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Ref.:	SettleLake2013	(8 pages)
To:	Harbour East - Marine Drive Community Council (HEMDCC), HRM	
From:	S. M. Mandaville Post-Grad Dip., Professional Lake Manage. Chairman and Scientific Director	
Date:	October 30, 2013	
Subject:	SETTLE LAKE, Dartmouth:- Eutrophic, comparison with HRM's data of 2006-2011, and suggested restoration parameters	

(*cf.* http://lakes.chebucto.org/WATERSHEDS/COWBAYR/SETTLE/settle.html)

Please feel free to ask me any questions, and I will endeavour my level best to respond either via emails and/or in person at one of your meetings, if invited to do so.

Restoration parameters for consideration by the HEMDCC are suggested on page-3.

I have provided a synopsis of the relevant data from various known sources referenced appropriately (see page-5). These are all deep station values (shallow zone values may differ considerably). A summary of the historical phytoplankton have been noted on page-8.

Of specific interest here are the Ch*a* (chlorophyll*a*) values which are representative of the `algal production'. HRM's Ch*a* data ranged 1.24–57.16 µg/l during the years 2006 to 2011 (analyzed at private labs) which is alarming. Compare that with our 1991-1992 data of 4.0-19.4 µg/l (lab work at the Environment Canada lab in Moncton), and Paul Mandell's grad thesis 1991-92 data of 1.47–18.93 µg/l (lab work at the provincial QEII labs).

The TP (total phosphorus) values which are representative of the `limiting nutrient':- HRM's TP data ranged 9–82 µg/l during the years 2006 to 2011 (analyzed at private labs) which is alarming as well. Compare that with our data 1991-1992 data of 18-31 µg/l (lab work at the Environment Canada lab in Moncton), and Paul Mandell's grad thesis 1991-92 data of 4-34 µg/l (lab work at the provincial QEII labs). Our modelled hindcast cultural (+0.173 kg/ha.yr precipitation) value is 3.2 µg/l, and Queen's University pre-industrial (i.e., pre-1850's) diatom inference value is 7.94 µg/l.

I include the predictive phosphorus modelling conducted by my team some years back (results updated in page-5, and the pictorial model in page-7).

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Environment Canada (2004) published a table which was derived from the 18-country OECD peer consensus (http://lakes.chebucto.org/TPMODELS/OECD/oecd.html) which I reproduce below:-

Table 4.1 Trophic classifications of lakes, with their corresponding phosphorus and chlorophyll concentrations and transparency (Secchi depth) (sources: Wetzel 2001; Vollenweider and Kerekes 1982).

Trophic level	Total Phosphorus (μg·L⁻¹)		Chlorophyll *a* (μg·L⁻¹)		Secchi depth (m)	
	Wetzel (2001)	Vollenweider and Kerekes (1982)	Vollenweider and Kerekes (1982)		Vollenweider and Kerekes (1982)	
			Mean	Max	Mean	~~Max~~ Min.
Ultra-oligotrophic	< 5	< 4	< 1	< 2.5	> 12	> 6
Oligo-mesotrophic	5-10	4-10	< 2.5	< 8	> 6	> 3
Meso-eutrophic	10-30	10-35	2.5-8	8-25	6-3	3-1.5
Eutrophic	30-100	35-100	8-25	27-75	3-1.5	1.5-0.7
Hypereutrophic	> 100	> 100	> 25	> 75	< 1.5	< 0.7

To further understand the relevance of Ch*a* values, kindly note that the Kings County of Nova Scotia set a maximum objective Ch*a* values in the low range of 2.5 μg/l for 18 lakes. I herewith insert a scan from their policy in my archives:-

Kings County adopted water quality objectives for 18 lakes in the county, through amendment of MPS and LUB. The maximum objective value of chlorophyll-a for most of these lakes is 2.5 μgm/L. Seven of the lakes' objectives were set below the level of 2.5. Based on predictive modelling, the estimated maximum number of dwellings that could be added to the contributing area without exceeding the threshold value was established. This number of dwellings was set as a limit for development in the LUB. Policy in the MPS enables application for a permit with a development having "near-zero impact" through site standards or performance standards. Primarily this condition is expected to be met with septic field fill with a 20 year phosphorus input retention and a requirement to replace the fill every 20 years. A condition in adopting these limits was implementation of an annual monitoring program for a minimum of six years. The sampling required was to be completed by volunteers.

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Suggested deliberation for restoration by the community council (CCME):

(i) See the CCME's fact sheet (2004) for the phosphorus guidance framework (http://documents.ccme.ca/download/en/205/).

(ii) The CCME's framework recommends a maximum enrichment of 50% increase over the hindcast value of TP, and to not exceed the trigger range. The hindcast cultural (+0.173 kg/ha.yr precipitation) value is 3.2 µg/l, hence 50% increase results in a conc. of 4.8 µg/l, but the relevant trigger range is the stringent <4 µg/l. As an exception, 5.0 µg/l can be a compromise which is also very stringent for this lake.

(iii) Further compromise:- The pre-industrial (pre-1850) TP value is 7.94 µg/l; 50% increase would be 11.9 µg/l which would exceed the trigger range for this of 4-10 µg/l. Hence, the max. acceptable value could be 10 µg/l. Lake restoration results from elsewhere have been widely published in the scientific handbooks and published papers.

Total phosphorus (TP) trigger ranges for Canadian lakes and rivers (CCME, 2004)

Trophic status	TP (µg/l)
Ultra-oligotrophic	< 4
Oligotrophic	4-10
Mesotrophic	10-20
Meso-eutrophic	20-35
Eutrophic	35-100
Hyper-eutrophic	> 10

Per the CCME (2004), the framework offers a tiered approach where phosphorus concentrations should not (i) exceed predefined 'trigger ranges'; and (ii) increase more than 50% over the baseline (reference) levels. The trigger ranges are based on the range of phosphorus concentrations in water that define the reference trophic status for a site (i.e., hindcast values). If the upper limit of the range is exceeded, or is likely to be exceeded, further assessment is required. When assessment suggests the likelihood of undesired change in the system, a management decision must be made.

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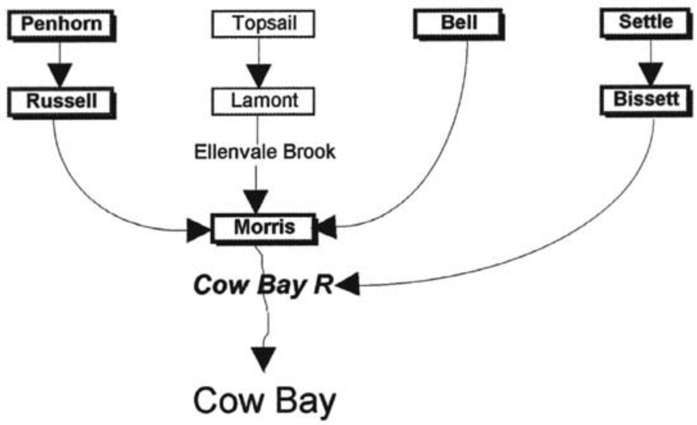
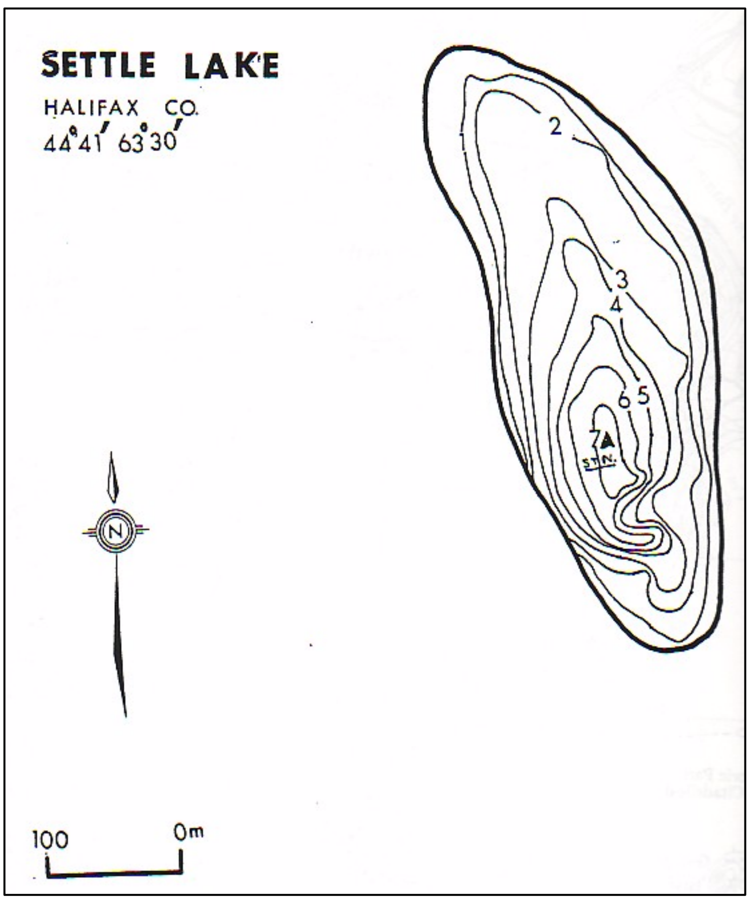
The flow chart developed by us



Lake bathymetry (as supplied by the NS. Dept. of Fisheries)



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Deep station data archives (shallow area data can vary significantly)

Source of field data	Date(s) of sampling	#s of sampling events and type of sampling Deep stn.	TP (µg/l) mean	TP (µg/l) range	Cha (µg/l) mean	Cha (µg/l) range
BIO	Apr. 1980	1# (surf.)	3.0	-	-	-
SWCSMH	June-Oct. 1990	3#s (arms depth)	21.9	14.8 – 34.1	6.02	3.90 – 9.54
BIO	Apr. 1991	1# (surf.)	4.0	-	12.084	-
Dart. Eng. Dept.	Aug. 1991	1# (surf.)	-	-	6.3	-
SWCSMH's Predictive Modelling (also see graph on page-7)		Pre-cultural (+0.173 kg/ha.yr precipitation)	3.2	-	-	-
		1993 Serv. Res. @ 0.52 kg/ha.yr	11.6	-	-	-
		1993 Serv. Res. @ 1.1 kg/ha.yr	22.2	-	-	-
Mandell	1991-92	30#s (surf.)	17.0	4 – 34	7.53	1.47 – 18.93
SWCSMH	1991-92	10#s (vol. wtd.)	22.0	18 – 31	8.0	4.0 – 19.4
Dart. Eng. Dept.	Aug. 1992	1# (surf.)	-	-	3.6	-
BIO	March, 2000	1#s (surf.)	22.0	-	2.158	-
Thiyake's Paleo Inference Model	Pre-1850's (Bottom layer of core)	Queen's University Diatom Inference Model	7.94	-	-	-
	Early 2000's (Top layer of core)		28.18	-	-	-
HRM	2006	2#s (1 m.)	22.5	20 – 25	7.10	1.92 – 12.27
HRM	2007	3#s (1 m.)	14.3	9 – 24	12.72	1.37 – 27.67
HRM	2008	3#s (1 m.)	24.0	15 – 38	25.84	8.41 – 57.16
HRM	2009	3#s (1 m.)	30.0	22 -39	6.02	1.24 – 9.29
HRM	2010	3#s (1 m.)	45.7	21 – 82	17.54	7.91 – 23.00
HRM	2011	3#s (1 m.)	33.0	17 – 45	27.04	9.69 – 55.13

(Acronyms & brief explanation on next page)

Acronyms & brief explanation of the aforesaid table

vol. wtd.= volume weighted discrete depth sampling
arms depth.= sampling at arms depth
surf.= surface samples
1 m.= 1 metre depth sampling

BIO- Bedford Institute of Oceanography
SWCSMH- Soil & Water Conservation Society of Metro Halifax's research
SWCSMH's predictive modelling- Computer modelling carried out by the Soil & Water Conservation Society of Metro Halifax
Mandell- Paul Mandell's MSc thesis (1994) at Dalhousie University
HRM- Halifax Regional Municipality (2006 to 2011; the Ch*a* values are means of the 2 methodologies reported)
Thiyake- Thiyake Rajaratnam's MSc thesis (2009) at the Queen's University in Kingston, Ontario under a major NSERC grant. The grant was for the first ever paleolimnology conducted on lakes across Nova Scotia (I calculated the antilog values from her reported log values based on the diatom inference model)

Basic Morphometric and Hydrologic data

(computed by us from bathymetric maps supplied by the Provincial Fisheries Dept.)

- Shoreline length= 1.036 km
- Surface area= 5.3 ha
- maximum depth= 7 m; mean depth= 3.2 m
- volume= 0.168×10^6 cu.m.
- watershed (headwater lake)= 31.1 ha
- Flushing rate= 2.1 times/yr (approx.)
- In-lake TP retention= 0.65

- Zr , Relative depth= 2.7 % ………. (for most lakes, Zr < 2%. Deep lakes with small surface areas exhibit greater resistance to mixing and usually have Zr > 4%).
- DL, Shoreline dev.= 1.3 …………. (DL is important because it reflects the potential for development of littoral communities which are usually of high biological productivity).
- Dv, Deve. of volume= 1.4 ………….. (For the majority of lakes, Dv will be greater than 1 (i.e. a conical depression).
- Index of Basin Permanence (IBP)=0.16×10^6 cu.m/km ………… (The IBP is a morphometric index that reflects the littoral effect on basin volume. Lakes within the Atlantic National Parks (IBP < 0.1) are dominated by rooted aquatic plants and indicate senescence (excessive shallowness, high water color and high TP).

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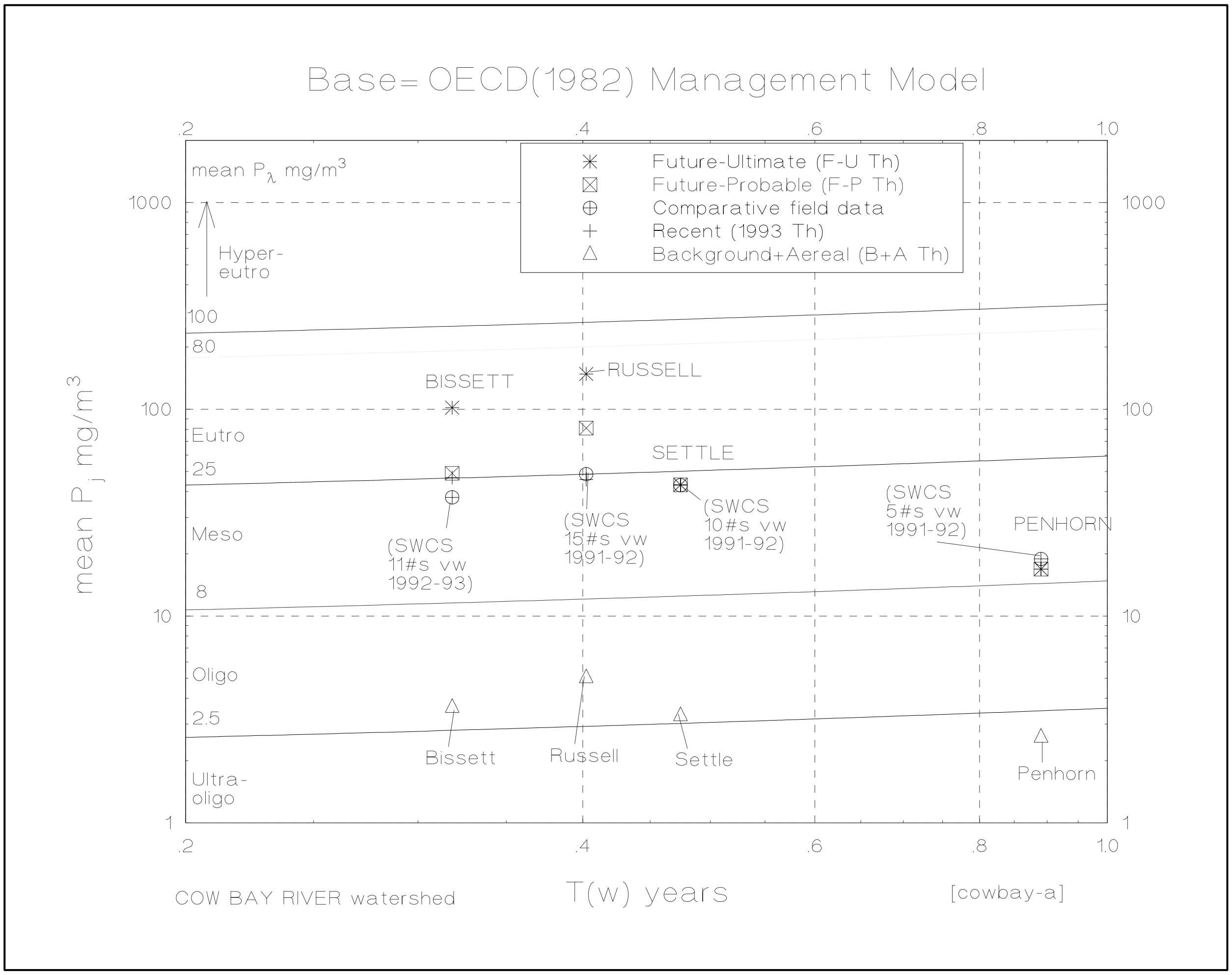
Our predictive model utilizing the 18-country OECD (Organization for Economic Co-Operation and Development) peer consensus base models



Notes for the log-log graph above:-

The X-axis is the water retention time. The Y-axis is the inflow TP concentration. The pelagic (i.e., open water) phosphorus concentrations are shown as curved lines with values of 2.5, 8, 25, 80, and 100 µg/l expressed as total phosphorus (TP)) delineating the OECD management model categories of nutrient enrichment. Chlorophyll*a* values have not been plotted though they can be with some more work. We have also not updated the model with the latter field data of various sources inclusive of HRM's from the Table since it will get cluttered.

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Summary only of select phytoplankton analyses (does not include all yet)

(*cf.* SWCSMH, 1992. 56 leaves. Refer to that report for the detailed listing of species.)

This lake differed somewhat from the others in having some of the same species dominant throughout the summer. There was a gradual shift from Stauastrum species and dinoflagellates early on to dinoflagellates and Anabaena species in late summer.

(*cf.* SWCSMH, 1993. 120p. Refer to that report for the detailed listing of species.)

Both the late summer and early autumn survey dates here provided the most heavily populated samples of all of the lakes examined in this study. Blue-green algal species dominated the summer sample. *Microcystis* and associated *Anabaena* species were the most commonly represented organisms, as well as some *Peridinium* and *Closterium* species. The number of Diatoms remained comparable in both samples, as did the occurrence of *Microcystis* colonies, but in the autumn assemblage, there was a general shift toward more Chlorophycean species and Desmids. *Anabaena* was absent from this sample, and *Botryococcus* and *Dinobryon* became more frequently represented.

(*cf.* Sherwood, 1994. 15 leaves. Refer to that report for the detailed listing of species.)

The diatom forms found in Settle Lake were very diverse in morphology, and dominant taxa were difficult to identify from the relatively even combination of species. A high biomass was also present as in Russell Lake. The dominant species were *Tabellaria flocculosa*, *Fragilaria brevistriata* var. *brevistriata*, *Cyclotella stelligera*, and *Diatoma vulgare*. Cyclotella is normally a planktonic genus, and it is possible that a significant number of cells were trapped in the sample with the surrounding water at the time of sample preparation.