FLOW
FORUM FOR LEADERSHIP ON WATER

24/09/2013

COMBATING CLIMATE CHANGE IMPACTS ON PHOSPHORUS IN THE GRAND RIVER AND TO LAKE ERIE

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Prepared for: GRAND RIVER CONSERVATION AUTHORITY and FRESHWATER FUTURE

THE ISSUES

The trajectory towards a eutrophic state in Lake Erie, in the 1960s, has been well documented in a study for the International Joint Commission, 1969. Subsequently under the Canada-U.S. Great Lakes Water Quality Agreement of 1972 much of the phosphorus discharge from detergents and from point sources, industry and municipalities, was curtailed and in the 1980s and early 1990s the lake improved and became mesotrophic or even oligotrophic with much reduced algal blooms. Tragically the late 1990s and the 2000s have seen a reversal of the trend with Erie becoming increasingly eutrophic again, due to change in land use and management and to the rapidly changing climate. It has been estimated that in the 2000s, more than ¾ of the total phosphorus loading is coming from diffuse land sources with an estimated 53% from tributaries to Erie that are monitored. (IJC 2013)

There has been debate in scientific circles as to whether increased phosphorus loading to the lakes, particularly dissolved reactive phosphorus which is readily bio-available, is due to changes in land use or to changes in climatic factors. It is probably a combination of the two. The purpose of this study is to provide information to assess the climate change component.

This analysis seeks to quantify trends to date due to climate change effects on runoff events and phosphorus loads. Also considered are the likely future effects, due to increased frequency of heavy rain events. Some remedial actions to reduce the water quality impacts on the Grand River, Canada's largest tributary to Lake Erie are outlined.

A Grand River Conservation Authority (GRCA) study by Cooke and Minshall (2011) indicates that biological activity in the Grand River system, and especially its reservoirs, is influenced by phosphorus loading in the late spring and warm weather months, but not so much in the snowmelt influenced runoff period. The GRCA study also refers to the importance in low flow periods of phosphorus point sources from sewage treatment plants, particularly from Waterloo and Kitchener.

The International Joint Commission has also stimulated studies of climate change impacts on Lake Erie, especially from the U.S. side of the basin (Ludsin & Hook, 2013). Interactive effects of nutrient inputs and climate change on Lake Erie fish community) and the IJC's Lake Erie Priority summary report 2013.

It has been recognized for some time that several manifestations of the changing climate, driven by greenhouse gases, have the potential to influence the eutrophication of water bodies. Both in theory (the Clausius-Clapeyron equation) and in experience, the warming atmosphere holds increasingly more water vapour (precipitable water). Thus when conditions are right to produce rain, it more frequently rains intensely, resulting in surface and sub-surface runoff. For lakes, climate change drives loss of winter ice, higher surface water temperatures and longer stratification periods, in addition to greater phosphorus loading, particularly in dissolved form discharged in runoff events (Schindler, et al., 2012). All of these factors are conducive to more and greater frequency of harmful algal blooms (habs). It has been found that phosphorus concentrations rise in higher flow events, in both the Grand River (Cooke, 2011) and in the Red River system in Manitoba (Schindler, 2013). Thus runoff events have a double effect, greater flow volumes and higher phosphorus concentrations in that flow.

This study will consider climatic changes in the Grand River watershed, a major tributary basin of Lake Erie. The findings are applicable to a considerable extent to other Ontario rivers tributary to the Great Lakes. Increases in phosphorus concentrations in the Grand River and its tributaries have been postulated to be due, in part, to greater numbers of runoff events from heavy rain periods and more frequent rain on snow episodes. For this study we examine first, whether the number of runoff events has indeed increased from the 1970s to the 2000s.

TRENDS IN RUNOFF EVENTS

To examine whether any trends have occurred in the number of runoff events, hydrometric records for three locations in the Grand River system were analysed. Stations selected were ones with seven years of record in the early 1970s (or combined with the late 1960s) and at least seven years in the 2000s. The number of events with fairly sudden doubling of the ambient flow, with peak discharge exceeding a certain threshold, was tabulated. For the main river at Brantford, peak flow thresholds of at least 200 and 400 cubic metre/sec were chosen. For a headwaters station (Marsville), thresholds of 20 and 50 cms were used and for the tributary Nith River above Nithburg, 20 cms was used. For several other locations, dams and storage upstream confounded the analysis. The rise from ambient flow to peak was required to be within 4 days at Brantford with a 5200 km^2 drainage basin and within 2 days at Marsville 663 km^2 and Nithburg 326 km^2. These were the criteria used to characterize a runoff event.

Results are given in Table 1

It will be seen from Table 1 that for modest runoff events (lower peak thresholds) the increase over the 30+ year period in number of events was in the range of 16 to 20% (or an average of 18%). However for the larger events analyzed, a much higher percentage increase was observed (36% and 63%), but the sample size was very small and results cannot be considered reliable.

ARE MORE RUNOFF DAYS DUE TO CHANGES IN RAINFALL?

How do these increases in numbers of observed runoff events compare to changes in frequency of heavy rains? The most thorough analysis of trends in intense precipitation was done in the U.S. Global Change Program and published in their 2009 report (Karl, et al.) for the U.S. part of the Great Lakes basin. In that report, the percentage increase in frequency of daily rains greater than those with only a 1% chance of occurring from past records, for U.S. parts of the Lake Erie and Huron basins, averaged 27% from 1958 to 2007. This corresponds reasonably well with the findings in this report of an 18% increase in numbers of runoff events in from about 1970 to the 2004-2010 period.

A comprehensive heavy rain event analysis, similar to the Karl et al. study has not been done in Canada. However, for southern Ontario it has been estimated that the number of days with rainfalls ≥ 95th percentile increased by 6 days per year from 1950 to 2007 (Vincent and Mekis, 2009). The frequency of heavy rain events in spring (April, May, June) increased by about 5% per decade from 1960 to 1990 (Stone, Weaver & Zwiers, 2000). A later summary for Soil and Water Conservation Society (2007) concluded that very heavy rainfall in durations ranging from one day to twenty minutes, has increased about 5% per decade since 1970. These precipitation trends are also similar to the observed trends in runoff events.

It should be noted as well that there have been changes in seasonal total precipitation for this region as reflected in Table 2, (page 7). In winter and especially spring, there are trends towards less snow and more rain. This suggests that more runoff producing rain-on-snow events are occurring in recent years, but this is more difficult to quantify than rain only events.

The evidence from runoff and rainfall data points strongly to an approximately 18% increase since 1970 in number of days with rain-produced runoff. This may be an underestimate of number of runoff events since runoff from snowmelt due to sudden warm episodes without heavy rains has not been included. However, for discharges of dissolved reactive phosphorus into waterways, a form more bio-available, runoff during the growing season, after snow has melted, is more effective. Rain-on-snow events can produce significant erosion as can extremely heavy rains, adding particulate phosphorus with sediment particles. This, of course, adds to total phosphorus loadings to rivers and lakes. Some particulate phosphorus becomes bio-available only over a period of time, although organic and non-apatitic inorganic forms are also biologically reactive.

Some analysts have suggested that the recent re-increase in harmful algal blooms in Lake Erie has been due to a large increase in loading of dissolved reactive phosphorus, rather than total phosphorus load increases. This highly bio-available form of the nutrient is thought to have two main sources:

1. Wastewater treatment plants, and
2. Surface and near sub-surface runoff events.

Such runoff events can, if large, result in bypass or overflow of wastewater treatment facilities. However, the discharges from such treatment facilities in non-high runoff periods have not increased much.

It seems likely then that greater frequency of high intensity rain and rain on snow events combined with an increase in phosphorus on agricultural and urban surfaces are the main causes of this unfortunate trend.

One of the challenges in this analysis is that chemical analysis sampling in Canada and Ontario is generally done only on a weekly basis. However, it is likely that a substantial portion of phosphorus discharge occurs in the short runoff events of a few days, often not captured in the sampling. Thus, loading of phosphorus to the Great Lakes and its tributaries has likely been increasingly underestimated as frequencies of heavy rain and runoff events have increased

FUTURE INTENSE RAINS AND RUNOFF EVENTS

Will the observed trends continue or accelerate?

Projections of future intense rain events have been made by climate models assuming continued warming due to greenhouse gases. In addition, extension of observed trends over the past four decades may be good indicators of future trends. If results are similar in these two approaches, greater confidence can be placed in the projections.

The data on observed and projected trends in climatic parameters by these two methods have been summarized for various regions of Canada (Bruce 2011). For southern Ontario, they suggest that the frequency of high intensity rains of the reference period 1975 to 1995, will be doubled by 2050. There will also be a small increase in the intensity of the heaviest events – about 10% by 2050. If we only consider the increased frequency, the suggestion is that the 16 to 20% (5% per decade) increase to 2004-2010 in frequency is only about 1/3 to 1/2 of the total change we may see by about 2050. It is assumed here that the lower runoff event threshold would have resulted in significant dissolved phosphorus discharged to the Grand River and its tributaries. From the above analysis of potential effects of climate change driven frequencies of heavy rainfalls, the frequency of runoff events with significant discharge to the river and to Lake Erie of the nutrient phosphorus, and other contaminants, will continue to increase and probably accelerate for many decades. The increase in runoff events to 2050 from 2010 could be more than twice the change in the forty years from 1970 to 2010.

REMEDIAL RESPONSES

The implication of these results is that remedial actions are imperative to reduce rates of eutrophication in the Grand River basin and Lake Erie. Better monitoring data is essential to improving the efficiency and effectiveness of on-the-ground efforts to minimize polluted runoff events.

In particular, this should include:

1. **Frequent monitoring** of P and other contaminants during runoff events,
2. Greater intensity of chemical monitoring at outlets of key contributing sub-basins,
3. Extensive monitoring of sewage outfalls and municipal and suburban stormwater runoff.

There are a number of well recognized steps that can be taken in urban and agricultural watersheds to reduce numbers and volumes of runoff events and the phosphorus loads they carry. They include:

Rural and Agricultural Areas

1. Protection or restoring upstream wetlands and water storage areas,
2. Ensuring perennial cover crops, to minimize runoff events,
3. Reducing spread of phosphorus-rich fertilizers and manure, especially in spring, and before predicted heavy rain events,
4. Ensuring careful calibration of spreaders and limit application rates to necessary amounts,
5. Controlling and storing manure in animal feed lots, and where practical using it to produce energy and other products,
6. Minimize P in livestock feed,
7. For high P soils, plant crops and grasses with high uptake,
8. In erodible soil areas, riparian buffer strips are needed to reduce total P discharges.

Urban Areas:

1. Using porous pavements more extensively,
2. More and larger retention basins in stormwater management systems,
3. Reduce stormwater overflows into sanitary systems: in some communities by detaching roof drainage downspouts from storm sewers,
4. Ensuring optimum P removal at sewage treatment plants,
5. Reducing pet wastes on urban streets.

For suburban areas, adopting the first recommendation for agricultural areas would be valuable.

However, to carry out all of such measures, or more, in a sizable watershed is costly in total and requires cooperation of a large number of landowners and other citizens. Analysis in many countries, in Ontario (Dickinson, 2007, Lean, 2007) and Manitoba (Holweger and Vanrobaeys, 2013) suggests that only a small portion of a watershed contributes to high phosphorus concentration runoff. If policies were adopted to concentrate attention on these critical areas that are larger contributors, a bigger “bang for the buck” could be obtained. There is a significant human dimension to securing adoption of appropriate on-farm measures. Early adopters are often community or family leaders and can be encouraged to provide good examples.

Much data on each contributing sub-watershed are required to identify the key contributing areas.

Data needed include:

a) Land-use class
b) Elevations and slopes
c) Soil types
d) Measured or estimated climatic and runoff data
e) Storage, natural and artificial
f) Cropping systems
g) Tillage practices
h) Manure application and timing and/or storage
i) Fertilizer application rates.

Agriculture and Agrifood Canada recommends use of the internationally recognized Soil and Water Assessment Tool (SWAT), to integrate these various data types by sub-watershed. This can be used to identify parts of a larger watershed needing intensive action (Holweger and Vanrobeays, 2013). A SWAT/EPIC model has been used successfully in southeast Quebec to estimate P cycling and transport by overland flow (Rousseau, et al., 2013). In this Quebec study, sediment routing algorithm of SWAT was used to account for the effects of bed degradation in the river.

For the Boyne watershed in Manitoba total phosphorus discharges on average were up to 30 tons per year from some sub-watersheds, but less that 5 tons per year from most parts of the larger basin. For the whole watershed, the total phosphorus (TP) load averaged 22 tons/year or 0.20 lbs. per acre. Scenarios of the potential impact of land-use changes can be simulated with the SWAT model. In the case of the Boyne, conversion of cropland to forage, and conversion to wetland, was simulated. These simulations illustrated the reductions in phosphorus loading that could be achieved with vigorous actions.

Similarly, studies for SWCS Ontario, 2007, focussed mainly on erosion and particulate phosphorus associated with it, which combined with phosphorus dissolved in runoff events, constitute total phosphorus loading. Dickinson, et al., produced estimated numbers for average seasonal soil loss and runoff from southern Ontario in Uplands and Lowlands with several crop tillage systems (Table 3. Page 7). Runoff which transports mostly dissolved phosphorus was much greater in Lowlands. But eroded soil and particulate phosphorus was more important in Upland areas. Dickinson and colleagues also estimated impacts on erosion soil loss, and on runoff, as percentage increases for each percentage increase in rain intensity in spring and in summer. Soil losses were estimated to increase 2 to 3% for each percentage increase in rain intensity. For spring rains, surface runoff quantity increases are 1.8 to 3.1% per one percentage increase in spring rain intensities but less (1.3 to 1.4%) for lowland corn and grain, and for larger summer heavy rain events. The estimates are based on runoff and soil loss data from more than three decades of information from runoff plots at University of Guelph, combined with GDVFS model results. In this Ontario work as well as in Manitoba studies, there is a strong message that targeting specific, relatively small runoff and erosion-prone parts of the watershed is an efficient and economical approach (Sudra, et al., 1990**). However, this may require rethinking agricultural support programs that tend to be available to all farmers in a watershed or a region. Devising politically acceptable targeted programs is required.**

CONCLUSIONS

With more frequent intense rain events in spring and summer in a warming climate, more frequent runoff episodes are occurring. Data were examined from several hydrometric stations on the Grand River and its Nith tributary for a 7 year period around 1970 compared to a 7 year period in the early 2000s. It was found that runoff events increased by 16 to 20% and very large runoff events were 1/3 to 2/3 times more frequent. These results are reasonably consistent with observed increases of about 5% per decade in heavy rain events.

Such events are known to dissolve the nutrient phosphorus available on rural and urban land surfaces resulting in discharges of phosphorus to the river and subsequently to Lake Erie. Observed increased frequency of such occurrences in the changing climate, and projections of an escalation in frequency of such events indicate the need for strong actions to minimize both available phosphorus on land, and runoff events.

A short review is given of actions that can be taken on the land to minimize both frequency of runoff events and phosphorus loading. This review is based on studies summarized by Agriculture and Agrifood Canada for the Lake Winnipeg basin and by University of Guelph for southern Ontario. A key finding of both is that targeting of those relatively small parts of watersheds particularly susceptible to erosion and runoff, is far more effective than watershed-wide approaches. Reduction of pollution-laden runoff from urban and suburban regions, through a range of measures, is also essential.

From the foregoing analysis, the frequency of runoff events carrying nutrients and contaminants is likely to continue to increase in the warming climate. Thus, for Ontario tributary basins to the lower Great Lakes (Erie and Ontario), the expectation is for an increase in phosphorus loading to water courses and the Lakes unless vigorous action is taken. These actions should be targeted towards:

a) Reducing runoff from heavy rain events, and
b) Reducing phosphorus available on the surface and top soil layer of urban and agricultural lands.

Without such vigorous action, increasing phosphorus loading to the lower Great Lakes is expected. Combined with higher water temperatures, less winter ice and longer periods of lake water stratification, this increase in phosphorus loading, if unchecked, will result in rapid trends towards more eutrophic states of the lower Great Lakes.

Acknowledgements: My appreciation, to Lorrie Minshall, Sandra Cooke, and other knowledgeable staff members of the Grand River Conservation Authority for their valuable advice. Thanks also to Kearon Bennett of Ottawa Engineering for computer analyses of hydrometric data and to Nancy Goucher, formerly of FLOW for editorial review of an earlier draft.

TABLE 1

Trends in runoff events

Station	Gauge #	Drainage Area km^2	Period	Increase delay	Increase factor	Max. flow threshold cms	# of events	Percentage Change	Max. flow Threshold cms	# of Events	Percentage Change
Grand River at Brantford	02GB001	5200.52	1967-1973 2004-2010	4 4	2 2	400 400	6 10	67%	200 200	28 33	18%
Nith River above Nithburg	02GA038	326	1973-1979 2004-2010	2 2	2 2	20 20	45 54	20%			
Grand River near Marsville	02GA014	663.01	1973-1979 2004-2010	2 2	2 2	50 50	22 30	36%	20 20	49 57	16%

Ottawa Engineering 2013

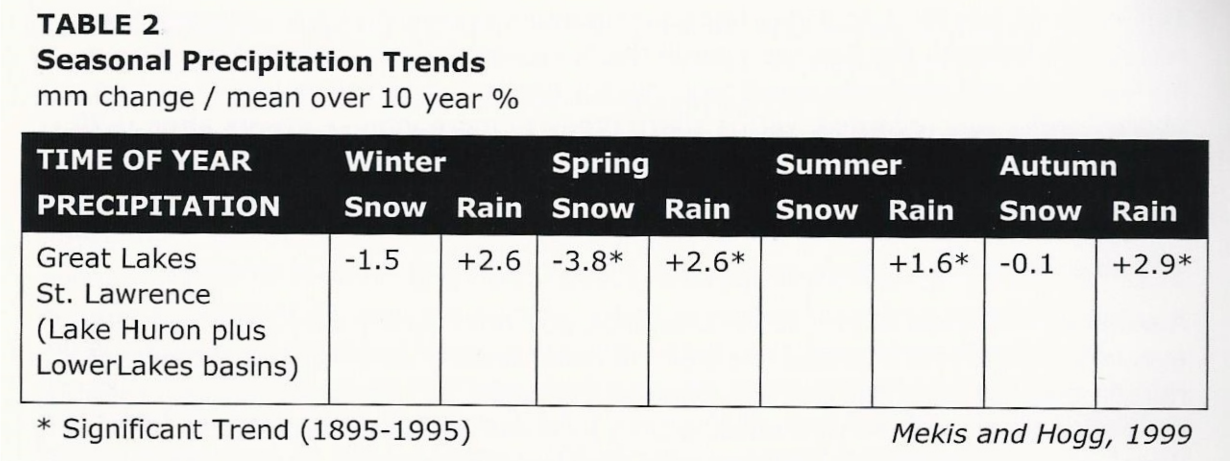

TABLE 2

Seasonal Precipitation Trends

mm change / mean over 10 year %

TIME OF YEAR	Winter		Spring		Summer		Autumn	
PRECIPITATION	Snow	Rain	Snow	Rain	Snow	Rain	Snow	Rain
Great Lakes St. Lawrence (Lake Huron plus LowerLakes basins)	-1.5	+2.6	-3.8*	+2.6*		+1.6*	-0.1	+2.9*

* Significant Trend (1895-1995)

Mekis and Hogg, 1999

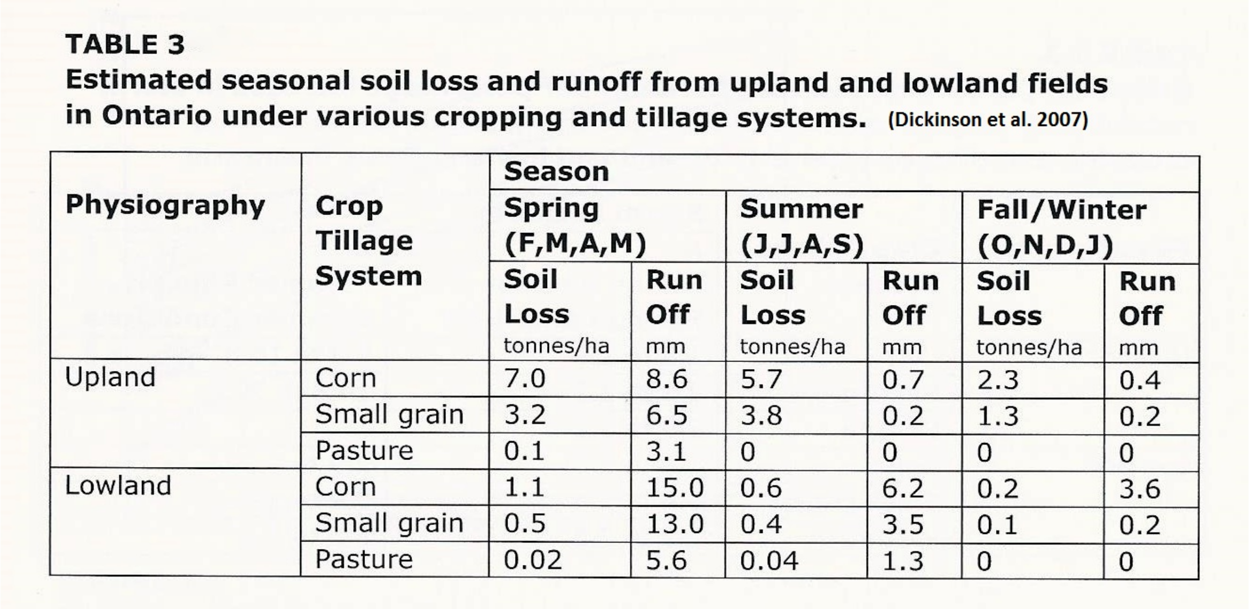

TABLE 3

Estimated seasonal soil loss and runoff from upland and lowland fields in Ontario under various cropping and tillage systems. (Dickinson et al. 2007)

Physiography	Crop Tillage System	Season					
		Spring (F,M,A,M)		Summer (J,J,A,S)		Fall/Winter (O,N,D,J)	
		Soil Loss tonnes/ha	Run Off mm	Soil Loss tonnes/ha	Run Off mm	Soil Loss tonnes/ha	Run Off mm
Upland	Corn	7.0	8.6	5.7	0.7	2.3	0.4
	Small grain	3.2	6.5	3.8	0.2	1.3	0.2
	Pasture	0.1	3.1	0	0	0	0
Lowland	Corn	1.1	15.0	0.6	6.2	0.2	3.6
	Small grain	0.5	13.0	0.4	3.5	0.1	0.2
	Pasture	0.02	5.6	0.04	1.3	0	0

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