Annapolis River 2007 Annual Water Quality Monitoring Report

including results from the

Annapolis River Guardians Volunteer Water Quality Monitoring Program

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This report is available electronically at *www.annapolisriver.ca*

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The Acadia Centre for Estuarine Research

Nova Scotia Department of Environment and Labour

Human Resources and Skills Development Canada

Executive Summary

In 2007, the Annapolis River Guardians completed their 16th year of continuous water quality monitoring on the Annapolis River. Ten volunteers monitored eight sites over the course of the season, which ran from April to November. A number of parameters were measured, including dissolved oxygen, E.coli bacteria, air and water temperature, pH and conductivity, as well as local weather conditions.

E.coli bacteria levels along the Annapolis River during 2007 were lower than those observed in 2006, with the exception of the upper river monitoring stations. Of the 116 E.coli bacteria samples collected and analyzed, 33% (38) exceeded the contact water recreation guideline of 200 cfu/100ml. In 2006, 46% of E.coli samples exceeded this threshold. In 2007, water samples were collected at an additional monitoring station in the Aylesford area at Aylesford Road. The comparison of monitoring results from this and the nearby, existing Aylesford station, has provided a number of useful insights into the nature of fecal contamination in this area.

Over 16 years of monitoring, mean dissolved oxygen saturation (DOSAT) levels have remained in the range of 80-94%. In 2007, the mean DOSAT level was 87%. As a result of the regular monitoring provided by the Annapolis River Guardian program, low DO levels were observed in the lower river in 2005, which prompted a more in-depth examination in 2006 and 2007. In the tidal section of the Annapolis River between Bridgetown and Hebb's Landing, DO levels in the underlying saltwater fell to levels below 2 mg/L (DOSAT <25%) during the late summer and autumn. Similar observations were recorded in 2006.

The mean summer water temperature for the Annapolis River during 2007 was 18.3ºC, 0.8ºC cooler than for the same period in 2006. As in previous years, water temperatures during 2007 continued to reach levels stressful to aquatic life regularly during the summer months (>20ºC).

The pH levels at each of the River Guardians sites were consistently within the recommended range for the protection of aquatic life (6.5-9.0). Mean pH values for the eight monitoring locations along the Annapolis River ranged between 7.2 and 7.4.

The mean nitrate concentration during 2006 and 2007 was 0.45 mg/L. While this concentration may indicate anthropogenic inputs, it does not exceed the suggested guideline level of 1.0 mg/L. Phosphorus, during 2006 and 2007 and numerous locations, approached or exceeded the suggested guideline level of 0.030 mg/L. These elevated phosphorus concentrations are believed to have a role in excessive periphyton growth and depression of dissolved oxygen levels in the tidal portion of the river.

As part of CARP's Quality Assurance Project Plan, regular quality control samples were collected. The accuracy of River Guardian dissolved oxygen readings were estimated at +/- 0.003 mg/L, compared with 0.60 mg/L recorded in 2006. Field and travel blank samples, collected to check for cross contamination, consistently had E.coli counts of less than 5 cfu/100ml. E.coli split samples had a Relative Percent Difference of 43%.

Introduction

History

The Annapolis River Guardians volunteer monitoring program began collecting water quality data in the Annapolis River watershed in 1992. The Clean Annapolis River Project (CARP) initiated the program as a public awareness project, and has had numerous volunteer sample collectors over the years. It is one of the longest running and most extensive volunteer based water quality programs in Eastern Canada. It is also CARP's longest running and only ongoing project. At least 90 volunteers from the Annapolis Valley community have participated in the program over the years, with over 3500 water samples being collected and analyzed.

The program was initiated in the early 1990's by Dr. Graham Daborn and Dr. Mike Brylinsky of the Acadia Centre for Estuarine Research (ACER). Many groups were involved in the planning process for the program, including staff with the Nova Scotia Department of Health, the Nova Scotia Department of Environment, Nova Scotia Community College, and CARP. Although the program has undergone slight changes over the last ten years, its core has remained the same.

The initial program design called for 11 sites to be monitored by 17 volunteers. The initial response from the community was excellent and the project was significantly expanded between 1992 and 1994. In 1994, 38 sites were monitored by 43 River Guardians from 36 households (Pittman *et al* 2001). This intensity of monitoring placed considerable strain on the capacity of CARP. While some of the initial enthusiasm surrounding the program has diminished, a core group of 8 to 15 dedicated volunteers has been maintained over the past number of years.

Program Objectives

The Annapolis River Guardians program has four objectives:

- To establish and support a regular observation system that provides an early warning of environmental problems.
- To provide a long-term record of the river's health.
- To develop interest in the Annapolis River and community stewardship to ensure a viable resource for future generations.
- To provide a knowledgeable group of local individuals who can promote the preservation, rehabilitation, and use of these aquatic resources in the future.

Overview of 2007 Monitoring Season

The 2007 monitoring season commenced on April 30th and concluded on November 12th. Samples were collected fortnightly, with a total of approximately 116 sampling events during the season. Samples were analysed for a variety of parameters, including E.coli bacteria, dissolved oxygen, temperature, pH and conductivity. Further information on the sampling procedures can be found in Appendix A.

Eight stations were sampled along the Annapolis River. Further information on these sampling locations is contained in Appendix B. Figure 1 shows the Annapolis Watershed and the 2007

monitoring sites. The data collected by the volunteers is stored in an in-house Microsoft Access database at the CARP office.

Figure 1. Annapolis watershed with 2007 River Guardian monitoring sites identified by stars.

The 2007 River Guardian sampling locations (with their identification numbers) were:

49 – Bridgetown	40 – Paradise	35 – Lawrencetown	25 – Middleton
18 – Wilmot	13 – Kingston	00 – Victoria Road, Aylesford	AY40 – Aylesford Road, Aylesford

All sample sites were located on the main stem of the Annapolis River.

In the autumn of 2005, CARP was alerted by a member of the community of foul odours in the vicinity of Middleton's Riverside Park. Subsequent investigation and collection of water samples from Lily Lake Brook, a tributary of the Annapolis River, indicated very elevated E.coli levels (>20,000

cfu/100 ml). Town of Middleton staff and Department of Environment and Labour officials were alerted to these results. The problem was traced back to limitations in the Town's sewage infrastructure. When heavy rains occurred, the water was collected through the combined sewer system and exceeded the capacity of the sewage treatment plant (STP). This resulted in the discharge of untreated waste to the Lily Lake Brook and the Annapolis River.

The Town was subsequently placed under order by the Department to address these discharges. For a variety of reasons, little progress was made, which lead the CARP Board of Directors to write to the Town in the spring of 2007, expressing its concerns over the discharge of untreated wastes and impacts on downstream water uses. With the hiring of a new Chief Administrative Officer, the Town of Middleton has made a number of important steps in addressing the problems associated with its STP. In the autumn of 2007, a temporary repair to the STP was made to ensure that untreated waste would not be released into the Lily Lake Brook during peak flow events. The Town has commissioned CBCL Ltd. to prepare a Preliminary Design Study for the upgrading of the sewage treatment plant. At the time of writing, CARP is assisting the Town in reviewing submissions for the full design and construction of a new lagoon-based sewage treatment facility. Subject to federal and provincial funding being secured, it is envisioned that construction of the new STP would commence in 2009.

This case serves as an example of how community water quality monitoring programs, such as CARP, can help to identify water quality issues, motivate regulators and polluters to address the problem and work with all parties to ensure the long-term health of the Annapolis watershed.

2007 Monitoring Results

E.coli Bacteria

Introduction

Escherichia coli (E.coli) are rod-shaped, aerobic, lactose fermenting bacteria. They are gram-stain negative, thermotolerant and appear as dark blue colonies when cultured in the laboratory. Fecal matter of warm-blooded animals is the predominant source of E.coli bacteria. Because they occupy the same ecological niche as many human pathogens, such as *Cryptosporidium*, E.coli are used as indicators for the possible presence of other potentially dangerous pathogens. E.coli have been identified in the past as a major cause of concern in the Annapolis River watershed (Pittman *et al* 2001). The potential sources of fecal contamination in the watershed include central sewage treatment plants, malfunctioning on-site septic systems, aquatic wildlife (i.e. beavers, muskrats, waterfowl), domestic animals, and livestock.

Many factors in a particular ecosystem affect the abundance of E.coli in rivers. These include the type of source, the transport mechanism with which the E.coli is deposited, and precipitation. The result is that E.coli densities in surface waters can be highly variable. Their survival in surface waters is not well understood, and is dependent on many factors. These include predation by other organisms, amount of sunlight, salinity of the water, temperature, as well as composition and abundance of sediment (Davies *et al* 1995). There are a range of estimates for the survival times of the commonly monitored E.coli in various media:

- Cow pats: 49 days at 37^{o}C, 70 days at 5^{o}C (also dependent on moisture content) (Chalmers *et al* 2000)
- Drinking water: Between 28 and 84 days (Edberg *et al* 2000)
- Soil cores with grass roots: 130 days (Chalmers *et al* 2000)
- In situ freshwater sediment: 57 days (Davies *et al* 1995)

Over the period of 1992 to 2007, numerous initiatives have been undertaken which have contributed to the improvement of water quality in the Annapolis River. For example, in the winter of 1994, 14 Wing Greenwood discontinued the discharge of untreated aircraft wash-water into a tributary of the Annapolis River. In August 1998, the base discontinued the operation of its own sewage treatment plant, redirecting its waste to the Greenwood municipal facility.

While the core River Guardian monitoring program has been maintained over the period of 1992 to 2007, a number of modifications have been made. For example, in 1996, the collection of E.coli samples was standardized to a fortnightly basis. During the period of 1997 to 2002, fecal coliform numbers were determined using the IDEXX Colilert procedure, which specifically identifies *E. coli*. With the change to a new laboratory, the 2003 and 2004 samples were analyzed using the Membrane Filtration procedure, which enumerates fecal coliforms (see Appendix A). In 2005, the Science Advisory Committee for the Annapolis River Guardians advised that bacteria monitoring be switched from fecal coliforms to E.coli, to bring the program more in line with current guidance at a national level. To ensure the continuity of the historic dataset, it was decided to collect split samples

for the first two months of the season, to allow parallel testing for fecal coliform and E.coli. This process confirmed that the two methods do not give statistically different results. Further information on the parallel testing and statistical analysis can be found in the 2005 Annual Report for the Annapolis River Guardians (Beveridge *et al* 2006).

Canadian Water Quality Guidelines

Various government agencies have developed water quality guidelines to protect the safety of the general public. Health Canada is responsible for the guidelines for drinking and recreational waters. The Canadian Council of Ministers of the Environment (CCME) has incorporated these guidelines in the comprehensive Canadian Water Quality Guidelines (CCME 2002). CARP has summarized the guidelines for fecal bacteria contamination into a concise table for public awareness purposes (Table 1).

Table 1. Summary of water quality guidelines for fecal coliforms.

cfu*/100ml	Water Use	Explanation/Source
0	Acceptable for drinking	CCME/Health Canada, fecal coliforms/100ml.
< 50	Acceptable for livestock watering	Interpretation of CCME narrative "high-quality water given to livestock" (total coliforms).
< 100	Acceptable for food crop irrigation	Tentative Maximum Concentration. CCME Guidelines (fecal coliform bacteria/100ml).
< 200	Acceptable for recreational use	CCME/Health Canada, Geometric Mean of 5 samples taken during a period not to exceed 30 days, should not exceed 200 cfu/100 ml.
cfu = colony forming units		

Monitoring Results

The high variability of fecal bacteria measurements presents a number of challenges with respect to data analysis. Samples collected from a single site, on separate occasions, can vary by two and sometimes three orders of magnitude (e.g. 3 cfu/100 ml to 3000 cfu/100 ml). The use of standard data analysis methods, such as calculating and comparing mean values, inadequately describes the distribution of fecal bacteria results. The following analysis is therefore based on the proportion of samples analysed that exceed particular water quality thresholds. This approach was chosen as it best presents, to decision-makers and resource managers, whether the water at a site is unsuitable for particular uses.

While this approach eliminates the bias of calculating means with highly variable data, it presents another type of bias. If the majority of samples one year fall slightly below a guideline threshold (e.g. 200 cfu/100 ml), a small increase in fecal coliform concentration the next year may cause the proportion of samples above 200 cfu/100 ml to increase significantly. This would give the appearance that the water quality had worsened considerably, when in fact the mean coliform concentration may have only increased slightly. In order to ensure the differences observed in the following analysis are real, a box-whisker plot was prepared to compare the distribution of the 2006 and 2007 E.coli results (see Figure 2). The box plot shows the 25th and 75th percentiles as well as

the median for each site. The minimum and maximum results are also shown. The three water quality guidelines for E.coli discussed in the report are shown as dotted lines at 50, 100, and 200 cfu/100ml. It is important to note that the y-axis of the graph is plotted using a logarithmic scale (Log E.coli).

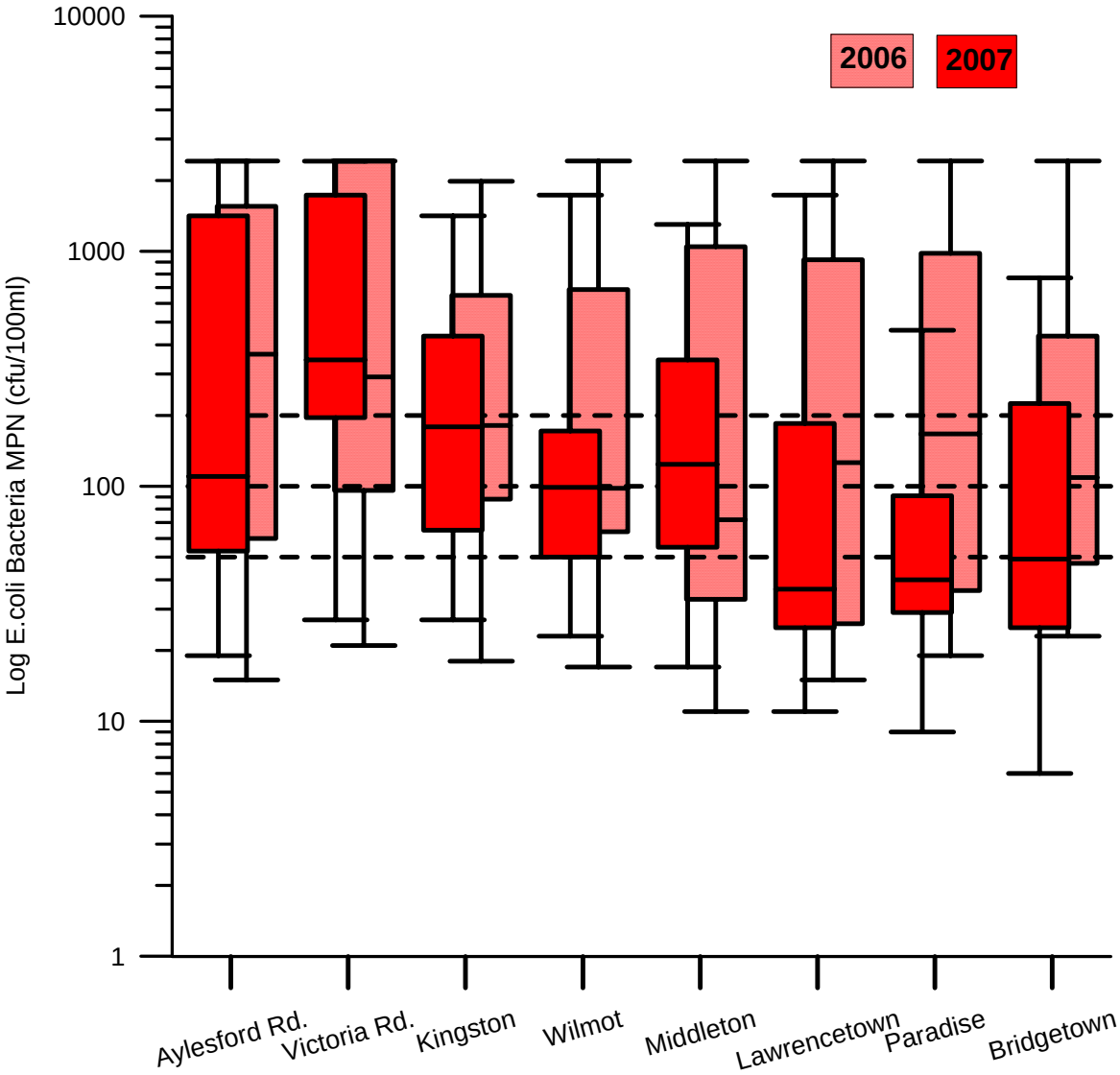

Figure 2. Box and whisker plot of Annapolis River Guardian E.coli bacteria results for 2006 and 2007.

From Figure 2, it is evident that during 2007 there was a decrease in E.coli bacteria counts compared to 2006, over much of the river. E.coli bacteria levels were highly variable across most monitoring sites. The median bacteria level decreased for all sites, with the exception of Aylesford at Victoria Road and Middleton. It is important to note that the Middleton River Guardian sample station is upriver of the discharge from the Middleton Sewage Treatment Plant.

The E.coli ranges shown in Figure 2 are artificially capped at 2420 MPN cfu/100 ml, as this is the maximum value possible with the IDEXX Colilert testing system. It is interesting to note that for the Aylesford at Aylesford Road station, while a similar range of E.coli levels was observed over the two years, the median value in 2007 was significantly lower. E.coli bacteria levels in the lower river (Lawrencetown, Paradise and Middleton) were significantly lower in 2007.

Figure 3 presents all E.coli data collected in 2007 on the Annapolis River with daily total precipitation at Kentville[1]. While most results were less than 1000 cfu/100 ml, on five distinct occasions, significantly higher E.coli values were observed. An observable pattern is evident from the data, with elevated E.coli counts following within a few days of a rain event.

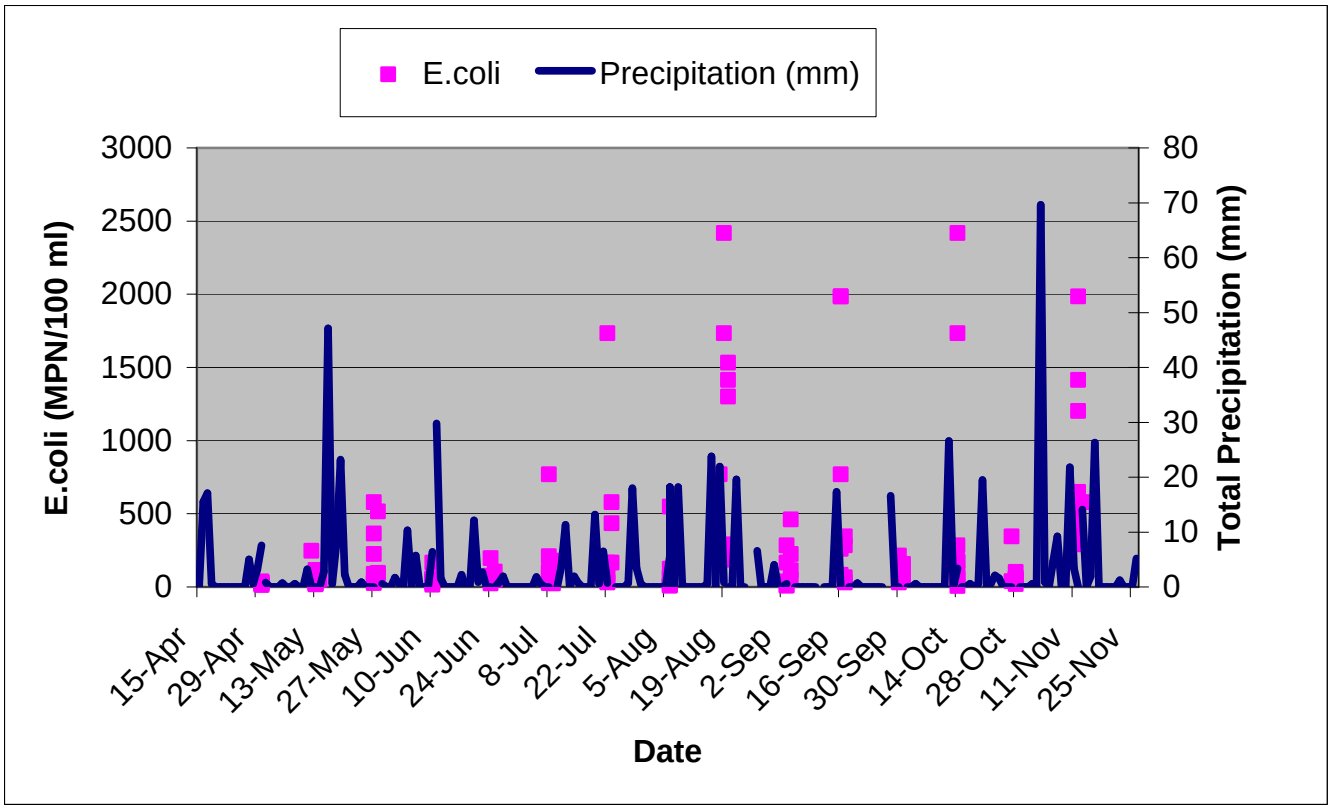

Figure 3. 2007 Annapolis River Guardian E.coli and precipitation data.

Table 2 presents the proportion of E.coli bacteria samples collected through the 2007 River Guardian program which exceeded 50 cfu/100 ml, the water quality guideline for livestock watering. For example, at Aylesford in 2007, 0.93 or 93% of water samples collected had E.coli bacteria counts in excess of 50 cfu/100ml, as compared to 93% in 2006 and 61% in 2005. From the data presented in Table 2, a similar or slightly fewer number of samples exceeded 50 cfu/100 ml during 2007, compared to 2006. Upon examining the data, it appears as though Lawrencetown had a significant improvement in bacterial water quality, occurring between 1996 and 1998. The cause of this improvement is not known.

[1] Precipitation data for August 4 to 10 and August 15 to 26 were missing from the Kentville record. For these dates, precipitation data from the Kejimkujik station was used.

Table 2. Proportion of fecal bacteria samples exceeding 50 cfu/100 ml over the duration of the Annapolis River Guardian program.

	Aylesford Road	Aylesford	Kingston	Wilmot	Middleton	Lawrencetown	Paradise	Bridgetown
1992		1.00	0.33	1.00	1.00	1.00	1.00	
1993		0.91	0.79	0.81	0.86	0.93	0.86	
1994		0.83	0.73	0.88	0.91	0.81	0.86	0.92
1995		0.40	0.14			0.80	0.50	0.71
1996		0.50	0.80		0.75	0.93	0.75	0.80
1997		0.86	0.81	0.81	0.88	0.71	0.50	0.65
1998		0.92	0.75	0.40	0.50	0.55	0.60	0.75
1999		0.86	0.67	0.71	0.55	0.33	0.43	0.65
2000		0.60	0.53	0.45	0.46	0.50	0.57	0.36
2001		0.67	0.83	0.83	0.54	0.33	0.55	0.20
2002		1.00	0.53	0.64	0.38	0.38	0.20	0.60
2003		1.00	0.90	1.00	0.56	0.50	0.50	0.55
2004		0.94	0.93	1.00	0.85	0.79	0.86	0.86
2005	0.53	0.61	0.53	0.63	0.47	0.53	0.61	0.56
2006	0.80	0.93	0.93	0.80	0.60	0.60	0.67	0.73
2007	0.79	0.93	0.92	0.73	0.80	0.43	0.47	0.47

Table 3 presents the proportion of River Guardian samples exceeding the water quality guideline for food crop irrigation (100 cfu/100 ml). In 2007 at the upper river sample stations, a similar number of samples exceeded 100 cfu/100 ml compared to 2006. At sample stations on the lower river (Lawrencetown, Paradise, Bridgetown), fewer samples exceeded 100 cfu/100 ml, compared to 2006. The 2004 to 2007 exceedences of this threshold are also compared in Figure 4.

Table 3. Proportion of fecal bacteria samples exceeding 100 cfu/100 ml over the duration of the Annapolis River Guardian program.

	Aylesford Road	Aylesford	Kingston	Wilmot	Middleton	Lawrencetown	Paradise	Bridgetown
1992		1.00	0.00	0.67	0.67	0.67	1.00	
1993		0.82	0.57	0.69	0.71	0.79	0.71	
1994		0.67	0.55	0.88	0.82	0.75	0.57	0.69
1995		0.40	0.14			0.80	0.50	0.57
1996		0.50	0.50		0.63	0.79	0.56	0.60
1997		0.71	0.44	0.69	0.63	0.36	0.14	0.53
1998		0.83	0.50	0.10	0.50	0.27	0.40	0.25
1999		0.71	0.53	0.43	0.45	0.00	0.29	0.41
2000		0.60	0.40	0.27	0.23	0.33	0.43	0.07
2001		0.56	0.42	0.50	0.31	0.08	0.45	0.13
2002		1.00	0.33	0.29	0.06	0.38	0.10	0.27
2003		0.70	0.80	0.45	0.33	0.29	0.25	0.36
2004		0.94	0.79	0.79	0.62	0.50	0.64	0.79
2005	0.42	0.50	0.47	0.58	0.21	0.21	0.28	0.11
2006	0.73	0.73	0.64	0.47	0.40	0.53	0.60	0.53
2007	0.57	0.87	0.62	0.47	0.53	0.29	0.20	0.33

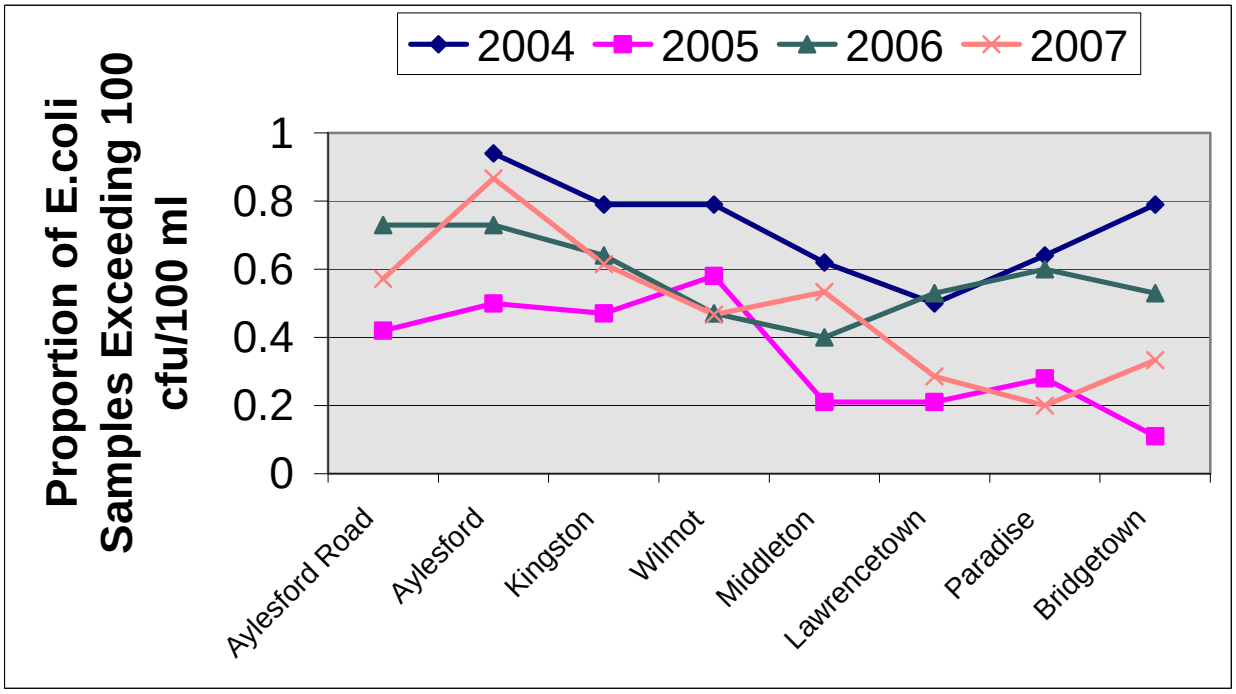

Figure 4. Proportion of fecal bacteria samples exceeding 100 cfu/100ml for 2004 to 2007.

As is evident in Figure 4, two monitoring sites (Aylesford and Middleton) had a higher proportion of samples exceeding 100 cfu/100 ml in 2007, compared to 2006. Table 4 presents the proportion of E.coli bacteria samples exceeding 200 cfu/100 ml, the water quality guideline for water contact recreation. The table shows a general decrease with respect to this threshold for seven of the eight monitoring stations. Figure 6 presents the proportion of E.coli bacteria samples collected at Aylesford that exceed 200 cfu/100 ml. Over 16 years of monitoring, the data from this site is observed to be highly variable, with the 2007 results approaching those observed in 2004 and 2006.

Table 4. Proportion of E.coli bacteria samples exceeding 200 cfu/100 ml over the duration of the Annapolis River Guardian program.

	Aylesford Road	Aylesford	Kingston	Wilmot	Middleton	Lawrencetown	Paradise	Bridgetown
1992		0.50	0.00	0.67	0.67	0.33	0.33	
1993		0.55	0.21	0.50	0.29	0.57	0.36	
1994		0.50	0.55	0.56	0.55	0.31	0.57	0.46
1995		0.20	0.14			0.40	0.33	0.29
1996		0.50	0.40		0.38	0.43	0.44	0.40
1997		0.43	0.13	0.19	0.13	0.07	0.07	0.06
1998		0.58	0.13	0.00	0.25	0.09	0.20	0.08
1999		0.43	0.33	0.29	0.18	0.00	0.14	0.18
2000		0.40	0.07	0.18	0.15	0.25	0.43	0.00
2001		0.22	0.25	0.33	0.15	0.08	0.09	0.13
2002		0.50	0.13	0.14	0.00	0.00	0.00	0.13
2003		0.10	0.40	0.27	0.22	0.21	0.08	0.27
2004		0.71	0.36	0.21	0.23	0.29	0.43	0.29
2005	0.21	0.44	0.21	0.05	0.11	0.00	0.06	0.06
2006	0.67	0.67	0.50	0.33	0.33	0.40	0.47	0.33
2007	0.29	0.73	0.46	0.20	0.27	0.21	0.13	0.33

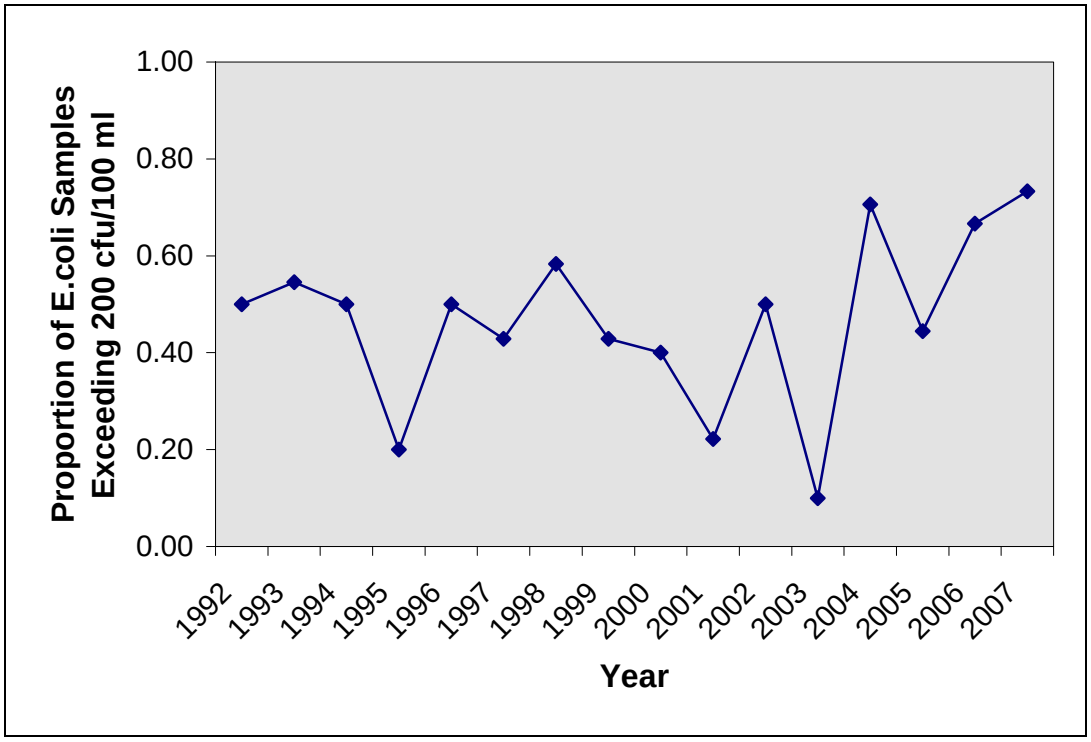

Figure 5. Proportion of E.coli bacteria samples collected at Aylesford exceeding 200 cfu/100 ml over the duration of the Annapolis River Guardian program.

During the summer of 2003, CARP staff undertook a survey of tributaries to the Annapolis River in the Aylesford area, as part of the larger Aylesford East Project, to identify watercourses with impaired

water quality (Sharpe and Sullivan 2004). A number of tributaries were identified as having elevated fecal coliform and nutrient levels, including Patterson, Parker and Skinner Brooks. These tributaries originate on the North Mountain and enter the Annapolis River approximately 2km above the Aylesford River Guardian sample site (Site 00 – Aylesford at Victoria Road).

Commencing with the 2005 monitoring season, an additional monitoring site was added (Site AY40) at Aylesford Road, approximately 2.5 km upstream of the Site 00 Aylesford location. The purpose of this was to collect regular samples above and below the mouth of the above brooks, to assess if there was a significant difference in fecal bacteria results. Figure 6 presents the monitoring results for the AY40 (Aylesford Road) and 00 (Victoria Road) locations. Table 5 presents the respective geometric means for these two sample stations.

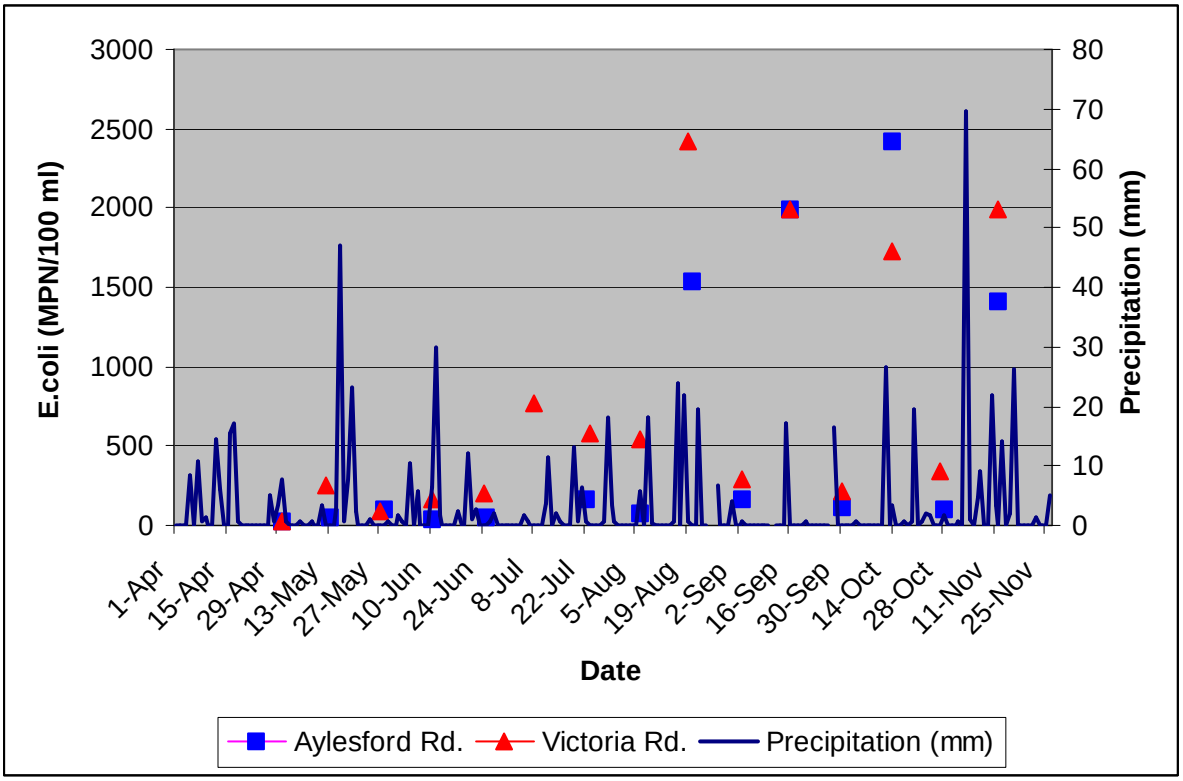

Figure 6. Fecal bacteria densities for the Aylesford monitoring sites.

The E.coli bacteria levels for the two monitoring sites are very similar from April to June, after which the downstream Aylesford site (00) exhibited higher bacteria levels during July. From late August to October, E.coli levels at the two sites were highly variable. The elevated E.coli levels during this period do not appear to be associated with precipitation events.

When the data for an entire season for each monitoring station is considered, E.coli results are found to be highly variable, with large standard errors (Table 5). From this, it must be concluded that the geometric means for the two stations may not be statistically different. The data in Table 5 must be considered together with temporal trends presented in Figure 6.

Table 5. Geometric means and standard error Aylesford sample stations (E.coli reported as MPN cfu/100 ml).

Year	Aylesford at Aylesford Road (upstream)		Aylesford at Victoria Road (downstream)	
	Geometric Mean	Standard Error	Geometric Mean	Standard Error
2005	88	67	183	53
2006	294	228	382	279
2007	227	227	412	212

During October and November 2007, additional samples were collected in the Aylesford East area to better understand the nature of contaminant sources. As was mentioned earlier, between the two Aylesford River Guardian sample stations (#00 - Aylesford at Victoria Road and AY40 – Aylesford at Aylesford Road), three brooks enter the Annapolis River: Patterson, Parker and Skinner Brooks. A map showing the location of these brooks and sample locations is shown in Figure 7. Land uses in these sub-catchments include dairy and beef farms, a large commercial cranberry bog and scattered residential dwellings. Samples were collected on October 29 and November 11 on these three brooks, with the E.coli results presented in Tables 6 and 7. Sample sites were deliberately placed at upstream and downstream locations in an effort to identify possible contaminant sources.

Figure 7. Aylesford East sample locations.

Table 6. E.coli results (MPN/100 ml) at Patterson Brook

Sample ID	Location	October 29	November 11
AY15 (upstream location)	Patterson Brook at Brooklyn Road (Hwy221)	34	914
AY10 (downstream location)	Patterson Brook at Hwy 1, near confluence with Annapolis River	1203	2419

Table 7. E.coli results (MPN/100 ml) at Parker/Skinner Brooks

Sample ID	Location	October 29	November 11
AY25 (upstream location)	Parker Brook at Brooklyn Road (Hwy221)	291	166
AY35 (upstream location)	Skinner Brook at Brooklyn Road (Hwy221)	649	461
AY20 (downstream location)	Combined Parker/Skinner Brooks at Hwy 1, near confluence with Annapolis River	219	770

From this limited data, the three Brooks investigated appear to all be potential contaminant sources of the Annapolis River. In the case of Patterson Brook, fecal contamination appears to be entering the brook both above and below Brooklyn Road. A similar conclusion can be drawn for both Parker and Skinner Brooks.

Patterson Brook was identified by MacMillan *et al* (2005) as one of the few streams in the Annapolis watershed with consistently cool water temperatures throughout the summer months. The stream was also found to contain high populations of brook trout. Patterson Brook may therefore have the appropriate combination of cool water and necessary habitat to serve as nursery and/or summer refuge for brook trout. For these reasons, any contamination present should be investigated and remediated where possible.

Recommendations

- Continue regular River Guardian E.coli monitoring at the eight main river sample locations.
- Conduct simultaneous monitoring at Sites 00 and AY40, together with intervening tributary streams.
- Conduct a foot survey of the Annapolis River between these two sites and the intervening tributary streams to identify possible contamination sources.
- Review current and historic air photos of this area to identify land use changes and possible sources of contamination.

Dissolved Oxygen

Introduction

Dissolved oxygen (DO) is a widely used and important general indicator of the health of a river system (Addy *et al* 1997). Aquatic organisms require oxygen in solution for internal respiration. Oxygen in the atmosphere, which is readily available to terrestrial organisms, must be dissolved into the water and is present at much lower concentrations. Wind, wave action, rainfall, and photosynthesis help aerate waterways and increase dissolved oxygen levels. Sewage, lower rates of photosynthesis, and limited diffusion from the atmosphere due to ice cover can all lead to decreased oxygen levels.

As the temperature of water decreases, a greater concentration of oxygen is able to dissolve in the water. The amount of oxygen in water can be reported in two ways, either as a concentration measurement (mg/L) or as percent saturation. Water reaches its saturation point when it can no longer dissolve any additional oxygen for a given temperature. High levels of photosynthesis or turbulent conditions can "supersaturate" the water, resulting in saturation levels greater than 100%. Dissolved oxygen levels below 60% saturation are known to cause stress to aquatic life, particularly cold-water fish species (Mackie 2004).

Monitoring Results

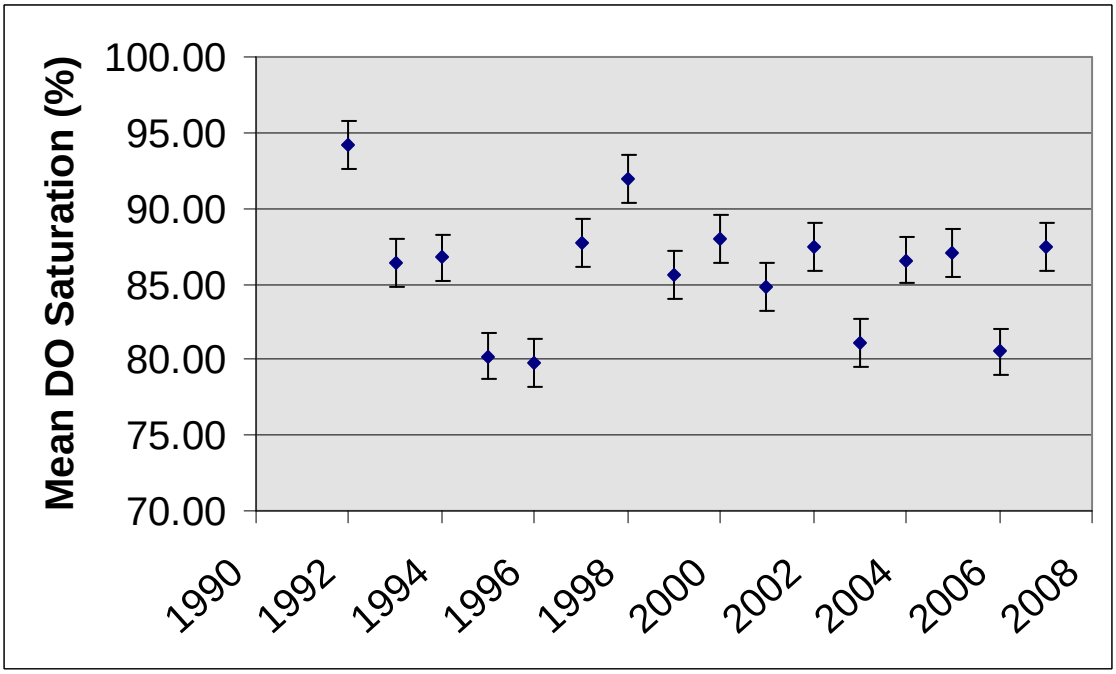

Figure 8. Mean dissolved oxygen saturation (DO SAT) by year, 1992 to 2007 (showing standard error of the mean).

Figure 8 shows that during the period of 1992 to 2007, annual mean dissolved oxygen (percent saturation) levels have varied from a high of 94.2% in 1992, to a low of 79.7% in 1996. For the

values recorded during 2007, the mean dissolved oxygen saturation was 87.4%, compared with 80.5% in 2006. This value is within the normal range of variability observed for the Annapolis River. The standard error of the mean is shown with error bars.

Figure 9 presents the 14-year mean dissolved oxygen (percent saturation) values for each of the main river monitoring sites. The standard error of this mean is shown with error bars. This is overlaid with the mean values for the 2007 monitoring season. From these data it is evident that DO values in 2007 for the two Aylesford stations and Paradise were higher than the long term average for the river. The 2007 average for Bridgetown was below the long-term average. There does not appear to be a significant increasing or decreasing trend for any of the sites. A 14-year mean for Middleton is not available, as dissolved oxygen monitoring was not conducted at this site during 1995, 1996, and 1997.

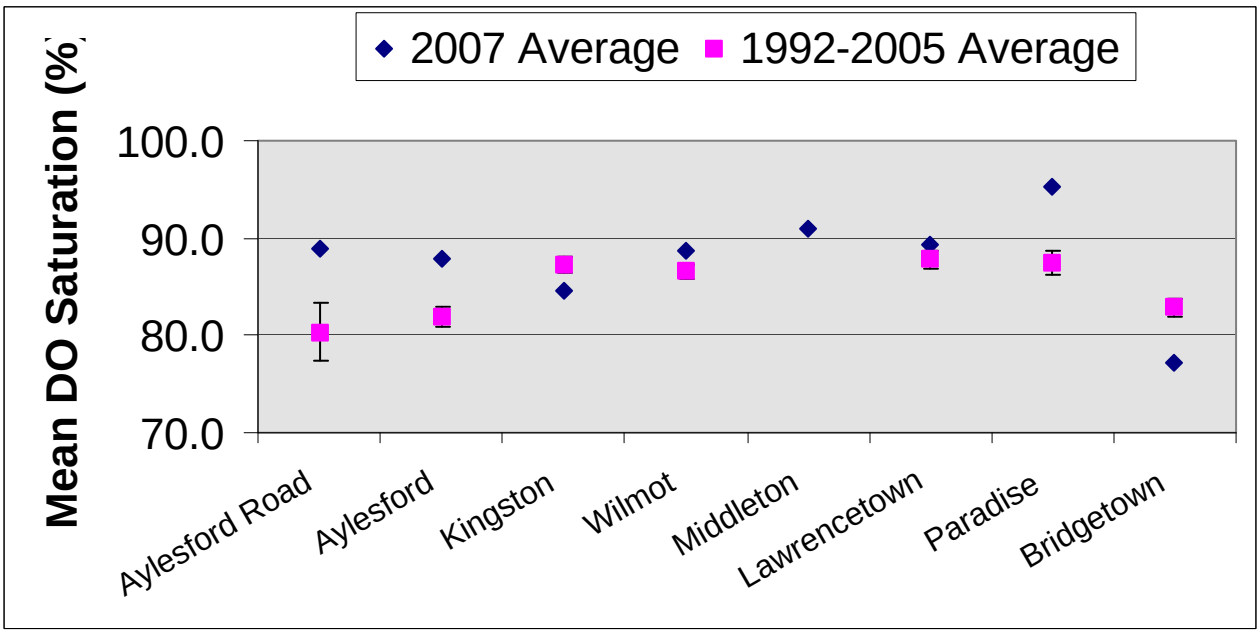

Figure 9. Mean dissolved oxygen saturation (DO SAT) by sampling site, 1992 to 2005, with means showing standard error of the mean.

As is indicated in Figure 9 and Table 8, dissolved oxygen levels were observed below 60% saturation on two occasions, both at Bridgetown. The Canadian dissolved oxygen water quality guideline for the protection of freshwater aquatic life is 5.5 mg/L (CCME 2002). Only two of the ninety-nine water samples analyzed by the Annapolis River Guardians in 2007 had a dissolved oxygen level below this guideline level (Bridgetown, October 1, 2.8 mg/L; Aylesford Road, July 24, 4.4 mg/L). The low dissolved oxygen observed at Bridgetown is believed to be associated with a wider pattern of depressed DO levels in the tidal section of the Annapolis River. This is discussed in further detail in Appendix D. The cause of the depressed oxygen at Aylesford is not known.

Table 8. Dissolved oxygen percent saturation (DOSAT) thresholds for Annapolis River.

Site and Site Number	Number of Samples collected in 2007	Number of Samples with DOSAT below 60%	Number of Samples with DOSAT below 75%	Number of Samples with DOSAT above 75%
Aylesford Road (AY40)	14	0	1	13
Aylesford (00)	13	0	3	10
Kingston (13)	5	0	0	5
Wilmot (18)	11	0	0	11
Middleton (25)	2	0	0	2
Lawrencetown (35)	11	0	1	10
Paradise (40)	13	0	0	13
Bridgetown (49)	13	2	5	8

Diurnal Fluctuations in Oxygen

Dissolved oxygen levels are know to fluctuate naturally through the course of the day in response to cellular activity of aquatic plants, algae and other organisms. Cellular respiration occurs continuously, consuming oxygen. Photosynthesis occurs only during daylight hours, producing oxygen. The net effect of these two processes is that dissolved oxygen levels reach a daily peak in the late afternoon, after a full day of photosynthesis, and a daily low at around dawn.

As was discussed above, Environment Canada maintains a water quality monitoring station at Wilmot, which automatically records hourly DO measurements. The Environment Canada data demonstrates that this daily, or diurnal, cycle of dissolved oxygen occurs in the Annapolis River over much of the year (May to October). During 2007, the degree of diurnal fluctuation was found to be the greatest during early August. Figure 10 presents a seven-day snapshot of this diurnal cycling. Daily peaks in DO occur at approximately 3.00 to 4.00 pm. Daily lows in DO occur at approximately 5.00 to 7.00 am. The maximum daily amplitude was in excess of 4 mg/L. The magnitude of this daily fluctuation highlights the importance of River Guardian samples being collected at a standardized time of 12.00 noon. The fact that not all samples are collected at 12.00 noon therefore represents a source of variability in the results.

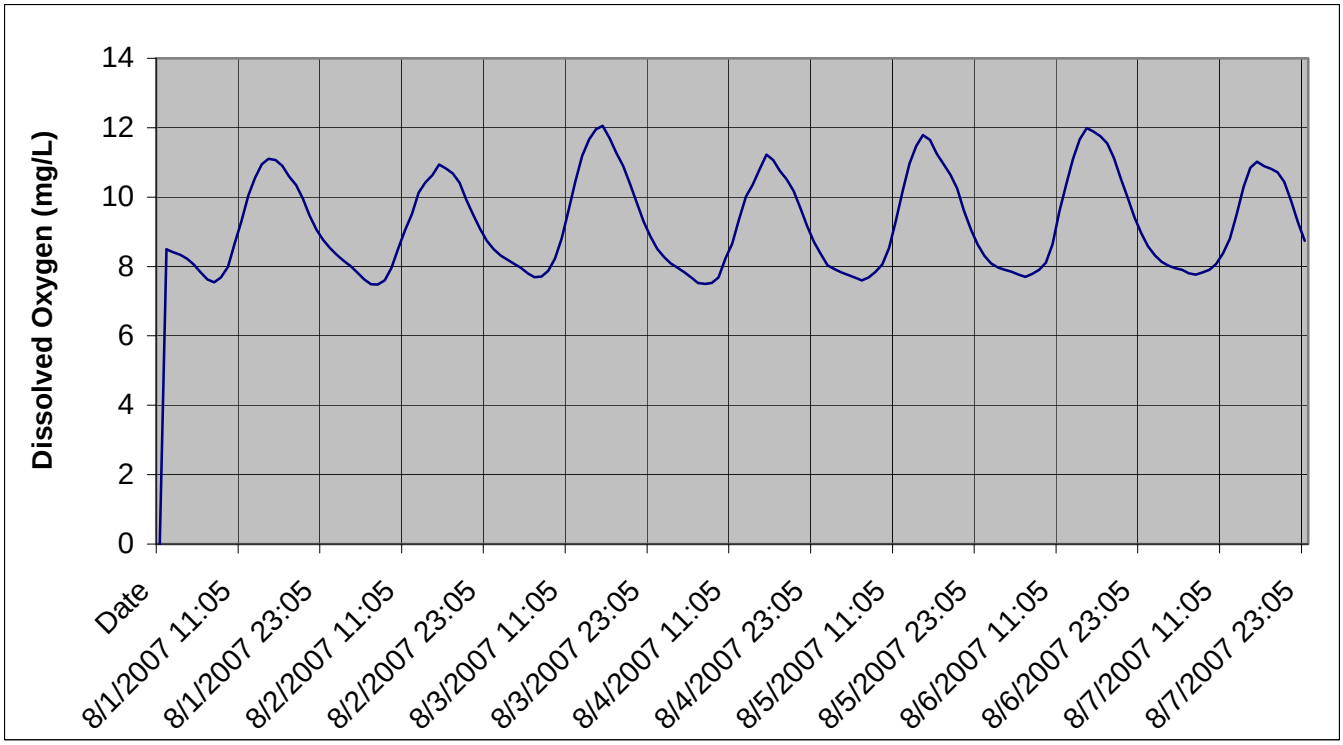

Figure 10. The natural diurnal fluctuations of dissolved oxygen, recorded on the Annapolis River at Wilmot.

Recommendations

- Continue regular River Guardian DO monitoring program at eight main river sample locations.

Additional recommendations concerning monitoring oxygen levels in the Annapolis River estuary are contained in Appendix D.

Temperature

Introduction

Water temperature, like dissolved oxygen, serves as a broad indicator of water quality. The temperature of water has a direct bearing on the aquatic species present and their abundance. For example, trout and salmon species experience stress at water temperatures in excess of 20ºC, with lethality occurring after prolonged exposures to temperatures over 24ºC (MacMillan *et al* 2005).

Monitoring Results

The mean summer water temperature for the Annapolis River in 2007 was 18.3ºC, 0.8ºC cooler than for the same period in 2006. As in previous years, water temperatures during 2007 continued to reach levels stressful to aquatic life regularly during the summer months. Figure 11 presents the mean summer water temperature (July, August, September) by year for all the mainstem monitoring sites. Figure 11 also includes the 1993 to 2007 mean summer water temperature (18.6 ºC).

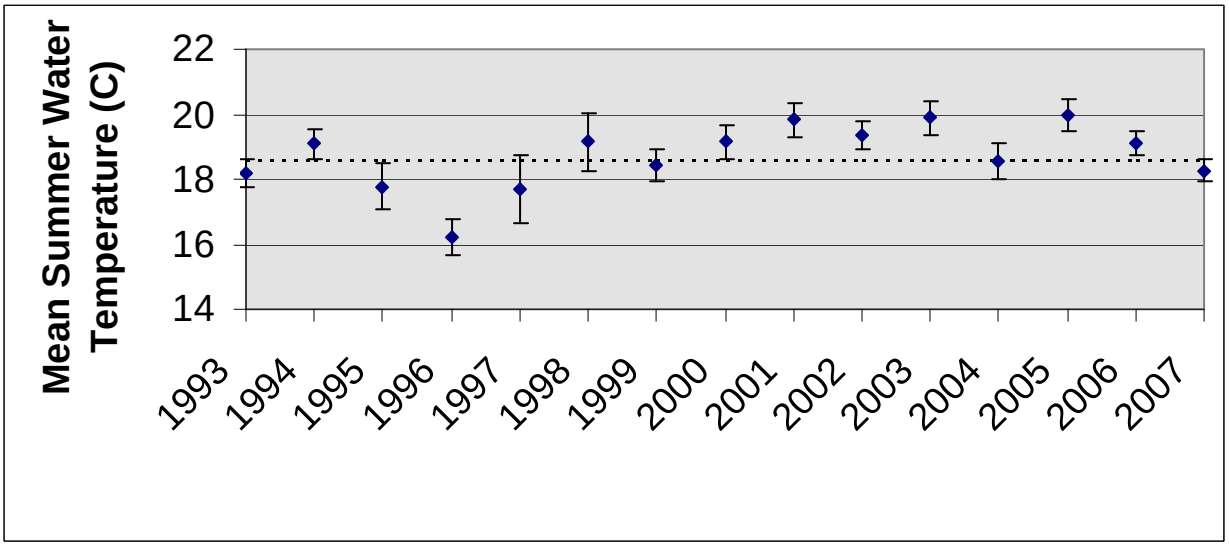

Figure 11. Mean summer water temperature by year (showing standard error of the mean) with 1993-2007 mean shown as dashed line.

The data from previous River Guardians annual reports suggested a gradual increase in temperature in the lower river sites, particularly in the summer data. Figure 12 presents the mean summer water temperature along the main Annapolis River in 2007, indicating that while the river progressively warmed from Aylesford to Lawrencetown, there was some cooling at Paradise and Bridgetown. It is unclear if the increase in temperature of water in the Annapolis River between Aylesford and Lawrencetown is due to direct warming of water within the main stem due to solar radiation, or inputs of warmer water from tributaries. Between Aylesford and Lawrencetown, a number of major tributaries (South Annapolis, Fales and Nictaux) join the Annapolis River, along with many small tributaries. Limited temperature data exists for these tributaries.

Of the 88 temperature measurements recorded during the months of July, August and September in 2007, 31% exceeded 20ºC. The maximum temperature observed was 25.4ºC, recorded at Paradise on August 6, 2007.

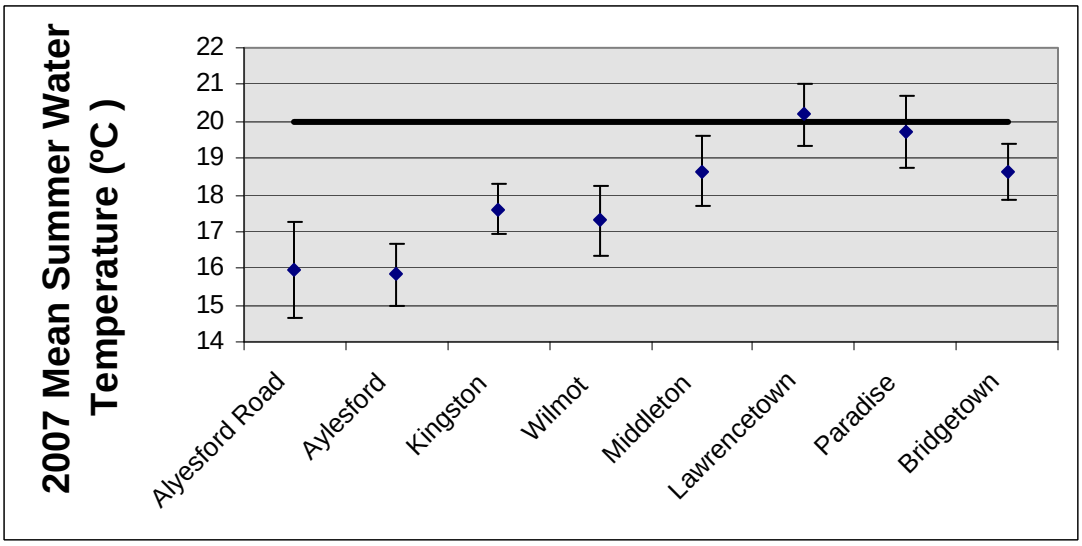

Figure 12. Mean 2007 summer water temperatures by site, with standard error of the mean and 20ºC threshold.

Recommendations

- Continue regular River Guardian temperature monitoring program at eight main river locations.
- Investigate the temperature increase on the Annapolis River between Aylesford and Lawrencetown. This may include collection of thermal status data on tributaries to the Annapolis River.
- Install temperature loggers in candidate streams to assess for fish habitat improvements.
- Temperature data loggers should be calibrated immediately prior to deployment and at least once *in situ*. These procedures should be added to the QA/QC Project Plan.

pH and Conductivity

Introduction

pH is a measure of the acidic/basic nature of water and is determined by measuring the concentration of the hydrogen ion (H^+). It is expressed on a logarithmic scale from 0 to 14, zero being the most acidic. Because the scale is logarithmic, every unit decrease in the pH scale represents a tenfold increase in acidity. To ensure the health of freshwater aquatic life, pH levels should not vary beyond the range of 6.5-9.0 (CCME, 2002). Levels below 5.0 are known to negatively affect many species of fish, including salmon and trout. pH varies naturally depending on the underlying soil type and its buffering capacity; however it can also be influenced by anthropogenic means, such as acid precipitation.

pH and conductivity were measured on the day following River Guardian collection by CARP staff using the portable HydroLab Quanta water meter (see Appendix A for more details on sampling procedure and meter calibration).

Monitoring Results

Table 9 shows that pH values all along the Annapolis River are generally good, being only very slightly acidic. In total, 125 individual pH measurements were made during 2007. The pH values are consistently well within the range recommended by the CCME for the protection of freshwater aquatic life. A number of the principal tributaries of the Annapolis River pass through the Torbrook geologic formation, which buffers rivers and streams in the watershed from acidification.

Table 9. 2007 mean pH values at each River Guardian monitoring site.

Site	Mean pH	Standard Deviation
Aylesford at Aylesford Rd. (AY40)	7.2	0.2
Aylesford at Victoria Rd. (00)	7.2	0.2
Kingston (13)	7.3	0.3
Wilmot (18)	7.2	0.4
Middleton (25)	7.2	0.4
Lawrencetown (35)	7.3	0.5
Paradise (40)	7.4	0.7
Bridgetown (49)	7.3	0.5

pH data collected from eight main river sites for 2003 to 2007, using the Quanta Hydrolab meter, are presented below (Figure 13). From the plot, there is no statistically significant year-to-year variation. During the early years of the Annapolis River Guardians program, pH was regularly measured at many of the main river sample locations. During this period, the mean pH was 6.95, based on 620 individual measurements. This historic pH is similar to that observed during the 2003 to 2007 period.

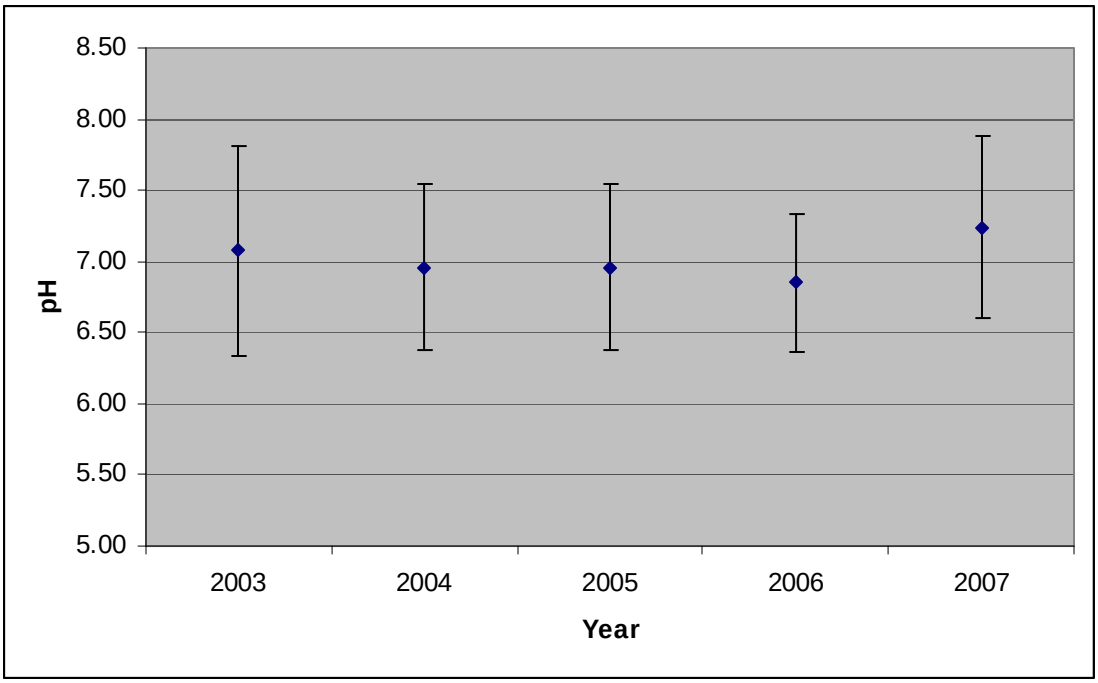

Figure 13. pH measurements from Annapolis River, 2003 to 2007, with standard error of mean.

Recommendations

- Regular pH monitoring should be continued at the eight Annapolis River Guardian monitoring locations.

Nutrients (Nitrogen and Phosphorus)

Introduction

Elevated levels of nitrate in aquatic systems can originate from a variety of sources, including domestic on-site and municipal wastewater discharges, the use of chemical fertilizers and manure on urban and agricultural land, industrial discharges, and atmospheric deposition. Nitrogen concentrations in water can be reported in a number of forms, including: nitrate, nitrate + nitrite, ammonia and dissolved inorganic nitrogen (DIN).

In a survey of 11 mainland Nova Scotia Rivers, Dalziel *et al* (1998) found the Annapolis River to have the highest silica levels, as well as elevated nitrate concentrations. These and other historic nitrogen monitoring results for the Annapolis River are shown in Table 10.

Table 10. Historic nitrogen levels in the Annapolis River.

Period	Number of Samples		Total Nitrogen	Nitrate + Nitrite-N	Ammonia	Source
			(mg/L)	(mg/L)	(mg/L)	
1992 to 1996	14	Mean		0.519	0.030	Dalziel et al, 1998
		Max		1.466	0.060	
		Min		0.151	0.012	
2004	2	Mean	0.74			CABIN, 2004[2]
2005	6	Mean	0.60			CABIN, 2005[3]

Dodds and Welch (2000) have suggested Total Nitrogen limits between 0.25 and 3.0 mg/L and DIN limits between 0.02 and 1.0 mg/L in order to limit excessive chlorophyll, periphyton and macrophyte growth in fresh water systems.

Phosphorus is an essential nutrient required by plants and animals, with phosphorus-containing organic compounds found in all living matter. Orthophosphate ($PO4^{3-}$) is the only form readily used as a nutrient by plants and organisms. Because of its low dissolved concentrations, phosphorus can be the limiting nutrient in fresh waters. Elevated phosphorus levels in surface waters can lead to algal blooms (Ironside 2001).

While phosphorus is a naturally occurring element in rocks and soils, anthropogenic sources are the predominant cause of elevated concentrations leading to impaired water quality. Anthropogenic sources include human and animal waste, atmospheric inputs, industrial waste and artificial fertilizers. A total phosphorus concentration of 0.030 mg/L is a recommended water quality guideline to avoid excessive plant growth in rivers and streams (OMEE 1994). Total phosphorus levels in excess of 0.030 mg/L are an indicator of eutrophic surface waters (Mackie 2004). Dodds

[2] CABIN, 2004 – Canadian Aquatic Biomonitoring Network protocol. Samples collected by CARP staff at Aylesford and Kingston on Annapolis River (18/10/04 and 20/10/04, respectively).

[3] CABIN, 2005 – Canadian Aquatic Biomonitoring Network protocol. Samples collected by CARP staff at Aylesford, Kingston and Paradise on Annapolis River (Samples collected 13/9/05 and 14/9/05).

and Welch (2000) have suggested Total Phosphorus limits of 0.002 to 0.07 mg/L L in order to prevent excessive chlorophyll, periphyton and macrophyte growth in fresh water systems. Historic phosphorus monitoring results for the Annapolis River are shown in Table 11.

Table 11. Historic phosphorus levels in the Annapolis River.

Period	Number of Samples		Phosphate-P	Total Phosphorus	Source
			(mg/L)	(mg/L)	
1992 to 1996	14	Mean	0.017		Dalziel et al, 1998
		Max	0.032		
		Min	0.007		
2004	2	Mean		0.055	CABIN, 2004
2005	6	Mean		0.087	CABIN, 2005
		Max		0.142	
		Min		0.043	

As part of the investigation of low dissolved oxygen levels in the lower Annapolis River in 2005 and 2006, nutrient samples were collected. A total of 15 samples were collected in the Bridgetown area during 2006. Of the 15 phosphorus samples collected in 2006, 8 (53%) were at or above the 0.030 mg/L guideline level. This compares with 10 samples (67%) exceeding the limit in 2005.

Table 12 presents nutrient results collected by Environment Canada staff at Wilmot (N = 10) and Lawrencetown (N = 9) between June 16, 2006 and June 26, 2007. Nitrate and phosphorus levels are similar to those observed in the lower Annapolis River in 2006.

Table 12. 2006/7 nutrient results for Wilmot and Lawrencetown (Environment Canada).

	Wilmot				Lawrencetown			
	Total Nitrogen (mg/L)	Nitrate (Dissolved) (mg/L)	Total Phosphorus (mg/L)	Sulphate (Dissolved) (mg/L)	Total Nitrogen (mg/L)	Nitrate (Dissolved) (mg/L)	Total Phosphorus (mg/L)	Sulphate (Dissolved) (mg/L)
Mean	0.70	0.33	0.035	6.75	0.59	0.25	0.028	6.44
Median	0.72	0.40	0.032	6.80	0.57	0.26	0.027	6.80
Minimum	0.53	0.09	0.021	3.17	0.46	0.07	0.018	3.27
Maximum	0.85	0.60	0.060	11.69	0.77	0.32	0.056	9.16

Overall, nitrogen levels in the Annapolis River, which indicate anthropogenic inputs, appear to be exceeding concentrations that may lead to adverse ecological impacts. Phosphorus, on both the main river and in the estuary, is approaching or exceeding the suggested guideline level of 0.030 mg/L. These elevated concentrations are believed to have a role in excessive periphyton growth and depression of dissolved oxygen levels in the tidal portion of the river.

Recommendations

- Conduct regular nutrient monitoring along the Annapolis River for nitrogen and phosphorus.

Recommendations

Recommendations for the River Guardians Program

- Continue regular River Guardian E.coli monitoring at the eight main river sample locations.
- Conduct simultaneous monitoring at Sites 00 and AY40, together with intervening tributary streams.
- Conduct a foot survey of the Annapolis River between these two sites and the intervening tributary streams to identify possible contamination sources.
- Review current and historic air photos of this area to identify land use changes and possible sources of contamination.
- Continue regular River Guardian DO monitoring program at eight main river sample locations.
- Investigate the temperature increase on the Annapolis River between Aylesford and Lawrencetown. This may include collection of thermal status data on tributaries to the Annapolis River.
- Continue regular River Guardian temperature monitoring program at eight main river locations.
- Install temperature loggers in candidate streams to assess for fish habitat improvements.
- Temperature data loggers to be calibrated immediately prior to deployment and at least once *in situ*. These procedures should be added to the QA/QC Project Plan.
- Regular pH monitoring should be continued at the eight Annapolis River Guardian monitoring locations.

Recommendations for CARP

- Complete the Quality Assurance Project Plan for all of CARP's Water Quality monitoring programs.

Additional Recommendations (carried forward from previous years)

- Examine the relation between observed increases in water temperature and air temperature data to determine if increases are due to climate trends, riparian changes, or other factors that may be influencing flow patterns.
- Examine in further detail the water temperature data to determine whether any statistically significant trends are occurring.
- Examine the relationship between fecal coliform levels at each site over 5-10 years and the precipitation data in order to better understand the influence from different sources (i.e. surface vs. on-site sources).

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Appendices

Appendix A – Parameters Tested and Methodologies

Parameters Analyzed in 2007	Additional Parameters Analyzed in Previous Years of the Program
E.coli bacteria densities	Salinity
Dissolved Oxygen	Chlorophyll a
Temperature (Water and Air)	Total Suspended Solids (TSS)
Weather conditions	Colour
pH, Conductivity, Total Dissolved Solids	Transparency
Nitrate, Nitrite, Ammonia, Phosphate	Nitrate-N, Chloride, Sulphate, Total Phosphate

Water Collection for Fecal Bacteria Analysis

Following the contamination of some sampling equipment in 2003, a new collection procedure for fecal coliform samples was developed and used during the 2004, 2005, 2006 and 2007 seasons. The sample collection unit is shown in Figure A1.

Figure A1. Collection Unit Used for Fecal Coliform Samples in 2007.

The open sample bottle is secured in the clamp, and lowered from the mid-span of the bridge into the river, to a depth of 1 meter. Samples are collected on the upstream side of bridges, where a safe pedestrian walkway exists. After collection, water samples are refrigerated until delivery to the lab, typically within 24 hours of collection.

Enumeration of Fecal Bacteria

Prior to the 2005 season, bacterial samples collected by Clean Annapolis River Project's Annapolis River Guardians program were tested for Fecal Coliforms (FC) using the Membrane Filtration method. During the winter of 2005, the program's Science Advisory Committee suggested that the program switch to testing for E.coli (EC) using the Most Probable Number method, to bring testing more in line with national guidelines. In order to ensure the continuity of the dataset, a period of duplicate analysis with the two methods was conducted. Duplicate samples were analysed using the two methods over a two-month period (four biweekly sample events at eight locations along the river). Analysis of the paired results indicated no significant difference between the two testing methods. Further information on the comparison of the two testing methodologies is presented in the 2005 Annapolis River Guardian Report, Appendix C, which is available at the CARP office.

All fecal bacteria samples were submitted to the Valley Regional Hospital Microbiology Laboratory in Kentville, Nova Scotia. The Valley Regional lab is recommended by the Nova Scotia Department of Environment and Labour to perform water quality analysis. From 1997 to 2003 and again since 2005, fecal bacteria densities were determined using the IDEXX Colilert procedure, to give a Most Probable Number of *E. coli* bacteria present. For the 2004 sample season, fecal coliform analysis was performed using the membrane filtration method.

Dissolved Oxygen Content

Dissolved oxygen samples are collected from the mid-span of bridges using a horizontal van Dorn sampler, at a depth of 1 meter. Dissolved oxygen in mg/L is determined using the modified Winkler titration using pre-packaged Hach reagents. The Winkler titration procedure is a widely recognized standard for determining dissolved oxygen. The procedure is reported to have an accuracy of at least +/- 1 mg/L. Dissolved oxygen as percent saturation is determined using Rawson's nomogram. Further information on the collection and analysis procedure for dissolved oxygen can be found in the Annapolis River Guardians Procedure Manual, which is available at the CARP office.

Temperature

The Annapolis River Guardians used a combination of glass/alcohol and digital thermometers during 2007. Prior to the start of the season, all thermometers were compared with the temperature reading from CARP's HydroLab Quanta water meter. This unit had recently been serviced and calibrated, with a reported accuracy of +/- 0.10 ºC. From this comparison, a correction factor was determined for each River Guardian thermometer. These correction factors were applied to all River Guardian temperature measurements.

pH and Conductivity

Water chemistry data, including pH and conductivity, was collected using CARP's portable HydroLab Quanta water quality monitoring meter. Data was collected on a fortnightly basis by CARP staff, typically the day following the volunteers' sampling day, at a set location on the riverbank at each River Guardian site. The meter was placed in the river approximately 1 to 2 meters away from the bank, and allowed to stabilize, usually two to three minutes. Once stabilized, the values were stored in the meter's memory and recorded on the data sheets upon return at the CARP office. The data is stored using an in-house Microsoft Access database. Approximately every two to three weeks, the

multi-sensor water meter was calibrated for pH, conductivity and dissolved oxygen according to the directions in the Operating Manual (Hydrolab Corporation 2002).

Procedures for Investigation of Low Dissolved Oxygen in Lower River

Weekly water samples (July 29 to November 12, 2007) were collected from the mid-span of Bridgetown bridge by van Dorn sampler, with temperature recorded and dissolved oxygen determined later by Winkler titration (Brylinsky 2000). Water samples were also collected periodically at fixed locations between Granville Centre and Bridgetown by boat, from May to October 2007. The location of sample sites was chosen to effectively cover the section of the river where depressed dissolved oxygen levels occurred in 2005 and 2006. Sample sites were situated every 3 to 5 km along the river, with all samples being collected at mid-stream.

Water quality parameters (temperature, conductivity, salinity, dissolved oxygen, pH) were recorded on-site using a Hydrolab Quanta multi-probe meter. Samples at depth were retrieved using a horizontal van Dorn sampler. Nutrient samples (Silicate, Nitrate, Nitrite, Ammonia, Phosphate) were field-filtered using Millipore glass fibre filters (Cat. No. APFC02500) and handled in accordance with Bedford Institute of Oceanography (BIO) protocols. Nutrient analysis was conducted at BIO by Colorimetric Segmented Flow using a Technicon II.

Appendix B – Sites Monitored

Water samples were collected during 2007 by the Annapolis River Guardians program at the locations shown in Table B1. Coordinates are reported in Universe Transverse Mercator (Zone 20) and Latitude/Longitude, as recorded on a hand-held GPS unit.

Table B1. Coordinates for Annapolis River Guardian sample locations.

SITE	LOCATION	Easting	Northing
AY40	Aylesford, Aylesford Road, bridge	357328.48	4987755.13
00	Aylesford, Victoria Road, bridge at the Post Office	353313.34	4985418.70
13	Kingston, Bridge Street, bridge	346748.46	4982480.39
18	Wilmot, Old Mill Road, bridge	342100*	4979500*
25	Middleton, Highway 10, bridge	336981.58	4978044.59
35	Lawrencetown, Lawrencetown Lane, bridge	329581.15	4971984.70
40	Paradise, Paradise Lane, bridge	325738.51	4970620.51
49	Bridgetown, Queen Street, bridge	318900.00	4967621.30

** coordinates determined from 1:50,000 map sheet*

Appendix C – Quality Assurance / Quality Control Data

Introduction

Following a contamination event in 2003, CARP initiated a number of procedures to ensure the quality of data collected. In addition to instituting a new collection procedure for fecal bacteria, CARP has put in place a program of regular quality control checks on sampling equipment and methods. Further information on the quality assurance/quality control (QA/QC) program can be found in CARP's draft QA/QC Project Plan (Sharpe and Sullivan 2006). An important initial step in the QA/QC program is the training of volunteers. A refresher session was held for all volunteers on April 25, 2007 at Middleton Regional High School. During the 2007 season, CARP staff conducted visits with the Annapolis River Guardian volunteers on collection days in order to both collect a series of blank and split samples, as well as to ensure the consistency in collection procedures. In total, eighteen QA/QC samples were collected during the 2007 season. These were, in summary:

- 6 Dissolved oxygen split samples
- 3 E.coli travel blanks
- 2 E.coli field blanks
- 7 E.coli split samples

Background

For the purposes of CARP's water quality monitoring programs, a blank sample is one filled with water that is known not to contain any of the substance in question. For CARP's monitoring of E.coli bacteria, either distilled or un-chlorinated tap water is added to the sample bottle. Over the 2007 season, two different types of blanks were collected: travel blanks and field blanks.

- Travel blanks are obtained by filling the sample bottle with distilled/tap water before the start of a sampling day, and placing them in the same cooler among other surface water samples. Travel blanks are used to ensure there is no cross contamination between samples while they are being transported in the same cooler and should always produce plates with no fecal bacteria growth.
- Field blanks are obtained by performing the entire sampling protocol (i.e.: attaching the bottle to the clamp, and lowering the apparatus to the water surface) but NOT submerging the bottle. The bottle is instead lifted up empty and filled with distilled/tap water on the bridge. This type of blank sample is used to test the sampling procedure and should also always produce plates with no fecal bacteria growth. A positive result on a field blank would lead to further investigations to determine the source of contamination (ie: operator, equipment, distilled water, etc).

Split samples are used to measure both precision and accuracy. Precision is expressed as the degree of agreement among repeated measurement of the same parameter and provides information on the reproducibility and consistency of the methods used. Accuracy, on the other hand, consists of how close a measurement is to the "true" value.

A split sample is single sample volume that is divided in two samples that are analysed separately. Split samples can provide information on the precision of the lab method (i.e.: the precision of Valley

Regional Hospital's E.coli analysis). Split samples can also provide information on the accuracy of the method used (i.e.: the accuracy of volunteers at the Winkler titration).

The degree of variability between two split samples can be evaluated by calculating their relative percent difference (RPD). The RPD is expressed as the absolute difference of the two measurements multiplied by 100 and divided by the average of the two values:

$$RPD = \frac{|X_1 - X_2| \times 100}{(X_1 + X_2) / 2}$$

When more than two samples are to be compared, the degree of variability is estimated by calculating their Relative Standard Deviation (RSD). Both the RPD and the RSD are expressions of precision. The smaller the value, the greater the precision.

$$RSD = \frac{s}{X_m} X\ 100$$

s = standard deviation
X_m = mean of duplicate samples

Accuracy is estimated by taking the absolute difference between the "true" value and the "test" value. When there are multiple measurements, the true value is subtracted from the average of the test measurements. The result is compared to acceptable accuracy standards for each individual method.

Accuracy = Test/Average value – True Value

Dissolved Oxygen

Dissolved oxygen split samples were taken in 2007 using a single volume of water from a van Dorn sampler. The accuracy of volunteer DO measurements was assessed through the collection of six split samples. The Winkler titration (described in Appendix A) is widely recognized has a standard for determining dissolved oxygen and is reported to have an accuracy of at least +/- 1 mg/L. Results from the split samples shown below in Table C1, indicate that the volunteers attain an average accuracy of +/- 0.003 mg/L (RPD = 9%). For comparison purposes, the average DO accuracy during 2006 was +/- 0.6 mg/L (RPD = 6%).

Table C1. Volunteers' level of accuracy at measuring dissolved oxygen using the Winkler titration.

Site	Date	Volunteer Result	True DO Result*	Accuracy	Relative Percent Difference
13	06-Aug-07	8.92	7.12	-1.8	22.4
00	14-Oct-07	9.05	9.03	-0.02	0.2
40	14-Oct-07	11.19	11.69	0.5	4.4
18	14-Oct-07	11.0	10.4	-0.6	5.6
35	14-Oct-07	9.55	10.15	0.6	6.1

49	28-Oct-07	9.2	10.5	1.3	13.2
			Mean	**-0.003**	**8.7**

* The 'True' DO value was determined by calculating an average of three Winkler titrations, performed by CARP staff.

E.coli Bacteria

Throughout the sampling season, a series of blank samples were submitted blind for analysis to the microbiology laboratory at Valley Regional Hospital. The three travel blanks analysed had coliform counts of 0, 0 and 5 cfu/100ml. The single travel blank sample with 5 cfu/100 ml may have been the result of limited cross-contamination between samples in the cooler or contamination of the test water used. The two field blanks collected showed no E.coli growth, indicating that the fecal bacteria sample collection procedure was not contaminating the samples.

Throughout the 2007 sampling season, a total of seven split samples were collected during the sampling visits with the volunteers. These samples were submitted to the Valley Regional Hospital Microbiology Laboratory under a fictitious sample identification number. The purpose of this was to assess the reproducibility of the E.coli MPN analysis method used. The results of this are presented in Table C2. The mean RPD for these split samples was found to be 42.5%. The mean RPD for the 2005 and 2006 seasons was 14.2% and 15.5%, respectively.

Between 2005/6 and 2007, a significant increase in the relative percent difference of E.coli split samples was observed. A principle change occurring between the 2006 and 2007 sampling seasons was the switch from the Synova Diagnostics Laboratory in Lawrencetown to the Microbiology Laboratory at Valley Regional Hospital. This change was undertaken as the Synova Laboratory was no longer able to conduct the analysis. Both laboratories use the same testing system, the Colilert Most Probable Number methodology. Beyond laboratory-specific techniques, there have been no other obvious changes in field procedures between the two seasons.

Table C2. Relative percent difference in duplicate samples analysed for fecal coliforms.

Site	Date	Volunteer Result E.coli MPN (cfu/100 ml)	QA/QC Result E.coli MPN (cfu/100 ml)	Relative Percent Difference (RPD)
13	06-Aug-07	154	147	4.7
25	01-Oct-07	118	157	28.4
00	14-Oct-07	1733	>2419	N/A
40	14-Oct-07	91	53	52.8
18	14-Oct-07	172	93	59.6
35	14-Oct-07	53	30	55.4
49	28-Oct-07	43	75	54.2
			Mean	**42.5**

Appendix D – Investigation of Low Dissolved Oxygen Levels in Lower Annapolis River

Low dissolved oxygen (DO) levels observed at Bridgetown in 2004, 2005 and 2006 prompted a more in-depth study of the lower Annapolis River in 2007. The information reported here supplements findings from the 2006 field season, reported separately (Report on the Investigation of Low Dissolved Oxygen Levels in the Annapolis River Estuary, Andy Sharpe, CARP, March 2007). This report is available at the CARP office or www.annapolisriver.ca

Monitoring of the tidal section of the Annapolis River was undertaken between May 28 and November 12, 2007, with samples being collected by boat and from the midspan of the Bridgetown bridge. Sample collection and analysis procedures used were the same as those used in 2006, and are described in the March 2007 report.

The study area is identified in Figure D1, with specific sample locations and adjacent communities identified in Figure D2.

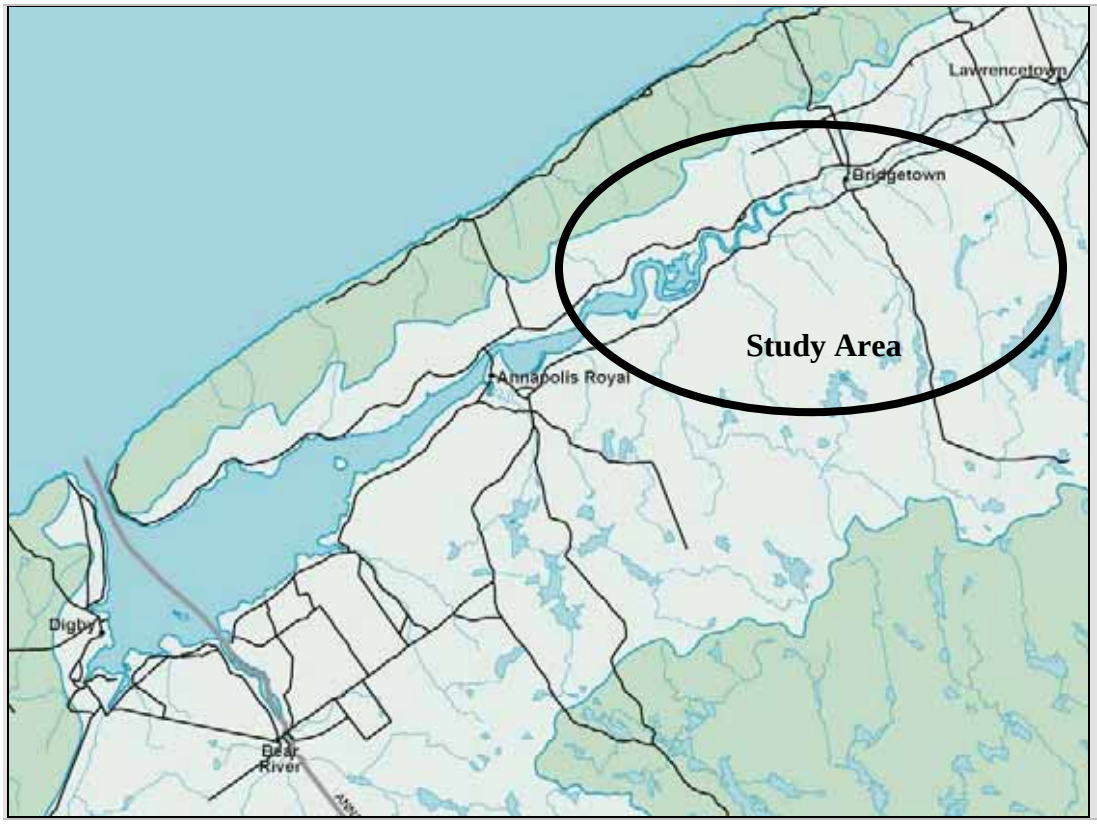

Figure D1. Study area locator map.

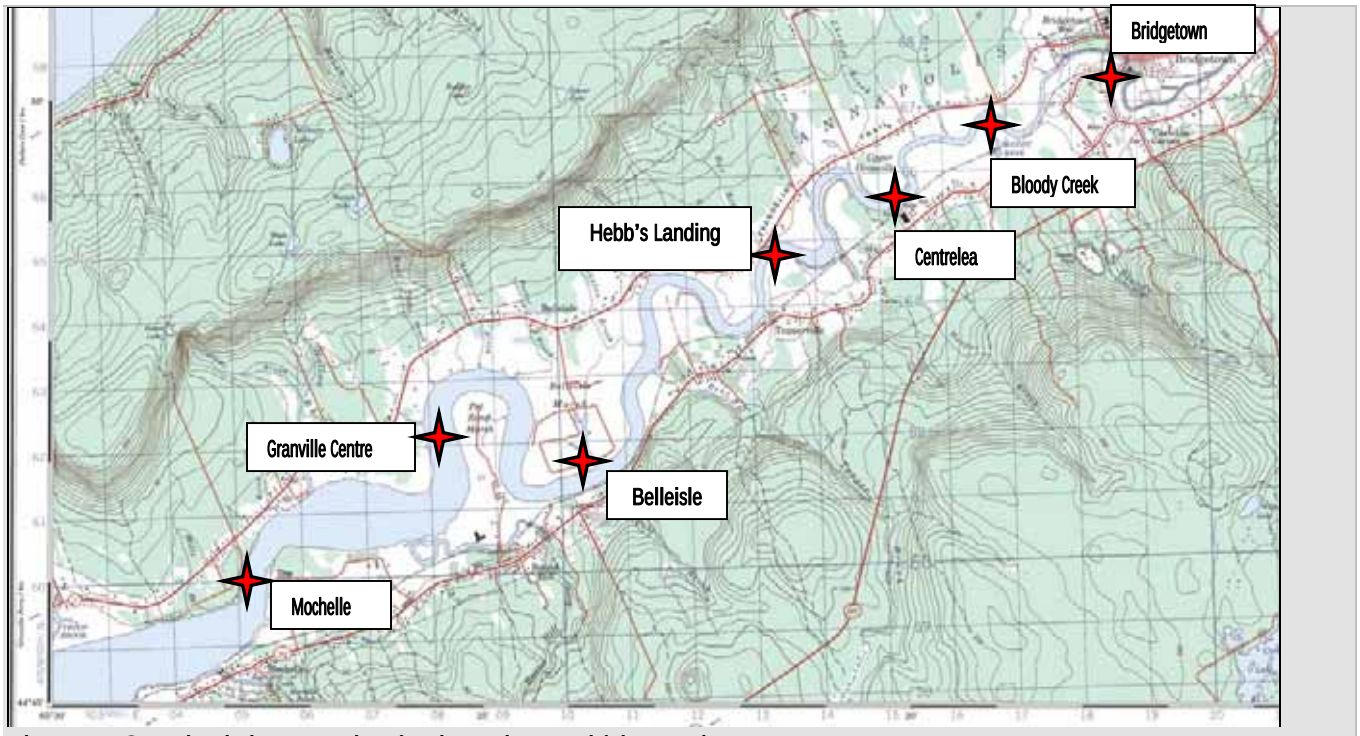

Figure D2. Principle sample site locations within study area.

The objectives of the 2007 sampling effort were:

- To determine if low dissolved oxygen levels were observed during a period when the Annapolis Royal tidal generating station was operating under normal conditions, and
- If low DO levels were observed, over what geographic and spatial extent did they occur.

Stratification

The Annapolis River was observed to exhibit stratification between May and October 2007, over the section lying between Hebb's Landing to near Bridgetown. The river in this zone was found to have a wedge of saline water lying below the outflowing (lower salinity) water. Within this zone, the thermocline[4] and halocline[5] were found to be closely associated, lying at a depth of 1.5 to 2.0 m. The temperature and salinity gradients were found to disappear at about 32 km above the causeway (between Bridgetown and Paradise). Similar observations were recorded by Jessop (1976), Daborn *et al* (1982) and Sharpe (2007). The lateral location of the salt wedge zone was found to be highly responsive to precipitation events and river discharge.

Dissolved Oxygen Levels

Dissolved oxygen (DO) levels in the tidal section of the Annapolis River in 2007 were observed to follow a pattern similar to that in 2006, with levels decreasing progressively to reach a minimum in late summer, followed by a rebound in the early autumn (Figure D3). For the samples collected by boat, the Hydrolab Quanta meter was used, allowing simultaneous recording of the water's specific

[4] Thermocline – the layer of water within the river where an abrupt change in temperature occurs.
[5] Halocline – the layer of water within the river where an abrupt change in salinity occurs.

conductivity. No conductivity measurements were made of the samples collected at the Bridgetown bridge. These results though are included in Table D3 to illustrate the range of DO values observed.

The lowest DO values observed in 2007 occurred on August 28: 0.24 mg/L (Bridgetown Railway Bridge), 0.32 mg/L (Jubilee Park, Bridgetown) and 0.60 mg/L (Bloody Creek). The three samples were collected near the bottom at depths of 2.7 m to 3.4 m and in water having a specific conductivity of 30 to 35 mS/cm (water of near marine origin).

The geographic extent of observed DO values less than 5 mg/L extended from near the Britex Plant at Centrelea upstream to near the former railway bridge at Bridgetown, a distance of approximately 6 km. Many of the depressed DO values recorded in 2006 and 2007 were recorded in this same stretch of the river. The temporal extent of depressed DO values appeared to be shorter in 2007 than that observed in previous years.

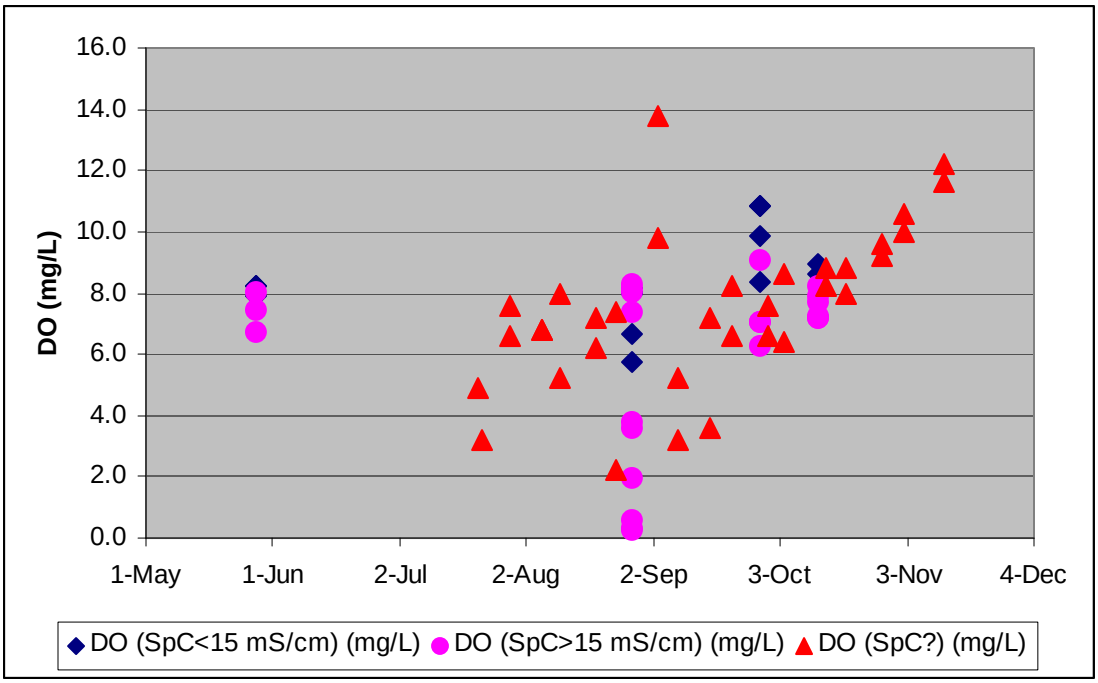

Figure D3. Dissolved oxygen in the lower Annapolis River, sorted by specific conductivity.

Nutrient Samples

A total of 68 nutrient samples were collected at various locations and depths in 2007. These samples have been forwarded to the Bedford Institute of Oceanography for analysis of nitrate, nitrite, ammonia, silica and phosphate. At the time of writing, these analysis results were not available.

Discussion

Sharpe (2007) suggested a number of factors that may contribute to the depression of DO levels, including:

- The natural geometry of the lower Annapolis River, together with its partial barrier from the Annapolis Basin due to the causeway at Annapolis Royal,
- The disruption of regular tidal flushing through the causeway due to planned maintenance on the Tidal Generating Station, and
- Strong thermal and haline stratification, with low freshwater discharge during summer months, upstream nutrient inputs, elevated summer water temperatures with lower dissolved oxygen saturation and stratification extending upstream.

Monitoring conducted during 2007 confirmed that the tidal section of the Annapolis River experienced depressed DO levels below the halocline, similar to that observed in 2006, 2005 and possibly 2004. The Tidal Generating Station experienced normal operating conditions in 2007, allowing tidal flows into the lower Annapolis River twice daily. Although the duration of the 2007 low DO event may have been slightly shorter than the event in 2006, there is insufficient data to confirm this. From these data, it appears as though the natural morphology of the river coupled with the residual effect of the Annapolis Royal causeway and elevated upstream nutrient inputs may be the driving factors in the seasonal depression of DO levels.

Although the seasonal depression of DO levels in the tidal section of Annapolis River may result in significant impacts on aquatic life, there do not appear to be any immediate fixes that can be undertaken to address the situation. Of the three driving factors (river morphology, causeway, and upstream nutrient inputs), the latter is the only one upon which action can be easily initiated. CARP has had, and is continuing with, a long-term initiative to reduce both point and non-point nutrient sources. Some of these activities have included:

- Working with municipalities to ensure sewage treatment plants are working effectively. CARP worked with the Town of Annapolis Royal to develop an engineered wetland for tertiary sewage treatment. Middleton and Bridgetown are currently considering the construction of engineered wetlands.
- Working with rural households, through the Environmental Home Assessment Program, to ensure that on-site septic systems are working effectively.
- Working with farmers to exclude livestock from waterways and re-establish riparian buffers.

Based on the observations of low DO levels in 2005, 2006 and 2007, it is recommended that these and related activities that address point and non-point sources of nutrient inputs to the Annapolis River be continued.