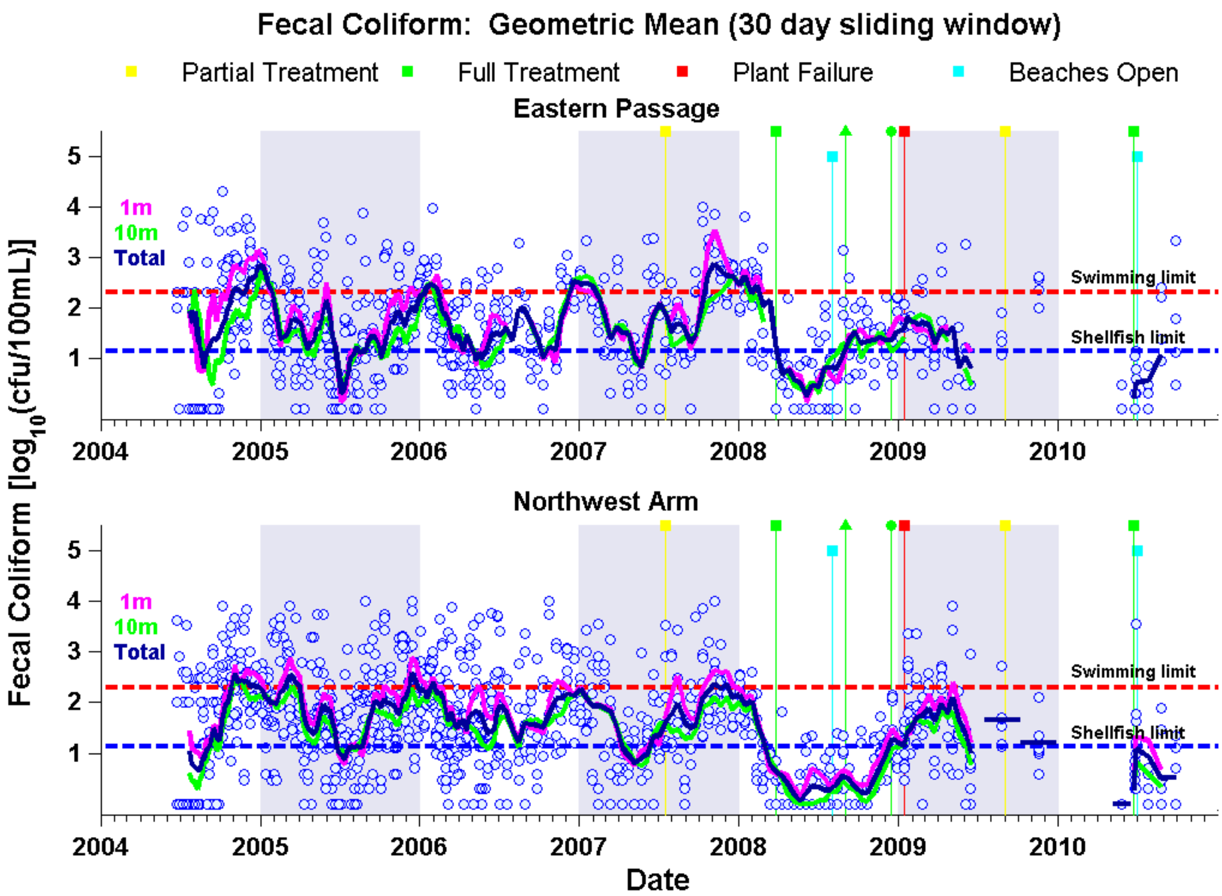

Figure 2.3 Time series of the geometric mean of Fecal Coliform measurements in two subsections of Middle Harbour. Raw data points are also shown in background. Note the green timestamps for full treatment at Halifax (square), Dartmouth (triangle) and Herring Cove (circle) WWTFs.

2.3 Ammonia Nitrogen Levels

Ammonia nitrogen is an important component in the nutrient balance in Halifax Harbour, and in high concentrations has potential for toxic effects. There is no marine water quality guideline for ammonia. The laboratory reportable detection limit has been 0.05 mg/L throughout the water quality monitoring program.

Ammonia nitrogen has been monitored in samples from the seven chemistry sites from every section of the Harbour. The time series of the ammonia nitrogen concentration at each water depth level of every site are presented in Appendix B. It is evident that with a few exceptions, the levels have always been below or slightly above the detection limit. There does not appear to be a correlation between ammonia nitrogen concentration and seasonal meteorological or oceanographic forcing and sewage loading conditions.

The operation of the WWTFs in 2010 appears to have resulted in slightly elevated levels at some sites, particularly in the Inner Harbour section; however, the fact that only four surveys included chemical analyses in the after-treatment period, there is not enough evidence to suggest a convincing trend or spatial distribution. The ammonia nitrogen concentration statistics for the three comparison periods are presented in Section 3.

2.4 Total Suspended Solids Levels

The levels of total suspended solids (TSS) have been monitored at the seven chemistry sites. The time series of TSS concentrations are presented in Appendix C.

The TSS concentrations in the Harbour are moderate and relatively constant throughout the full duration of the monitoring program, with the exception of the period of early 2005 to mid-2006 when the levels rose and exceeded 10 mg/L in all areas. There appears to be no strong correlation in space or time with meteorological, oceanographic or sewage loading conditions. The levels after full sewage treatment in 2010 are slightly depressed compared to the baseline. The TSS concentration statistics for the three comparison periods are presented in Section 3.

2.5 Metals Levels

The levels of several metals have been monitored at the chemistry sites throughout the duration of the monitoring program. The initial format of the analysis, from the beginning of the program to November 2005, did not include all metals for which guidelines were set by the HHTF. Moreover, for some metals the reportable detection limits were higher than the HHTF guideline. The analysis was therefore dropped in November 2005 and a more comprehensive, high resolution analysis was initiated in August 2006. Time series of the concentration of iron and seven metals for which HHTF guidelines exist are presented in Appendices D through K. These plots depict as well the change in the detection limits as the program progressed.

A wider set of metals than those prescribed by the HHTF was included in the low-resolution analysis at the beginning of the program. The levels were reported in the Survey and Quarterly Reports. As the levels were mostly below the level of detection or not of concern, the analysis of these metals was discontinued except for supplemental samples of visible sewage features.

Since the high-resolution metals analysis began, copper and mercury were the metals that most frequently exceeded the guidelines, although the mean levels are mostly well below the guidelines for all metals. With the established set of reportable detection limits, the metal that was regularly closest to the exceedance level was copper, with a mean value below 20% of the guideline value.

The metal statistics for the after-treatment period of 2010 are given in Section 3.

2.6 $CBOD_5$

The level of Carbonaceous Biochemical Oxygen Demand ($CBOD_5$) was measured early in the program, and the results were reported in the first three Quarterly Reports. In May 2005 the $CBOD_5$ analysis was eliminated due to there being an insignificant number of regular samples with detectable levels at the 5 mg/L level. The $CBOD_5$ was retained as a tracer for the supplemental sampling program only.

2.7 Total Oils and Grease

The level of total oils and grease (TOG) was measured in the beginning of the program, up to November 2005. The analysis was discontinued due to lack of detection; however it was retained for supplemental samples in which low water quality may be expected.

3 Water Quality Effects, Statistics and Conclusions

3.1 Water Quality Parameters After Full Treatment in 2010

The following section summarizes the data collected from 25 June to 28 September 2010 (surveys 190 to 194). The results of the individual surveys are documented in the Survey Reports. It should be noted that the survey conducted on 25 June did not include samples for chemical analysis. Therefore the ammonia nitrogen, total suspended solids and metals statistics are based on surveys 191 to 194 with fewer data for comparison to the two other longer and well-sampled periods before full treatment of the WWTFs.

In the following section, the data for the period are discussed in terms of compliance/exceedance of applicable water quality guidelines set by the HHTF, and a comparison is made with baseline levels in order to illustrate the effect that the operation at full capacity of all three wastewater treatment facilities has had on water quality in Halifax Harbour. In Section 2 the baseline level period was defined as lasting from the beginning of the program up until the Halifax WWTF first accepted sewage in July 2007. This is the period that has been used to extract the statistics presented as the baseline against which the results are compared.

3.1.1 Sampling Bias

There are two significant environmental factors that can potentially affect the results: the water level at the time of sampling, and the accumulated precipitation in the days immediately preceding a survey. Water level variations in the Harbour are caused by the tides and meteorological forcing. The tides in Halifax Harbour are classified as semidiurnal, meaning that there are two high and two low tides in a day. The probability distribution of water level (above chart datum) as derived from the tide gauge at the Naval Dockyard in Halifax (CHS station 490) for the period June to September 2010 is shown in Figure 3.1. In an ideal situation each site would be sampled in a distribution similar to the overall baseline distribution. Figure 3.2 and Figure 3.3 show the distribution of water levels at each site at the time of sampling (blue bars) compared to the overall water level distribution for the period, as represented by the red line recreated from Figure 3.1. The range of water levels was relatively well sampled given the low number of surveys. The sites in the Inner Harbour and in Bedford Basin had a bias towards lower water levels, which may have resulted in lower dilution and slightly higher biased bacterial concentrations. The sites in the Outer Harbour were biased toward higher water levels.

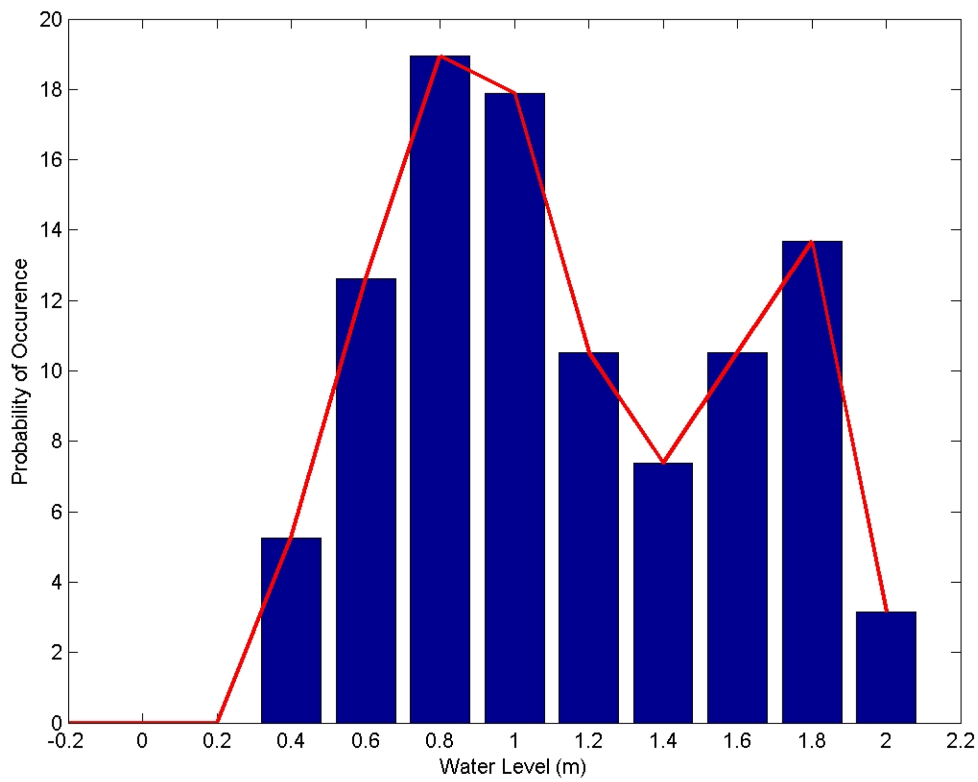

Figure 3.1 Probability distribution of water levels in Halifax Harbour, June to September 2010.

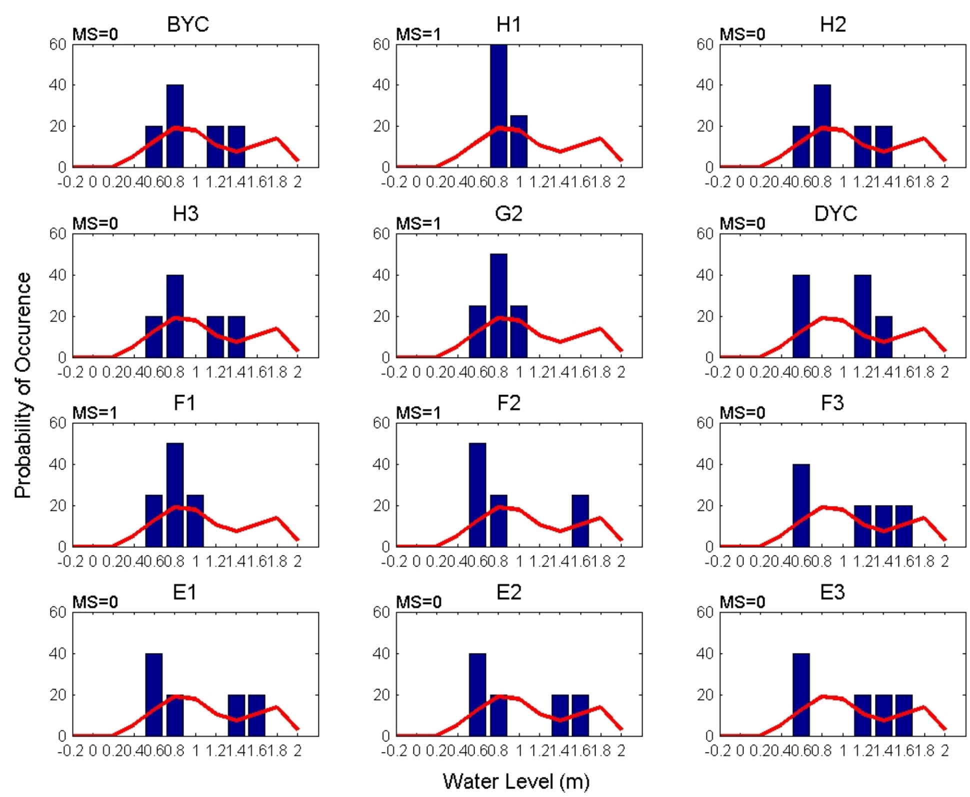

Figure 3.2 Water level distribution at Bedford Basin and Inner Harbour sites during sampling (25 June to 28 September 2010). Note: MS = Missed samples.

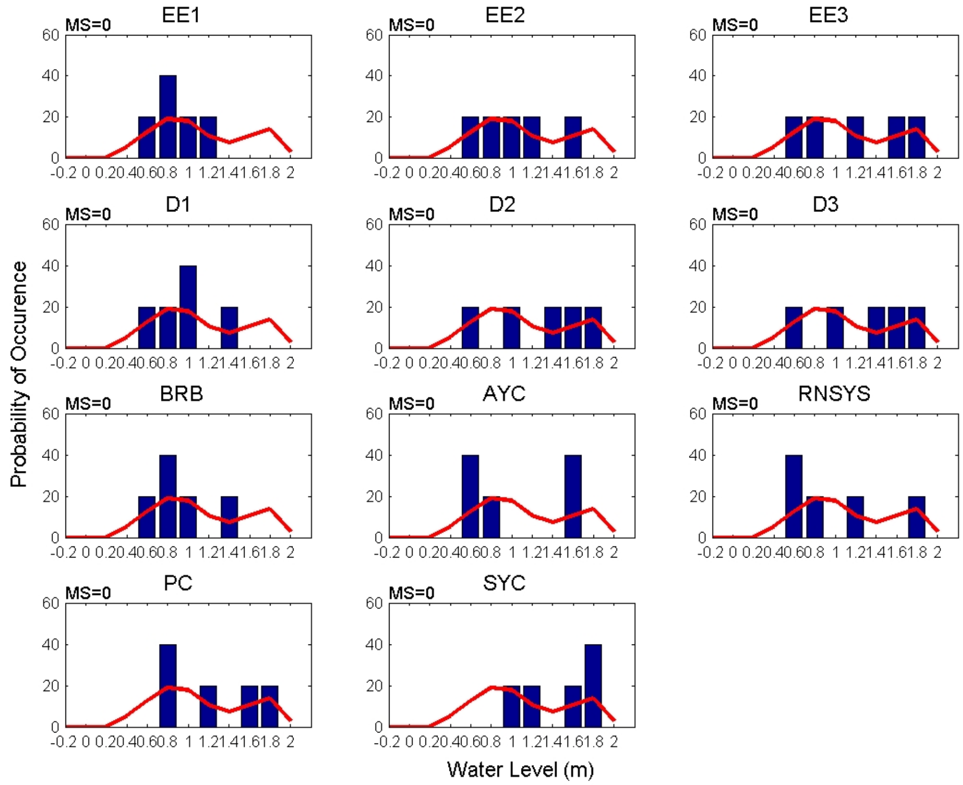

Figure 3.3 Water level distribution at Inner and Middle Harbour sites during sampling (25 June to 28 September 2010). Note: MS = Missed samples.

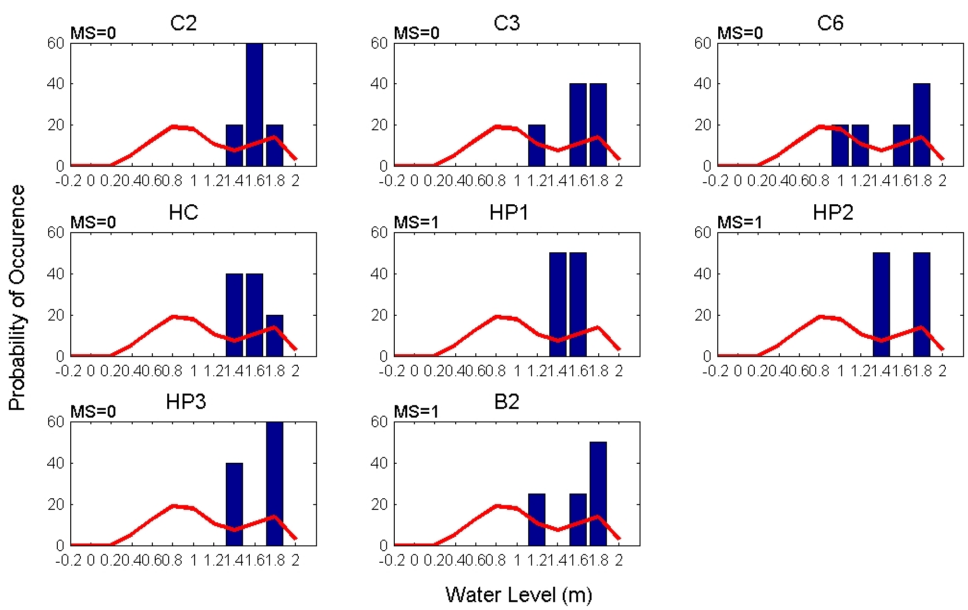

Figure 3.4 Water level distribution at Middle and Outer Harbour sites during sampling (25 June to 28 September 2010). Note: MS = Missed samples.

Another factor potentially biasing the results is precipitation. Rainfall affects both the sewage loads and the dynamics of the Harbour. In a combined sewer system, like in Halifax, increased flow due to a rainfall event can mobilize material that has collected in the sewer pipes in low flow conditions resulting in quite high loads. Additionally, in response to the increased fresh water input, the harbour can become more stratified, enhancing estuarine circulation. The combination of increased flow and stratification can have a significant effect on the near field behaviour of the plumes from the outfalls. These effects lag the rainfall and persist for a period of time after the rain stops. The duration of the impact, of course, depends on the magnitude of the rain event and the condition of the watershed. For purposes of discussion we have, somewhat arbitrarily selected a three-day (72-hour) precipitation window for our analysis.

The red line in Figure 3.5 depicts the probability distribution of cumulative 72-hour precipitation for the full after-treatment period. The blue bars in this figure represent a similar analysis performed for sampling days only. It is apparent that days with no precipitation represented 40 % of sampling days, but they accounted for 60% of the total period. In addition, days with 10 mm and 25 mm of precipitation each represented 20 % of the sampling days, even though they account for less than 10 % each for the total period. Therefore Figure 3.5 indicates that, given the limited number of surveys, there is a bias towards high-precipitation events, while days with no precipitation are underrepresented. As a result, the measured bacteria concentration values are on average higher than they would be if the full range of precipitation events was well represented.

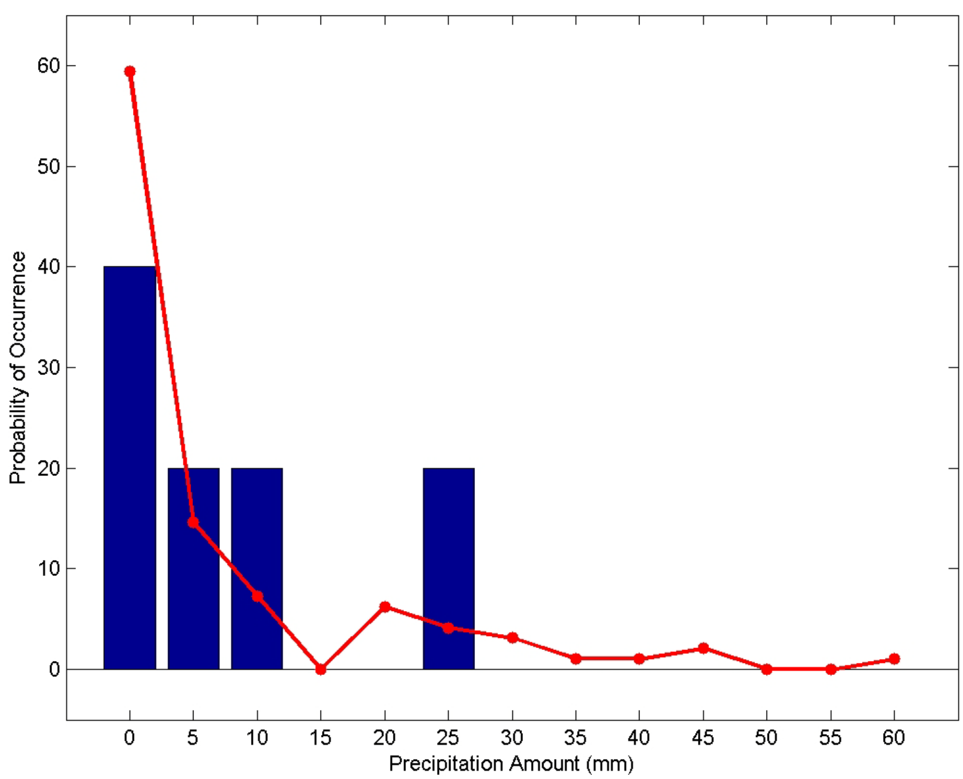

Figure 3.5 Probability distribution of cumulative 72-hour rainfall (25 June to 28 September 2010).

3.1.2 Bacteria Levels

During the surveys in 2010, enterococci bacterial concentrations were measured for the first time since the beginning of the monitoring program for comparison to fecal coliform data. According to the Canadian Environmental Quality Guidelines enterococci bacteria are recommended as a better indicator of fecal waste contamination in salt water.

Maps representing the geometric mean values of both fecal coliform and enterococci over all samples during the after-treatment period are presented in Figure 3.6. In this figure, the fecal coliform data are expressed in MPN (most probable value), assumed to be equivalent to CFU (coliform forming units) for comparison purposes. Values in red exceed swimming guidelines (200 mpn/100 mL); values in blue exceed shellfishing guidelines (14 mpn/100 mL); and values in green indicate suitability for either activity. Separate maps are presented for the 1-m and 10-m water depth samples.

The fecal coliform and enterococci concentrations are well correlated at most sites, with a few exceptions. A vast majority of the sites show mean bacteria levels below all limits, with only a few sites with levels above the shellfishing limit. The geometric mean bacteria values meet or exceed the goals set by the HHTF at all sites in Halifax Harbour, with the exception of the station in the immediate vicinity of the Herring Cove WWTF. The raw data indicate that limits were marginally exceeded during some surveys at individual sites. These swimming limit exceedances occurred twice at the HC site, and once each at the C6, BRB, SYC, DYC, RNSYS and PC sites.

3.1.2.1 Comparison Against Baseline Values

The geometric mean of fecal coliform concentrations over the Harbour sections for each individual survey are plotted against the mean levels for the full baseline period and the transition period in 2008 in Figure 3.7 and Figure 3.8. The fewer number of surveys for the period of full treatment by all the three WWTFs in 2010 does not allow for a comparison over all seasons, however it indicates lower levels of contamination in all sections of the harbour compared to the baseline period. The levels in 2008 mostly satisfy the guidelines and are comparable to the final results in 2010, especially during the summer months when recreational activities would be more widespread in the Harbour.

The fecal coliform geometric mean was calculated for the full length of the comparison periods for the different sections of the Harbour, and the results are presented in Table 3.1. The averages for these three periods are based upon differing sample sizes and seasonal extents, and are compared on that basis. Thus, the 2010 data do not capture the full range of seasonal effects, including elevated fecal coliform values during late fall and winter. Nevertheless, the data show that a significant improvement was achieved in most areas (except Outer Harbour) in the year 2008, and the bacteria levels were on average even lower after treatment in 2010.

The greatest improvement in mean bacteria levels is found in the 1-m water samples in the Inner Harbour, where the 2010 value (6 CFU/100 mL) is at 1.2 % of the baseline value (491 CFU/100 mL), or a 98.8 % reduction in bacterial levels from baseline conditions, and below all bacteria water quality guidelines for the Harbour. Overall, the Inner Harbour bacteria levels in 2010 are at about 3% of the baseline levels, amounting to a reduction of 97 % over baseline conditions. These numbers indicate that the wastewater treatment process met or exceeded the goals for this area in the Harbour, which is particularly significant given the fact that this was the most highly contaminated area before operation of the WWTFs. The second most contaminated area during the baseline period was the Middle Harbour, where the 2010 mean levels are at approximately 9.5% of the baseline values and below the shellfishing guideline of 14 CFU/100 mL. Since the applicable guideline for this area is the swimming limit of 200 CFU/100 mL, the improvement exceeds the goals set by the HHTF. The statistics for Eastern Passage and Northwest Arm, both of which are part of Middle Harbour, indicate that the greatest improvement was at the sites in the Northwest Arm, where the levels were below all guidelines also in the 2008 transition period. In the Bedford Basin, both the 2008 and the 2010 levels are below all guidelines, with the 2010 bacteria values at about 12.5 % of the baseline levels, a reduction by 87.5 % from baseline conditions. Therefore the improvement in bacteria levels achieved in 2010 exceeds the goals set by the HHTF for this area.

The strictest shellfish harvesting guideline is only applicable to the Outer Harbour, therefore this is the area most susceptible to guideline exceedances during the fall and winter seasons when bacteria levels are likely to be elevated due to meteorological factors. The Outer Harbour was the only area where higher mean bacteria values were observed in the transitional period of 2008 compared to the baseline period. During the baseline period and the transition period of 2008, only the mean bacteria levels at the 1-m water depth were in violation of the guideline, with 23 and 24 CFU/100 mL for each period respectively. The total mean levels measured in 2010 indicate a reduction of 85% relative to the baseline. Given the fact that the bacteria concentration at the 1-m water depth from 2010 is significantly lower at 4 CFU/100 mL, it is expected that the mean levels should remain within guidelines throughout the year, with possible localized exceedances during storm events.

If the seasonal trends seen in 2008 in Figure 3.7 and Figure 3.8 are taken as an indication for the trends in 2010, it can be expected that the geometric mean of fecal coliform concentrations should satisfy the recreational guideline in all areas of Halifax Harbour during all seasons, but may not satisfy the shellfish harvesting guideline in the Outer Harbour during fall and winter.

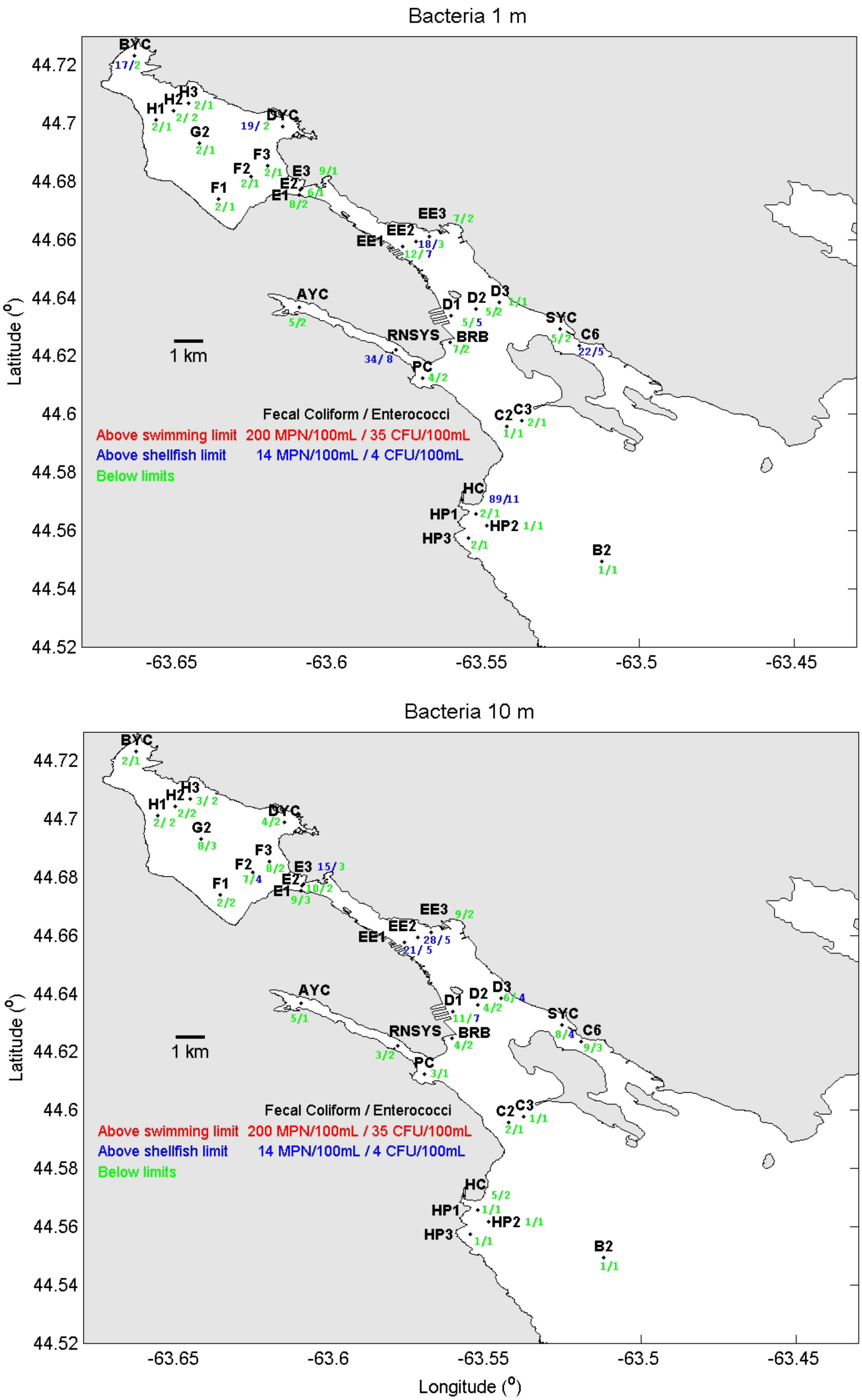

Figure 3.6 Bacteria geometric mean at 1-m and 10-m water depths over the period 25 June to 28 September 2010.

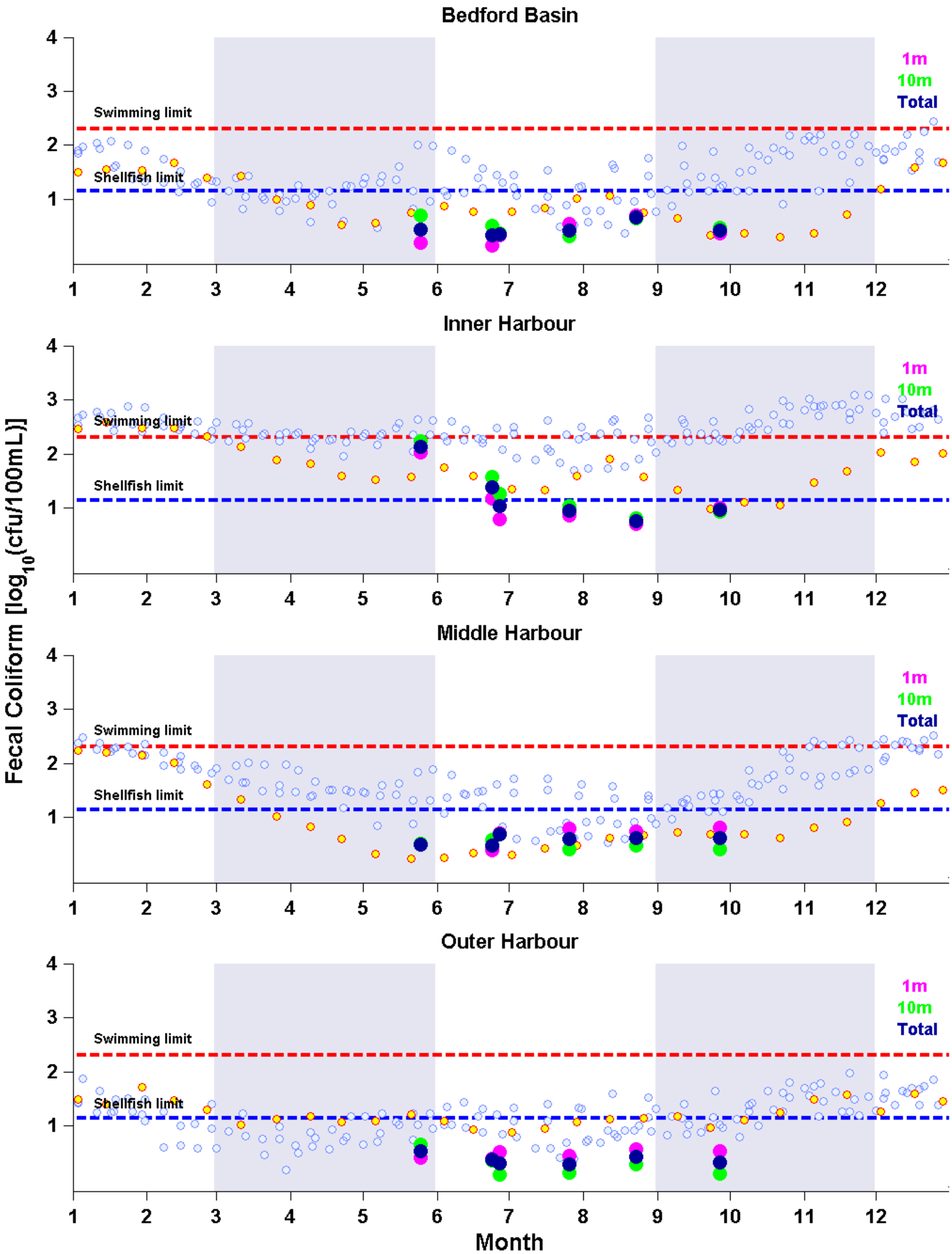

Figure 3.7 Fecal coliform geometric mean in the HHTF (1990) sections for the background period (pale blue dots), the year 2008 (yellow dots) and after treatment (large dots).

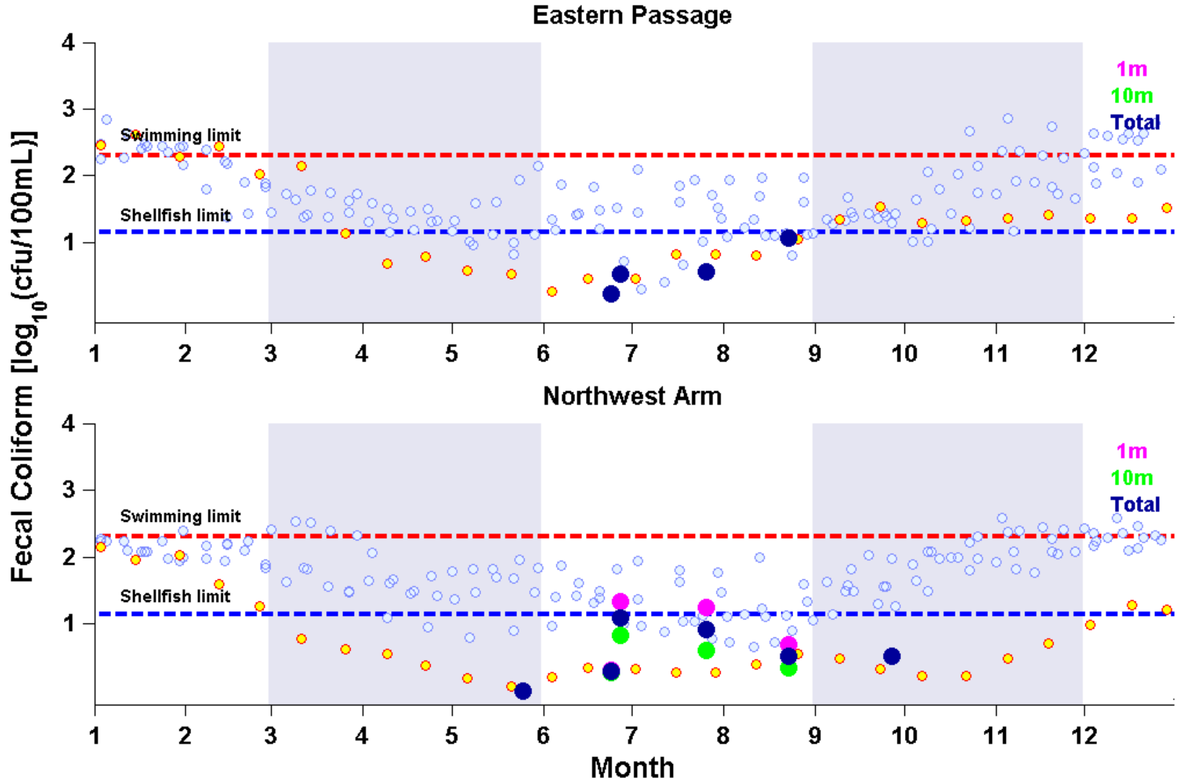

Figure 3.8 Fecal coliform geometric mean in two subsections of Middle Harbour for the background period (pale blue dots), the year 2008 (yellow dots) and after treatment (large dots).

Fecal Coliform Geo. Mean (CFU/100mL)		Bedford Basin	Inner Harbour	Middle Harbour	Outer Harbour	Eastern Passage	NW Arm
1 m	Baseline (133)	17	491	62	23	59	77
	Year 2008 (27)	8	65	12	24	22	7
	After Treatment (5)	3	6	6	4	10	9
10 m	Baseline (133)	33	159	29	8	34	41
	Year 2008 (27)	10	52	7	12	17	4
	After Treatment (5)	3	11	4	1	8	4
Total	Baseline (133)	24	279	42	13	45	56
	Year 2008 (27)	9	58	10	17	20	6
	After Treatment (5)	3	8	4	2	9	6

Table 3.1 Fecal coliform geometric mean over the three comparison periods. Note the number of surveys included in the comparison periods.

3.1.3 Ammonia Nitrogen

Ammonia nitrogen concentrations have been slightly above detection throughout the monitoring program, and generally did not follow a particular spatial pattern during the baseline period and during year 2008. This is reflected in the mean and maximum values presented for all the chemistry sites in Table 3.2. It is apparent, however, that after full treatment began in 2010, there is a tendency toward higher mean values in the Inner Harbour and the Narrows (sites D2, EE2, E2), and at 1-m water depth in the Outer Harbour at B2. The mean values in the Bedford Basin are comparable to baseline and 2008 levels. This pattern is illustrated in the plot of mean ammonia nitrogen values in Figure 3.9. The maximum values in 2010 are highest in the Inner Harbour, with lower values in the Middle and Outer Harbour, and lower values still in the Narrows and Bedford Basin. Compared to baseline levels, there is an increase in some areas and a decrease of the maximum values in other areas, with no distinguishable pattern.

During the baseline period, prior to the Harbour Solutions Project, the effluent had been released from dispersed outfalls throughout the harbour. The trend of mean values seen in the period after treatment is likely explained by the more consolidated output from the outfalls of the Halifax and Dartmouth WWTFs in the Inner Harbour, as treated effluent is the dominant source of ammonia nitrogen during the summer months.

(a) Ammonia Mean (mg/L)		B2	D2	EE2	E2	F2	G2	H2
1 m	Baseline (133)	0.03	0.06	0.07	0.07	0.06	0.06	0.07
	Year 2008 (27)	0.03	0.06	0.11	0.06	0.06	0.06	0.07
	After Treatment (4)	0.14	0.16	0.22	0.13	0.11	0.07	0.05
10 m	Baseline (133)	0.05	0.05	0.06	0.07	0.08	0.06	0.08
	Year 2008 (27)	0.03	0.06	0.08	0.05	0.06	0.07	0.06
	After Treatment (4)	0.05	0.17	0.07	0.10	0.12	0.06	0.07
Total	Baseline (133)	0.04	0.06	0.07	0.07	0.07	0.06	0.08
	Year 2008 (27)	0.03	0.06	0.09	0.06	0.06	0.07	0.07
	After Treatment (4)	0.10	0.17	0.15	0.12	0.12	0.07	0.06

(b) Ammonia Maximum (mg/L)		B2	D2	EE2	E2	F2	G2	H2
1 m	Baseline (133)	0.15	0.19	0.26	0.17	0.16	0.20	0.23
	Year 2008 (27)	0.11	0.22	1.10	0.11	0.22	0.10	0.15
	After Treatment (4)	0.30	0.30	0.43	0.26	0.12	0.17	0.12
10 m	Baseline (133)	0.94	0.18	0.49	0.21	0.26	0.18	0.26
	Year 2008 (27)	0.23	0.14	0.42	0.11	0.14	0.21	0.13
	After Treatment (4)	0.10	0.33	0.14	0.29	0.17	0.12	0.20
Total	Baseline (133)	0.94	0.19	0.49	0.21	0.26	0.20	0.26
	Year 2008 (27)	0.23	0.22	1.10	0.11	22	0.21	0.15
	After Treatment (4)	0.30	0.33	0.43	0.29	0.17	0.17	0.20

Table 3.2 Ammonia nitrogen statistics for the three comparison periods. Note the number of surveys included in the comparison periods.

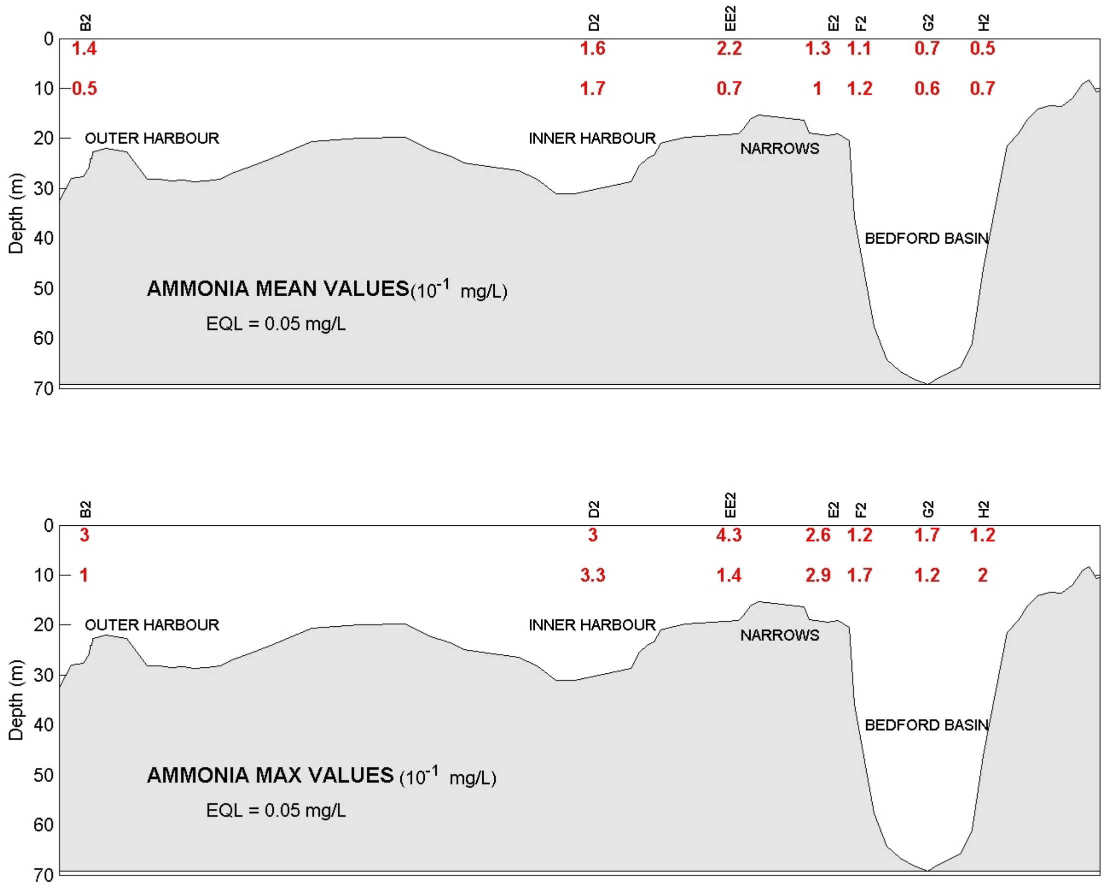

Figure 3.9 Ammonia nitrogen mean and maximum values after full treatment in 2010.

The increased concentrations in the Inner Harbour may contribute to the elevated values in the Narrows and the Middle Harbour, but the cause of the increase seen in the Outer Harbour is not clear. Due to the lower number of samples in the after-treatment period (n=4), these trends are to be taken with some reservation. It should be noted that there are no ammonia nitrogen guidelines set by the HHTF, and the primary treatment at the WWTFs was not expected to reduce the ammonia levels in the treated effluent.

3.1.4 Total Suspended Solids

The distribution of TSS during the 2010 period considered here shows a tendency for elevated values in the Narrows, with the highest mean and the maximum values found at EE2. During the period represented here, the plankton activity in the harbour was also significant and may have contributed to the TSS values. It is likely that the spatial pattern observed is influenced by the elevated values of ammonia nitrogen in the Inner Harbour that provide nutrients to support a higher and prolonged plankton biomass.

The mean and maximum TSS values for the three comparison periods are shown in Table 3.3. It is evident that there is a reduction in both the mean and maximum values at all sites, with a decrease to about 60% of the baseline for the mean TSS values, and to about 25-50% of the baseline for the maximum TSS values. These results therefore show a significant improvement, despite the influence of the relatively higher phytoplankton activity during the observation period. Significant reductions compared to the baseline are also apparent in the 2008 dataset.

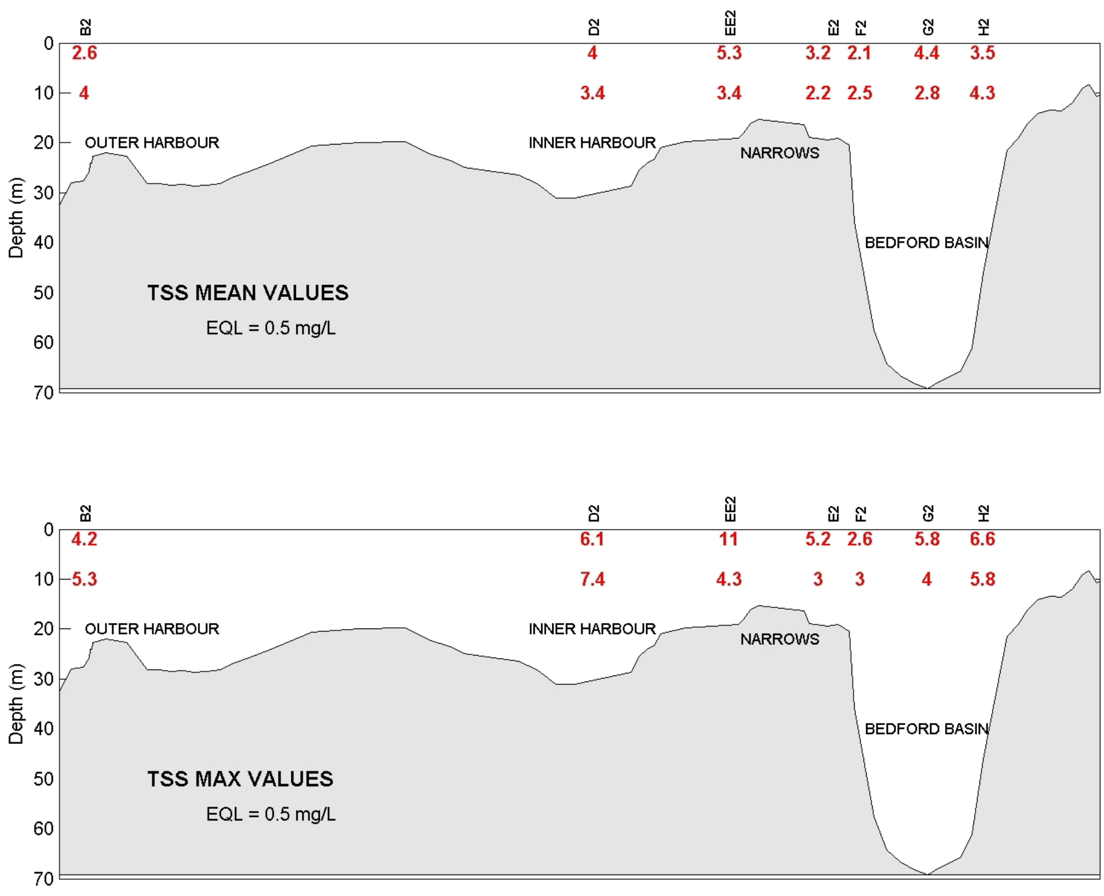

Figure 3.10 Total suspended solids mean and maximum values after full treatment in 2010.

(a) TSS Mean (mg/L)		B2	D2	EE2	E2	F2	G2	H2
1 m	Baseline (133)	4.2	5.3	5.8	6.2	6.3	5.8	6.0
	Year 2008 (27)	3.3	3.2	3.7	3.7	4.6	4.1	4.3
	After Treatment (4)	2.6	4.0	5.3	3.2	2.1	4.4	3.5
10 m	Baseline (133)	4.4	5.5	5.7	5.9	6.2	6.2	5.9
	Year 2008 (27)	3.0	3.3	3.5	3.8	3.6	4.9	3.6
	After Treatment (4)	4.0	3.4	3.4	2.2	2.5	2.8	4.3
Total	Baseline (133)	4.3	5.4	5.8	6.1	6.3	6.0	6.0
	Year 2008 (27)	3.2	3.3	3.6	3.8	4.1	4.5	4.0
	After Treatment (4)	3.3	3.7	4.3	2.7	2.3	3.6	3.9

(b) TSS Maximum (mg/L)		B2	D2	EE2	E2	F2	G2	H2
1 m	Baseline (133)	21	29	18	41	35	17	19
	Year 2008 (27)	12	10	9.1	7	11	12	11
	After Treatment (4)	4.2	6.1	11.0	5.2	2.6	5.8	6.6
10 m	Baseline (133)	18	26	19	33	37	18	34
	Year 2008 (27)	6	7	7.2	12	8	12	8.6
	After Treatment (4)	5.3	7.4	4.3	3.0	3.0	4.0	5.8
Total	Baseline (133)	21	29	19	41	37	18	34
	Year 2008 (27)	12	10	9.7	12	11	12	11
	After Treatment (4)	5.3	7.4	11.0	5.2	3.0	5.8	6.6

Table 3.3 Total suspended solids statistics for the three comparison periods. Note the number of surveys included in the comparison periods.

3.1.5 Metals

The results of the metals analysis for the 2010 after-treatment period are summarized in Figure 3.11. The mean levels for all metals are below the guidelines set by the HHTF, however there were two exceedances of copper and four exceedances of mercury guidelines. The exceedances were in the Inner and Outer Harbour. Copper and mercury are the metals that most frequently exceeded the guidelines throughout the whole monitoring period; however there is no established pattern in space and time.

The time series plots in Appendices D to K indicate that no apparent effects on metals concentrations are seen in the transition period in 2008 and the final results in 2010 when compared to the baseline levels and as measured with the adequate high-resolution analysis employed since August 2006. Higher values and more frequent exceedances of zinc and lead were seen in the results prior to November 2005, when a lower resolution analysis was used, however the reason for this is not known. These findings indicate that the released effluent may not be the dominant source of metals in the Harbour.

Overall the guidelines set by the HHTF are met, however further investigation of the sources of intermittent exceedances in copper and mercury guidelines is warranted.

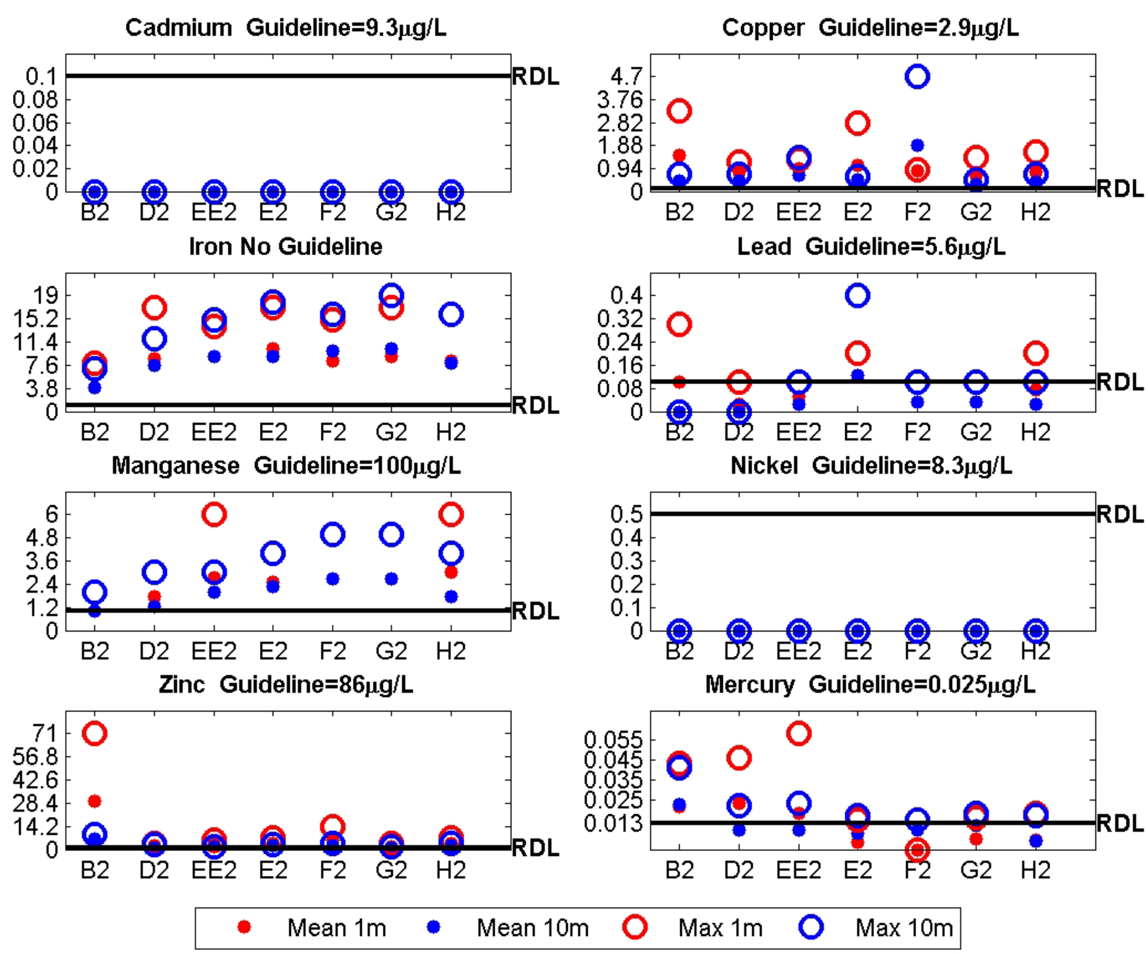

Figure 3.11 Metal concentration mean and maximum values after full treatment in 2010.

3.2 Effects of Sewage Treatment Operations on Water Quality

The Halifax Harbour Water Quality Monitoring Program has resulted in a vast amount of information on a wide set of variables, including water quality parameters and oceanographic measures of the dynamic state of Halifax Harbour. These have been analyzed and interpreted in the context of meteorological forcing derived by publicly available data from Environment Canada, resulting in the publication of Survey Reports, Quarterly Reports and annual summaries in the period between June 2004 and September 2010. This monitoring program was able to track the evolution of water quality and the state of the Harbour as the sewage treatment operations were gradually established.

In this report the indicators of water quality in Halifax Harbour have been summarized to present a clear view of the changes that have resulted from the operation of the wastewater treatment facilities in Halifax, Dartmouth and Herring Cove. Three periods have been defined for comparison of the main water quality indicators: a baseline period before any sewage treatment took place, the transition period in year 2008 during which sewage treatment was partially or intermittently conducted at variable capacities at the three WWTFs, and the period from June to September 2010 when all WWTFs were in full operation.

The analysis shows that the goals for water quality set by the HHTF have been largely met. The primary indicator of water quality and the one with the highest impact for human health is the fecal coliform concentration. The measurements have shown vast improvements in all areas of the Harbour during the period when all WWTFs were in full operation, on average meeting or exceeding the goals set by HHTF. Sampling was conducted mostly on a monthly basis in 2010 and it did not cover all seasons of the year. Therefore seasonal variations are not captured for comparison with the previous periods. However, analysis of data in the transitional period in 2008 showed vast improvements in the bacteria levels starting from spring 2008, with only the Halifax WWTF in operation, through the end of the year when all three WWTFs were in operation. The effect of the operation of the Halifax and later Dartmouth WWTF in 2008 was apparent in all areas of the Harbour except the Outer Harbour. With the failure of the Halifax plant in January 2009 the bacteria levels increased, but not to the baseline levels seen before the cleanup began. With the operation of all three WWTFs in Halifax, Dartmouth and Herring Cove, the bacteria levels are expected to stay below the applicable guidelines based on intended use of each section of the Harbour.

The analysis of chemistry data shows that the guidelines for metals concentrations have been met on average, however intermittent exceedances of copper and mercury guidelines still occur. The spatial and temporal distribution of these exceedances does not allow for the identification of a single source of contamination, and further investigation into the issue is warranted.

The analysis of ammonia nitrogen levels shows an increase in the mean levels in 2010, up to twice the baseline values in the Inner Harbour area. This is not unexpected, as the effluent outfalls in 2010 were consolidated to the Inner Harbour area, while they were more widely dispersed through the harbour during the baseline period. Furthermore, the primary treatment process is not expected to diminish the ammonia nitrogen levels in the treated effluent. There are no guidelines set by HHTF for ammonia nitrogen, however there is the potential that elevated values may create the conditions for more frequent algal blooms in the Harbour, which may temporarily and locally reduce dissolved oxygen levels below the applicable guidelines. The measured dissolved oxygen levels in 2010 have been high and satisfying all applicable criteria in all areas of the Harbour, with local exceptions likely related to the observed elevated phytoplankton activity. The Bedford Basin deep water is prone to natural depression of dissolved oxygen, as it represents a deep fjord with a shallow sill that prevents intrusions of oxygenated continental shelf water through most of the year.

The mean levels of total suspended solids in the Harbour have been reduced to approximately 60% of the baseline levels, with a tendency for higher values in the Inner Harbour where the outfalls of the Halifax and Dartmouth WWTFs are located. This is an expected effect of the concentration of the TSS sources in the Inner Harbour by the placement of the Halifax and Dartmouth WWTF outfalls in this area. Due to the fact that the ambient TSS level is not explicitly defined, it is unclear whether the current TSS levels meet the HHTF guideline of 10% above ambient level. Furthermore, the available data for Halifax Harbour do not allow for the estimation of the purely anthropogenic contribution toward the observed TSS concentrations. Given the fact that the values are relatively low above the detection limit and natural plankton activity in the Harbour can contribute significantly, there is no indication that the current levels are abnormal or that they can be reduced further.

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5 APPENDIX

5.1 APPENDIX A: Fecal Coliform Raw Data and Geometric Mean Time Series

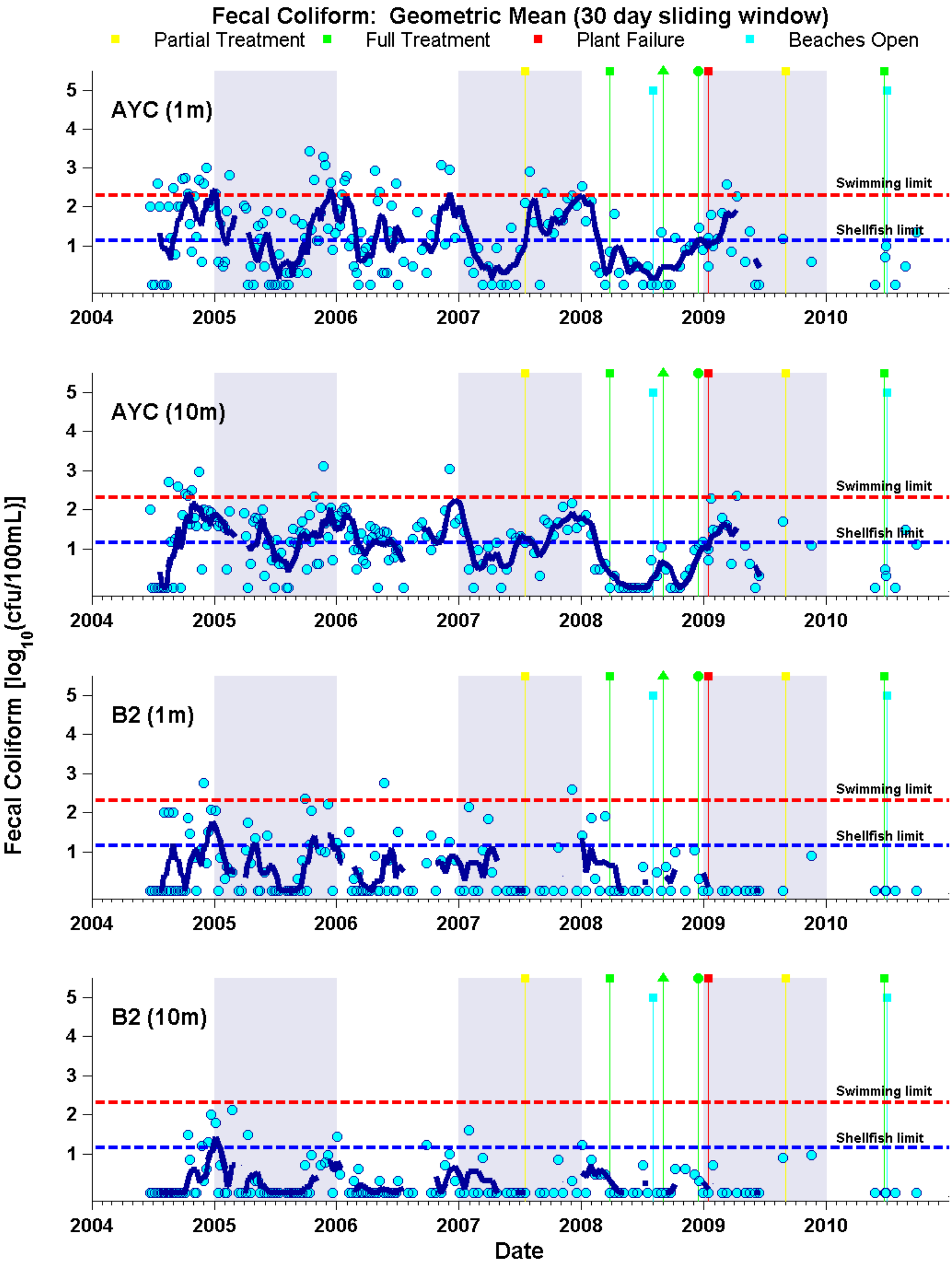

Figure 5.1 Fecal coliform raw data (cyan dots) and geometric mean (blue line). Note the green timestamps for full treatment at Halifax (square), Dartmouth (triangle) and Herring Cove (circle) WWTFs.

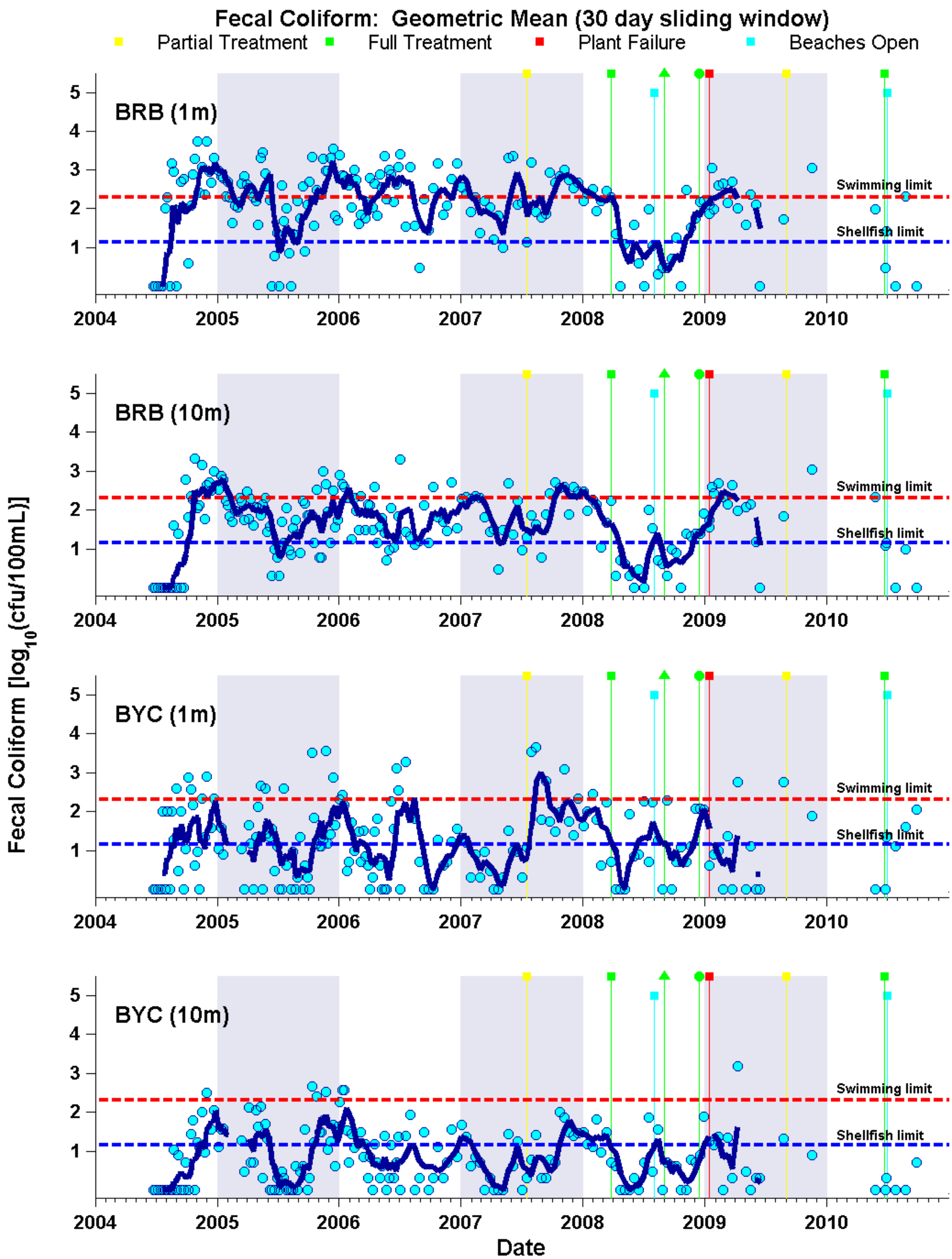

Figure 5.2 Fecal coliform raw data (cyan dots) and geometric mean (blue line). Note the green timestamps for full treatment at Halifax (square), Dartmouth (triangle) and Herring Cove (circle) WWTFs.

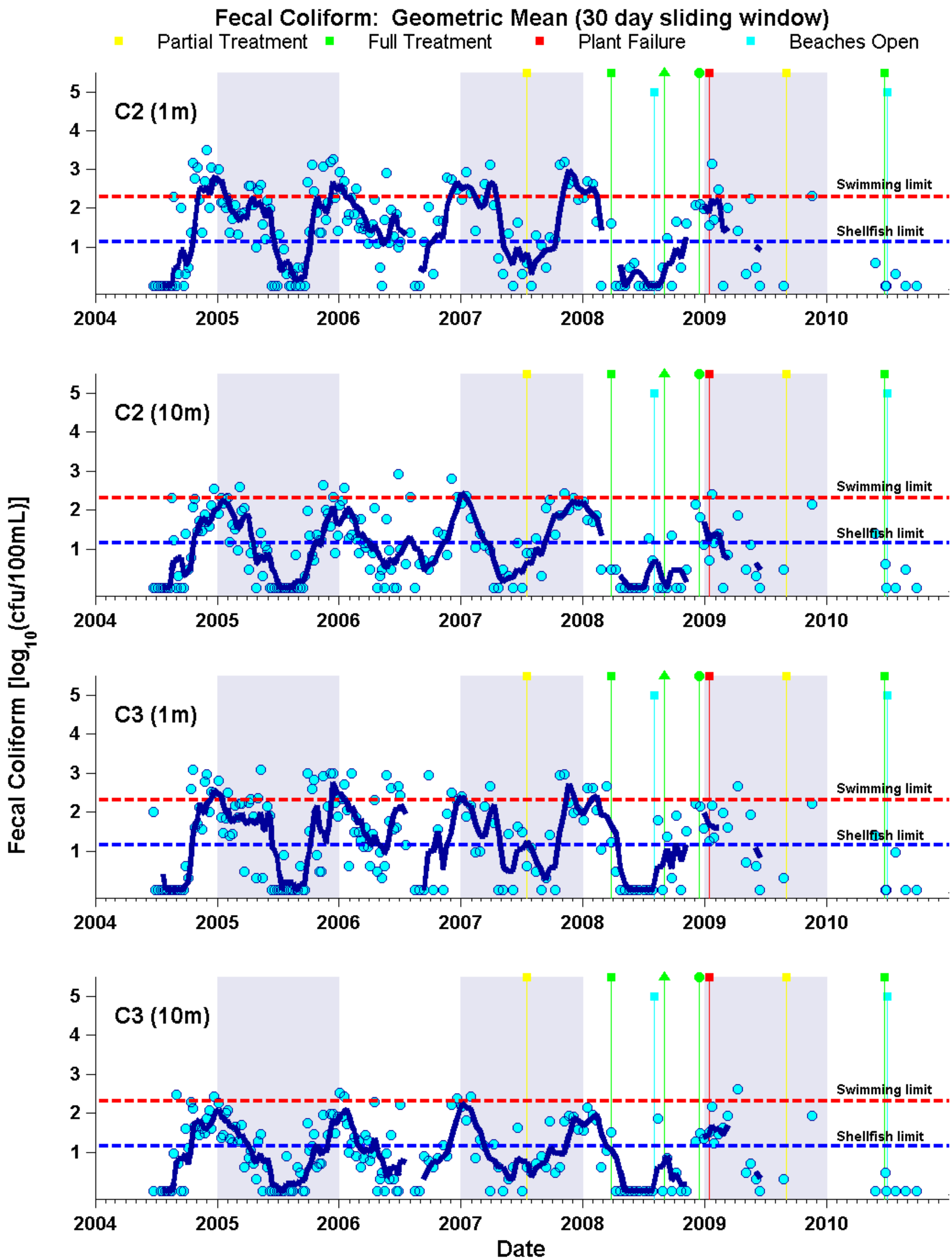

Figure 5.3 Fecal coliform raw data (cyan dots) and geometric mean (blue line). Note the green timestamps for full treatment at Halifax (square), Dartmouth (triangle) and Herring Cove (circle) WWTFs.

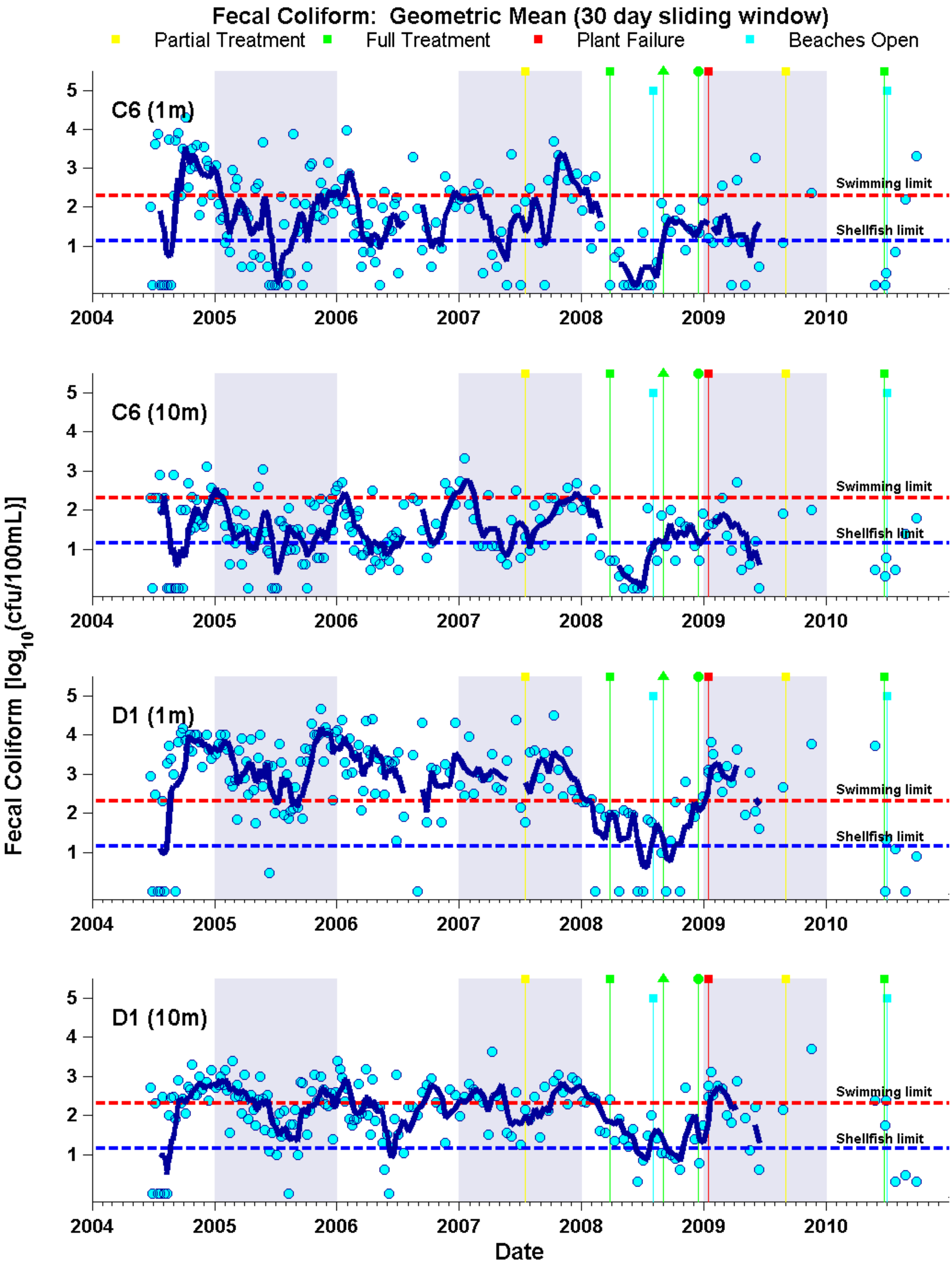

Figure 5.4 Fecal coliform raw data (cyan dots) and geometric mean (blue line). Note the green timestamps for full treatment at Halifax (square), Dartmouth (triangle) and Herring Cove (circle) WWTFs.

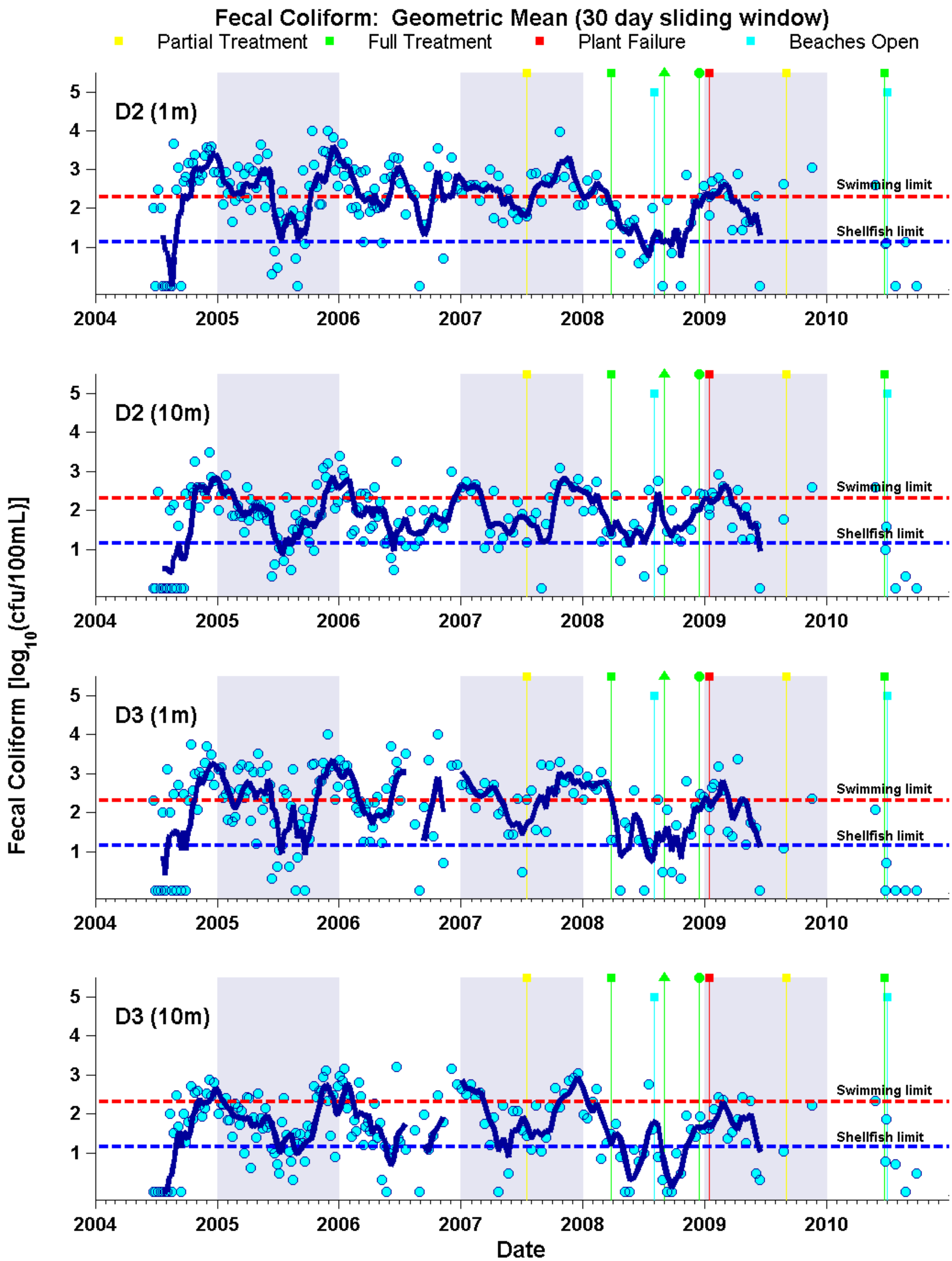

Figure 5.5 Fecal coliform raw data (cyan dots) and geometric mean (blue line). Note the green timestamps for full treatment at Halifax (square), Dartmouth (triangle) and Herring Cove (circle) WWTFs.

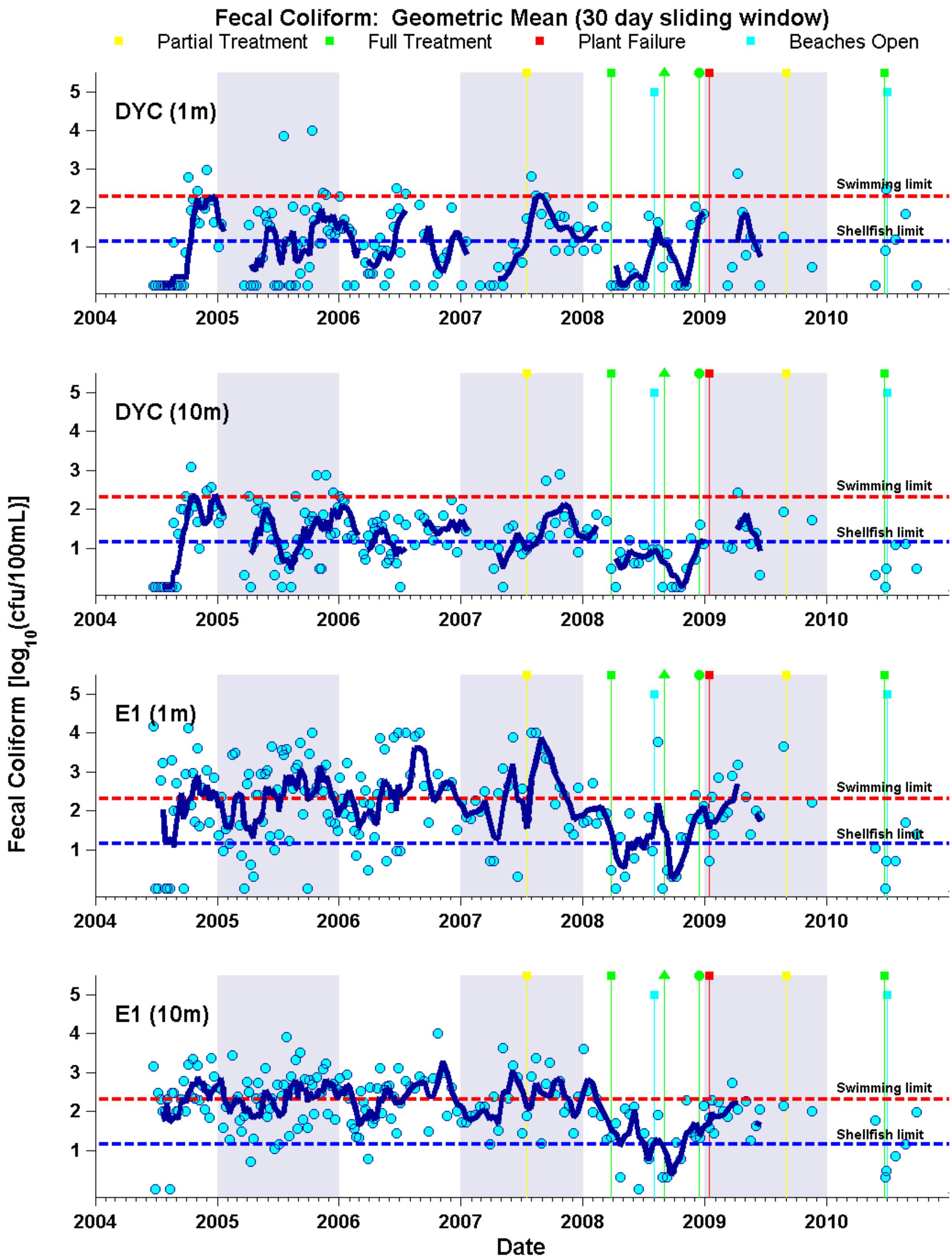

Figure 5.6 Fecal coliform raw data (cyan dots) and geometric mean (blue line). Note the green timestamps for full treatment at Halifax (square), Dartmouth (triangle) and Herring Cove (circle) WWTFs.

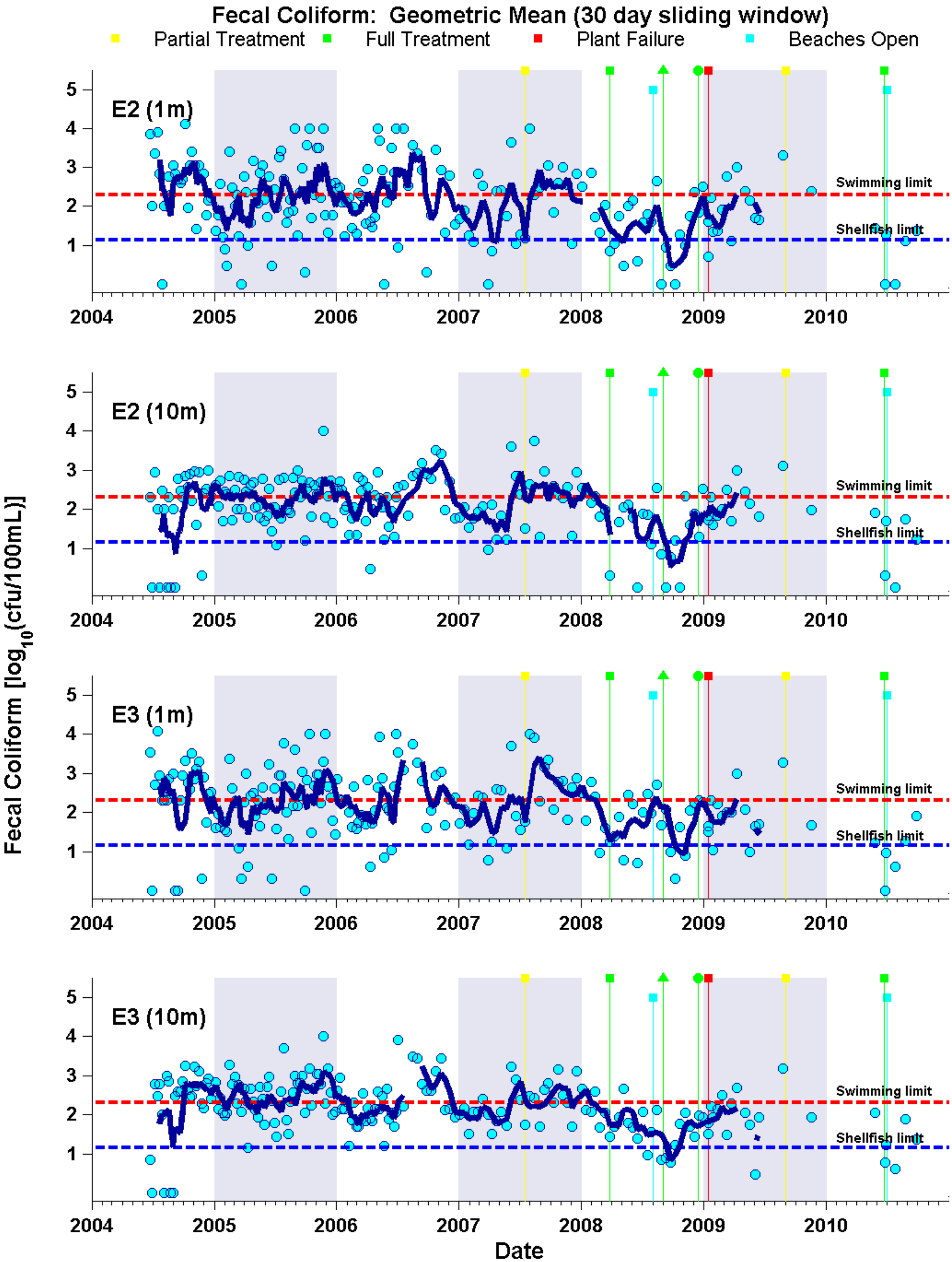

Figure 5.7 Fecal coliform raw data (cyan dots) and geometric mean (blue line). Note the green timestamps for full treatment at Halifax (square), Dartmouth (triangle) and Herring Cove (circle) WWTFs.

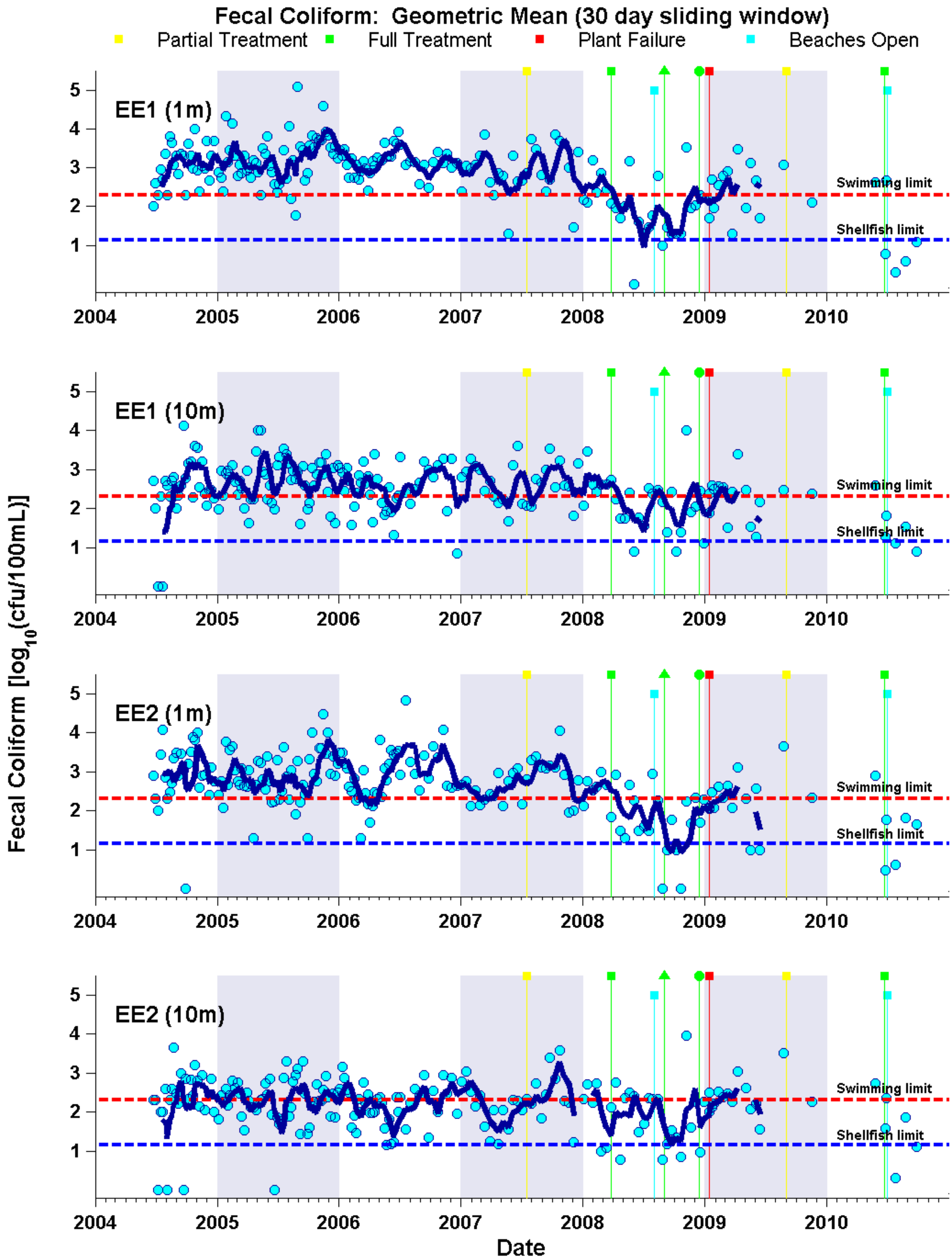

Figure 5.8 Fecal coliform raw data (cyan dots) and geometric mean (blue line). Note the green timestamps for full treatment at Halifax (square), Dartmouth (triangle) and Herring Cove (circle) WWTFs.

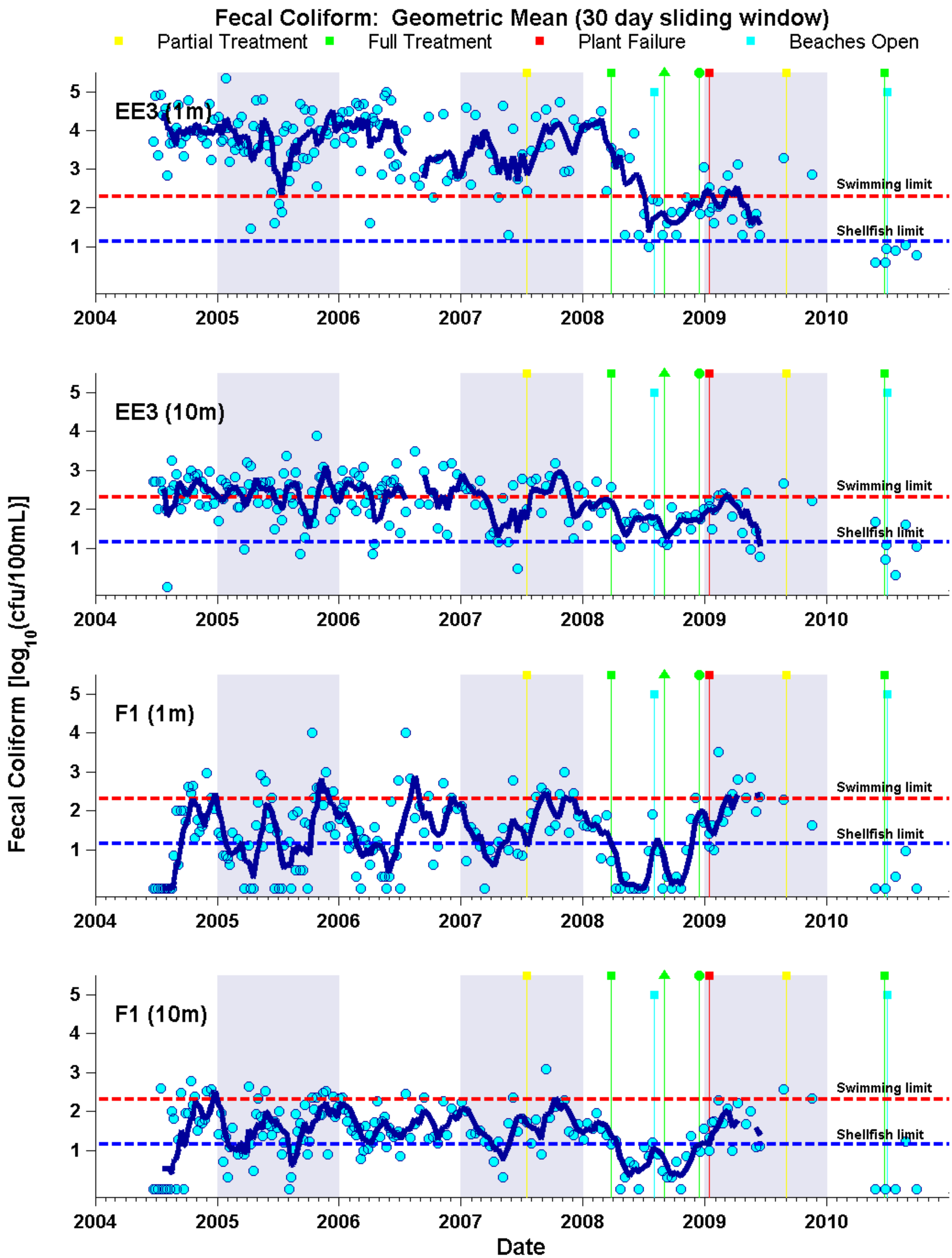

Figure 5.9 Fecal coliform raw data (cyan dots) and geometric mean (blue line). Note the green timestamps for full treatment at Halifax (square), Dartmouth (triangle) and Herring Cove (circle) WWTFs.

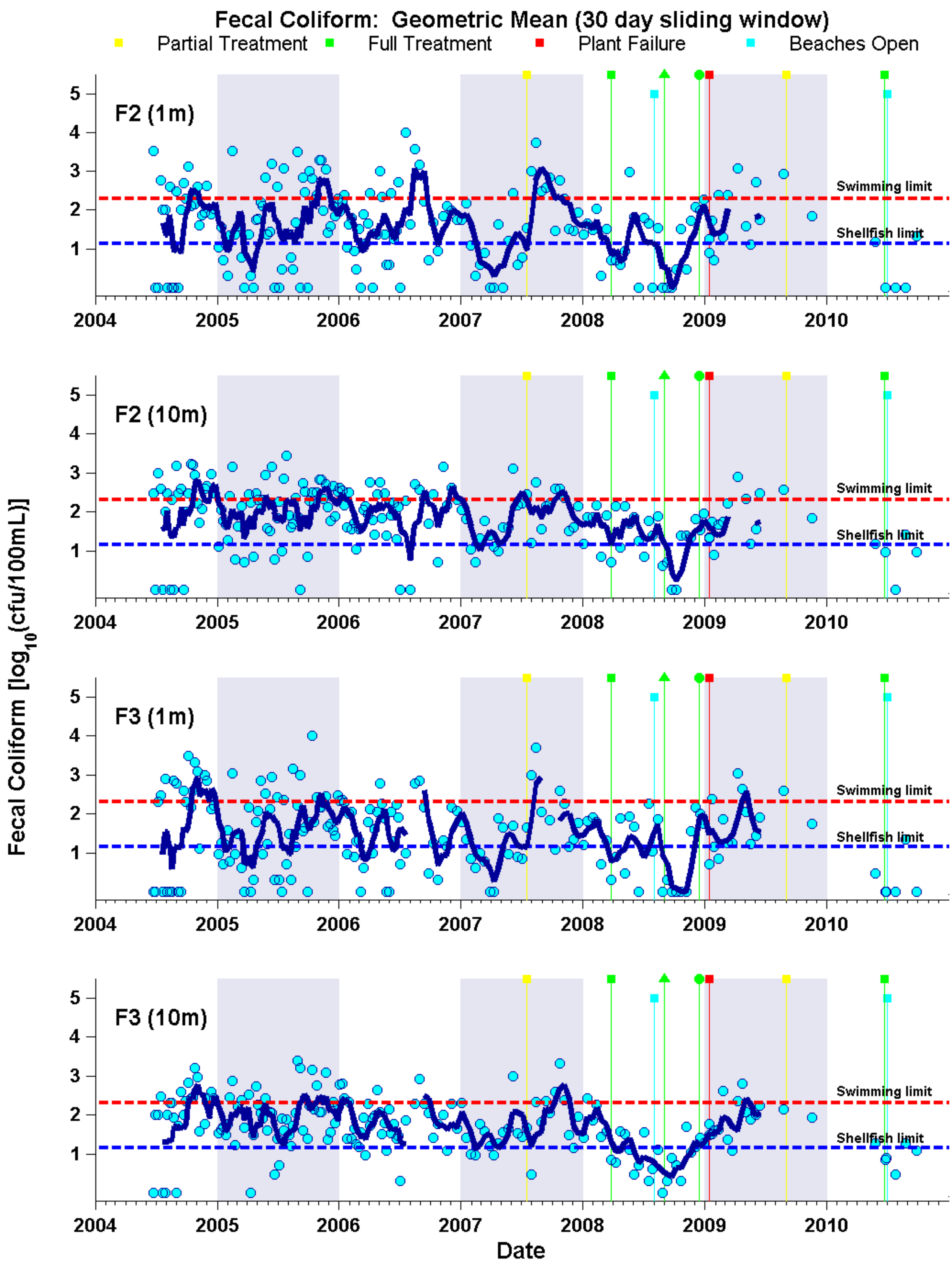

Figure 5.10 Fecal coliform raw data (cyan dots) and geometric mean (blue line). Note the green timestamps for full treatment at Halifax (square), Dartmouth (triangle) and Herring Cove (circle) WWTFs.

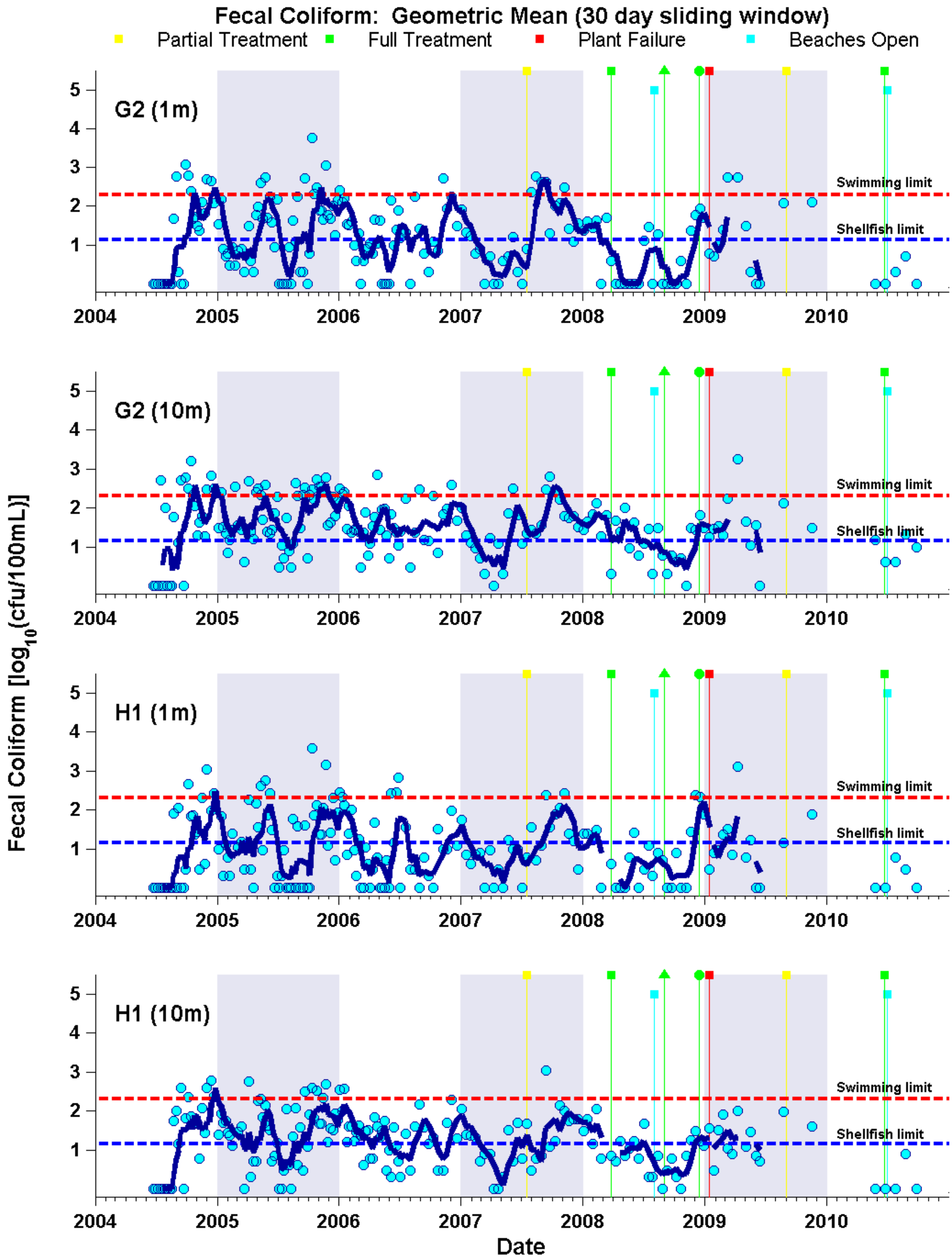

Figure 5.11 Fecal coliform raw data (cyan dots) and geometric mean (blue line). Note the green timestamps for full treatment at Halifax (square), Dartmouth (triangle) and Herring Cove (circle) WWTFs.

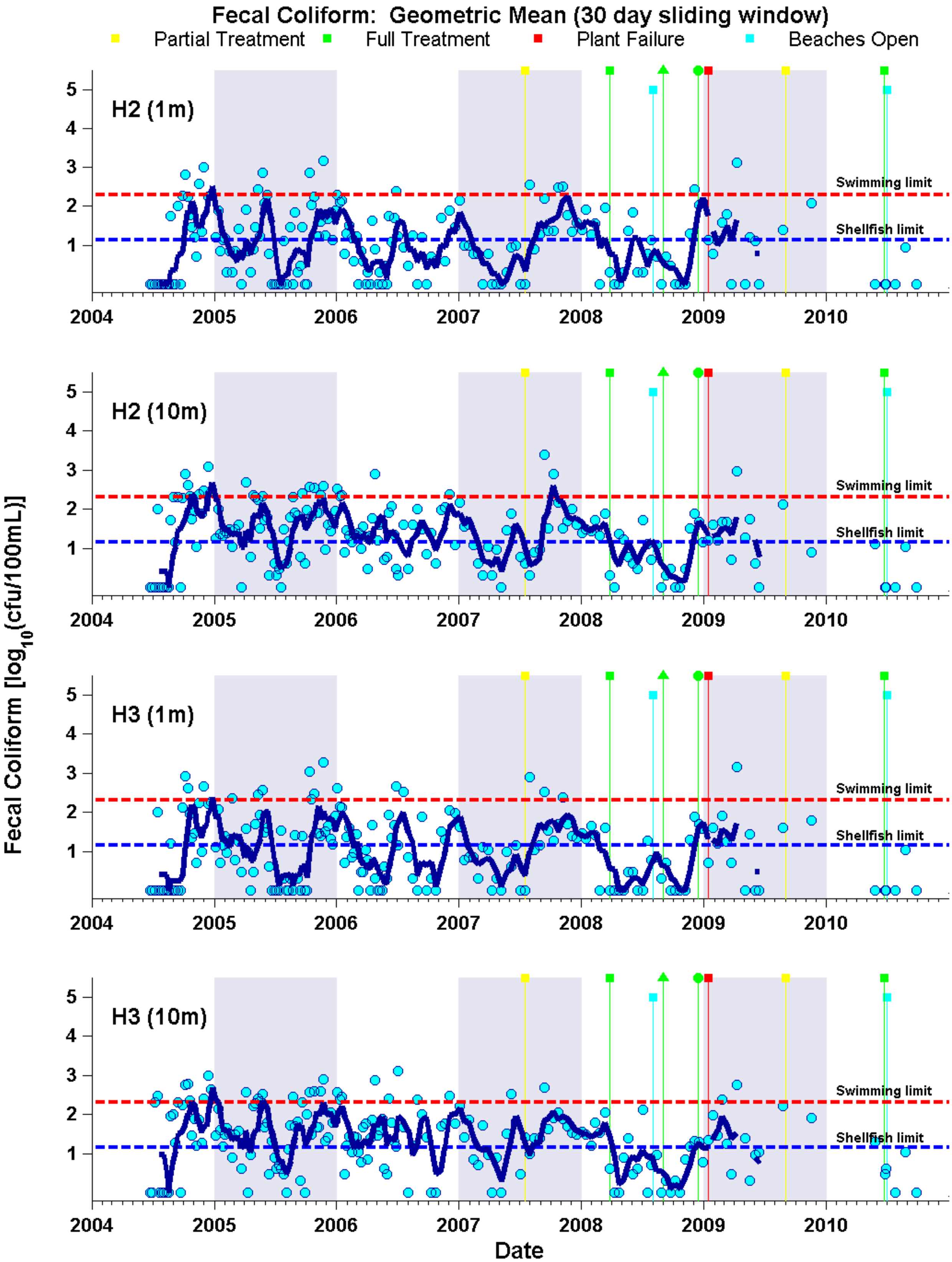

Figure 5.12 Fecal coliform raw data (cyan dots) and geometric mean (blue line). Note the green timestamps for full treatment at Halifax (square), Dartmouth (triangle) and Herring Cove (circle) WWTFs.

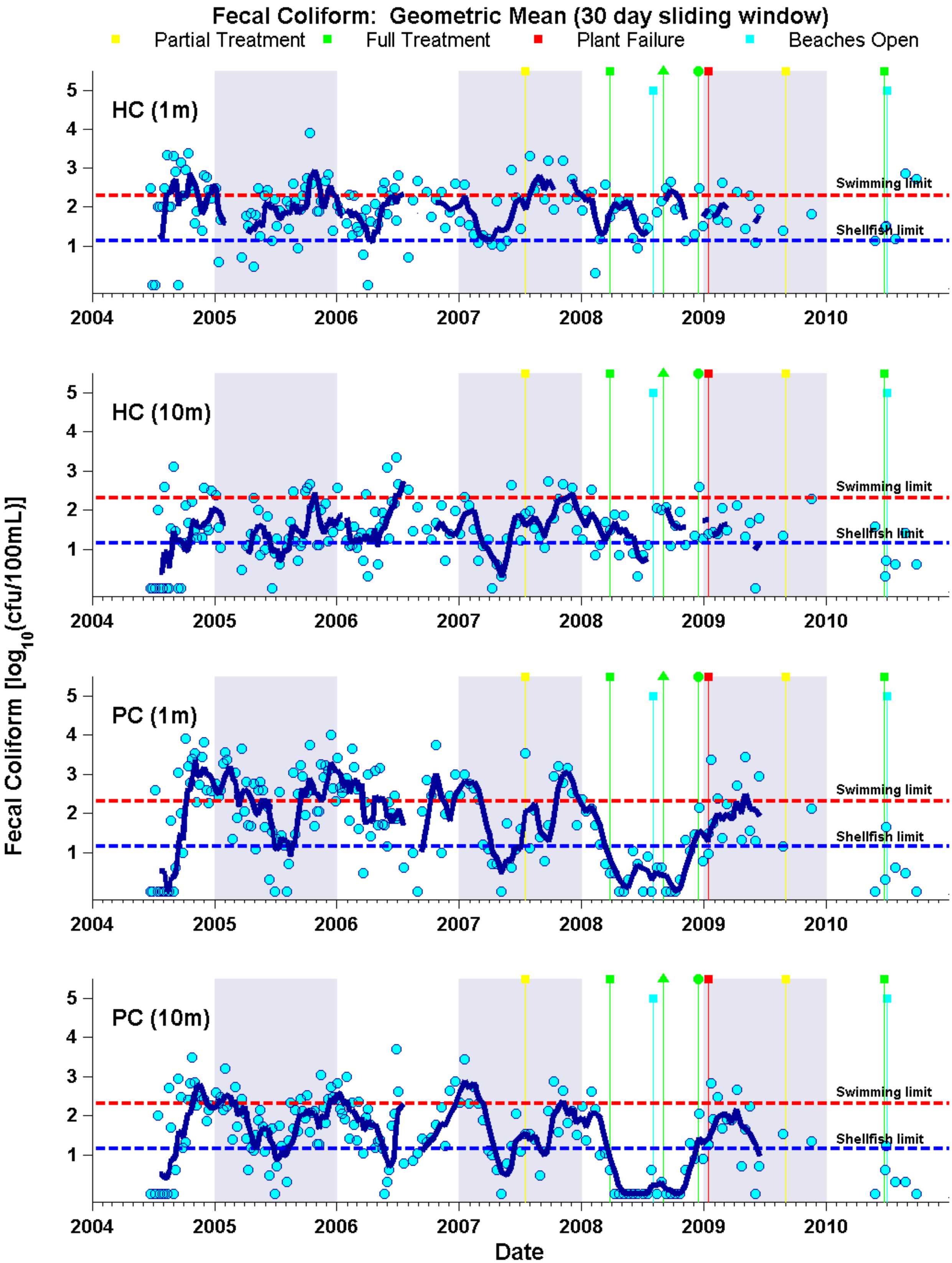

Figure 5.13 Fecal coliform raw data (cyan dots) and geometric mean (blue line). Note the green timestamps for full treatment at Halifax (square), Dartmouth (triangle) and Herring Cove (circle) WWTFs.

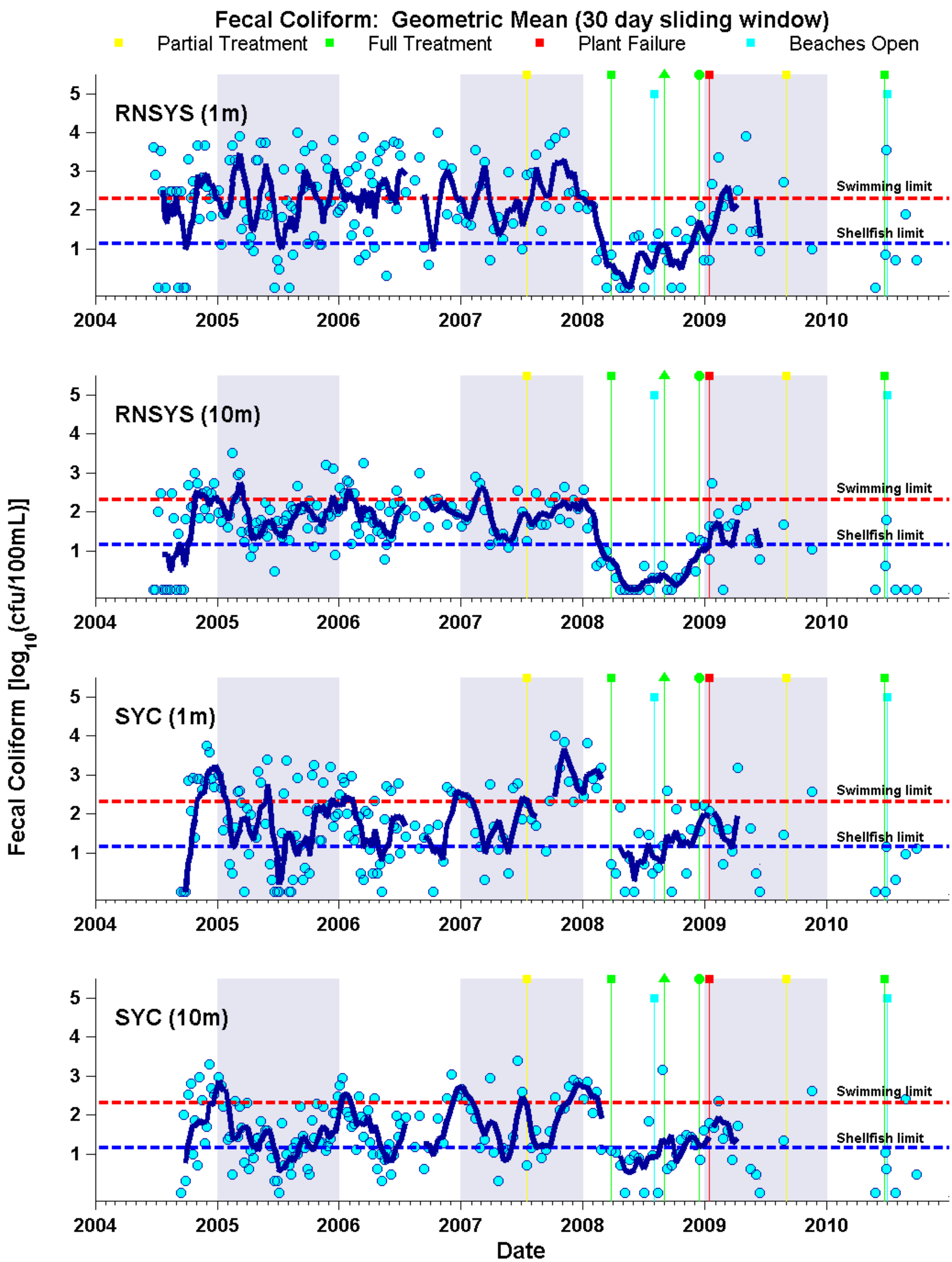

Figure 5.14 Fecal coliform raw data (cyan dots) and geometric mean (blue line). Note the green timestamps for full treatment at Halifax (square), Dartmouth (triangle) and Herring Cove (circle) WWTFs.

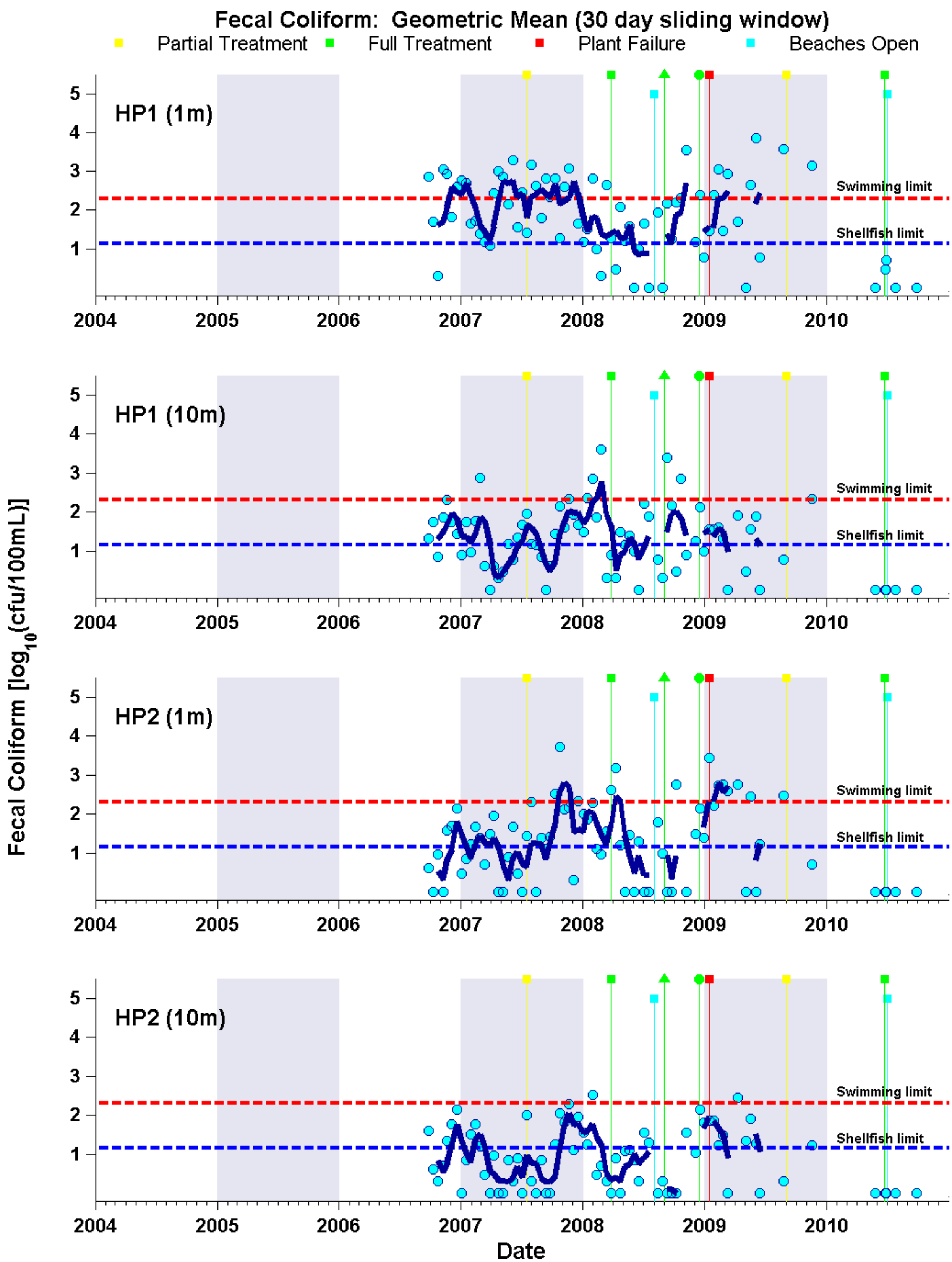

Figure 5.15 Fecal coliform raw data (cyan dots) and geometric mean (blue line). Note the green timestamps for full treatment at Halifax (square), Dartmouth (triangle) and Herring Cove (circle) WWTFs.

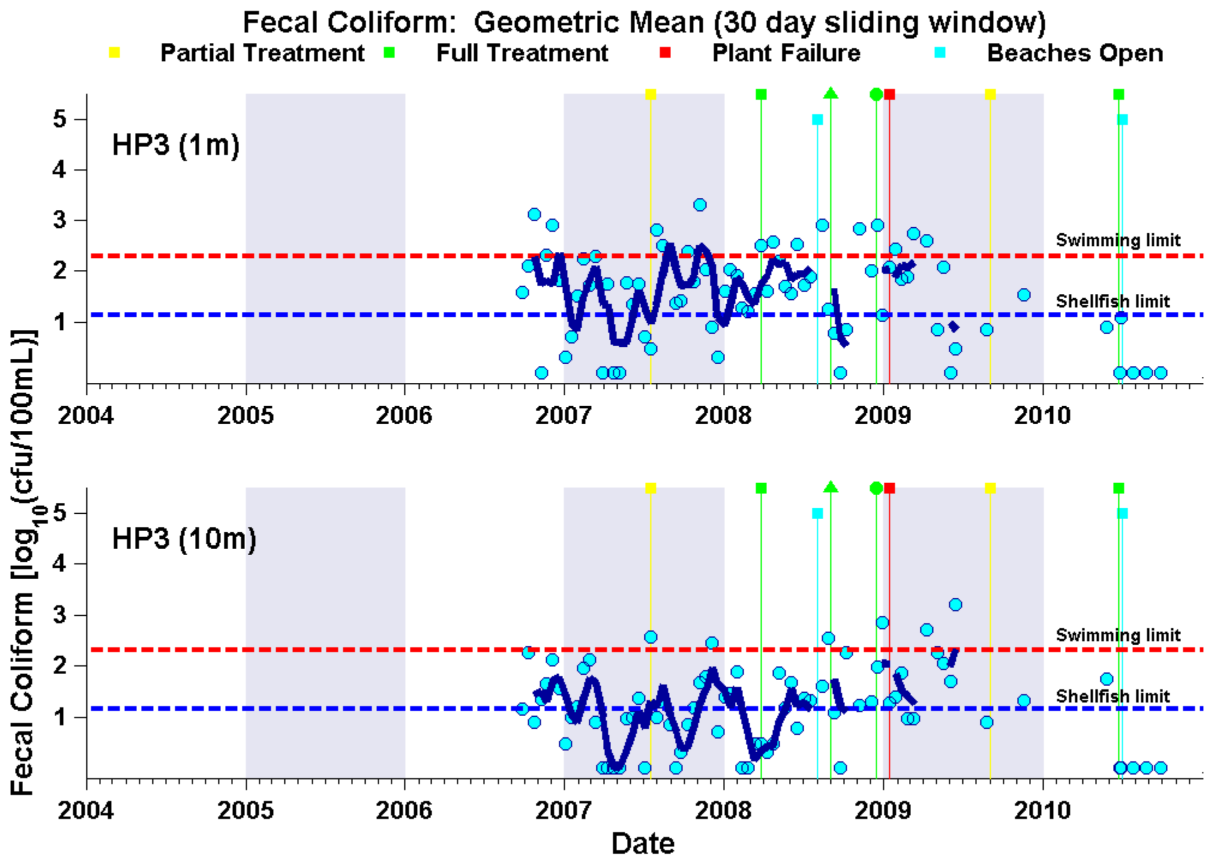

Figure 5.16 Fecal coliform raw data (cyan dots) and geometric mean (blue line). Note the green timestamps for full treatment at Halifax (square), Dartmouth (triangle) and Herring Cove (circle) WWTFs.

5.2 APPENDIX B: Ammonia Nitrogen Time Series

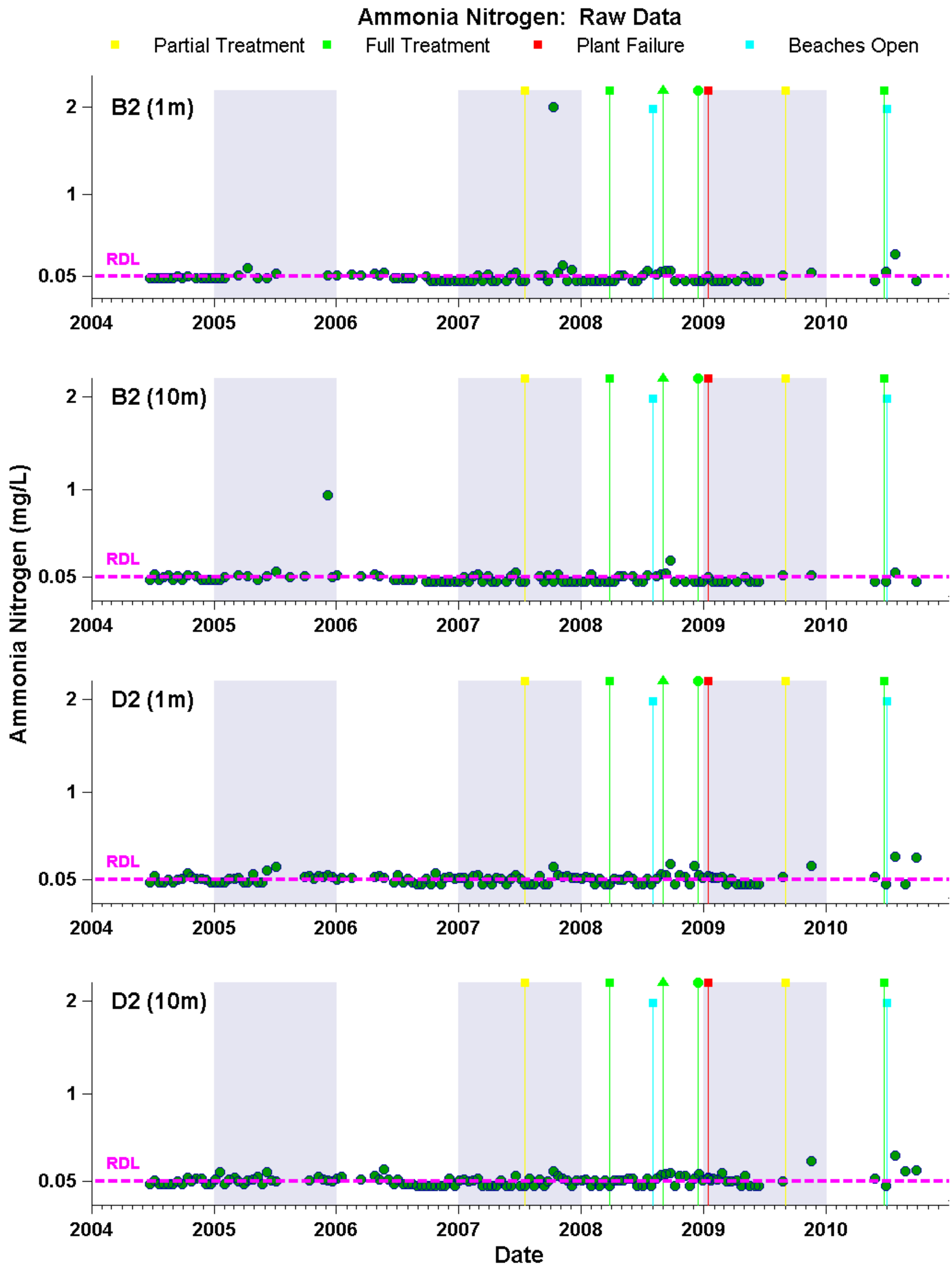

Figure 5.17 Ammonia nitrogen raw data. Note the reportable detection limit (RDL) line. Note the green timestamps for full treatment at Halifax (square), Dartmouth (triangle) and Herring Cove (circle) WWTFs.

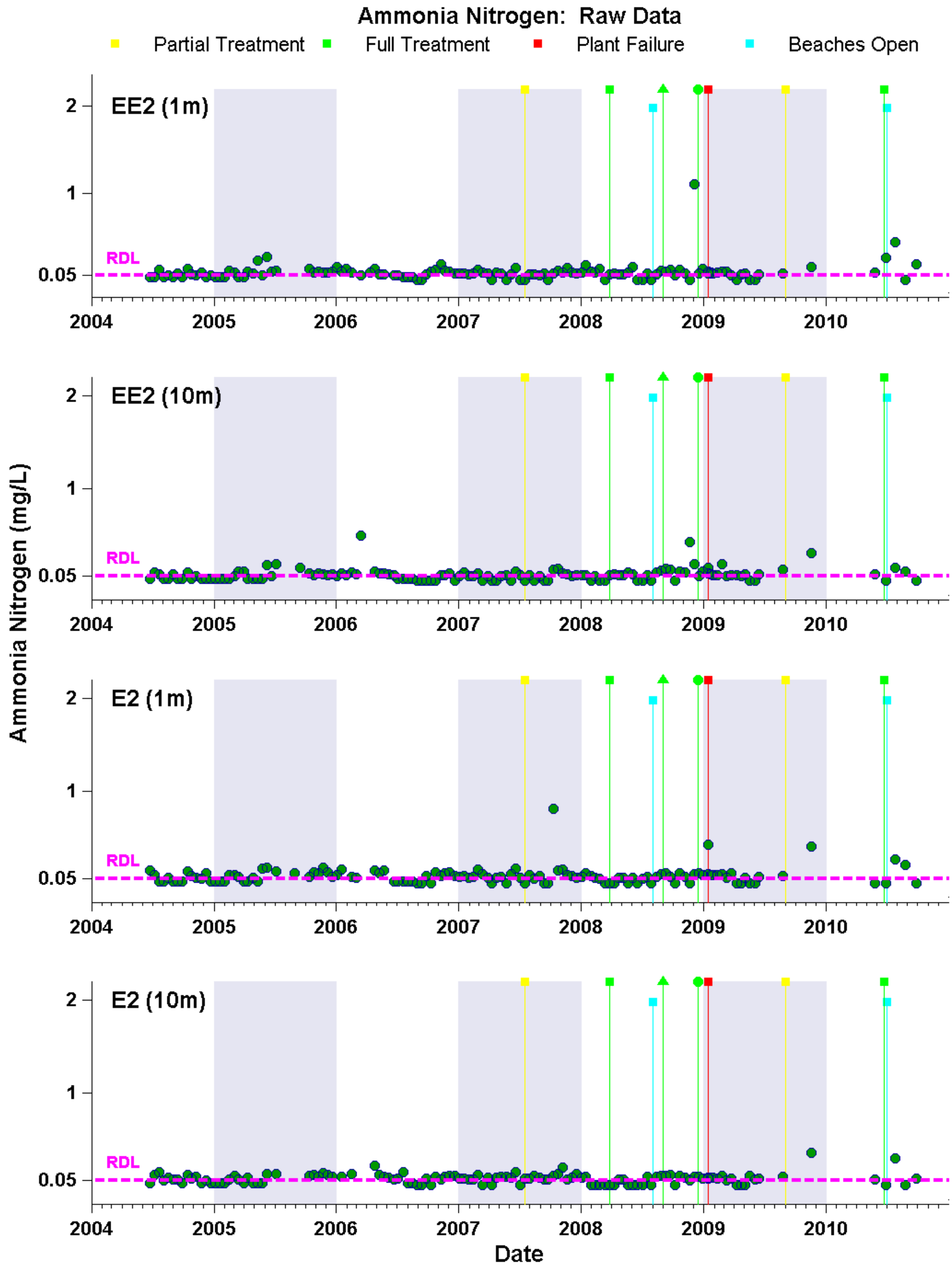

Figure 5.18 Ammonia nitrogen raw data. Note the reportable detection limit (RDL) line. Note the green timestamps for full treatment at Halifax (square), Dartmouth (triangle) and Herring Cove (circle) WWTFs.

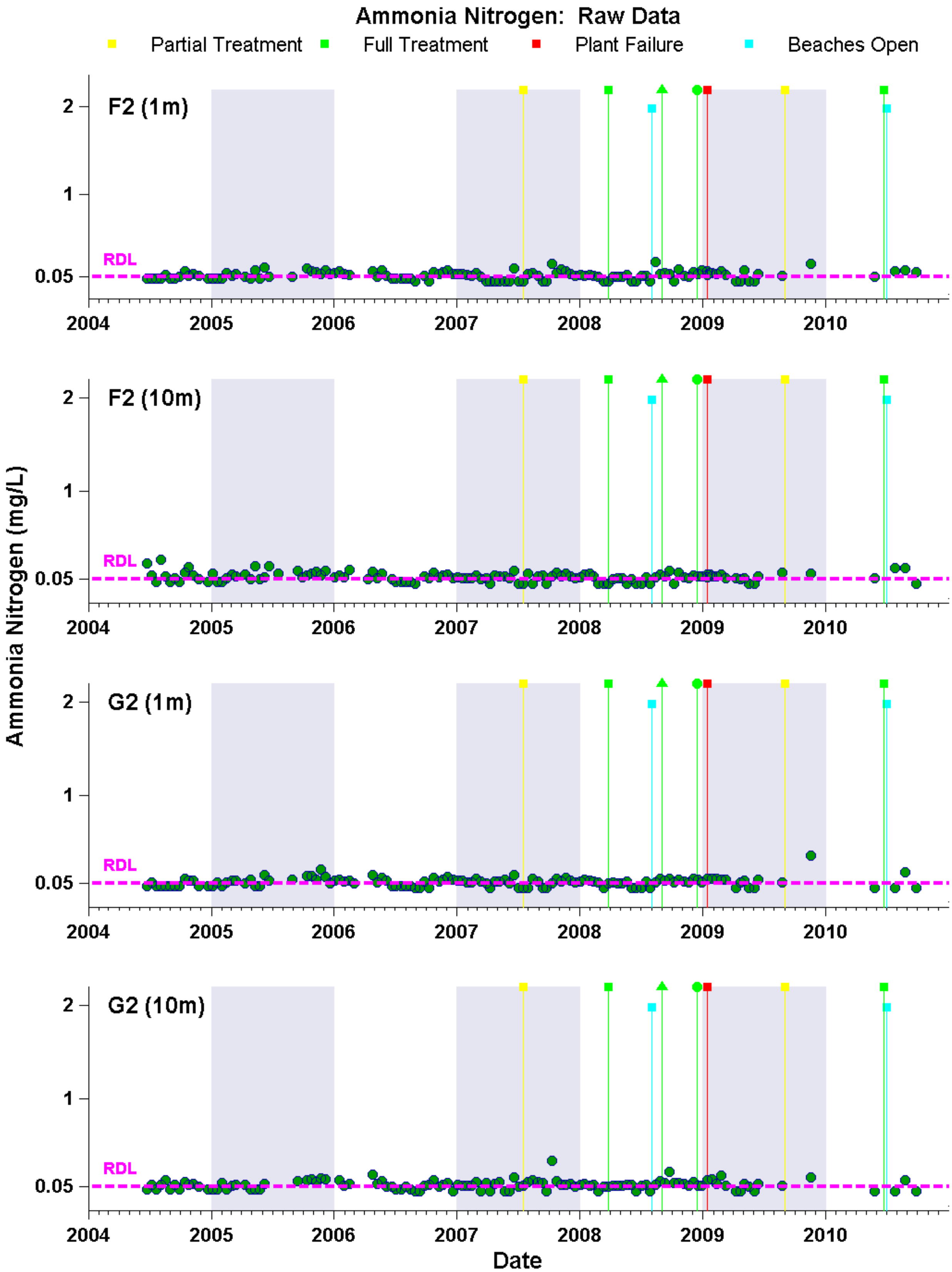

Figure 5.19 Ammonia nitrogen raw data. Note the reportable detection limit (RDL) line. Note the green timestamps for full treatment at Halifax (square), Dartmouth (triangle) and Herring Cove (circle) WWTFs.

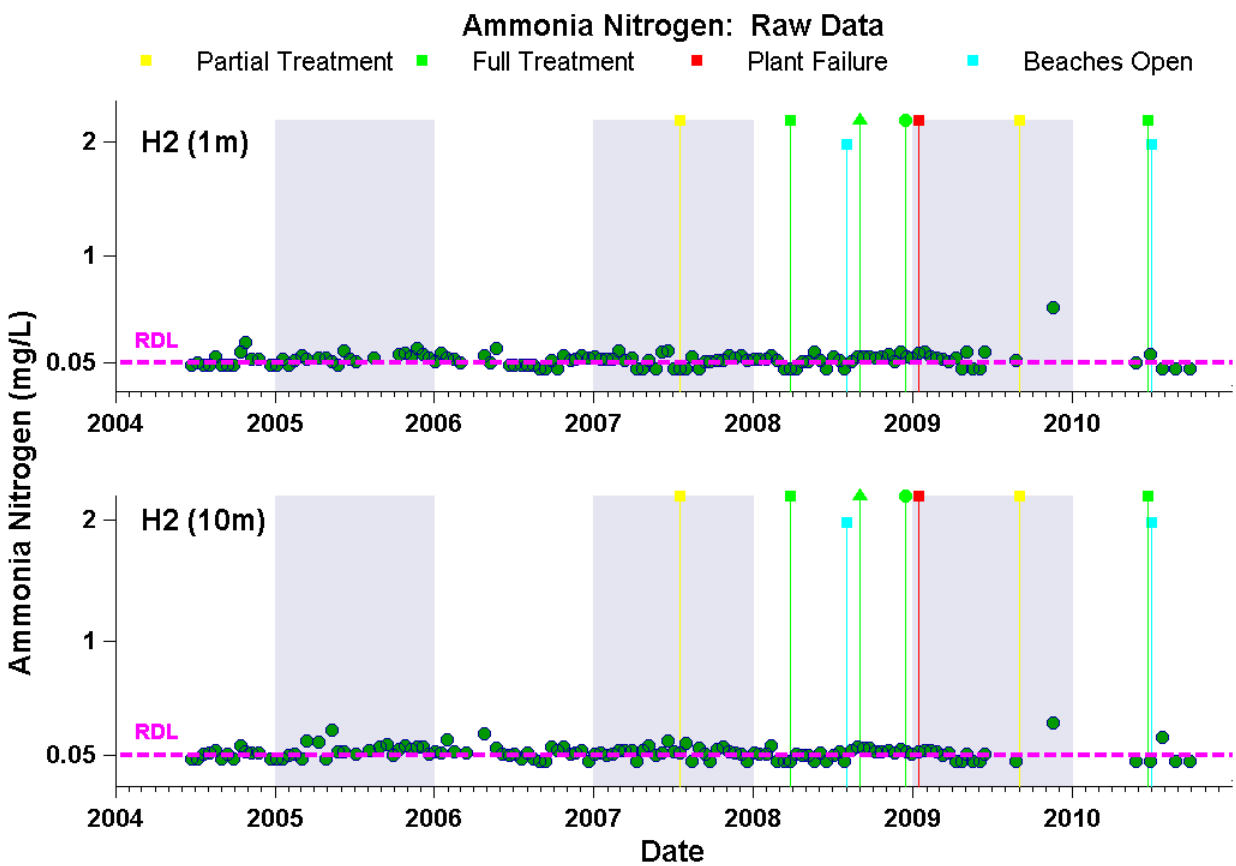

Figure 5.20 Ammonia nitrogen raw data. Note the reportable detection limit (RDL) line. Note the green timestamps for full treatment at Halifax (square), Dartmouth (triangle) and Herring Cove (circle) WWTFs.

5.3 APPENDIX C: Total Suspended Solids Time Series

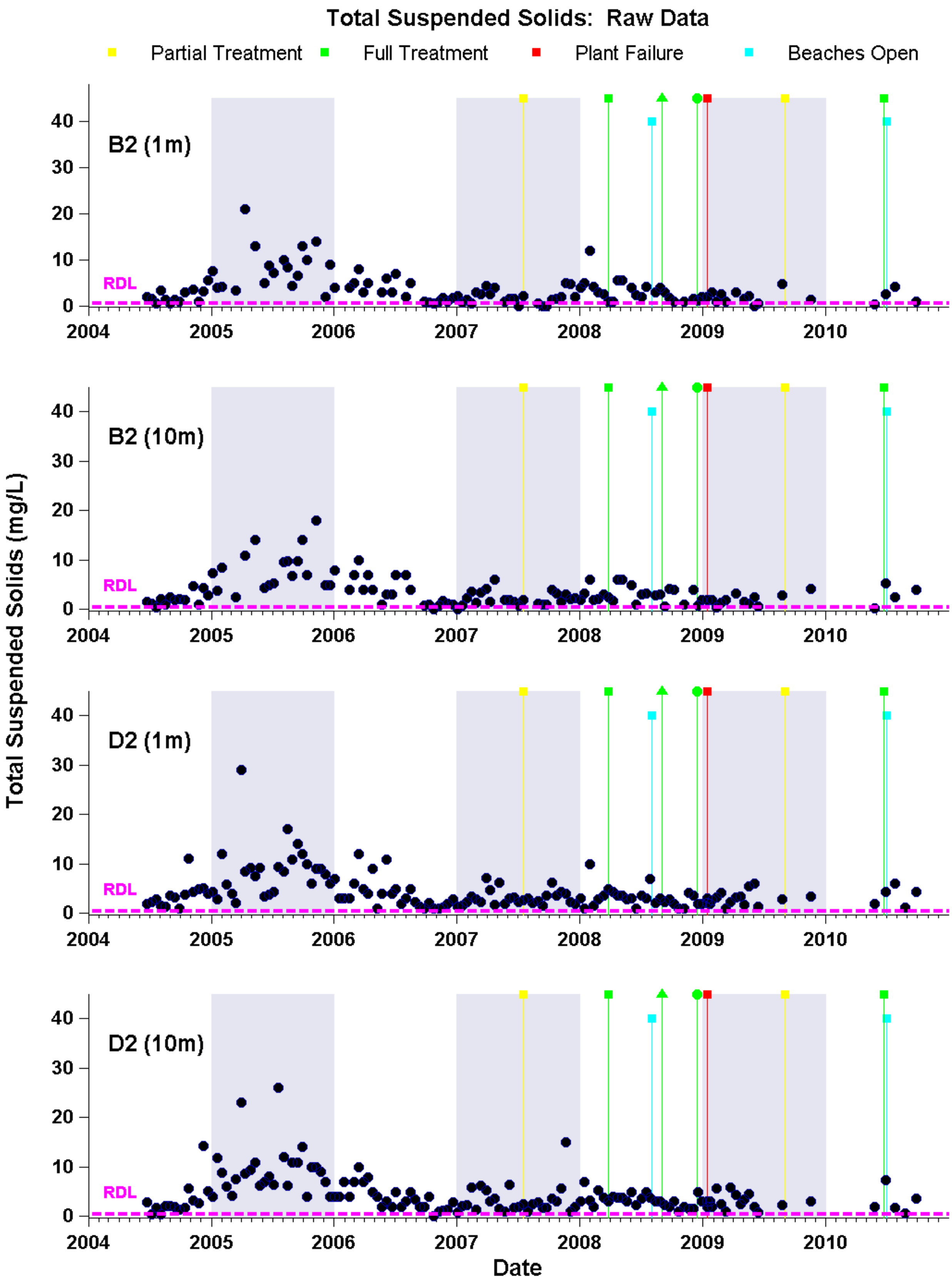

Figure 5.21 Total suspended solids raw data time series. Note the reportable detection limit (RDL) line, and the green timestamps for full treatment at Halifax (square), Dartmouth (triangle) and Herring Cove (circle) WWTFs.

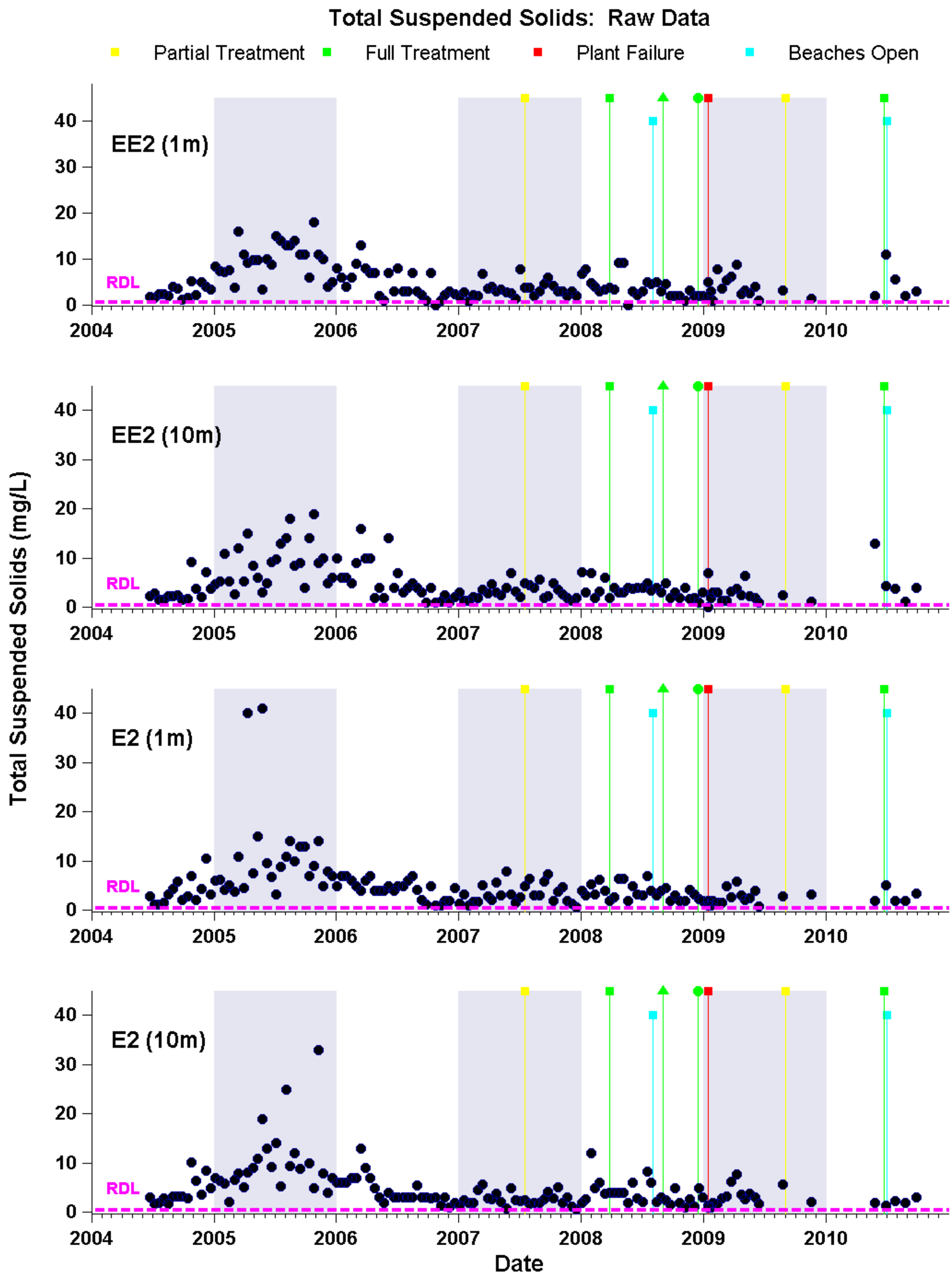

Figure 5.22 Total suspended solids raw data time series. Note the reportable detection limit (RDL) line, and the green timestamps for full treatment at Halifax (square), Dartmouth (triangle) and Herring Cove (circle) WWTFs.

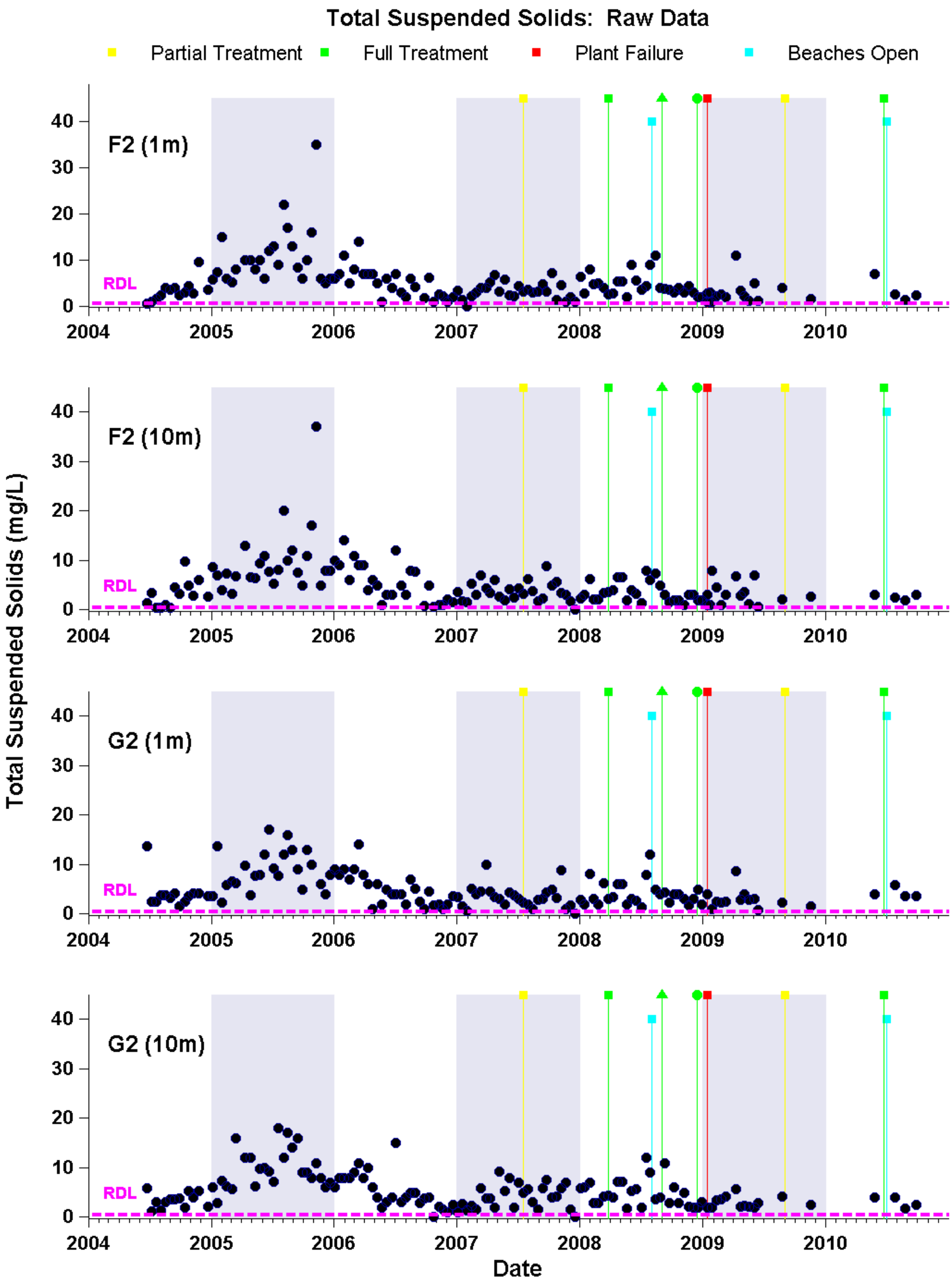

Figure 5.23 Total suspended solids raw data time series. Note the reportable detection limit (RDL) line, and the green timestamps for full treatment at Halifax (square), Dartmouth (triangle) and Herring Cove (circle) WWTFs.

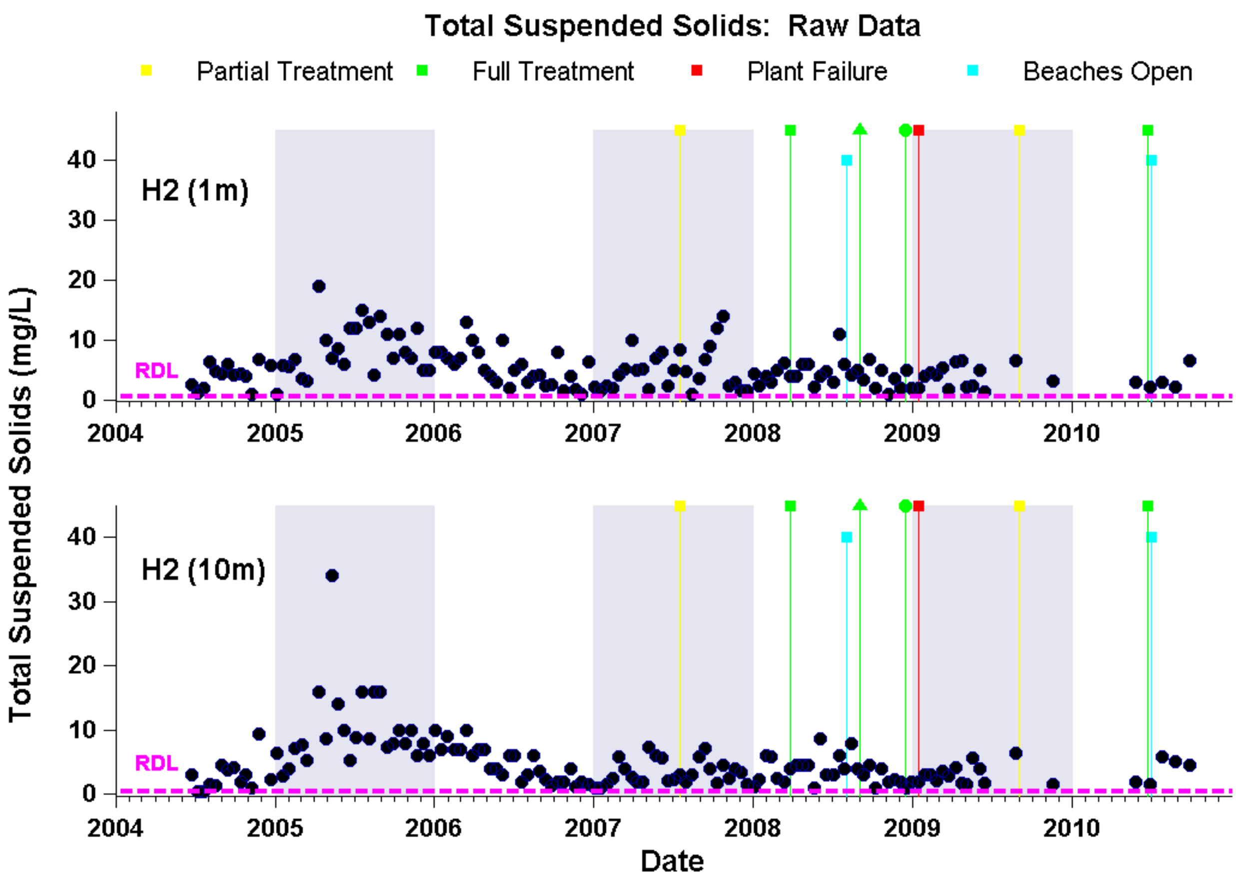

Figure 5.24 Total suspended solids raw data time series. Note the reportable detection limit (RDL) line, and the green timestamps for full treatment at Halifax (square), Dartmouth (triangle) and Herring Cove (circle) WWTFs.

5.4 APPENDIX D: Cadmium Concentration Time Series

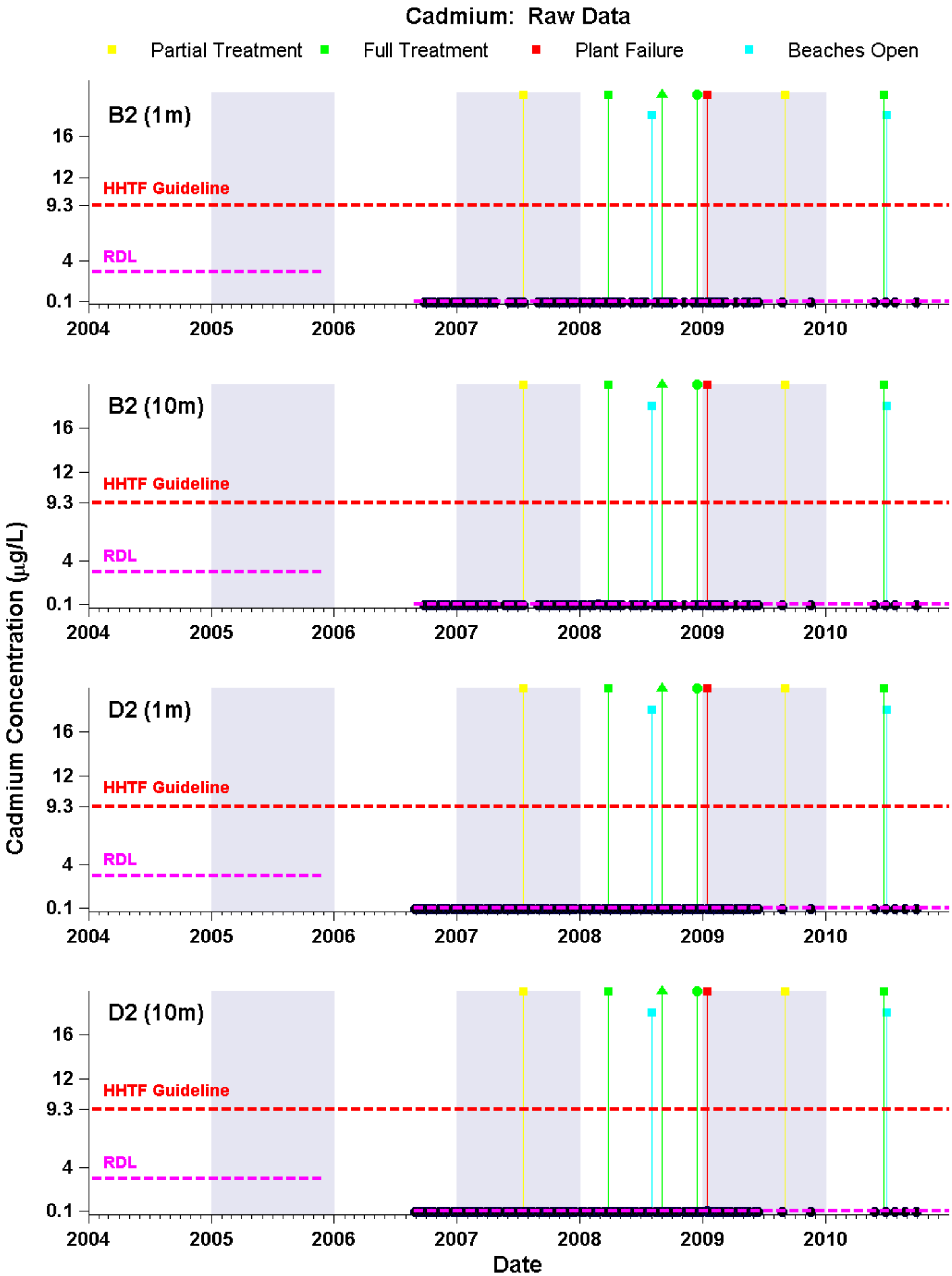

Figure 5.25 Cadmium concentration time series. Note the change in reportable detection limit (RDL) in 2006, and the green timestamps for full treatment at Halifax (square), Dartmouth (triangle) and Herring Cove (circle) WWTFs.

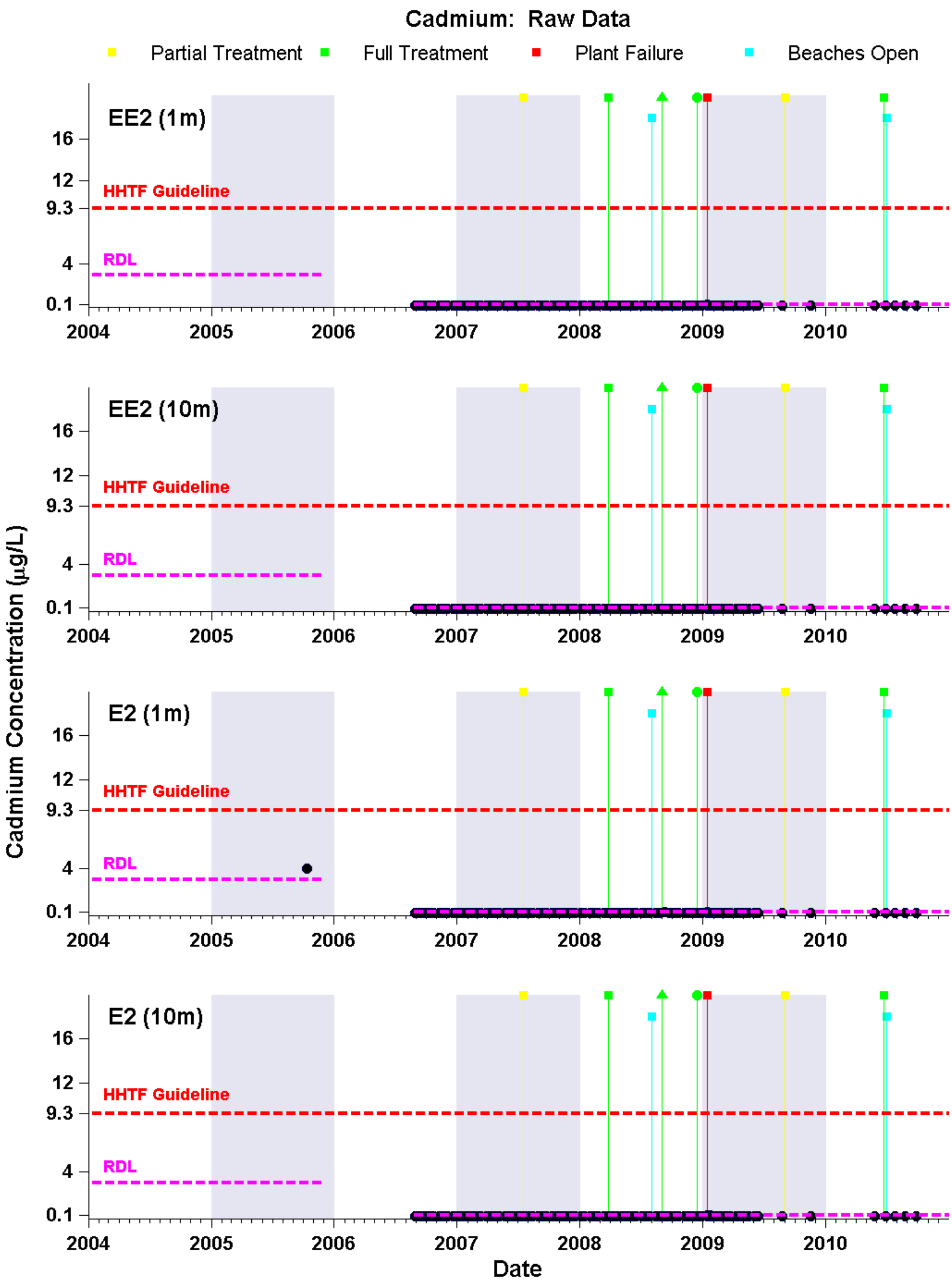

Figure 5.26 Cadmium concentration time series. Note the change in reportable detection limit (RDL) in 2006, and the green timestamps for full treatment at Halifax (square), Dartmouth (triangle) and Herring Cove (circle) WWTFs.

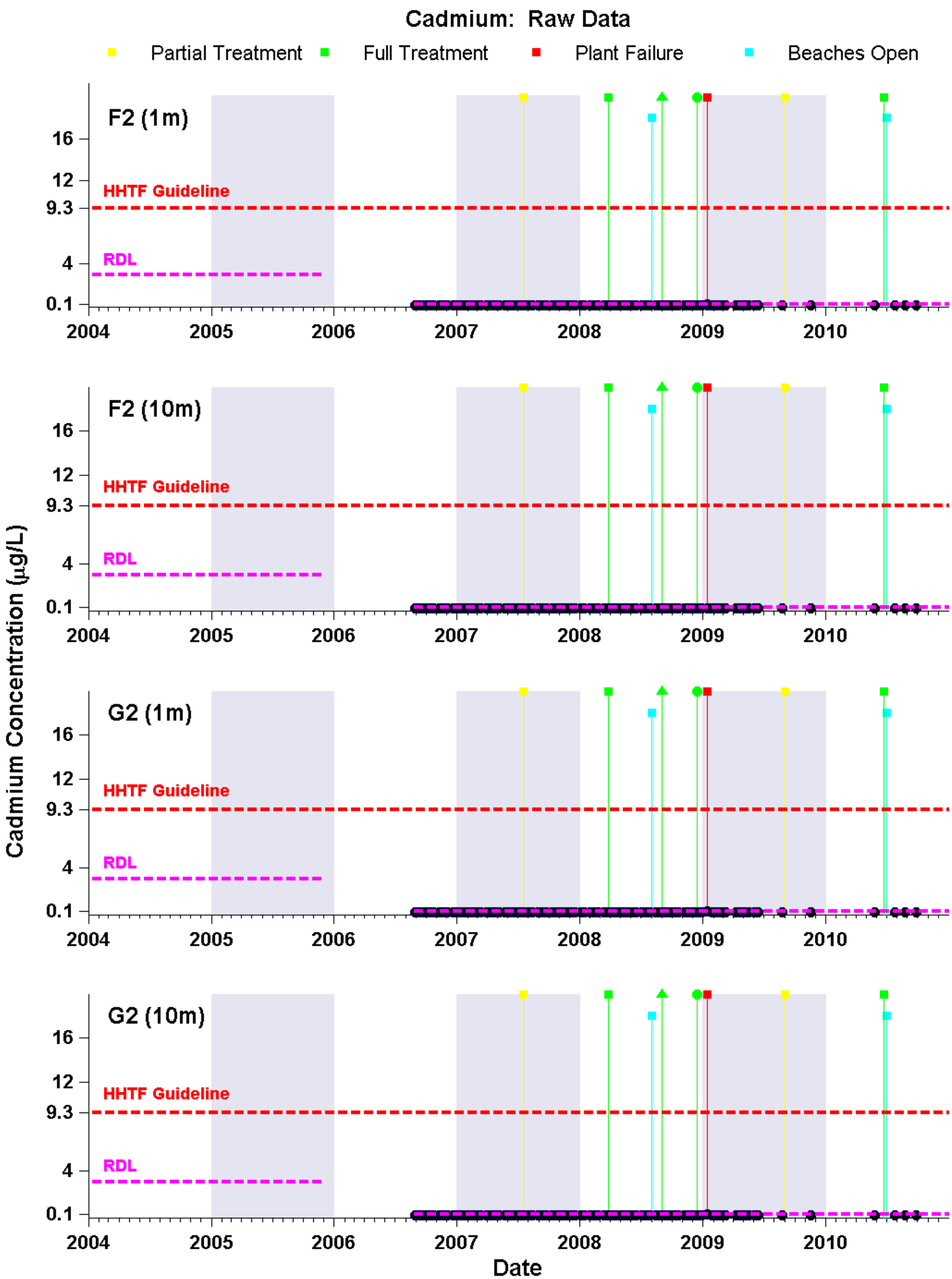

Figure 5.27 Cadmium concentration time series. Note the change in reportable detection limit (RDL) in 2006.

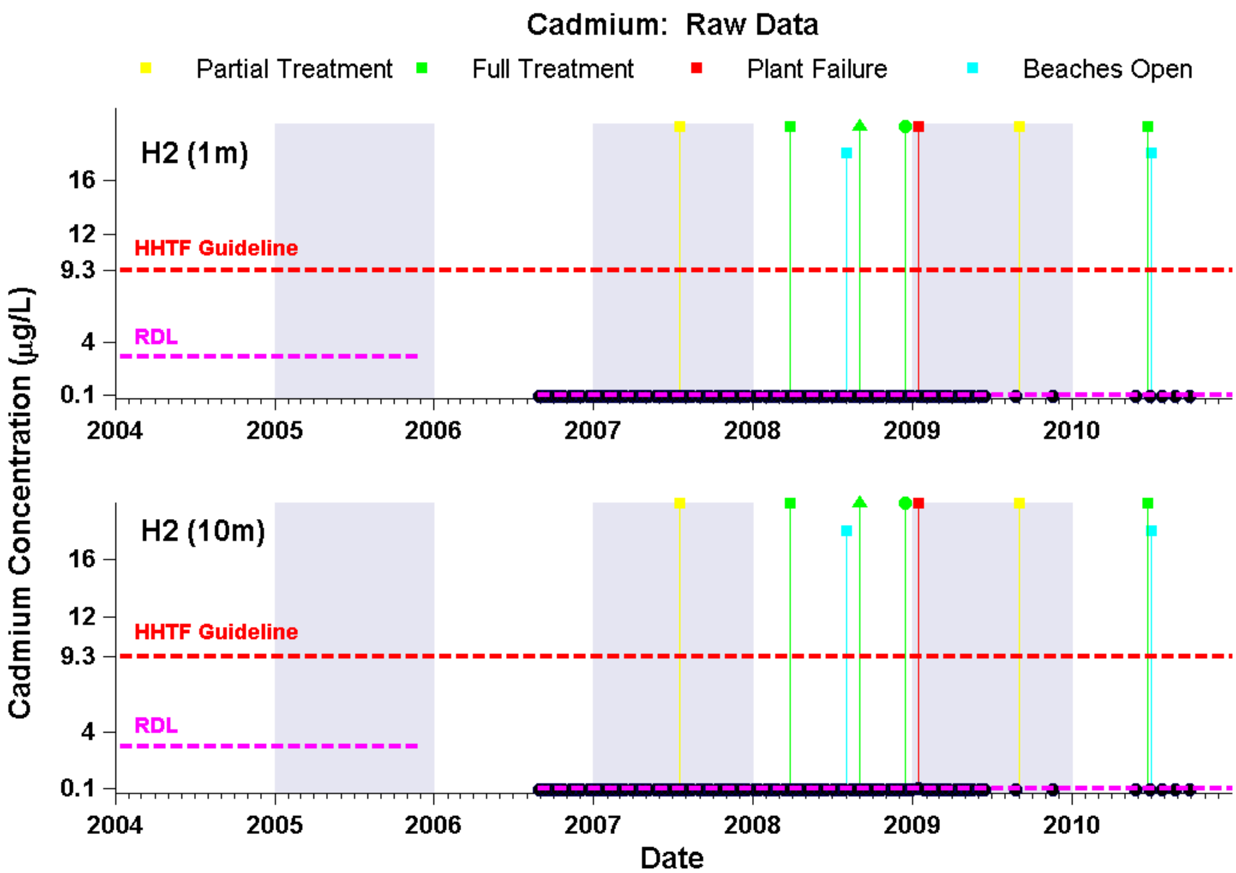

Figure 5.28 Cadmium concentration time series. Note the change in reportable detection limit (RDL) in 2006, and the green timestamps for full treatment at Halifax (square), Dartmouth (triangle) and Herring Cove (circle) WWTFs.

5.5 APPENDIX E: Copper Concentration Time Series

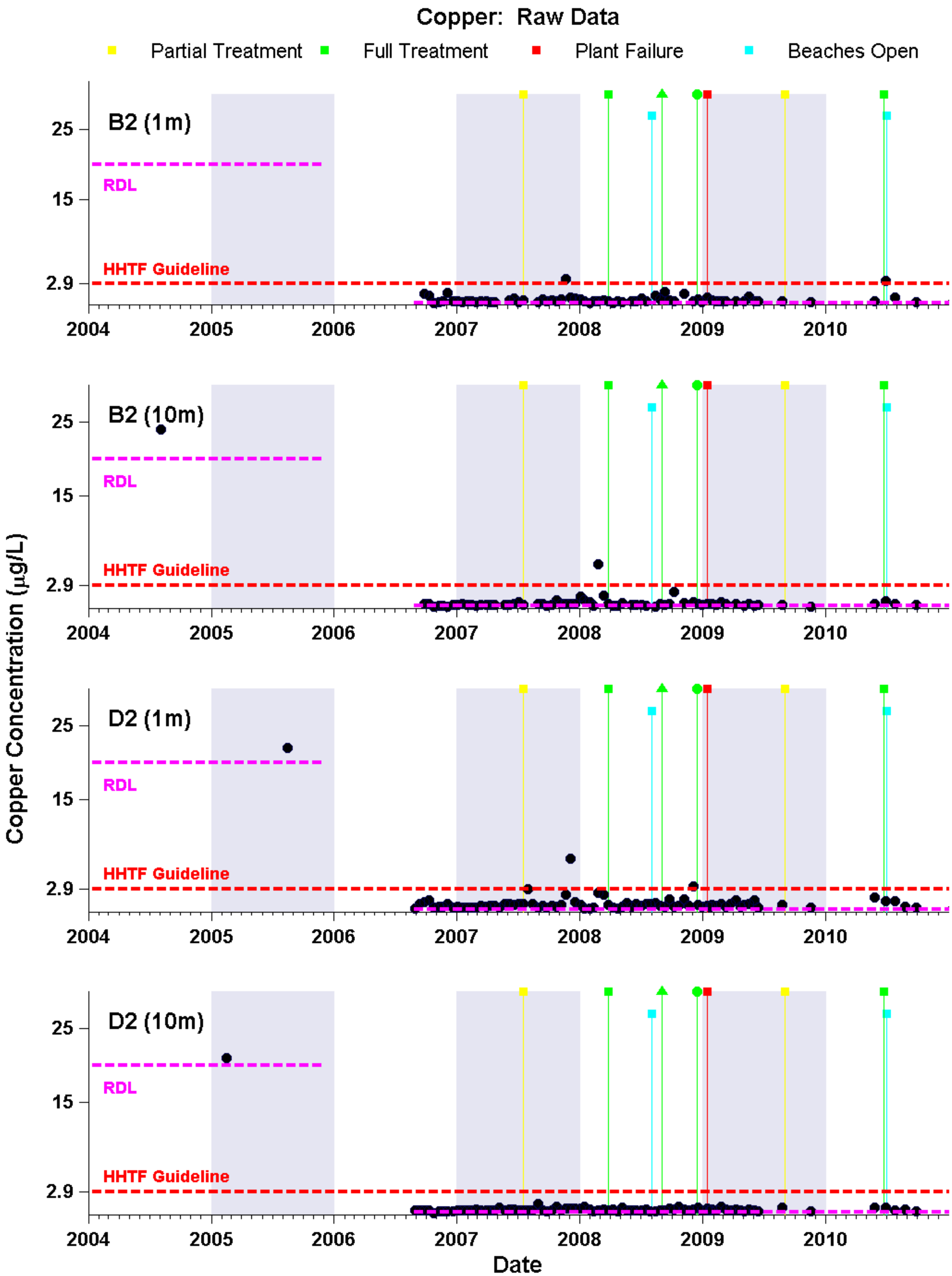

Figure 5.29 Copper concentration time series. Note the change in reportable detection limit (RDL) in 2006, and the green timestamps for full treatment at Halifax (square), Dartmouth (triangle) and Herring Cove (circle) WWTFs.

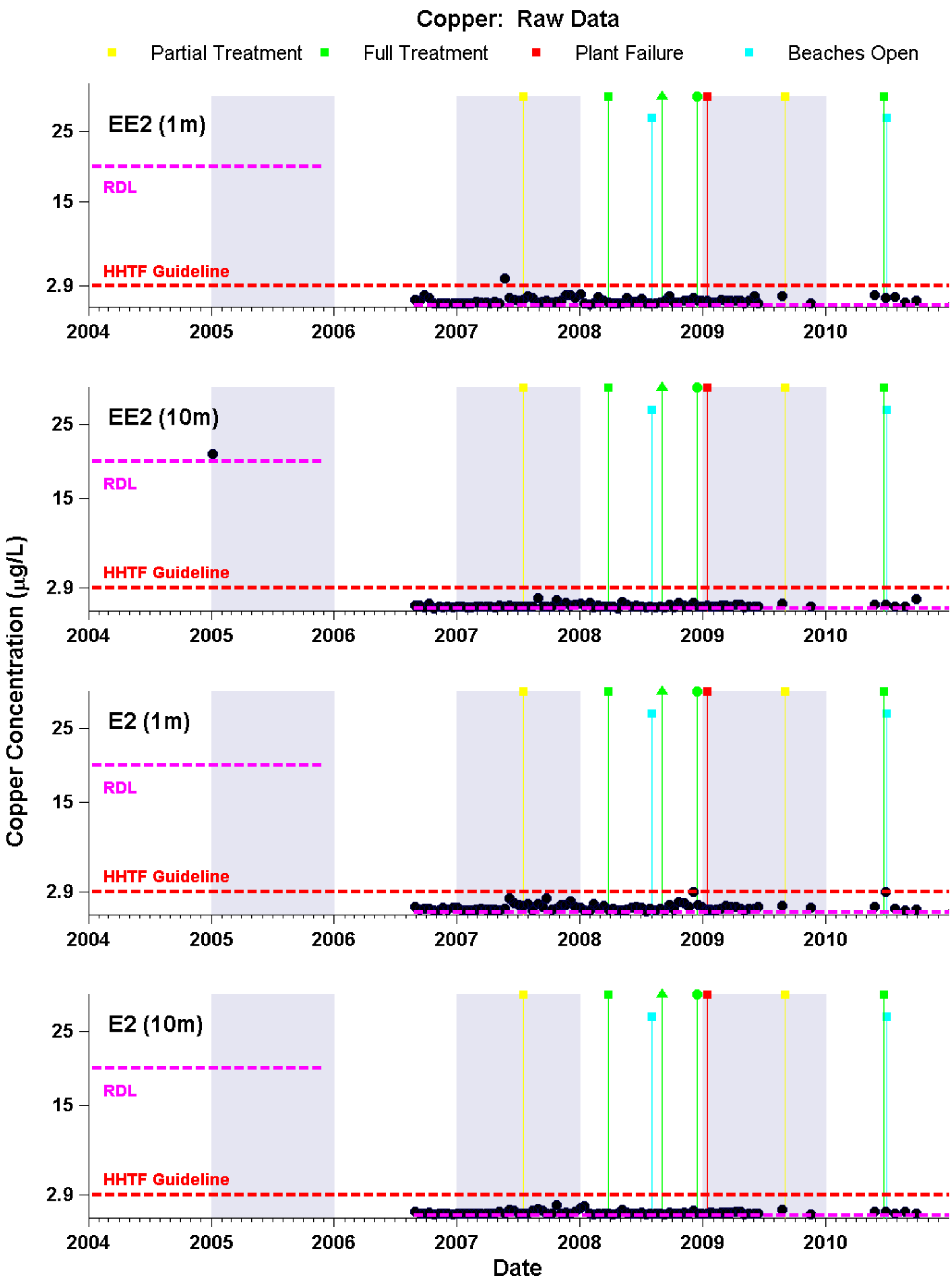

Figure 5.30 Copper concentration time series. Note the change in reportable detection limit (RDL) in 2006, and the green timestamps for full treatment at Halifax (square), Dartmouth (triangle) and Herring Cove (circle) WWTFs.

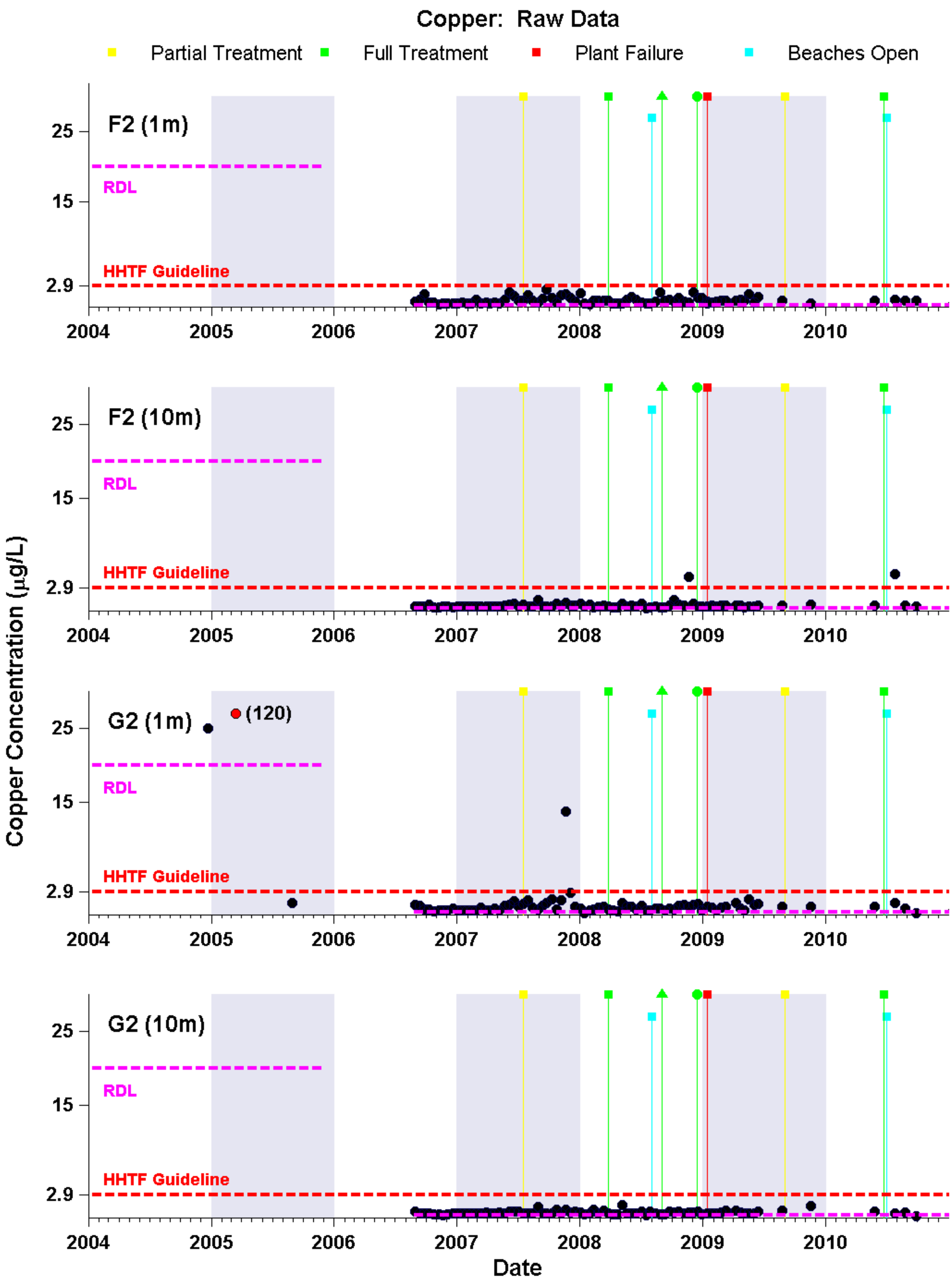

Figure 5.31 Copper concentration time series. Note the change in reportable detection limit (RDL) in 2006, and the green timestamps for full treatment at Halifax (square), Dartmouth (triangle) and Herring Cove (circle) WWTFs.

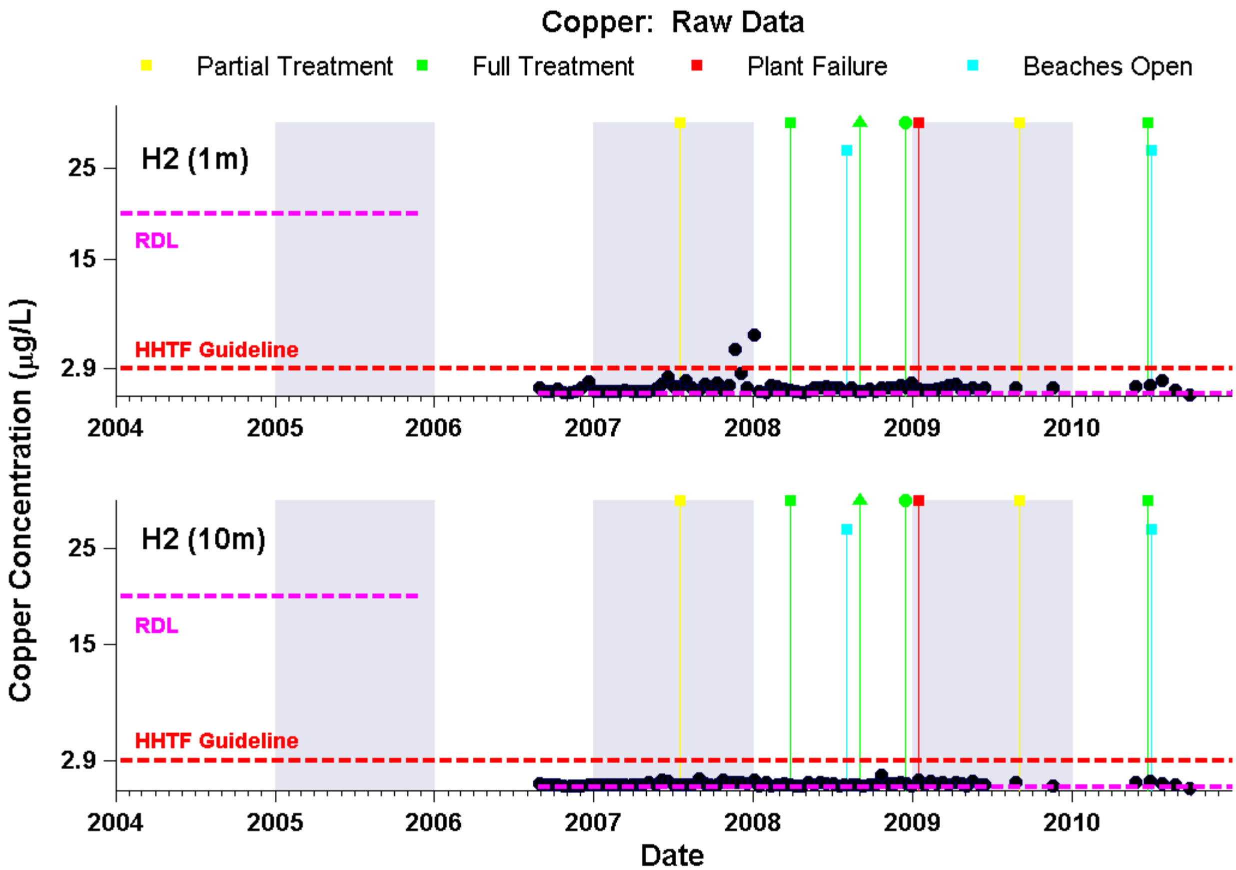

Figure 5.32 Copper concentration time series. Note the change in reportable detection limit (RDL) in 2006, and the green timestamps for full treatment at Halifax (square), Dartmouth (triangle) and Herring Cove (circle) WWTFs.

5.6 APPENDIX F: Iron Concentration Time Series

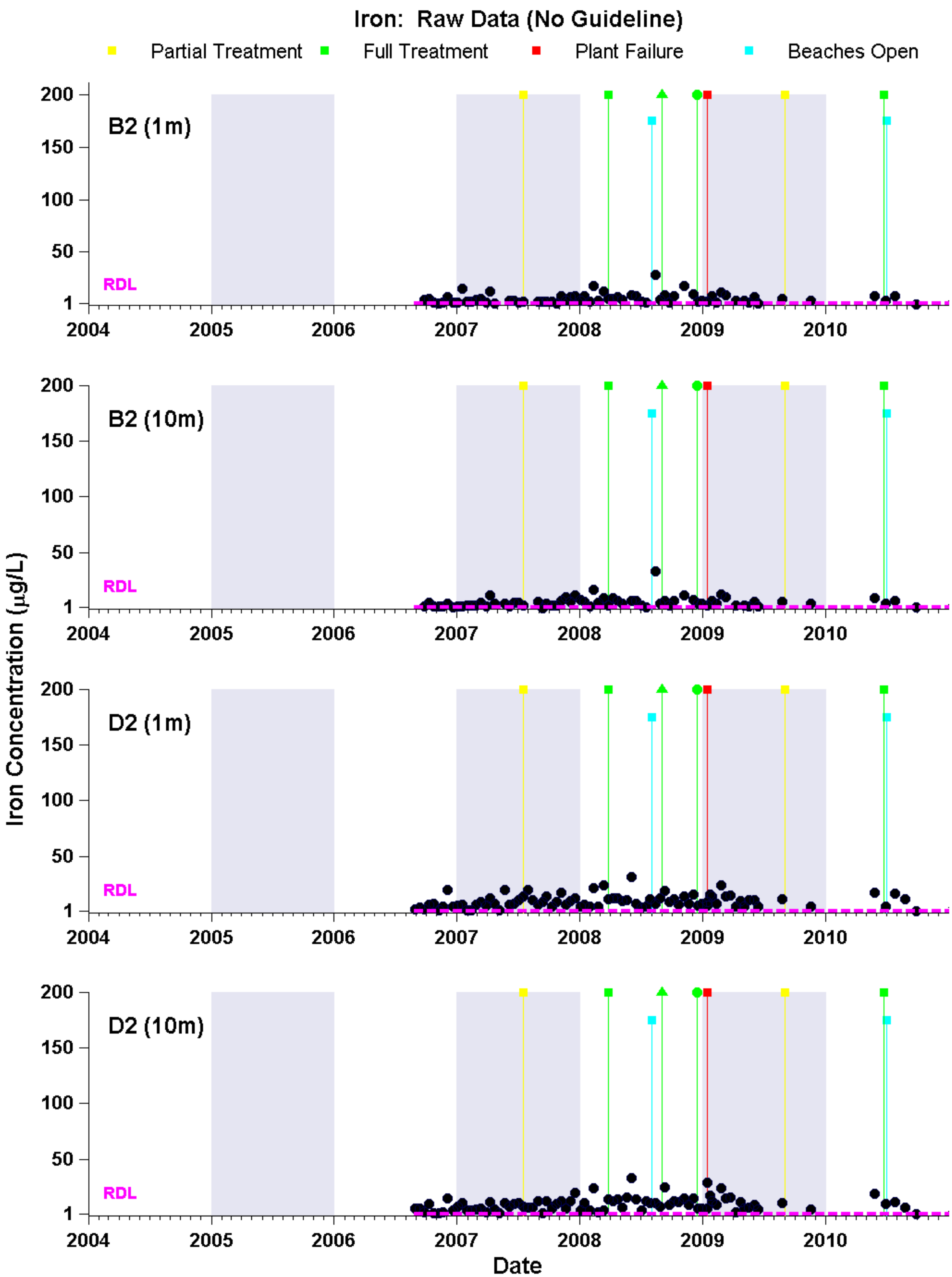

Figure 5.33 Iron concentration raw data time series. Note the reportable detection limit (RDL) line, and the green timestamps for full treatment at Halifax (square), Dartmouth (triangle) and Herring Cove (circle) WWTFs.

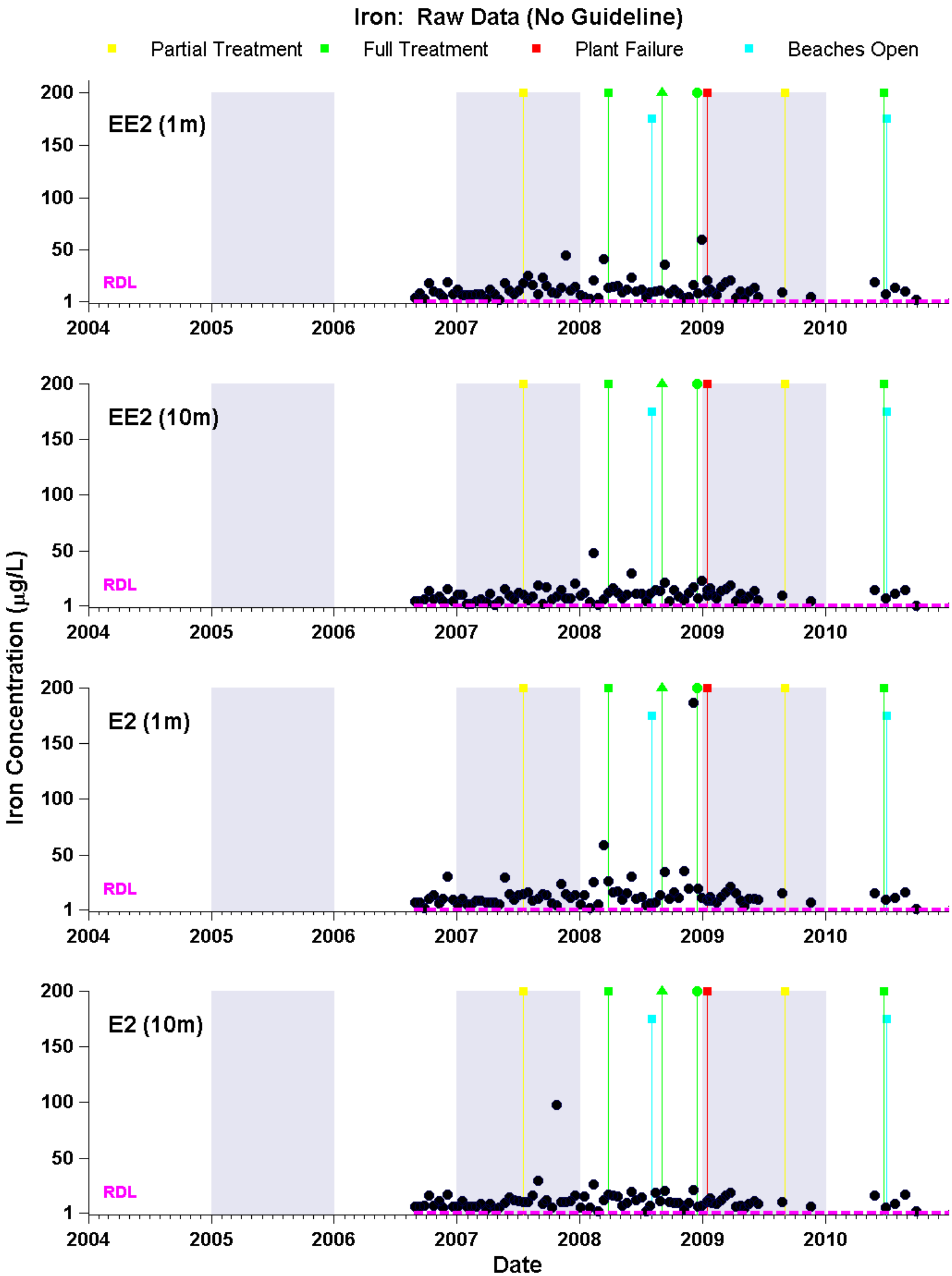

Figure 5.34 Iron concentration raw data time series. Note the reportable detection limit (RDL) line, and the green timestamps for full treatment at Halifax (square), Dartmouth (triangle) and Herring Cove (circle) WWTFs.

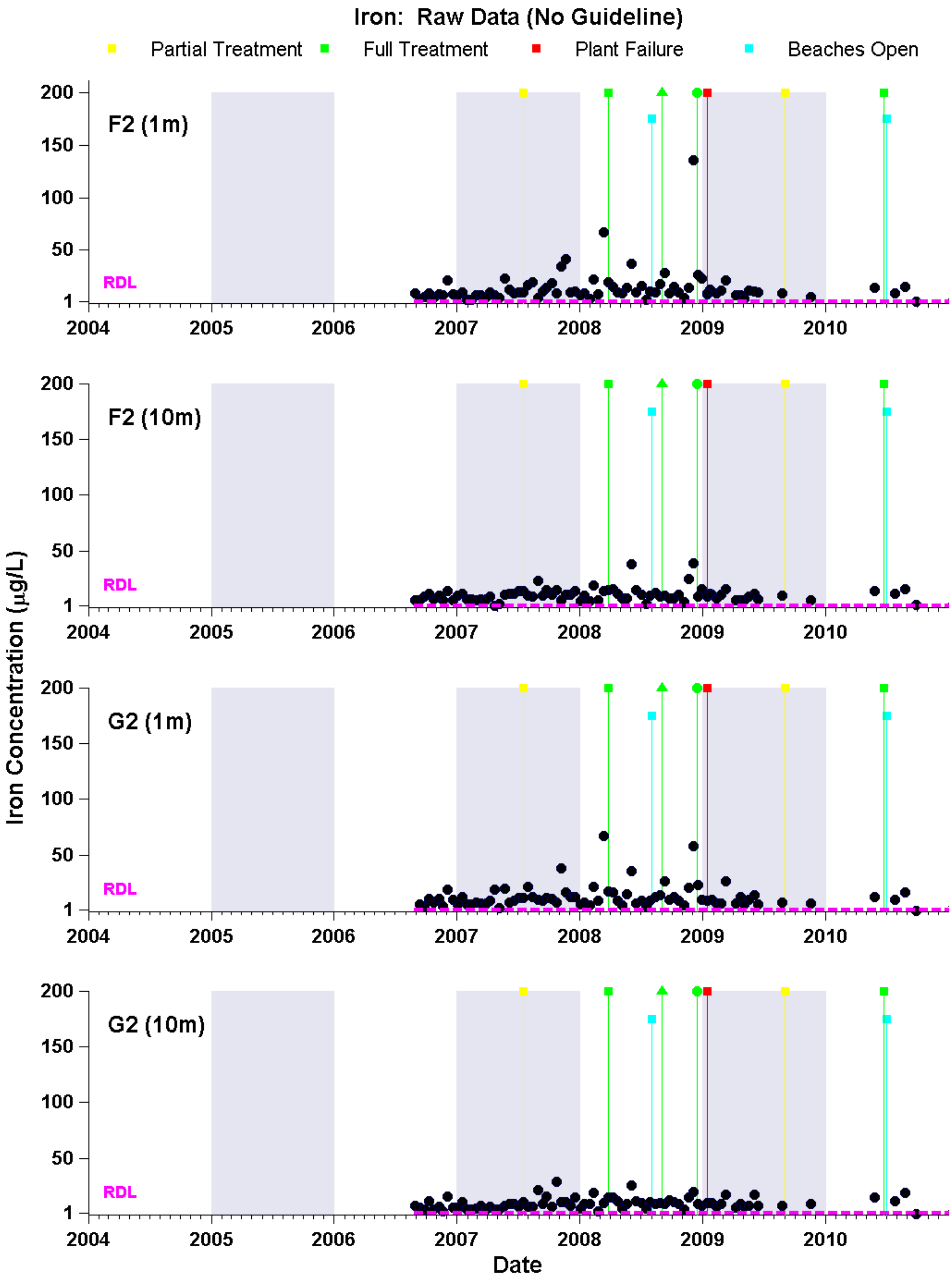

Figure 5.35 Iron concentration raw data time series. Note the reportable detection limit (RDL) line, and the green timestamps for full treatment at Halifax (square), Dartmouth (triangle) and Herring Cove (circle) WWTFs.

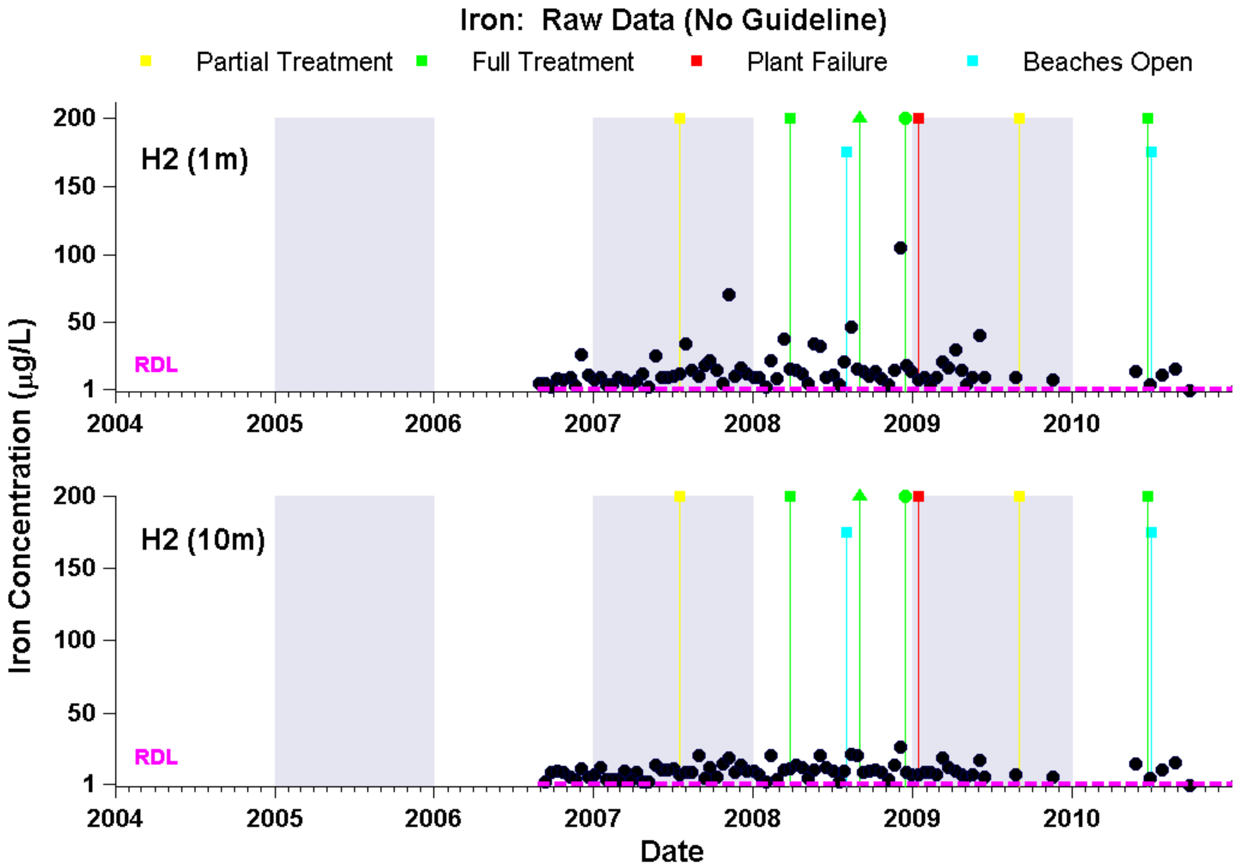

Figure 5.36 Iron concentration raw data time series. Note the reportable detection limit (RDL) line, and the green timestamps for full treatment at Halifax (square), Dartmouth (triangle) and Herring Cove (circle) WWTFs.

5.7 APPENDIX G: Lead Concentration Time Series

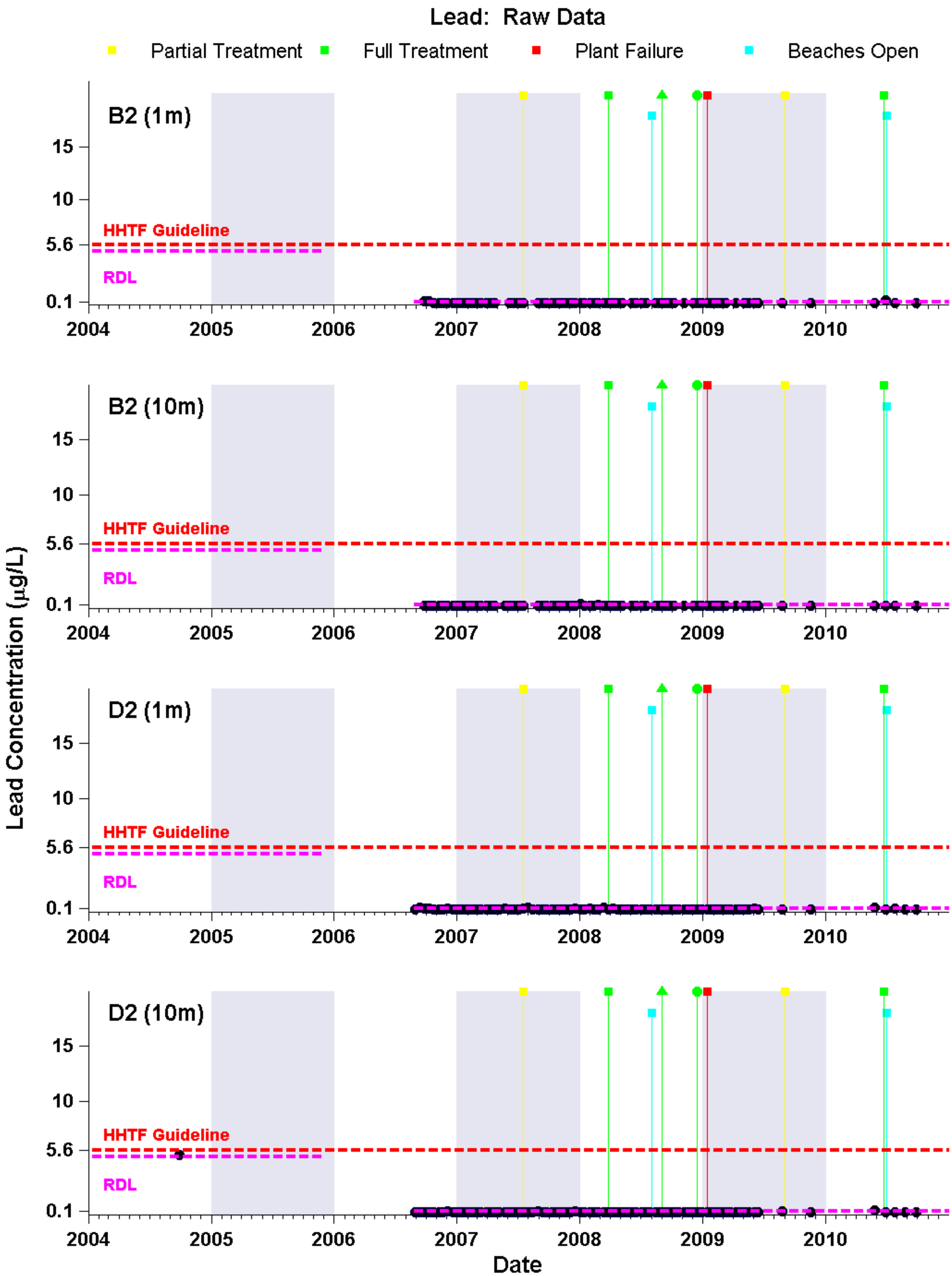

Figure 5.37 Lead concentration time series. Note the change in reportable detection limit (RDL) in 2006, and the green timestamps for full treatment at Halifax (square), Dartmouth (triangle) and Herring Cove (circle) WWTFs.

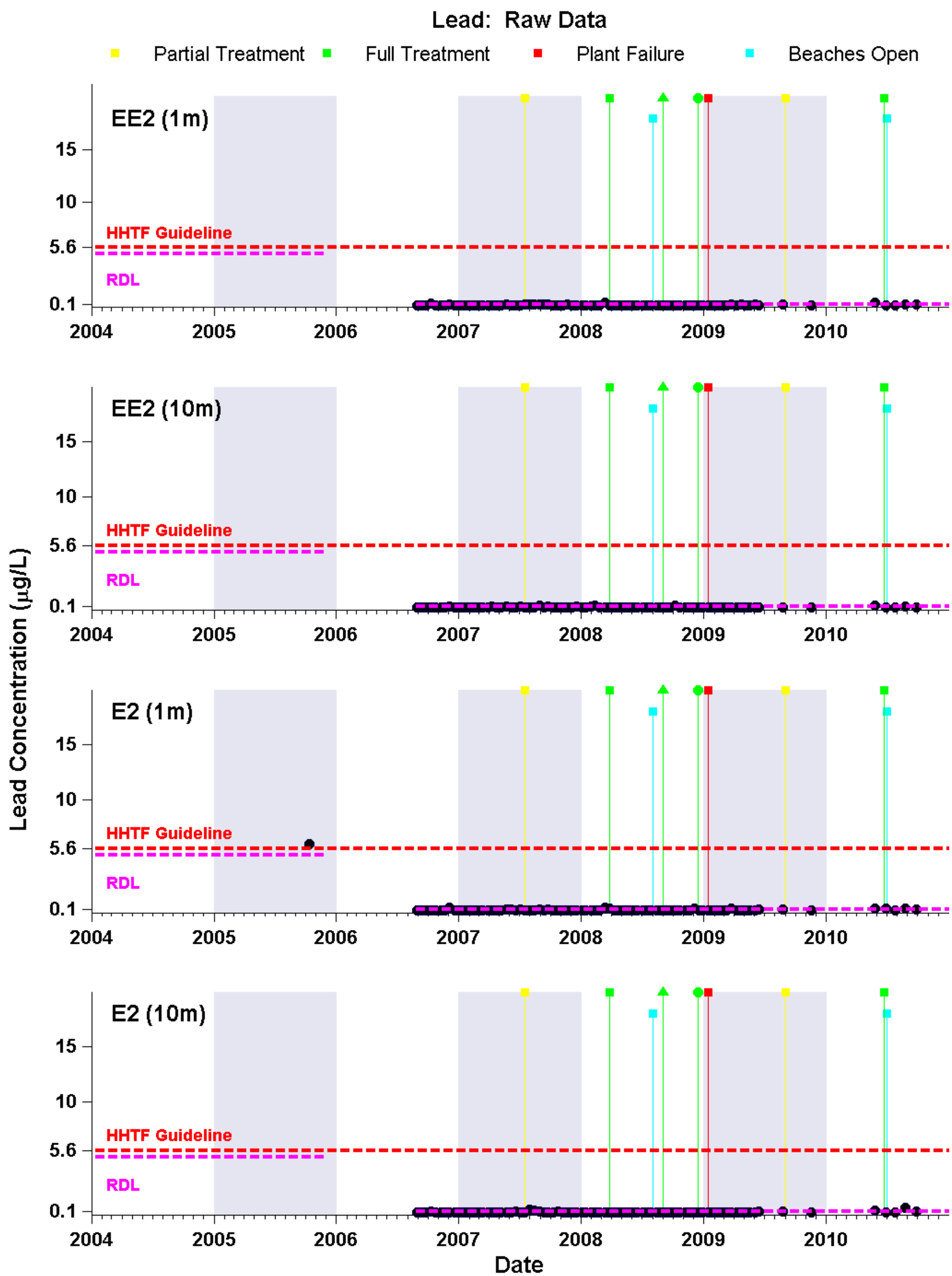

Figure 5.38 Lead concentration time series. Note the change in reportable detection limit (RDL) in 2006, and the green timestamps for full treatment at Halifax (square), Dartmouth (triangle) and Herring Cove (circle) WWTFs.

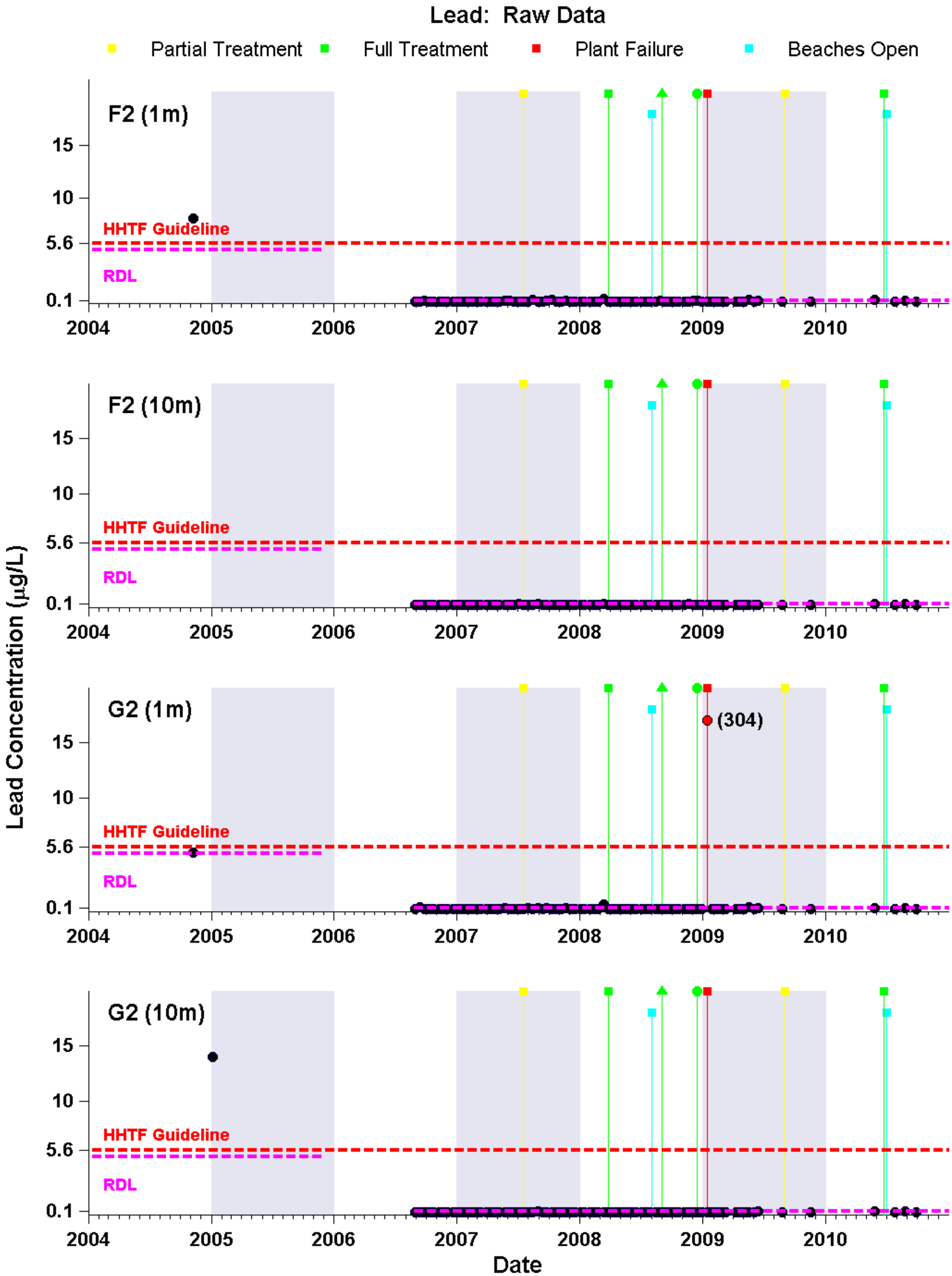

Figure 5.39 Lead concentration time series. Note the change in reportable detection limit (RDL) in 2006, and the green timestamps for full treatment at Halifax (square), Dartmouth (triangle) and Herring Cove (circle) WWTFs.

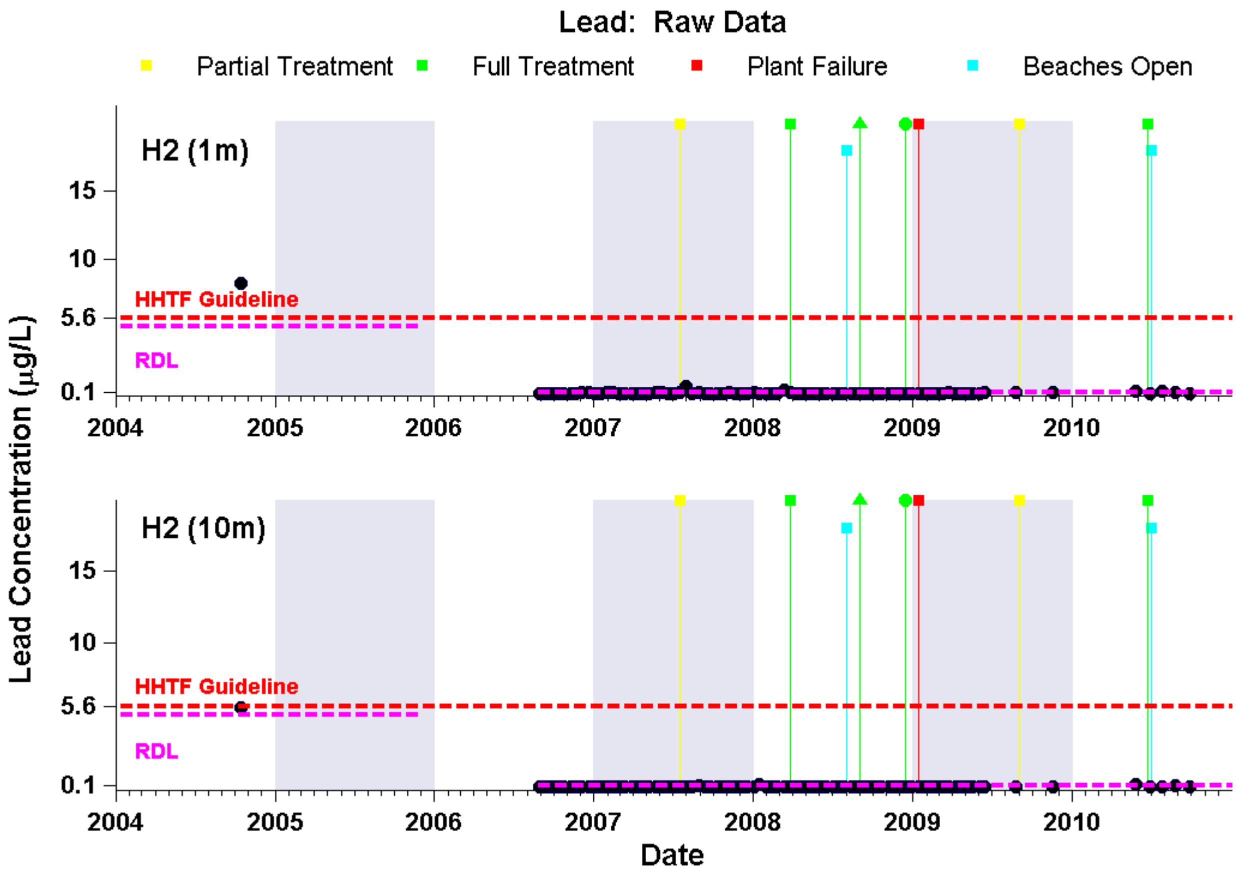

Figure 5.40 Lead concentration time series. Note the change in reportable detection limit (RDL) in 2006, and the green timestamps for full treatment at Halifax (square), Dartmouth (triangle) and Herring Cove (circle) WWTFs.

5.8 APPENDIX H:Manganese Concentration Time Series

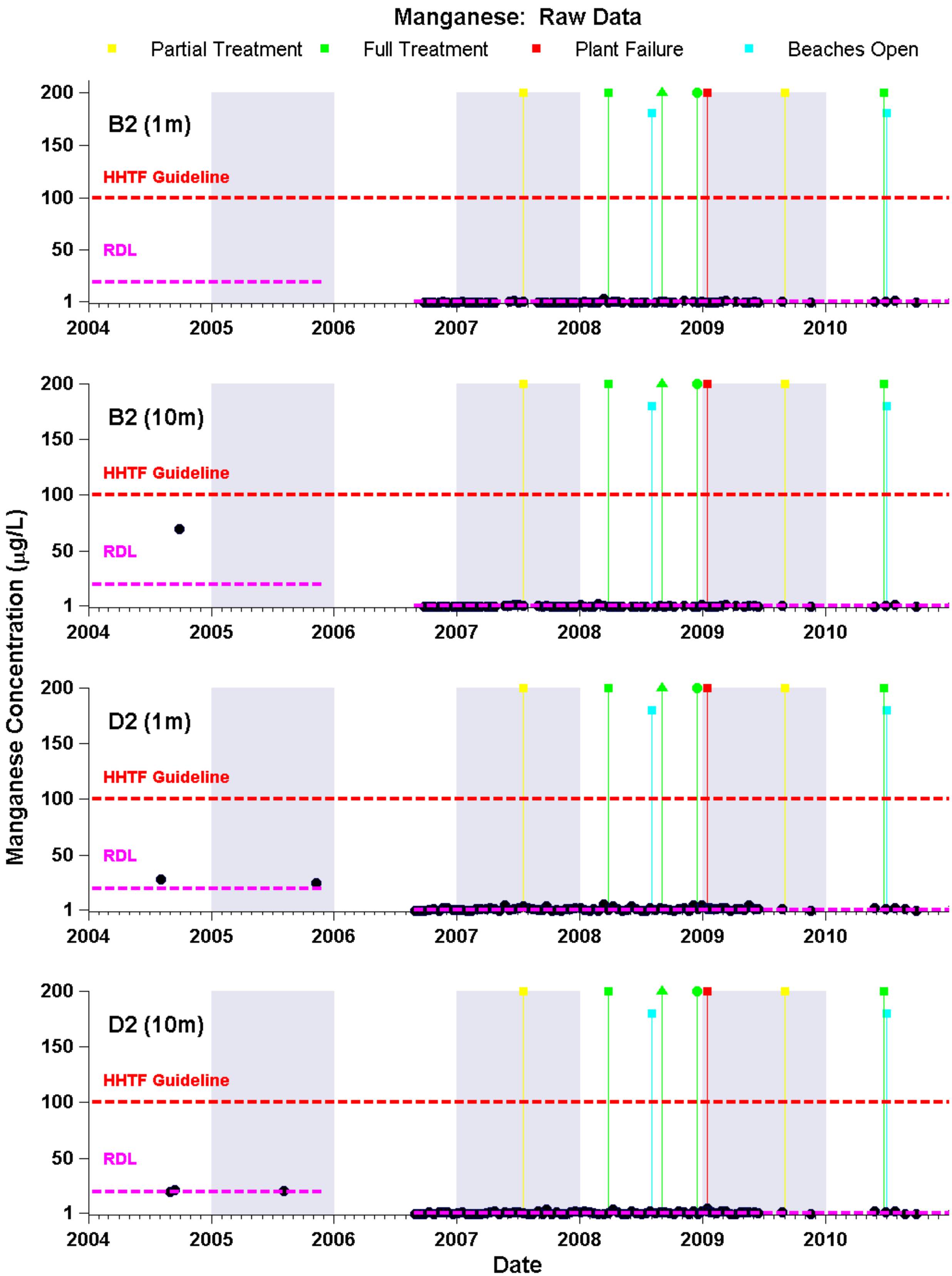

Figure 5.41 Manganese concentration time series. Note the change in reportable detection limit (RDL) in 2006, and the green timestamps for full treatment at Halifax (square), Dartmouth (triangle) and Herring Cove (circle) WWTFs.

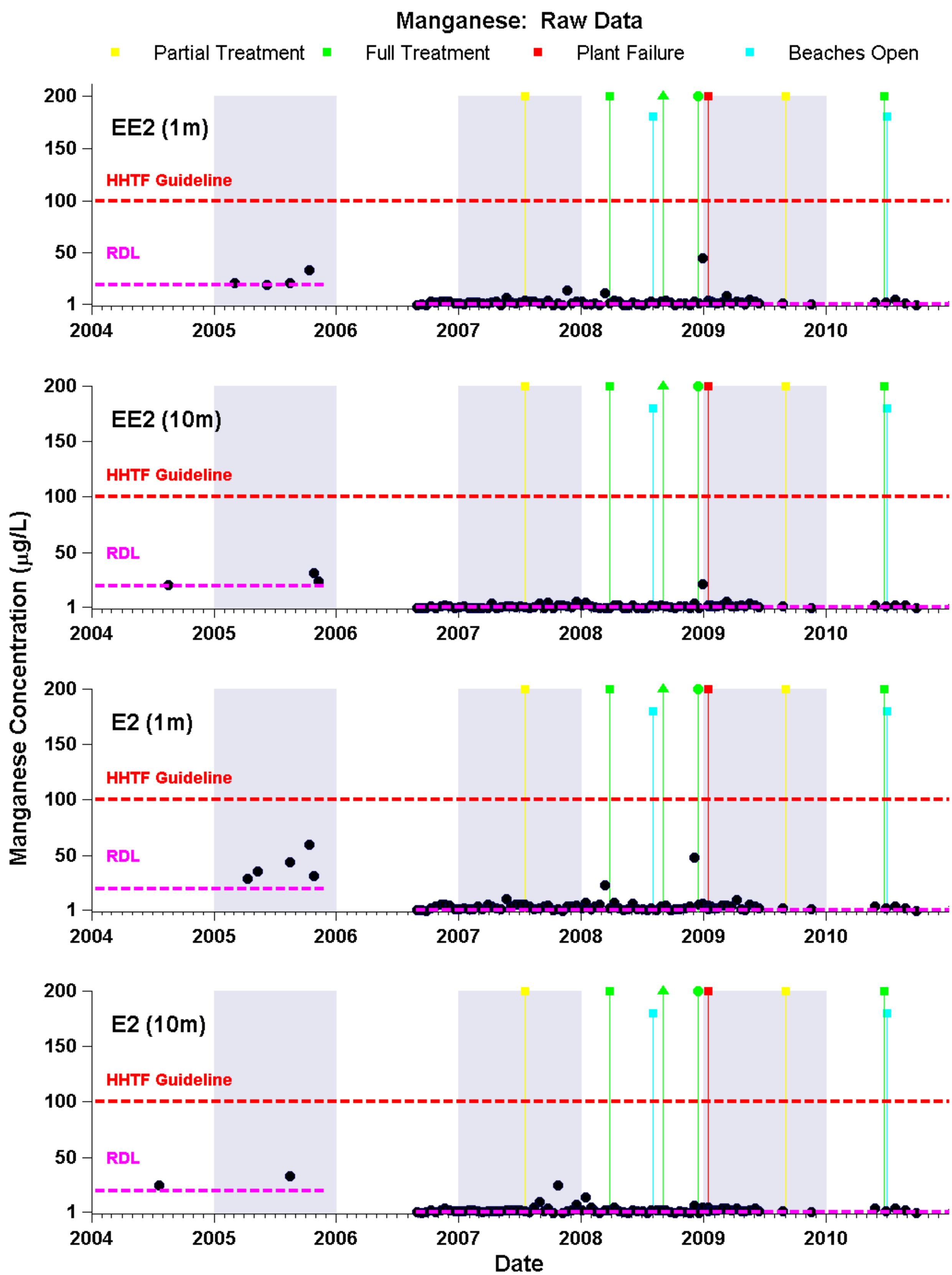

Figure 5.42 Manganese concentration time series. Note the change in reportable detection limit (RDL) in 2006, and the green timestamps for full treatment at Halifax (square), Dartmouth (triangle) and Herring Cove (circle) WWTFs.

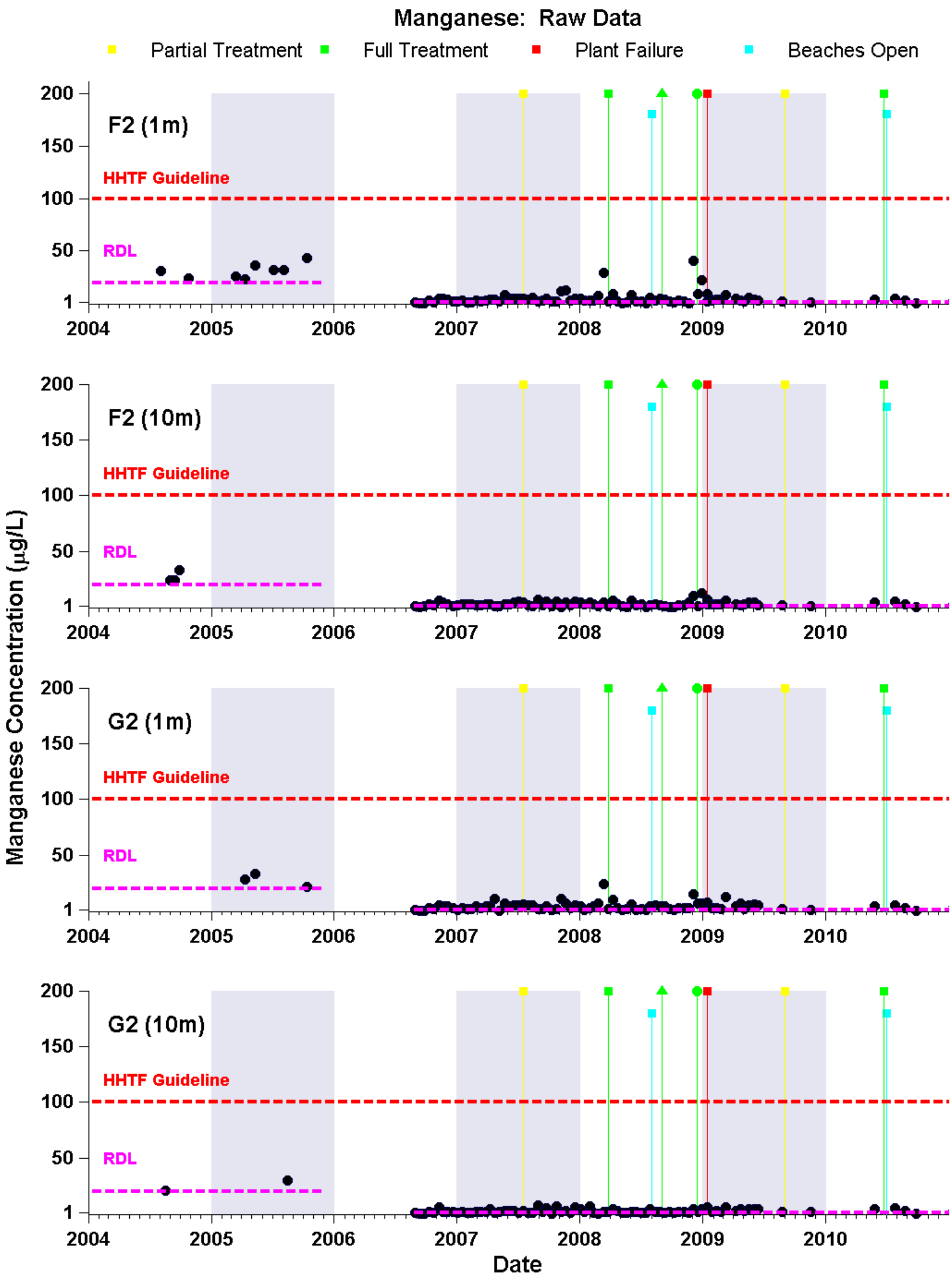

Figure 5.43 Manganese concentration time series. Note the change in reportable detection limit (RDL) in 2006, and the green timestamps for full treatment at Halifax (square), Dartmouth (triangle) and Herring Cove (circle) WWTFs.

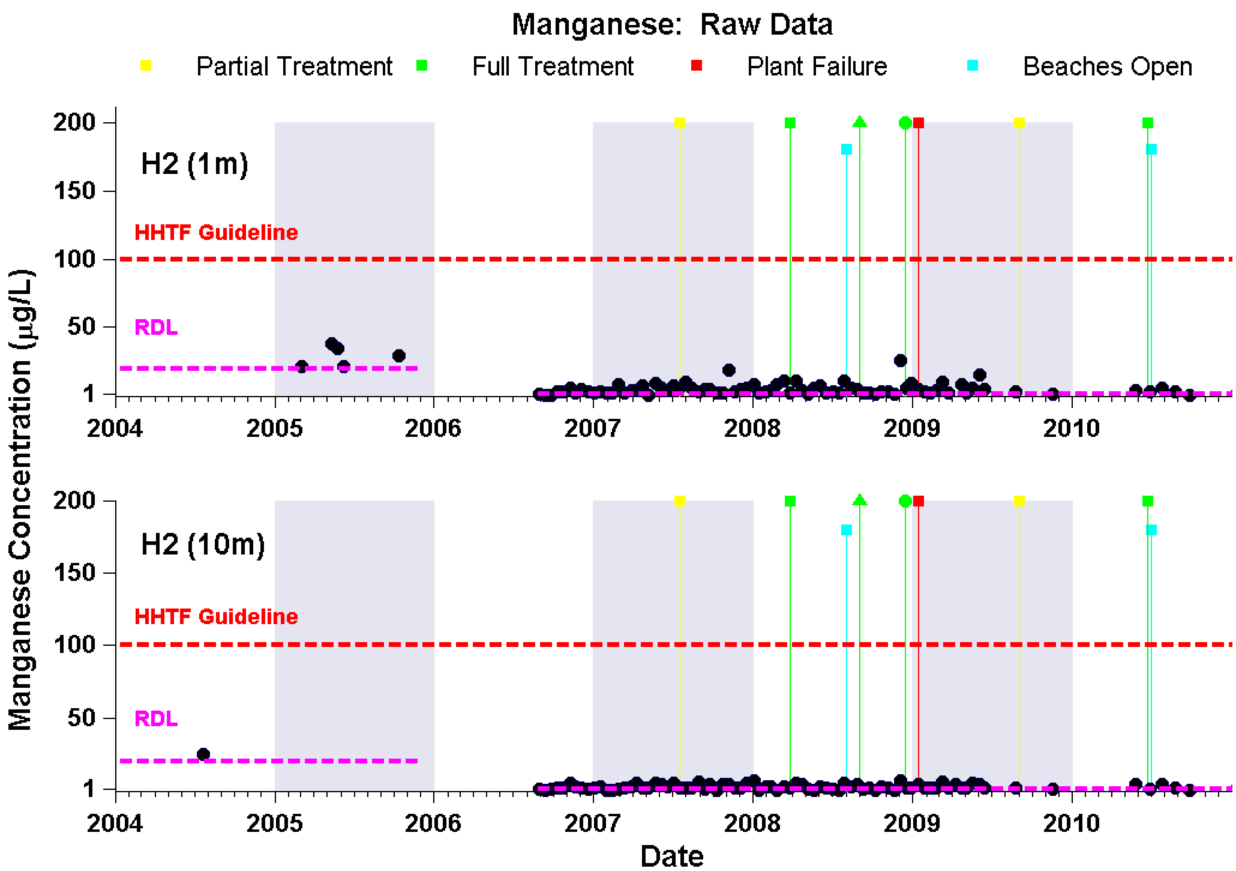

Figure 5.44 Manganese concentration time series. Note the change in reportable detection limit (RDL) in 2006, and the green timestamps for full treatment at Halifax (square), Dartmouth (triangle) and Herring Cove (circle) WWTFs.

5.9 APPENDIX I: Mercury Concentration Time Series

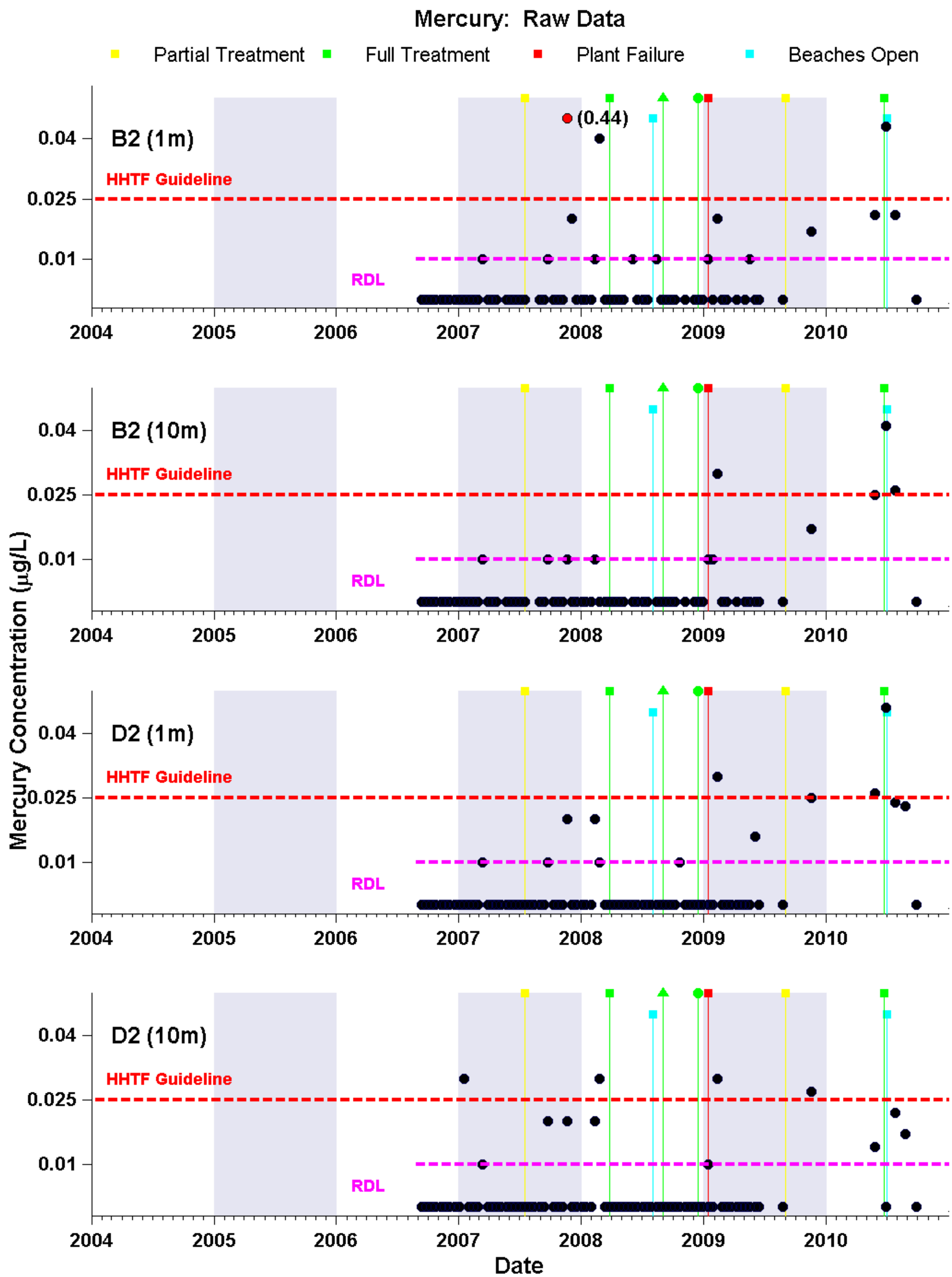

Figure 5.45 Mercury concentration time series. Note the reportable detection limit (RDL) line, and the green timestamps for full treatment at Halifax (square), Dartmouth (triangle) and Herring Cove (circle) WWTFs.

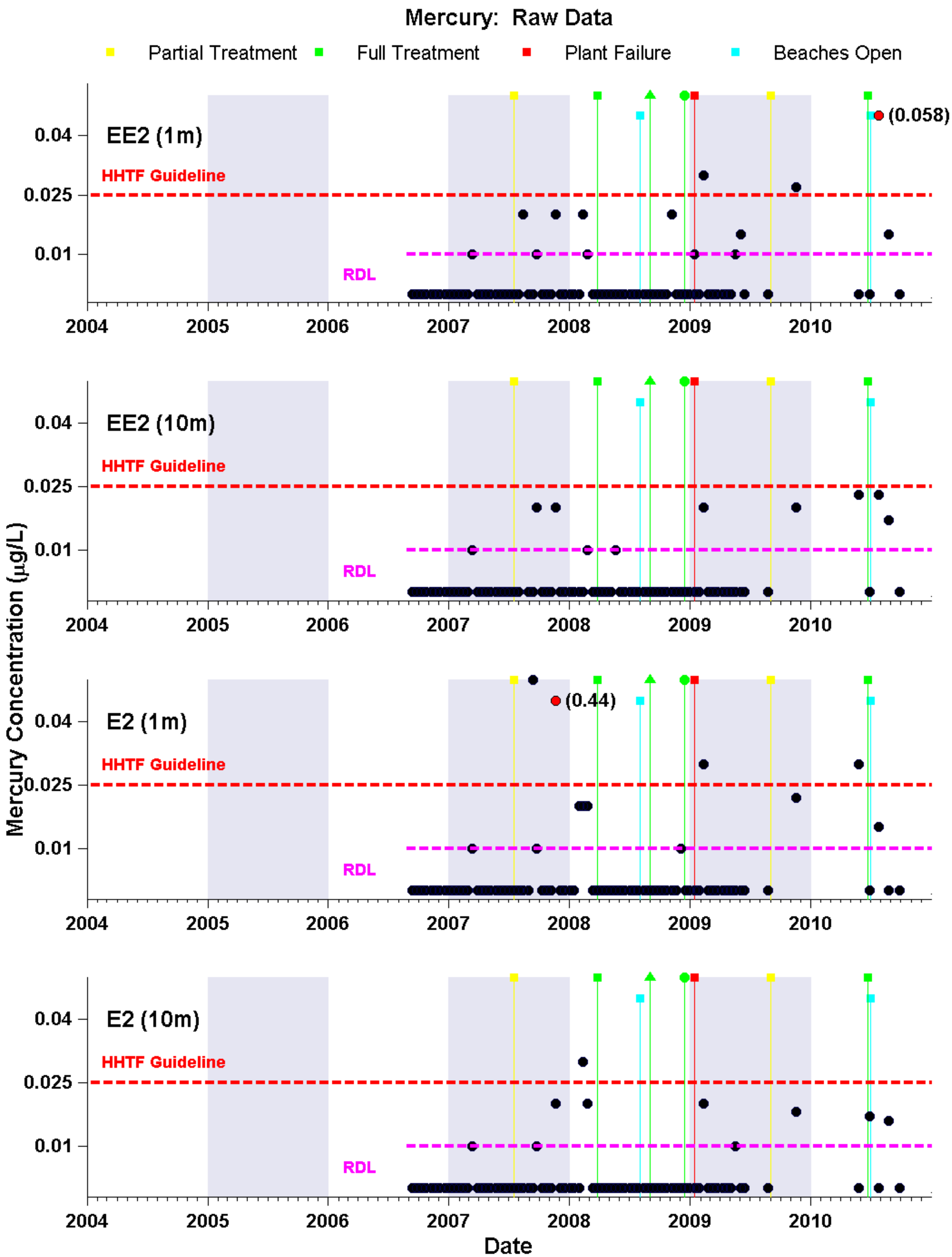

Figure 5.46 Mercury concentration time series. Note the reportable detection limit (RDL) line, and the green timestamps for full treatment at Halifax (square), Dartmouth (triangle) and Herring Cove (circle) WWTFs.

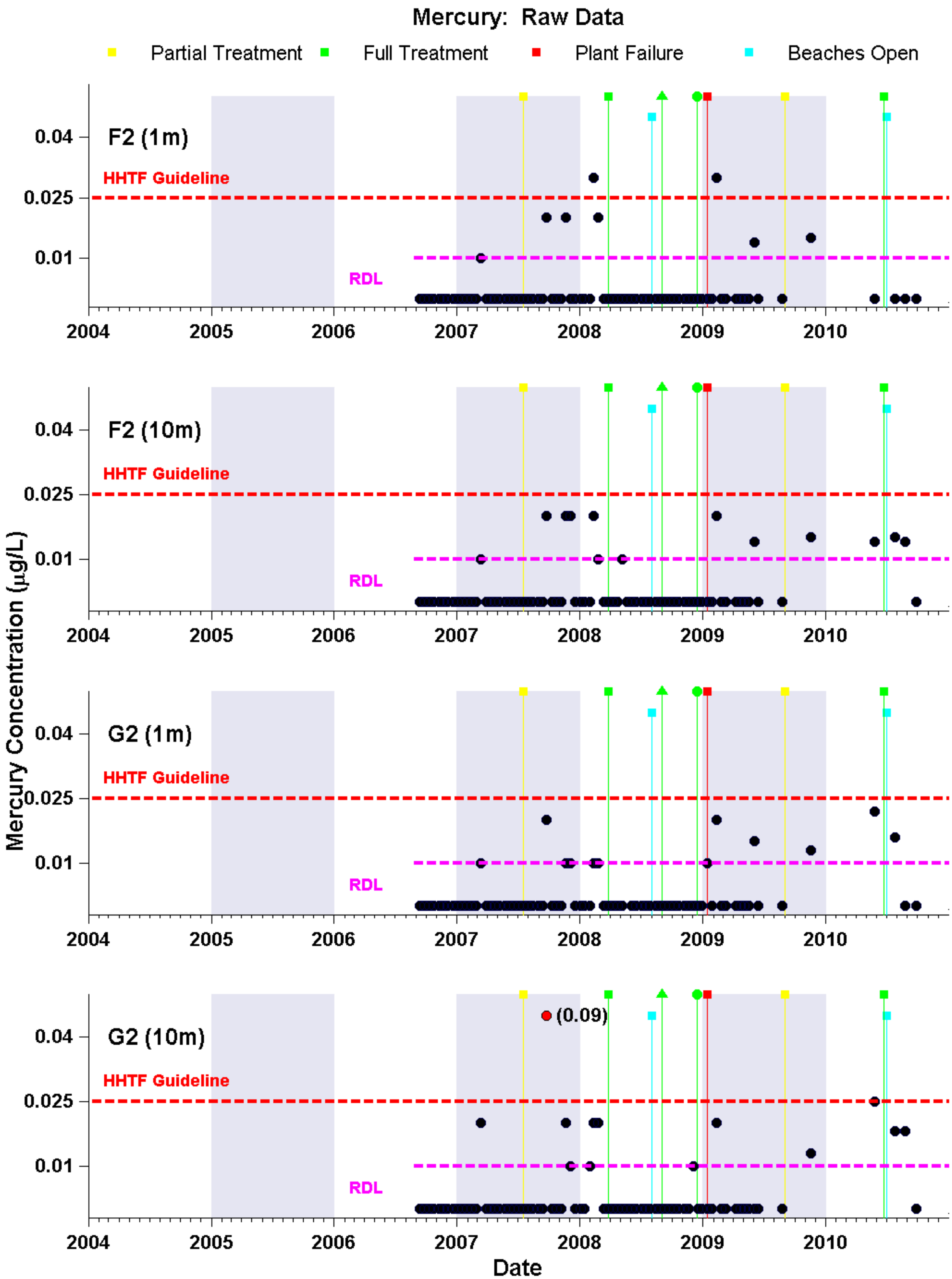

Figure 5.47 Mercury concentration time series. Note the reportable detection limit (RDL) line, and the green timestamps for full treatment at Halifax (square), Dartmouth (triangle) and Herring Cove (circle) WWTFs.

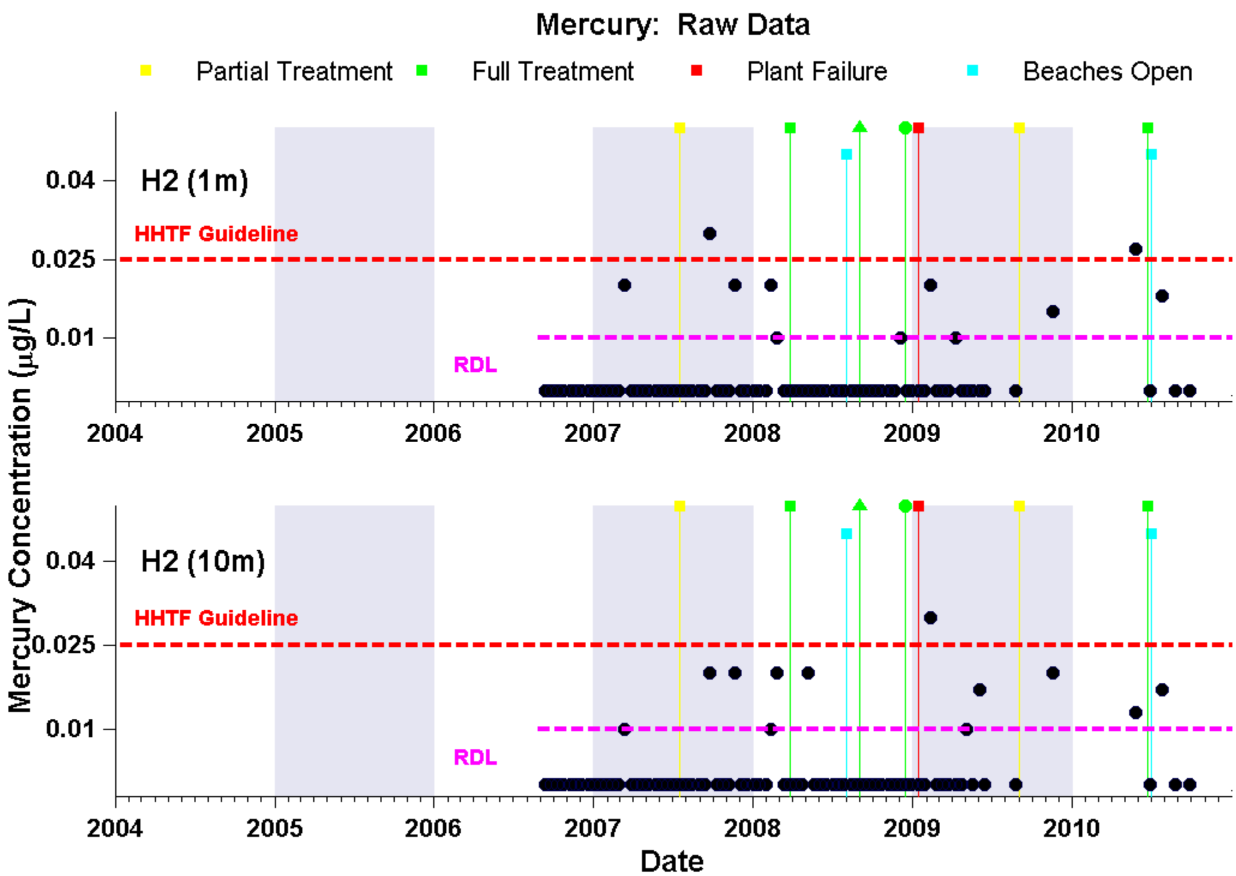

Figure 5.48 Mercury concentration time series. Note the reportable detection limit (RDL) line, and the green timestamps for full treatment at Halifax (square), Dartmouth (triangle) and Herring Cove (circle) WWTFs.

5.10 APPENDIX J: Nickel Concentration Time Series

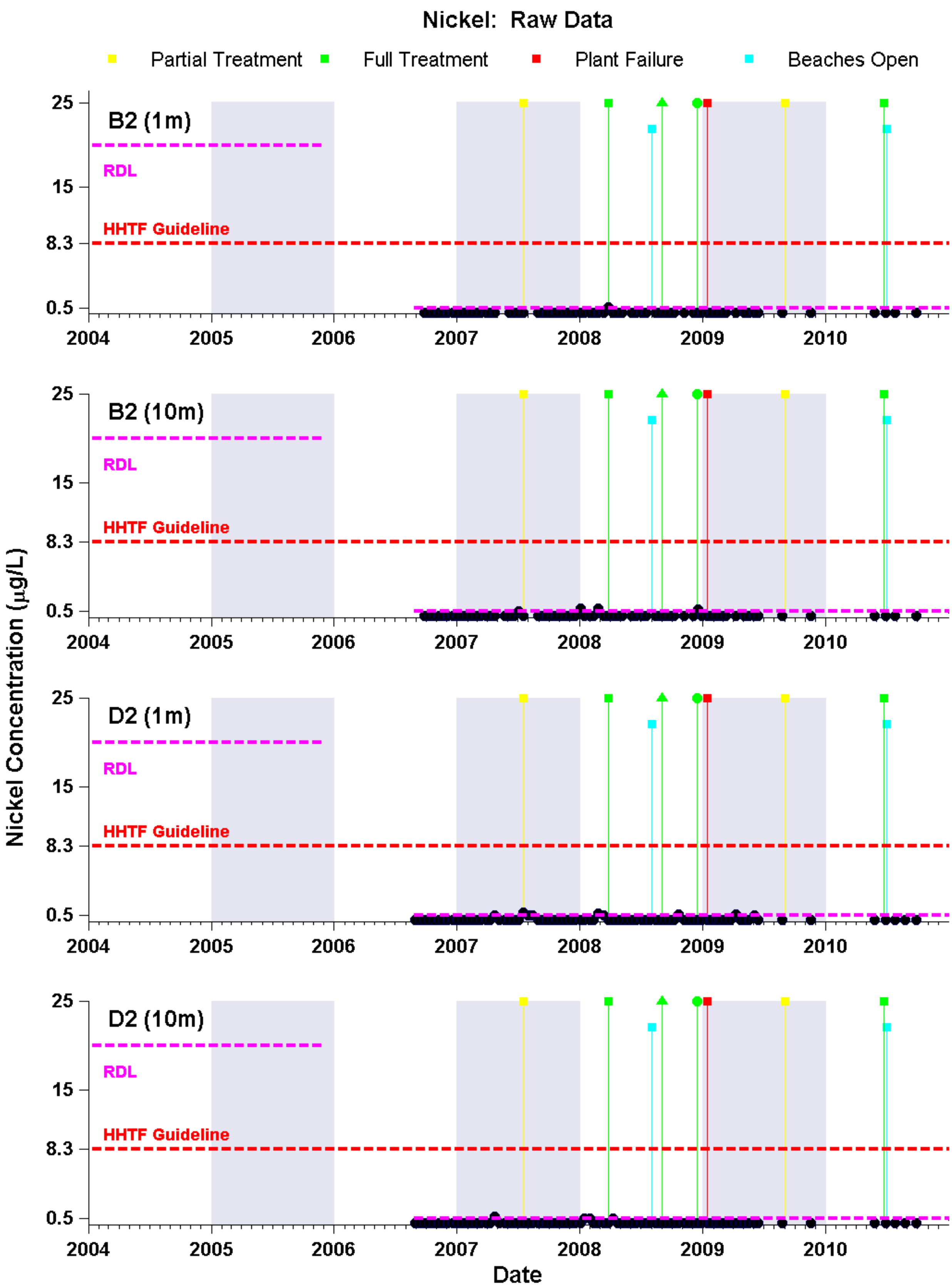

Figure 5.49 Nickel concentration time series. Note the change in reportable detection limit (RDL) in 2006, and the green timestamps for full treatment at Halifax (square), Dartmouth (triangle) and Herring Cove (circle) WWTFs.

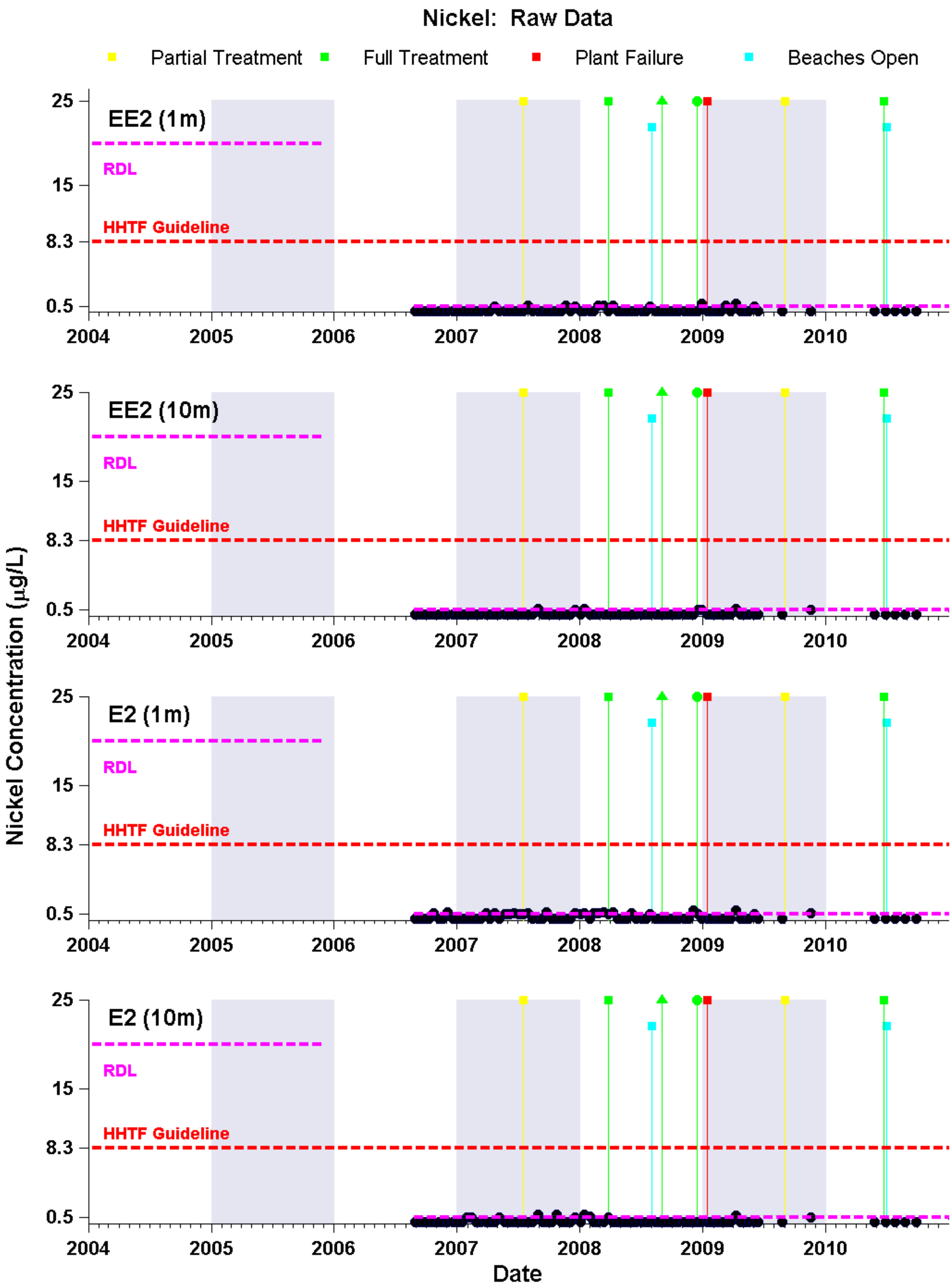

Figure 5.50 Nickel concentration time series. Note the change in reportable detection limit (RDL) in 2006, and the green timestamps for full treatment at Halifax (square), Dartmouth (triangle) and Herring Cove (circle) WWTFs.

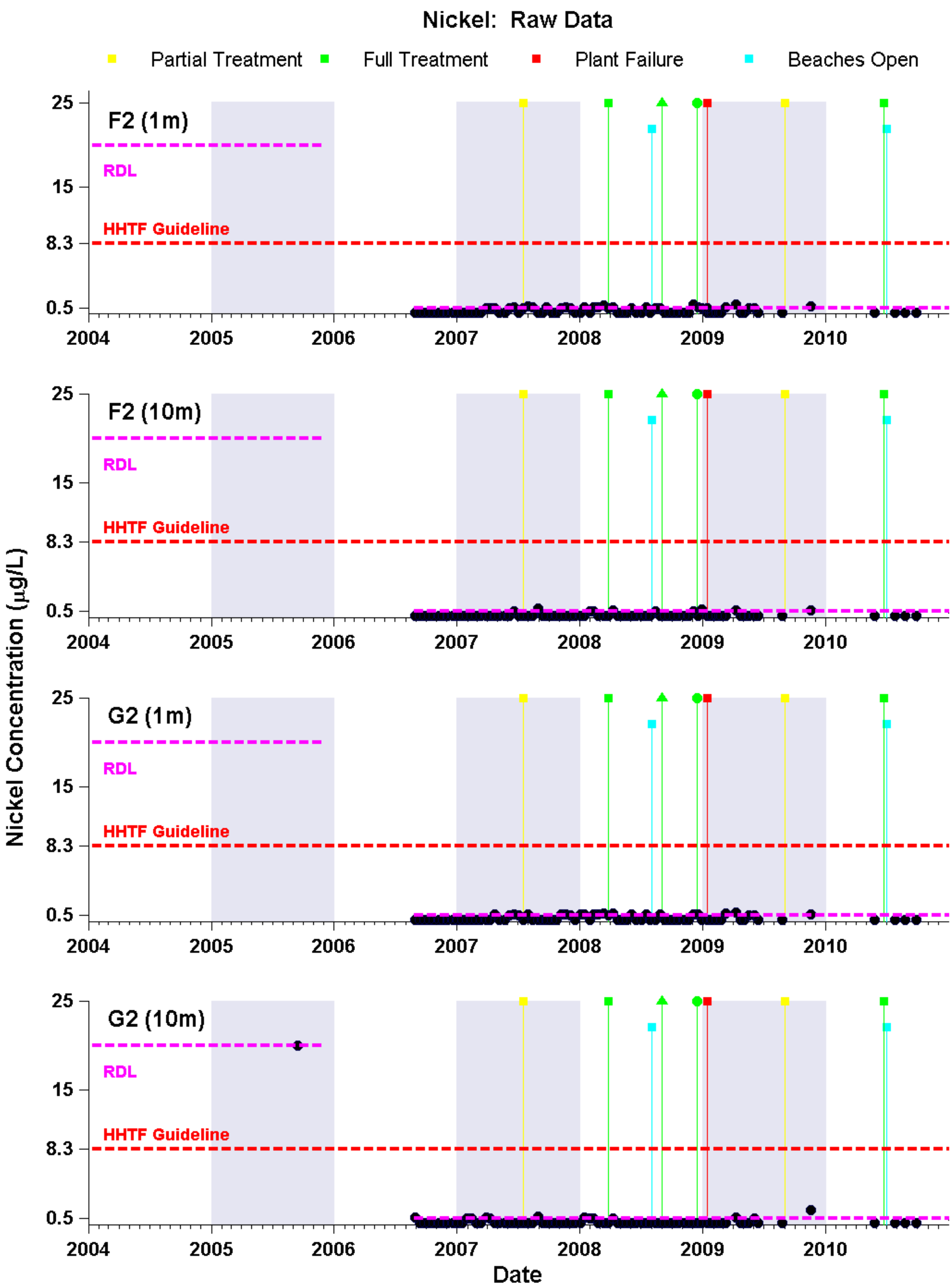

Figure 5.51 Nickel concentration time series. Note the change in reportable detection limit (RDL) in 2006, and the green timestamps for full treatment at Halifax (square), Dartmouth (triangle) and Herring Cove (circle) WWTFs.

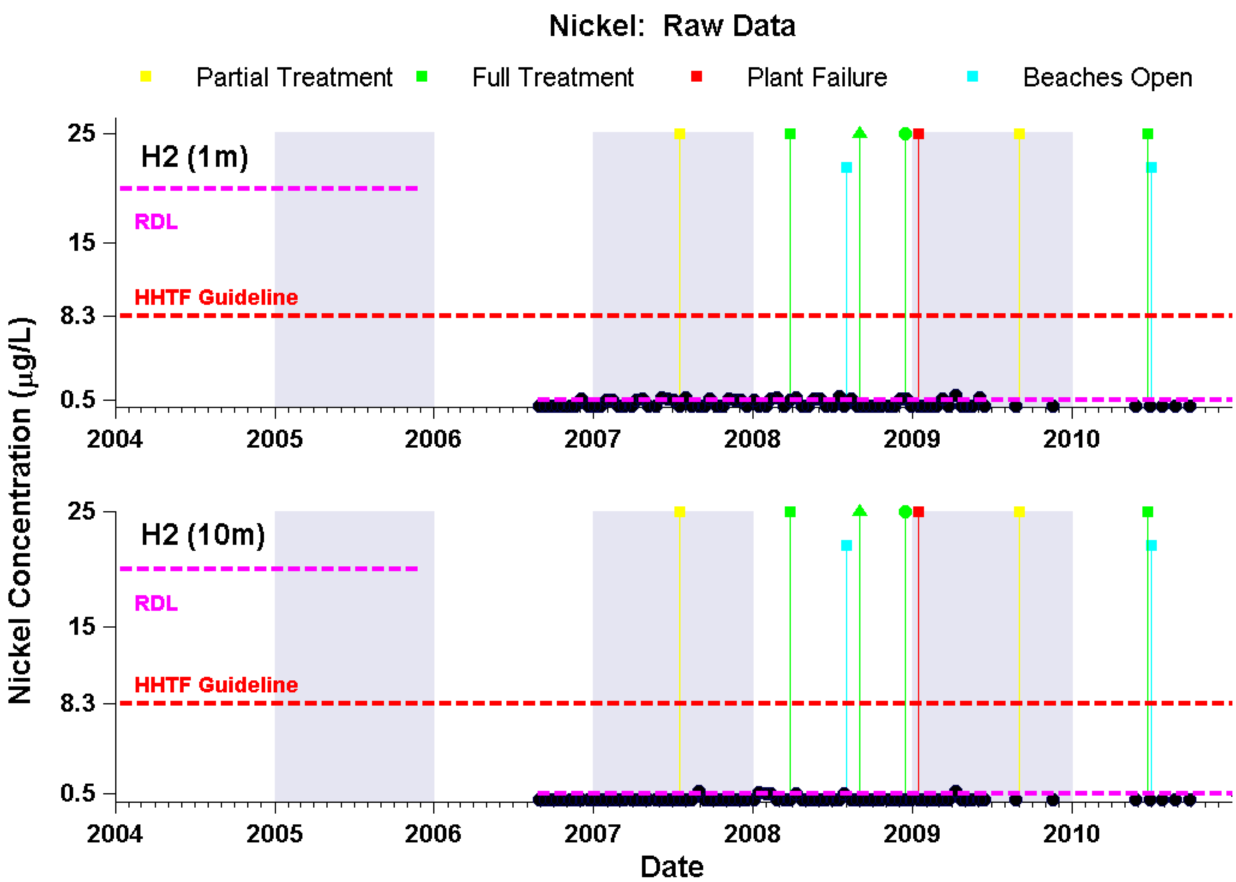

Figure 5.52 Nickel concentration time series. Note the change in reportable detection limit (RDL) in 2006, and the green timestamps for full treatment at Halifax (square), Dartmouth (triangle) and Herring Cove (circle) WWTFs.

5.11 APPENDIX K: Zinc Concentration Time Series

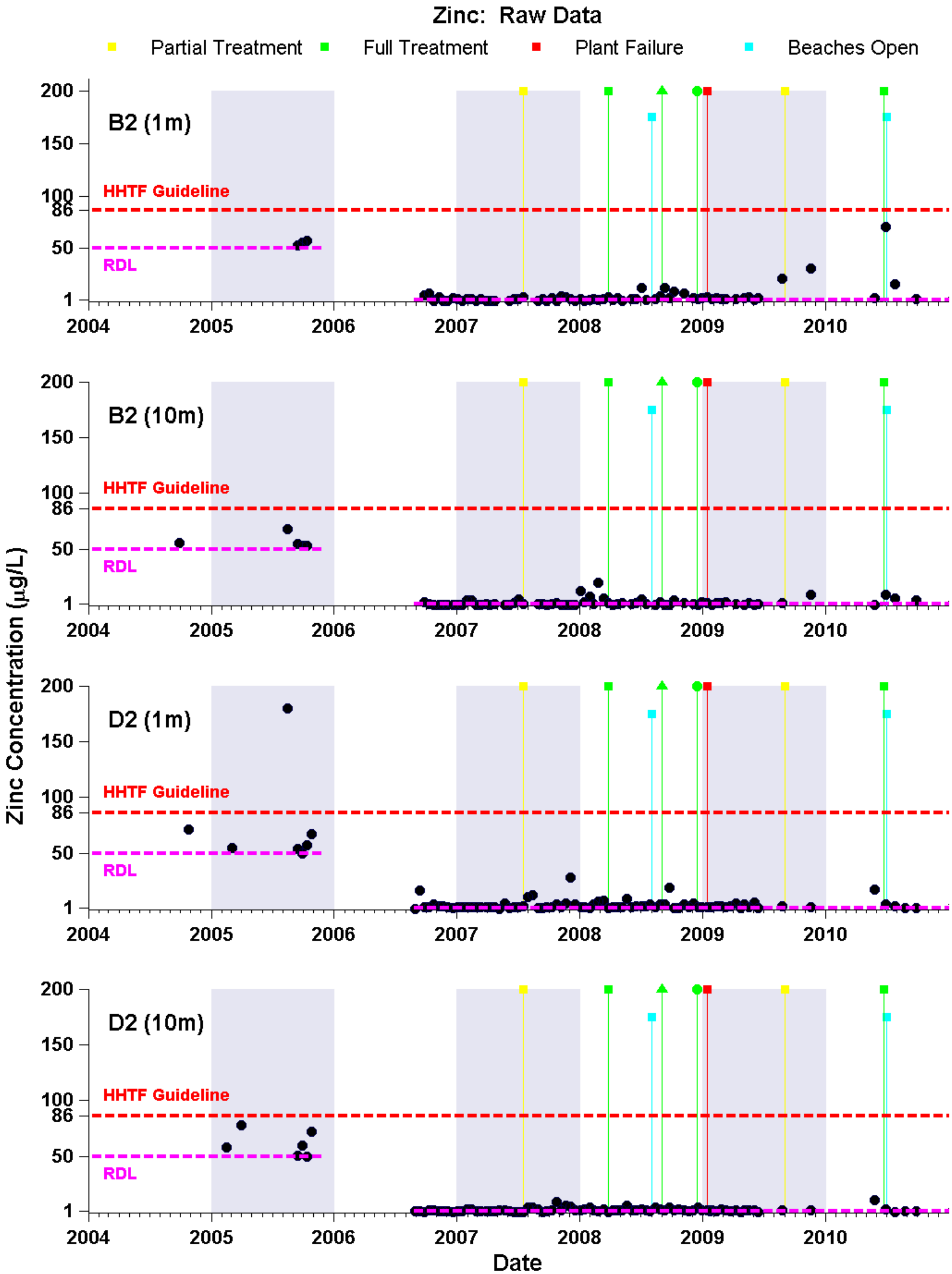

Figure 5.53 Zinc concentration time series. Note the change in reportable detection limit (RDL) in 2006, and the green timestamps for full treatment at Halifax (square), Dartmouth (triangle) and Herring Cove (circle) WWTFs.

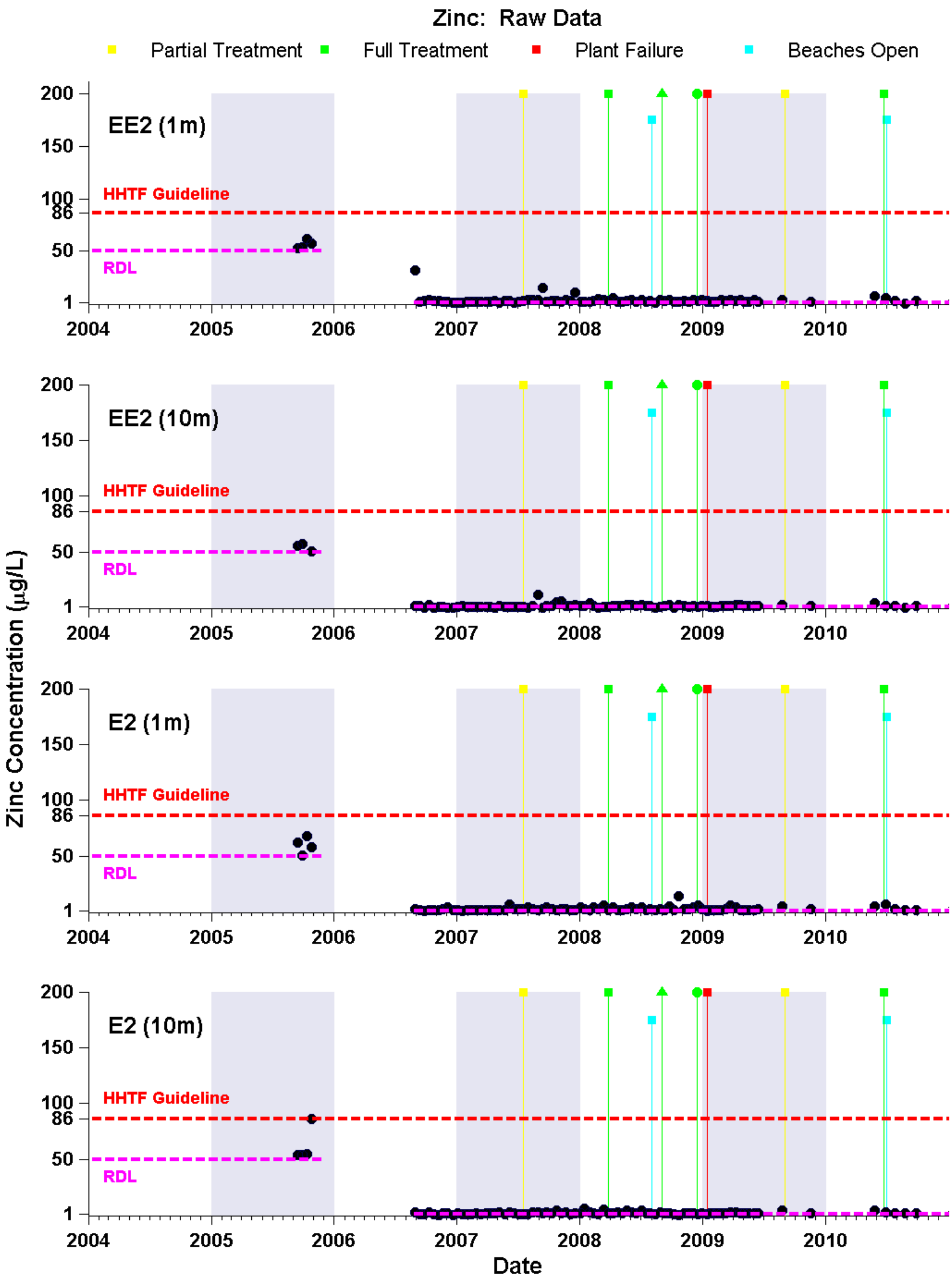

Figure 5.54 Zinc concentration time series. Note the change in reportable detection limit (RDL) in 2006, and the green timestamps for full treatment at Halifax (square), Dartmouth (triangle) and Herring Cove (circle) WWTFs.

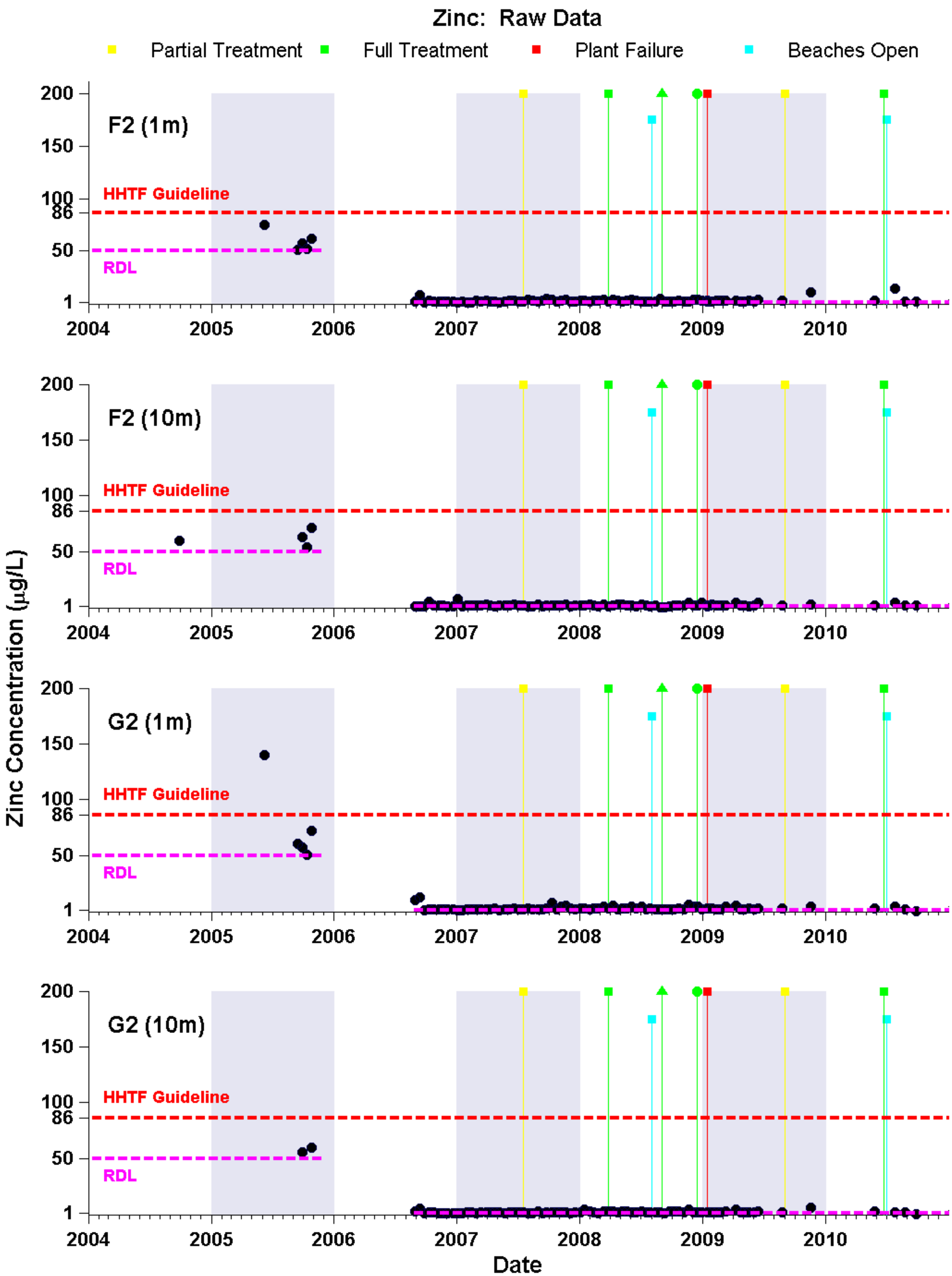

Figure 5.55 Zinc concentration time series. Note the change in reportable detection limit (RDL) in 2006, and the green timestamps for full treatment at Halifax (square), Dartmouth (triangle) and Herring Cove (circle) WWTFs.

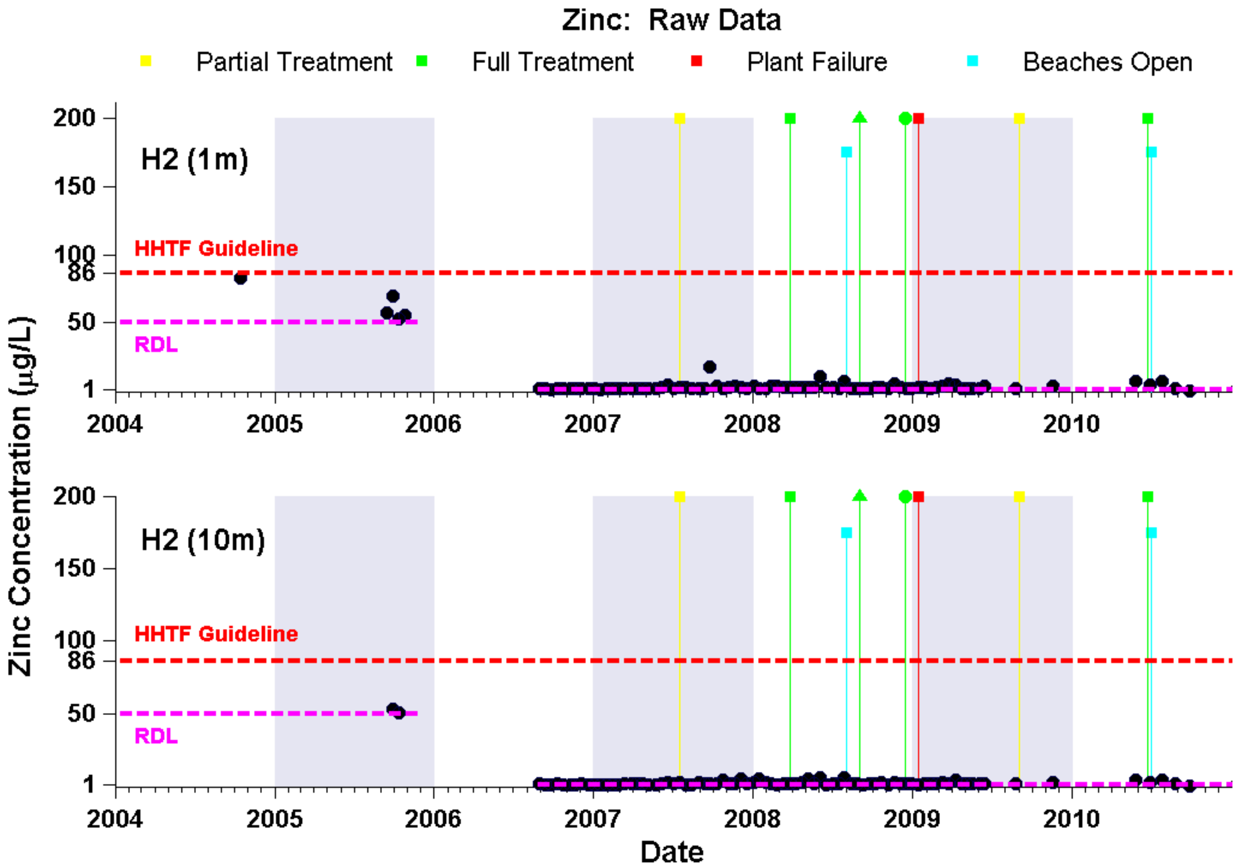

Figure 5.56 Zinc concentration time series. Note the change in reportable detection limit (RDL) in 2006, and the green timestamps for full treatment at Halifax (square), Dartmouth (triangle) and Herring Cove (circle) WWTFs.