Report on the Investigation of Low Dissolved Oxygen Levels in the Annapolis River Estuary

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Executive Summary

Water quality monitoring was conducted on the lower Annapolis River (Bridgetown to Annapolis Royal) between April 9 and November 1, 2006, to investigate the depression of dissolved oxygen levels. During the summer and early autumn of 2006, water below the halocline of the Annapolis River estuary was found to have depressed levels of dissolved oxygen (DO). Using a variety of sampling and analysis methods, dissolved oxygen in the underlying saltwater was found to be in the range of 2 to 5 mg/L, with a lowest recorded value of 1.5 mg/L, on October 5, 2006. The zone of oxygen depleted saltwater below the halocline was found to extend from at least 1 km above the Town of Bridgetown to at least 20 km downstream. The DO levels observed are well below the national and provincial water quality guidelines for the protection of aquatic life. DO levels observed are sufficiently low to cause stress, displacement or death of aquatic life.

Based on available information, the following causative factors are proposed to explain the seasonal depression of dissolved oxygen below the halocline:

- The natural geometry of the lower Annapolis River, together with its partial barrier from the Annapolis Basin due to the causeway, coupled with,
- 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.

It is felt that these factors lead to phytoplankton growth in the euphotic zone, followed by sinking and decay below the halocline. The strong stratification limits the replenishment of DO in the salt water due to mixing, resulting in a progressive depletion of DO during the summer. High autumn river discharges, high wind velocities and decreased water temperatures lead to a break-down of the stratification with mixing and re-oxygenation of the deeper waters within the estuary during the autumn and winter.

Acknowledgements

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The following individuals have provided input on study design, sampling methodology, data analysis and review of the final report:

- Ronald Jones, P. Eng., Bridgetown
- Drs. Anna Redden and Mike Brylinsky, Acadia Centre for Estuarine Research, Acadia University
- Dr. Phillip Yeats, Department of Fisheries and Oceans
- Dr. Murray Charlton, National Water Research Institute, Environment Canada
- Michael Allen, Nova Scotia Power

This work has been possible through the significant contribution by Ronald Jones, in the collection of weekly dissolved oxygen profiles at Bridgetown.

Introduction

Over the past 15 years, Clean Annapolis River Project (CARP) has undertaken a number of water quality monitoring programs, including the Annapolis River Guardians, on the Annapolis River and its tributaries. These programs have sought to assess the status and trends in water quality on the Annapolis River, while identifying and remediating sources of contamination.

The Annapolis River above Annapolis Royal is tidally influenced, with the effect of the tides reaching as far as Paradise, a distance of approximately 42 km. The region of the river immediately above the causeway and tidal generating station at Annapolis Royal is well mixed and vertically homogeneous, due to the turbulent flow through the sluice gates twice daily. Above this region, the river becomes a two-layered salt-wedge type estuary, with fresh to brackish water overlying salt water. The stability of this stratification has been found to be highly variable, being influenced by river discharge, tidal flow, and the occurrence of storm and high wind events (Daborn *et al* 1982).

Objectives of 2006 Monitoring Activities

1. To understand the spatial and temporal occurrence of dissolved oxygen (DO) depletion in the lower Annapolis River.
2. To identify possible causative and/or driving factors for this depletion.

Study Area

The study area is identified in Figure 1, with specific sample locations and adjacent communities identified in Figure 2. Specific information on sample locations is presented in Appendix A.

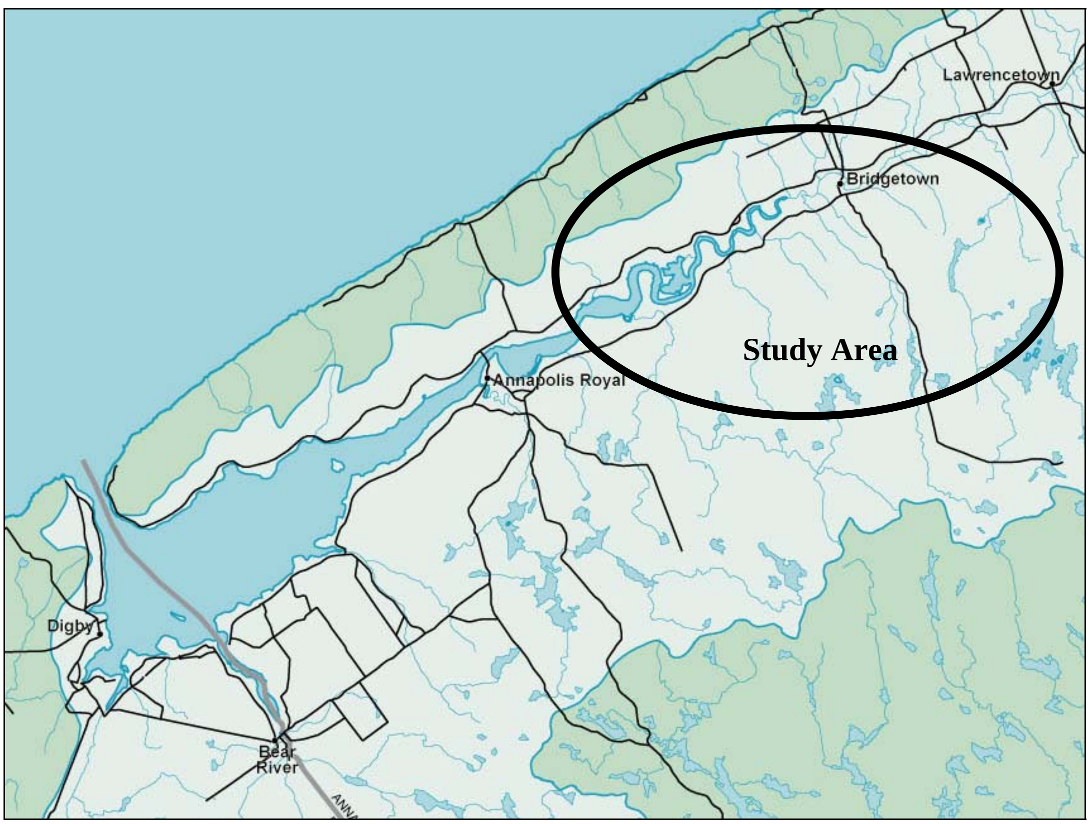

Figure 1. Study area locator map.

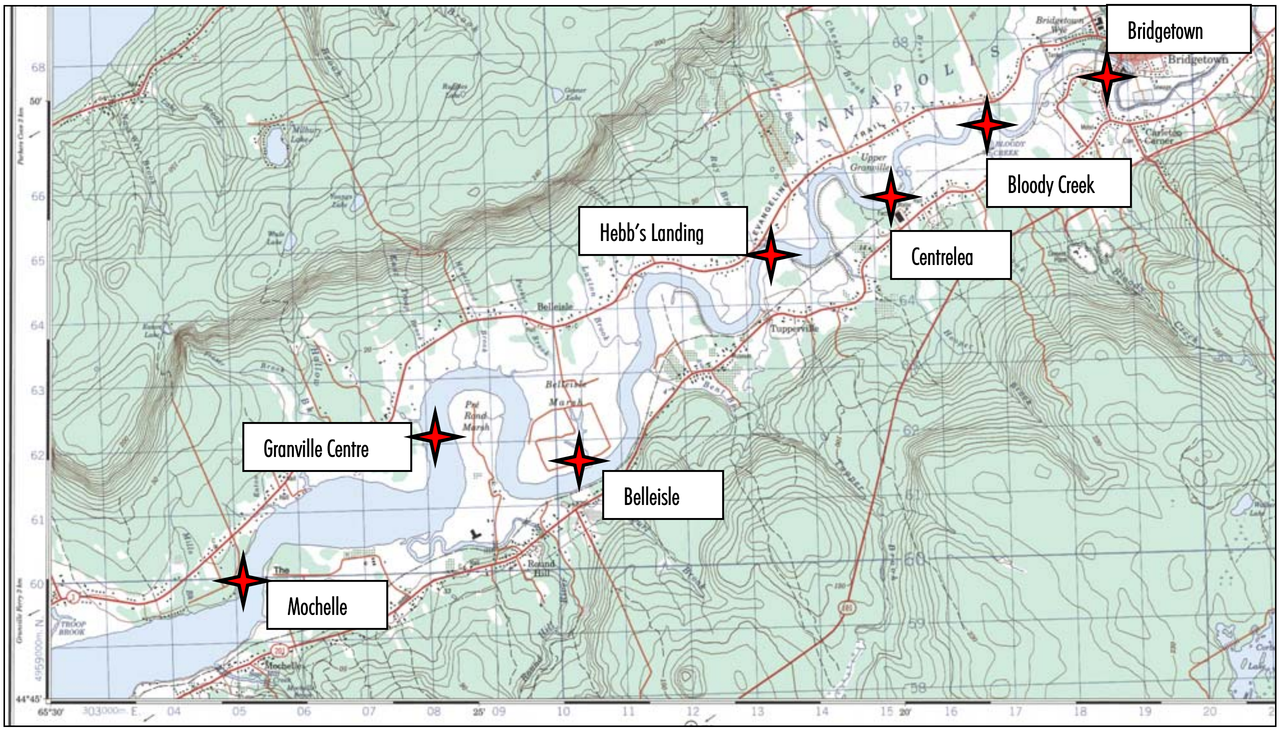

Figure 2. Principle sample site locations within study area.

Materials and Methods

Weekly water samples (April 9 to October 29, 2006) 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 at fixed locations between Granville Centre and Bridgetown every three to four weeks by boat, from June to November 2006. The location of sample sites was chosen to effectively cover the section of the river where depressed dissolved oxygen levels occurred in 2005. 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. Chlorophyll A samples were collected into opaque bottles and refrigerated until filtering with Millipore 0.45 um (Cat. No. HAWP04700) filter papers. Subsequent processing was conducted according to Wetzel (1990), using an Ultrospec II spectrometer. Turbidity samples were refrigerated and analysed using a Hach 2100P Turbidimeter. 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 protocols. Nutrient analysis was conducted at the Bedford Institute of Oceanography by Colorimetric Segmented Flow using a Technicon II. Further information on quality control measures used are contained in Appendix B.

Results

<u>Historic Stratification of Estuary</u>

Jessop (1976) conducted a physical survey of the Annapolis River following the construction of the causeway at Annapolis Royal, but prior to the installation of the tidal generating station. The river between the causeway and Bridgetown was observed to be a highly stratified estuary, with a wedge of saline water lying below the outflowing (lower salinity) water.

Beyond the 10 km mark upriver of the causeway, the thermocline[1] and halocline[2] 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).

Daborn *et al* (1982) conducted an ecological study of the lower Annapolis River and Basin, immediately prior to the installation of the tidal generating station. The lower river was found to be highly stratified, with pycnocline[3] occurring at a depth of 2 to 4 m. Dissolved oxygen levels in the Annapolis River immediately above the causeway were found to be in the range of 75 to 100% saturation, over the period of May to November. Dissolved oxygen monitoring was not conducted further upstream.

2006 Results

Wherever possible during the 2006 monitoring season, the depth of the halocline was recorded by slowly lowering the salinity probe at midstream and recording the depth were the rapid transition from fresh to saline water occurred. The transition zone between fresh and saline water was typically quite narrow, in the order of 0.1 to 0.3 m. On a number of occasions, strong river currents prevented the recording of the halocline depth as the probe was carried downstream of the anchored boat. For 33 observations, the mean depth of the halocline was 1.70 m (Standard Error 0.13 m, Minimum 0.8 m, Maximum 4.3 m). The lateral location of the halocline was highly responsive to river discharge, being pushed downriver following heavy rains and advancing upriver during dry periods with reduced river flow.

During the period of June to October 2006, the Annapolis River was found be consistently stratified (i.e. were a clear thermocline and halocline was observed). The stratification typically ranged from Hebb's Landing to near Bridgetown (20 to 30 km, respectively, above the Annapolis Royal causeway). On September 29, the stratification was observed to extend further upstream, to near the Hwy 101 Bridge (34 km above causeway). On October 5, stratification was found to extend further downstream to Mochelle, approximately 12 km from the causeway.

Temporal Pattern of Dissolved Oxygen in Above and Below the Halocline

Monitoring conducted in 2006 indicated that dissolved oxygen levels fell progressively through the late summer, reaching a minimum in early October. The lowest dissolved oxygen value (1.5 mg/L) was recorded on October 5 at Mochelle, at a depth of 4 m. Figure 3 below summarizes the mean monthly dissolved oxygen values for both the freshwater and saltwater components of the estuary. Error bars denote standard error around the mean.

The last sample collection day for the 2006 season (November 1) followed a period with significant rainfall, with increased river discharge observed. It is possible the vigorous mixing due to increased discharge, coupled with falling surface temperatures, may have lead to a breaking down of the stratification and the introduction of oxygenated surface water into the underlying salt water. No further sampling was conducted in the autumn of 2006 due to poor weather.

[1] Thermocline – the layer of water within the river where an abrupt change in temperature occurs.
[2] Halocline – the layer of water within the river where an abrupt change in salinity occurs.
[3] Pycnocline – a layer of rapid change in water density with depth, mainly caused by changes in water temperature and salinity.

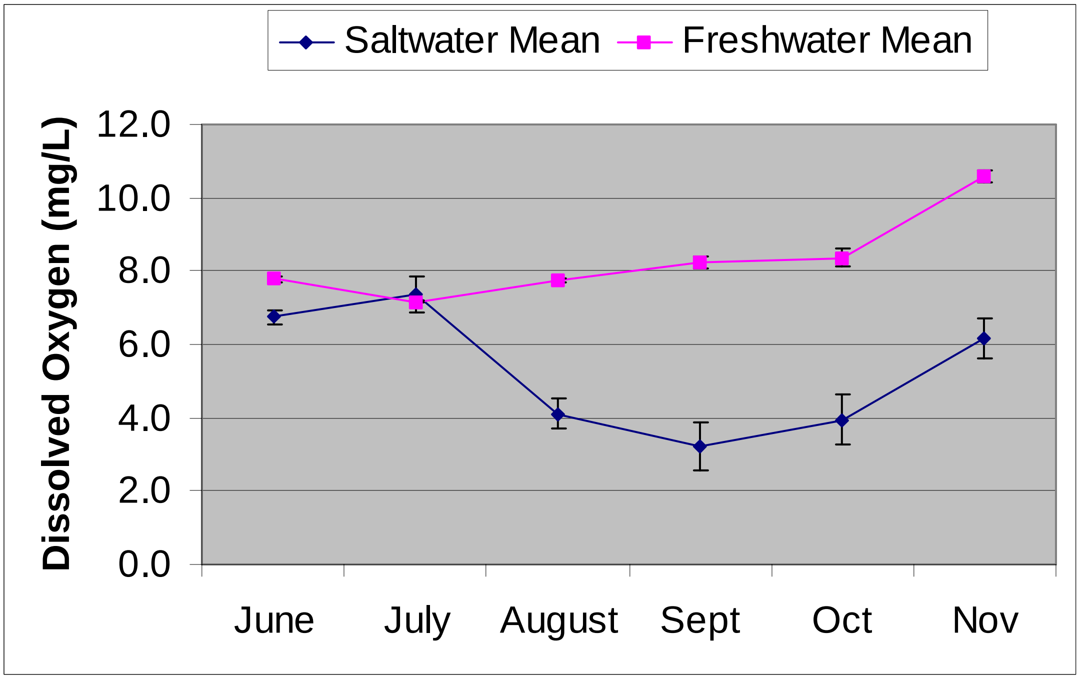

Figure 3. Temporal pattern of dissolved oxygen in lower Annapolis River.

A similar pattern of dissolved oxygen depletion occurred in 2005. At sample locations from Bridgetown to Centrelea, a sharp stratification occurred between the overlying freshwater and the underlying saltwater. This stratification occurred at a depth of between 1.3 and 1.7 m. For these locations, the mean DO during September 2005 from 17 samples below the halocline was 3.52 mg/L. The lowest DO value recorded in 2005 was 1.69 mg/L on September 15. The overlying fresh water at these locations had a mean DO of 8.15 mg/L.

It is interesting to note that on September 6, 2004, a single low DO value of 4.80 mg/L was reported at Bridgetown. This report was followed up by additional DO measurements being taken from shore using a portable water meter. All subsequent DO readings were found to be acceptable. It is possible that a similar low-DO event was occurring in the Annapolis River in the late summer of 2004, but because additional sampling was only conducted from shore in water <1 m deep, the event was not identified.

The Canadian Water Quality Guidelines recommend dissolved oxygen levels in the range of 5.5 to 9.5 mg/L for the protection of freshwater aquatic life, and greater than 8.0 mg/L for the protection of marine aquatic life. The Ministry of Environment (British Colombia) Water Quality Guidelines suggest an instantaneous DO minimum of 5 mg/L and a 30 day minimum mean of 8 mg/L, for the protection of fresh, marine and estuarine life. The DO levels observed in August, September and October 2006 in the Annapolis River estuary are well below the minimum levels suggested by these guidelines and have the potential to cause stress, displacement or death of aquatic life.

Chlorophyll A and Phaeophytin

As expected, Total Chloropigment (Chlorophyll A + Phaeophytin) peaked during mid summer, in the range of 5 to 10 ug/L (July 1st = Julian Day 182) (Figure 4). Total Chloropigment values in this range are consistent with a moderately enriched system. The highest Total Chloropigment value (22.9 ug/L) was recorded on July 10, 2006 in the Annapolis River headpond, approximately 5 km above the Annapolis Royal causeway, at a depth of 0.3 m.

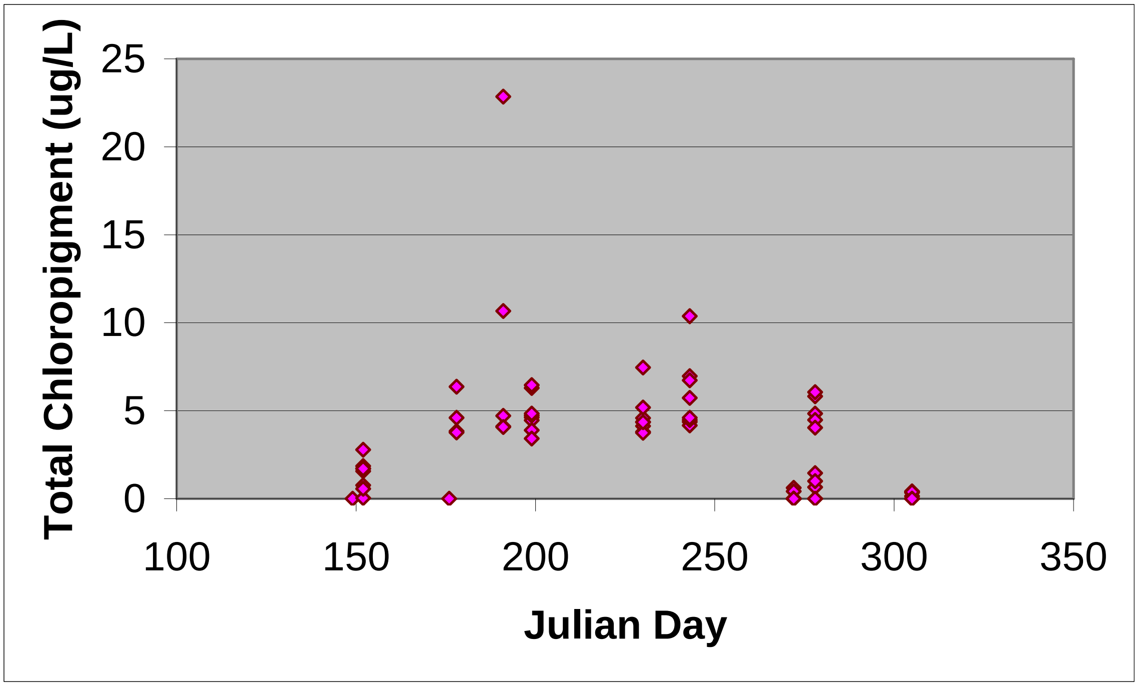

Figure 4. Total Chloropigment by Julian Day.

Appreciable quantities of Phaeophytin were recorded during the sampling season. It is unclear if the Phaeophytin was present in the water column at the time of sample collection or was produced during sample handling. The mean Chlorophyll A/Phaeophytin ratio was 0.96, Standard Deviation 3.3.

<u>Nutrient Inputs to Estuary</u>

During each boat-based sampling cruise, samples were collected at the upriver (n = 15) and downriver (n = 13) ends of the stratified zone. The purpose of this was to gain an understanding of the landward and seaward inputs into this zone. The respective ends of the stratification, and hence sample locations, were determined with the use of on-site conductivity measurements.

The following nutrient and chlorophyll data (Table 1) was segregated as follows:

- Freshwater: (>25 km from Annapolis Royal causeway), Conductivity <0.5 mS/cm
- Saltwater: (<21 km from Annapolis Royal causeway), Conductivity >30 mS/cm, (corresponds to salinity >18 pss)

Table 1. Chloropigment and nutrient concentration in freshwater and marine inputs to the lower Annapolis River.

	ChlA (ug/L)	Phaeo (ug/L)	DIN (uM)	Nitrate (uM)	Nitrite (uM)	Ammonia (uM)	Silica (uM)	Phosphate (uM)
Freshwater								
Mean	**0.721**	**2.183**	**22.00**	**18.26**	**0.246**	**3.507**	**20.78**	**0.304**
Standard Error	0.259	0.596	1.87	1.09	0.017	1.343	1.81	0.036
Median	**0.337**	**2.038**	**18.15**	**16.74**	**0.260**	**1.293**	**19.41**	**0.306**
Standard Deviation	1.002	2.308	7.23	4.23	0.066	5.201	7.02	0.141
Minimum	0.000	0.000	15.65	13.10	0.146	0.000	7.71	0.105
Maximum	2.808	6.296	36.53	27.38	0.367	15.705	36.40	0.715
Saltwater								
Mean	**1.642**	**2.921**	**16.25**	**7.35**	**0.579**	**8.374**	**32.98**	**1.154**
Standard Error	1.043	0.840	2.41	1.03	0.085	1.717	2.39	0.126
Median	**0.000**	**2.560**	**17.31**	**7.21**	**0.447**	**7.728**	**33.72**	**1.254**
Standard Deviation	3.762	3.029	8.70	3.73	0.307	6.189	8.63	0.454
Minimum	0.000	0.000	4.57	1.14	0.281	0.000	21.34	0.212
Maximum	13.488	9.370	32.09	14.33	1.247	16.515	49.10	1.713

Freshwater inputs to the Annapolis River estuary were found to have higher levels of Dissolved Inorganic Nitrogen (DIN) (Nitrate + Nitrite + Ammonia) than seawater, principally due to elevated nitrate concentrations. For the freshwater inputs, the DIN to Phosphate ratio is 72, indicating that phosphorus may be limited. Seawater inputs exhibited a DIN to Phosphate ratio of 14, very close to the Redfield ratio of 16:1. Seawater inputs into this system had higher ammonia, silica and phosphate concentrations than freshwater inputs.

For comparison, the following literature values (Table 2) are presented.

Table 2. Literature nutrient data.

Reference	Waterbody	Period	DIN	Nitrate	Nitrite	Ammonia	Silica	Phosphate
			(uM)	(uM)	(uM)	(uM)	(uM)	(uM)
Dalziel *et al*, 1998	Annapolis River, mean, (n=14)	1992 to 1996	38.84	37.06[4]		1.781	23.67	0.540
Keizer *et al*, 1996	Annapolis Basin, (n = 78)	1988 to 1994		1 to 10		0 to 5	2 to 12	0.5 to 1.0

In the 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. While slightly lower silica and nitrates levels were observed during the 2006 sampling program, the concentrations in the freshwater inputs to the estuary were still higher than those observed in saltwater.

The 2006 concentrations of ammonia, silica and phosphate were greater than the range observed by Keizer *et al* (1996) in the 1988 to 1994 survey of the Annapolis Basin. Keizer found ammonia to exhibit a pattern of lower concentrations in the spring and early summer, with higher and more variable concentrations in the autumn. Silica concentrations were found to vary seasonally, with fall and winter concentrations in the range of 6 to 9 uM and summer concentrations at less than 4 uM. Phosphate concentrations were found to have a seasonal pattern, with higher concentrations, approaching 1

[4] Nitrate + nitrite

uM in the winter, and lower concentrations, about 0.5 uM, in the summer. Significant interannual variations were also observed.

Figure 5 presents Dissolved Inorganic Nitrogen (DIN) and Phosphate data for the Annapolis Basin collected by Keizer et al (1996) between 1989 and 1994 in the Annapolis Basin below the causeway. Dr. Philip Yeats of Bedford Institute of Oceanography has shown that these data follows a predictable annual pattern, which closely follows the Redfield ratio, outlined as the rectangle and straight lines. These data have been overlain with samples collected in 2006 by CARP on the lower Annapolis River. All of the CARP samples (shown as circles and squares with crosses) were collected above the Annapolis Royal causeway.

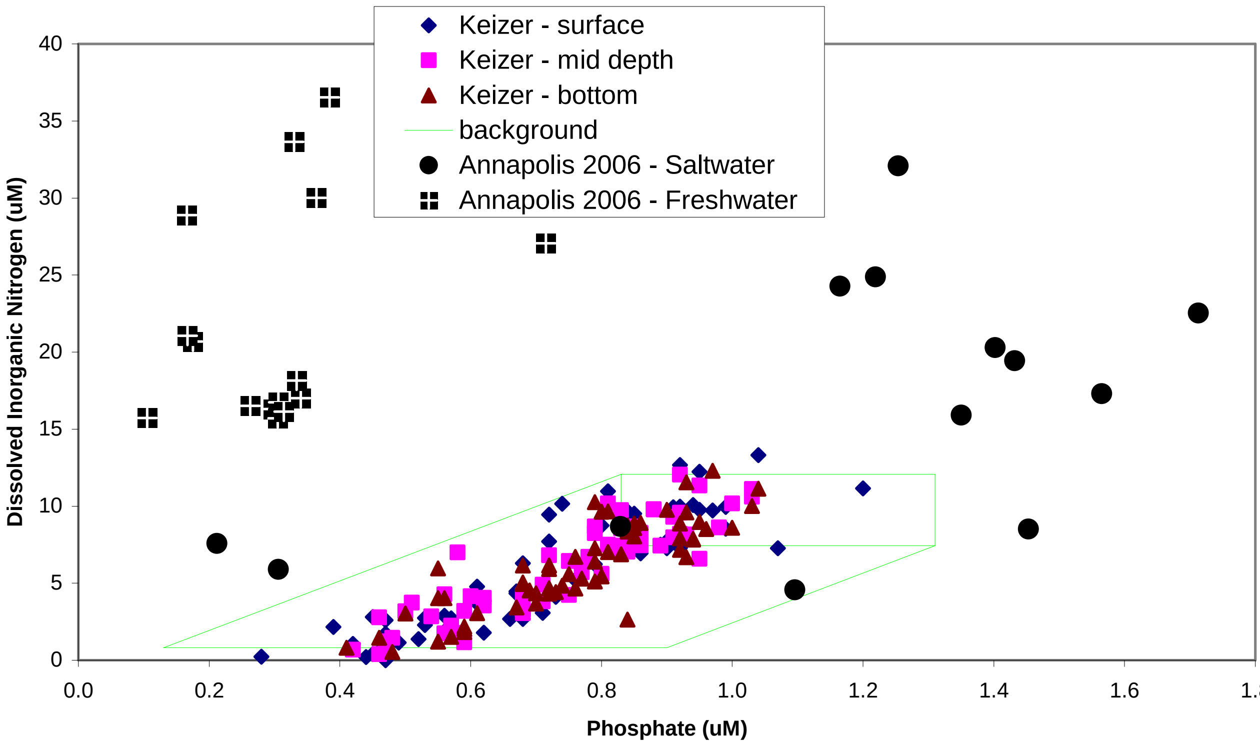

Figure 5. Dissolved Inorganic Nitrogen and Phosphate for Annapolis system.

Yeats has hypothesized that such a plot can be instructive in understanding a system's nutrient dynamics (pers. com):

- If high concentrations are within an area on the plot that is bounded by extensions of the two sloped sides of the box, then nutrients are high but in marine proportions. Such a situation could arise from biological trapping of natural inputs if circulation is poor, or by an external input of nutrients with marine ratios (e.g. fish plant wastes). If high concentrations are from natural trapping, they should only occur in late summer/fall.
- If high concentrations have excess DIN over P (i.e. above left hand sloped side of box), this suggests external input that is high in N (e.g. fertilizer runoff).
- If high concentrations have excess of P (i.e. to the right of the right hand sloped side of box), this would indicate a nutrient source high in P, such as sewage.

Based on this model, the data presented in Figure 5 indicates elevated nitrogen in freshwater that is entering the Annapolis River estuary. Nutrients in the saltwater of the estuary have comparable ratios to that seen in marine systems, but with higher concentrations. Nitrogen concentrations are similar to those in the freshwater inputs, with phosphorus concentrations significantly higher than that seen in freshwater. These results are consistent with the model proposed by

Yeats, due to poor circulation and trapping of nutrients behind the Annapolis Royal causeway. It should be noted though that the model was developed for salt water systems, with its applicability to fresh water systems untested.

Relationship of Nutrients to Oxygen Levels

No significant relationship was observed in examining DIN versus dissolved oxygen levels. A weak relationship was observed between increasing nitrate concentrations and increasing DO levels. Similarly, ammonia levels were found to decrease with increasing DO levels (Tables 3 and 4).

Table 3. Nutrients for water with dissolved oxygen < 4 mg/L.

	Total-DIN (uM)	Nitrate (uM)	Nitrite (uM)	Ammonia (uM)	Silica (uM)	Phosphate (uM)
Mean	22.01	9.71	0.77	11.52	32.31	1.23
StDev	8.76	5.43	0.35	5.59	7.78	0.40
Median	**16.22**	**13.82**	**0.25**	**2.16**	**19.54**	**0.32**
Count	12	12	12	12	12	12
StError	2.53	1.57	0.10	1.62	2.25	0.11
Min	4.57	1.14	0.21	2.17	18.42	0.27
Max	32.81	19.38	1.33	19.90	43.83	1.71

Table 4. Nutrients for water with dissolved oxygen > 6 mg/L.

	Total-DIN (uM)	Nitrate (uM)	Nitrite (uM)	Ammonia (uM)	Silica (uM)	Phosphate (uM)
Mean	20.73	16.07	0.31	4.35	23.47	0.46
StDev	7.35	5.56	0.13	5.43	9.15	0.34
Median	**17.01**	**15.45**	**0.29**	**2.07**	**18.99**	**0.34**
Count	43	43	43	43	43	43
StError	1.12	0.85	0.02	0.83	1.40	0.05
Min	5.90	5.54	0.15	0.00	7.71	0.11
Max	36.53	27.38	0.97	16.55	49.10	1.52

Mackie (2004) reports that mobilization of phosphorus from sediments increases with decreasing dissolved oxygen. This is consistent with the decreasing linear relationship was observed between dissolved oxygen and phosphate in the lower Annapolis River (Figure 6). Mackie notes though that redox conditions and pH at the sediment-water interface control, in part,control the mobilization rate of phosphorus from sediments to water. The pH of the water column above and below the halocline was very similar, at pH 7.0 and 7.4, respectively. It is therefore unclear if deposits of organic material in the lower meandering section of the river are providing a reservoir of phosphorus when oxygen levels fall.

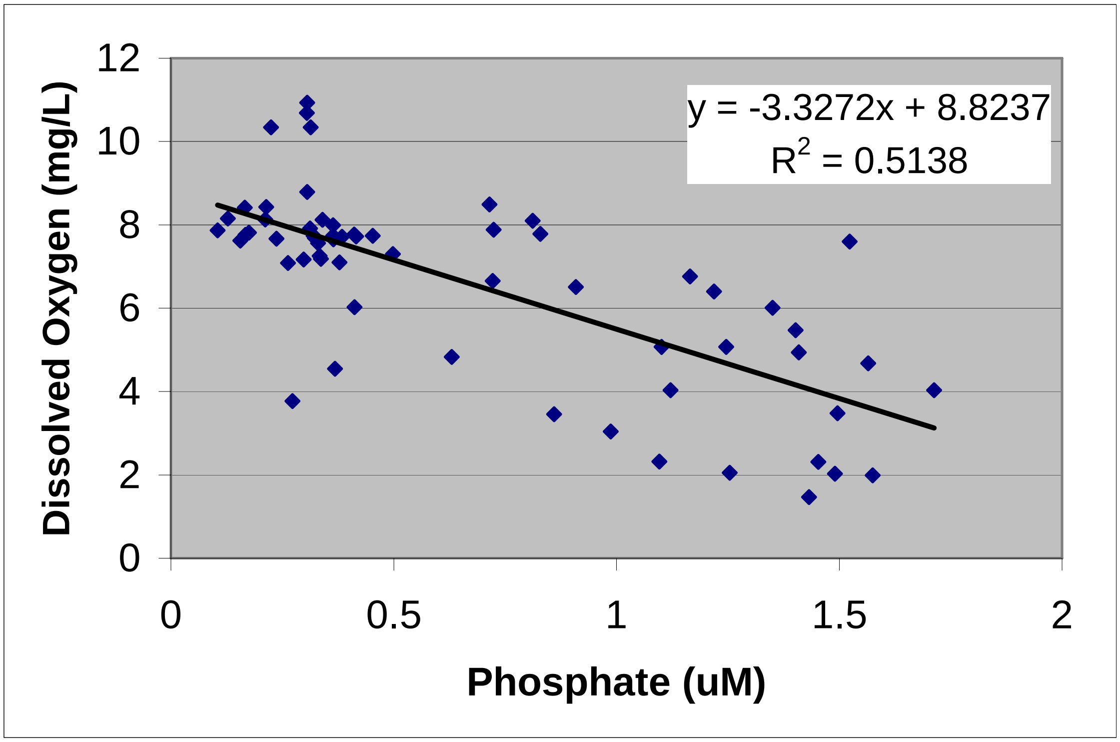

Figure 6. Dissolved Oxygen versus Phosphate.

A positive linear relationship was observed between phosphate and conductivity during 2006 (Figure 7). The salt water below the halocline was found to have elevated phosphate concentrations. In Figure 7, the two data points identified as circles are classified as outliers and not included in regression analysis. The two outliers were collected at the same location and on the same day. It is unclear why they are significantly different from others, although sample contamination is a possibility.

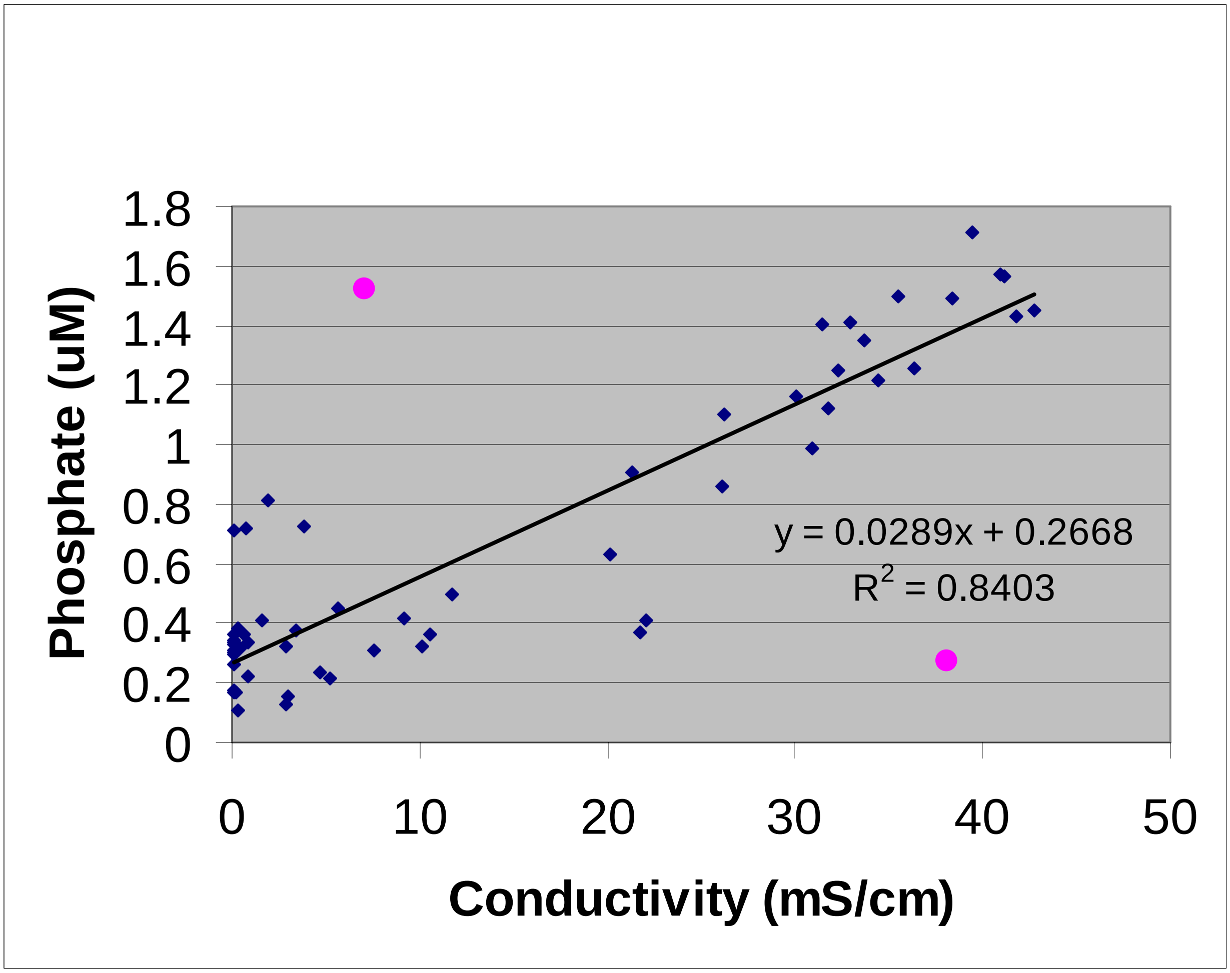

Figure 7. Phosphate versus Conductivity.

Turbidity and Secchi Depth

Data for the 2006 monitoring season was partitioned based on conductivity and distance from the Annapolis Royal causeway in order to assess the respective inputs of freshwater and saltwater into the estuary. The mean Secchi Depth in fresh and salt water was found to be 0.94 m and 1.18 m, respectively (Table 5). The relatively low Secchi Depth is thought to be due to the highly coloured waters that naturally occur in the Annapolis and other rivers in Nova Scotia.

Table 5. Turbidity and Secchi Depths for Fresh and Saltwater.

	Freshwater (Conductivity <0.5 mS/cm, >25 km from causeway)		Saltwater (Conductivity >30 mS/cm, <21 km from causeway)	
	Secchi Depth (m)	Turbidity (NTU)	Secchi Depth (m)	Turbidity (NTU)
Mean	0.94	2.87	1.18	2.62
Standard Deviation	0.18	5.62	1.13	2.02
Count	5	15	10	13
Standard Error	0.42	0.74	0.36	0.56
Minimum	0.73	0.19	0.48	0.80
Maximum	1.15	22.96	4.33	6.72

Discussion

As a partially enclosed tidal system, the morphology of the Annapolis River estuary may have role in dissolved oxygen processes. Kelly (1996) highlighted the importance of physical flushing via freshwater flows or tidal mixing/exchange as a factor in shaping an estuary's vulnerability to eutrophication. Strain and Yeats (1999) identified that 'the ability of an inlet to absorb wastes must be closely related to its flushing characteristics, which in turn are determined by its circulation and geometry.' In their study of 34 Nova Scotia inlets, the presence or absence of a sill, and the degree to which the sill interferes with water exchange between a site in an inlet and open coastal water was found to be the dominant geometric factor contributing to eutrophication.

As was discussed earlier, the lower Annapolis River is separated from the Annapolis Basin and Bay of Fundy by the causeway and tidal generating station at Annapolis Royal, which is operated by Nova Scotia Power. Under normal operations, floodgates are opened twice daily allowing water to enter the lower Annapolis River. Water is discharged through the turbine on the falling tide to generate electricity.

The Nova Scotia Power Tidal Generating Station at Annapolis Royal was off-line for routine maintenance from Labour Day weekend until early 2007. During early September, for a period of approximately two weeks, the floodgates were not opened on a daily basis. For the remainder of the autumn, the floodgates were used on an irregular pattern to allow seawater to enter and exit from the lower river.

During typical operating conditions, the tidal station discharges approximately 14,000,000 m^3/day (combination of two flood tides) through the turbine and two fishladders into the lower Annapolis River estuary. The daily mean discharge of the Annapolis River at the Lawrencetown Gauging Station for the months of July, August, September and October is 824,256 m^3/day (based on data from 1984 to 2003). If no other freshwater inputs or losses are considered between Lawrencetown and Annapolis Royal, river discharge thus represents 5.9% of the volume discharged through the turbine and fish ladders. The balance is made up of seawater admitted through the causeway gates. While an approximation, this figure demonstrates the limited contribution to freshwater to flow dynamics in the Annapolis estuary in the later summer and early autumn period.

Conclusion

One of the objectives of the 2006 monitoring season was to ascertain the temporal and spatial extent of the dissolved oxygen depletion in the lower Annapolis River. Based on available information, it is known that between early July and October 2006, DO levels in the stratified portion of the river below the halocline decreased significantly. During this period, oxygen levels in the underlying salt water fell to a median value of 3.6 mg/L (40.4% saturation). The minimum DO level observed was 1.5 mg/L on October 5, 2006. The median temperature of this salt water was 15.9 ºC for 28 samples. The zone of DO depleted saltwater extends over at least 20 km of the lower Annapolis River estuary. These seasonal patterns are consistent with those observed in 2005, and possibly 2004. The DO levels observed are well below the national and British Colombia provincial Water Quality Guidelines for the protection of aquatic life. DO levels observed are sufficiently low to cause stress, displacement or death of aquatic life.

A second objective of the 2006 monitoring season was do identify possible mechanisms for the observed oxygen depletion. Based on available information, the following causative factors are proposed to explain the seasonal depression of dissolved oxygen below the halocline:

- The natural geometry of the lower Annapolis River, together with its partial barrier from the Annapolis Basin due to the causeway, coupled with,
- 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.

It is felt that these factors lead to phytoplankton growth in the euphotic zone, followed by sinking and decay below the halocline. The strong stratification limits the replenishment of DO in the salt water due to mixing, resulting in a progressive depletion of DO during the summer. High autumn river discharges, high wind velocities and decreased water temperatures lead to a break-down of the stratification with mixing and re-oxygenation of the deeper waters within the estuary during the autumn and winter.

In such a scenario, incoming tidal flow through the causeway gates would not travel very far up the river. Rather, it would act like a growing dam that displaces the existing salt water below the stratification towards upstream with minimal mixing. This would result in the underlying salt water migrating up and down stream as a plug pushed around by the tidal flows. In this way, once the freshwater flows allow a salt wedge to remain in the river, the underlying salt water might remain there more or less intact, or at least have insufficient mixing with the tidal flows. These conditions would allow progressive oxygen depletion below the halocline.

Given the natural morphology of the estuary, man-made structures (causeway) and upstream nutrient inputs, the lower Annapolis River may be prone to eutrophication. Changes in the flow dynamics, such as planned or unforeseen maintenance of the tidal generating station with reduced tidal flushing, may be sufficient to push the system into a eutrophic state, particularly during the late summer and early autumn period. These findings may provide benefit to Nova Scotia Power in deciding when to plan maintenance activities and the importance of regular tidal flushing.

Monitoring Plans for 2007

The preliminary objectives for 2007 monitoring activities on the lower Annapolis River are:

- To understand the spatial and temporal occurrence of dissolved oxygen (DO) depletion in the lower Annapolis River in conjunction with operations at the Annapolis Royal Tidal Generating Station (both typical operations and planned maintenance) on DO depletion.
- To investigate possible driving factors for the depletion of DO in the lower Annapolis River, including reservoirs of sediment organic material.
- To identify the possible impact of DO depletion on benthic communities.

These objectives will be achieved through the following actions:

- Monthly monitoring of water quality by boat (May to October) between Annapolis Royal and Bridgetown.
- Conducting profile measurements at predetermined sites for DO, temperature, and salinity using portable water meter, van Dorn sampler and Winkler titrations.
- Collection of water samples for analysis of inorganic nutrients. (Phil Yeats at BIO – nitrate + nitrite, ammonia, silica, phosphate); Chlorophyll a, turbidity, and Secchi disk depth.
- Collection of sediment cores from the lower Annapolis River to measure organic material determination by combustion.
- Deployment of DO/salinity dataloggers at the upstream edge of saltwedge zone (subject to obtaining required equipment).

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Appendix A

Annapolis River Sample Locations – all sites mid-channel

Site Code (AR)	UTM - Northing	UTM - Easting	Zone	Site Name	Map Datum
45	4967825	320598	20T	Hwy 101 Bridge at Bridgetown	NAD83
49	4967621	318900	20T	Bridgetown Bridge	NAD83
51	4967730	318639	20T	Jubilee Park	NAD83
53	4966613	317017	20T	Bloody Creek	NAD83
60	4965635	315473	20T	Britex Plant	NAD83
64	4964853	313316	20T	Hebbs Landing, Bellisle	NAD83
67	4964435	311634	20T	Belleisle - Mouth of Gesner Brook	NAD83
71	4961580	310619	20T	Bellisle Marsh	NAD83
75	4962462	308229	20T	Granville Centre	NAD83
81	4959933	305244	20T	Mochelle	NAD83
83	495857	302587	20T	French Basin	NAD83

Appendix B

Quality Control Measures

Standard operating protocols were used in the collection and analysis of samples. The Hydrolab Quanta water meter was calibrated before each use. During each boat-based sample cruise, an equipment blank was prepared by flushing the van Dorn sampler with MilliQ deionised water. Sample bottles for nutrients, turbidity and chlorophyll A were then filled using this rinse water. The subsequent analysis results provided correction factors that were applied to the laboratory results.

During each sample cruise, a dissolved oxygen sample was collected, analysed by Winkler titration and subsequently compared to the DO values recorded with the Hydrolab Quanta water meter. On average, the Hydrolab recorded DO values were 0.18 mg/L less than those determined with the Winkler titration. Given that the sample range for DO was approximately 1 to 10 mg/L, the error associated with the use of Hydrolab Quanta is minor and predictable.

Replicate samples were collected on two occasions at two depths, to assess the homogeneity of the water body and variability within the analysis. The variability between these replicates, reported as Relative Standard Deviation, are showed below.

Parameter	**Relative Standard Deviation (%)**	**Parameter**	**Relative Standard Deviation (%)**
Temperature	0.9	Turbidity	7.4
Conductibility	14.1	Nitrate	8.3
Dissolved Oxygen	6.9	Nitrite	9.7
pH	1.9	Ammonia	17.3
Salinity	16.1	Silica	7.0
		Phosphate	10.8