Report No.:	WMPSC-2011-06-01	**Date:**	June 7, 2011
To:	Grand River Water Management Plan Steering Committee		
From:	Water Quality Working Group		
Subject:	Conceptual Understanding of Phosphorus Delivery in the Grand River Watershed		

REPORT:

The most significant water quality issue in the Grand River Watershed is the eutrophication of the river from both anthropogenic and natural sources. Eutrophication is a term used to describe the addition of nutrients, specifically nitrogen, phosphorus and/or carbon to freshwaters and the resulting increased growth of freshwater plants and algae. Nutrients are essential for plant and animal growth but their overabundance in freshwater systems can cause a number of adverse ecological effects (USGS 2009).

The Province of Ontario sets an objective of 0.030 mg Total Phosphorus / L as a threshold to limit the growth of aquatic plants and algae in rivers (Ministry of the Environment, 1999); however, this is only an interim guideline as the science behind phosphorus plant growth mechanisms and bioavailability is complex. Generally, phosphorus levels in the Grand River system tend to exceed the Provincial Objective (**Error! Reference source not found.**Figure 1). It is generally understood that phosphorus is the limiting nutrient in the Grand River system (Barlow-Busch 2006) and it's excess tends to facilitate the prolific growth of aquatic weeds and algae in some reaches.

Total phosphorus dynamics in rivers tends to be influenced by river flow (Doyle 2005) In general, higher phosphorus levels are seen in the river during high flows when overland runoff from snowmelt or significant rainfall events move a lot of water and soil off the land and into smaller streams, and then larger rivers. This tends to be true for the Grand River system. Figure 2 illustrates relatively strong relationships between phosphorus concentrations and flow at select monitoring sites within the Grand River system. Conversely, phosphorus levels tend to be lower during low flows such as summer when there is very little surface runoff and there is significant biological uptake by aquatic plants and/or algae (Figure 1)

The purpose of this technical paper is to describe the conceptual understanding of phosphorus dynamics in the Grand River system, characterize some of the mechanisms that drive phosphorus delivery / transport in surface waters and identify possible significant phosphorus contributing areas. To achieve this, phosphorus levels in the river will be illustrated from the headwaters, near Leggatt to Dunnville near the mouth of the Grand River during different hydrologic regimes which typically occur during different seasons. Understanding phosphorus dynamics in the river during different seasons and under different hydrologic regimes is important as there are different mechanisms contributing phosphorus to the river (point source discharges versus nonpoint source runoff) and water quality issues (e.g. prolific aquatic plant growth and subsequent large fluctuations in dissolved oxygen) depending on the season.

As a first attempt to qualitatively assess the phosphorus dynamics in the Grand River system, the most recent five year dataset (2006-2010) from the Provincial Water Quality Monitoring Network (PWQMN) was explored in the context of the hydrologic regime (e.g. high flows and low flows). Since 2004, effort has been made to collect PWQMN samples that characterize the hydrologic regime (high and low flows) across open water seasons (March through November). The highest river flows typically occur during spring runoff which typically occurs during the months of March and April (see Figure 3). In contrast, low flows are typically observed during the summer months of June, July, August and September (see Figure 3). River phosphorus dynamics during the winter months cannot be explored for this paper as the Provincial Water Quality Monitoring Network is limited to sample collection from March until November.

Total phosphorus and phosphate data from the PWQMN dataset were queried and the median statistic (50^{th} percentile) was calculated for the spring (March, April) and summer (June, July, August, September) for those sampling sites on the Grand River between Leggatt and Dunnville (Figure 4). The median statistic provided the best representation of 'typical' conditions; it describes neither the maximum nor the minimum values yet it was used to hypothesize the mechanisms driving phosphorus levels in the Grand River. These data were plotted in figures to spatially depict the dynamics in phosphorus concentrations as the river flows from the headwaters near Leggatt to Dunnville near the mouth of the Grand River.

The following sections describe the conceptual understanding of phosphorus dynamics in the watershed under both high and low flow regimes. Although this approach is qualitative, it is a start toward conceptually understanding phosphorus dynamics in a large river system. A more quantitative assessment of loads is required to fully describe those areas contributing greater amount of phosphorus to the Grand River (and therefore target those areas for phosphorus reduction strategies). In addition, detailed research is required, some of which is currently being undertaken by researchers from the University of Waterloo, to describe the detailed mechanisms behind phosphorus and aquatic plant/algae growth and transport into Lake Erie.

Conceptual Understanding of River Phosphorus Levels during High Flows

Generally, high river flows likely have a more significant impact on a downstream receiver. Although some sediment and nutrients are deposited in the river or taken up in aquatic biota through scouring and deposition, most of the load, or mass of sediment or nutrients transported by the river is likely transferred to a downstream receiver or end point. Further, there is little biological activity or processing in the river when high flows typically occur, due to cold temperatures; therefore, the high nutrient levels seen in the river are likely not as much a concern as they are during the summer low flows when biological activity is high. In the Grand River System, the downstream receivers are, generally, the large flood control reservoirs and Lake Erie. Therefore, during high spring flows, the endpoints of concern are generally these waterbodies.

In general, total phosphorus concentrations in the Grand River tend to increase in concentration from the headwaters to the mouth (Figure 5). During high flows in the spring, total phosphorus levels in the Grand River near Leggatt already tend to exceed the provincial guideline of 0.030 mg/L. Runoff from the headwater area drains the Dundalk till plain and much of the water on the landscape tends to move off the land quickly carrying sediment and phosphorus. Concentrations gradually increase as the river flows toward Belwood Lake, which is a reservoir that is operated to control peak flows and hold water back before releasing more controlled flows downstream. The build up of phosphorus in the reservoir is released downstream as indicated by a marked increase in phosphorus between the sites upstream and downstream of

Shand Dam. Between the Shand Dam and West Montrose phosphorus levels don't tend to increase significantly, since the river collects flows from smaller tributaries with relatively low phosphorus and there are only two smaller point source discharges.

Phosphorus levels in the Grand River more than double after receiving flows from the Conestogo River. This is evident by a significant jump in median total phosphorus level seen in the Grand River at Bridgeport. The geology of the upper Conestogo River basin and the land use - some of the most intensive agricultural production in the watershed, likely influences the phosphorus levels in the Grand River as it flows into the Region of Waterloo.

It is hypothesized that urban stormwater runoff during the spring, combined with multiple point source discharges nearly doubles the phosphorus levels in the Grand River through the Region of Waterloo; however, the urban stormwater contribution to the river is not well characterized. The limited dataset and/or the Mannheim weir likely play a role in the phosphorus dynamics in the river at Freeport.

As the Grand River flows out of the large urban area toward Glen Morris, it receives the flow from the entire Speed/Eramosa catchment. The phosphorus levels tend to decrease but are still well above the provincial objective of 0.030 mg/L. Although there is a significant urban area within the Speed River subbasin, it also drains the Eramosa system which has some of the lowest river phosphorus concentrations in the watershed. Therefore, the Speed Eramosa River system likely helps to reduce the total phosphorus levels in the Grand River.

The Nith River and Whitemans Creek, both of which are unregulated rivers with extensive agricultural production, join the Grand River upstream of the City of Brantford. Spring high flows from the Nith River are significant and are about 24 percent of the Grand River (D. Boyd, pers. comm.). Median phosphorus levels in the Nith during high flows are relatively high at 0.113 yet levels can reach as high as 1.66 mg/L (maximum concentration sampled March 2007) during springtime. In contrast, phosphorus is not as high in Whitemans Creek as the median concentration for spring runoff is 0.089 mg/L and maximum levels are five times less than they are in the Nith River. The high levels seen in the Nith River during spring runoff conditions likely contribute to the doubling of total phosphorus levels in the Grand River in Brantford when compared to the levels seen at Glen Morris. The Grand River appears to be heavily influenced by the Nith River but also likely local urban runoff from the City of Brantford as well; however, there are no data describing the urban stormwater contributions through the City of Brantford.

As the Grand River flows out of Brantford toward York and Dunnville, it flows onto the Haldimand Clay plain. The transition onto the clay plain is significant with respect to phosphorus and sediment dynamics as clay particles are easily suspended in the water column giving the river a 'dirty' look. Phosphorus binds tightly to clay due to the adsorption properties of clay and therefore, phosphorus levels in the river would naturally increase throughout this region due to the influence of the geology. However, land use likely exacerbates the levels seen in the river.

Phosphorus levels tend to recede somewhat but the levels still remain well above the provincial objective. The dams in Caledonia and Dunnville likely play a significant role in the phosphorus dynamics in the river as they alter the fundamental hydraulic character of the river. The median total phosphorus levels during high spring flows at Dunnville (0.128 mg/L) are about four times the provincial objective but the maximum concentrations seen can be as high as 12 times the objective (0.360 mg/L). These very high levels are discharged to the eastern basin of Lake Erie and likely have a significant impact along the nearshore region of the lake (T. Howell, pers. comm.).

Conceptual Understanding of River Phosphorus Levels during Low Flows

Low flows typically occur in the Grand River during the hot summer months of June, July, August and September (see Figure 3Figure 3). This is the time period in which significant biological activity (e.g. photosynthesis and respiration) occurs and there is significant aquatic plant and algae growth in the river. Phosphorus is the key limiting nutrient in the Grand River and generally drives the aquatic plant growth; consequently, the more phosphorus in the river, the higher the productivity of these waters.

Unlike spring runoff in which there is a strong flushing effect and the endpoints of concern are the reservoirs or Lake Erie, river hydrology during the summer is not as dynamic. Except for large rainfall events, river flows in the summer and the biological activity in the river tend to be heavily influenced by local inputs like point source discharges. Therefore, the endpoint of concern within the Grand River system during the summer is likely more localized river reaches. It must be acknowledged, however, that the effects of high flows cannot be completely separated from the resulting biological activity of the river during the summer due to the spiralling or deposition of sediment and phosphorus in river reaches from upstream areas. Although the following may be an over simplified conceptualization of phosphorus dynamics during low river flows, it is a start at understanding the mechanisms driving phosphorus dynamics and the resulting biological effects which contribute to summer water quality issues in the river.

Median summer total phosphorus levels in the headwater region of the Grand River system tend to be at or slightly below the provincial objective of 0.030 mg/L (Figure 6). Flows in the summer in the upper Grand River region are sustained by discharges from the Luther Marsh in addition to some minor groundwater inputs from the Orangeville moraine. These sources of water to the river likely influence the low phosphorus levels found in the river.

In the hot summer months, Belwood Lake becomes thermally stratified which results in elevated phosphorus levels in the bottom waters due to hypoxic conditions. This phosphorus-rich water is discharged from the bottom valve of the Shand Dam to the tailwater region of the Grand. This effectively makes Belwood Lake a source of nutrients to the central Grand River.

The Grand River between the Shand Dam and the confluence of the Conestogo River collects flows from small groundwater fed streams (e.g. Carroll, Cox, Swan, Irvine). There are only two small point source discharges (e.g. Fergus and Elora), so the phosphorus in this reach tends to be assimilated without significant negative effects on the water quality. This results in a general decrease in phosphorus levels in the river as it flows from the Shand Dam to West Montrose.

Phosphorus levels in the Grand River tend to steadily climb once it receives the flow from the Conestogo River and then flows into the Region of Waterloo. The river receives the inputs from two substantive point source discharges – the Waterloo and Kitchener wastewater treatment plants and a number of smaller ones (Hespeler, Preston and Galt) which service a population of over 485,000 (2011) (Region of Waterloo, 2011). Given the low river flows in this reach, these inputs heavily influence the phosphorus levels and resulting biological activity in the river. The median total phosphorus level in the Grand River at Blair is twice the provincial objective and is likely one of the mechanisms driving the prolific aquatic plant/algae growth in this reach. Hood et al, (2009) at the University of Waterloo have determined that aquatic plants and algae in the central Grand River are a significant sink of phosphorus in the summer. Of particular note is the significant increase in phosphate (i.e. soluble reactive phosphorus) levels in the river at this point as well. Phosphate is considered to be the more biologically available form of phosphorus. The significant increase in phosphate at Blair is likely sourced from the upstream wastewater treatment plants, as it is acknowledged that wastewater effluent tends to have disproportionately high soluble phosphorus (Jarvie et al. 2006).

As the Grand River flows out of the central urban region, phosphorus levels tend to decrease or be assimilated by the biological processes in the river. The Speed River may also play a role in decreasing the total phosphorus levels in the river as well as total phosphorus levels tend to be much lower than in the Grand. Since there are few smaller point source discharges to the river between Cambridge and Brantford, the river tends to be able to assimilate phosphorus with limited impacts to the physiochemical regime of the river. For example, the fluctuations of dissolved oxygen in the river at Glen Morris, although quite dramatic, only occasionally fall below the provincial objective. Total phosphorus levels tend to continue to decrease as the river flows into Brantford. The Nith River and Whitemans Creek also tend to influence the decrease in phosphorus levels seen in the river, as phosphorus levels from these river systems are generally low (i.e. below the provincial objective) in the summer due to the significant discharge of groundwater that heavily influences the stream flows and stream chemistry in these systems.

Once the river flows out of Brantford and onto the Haldimand Clay plain, it is strongly influenced by the geology as the point sources tend to be relatively minor when compared to the flow in the river. The phosphorus levels in the Grand River increase dramatically as it flows from Brantford toward York and then Dunnville likely due to the clay particles in suspension which have a natural affinity for adsorbing phosphorus.

On-line dams in Caledonia and Dunnville also play a role in the phosphorus dynamics in the river. More detailed assessment of the southern Grand for a Canada-Ontario Agreement (COA) sponsored project in 2004 illustrated the influence of the dams in which phosphorus levels tended to 'spike' just above the dams (Figure 7) (Cooke, 2005). A build up of phosphorus-rich sediment; the lake-like behaviour of the river behind these dams; and localized biogeochemical processes likely contributes to the increased phosphorus levels found in the lower river reaches. Researchers at the University of Waterloo (Kuntz, Smith, Schiff et al.) have also documented the increasing total phosphorus levels and contrasting draw-down of biologically available phosphorus in the southern Grand River during in the summer months. Of particular note and interest is the corresponding increase in soluble reactive phosphorus at Dunnville, also likely influenced by the on-line dams and the lake-like behaviour of the river in this reach. The high levels of biologically available phosphorus in Dunnville (Figure 7), however, likely have significance to aquatic plant and algae growth along the nearshore of Lake Erie. Further research is required to fully characterize the phosphorus dynamics in the southern Grand River and its connection with the eastern basin of Lake Erie.

Summary

Our conceptual understanding of phosphorus dynamics in the Grand River system is limited to current river water quality monitoring activities, most notable the Provincial Water Quality Monitoring Network. Over the last 5 to 8 years, there has been a substantive research effort in characterizing phosphorus and nitrogen dynamics in the river; the predominant biological processes influencing river phosphorus concentrations; and aquatic biomass that we are only starting to synthesize and learn from (e.g. Schiff, Taylor, Smith et al). Our conceptual understanding allows water managers to highlight areas of focus for management and identify gaps in the collective understanding of phosphorus dynamics in the Grand River system. For example, agricultural best management practices should be targeted to those areas in the Conestogo and Nith rivers, as these are contributing areas during high flow events when the mechanism of phosphorus transport is overland runoff and the end points are reservoirs and Lake Erie. Alternatively, In addition, during low summer flows the mechanism contributing to elevated phosphorus levels is point source discharges; consequently attention must be made to reduce phosphorus levels in sewage effluent where those inputs of phosphorus to the river cannot be assimilated.

Furthering our understanding of phosphorus dynamics, as well as nitrogen, in the Grand River system will require a commitment to long term monitoring and additional research during all seasons, since different water quality issues can be seen during different times of the year. Further, more intensive monitoring is required to fully characterize and quantify phosphorus loads from contaminant source areas so that, in a progressive fashion, hot spots can be identified and appropriate land management actions can be adopted. Lastly, the sustainability of the Grand River system will require all agencies to do their part, so that the cumulative effects of phosphorus from the headwaters to the mouth can be reduced not only for the Grand River itself, but also for Lake Erie.

References

Barlow-Busch, L., Baulch, H.M., Taylor, W.D.. 2006. Phosphate uptake by seston and epilithon 3 in the Grand River, southern Ontario. Aquat.Sci. 68: 181-192

Cooke, S. 2004 (draft). Southern Grand River Rehabilitation Initiative: Water Quality Characterization. Grand River Conservation Authority, Cambridge, ON. 49p.

Doyle, M.W. 2005. Incorporating hydrologic variability into nutrient spiralling. J. Geophysical Research 110:

Hood, J., WD Taylor, S Schiff. 2009. Assessing the role of benthic macrophytic and macroalgal communities in N and P cycling using large scale spatial surveys. IAGLR Conference,

Jarvie, H., C. Neal, and P. Withers. 2006 Sewage-effluent phosphorus: A greater risk to river eutrophication than agricultural phosphorus? Science of the Total Environment 360 (2006) 246– 253

Kuntz, T. 2008. System and plankton metabolism in the lower Grand River, Ontario. Masters of Science Thesis, University of Waterloo, Waterloo, ON. 94p.

Ministry of the Environment. 1999. Water Management Policies, Guidelines, Provincial Water Quality Objectives of the Ministry of the Environment and Energy. Province of Ontario.

Region of Waterloo. 2011. Water and Wastewater Monitoring Report. Region of Waterloo, Kitchener, Ontario (http:www.region.waterloo.on.ca/en/aboutTheEnvironment/Wastewater2.asp)

USGS. 2009. Nutrients in the Nation's Waters--Too Much of a Good Thing? http://pubs.usgs.gov/circ/circ1136

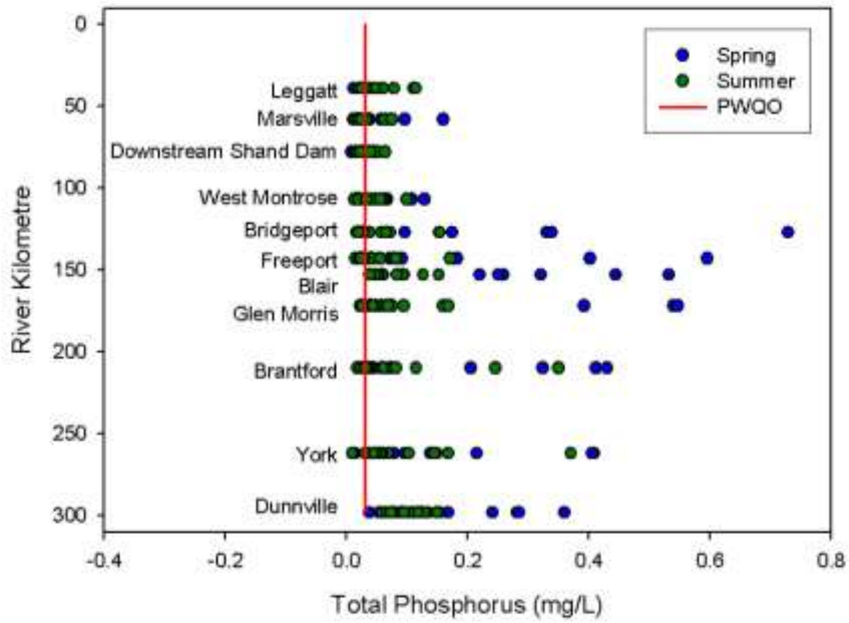

Figure 1. Total phosphorus concentrations at monitoring sites from the headwater region (e.g. Leggatt) to Dunnville on the Grand River for Spring high flows (blue dots) and summer low flows (green dots). The red line is the Provincial Water Quality Objective. Data from the Provincial Water Quality Monitoring Network (2006-2010).

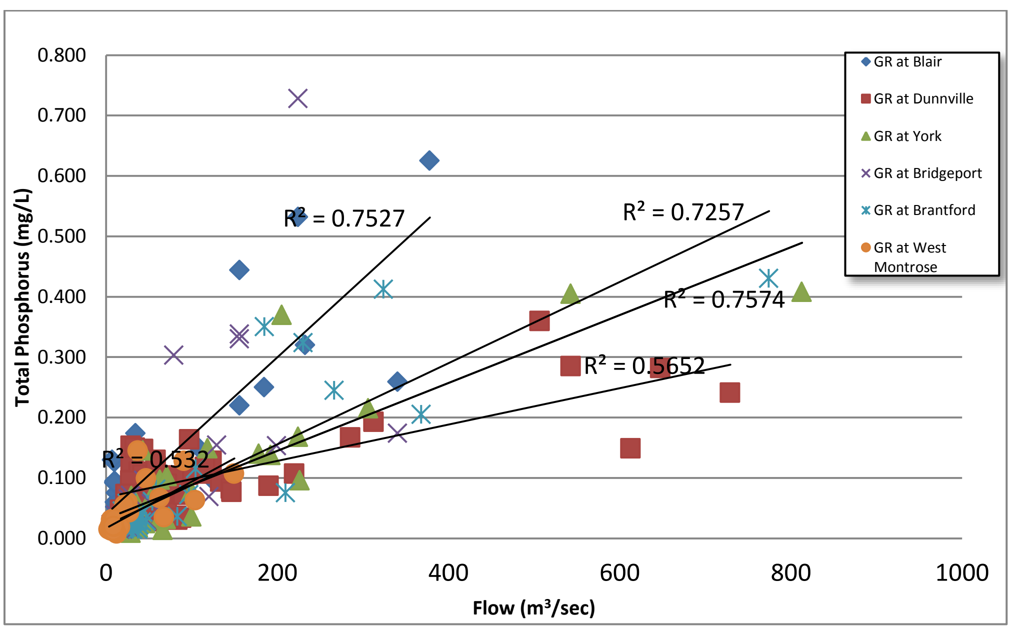

Figure 2. Relationship between total phosphorus (mg/L) and river flow (m^3/sec) at select locations on the Grand River. In general, the R^2 values illustrates a stronger relationship between total phosphorus concentrations and flow.

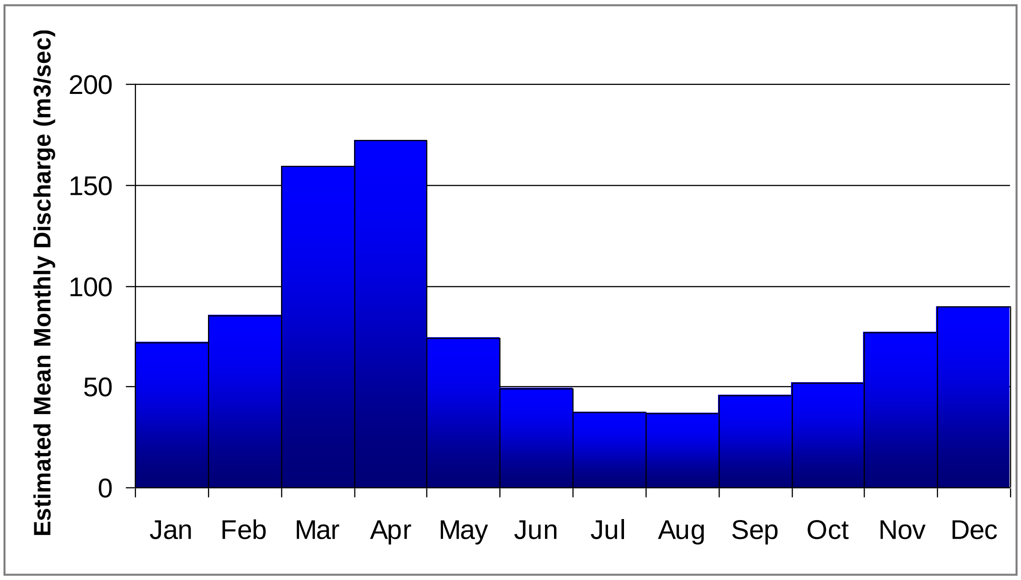

Figure 3. Mean monthly discharge at Port Maitland

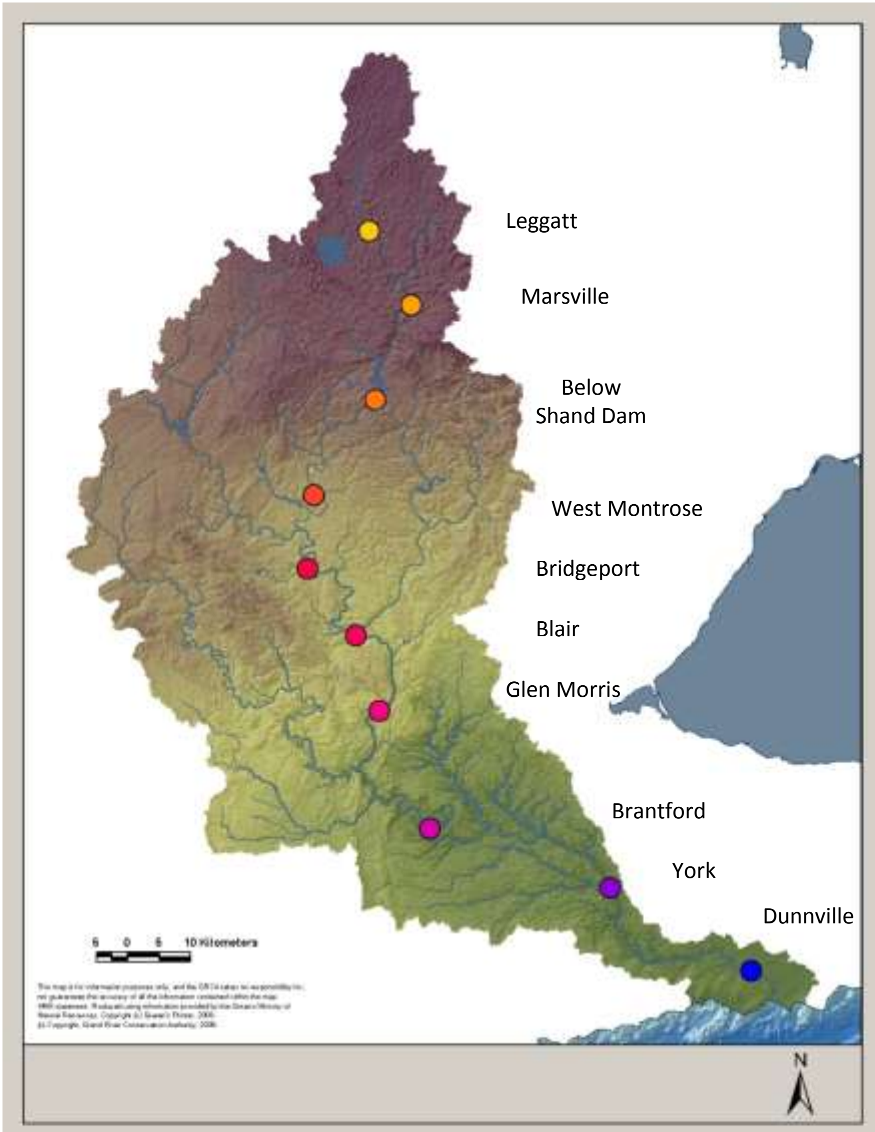

Figure 4. The Grand River watershed illustrating the Provincial Water Quality Monitoring network sampling sites along the Grand River

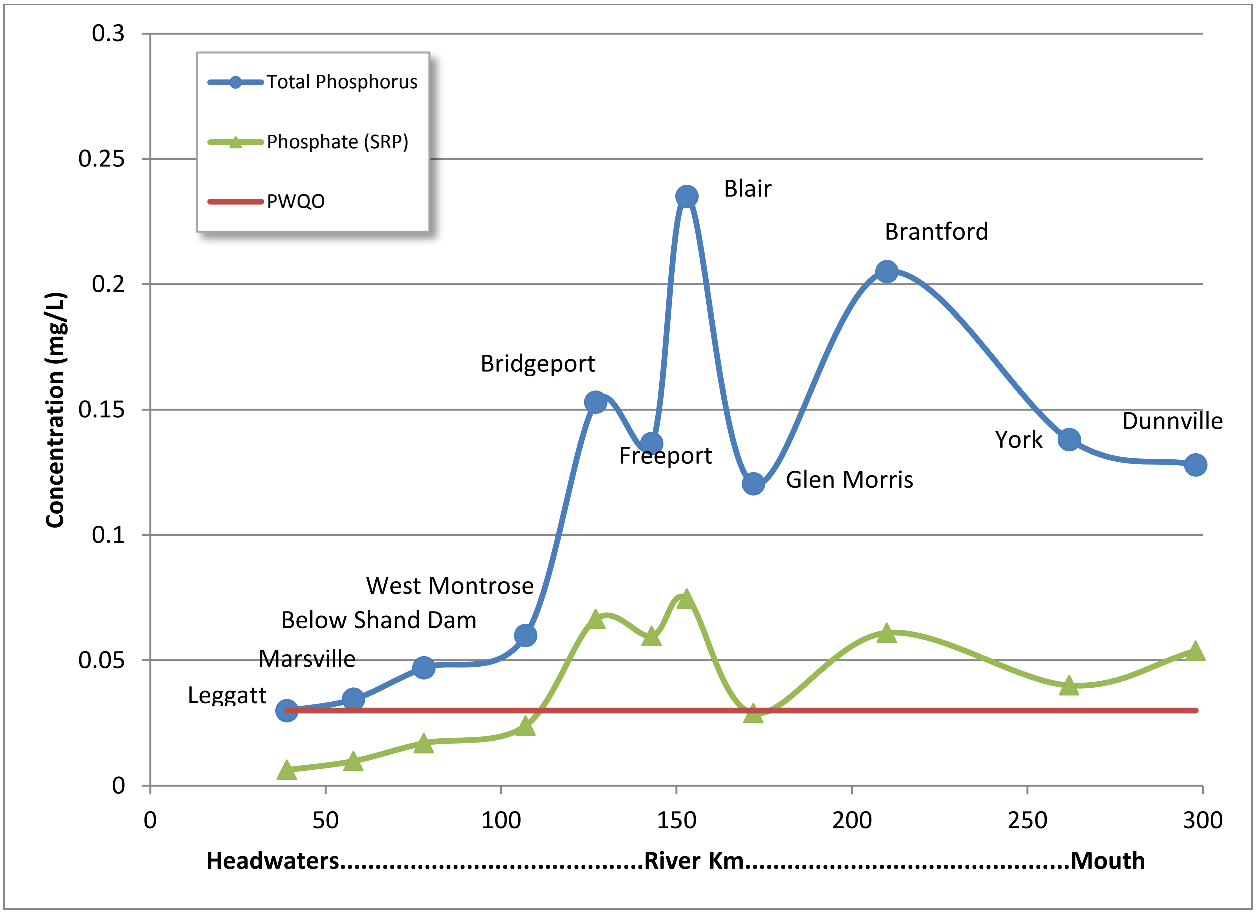

Figure 5. Representative total phosphorus and soluble reactive phosphorus (a measure of biologically available phosphorus or phosphate) concentrations along the Grand River from the headwaters (Leggatt) to the mouth of the Grand River near Dunnville during spring (e.g. March/April) high flow conditions. The red line is the Provincial Water Quality Objective of 0.030 mg/L.

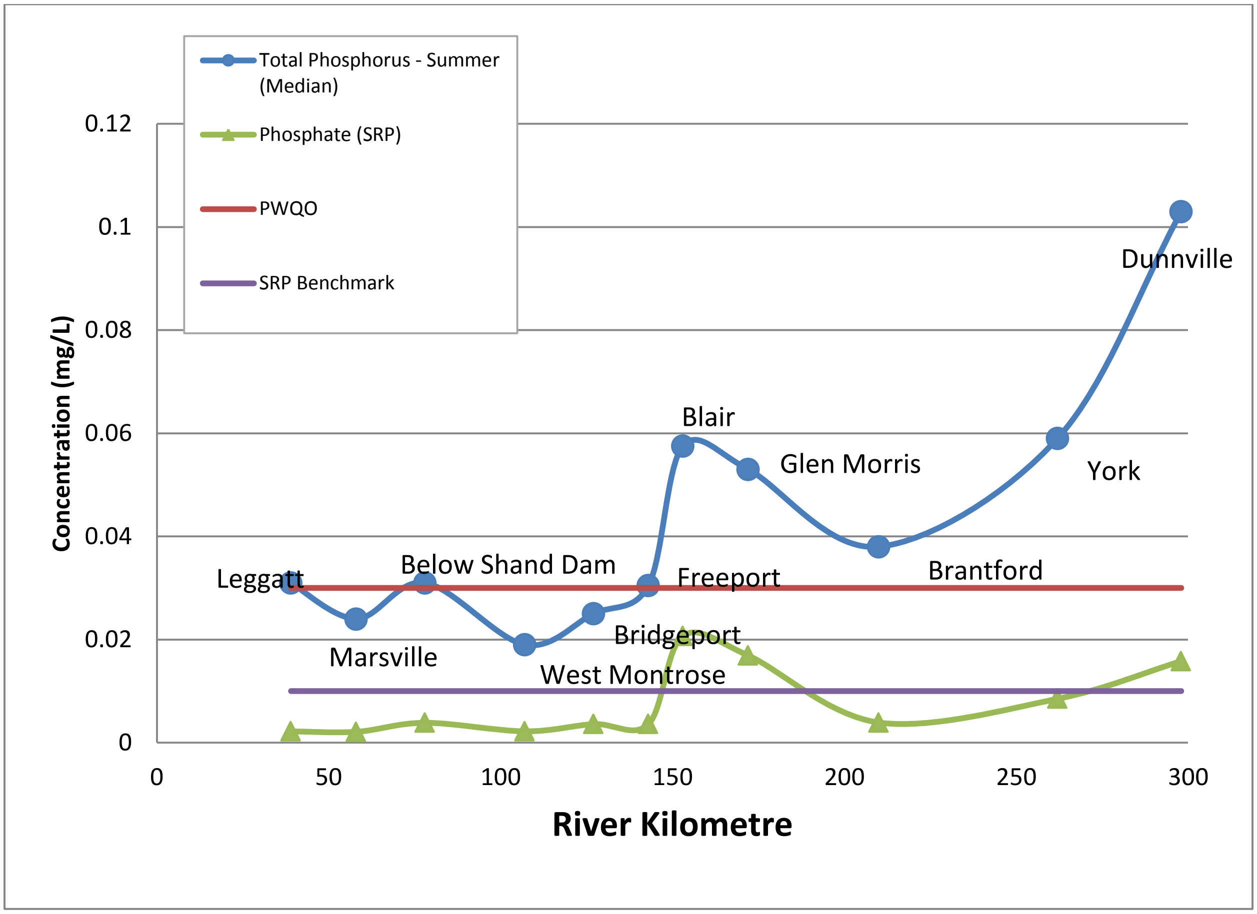

Figure 6 Representative total phosphorus and soluble reactive phosphorus (a measure of biologically available phosphorus or phosphate) concentrations along the Grand River from the headwaters (Leggatt) to the mouth of the Grand River near Dunnville during low flow conditions (e.g. June – September). The red line is the Provincial Water Quality Objective of 0.030 mg/L.

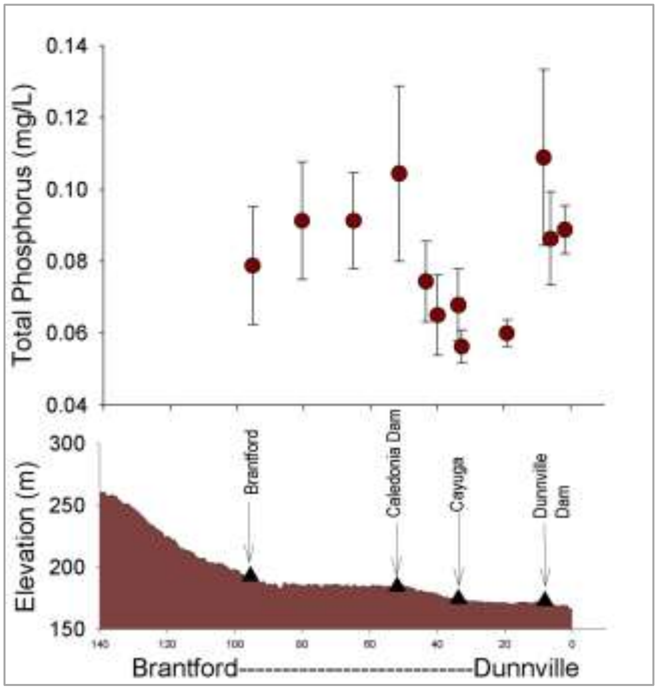

Figure 7. The average summer phosphorus levels (dot) and range (maximum and minimum) in the Grand River between Brantford and the Dunnville Dam. The bottom figure illustrates the elevation profile of the southern Grand River with the locations of on-line dams.

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