The Welland River Eutrophication Study in the Niagara River Area of Concern in Support of the Beneficial Use Impairment: *Eutrophication and Undesirable Algae*

Niagara River Remedial Action Plan

March 2011

Niagara River RAP
Welland River
Eutrophication Study
Technical Working Group

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Written by: Joshua Diamond
Niagara Peninsula Conservation Authority

On behalf of:
Welland River Eutrophication Technical Working Group

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Table of Acronyms

AOC	Area of Concern
BMPs	Best Management Practices
BOD	Bio-chemical (or biological) oxygen demand
BUI	Beneficial Use Impairment
CCME	Canadian Council of Ministers of the Environment
chl*a*	Chlorophyll-a
COD	Chemical Oxygen Demand
CSO	Combined Sewer Overflow
DO	Dissolved Oxygen
EC	Environment Canada
GRCA	Grand River Conservation Authority
HEC-HMS	Hydrologic Engineering Centre-Hydrologic Modeling System
MISA	Municipal-Industrial Strategy for Abatement
MNR	(Ontario) Ministry of Natural Resources
MOE	(Ontario) Ministry of the Environment
NAESI	National Agricultural Environmental Standards Initiative
NH_3	Total Ammonia
NOD	Nitrogenous Oxygen Demand
NPCA	Niagara Peninsula Conservation Authority
PWQMN	Provincial Water Quality Monitoring Network
PWQO	Provincial Water Quality Objectives
RAP	Remedial Action Plan
RMN	Regional Municipality of Niagara
SEL	Severe Effect Level (of provincial sediment quality guideline)
SOD	Sediment Oxygen Demand
SOLRIS	Southern Ontario Land Resource Information System
SW	Storm Water
TKN	Total Kjeldahl Nitrogen
TOC	Total Organic Carbon
TP	Total Phosphorus
TSS	Total Suspended Solids
TWG	Technical Working Group
WWTP	Waste Water Treatment Plant

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1.0 Introduction

1.1 Study Context

The Welland River Eutrophication Study was conducted in response to an Environment Canada (EC) Technical Review (2007) of the Beneficial Use Impairments (BUIs) and delisting criteria identified in the Niagara River Area of Concern (AOC) Stage 2 Report (1995). This review recognized that the existing delisting criteria for the BUI: *Eutrophication and Undesirable Algae* required updating, but also recognized the need for further study to fill data gaps. These recommendations are summarized in Appendix H of the Technical Review (2007). The Terms of Reference and subsequent Workplan for the Welland Eutrophication Study were written and implemented in late 2007 to address these data gaps and to outline the various monitoring requirements and study deliverables. These documents are found in **Appendix A**.

The Welland River Eutrophication Study was a three year study (2008-2010) led by the Niagara Peninsula Conservation Authority (NPCA) in partnership with the City of Welland, EC, Ontario Ministry of the Environment (MOE), Ontario Ministry of Natural Resources (MNR), and the Regional Municipality of Niagara (RMN). The Study was overseen by a Technical Working Group (TWG) comprising of study partners with relevant expertise in Eutrophication and Algae ecology. The TWG approved the Study Work Plan and met annually to discuss yearly results compiled by the NPCA in Technical Reports. The Minutes for all TWG meetings are found in **Appendix B.**

1.2 Welland River Background

The Welland River is the largest river tributary to the Niagara River Area of Concern (AOC). Located above the Niagara Escarpment, the Welland River watershed is a dense network of smaller tributaries with similar characteristics to the main river. It flows in an easterly direction, from its headwaters south-west of Hamilton in the Mount Hope area, and meanders over a course of 132 km until it reaches the Queenston-Chippawa Power Canal into which it presently discharges. It drains lands in Haldimand, Norfolk and Niagara over an area of approximately 880 km^2 and its watershed encompasses over 80% of the Canadian portion of the AOC (**Figure 1**). The Welland River watershed is in the Haldimand Clay Plain. The basin is very flat with an average gradient of 0.58 metres/kilometres and, due to the clay soils, it is imperfectly drained. In 1792, the river was described as “a dull muddy river running through a flat swampy country” by Mrs. Simcoe, wife of the first Lieutenant Governor of Upper Canada. Within the watershed, the major economic activity is agriculture and there are no major industries located upstream of the City of Welland.

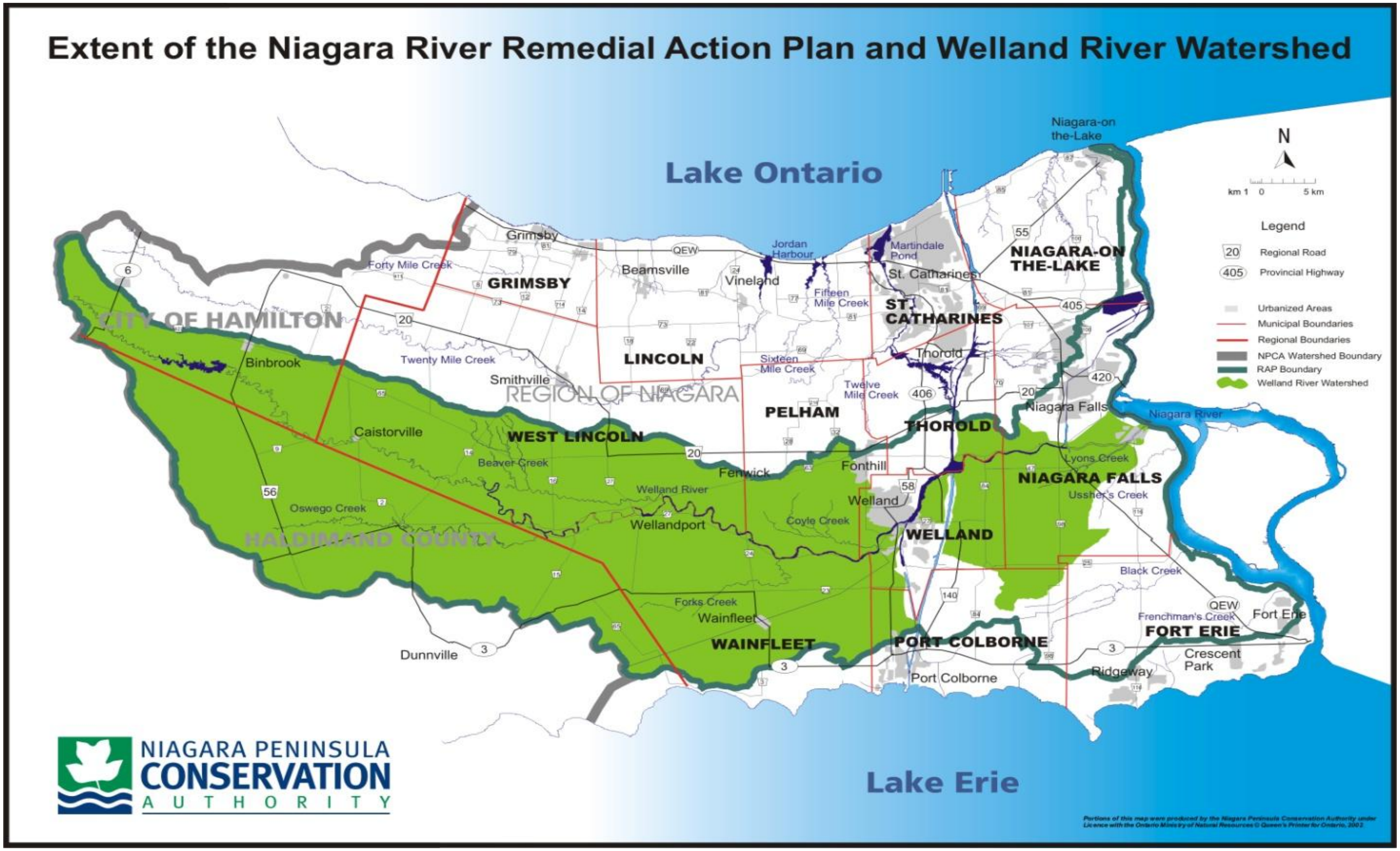

Figure 1: Extent of the Niagara River Remedial Action Plan and Welland River Watershed

Historically, the Welland River drained into the Niagara River at the Town of Chippawa. Along its entire route, the Welland River has been greatly altered by humans. In 1971, the NPCA constructed a dam on the river near Binbrook in the upper reaches of the watershed which created Lake Niapenco, also known as the Binbrook Reservoir. The dam was created for the purpose of low flow augmentation as the river often experienced periods of zero flow during drought conditions. Continuing eastward the river also flows through the City of Welland where it is siphoned under the Old and New Welland Ship Canals. The final outlet of Welland River water is via the Power Canal to the lower Niagara River at Sir Adam Beck generating stations. Considerable alterations made to the Welland River since European settlements have created an extremely complex system. The river has been channelized, relocated, dredged and diverted for both shipping and hydroelectric production. It has been described as one of the most complex river systems in Ontario, with seven physically different sections (Upper Welland River,

Lake Niapenco (Binbrook Reservoir), Welland River upstream of Port Davidson Weir, Welland River West of Welland to the Port Davidson Weir, Between the Two Canals (Lake Erie Diversion), Downstream of the New Canal to Power Canal and the Power Canal to Niagara River (Chippawa Channel, Niagara River Diversion). The net result of these activities causes flow barriers to the Welland River which, in turn, creates water dilution, sediment and pollutant trapping, and flow reversal patterns in the river. This situation makes it difficult to determine both the source and fate of sediment, phosphorous, bacteria and other pollutants entering the Welland River. The river exhibits all of the qualities of a degraded system (i.e. impaired water quality, and impaired fish & wildlife habitat and their communities).

In summary, the significant changes since European settlement include:

- Significant reduction of forest cover from urban development and agricultural practices;
- Draining of the land for agriculture;
- Increased erosion related to construction, agriculture and cattle access;
- Nutrient loading from Waste Water Treatment Plant and Combined Sewer Overflows;
- Impacts from the development and management of Binbrook Reservoir;
- Installation of weirs along various creeks and tributaries to the River;
- Changes associated with the construction of the Welland shipping canals;
- Historical dredging of the river channel from Port Davidson to the Niagara section of the River;
- Changes in flow regimes arising from diversions of water into and out of the Welland River and the flow reversal in the lower portion of the River due to hydroelectric operations; and
- Daily fluctuations in levels and flows from the control of the Chippawa-Grass Island Pool levels.

1.3 Historic Welland River Water Quality

Ambient water quality monitoring of the Welland River dates back to 1966 and continues to 1991 with water samples collected through the Provincial Water Quality Monitoring Network (PWQMN). The MOE continued monitoring at the Montrose Road station until 2003. In 1994 to 1996 the NPCA received a sampling allotment for continued water quality monitoring in the Welland River watershed.

The greatest problem identified in the historic water quality dataset of the Welland River upstream of the City of Welland is the chronically high phosphorus concentrations and its related effects throughout the watershed (RAP 1995). Total phosphorus (TP) concentrations (**Figure 2**) during this historic data set regularly exceeded the Provincial Water Quality Objective (PWQO) of 0.03 mg/L (MOE 1994). Generally, TP concentrations increase in the Welland River watershed from the headwater sections to the lower reaches near the City of Welland. It is at this point where the redirection of Niagara River water down the Welland River in Chippawa for Ontario Power Generation causes a dilution effect on water quality parameters. Historic phosphate concentrations (**Figure 3**) in the Welland River follow a similar trend to TP concentrations.

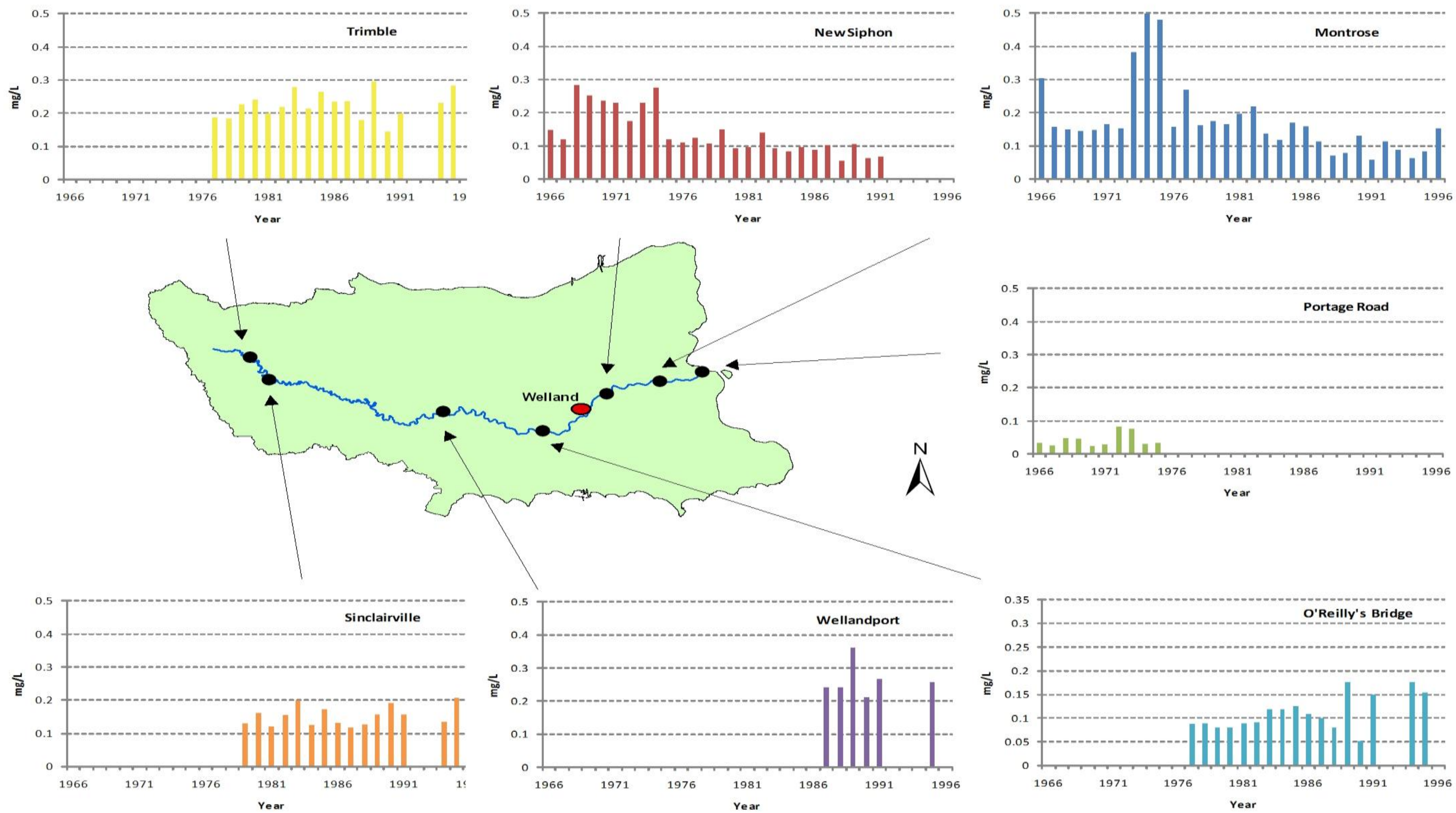

Figure 2: Historic PWQMN Total Phosphorus Concentrations (mg/L) in the Welland River from 1966 to 1996.

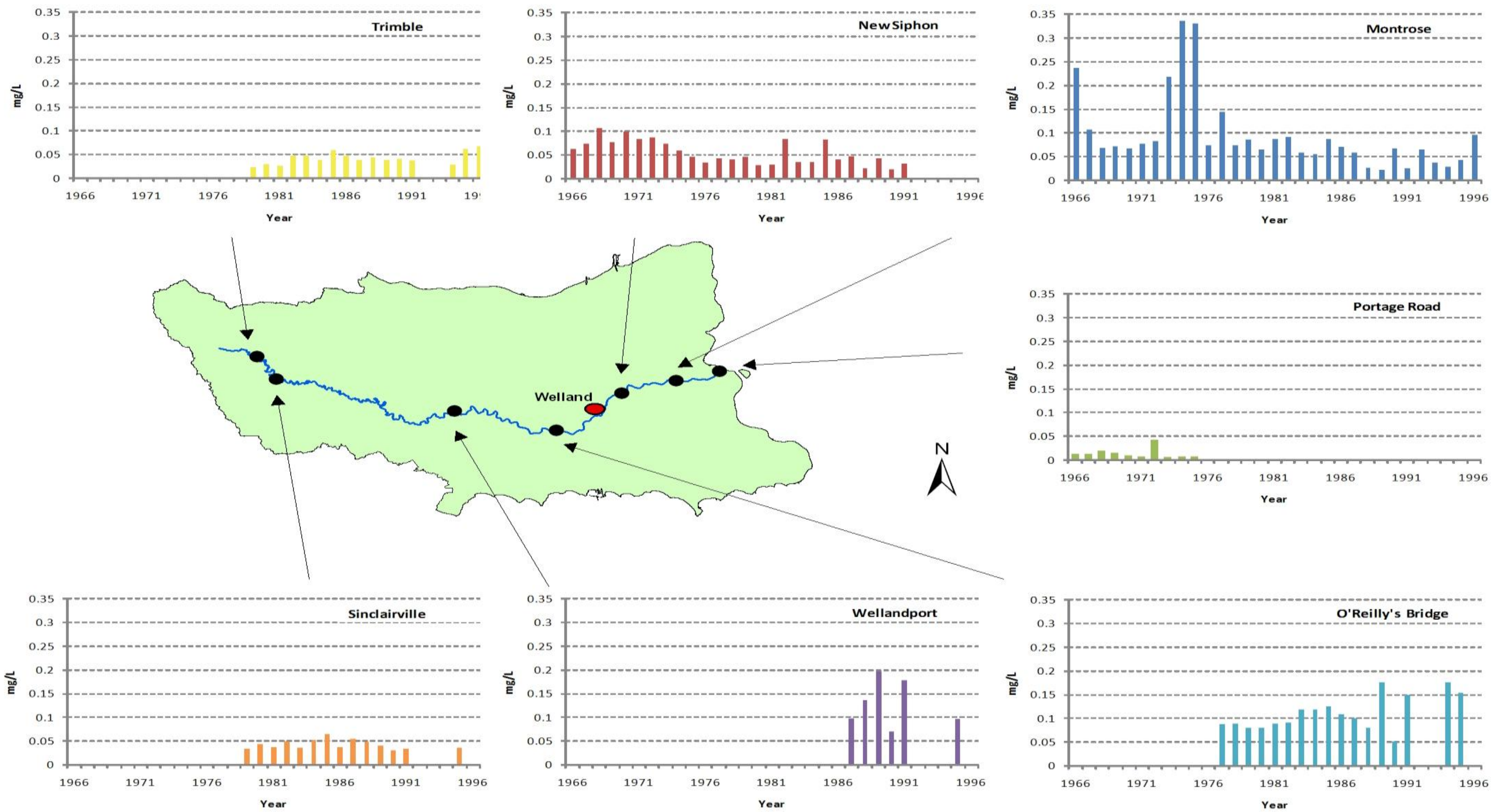

Figure 3: Historic PWQMN Phosphate Concentrations (mg/L) in the Welland River from 1966 to 1996.

The Welland River is the largest tributary of the Canadian portion of the Niagara River AOC and was identified through the RAP Stage 1 (Remedial Action Plan 1993) and RAP Stage 2 (Remedial Action Plan 1995) reports as a potential source for various contaminants to the Niagara River. The RAP evaluated the impairment status of several BUIs in the Niagara River RAP including the BUI: *Eutrophication and Undesirable Algae*. This evaluation designated the BUI: *Eutrophication and Undesirable Algae* in the Niagara River AOC as impaired.

In 2001, the NPCA initiated a Water Quality Monitoring Program with the purpose of gathering long-term surface water quality data. The funding for this program is supported through multiple partnerships. Within the Niagara River AOC, the MOE has reactivated two dormant PWQMN stations. The City of Hamilton and RMN provide funding for staff and lab analysis. EC has provided funding for this program for lab analysis through the Great Lakes Sustainability Fund. The current network of 73 water quality monitoring stations represents the largest and most comprehensive water quality monitoring program in the Niagara Peninsula. Water quality data collected through this program has been summarized in NPCA Annual Water Quality Reports (NPCA 2006-2010) and other Niagara River RAP reporting requirements (NPCA 2003, NPCA 2004). Water quality monitoring of the Welland River through this program continues to regularly find total phosphorus concentrations in the Welland River in exceedence of the PWQO (MOE 1994).

Between 2005 and 2007, a 10-year review of the framework for implementation of remedial actions was undertaken as part of the Niagara River (Ontario) RAP. This included review and, where applicable, revision of the status of BUIs. The EC (2007) Technical Review of Impairments and Delisting Criteria. Niagara River (Ontario) RAP reported anecdotal evidence of persistent and reoccurring algal blooms in the Welland River from the mid-1990s until 2007. This anecdotal evidence was mainly based on comments made by residents living in the Welland River watershed often in the summer. However, there is very little scientific data to verify that algae blooms are regularly occurring in the Welland River as a consequence of high nutrient concentrations. A water quality study of Binbrook Reservoir by the MOE staff (Gemza 1993) included an algae assessment and this study concluded the occurrences of algae blooms were very infrequent. But there were some blue-green algae blooms noted in mid to late summer. This generally agrees with NPCA field and technical staff observations over the years.

The EC Technical Review (2007) reported dissolved oxygen (DO) conditions were found in several sections of the Welland River were below PWQO (MOE 2004). This was mainly based on DO monitoring the NPCA conducted in the night-time of August 1994 to determine if low DO conditions were occurring. The NPCA determined that 86% of the night-time results were below the PWQO (MOE 2004). The EC Technical Review (2007) also used daytime supersaturation of DO as an indicator of the risk of oxygen depletion due to algal or macrophyte respiration. At NPCA Welland River water quality stations in 2003 and 2004, percent saturation of DO exceeded 100% in 19% of (25 of 129) samples. The EC Technical Review suggested DO impairments are likely caused by algae blooms and decomposition, macrophyte overgrowth and bio-chemical oxygen demand (BOD) from the City of Welland Combined Sewer Overflows (CSOs) and Waste Water Treatment Plant (WWTP). In 2007, NPCA deployed a DO logger in the Welland River at E.C. Brown Conservation Area and observed sustained DO conditions that were below the PWQO for parts of the summer. This supports EC Technical Review of the existing data that concentrations of DO are below the PWQO in some sections of the Welland River. Further data was still needed to determine the spatial range of these DO impairments.

In 2003, the RMN retained consultants as part of the Niagara Water Quality Protection Strategy (RMN 2003). These consultants carried out a simple mass balance modeling of contaminant loads in watersheds across the Niagara Peninsula and the Welland River. This analysis was incorporated into the EC Technical Review (2007) of the BUI for *Eutrophication and Undesirable Algae.* Modeling was conducted for TP, total Kjeldahl nitrogen (TKN), and total ammonia (NH_3), as well as other contaminants (*E. coli*, copper, Total Suspended Solids (TSS). Results were categorized by land area or effluent source including, CSO, urban storm water (SW), urban WWTP, agricultural lands, and parks/open space/forest (classed as “other”). Additional nutrient loading data was supplied by the MOE (2005) through Municipal-Industrial Strategy for Abatement (MISA) contaminant load calculations based on recent (2000-2002) effluent monitoring at WWTPs within the Welland watershed. Results of this work are shown in **Table 1** and **Table 2** below.

Table 1: Total phosphorus, ammonia, and total Kjeldahl nitrogen loadings and proportions of loadings from different land-uses within the Welland River watershed. Source - RMN, 2003 and MOE, 2005

Land-Use	TP (kg/yr)	%	NH_3 (kg/yr)	%	TKN (kg/yr)	%
Urban SW	2192.00	3.03	2192.00	0.78	1461.40	0.36
Urban CSO	867.00	1.20	N/A	0.00	N/A	0.00
Urban WWTP	7442.83	10.30	131813.43	46.68	156670.87	38.65
Agriculture	58993.63	81.67	145610.65	51.56	226823.84	55.95
Other	2738.54	3.79	2786.06	0.99	20417.65	5.04
Total	**72234.00**	**100.00**	**282402.14**	**100.00**	**405373.76**	**100.00**

Table 2: Phosphorus, ammonia, and total Kjeldahl nitrogen loadings to the Welland River from different land-use types, normalized by area (km^2) of that land-use type within the watershed. Source - RMN, 2003 and MOE, 2005

Land-Use	Area (km^2)	TP ($kg/km^2/yr$)	NH_3 ($kg/km^2/yr$)	TKN ($kg/km^2/yr$)
Urban	20.50	512.18	6535.57	7712.26
Agriculture	760.37	77.59	191.50	298.31
Other	417.03	6.57	6.68	48.96

A summary of RMN 2003 study results are as follows:

- Phosphorus loading from urban stormwater, agricultural land, and other lands was determined by mass balance modeling (RMN 2003). Loadings from CSOs were estimated using the XP-SWMM model and 1980 rainfall data (RMN 2003). Loadings from the City of Welland and Port Robinson Lagoon WWTPs were provided by MOE (MOE 2005);
- Agricultural land uses are the greatest source of phosphorus to the Welland River;
- Urban areas contribute a much greater load of nutrients per unit area based on the data shown above;
- Modeling results have not been calibrated with observed water quality.

The City of Welland is serviced by a complex collection system that includes a total of 18 CSO locations, a deep interceptor sewer, a storage facility, and two major pumping stations (RV Anderson and Associates and XCG Consultants LTD 2003). **Figure 4** shows the location of the CSOs in the City of Welland. A review conducted by RV Anderson and Associates and XCG Consultants LTD. (2003) found surcharge data along the interceptor sewer indicated surcharging conditions frequently occurred in the interceptor sewer during wet weather events. They also reported that during these wet weather events the hydraulic grade line in the interceptor sewer would exceed the overflow elevations at a number of CSO locations. Overflows at other locations were occurring due to the limited capacity of the diversion structures.

CSOs continue to affect the water quality of the Welland River. In 2009, the City of Welland and the RMN initiated a project to complete major sewer separation works in various areas of the City and to become compliant with the Ontario Ministry of the Environment Procedure F-5-5 (MOE 2001). It is anticipated that through this project 100% of the remaining CSOs will be separated within the next 8-10 years and 75% of wet weather flows will be captured upon completion of this separation.

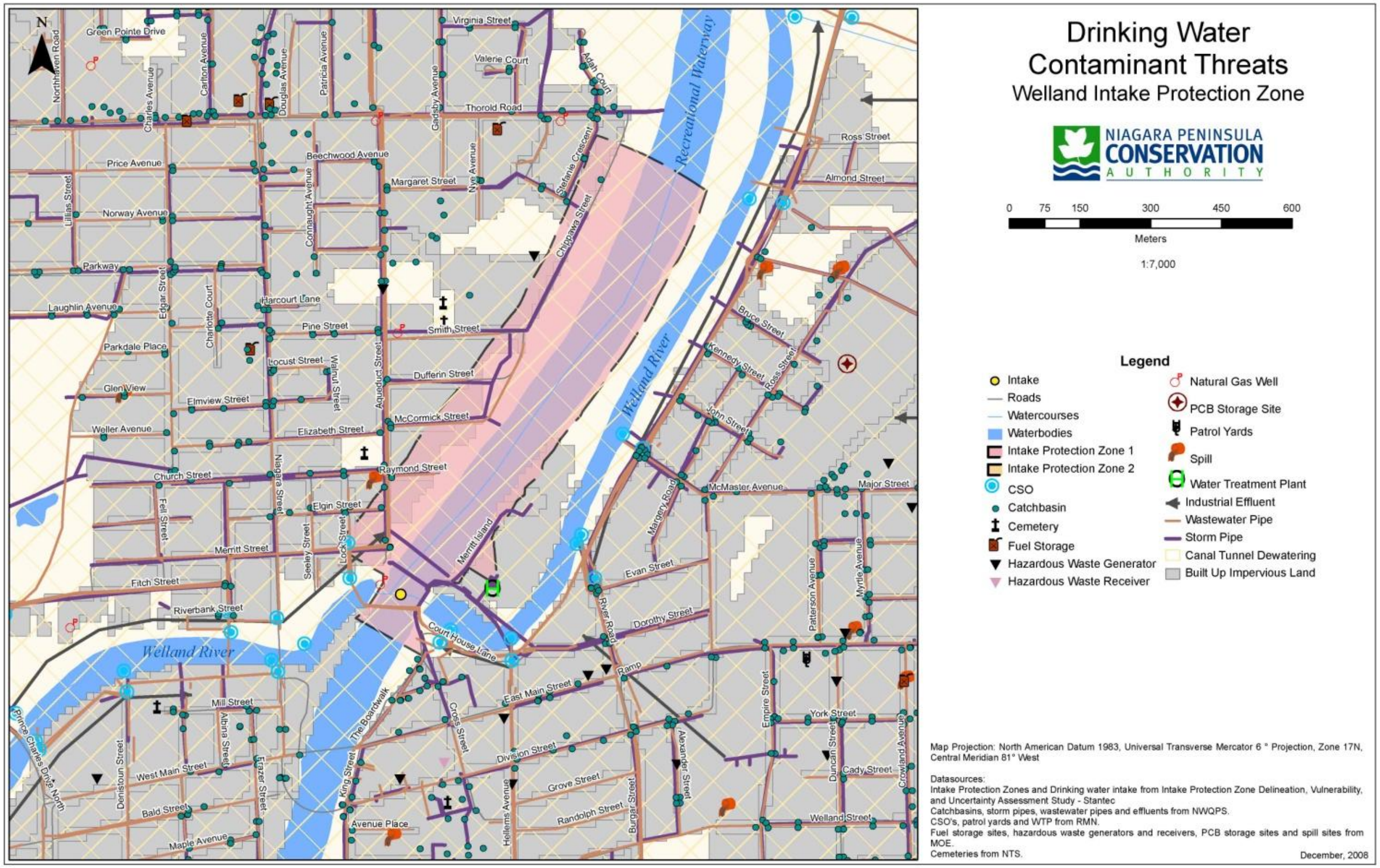

Figure 4: Combined Sewer Overflows in the City of Welland

1.4 Water Quality Improvement Programs

Since the establishment of the Niagara River AOC there have been many efforts to improve water quality in the Welland River watershed. The following items highlight the progress towards Implementing Priority RAP Actions to improve Welland River water quality. These include:

- The NPCA's Water Quality and Habitat Improvement Program received over $2.6M from Environment Canada's Great Lakes Sustainability Fund over 15 years (1994-2009) and restored wetland (147 ha), riparian (54 km) and forest (338 ha) habitats. It has also funded the containment of 81,776 m3/yr of manure and fenced 2,515 livestock;
- Completion of the detailed assessment for the 14 potentially contaminated sediment areas identified in the Stage 1 and Stage 2 documents;
- Completion of the Welland River Reef Cleanup Project to address Recommendation #16 in the RAP Stage 2 report (1995);
- The City of Welland's new Official Plan incorporates RAP supported policies for contaminated sediments in Lyon's Creek East; Natural Heritage; urban stormwater, reduction of CSOs, etc;
- Stormwater Management, Erosion and Sediment Policies completed through the Niagara Water Strategy for implementation by municipalities;
- Removal and mitigation of barriers to fish migration completed by the Niagara Restoration Council;
- Establishment of the Niagara Peninsula Conservation Authority's (NPCA) GIS restoration database;
- Natural Heritage Inventory of the Niagara River AOC report and mapping completed;
- Development of Natural Heritage Strategy for entire Niagara Region underway in collaboration with stakeholders;
- Ongoing implementation of the agreement between NPCA and Ontario Power Generation to mitigate the effects of Welland River flow reversal through restoration strategies such as wetland securement, riparian plantings, fish spawning improvements, etc;
- Ongoing sanitary/storm sewer separation in the City of Welland to reduce bypasses at the Water Pollution Control Plant;
- Regional and municipal infrastructure upgrades;
- Fisheries Community Monitoring and Implementation of the Walleye restoration project in the Welland River West and habitat enhancement projects planned (with some already implemented);
- Completion of the Niagara River Watershed Fish Community Assessment (2003 to 2007) by the MNR. This draft report indicates that the Welland River Fish Community has begun moving along the path to recovery from the severe pollution in the 1960s (partially due to uncontrolled sewage discharge) and implementation of MOE policy F-5-5.

1.5 Welland River Eutrophication Study Objectives

The purpose of the Welland River Eutrophication Study is to refine and implement the Recommendations for Monitoring and Assessment as formulated by the 2007 Technical Review Committee in Appendix H *Eutrophication and Undesirable Algae*. This is accomplished by addressing the following study objectives:

1) Characterize the biological response of the Welland River to high phosphorus inputs including the type, frequency, location and timing of algal blooms, and whether oxygen depletion (anoxia) is occurring in relation to aquatic plant and algae overgrowth;
2) Characterize concentrations of plant-available phosphorus versus sediment-bound phosphorus along the length of the Welland River;
3) Develop delisting criteria for the Welland River upstream of the Old Welland Canal which identify the desired conditions in the river with regard to dissolved oxygen and abundance of algae/aquatic plants;
4) Develop phosphorus loading targets for different subwatersheds of the Welland River upstream of the Old Welland Canal to meet delisting criteria, and;
5) Monitor success in meeting ambient targets for the Welland River through alterations to the existing AOC Tributary Monitoring Program.

The information found within this report is intended to assist the Niagara River RAP Coordinating Committee in determining the current Welland River watershed conditions relative to what the TWG believes are desirable and achievable goals for the BUI: *Eutrophication and Undesirable Algae*. Recommendations and conclusions are provided at the end of this report based on the data examined by the TWG.

2.0 Welland River Eutrophication Study

2.1 Study Design

In January 2008, the Technical Working Groups (TWG) approved the Study Work Plan found in **Appendix A**. As part of this Work Plan the results of each field season were reviewed by the TWG at the end of each field season. The Niagara Peninsula Conservation Authority (NPCA) produced annual Technical Reports (2008, 2009, and 2010) to summarize each field season's results. This allowed the TWG group an opportunity to adjust the next field season's monitoring to address any identified data gaps.

As part of the Work Plan, the NPCA continued to collect surface water quality grab samples at 23 monitoring stations in the Welland River watershed (**Figure 5**). Photos of the sample stations can be found in **Appendix C**. Samples were collected monthly from April to November each year of 2008, 2009 and 2010, and a mix of both dry and wet weather sampling was conducted. All samples were analyzed for nutrients, metals, bacteria, suspended solids, and general chemistry. These samples were sent for analysis at one or in some cases multiple laboratories, including the City of Hamilton Environmental Laboratory, Exova Accutest Laboratory in Ottawa, and the Ontario Ministry of the Environment (MOE) laboratory in Toronto. All three labs are accredited and the location where each sample was sent for analysis can be found in **Table 3**. The use of multiple labs for analysis reflects the funding arrangements and in-kind contributions that the NPCA has with its partners. To account for any potential differences in lab analysis for key study parameters, the TWG required duplicate samples be collected at all 23 stations and sent to the MOE lab for nutrient analysis as a quality assurance/quality control measure.

Figure 5: Welland River Eutrophication Study (2008-2010) water quality monitoring station locations

Table 3: Summary of monitoring stations sampled during the 2008-2010 field seasons

Station	Watershed	Laboratory	Municipality	Sample Location
WR00A	Welland River	Hamilton	City of Hamilton	Book Street
WR000	Welland River	Hamilton	City of Hamilton	Butter Road
WR001	Welland River	Hamilton	City of Hamilton	Airport Road
WR002	Welland River	Hamilton	City of Hamilton	Airport Road
WR003	Welland River	Hamilton	City of Hamilton	Tyneside Road
WR004	Welland River	Hamilton	City of Hamilton	Harrison Road
WR005	Welland River	Exova	West Lincoln	Church Road
WR006	Welland River	Exova	Township of West Lincoln	Port Davidson Weir
WR007	Welland River	MOE	City of Welland	O'Reilly's Bridge
WR010	Welland River	MOE	City of Welland	Bigger Road
BF001	Big Forks Creek	Exova	Township of Wainfleet	Gents Road
BU000	Buckhorn Creek	Hamilton	City of Hamilton	Trimble Road
BU001	Buckhorn Creek	Hamilton	City of Hamilton	Haldibrook Road
BV001	Beaver Creek	Exova	Township of West Lincoln	Canborough Road
CO001	Coyle Creek	Exova	City of Welland	Pelham Road
DR001	Drapers Creek	Exova	City of Welland	Colbeck Road
EL001	Elsie Creek	Exova	Township of West Lincoln	Regional Road #9
GR001	Grassy Brook	Exova	City of Niagara Falls	Montrose Road
LY003	Lyons Creek	Exova	City of Niagara Falls	Stanley Avenue
MI001	Mill Creek	Exova	Township of West Lincoln	Regional Road #14
OS001	Oswego Creek	Exova	Haldimand County	Diltz Road
OS002	Oswego Creek	Exova	Haldimand County	Canborough Road
TE001	Tee Creek	Exova	City of Niagara Falls	Schisler Road

The TWG identified the need to collect sestonic chlorophyll-a (chl*a*) samples to provide an estimate of algae concentrations in the Welland River. To do this, supplementary grab samples were collected monthly from April to November 2008, from May to November 2009 and from April to November 2010 (no results from July 2010) at all 23 stations. All samples collected were sent to the Canada Centre for Inland Waters laboratory for analysis. Chl*a* samples were corrected when pheophytin, a degradation product of chlorophyll, had become high enough to show up at the same absorption peak as chl*a*. The correction involves acidifying the sample and re-running the analysis. However, to be conservative for this analysis only the uncorrected concentrations are reported in this section. The TWG also identified the need to collect Dissolved Oxygen (DO) in the Welland River watershed as part of this study. The NPCA and MOE deployed DO loggers in the main Welland River channel and in various subwatersheds each field season. Specific details regarding sample location will be discussed later in the report. For the 2010 field season, weekly water samples at three tributaries (BV001, BF001 and OS001) were collected to capture a larger number of wet weather events.

The NPCA and MOE recorded flow measurements during grab sampling where conditions permitted safe access. Depth and velocity measurements were recorded along a single transect at each station. Where watercourse conditions were too deep for access, a stage measurement was recorded and a discharge was determined using NPCA rating curves where available.

2.2 Study Results

Sections **2.2.1** to **2.2.7** summarize the water quality data collected by the TWG during the 2008 to 2010 field seasons. Water quality parameters that are examined in this study include total phosphorus, phosphate, total nitrogen, nitrate, un-ionized ammonia, sestonic chlorophyll-a, and DO in the Welland River and its tributaries. Concentrations of nutrients in stream sediment are also summarized for select locations. All water quality data for each station is found in **Appendix D**.

2.2.1 Phosphorus

Phosphorus is a natural element found in rocks, soils and organic material and is an essential nutrient for plant growth (Smith 1992). Phosphorus clings tightly to soil particles and is often associated with suspended sediment. In natural and minimally impacted aquatic ecosystems phosphorus is generally in short supply and limits biological growth. However, in human impacted aquatic ecosystems excessive phosphorus concentrations can stimulate overgrowth of algae and other aquatic plants. The decomposition of this organic matter in turn depletes DO concentrations and stresses aquatic organisms such as fish and benthic invertebrates. Anthropogenic sources of phosphorus include fertilizers, and sewage discharges.

Total phosphorus is a measure of all forms of phosphorus in a water sample, and includes biologically available forms. This section will report on total phosphorus and phosphate. The interim Ontario Provincial Water Quality Objective (PWQO) for total phosphorus in streams and rivers is 30 µg/L (MOE 1994). This interim guideline represents the concentration of total phosphorus required to eliminate excessive plant growth in rivers and streams. There is no PWQO for phosphate, but the relative proportion of phosphate to total phosphorus can provide some understanding of potential biological response of the aquatic ecosystem system to this nutrient.

Both total phosphorus (TP) and phosphate were analyzed in samples collected from April to November in 2008-2010 for all stations. To achieve appropriate detection limits for this study total phosphorus samples were sent to Exova Laboratories and phosphate samples were analyzed at the MOE lab as filtered reactive phosphate (PO_4^{3}).

Ninety-nine percent of the grab samples collected in the 2008-2010 study failed to meet the interim PWQO of 30 µg/L for total phosphorus. Box and whisker plots of total phosphorus and phosphate concentrations are illustrated in **Figure 6** and **Figure 7** for each station. Monthly concentrations for total phosphorus and phosphate were plotted together to illustrate seasonal phosphorus variation at each station and are provided in **Appendix E.** The Welland River watershed has a significant phosphorus problem with mean TP concentrations for each station ranging from 200% to 1500% greater than the PWQO. The highest total phosphorus concentrations were observed at Big Forks Creek (BF001), Buckhorn Creek (BU000 & BU001), Beaver Creek (BV001), Oswego Creek (OS001 & OS002) and Tee Creek (TE001). Generally, TP concentrations in the main Welland River channel were similar except for station WR010 where a decline in TP concentration was observed. This is likely due to mixing and dilution from the Niagara River. The agricultural watersheds of Coyle Creek (CO001), Lyons Creek (LY003) and Mill Creek (MI001) as well as the urbanized watershed of Drapers Creek (DR001) had the lowest observed TP concentrations.

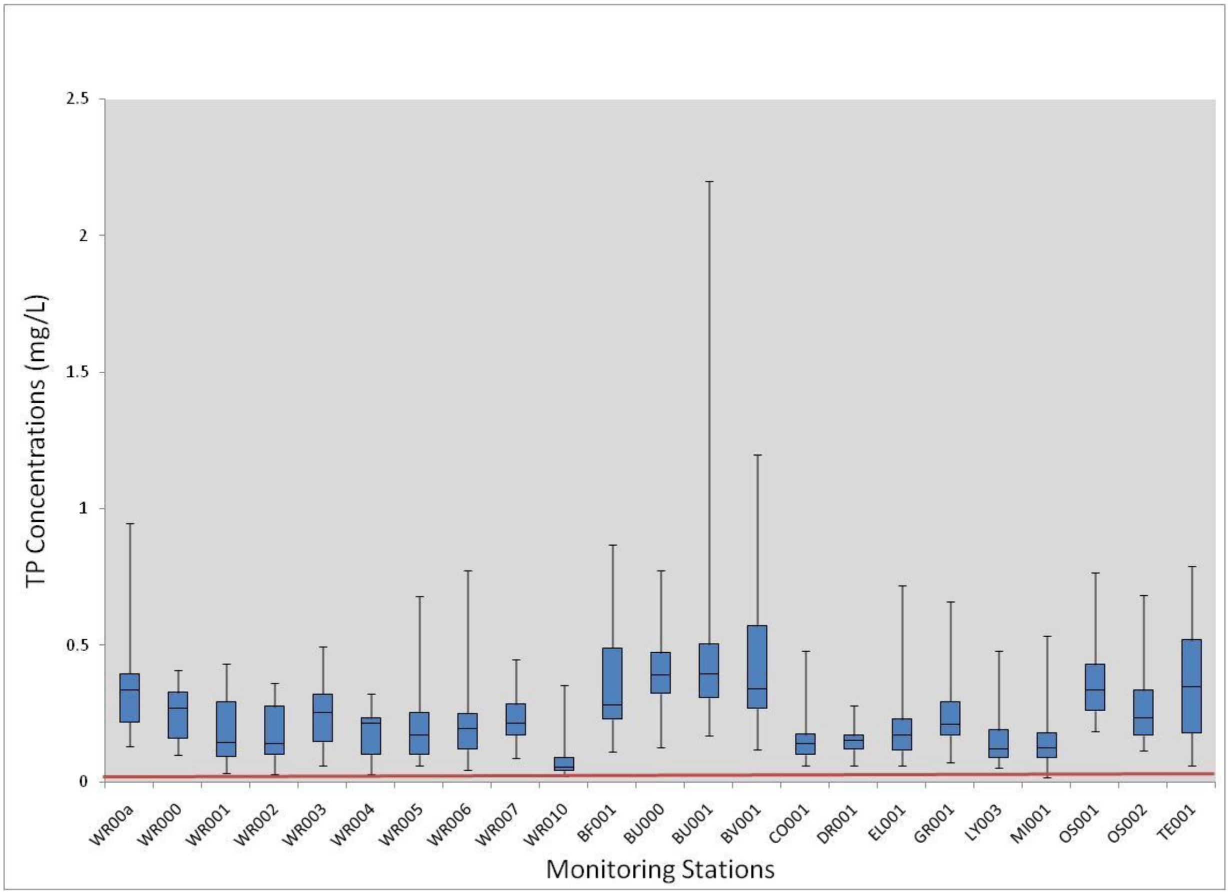

Figure 6: Box and Whisker Plot of total phosphorus concentrations (mg/L) of Welland River watershed monitoring stations for 2008-2010 (n=24 for each station). The box length of the box-and-whisker plots represents the inter-quartile range that contains the median value shown as a horizontal line. The whiskers represent the minimum and maximum values. Red line represents PWQO (1994) for total phosphorus.

The proportion of mean phosphate of mean total phosphorus concentrations for samples collected in the main Welland River channel ranged from 4% - 58% (**Table 4**). Phosphate concentrations increased sharply in the Welland River between stations WR004 and WR005 (**Figure 7**). This increase in phosphate concentrations continues downstream and peaks at station WR007 before decreasing at station WR010 likely due to mixing with the Niagara River (**Figure 6**). The proportion of phosphate observed in the Welland River tributaries ranged from 24% to 68% with most of these stations exceeding 50% (**Table 4**). The highest concentrations of phosphate were observed in Big Forks (BF001), Beaver Creek (BV001), Oswego Creek (OS001), and Tee Creek (TE001).

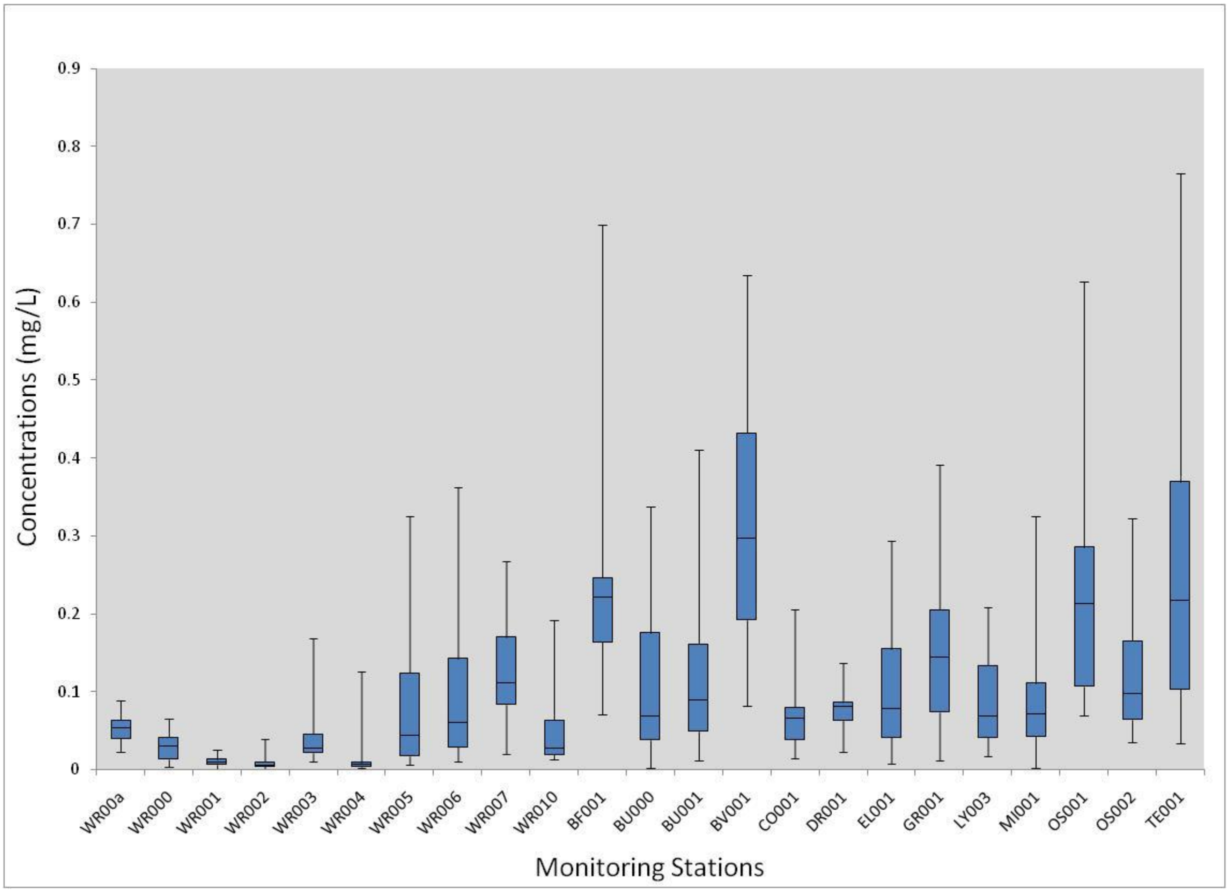

Figure 7: Box and Whisker Plot of phosphate concentrations (mg/L) of Welland River watershed monitoring stations for 2008-2010 (n=24 for each station). The box length of the box-and-whisker plots represents the inter-quartile range that contains the median value shown as a horizontal line. The whiskers represent the minimum and maximum values.

Table 4: Mean TP, mean phosphate and mean percent phosphate for Welland River watershed stations (2008-2010)

Station	Mean TP (mg/L)	Mean Phosphate (mg/L)	% Phosphate
WR00A	0.35	0.05	15
WR000	0.24	0.03	12
WR001	0.21	0.01	5
WR002	0.21	0.01	4
WR003	0.27	0.04	16
WR004	0.22	0.01	6
WR005	0.21	0.08	38
WR006	0.25	0.10	40
WR007	0.24	0.14	58
WR010	0.08	0.05	58
BF001	0.36	0.24	68
BU000	0.39	0.11	27
BU001	0.45	0.11	24
BV001	0.44	0.31	69
CO001	0.16	0.08	46
DR001	0.15	0.07	49
EL001	0.21	0.11	52
GR001	0.26	0.15	56
LY003	0.16	0.09	54
MI001	0.17	0.09	55
OS001	0.39	0.23	58
OS002	0.28	0.13	46
TE001	0.38	0.26	67

Based on field staff observations and precipitation data (**Appendix F)**, water quality sampling dates were identified as dry or wet weather events. Dry and wet-weather TP concentrations for the Welland River and subwatershed tributaries are shown in **Figures 8** and **9**. Based on these data, it was found only the mid-sections of the Welland River (WR005, WR006, and WR007) and four subwatershed tributaries (BU001, CO001, MI001 and OS002) had significantly greater TP concentrations ($p<0.05$, Mann Whitney U-Test) during wet weather events. This may suggest that these stations are more responsive to wet weather events than other stations. Surprisingly, Draper's Creek station (DR001) was observed to be the least responsive to wet weather events despite being the most urbanized tributary in the Welland River watershed. However, the TWG agreed that these data are limited and only provide a coarse examination of wet weather sampling because wet weather events were not directly targeted in 2008 and 2009. In 2010, the TWG deployed an ISCO automatic sampler on Beaver Creek (BV001) to target wet weather events, but lack of precipitation during the sample period only allowed for one composite sample to be collected.

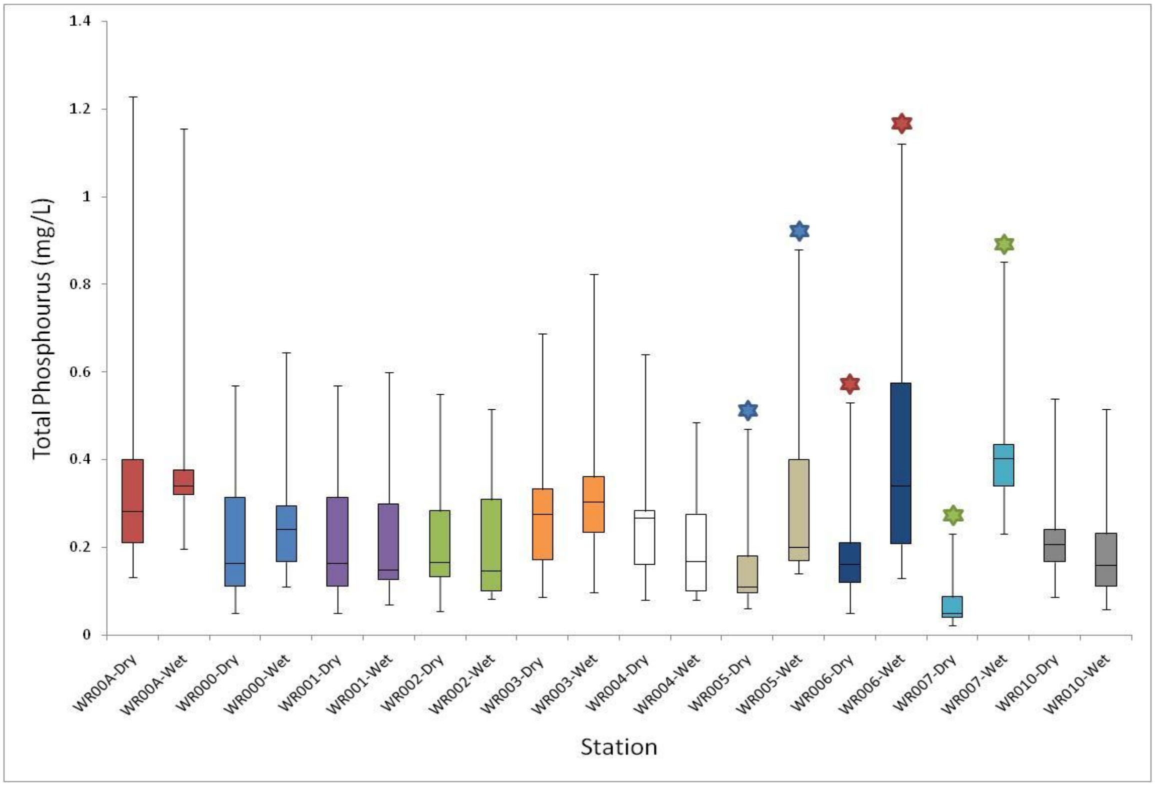

Figure 8: Box and Whisker Plot of Total Phosphorus (mg/L) of Welland River watershed monitoring stations for 2008-2010 accounting for dry vs. wet weather sampling events (n=16 for dry and n=8 for wet at each station). The box length of the box-and-whisker plots represents the inter-quartile range that contains the median value shown as a horizontal line. The whiskers represent the minimum and maximum values. Star symbols of the same colour denote significant differences (Mann Whitney U-Test, $p<0.05$) between dry and wet sampling at a water quality station.

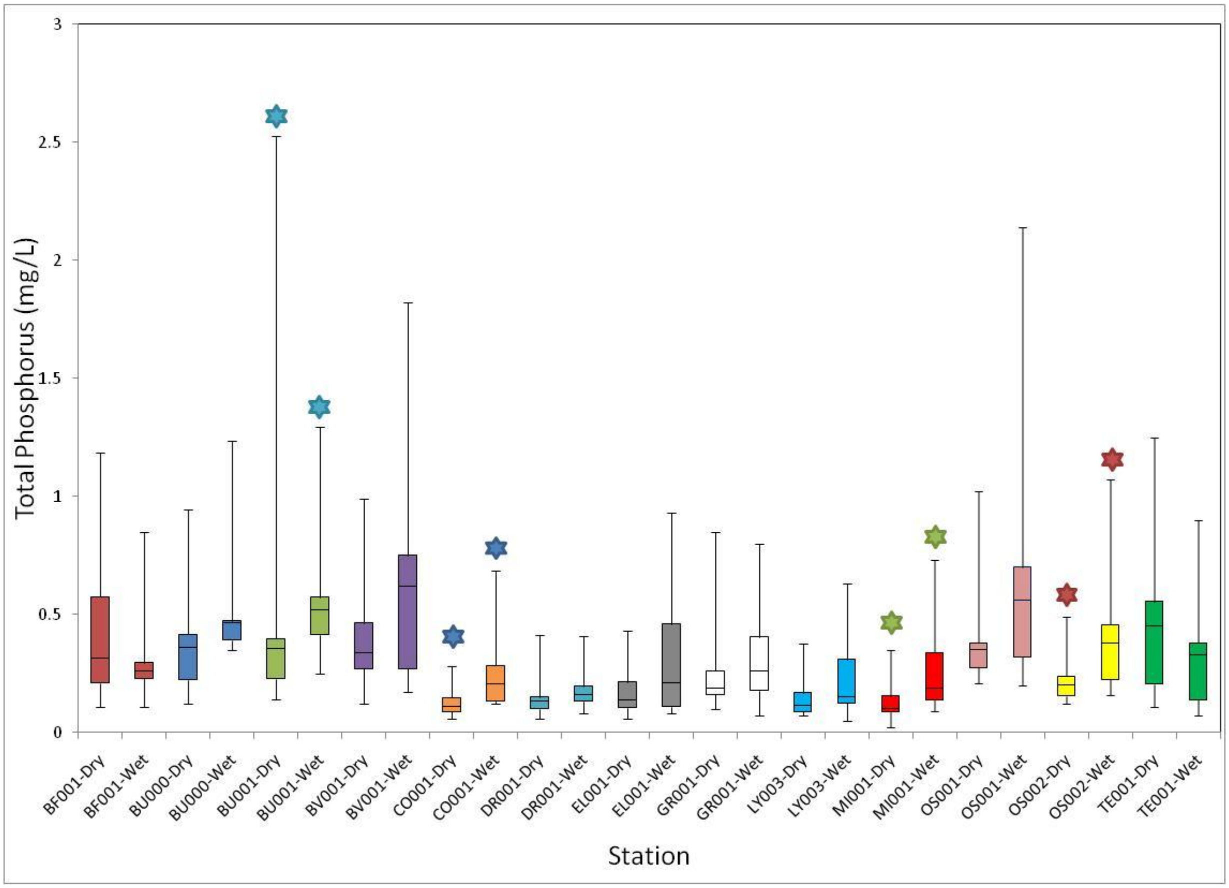

Figure 9: Box and Whisker Plot of Total Phosphorus (mg/L) of Welland River subwatershed monitoring stations for 2008-2010 accounting for dry vs. wet weather sampling events (n=16 for dry and n=8 for wet at each station). The box length of the box-and-whisker plots represents the inter-quartile range that contains the median value shown as a horizontal line. The whiskers represent the minimum and maximum values. Star symbols of the same colour denote significant differences (Mann Whitney U-Test, $p<0.05$) between dry and wet sampling at a water quality station.

In 2010, additional weekly sampling was initiated by MOE and NPCA staff in the three most nutrient enriched tributaries (BV001, BF001 & OS001) to better characterize their TP and phosphate concentrations in terms of potential seasonal differences. Weekly TP concentrations are shown in **Figure 10**. Generally, like the less frequent monitoring conducted at the other stations, TP concentrations were substantially greater than the PWQO (1994) for all three watersheds. There was a summertime increase in TP at all three stations with Big Forks (BF001) having the highest single concentration of 2.5 mg/L. Phosphate concentrations (**Figure 10**) in all three tributaries were highly variable with greater summertime concentrations observed at stations BF001 and OS001.

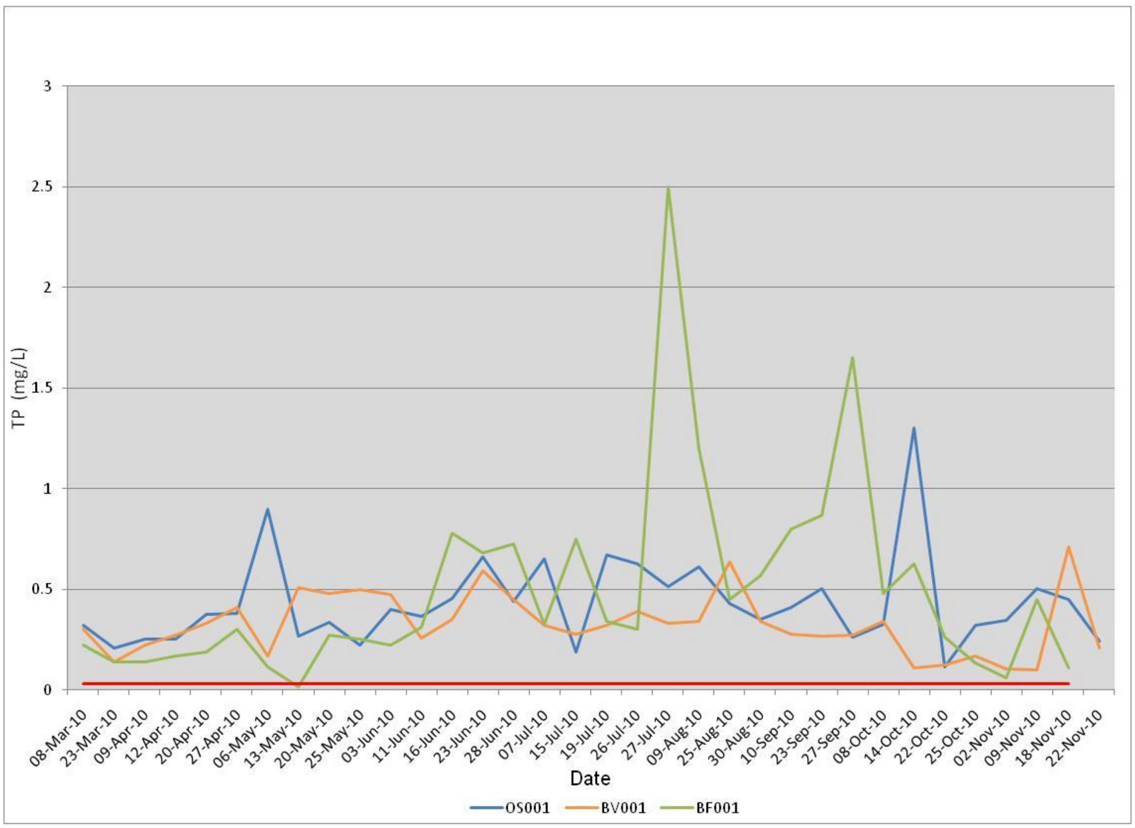

Figure 10: Weekly Total Phosphorus (TP) Concentrations for Oswego (OS001), Beaver (BV001) and Big Forks (BF001) Creek Stations from March to November 2010 (n=34 for each station). Red line represents PWQO (1994) for total phosphorus.

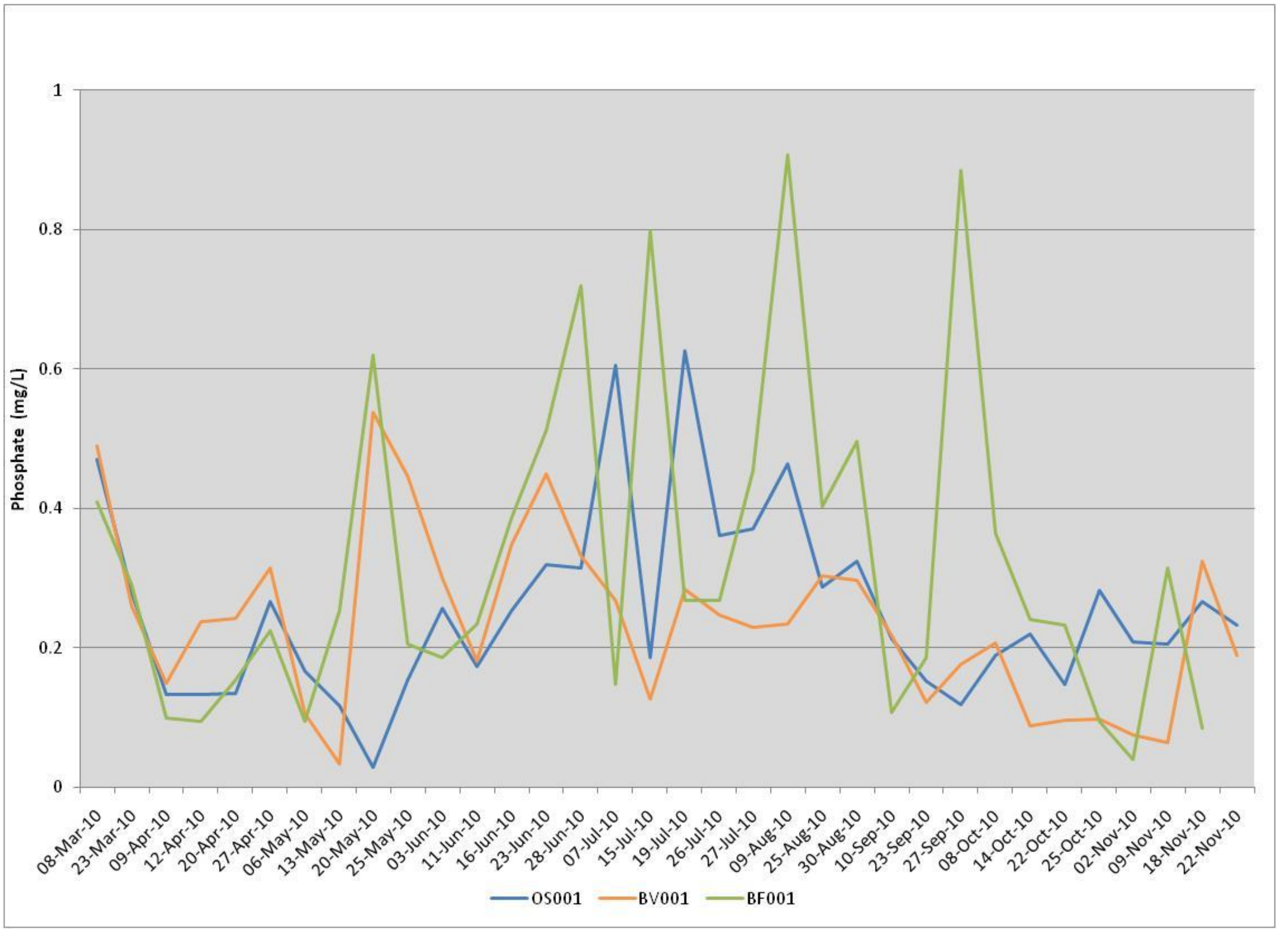

Figure 11: Weekly Phosphate Concentrations for Oswego (OS001), Beaver (BV001) and Big Forks (BF001) Creek Stations from March to November 2010 (n=34 for each station).

2.2.2 Phosphorus Loads

TP loads were calculated for each tributary station using two methods. The first method was the empirical flow measurements obtained at the time of sampling and the second method was using modeled runoff estimates from the computer program Hydrologic Engineering Centre - Hydrologic Modeling System (HEC-HMS). HEC-HMS is the U.S Army Corps of Engineers' Hydrologic Engineering Center Hydrologic Modeling System and a standard modelling program for water resource practitioners. HEC-HMS is a numerical simulation model designed to simulate the precipitation-runoff process of a watershed. The HEC-HMS surface water models were run in continuous mode at hourly intervals and calibrated to stream gauges where available.

For the first method, median annual TP loads from the 2008-2010 were used to calculate a mean TP load for each tributary station. The mean annual TP load was then divided by the tributary catchment area to obtain a unit area load or export coefficient for each tributary in kg/ha/yr. The TP loads for 2008-2010 using this method are summarized in **Appendix G**. A similar exercise was repeated using second method but with modeled runoff estimates. The modeled data was prepared by the NPCA and AquaResource Inc. (2010) as part of the NPCA Source Protection Area Tier 1 Water Budget. For each NPCA tributary stations, modeled runoff values from NPCA and AquaResources (2010) and annual TP concentrations were used to calculate annual TP loads. The calculated export coefficients using empirical and modelled flow methods are summarized in **Table 5** and ranked in **Table 6.**

The TP export coefficients calculated using the empirical flows were found to differ considerably from those determined using the modeled flows, differing by two to three orders of magnitude at some stations (i.e. BF001). The high degree of variability observed in the export coefficients calculated using the empirical flows is likely attributed to the skewed nature of the flow data. The empirical flow data contains a combination of zero and extreme flows at most stations, and many stations have a very limited number of data points (n<10) due to accessibility issues. As a result, the empirical flow data collected in 2008-2010 may not be representative of the range and duration of typical flow conditions at these stations.

Table 5: Summary of calculated TP export coefficients calculated using two different conditions: 1) modeled runoff and mean TP for 2003-2010, and 2) empirical flow data and mean TP for 2008-2010

	Modeled Runoff	Empirical Flow
Station	**TP (kg/ha/yr)**	**TP (kg/ha/yr)**
BF001	1.016223	0.023081
BU001	0.584550	0.046877
BV001	1.229904	0.103004
CO001	0.352576	0.084354
DR001	0.707525	0.139506
EL001	0.399798	0.010618
GR001	0.670758	0.069613
LY003	0.453525	n/a
MI001	0.412879	0.013662
OS001	0.733742	0.131231
TE001	1.021530	0.103239

Table 6: Summary of ranked TP export coefficients (highest to lowest) calculated using two different conditions (as described in **Table 5**)

Rank	Modeled Runoff	Empirical Flow
1	BV001	DR001
2	TE001	OS001
3	BF001	TE001
4	OS001	BV001
5	DR001	CO001
6	GR001	GR001
7	BU001	BU001
8	LY003	BF001
9	MI001	MI001
10	EL001	EL001
11	CO001	N/A (LY003)

Phosphorus loads (kg/ha/yr) of the Welland River subwatersheds were compared to the loads of Combined Sewer Overflows (CSOs) found in the City of Welland as well as the loads of other Non-Area of Concern (AOC) watersheds such as Twenty Mile Creek (NPCA unpublished data) and the Grand River (Cooke 2004). Generally three tiers (greater than non-AOCs, equal to non-AOCs, less than non-AOCs) of phosphorus export coefficients for the Welland River subwatersheds were apparent and these are summarized in **Figure 12**. As shown in **Figure 12,** Big Forks Creek (BF001), Beaver Creek (BV001), and Tee Creek (TE001) subwatersheds had substantially greater phosphorus loads than the non-AOC watershed. Phosphorus loadings in Buckhorn Creek (BU001), Drapers Creek (DR001), Grassy Brook (GR001) and Oswego Creek (OS001) subwatersheds were approximately equal to non-AOC watersheds. The Welland River also receives a significant load of phosphorus from CSOs in urban areas of the City of Welland. Coyle Creek (CO001), Elsie Creek (EL001), Lyons Creek (LY003) and Mill Creek (MI001) had phosphorus loads less than non-AOCs (**Figure 12)**. These data suggest that although all Welland River subwatersheds contribute a significant phosphorus load, there is a subgroup of subwatersheds that can be identified as the greatest phosphorus contributors in terms of their watershed size and these warrant special priority.

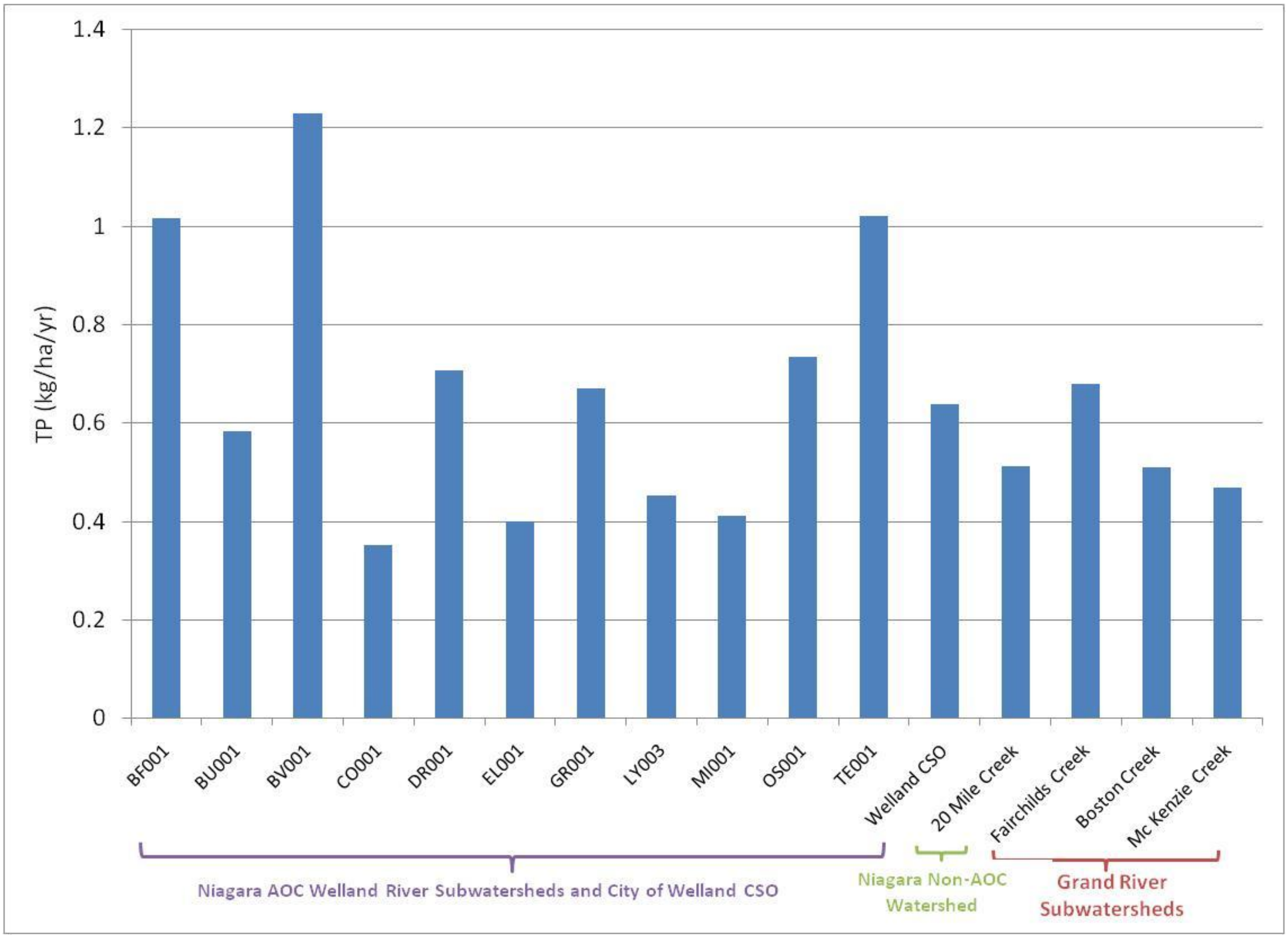

Figure 12: Total Phosphorus Loads (kg/ha/yr) for Welland River subwatersheds, City of Welland CSOs, Non-Niagara River AOC stations Twenty Mile Creek and Grand River (Fairchilds Creek, Boston Creek and McKenzie Creek) using actual water quality data (2003-2010) and modelled runoff.

2.2.3 Nitrogen

Nitrogen is one of the most abundant elements. About 80 % of the air we breathe is nitrogen. It is found in the cells of all living things and is a major component of proteins. The importance of nitrogen in the aquatic environment varies according to the relative amounts of the forms of nitrogen present such as ammonia, ammonium, nitrite, nitrate, or organic nitrogen. Nitrate is the most common form of nitrogen that occurs in surface water. In aerobic or oxygen-rich water, bacteria convert ammonium and nitrite to nitrate through a process known as nitrification. In anaerobic or oxygen-depleted water, these forms of nitrogen are converted to molecular nitrogen through denitrification, and this gas is released to the atmosphere. At elevated concentrations, nitrate, nitrite and un-ionized ammonia can be toxic to aquatic organisms and can contribute to excessive plant and algae growth in surface water. Anthropogenic sources of nitrogen include sewage discharges, animal waste, fertilizers and pesticides. This section will report on monthly nitrate-nitrogen, un-ionized ammonia (based on total ammonia) and total nitrogen (total dissolved inorganic and organic nitrogen) which were collected from April to November 2008 to 2010.

The interim Canadian Water Quality Guidelines for the Protection of Aquatic Life recommend that nitrate-nitrogen concentrations should not exceed 2.9 mg/L in surface water Canadian Council of Ministers of the Environment (CCME 2006). The Ontario Provincial Water Quality Objective (PWQO) for un-ionized ammonia in streams and rivers is 0.02 mg/L (MOE 1994). The CCME nitrate guideline and PWQO for un-ionized ammonia are based on chronic potential toxicity and are not threshold values for eutrophication. Dodds *et al.* (1998) published a range of stream trophic state values for total nitrogen with a eutrophic threshold concentration of 1.5 mg/L. This value will be used to assess the trophic state of the Welland River in relation to nitrogen.

The results of the nitrate-nitrogen data are presented in **Figure 13.** Approximately 3% of the grab samples collected from 2008-2010 exceeded the Canadian Environmental Quality Guideline of 2.9 mg/L for nitrate-nitrogen (2007). The highest median concentrations of nitrate-nitrogen were observed from the Big Forks subwatershed (BF001), the upper Welland River tributaries (WR001 & WR002), and Oswego Creek subwatershed (OS001 & OS002). The lowest median concentrations were observed at Mill Creek subwatershed (MI001), Lyons Creek subwatershed (LY003) and the main Welland River channel (WR003 & WR004) near Binbrook Conservation Area. The upper Welland River tributaries (WR001 & WR002) are small first order watercourses and likely represent a point source impact from the Hamilton airport deicing and anti-icing activities. The rest of the sampling stations, with the exception of Drapers Creek subwatershed which is mainly urbanized, represent agricultural watersheds with non-point sources.

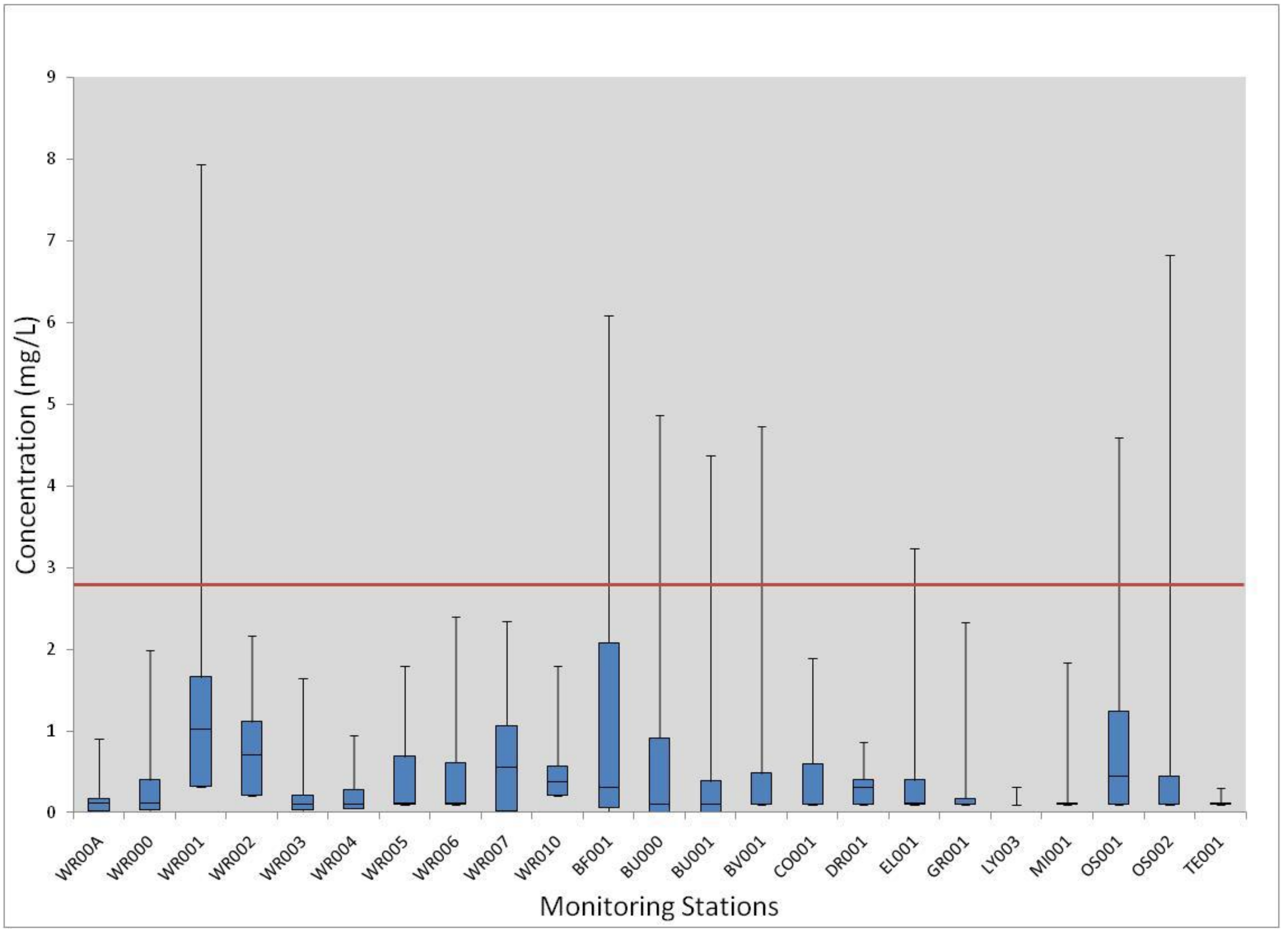

Figure 13: Box and Whisker Plot of Nitrate/Nitrogen concentrations (mg/L) of Welland River watershed monitoring stations for 2008-2010 (n=69 for each station). The box length of the box-and-whisker plots represents the inter-quartile range that contains the median value shown as a horizontal line. The whiskers represent the minimum and maximum values. Red line represents CCME water quality guideline (2007) of 2.9 mg/L for nitrate-nitrogen.

Un-ionized ammonia was converted from total ammonia using the conversion provided in the Ontario Ministry of Environment: Policies, Guidelines and Provincial Water Quality Objectives (1994).

$$f = 1/(10pKa\text{-}pH + 1), \text{ where } f \text{ is the fraction of NH3}$$

$$pKa = 0.09018 + 2729.92/T, \text{ where } T = \text{ambient water temperature in Kelvin } (K = (C + 273.16)$$

The results of the un-ionized ammonia are presented in **Figure 14** and were based on total ammonia adjusted for measured temperature and pH at the time of sampling**.** Un-ionized ammonia in the Welland River watershed is very low with less than 1% of the samples collected in 2008-2010 exceeding the Provincial Water Quality Objective (1994) of 0.02 mg/L for ammonia (un-ionized). The highest median concentrations observed were at stations WR010, WR004 and OS002 but these concentrations did not approach exceedance levels. Interestingly these higher un-ionized concentrations appear associated with sections of the watershed that are significantly affected by water flow structures such as WR004 (outlet of Binbrook Reservoir), WR007/ WR010 which are near the Welland Canal siphons, and OS002 which is near the Oswego Weir.

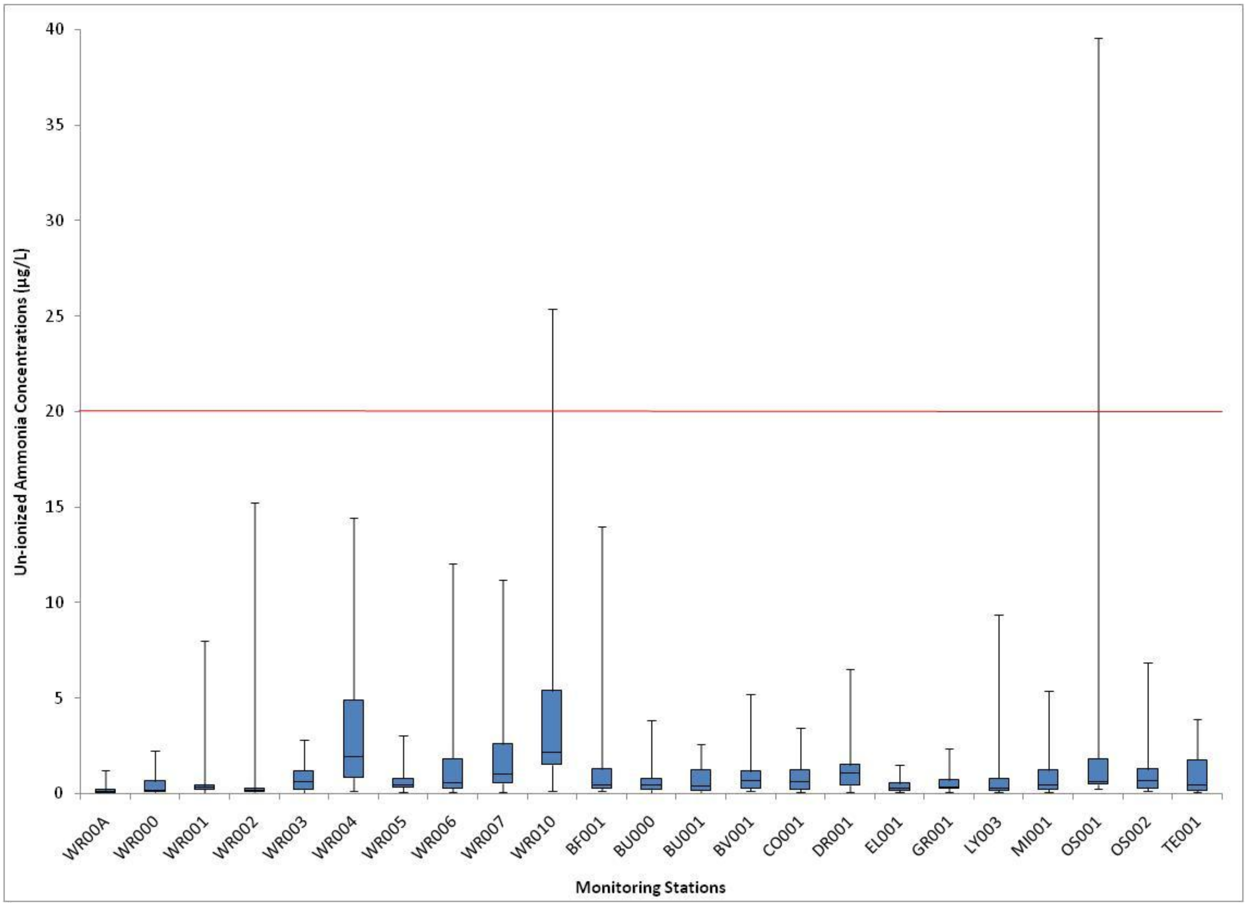

Figure 14: Box and Whisker Plot of Un-ionized Ammonia concentrations (mg/L) of Welland River watershed monitoring stations for 2008-2010 (n=69 for each station). The box length of the box-and-whisker plots represents the inter-quartile range that contains the median value shown as a horizontal line. The whiskers represent the minimum and maximum values. Red line represents PWQO (1994) of 0.02 mg/L for Un-ionized Ammonia.

The results of the total nitrogen data are presented in **Figure 15.** Approximately 42% of the grab samples collected from 2008-2010 exceeded the threshold of 1.5 mg/L of total nitrogen concentrations for eutrophic water (Dodds *et al.* 1998). The highest median concentrations of total nitrogen were observed at the Big Forks subwatershed (BF001), Beaver Creek (BV001), Buckhorn Creek, the upper Welland River tributary (WR001), and Oswego Creek subwatershed (OS001 & OS002). Generally the lowest median concentrations were in the upper Welland River tributaries (WR00A, WR000, WR001 and WR003) and subwatersheds Coyle Creek (CO001), Drapers Creek (DR001), and Lyons Creek (LY001).

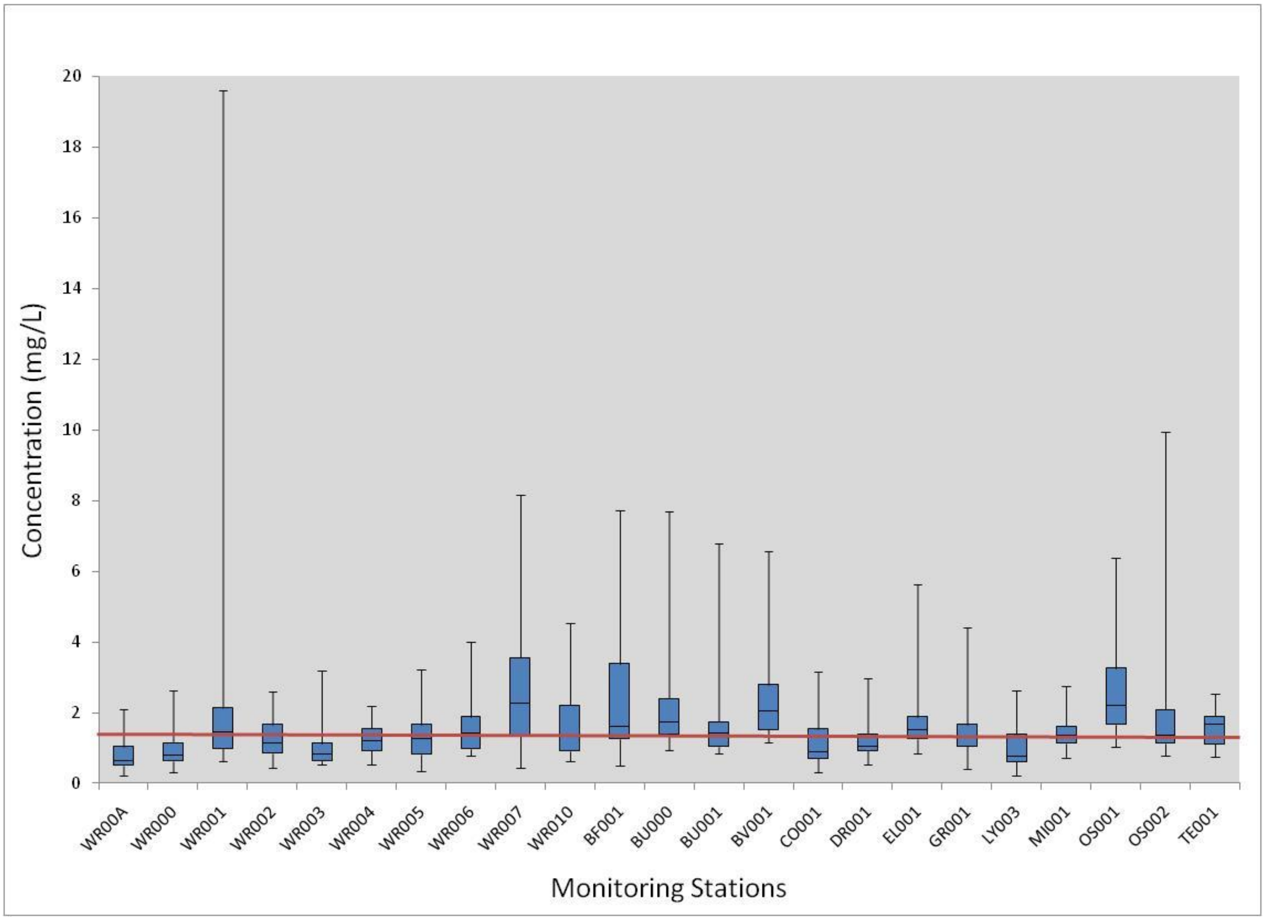

Figure 15: Box and Whisker Plot of Total Nitrogen concentrations (mg/L) of Welland River watershed monitoring stations for 2008-2010 (n=69 for each station). The box length of the box-and-whisker plots represents the inter-quartile range that contains the median value shown as a horizontal line. The whiskers represent the minimum and maximum values. Red line represents published concentration for eutrophic water quality conditions for streams (Dodds *et al.* 1998) of 1.5mg/L for total nitrogen.

2.2.4 Sestonic Chlorophyll-a (chla)

Chlorophyll-a (chl*a*) is the green pigment molecule found in all green plants including algae which carries out the bulk of energy fixation through the process of photosynthesis. Chl*a* is probably the most-often used estimator of algal biomass in lakes and streams. The amount of chl*a* found in a water sample is used as a surrogate measure of the concentration of phytoplankton. Sestonic chl*a* is the concentration of chl*a* extracted from algae in the water column. Benthic chl*a* is the concentration of chlorophyll-a extracted from the periphyton algae community that that lives on the submerged strata on photic zone of most aquatic ecosystems. Monitoring (sestonic and/or benthic chl*a*) for chl*a* concentrations in surface water is a long-accepted method used to assess the general biological status of an aquatic ecosystem, such as its trophic status or rates of primary production. High concentrations of chl*a* in surface waters can be an indicator of nutrient pollution, phosphorus in particular, because excess nutrients fuel the growth of algae. The senescence and decomposition of these organisms as well as their nocturnal consumption of oxygen can produce conditions that impair fish populations. Algae blooms which can occur in nutrient rich water contribute to a variety of water quality issues such as summer fish kills, foul odours and unfit drinking water.

Although there has been extensive work on defining ecologically and aesthetically acceptable concentrations of sestonic algae in lentic systems (e.g. lakes, reservoirs), there have been very few targets developed for lotic (e.g. riverine) ecosystems. This is because lentic and lotic systems differ in the way their food webs respond to nutrient enrichment and applying a lentic derived chl*a* target may not be appropriate (Chambers *et al.* 2008). There is also some controversy whether sestonic chlorophyll-a targets should be developed for streams and rivers because some or all of the sestonic chl*a* may be benthic chl*a* that has migrated from the stream bottom (Chambers *et al.* 2008). Chambers *et al.* (2008) selected 5 µg/L for sestonic chl*a* to assess nutrient status which is intermediate to the US EPA (2000) guideline of 8 µg/L for streams and the 3 to 5 µg/L ANZECC guideline for Australian lowland rivers (2000). Chambers *et al.* (2008) value of 5 µg/L is consistent with other studies and therefore appropriate to assess eutrophication conditions in the Welland River.

Only the uncorrected concentrations are reported in this section and all raw chl*a* data can be found in **Appendix H**. Results shown in **Figure 16** from the 2008-2010 field seasons were compared to the NASEI (Chambers *et al.* 2008) sestonic chl*a* target of 5 µg/L. During the 2008-2010 field seasons 495 sestonic chl*a* samples were collected and 148 samples or 30% of the samples exceeded the NASEI sestonic chl*a* target of 5 µg/L (Chambers *et al.* 2008). Sample stations along the main Welland River channel from WR005-WR007, Oswego Creek (OS001-OS002), and Buckhorn Creek (BU000) had the highest median concentrations of sestonic chl*a*. The highest sestonic chl*a* concentration for 2008-2010 was found to be 154.0 µg/L at Oswego Creek station (OS001). Sestonic chl*a* concentrations increased along the main Welland River channel from upstream to downstream but abruptly decreased at WR010 likely due to the mixing with the redirected Niagara River water. The lowest observed sestonic chl*a* concentrations were found at the headwater tributaries (WR00A & WR002) and end station (WR010) of the Welland River, Drapers Creek (DR001) and Beaver Creek (BV001). Generally chl*a* concentrations increased in 2010 when compared to 2008-2009 concentrations and this is likely the result of the hot and dry summer of 2010. Median sestonic chl*a* concentrations were also highest in the spring (**Figure 17**).

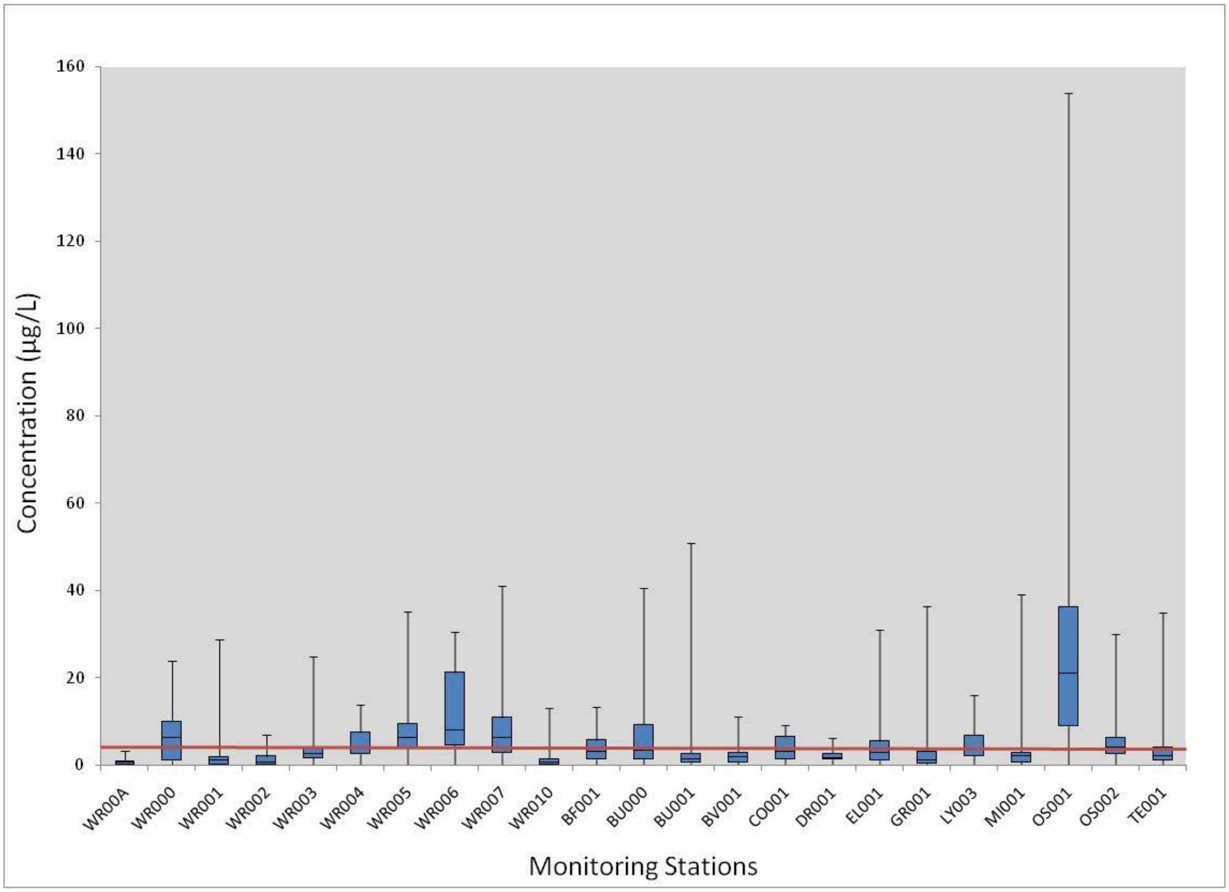

Figure 16: Box and Whisker Plot of uncorrected Chlorophyll-a concentrations (µg/L) of the Welland River watershed monitoring stations for 2008-2010 (n=69 for each station). The box length of the box-and-whisker plots represents the inter-quartile range that contains the median value shown as a horizontal line. The whiskers represent the minimum and maximum values. Red line represents NASEI (2008) sestonic chl*a* target of 5 µg/L.

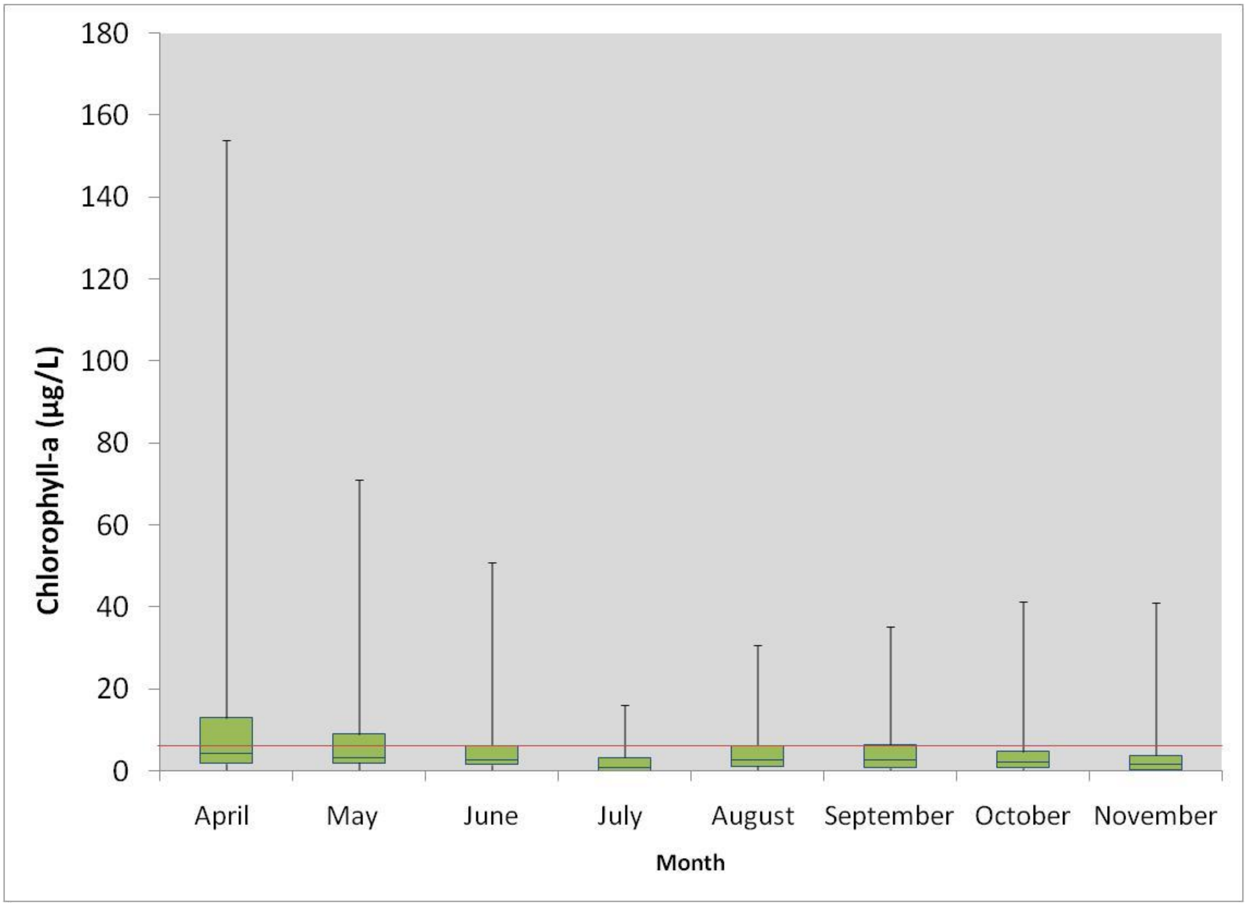

Figure 17: Box and Whisker Plot of monthly uncorrected Chlorophyll-a concentrations (µg/L) of pooled watershed monitoring stations for 2008-2010 (n=69 for each month except April n=46, July n=46). The box length of the box-and-whisker plots represents the inter-quartile range that contains the median value shown as a horizontal line. The whiskers represent the minimum and maximum values. Red line represents NASEI (2008) sestonic chl*a* target of 5 µg/L.

The TWG suggest that duckweed (*Lemna* spp.) blooms that occur in the central portions of the Welland River watersheds have likely been mistaken for algal blooms by the public. Although water conditions may be ideal for algae blooms, it is likely that duckweed is able to outcompete algae for sunlight. The TWG notes that these duckweed blooms do provide evidence that the nutrient levels in the river are high as duckweed thrives on elevated phosphorus and nitrogen levels. Duckweed in itself is not harmful and in some cases beneficial because it extracts nutrients from the water. The problem with overgrowth of duckweed is the DO it consumes through respiration and when it dies off and decays in the watercourse.

2.2.5 Dissolved Oxygen

Oxygen is the most abundant element of the earth's crust and waters combined. It is the single most important component of surface water for self-purification processes and the maintenance of aquatic organisms (such as fish and macroinvertebrates) which utilize aerobic respiration. Air contains approximately 20.9% oxygen gas by volume; however, the proportion of DO in water is about 35%. Oxygen is considered to be moderately soluble in water and this solubility is maintained by a complex set of conditions that include atmospheric/hydrostatic pressure, turbulence, temperature and salinity. Pollution affects DO concentrations by contributing oxygen-demanding organic matter such as sewage and manure. Agricultural runoff contains nutrients (phosphorus and nitrogen) that stimulate the growth of algae and aquatic plants. Although algae and aquatic plants contribute oxygen through photosynthesis, their overgrowth results in a net oxygen loss through the processes of respiration and decomposition. The Ontario MOE has developed a Provincial Water Quality Objective (PWQO) for DO in streams and this is shown in **Table 7**. The Welland River has been classified as a warm water fishery and therefore the PWQO for DO for Warm Water Biota will be applied for the Welland River Eutrophication Study.

Table 7: Provincial Water Quality Objectives for Dissolved Oxygen (1994).

Dissolved Oxygen Concentrations		
Temperature	**Warm Water Biota**	
°C	**% Saturation**	**mg/L**
0	47	7
5	47	6
10	47	5
15	47	5
20	47	4
25	48	4

As part of the Welland River Eutrophication Study, the NPCA and the MOE deployed DO sensors at a number of stations along the Welland River (WR004, WR005, WR007, Welland River at Chippawa Conservation Area and Welland River at the City of Welland) and in three subwatersheds Beaver Creek (BV001), Oswego Creek (OS001 and OS002), and Big Forks Creek (BF001). These stations are shown in **Figure 18**. There were 4 DO loggers available in 2008 and 2009 and 6 DO loggers available in 2010. DO loggers were rotated among the sites each year. The purpose of these loggers was to capture summertime DO concentrations. DO loggers were programmed to record hourly DO concentrations from late spring (May or June) until early fall (late September or October). DO logger data is provided in **Appendix I**.

Figure 18: Dissolved Oxygen Data Logger Locations 2008-2010.

Over the study period (2008-2010) the majority of DO loggers deployed in the main Welland River channel reported DO concentrations below the PWQO (**Appendix D**). Stations WR004, WR007, and Welland River at Chippawa Conservation Area had sustained DO concentrations below the PWQO. DO concentrations at WR005 in 2009 were above the PWQO as were DO conditions in the Welland River at the City of Welland station in 2009; daily back-flow of Niagara River water at this site may have improved DO concentrations. Although the majority of DO concentrations in the Welland River at the City of Welland station were above the PWQO they were highly variable and a significant reduction of DO was noted during a major rain event on August 8th, 2009. A similar response to this rain event was also found at Welland River at Chippawa Conservation Area. Abundant duckweed (*Lemna* spp.) growth was noted in the late summer of 2008 and 2009 at WR007 and the Welland River at the City of Welland station but this could not be directly linked to the DO concentrations.

As shown in **Appendix D** the majority of summer DO concentrations in the subwatershed stations BF001, BV001, OS001, and OS002 were found to be below the PWQO. In 2008, BF001 and BV001 experienced sustained low summertime DO conditions. In early summer of 2010 the BV001 station experienced large diurnal fluctuations (greater than 8 mg/L) in DO concentrations. Similarly, BF001 and OS001 loggers in 2010 reported some large fluctuations in daily DO concentrations throughout the season. Abundant macrophyte growth was noted at BV001 and OS001 in 2008 and 2010. Duckweed (*Lemma* spp.) overgrowth was noted at BF001 for 2008 and 2010. In addition, these subwatersheds often have water conditions that are stagnant which likely aggravate the DO conditions at these sites. Less impaired DO concentrations were observed at OS001 in 2008 and OS002 in 2009. The differences in DO profile between years at BV001, BF001, and OS001 highlight the yearly variation at each station.

2.2.6 Correlation Analysis

Scatter plots were used to investigate the possible relationships between several combinations of water quality parameters that are of concern in the Welland River Eutrophication Study. These parameters include Total Phosphorus (TP), Phosphate, Chlorophyll-a, and Total Suspended Solids (TSS) from the 2008-2010 field seasons. Pearson Correlation Coefficients were calculated to assess the strength of the relationship on the pooled data set (all stations) and site specific data (individual stations) and these are summarized in **Table 8** and **Table 9**. Scatter plots are provided in **Appendix J**. To investigate the relationship of nutrients (phosphorus and nitrogen) with sesontic algae (chl*a*) Regression Analysis was conducted on the pooled data.

With the pooled dataset the strongest correlation that was found was between TSS and TP (**Table 8**). This relationship is not surprising as phosphorus is associated with soil particles found suspended in the water. This relationship occurs in part because of sediment runoff from agricultural lands and increased water flow that has scoured sediment from the stream bottom and banks increasing the amount of solids in the water column. When site specific TSS and TP correlations were examined, the majority of the central Welland River monitoring stations had significant ($p<0.05$) positive relationships (**Table 9**). Monitoring stations on the main Welland River channel near Binbrook Reservoir and some subwatershed tributaries did not show significant relationships between TP and TSS. The TWG could not determine why these stations have different TP and TSS relationships.

The link between phosphorus and sestonic Chl*a* was not clear as there were no significant relationship between these parameters for the pooled data ($F=2.327$, $r^2=0.01$, $p>0.05$). Similarly, no significant relationship ($F=0.9699$, $r^2=-0.00014$, $p>0.05$) could be found between pooled TN and sesontic chl*a*. The lack of correlation with Chl*a* to phosphorus and nitrogen may be the result of measuring sesontic Chl*a* and not benthic Chl*a*. The TWG has noted that benthic Chl*a* may be a better measure of primary production in river systems. Therefore, the link from phosphorus (and nitrogen) to primary production should not be disregarded because not all sources of primary production have been measured. Only station WR010 found in the lower Welland River was found to have a strong positive relationship with phosphorus. This may be the result of the backwater effect of the Niagara River at this station which is potentially causing lentic conditions where phosphorus and sestonic chl*a* relationships are stronger.

Table 8. Pearson Correlation Coefficient Summary (n=573 for all other combinations) for pooled 2008-2010 data. Yellow highlighted cells represent significant relationship to 0.05 level.

Parameter	Pearson R Correlation
TP & Chl*a*	0.04
TP & TSS	0.43
Phosphate & Chl*a*	0.01
Phosphate & TSS	0.2
TN & Chl*a*	0.01
	Significant to 0.05 level

Table 9. Station Specific Pearson Correlation Coefficient Summary (n=24 for all other combinations) for 2008-2010 data. Yellow highlighted cells represent significant relationship to 0.05 level. Green highlighted cells represent significant relationship to 0.01 level.

	Parameters		
Station	**TP & Chl*a***	**Phosphate & Chl*a***	**TP & TSS**
WR00A	-0.29	0.13	0.45
WR000	0.08	0.01	-0.12
WR001	0.1	-0.44	0.44
WR002	-0.03	-0.17	-0.16
WR003	0.08	-0.21	0.36
WR004	-0.09	-0.25	-0.25
WR005	-0.12	-0.26	0.81
WR006	-0.29	-0.43	0.93
WR007	0.34	0.05	0.44
WR010	0.81	0.69	0.89
BF001	0.15	0.34	0.28
BU000	0.26	-0.06	0.19
BU001	-0.07	0.16	-0.15
BV001	0.23	0.19	0.75
CO001	-0.13	-0.21	0.75
DR001	-0.24	-0.6	0.86
EL001	-0.06	0.04	0.67
GR001	-0.05	-0.31	0.82
LY003	-0.01	-0.19	0.79
MI001	-0.14	-0.11	0.71
OS001	-0.1	0.15	0.18
OS002	-0.11	-0.08	0.75
TE001	-0.16	-0.09	0.4

2.2.7 Sediment Samples

MOE staff collected surface sediment samples at WR007, WR006, WR005, BF001, BV001, OS001, and OS002 on October 10, 2008 and OS001, CO001 and OS002 were collected on Oct 30, 2009 to determine sediment quality. Sediment samples were taken at all sites except WR005 using a sediment Ponar dredge with 1 to 2 sediment grabs taken while sediment samples at WR005 was collected using a stainless steel mixing spoon and pan. All samples were homogenized in a stainless steel pan and placed in a 250 mL amber glass jar. Sampling equipment was cleaned and triple-rinsed with hexane between sampling stations. Sediment samples were analyzed for nutrients, moisture and particle size. The results from both the 2008 and 2009 sediment sampling are summarized in **Table 10** and are compared to the Guidelines for the Protection and Management of Aquatic Sediment Quality in Ontario (MOE 1993). All samples collected were found to exceed the Lowest Effect Level Sediment Quality Guideline for total organic carbon (TOC), total Kjeldahl nitrogen (TKN) and TP, indicating that sediment quality is marginally polluted and will affect some benthic organisms at these locations. One sample in 2008 was at the Severe Effect Level (SEL) and none of the samples collected in 2009 were found to exceed the SEL for these parameters.

Table 10: MOE sediment sampling results for 2008 and 2009. Yellow cells indicate that MOE Lowest Effect Level has been exceeded and Red cells indicate Severe Effect Level has been exceeded.

	Parameter			
	TOC (µg/g dry)	**TKN (µg/g dry)**	**TP (µg/g dry)**	**Moisture (%)**
WR007 (Oct 10 2008)	52000	2200	1200	62
WR006 (Oct 10 2008)	28000	1800	1200	63
WR005 (Oct 10 2008)	40000	1500	960	54
BF001 (Oct 10 2008)	69000	3400	1200	77
BV001 (Oct 10 2008)	48000	2100	2000	53
OS001 (Oct 10 2008)	67000	2800	980	52
OS002 (Oct 10 2008)	39000	1700	920	55
GR001 (Oct 30 2009)	19000	600	690	33
CO001 (Oct 30 2009)	24000	1300	830	42
OS002 (Oct 30 2009)	26000	1800	920	62
Guideline for the Protection and Management of Aquatic Sediment Quality in Ontario (1993)				
Lowest Effect Level (ug/g)	**10000**	**550**	**600**	**n/a**
Severe Effect Level (ug/g)	**100000**	**4800**	**2000**	**n/a**

A scatter plot of paired sediment TP concentrations and mean surface water TP concentrations at each station is shown in **Figure 19.** There is a moderate positive relationship between these two variables. This may indicate two possible scenarios where the large TP load in the water column is settling out into the sediment at these locations or the sediment TP in the watersheds is contributing a significant proportion of the phosphorus observed in the surface waters. **Figure 19** also provides additional evidence to the hypothesis that a number of subwatersheds such as Beaver Creek (BV001), Big Forks Creek (BF001) and Oswego Creek (OS001) are more impacted than others. It should also be noted that Coyle Creek appears to be the least impacted subwatershed (**Figure 19**).

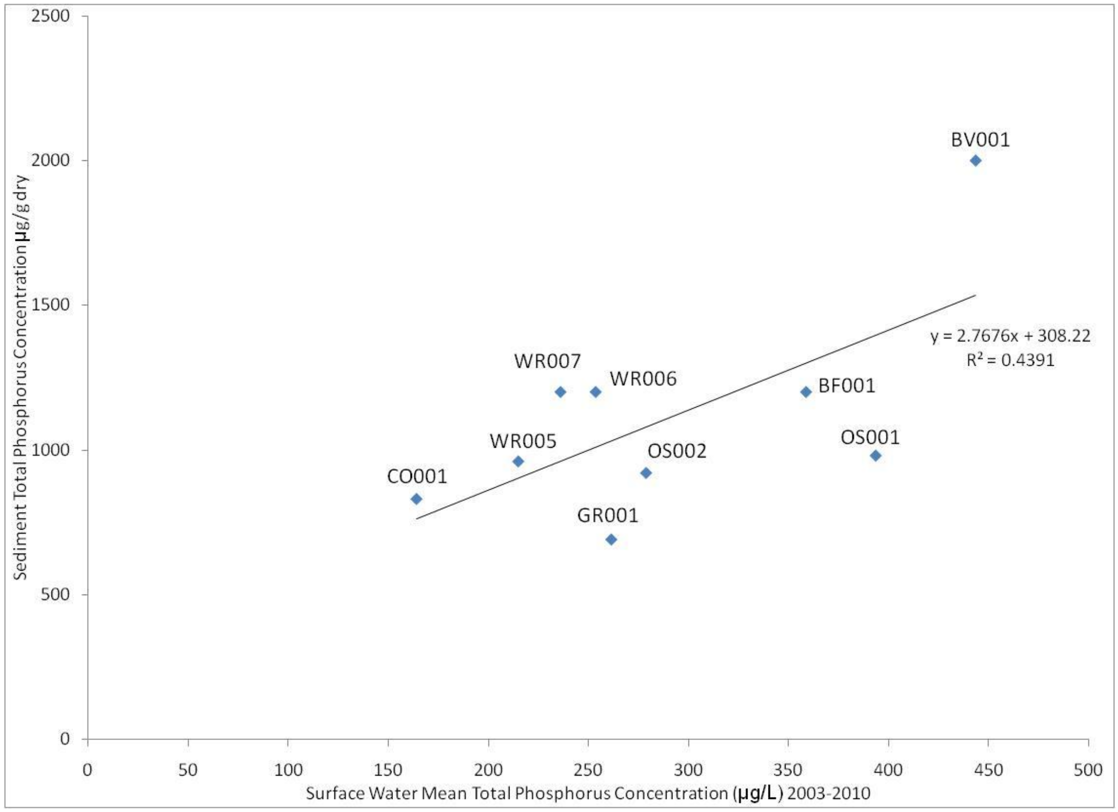

Figure 19: Scatter plot of mean surface water TP concentrations (µg/L) 2008-2009 and Sediment TP concentrations (µg/g dry) 2008-2009 for select monitoring stations in the Welland River watershed.

2.3 Data Summary

- The Welland River is a eutrophic watershed characterized by very high phosphorus concentrations. Ninety-nine percent of the grab samples collected in the 2008-2010 study failed to meet the interim PWQO of 30 µg/L for total phosphorus. The central portions of Welland River (WR005, WR006 and WR007) and the subwatersheds Big Forks Creek (BF001), Buckhorn Creek (BU000 & BU001), Beaver Creek (BV001), Oswego Creek (OS001) and Tee Creek (TE001) have the highest phosphorus concentrations in Niagara River AOC.
- Downstream of the Binbrook Reservoir, the portion of total phosphorus consisting of phosphate is greater than 50% in the samples. The highest concentrations of phosphate was observed in Big Forks Creek (BF001), Beaver Creek (BV001), Oswego Creek (OS001), and Tee Creek (TE001).
- The Welland River watershed is nitrogen enriched with approximately 42% of the grab samples collected in the study period exceeding the total nitrogen concentration for eutrophic water described by Dodds *et al.* (1998). The highest mean concentrations of total nitrogen were observed at the Big Forks subwatershed (BF001), Beaver Creek (BV001), Buckhorn Creek, and the upper and lower Oswego Creek subwatershed (OS001 & OS002). From 2008 to 2010, 3% of the samples exceeded the CCME for

nitrate-nitrogen (2006) and 1% of samples exceeded the PWQO (1994) for un-ionized ammonia (1994).

- The central portion of the Welland River watershed was found to have summertime DO concentrations below the PWQO for warm water biotic. Monitoring stations with observed DO impairments include Big Forks Creek (BF001), Beaver Creek (BV001), Oswego Creek (OS001 and OS002) and the Welland River (WR007, Prince Charles Drive Station, and Chippawa Conservation Area). Stations that were not monitored due to lack of resources include: Coyle Creek (CO001), Drapers Creek (DR001), Elsie Creek (EL001), Mill Creek (MI001), Lyons Creek (LY003), Tee Creek (TE001) and Welland River (WR00A, WR000, WR001, WR002, WR003, WR006 and WR011). Although a primary stressor could not be determined, it is likely that a number of stressors are impairing DO concentrations in the Welland and they may include respiration by plants and algae partially related to the overgrowth of macrophyte vegetation (e.g. duckweed), flow impairments, Nitrogenous Oxygen Demand (NOD), Biological Oxygen Demand (BOD), Sediment Oxygen Demand (SOD) and Chemical Oxygen Demand (COD).
- The correlation analysis found a significant relationship between TP and TSS. This relationship is not surprising as phosphorus is associated with soil particles found suspended in the water. There was no relationship between TP and sestonic Chl*a* and TN and sestonic Chl*a*. This may suggest that the bulk of the primary productivity may be associated with the periphyton and duckweed.
- All samples collected in 2008 and 2009 were found to exceed the Lowest Effect Level Sediment Quality Guideline for TOC, TKN and TP, indicating that sediment quality is marginally polluted and will affect some benthic organisms at the sample locations.

3.0 Delisting Criteria

3.1 Background

In 1987, the governments of Canada and the United States identified or (listed) 43 Areas of Concern (AOC) along the Great Lakes shorelines in which the aquatic environment was particularly degraded. As a response, Remedial Action Plans (RAPs) were developed and implemented to address the water quality issues that led to the listing of within these AOCs, each issue of concern is known as a Beneficial Use Impairments (BUI). The Great Lakes Water Quality Agreement identified a common suite of 14 BUIs to be considered and potentially identified for each AOC. Any BUI identified for an AOC must be addressed before it can be delisted which would allow for removal of an area from the list of AOCs. In the Niagara River RAP Stage 2 Update Report (2009), the Niagara River AOC had nine of fourteen BUIs identified. The Eutrophication/Undesirable Algae Beneficial Use Impairment was listed as “impaired” partially based on the total phosphorus (TP) concentrations in the Welland River which exceeded the RAP Stage 2 delisting criteria and Provincial Water Quality Objectives (PWQO) of 30 µg/L (Remedial Action Plan 1995). Other reasons for this designation include depletion of dissolved oxygen (DO), observed impairment to fish and benthos communities, and anecdotal evidence of algae blooms (Environment Canada 2007). The main stressors identified were excessive nutrients from municipal Combined Sewer Overflows (CSOs) and Waste Water Treatment Plants (WWTPs), as well as non-point sources from tributaries draining agricultural lands. The Eutrophication/Undesirable Algae BUI continues to be a key focus of the Niagara River RAP.

3.2 Delisting Criteria Definition

Delisting criteria are endpoints for remedial action. Delisting criteria define the desired state of the Great Lakes at some future point of recovery following the implementation of remedial actions. These remedial actions need to be informed by monitoring program results or collective lines of evidence in such a way that those who implement RAPs can adapt remedial actions and priorities based on new information about the state of recovery of the ecosystem. Ideally, monitoring programs, delisting criteria, remedial actions and priorities are complementary and interrelated. To realize this ideal, the following conditions need to be met:

- Delisting criteria should contain targets for which achievement can be shown using existing or plausible future monitoring program results. This way, monitoring data can answer the question “Has recovery been achieved?”
- Many times it is not a single monitoring program or set of data that is being used to make the decision if the delisting criterion has been met. Rather numerous lines of evidence are all being pulled together to try and get a complete picture of the status of the BUI against the delisting criteria.
- Delisting criteria should also suggest indicators to evaluate the state of ecosystem impairment. This would allow the status of the impairment to be evaluated using existing

or novel monitoring program results. This way, monitoring data can answer the question "How close are we to achieving recovery?"

- When reporting on progress of ecosystem recovery using indicators and targets, indicators should provide information that can be used to adapt or reinforce remedial actions, helping to answer the question "If recovery has/has not been achieved, what are the next steps?".
- Delisting criteria, indicators, and targets should all relate directly back to Impairments BUIs, which form the basis for problem definition in RAP.
- The BUI must be linked directly to the ecological health of the Great Lakes. If an identified impairment is found not to be linked to the ecological health of the Great Lakes than it is not an impairment of interest to the RAP.

3.3 Rationale for New Delisting Total Phosphorus Criteria

There are several existing criteria calibrated to riverine systems in Canada for TP that could be used as possible delisting criteria (**Table 11**). The TP concentrations identified in these criteria generally represent minimally impacted conditions. The Niagara River RAP Stage 2 delisting criteria is the current MOE Provincial Water Quality Objective (PWQO) of 30 µg/L for streams and rivers which was established to eliminate excessive algae growth (MOE, 1994). The PWQO is commonly used by governmental agencies in the province to access watershed health.
A second delisting criteria approach based on defined Ecoregion criteria (Gartner Lee Ltd 2006) investigated background concentrations of TP in streams by accounting for regional variability of soils, climate, and vegetation found throughout Ontario. This approach used the 25th percentile of baseline concentrations for TP for each specific Ecoregion. The Welland River watershed falls within the Lake Erie Lowland Ecoregion which has a corresponding TP concentration criterion of 32 µg/L.

Next, the 2008 National Agricultural Environmental Standards Initiative (NAESI) was an agreement between Environment Canada and Agriculture and Agri-Food Canada to develop new environmental standards for key theme areas such as air, water, pesticides and biodiversity. Within the water theme, the NAESI approach determined that the Ideal Performance Standard for surface water quality in agricultural watersheds could be achieved with a TP concentration of 24 µg/L. This concentration was deemed necessary for achieving good biological conditions in surface water for 3 of 4 biological attributes such sestonic algal biomass, benthic algal biomass, benthic diatom composition and benthic macroinvertebrate composition.

Outside of Canada, there are some TP guidelines and standards for minimally impacted conditions but generally these concentrations are not substantially different from the concentrations found in **Table 11**.

Table 11: Published Stream Total Phosphorus Criteria for riverine Systems in Canada.

Method	Total Phosphorus µg/L
Provincial Water Quality Objective (MOE, 1994)	30
Ecoregion (Gartner Lee Ltd., 2006)	32
NAESI (Environment Canada, 2008)	24

A technical review of impairments and delisting criteria led by Environment Canada (2007) concluded that the selection of the PWQO or another similar criterion for TP may be too arbitrary. The PWQO, Ecoregion and NAESI criteria represent minimally impacted or completely forested watershed conditions and do not account for the permanent irreversible land use of watersheds both within and AOCs and other urbanized or agricultural areas around the Great Lakes. Based on this constraint it was recommended that a more realistic TP delisting criterion be developed for the Niagara River AOC tributaries that is scientifically-based and achievable through Best Management Practices (BMPs).

3.3.1 Delisting Criteria Focus

The Welland River is a slow moving, low gradient watercourse that has a very unique hydrology. The headwaters of the Welland River are tightly controlled by the Binbrook Dam in Hamilton. In the lower reaches, the Hydro Control Dam diverts vast quantities of water from the Niagara River into the Welland River. The water levels within the Welland River are completely controlled by the operating range of the Hydro Control Dam and as such the Welland River acts like a linear 60 km long reservoir. In addition, the Welland River is diverted through siphons under the old and new Welland Canals. This has lead to water stagnation, reversed flows and limited flushing of particles from the Welland River system. The Niagara River RAP Technical Working Group (TWG) noted that due to the unique hydrology of the Welland River, it wasn't realistic to expect ideal river conditions in the Welland River main channel. Based on this the TWG recommends that loading targets and delisting criteria determined through the Welland River Eutrophication Study should be applied to the subwatersheds of the Welland River. The TWG decided to focus on the subwatersheds because potential improvements to water quality could be quantified, which in theory should cascade down to water quality improvements in the Welland River channel. This generally agrees with the study objectives #4 and #5 of the Welland River Eutrophication Study.

3.4 Development of New TP Delisting Criteria

At the commencement of this study, the TWG conducted a literature review and identified that the agencies managing the St. Lawrence River, Cornwall, AOC had adopted new delisting criteria for TP based on an export coefficient approach (AECOM 2009). With this approach, specific TP criteria can be determined for each subwatershed based on its land use. After an initial review, the TWG decided to proceed with an expanded version of this approach for the Welland River Eutrophication Study. The expanded version of this export coefficient approach included the calculation of three new sets of TP delisting criteria through three different methods, as summarized as approaches #1- #3 below.

In addition to the Export Coefficient Approaches, the TWG also considered a 25th Percentile Approach that is also summarized below.

3.4.1 Export Coefficient Approach #1

The first export coefficient delisting criteria option follows the approach proposed by AECOM (2009) that was eventually adopted for use for the St. Lawrence River, Cornwall, AOC. The delisting criteria determined in the AECOM report (2009) were based on export coefficients published by Winter and Duthie (2000) for the Laurel Creek watershed in the Grand River for various land use activities (**Table 12**). Despite the large number of published export coefficients in the literature (Mitch and Trew 1982, Dodd et al. 1992, USEPA 2002, Jeje 2006), the values (**Table 12**) used by Winter and Duthie (2000) were deemed appropriate for the Cornwall study area because: (1) Soils (loam, silt-loam, clay, and sand) in both study areas were reasonably similar; (2) Both watersheds had similar agricultural land uses; (3) The study area was located in southern Ontario with comparable climate and geology; (4) The research of Winter and Duthie (2000) is recent and based on the best available science to date. For the Welland River Eutrophication Study, the TWG also agreed that these same reasons were valid enough to consider Winter and Duthie (2000) export coefficients for use as a starting point.

Like the AECOM study (2009) a run-off value from Natural Resources Canada (2009) was used to gauge the volume of water that is contributed to the streams as a result of precipitation. In the case of Niagara, the runoff value was 0.30 m/yr. Based on the product of export coefficients and run-off values, a TP concentration was calculated for each land use type assuming 100% coverage of that type in each fictitious watershed **(Table 12).** The TP concentration calculated for woodland land use was 33 µg/L, a concentration consistent with the PWQO, Ecoregion and NAESI values that represent minimally impacted or completely forested watershed conditions.

Table 12: Total phosphorus export Coefficients (kg/ha/yr) in well managed systems for Urban, Crops, Pasture, and Woodland Land Uses (Winter and Duthie 2000) and mean TP concentration for a fictitious watershed with runoff of 0.30 m/yr.

Land use	P export (kg/ha/yr)	Mean TP in Fictitious Watershed (µg/L) (Runoff= 0.30 m/yr)
Urban	0.50	166
Crops	0.25	83
Pasture	0.20	67
Woodland	0.10	33

To calculate delisting criteria using these export coefficients and corresponding TP concentrations for use in the Welland River watershed, the percentage of land disturbance in each subwatershed was determined with information provided by the Ministry of Natural Resources as part of the Southern Ontario Land Resource Information System (SOLRIS) (2006 and 2007). Based on the SOLRIS data and with the assistance of the NPCA GIS staff interpretation, the land use was designated undisturbed if it was classified as Bog, Coniferous Forest, Deciduous Forest, Forest, Hedge Rows, Idle Land, Marsh, Mixed Forest, Open Shoreline, Open Water, Plantations, Shoreline, Swamp, and Vineyards. Based on these same data, land use was designated as disturbed if it was classified as: Annual Crop, Built-Up Impervious, Built-Up Pervious, Extraction, Mixed Agriculture, Mixed Crop, Monoculture, Orchards, Perennial Crop, Rural Land Use, and Transportation. From the SOLRIS mapping the percentage of land disturbance was determined for each subwatershed (**Table 1**).

Table 13: Percentage of Land Disturbance for Each Subwatershed based on SOLRIS (2006 & 2007)

Subwatershed	Station ID	% Disturbed
Elsie Creek	EL001	87
Buckhorn Creek	BU001	87
Big Fork Creek	BF001	82
Beaver Creek	BV001	79
Drapers Creek	DR001	77
Oswego Creek	OS001	77
Grassy Brook	GR001	74
Mill Creek	MI001	74
Tee Creek	TE001	70
Lyons Creek	LY003	69
Coyle Creek	CO001	65

Regression equations (**Appendix K**) were calculated for urban, crop and pasture export coefficients based on zero to one hundred percent watershed disturbance. A nomogram (**Figure 20**) was created showing the actual and target annual average total phosphorus concentrations of each watershed based on its percentage of disturbance in the watershed using the Winter and Duthie (2000) export coefficients for urban, crops and pasture. Like the AECOM study (2009) a range of TP concentrations for crop and pasture land uses for each watershed percent disturbance zones (80%-100%, 60%-80%, 40%-60%, 20%-40%, and 0%-20%) were complied and summarized in **Table 14.** In addition, a range of TP concentrations were complied for urban and crop land uses to accommodate the Drapers Creek subwatershed's predominantly urban land use (**Table 14**).

Following the AECOM study's approach, the mean TP concentrations between crop and pasture were calculated for five disturbance levels (80%-100%, 60%-80%, 40%-60%, 20%-40%, and 0%-20%). Mean TP concentrations were also calculated for the urban and crop land uses at the five disturbance levels **(Table 14)**. The mean TP concentrations for crop/pasture were designated for rural land uses and the mean TP concentration for crop/urban were designated for urban land use and these values are the delisting criteria for the corresponding level of disturbance.

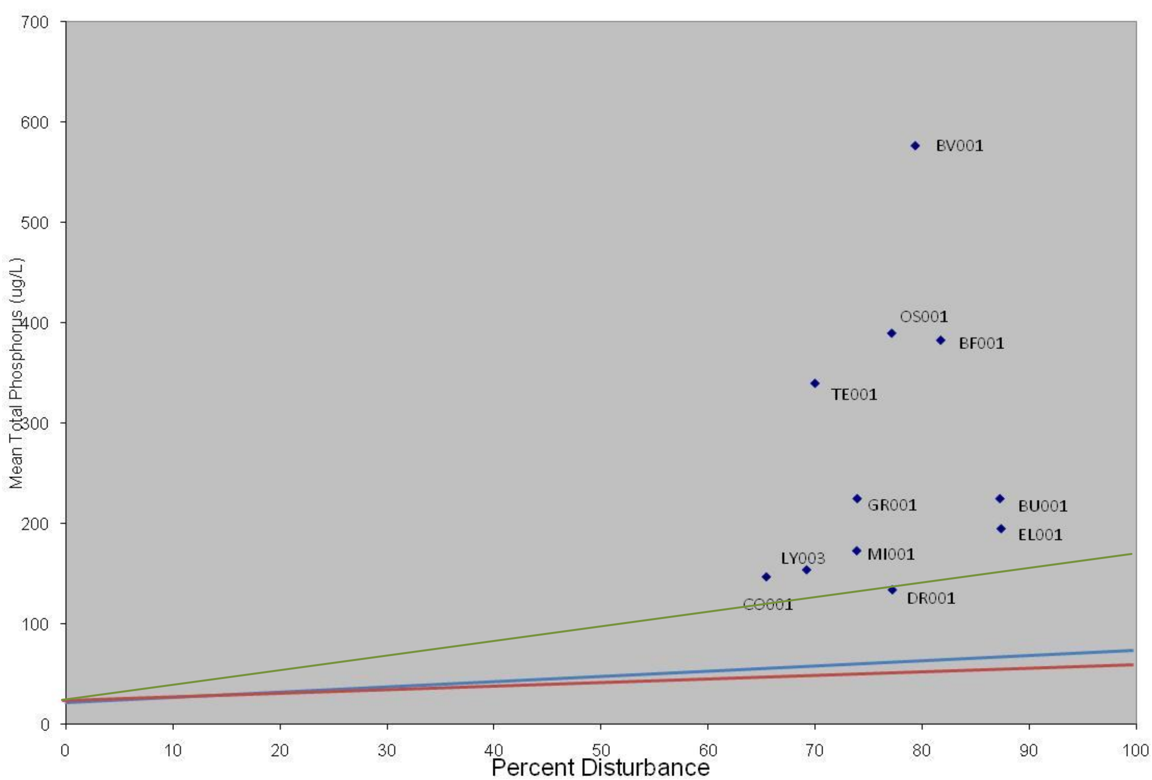

Figure 20: Nomogram of Actual and Target (urban – green line; crops – blue line; pasture – red line) Annual Average Phosphorus Concentrations at Tributary Mouths for a Given Percentage of Disturbance in the Watershed, Based on Export Coefficients for Crops and Pasture from Winter and Duthie (2000).

Table 14: Total Phosphorus Delisting Criteria derived from Export Coefficient Approach #1 using TP Export Coefficients from Winter and Duthie (2000) and runoff values from Natural Resources Canada mapping (2009).

% Disturbance	Range (µg/L) Pasture & Crop	Mean TP Concentrations to be used as Delisting Criteria (µg/L) for predominantly rural land uses	Range (µg/L) Crop & Urban	Mean TP Concentrations to be used as Delisting Criteria (µg/L) for predominantly urban land uses
80%-100%	64-72	68	72-152	115
60%-80%	55-64	60	64-126	97
40%-60%	47-55	53	55-100	79
20%-40%	39-47	44	47-73	60
0%-20%	<35	<35	<35	42

Table 15: Welland River Subwatershed Delisting Criteria and Loading Target using Export Coefficient Approach #1.

% Disturbance	Watershed	TP Concentration Delisting Criteria (µg/l)	TP Loading Target (kg/ha/yr)	Current Mean TP Concentration (µg/l)	% Reduction to Reach Delisting Criteria
80%-100% Rural Delisting Criteria	Elsie Creek (EL001) Buckhorn Creek (BU001) Big Forks Creek (BF001)	71	0.20	190 270 390	63 74 82
60%-80% Rural Delisting Criteria	Beaver Creek (BV001) Oswego Creek (OS001) Grassy Brook (GR001) Mill Creek (MI001) Tee Creek (TE001) Lyons Creek (LY003) Coyle Creek (CO001)	62	0.18	540 380 220 170 340 150 140	89 84 72 64 82 59 56
60%-80% Urban Delisting Criteria	Drapers Creek (DR001)	97	0.29	130	25

The TWG identified some limitations to the export coefficients used in Approach #1. The first limitation is that AECOM assumes all agricultural and urban practices have the same environmental management issues and solutions. As an example, Approach #1 assumes similar TP loadings from a parcel of land developed and managed for livestock agriculture is the same as a parcel of land developed and managed for tender fruit. Export Coefficient Approach #1 may also be over-simplifying a very complex process and may not be representative of all agricultural land uses. These export coefficients have been derived from literature values based on a small number of studied watersheds and may not account for the system variability.

Another limitation is the assumption that achieving the targeted nutrient loads by using Approach #1 will have a significant improvement to the BUI. Achieving the delisting criteria in Export Coefficient Approach #1 may not change the impairment status of this BUI as it is the biological response to phosphorus which is the issue, rather than phosphorus concentrations in itself.

3.4.2 Export Coefficient Approach #2

The second export coefficient delisting criteria approach is similar to Approach #1 by using the TP export coefficients provided by Winter and Duthie (2000), but differs by using local estimates of run-off (**Table 16**) from Niagara Peninsula Conservation Authority (NPCA) Source Water Protection Water Budget Final Report (NPCA and AquaResources Inc. 2010). These run-off values replace the Natural Resources Canada (2009) run-off estimates used in Approach #1. The methodology of deriving these run-off values is described in **Section 2.1.2** The NPCA and Aqua Resources (2010) run-off values can be seen as an improvement to the AECOM approach described in **Section 3.4.1** because of the use of local Niagara data in the derivation of TP concentration criteria.

Table 16: Subwatershed Run-off Values from Niagara Peninsula Conservation Authority and AquaResources Inc. 2010.

Subwatershed	Runoff m/yr
Beaver Creek (BV001)	0.23
Big Forks Creek (BF001)	0.26
Buckhorn Creek (BU001)	0.22
Coyle Creek (CO001)	0.25
Drapers Creek (DR001)	0.54
Elsie Creek (EL001)	0.21
Grassy Brook (GR001)	0.30
Lyons Creek (LY003)	0.30
Mill Creek (MI001)	0.24
Oswego Creek (OS001)	0.19
Tee Creek (TE001)	0.30

Like Approach #1, regression equations were generated for each subwatershed using the NPCA and AquaResources Inc. (2010) run-off values and Winter and Duthie (2000) urban, crop and pasture TP export coefficients based on zero to one hundred percent watershed disturbance. The TP delisting criteria for each subwatershed were calculated with the regression equations (**Appendix K**) by using the percentage of land disturbance corresponding to each subwatershed (**Table 13**) and the mean TP concentration of the Urban, Crop and Pasture export coefficient (Winter and Duthie 2000) for these land uses. **Table 17** shows the TP delisting criteria and the loading targets for the Welland River subwatersheds using the Export Coefficient Approach #2. Similar to Approach #1 the delisting criteria for rural land uses were applied to Beaver Creek, Big Forks Creek, Buckhorn Creek, Coyle Creek, Elsie Creek, Grassy Brook, Lyons Creek, Mill Creek and Tee Creek because these subwatersheds are predominantly rural with a variety of active and passive agriculture. The delisting criterion for urban land use was applied to Drapers Creek subwatershed as it is predominately urban with some rural areas.

Table 17: Welland River Subwatershed Delisting Criteria and Loading Target using Export Coefficient Approach #2.

Watershed	TP Concentration Delisting Criteria (µg/l)	TP Loading Target (kg/ha/yr)	Current Mean TP Concentration (µg/l)	% Reduction to Reach Delisting Criteria
Beaver Creek (BV001)	85	0.19	540	84
Big Forks Creek (BF001)	76	0.20	390	81
Buckhorn Creek (BU001)	94	0.20	270	35
Coyle Creek (CO001)	70	0.17	140	50
Elsie Creek (EL001)	97	0.20	190	49
Grassy Brook (GR001)	63	0.19	220	71
Lyons Creek (LY003)	61	0.18	150	59
Mill Creek (MI001)	77	0.19	170	55
Oswego Creek (OS001)	97	0.19	380	74
Tee Creek (TE001)	62	0.18	340	82
Drapers Creek (DR001)	61	0.33	130	53

The case of Grassy Brook, Lyons Creek and Tee Creek delisting criteria are virtually the same as those in Approach #1 because of similar run-off values. In most cases, the delisting criteria for each subwatershed are slightly higher than those values proposed in Approach #1. This is due to two reasons: 1) the delisting criteria in Export Coefficient Approach #1 provides a coarse delisting criteria value because it incorporates a large disturbance zone range of approximately 20% and that is not the case in Approach #2; 2) although runoff values are lower for some watersheds and theoretically less TP is entering the watercourse, the TP delisting criteria is set to control for a desired export coefficient on the flow of water that is believed to be entering the watercourse. Conversely, the delisting criteria of Drapers Creek decreased from Approach #1 because of the larger runoff value used in Approach #2. This means in this watershed that more TP is entering the watercourse through runoff but the TP export coefficients (**Table 12**) remain unchanged and therefore a lower TP concentration is permitted in the watercourse in order to meet the export coefficient.

The added benefit of Approach #2 compared to Approach #1 is the use of watershed specific run-off values (NPCA and AquaResources Inc. 2010) that have been used to calculate TP delisting criteria for each subwatershed. However, like Approach #1, applying this approach to each subwatershed will still require approximately a 50% to 90% reduction in ambient TP concentrations in the creeks in order to reach the proposed delisting criteria. Depending on the subwatershed, Approach #2 generally represents a doubling or tripling of the current delisting criteria of 30 µg/L.

The same limitation identified for Export Coefficient Approach #1 can be applied for Approach #2 because again Winter and Duthie (2000) export coefficients were used, which are literature values and do not account for variability in TP export even when all BMPs are in place. Another limitation is the assumption that achieving the targeted nutrient loads by using Approach #2 will have a significant improvement to the BUI. Achieving the delisting criteria in Export Coefficient Approach #2 may not change the impairment status of this BUI.

3.4.3 Export Coefficient Approach #3

The TWG members had several discussions with Dr. Jenny Winter (per. comm. 2009) regarding the TP export coefficients used by AECOM (2007) for the St. Lawrence River, Cornwall, AOC. Dr. Winter suggested another variation to determine delisting criteria by using an export coefficient calculated for the least disturbed watershed in the Niagara River AOC as in this case site-specific conditions are considered.

This third export coefficient delisting criteria option entails using the local estimates of run-off taken from NPCA Source Water Protection Water Budget Final Report (NPCA and AquaResources Inc. 2010) and with observed TP concentrations (2003-2010) of the least disturbed watershed in the Niagara River AOC to back-calculate an export coefficient. The least disturbed watershed in the Niagara River AOC based on SOLRIS mapping (**Table 13**) was Coyle Creek. The export coefficient of 0.3526 kg/ha/yr for Coyle Creek was then applied to the other subwatersheds to calculate specific subwatershed TP concentration delisting criteria. **Appendix K** contains the values used to calculate the Approach #3 delisting criteria shown in **Table 18**.

Table 18: Welland River Subwatershed Delisting Criteria and Loading Target using Export Coefficient Approach #3.

Watershed	TP Concentration Delisting Criteria (µg/l)	TP Loading Target (kg/ha/yr)	Current Mean TP Concentration (µg/l)	% Reduction to Reach Delisting Criteria
Beaver Creek (BV001)	155	0.35	540	71
Big Forks Creek (BF001)	135	0.35	390	65
Buckhorn Creek (BU001)	163	0.35	270	40
Coyle Creek (CO001)	140	0.35	140	Criteria Achieved
Elsie Creek (EL001)	168	0.35	190	12
Grassy Brook (GR001)	116	0.35	220	47
Lyons Creek (LY003)	117	0.35	150	22
Mill Creek (MI001)	145	0.35	170	15
Oswego Creek (OS001)	183	0.35	380	52
Tee Creek (TE001)	117	0.35	340	66

Approach #3 delisting criteria represents a two to six times increase in the existing delisting criteria of 30 µg/L. In order to achieve delisting criteria with this option, TP reductions ranging from 0% (Coyle Creek) to 70% (Beaver Creek) are required. The advantage of this option is the use of watershed-specific modelled run-off values (NPCA and AquaResources Inc. 2010) and the actual TP concentrations observed in the Coyle Creek watershed, which is likely close to the best-case scenario for the Niagara Region, and therefore the most realistic of the approaches considered thus far. In some cases the mean TP of several subwatersheds are very near to the Approach #3 delisting criteria. However with some subwatersheds, there are substantial reductions in TP concentrations required in order to achieve the delisting criteria, and as such, the focus of remedial actions would be on the more "anomalous" watersheds.

A limitation to using Approach #3 is the assumption that achieving the targeted nutrient loads found in Coyle Creek watershed will have a significant improvement to the BUI. Water quality found in the Coyle Creek subwatershed is impaired with observed TP concentrations 4 times greater that the PWQO. The land disturbance within the watershed is also quite significant at 65%. It is possible that this level of disturbance may not have the desired improvement to the Niagara River AOC but it may translate to the best case "achievable" improvement to the Niagara River AOC.

3.4.4 The 25th Percentile Approach

The TWG discussed a percentile approach where the 25th percentile of TP concentrations of NPCA long-term (2003-2010) monitoring data could be used as potential delisting criteria. The 25th percentiles and loading targets were calculated for each watershed and these are shown in **Table 19.**

Table 19: Welland River Subwatershed Delisting Criteria and Loading Target using 25th Percentile of Long-Term water quality monitoring data (2003-2010) for each subwatershed

Subwatershed	TP 25th Percentile (µg/l)	TP Loading Target (kg/ha/yr)	Current Mean TP Concentration (µg/l)	% Reduction to Reach Delisting Criteria
Beaver Creek (BV001)	268	0.6093	540	50
Big Forks (BF001)	215	0.5602	390	45
Buckhorn Creek (BU001)	114	0.2457	270	58
Coyle Creek (C0001)	95	0.2392	140	32
Drapers Creek (DR001)	100	0.5443	130	23
Elsie Creek (EL001)	100	0.2104	190	47
Grassy Brook (GR001)	143	0.4345	220	35
Lyons Creek (LY003)	100	0.3024	150	33
Mill Creek (MI001)	93	0.2247	170	46
Oswego Creek (OS001)	270	0.5213	380	29
Tee Creek (TE001)	180	0.5408	340	47

In order to achieve delisting criteria with this approach, TP reductions ranging from 23% (Drapers Creek) to 58% (Buckhorn Creek) are required. The advantage of this approach is the use of actual subwatershed water quality data for determining the delisting criteria. These data represent the natural variation that is observed in each subwatershed. This approach may be more achievable for some subwatersheds as the reductions of phosphorus are not as substantial as the export coefficient approaches. But in some subwatersheds (BU001, CO001, LY003, MI001) delisting criteria were lower than the delisting criteria of Export Coefficient Approach #3. Even if the delisting criteria of the 25th Percentile approach were achieved phosphorus concentrations are still high and it may not have the desired improvements to the BUI. In addition, a disadvantage of this approach is that it assumes similar efforts to reduce TP are required across all subwatersheds, when clearly there are watersheds that require more intense nutrient reduction focus.

3.4.5. Reference Watershed Approach

The TWG also considered a reference condition approach as an option for delisting. By identifying and selecting a non-AOC watershed with similar conditions (landuse, soils, topography, etc) it may provide a suitable target for delisting. The Environment Canada (EC) Technical Review (2007) identified several candidate watersheds and these include:

- 20-Mile Creek (Lake Ontario)
- Fairchild Creek (Lake Erie-Grand River watershed)
- McKenzie Creek (Lake Erie- Grand River watershed)
- Nanticoke Creek (Lake Erie)
- Big Otter Creek (Lake Erie)
- Big Creek (Lake Erie)

- Sydenham River (Lake St. Clair)
- Ausable River (Lake Huron)

From this group of candidate watersheds the TWG considered Twenty Mile Creek and the Grand River.

Twenty Mile Creek watershed is located in the NPCA jurisdiction and originates from the same headwater areas as the Welland River. Watershed conditions such as landuse and soils are very similar, although there are variations in stream geomorphology such as exposed bedrock in several sections of the stream channel. The NPCA does regularly monitor Twenty Mile Creek (2002-2010) and based on these data a median concentration of 116 µg/L could be considered as a target concentration.

The Grand River watershed is located just west of the Welland River watershed and like Twenty Mile Creek has similar watershed conditions such landuse and soil types (Haldimand Clay Plain). The Grand River Conservation Authority has informally adopted 78 µg/L as a TP target concentration for its water resource program. This value represents the median TP concentration of the entire Grand River long-term monitoring dataset. This concentration could also be considered as a possible target concentration for the Niagara River AOC.

Table 20: Welland River Subwatershed Delisting Criteria using Reference Watersheds (Twenty Mile Creek and Grand River) of Long-Term water quality monitoring data (2003-2010) for each subwatershed

Subwatershed	Current Mean TP Concentration (µg/l)	% Reduction to Reach Twenty Mile Creek Reference Condition Target	% Reduction to Reach Grand River Reference Condition Target
Beaver Creek (BV001)	540	79	86
Big Forks (BF001)	390	70	80
Buckhorn Creek (BU001)	270	57	71
Coyle Creek (C0001)	140	17	44
Drapers Creek (DR001)	130	11	40
Elsie Creek (EL001)	190	39	59
Grassy Brook (GR001)	220	47	65
Lyons Creek (LY003)	150	23	48
Mill Creek (MI001)	170	32	54
Oswego Creek (OS001)	380	69	79
Tee Creek (TE001)	340	66	77

The Reference Condition Watershed Approach may be a suitable option because it provides some non-AOC watershed TP targets. If the intention of the Niagara River RAP is restore to watershed conditions representative of what is currently found in southwestern Ontario then Twenty Mile Creek or the Grand River could be considered. Again, like other delisting criteria options a substantial reduction in TP would be required in a majority of subwatersheds in order to achieve of TP targets. In addition, a limitation to using the Reference Condition Approach is the assumption that achieving the nutrient targets will have a significant improvement to the BUI.

3.5 Consideration for Use of the Revised TP Delisting Criteria

The purpose of the Welland Eutrophication Study was to develop new total phosphorus delisting criteria that are scientifically-based, biologically meaningful, and achievable to bring about restoration of the *Eutrophication and Undesirable Algae* BUI for the Niagara River AOC. The several approaches developed by the TWG provide alternatives to the existing criteria of 30µg/L found in the Niagara River RAP Stage 2 report. However, there are several important items that the TWG identified that need to be considered before adopting new Delisting Criteria and Loading Targets.

1. It was not possible through this study to determine what the consequences of the new delisting criteria would be for the tributaries. It is not known whether achieving any of the devised TP targets would restore this BUI. This is because this study in part did not explicitly identify a strong link between phosphorus and the major BUI issues like degraded aesthetics (through algae/macrophyte overgrowth) and low DO conditions. The TWG noted that elevated TP concentrations are not an impaired beneficial use, but instead have the potential to bring about undesirable conditions, such as unsightly algae blooms or low DO concentrations that negatively impact the local fish community. Ideally, there needs to be some kind of a demonstration that the hard-to-achieve, massive reductions in TP loadings will address the larger issues of impaired oxygen concentrations and aesthetics.

2. The TWG suggested that it may be possible for a parcel of land to have all best management practices already implemented and still not meet the theoretical export coefficient delisting criteria noted in this report. If there are no additional management actions that can be implemented to reduce TP concentrations to the pre-defined targets, then the targets are unachievable, and thus, not consistent with the spirit and intention of the RAP.

3. The TWG noted that the effect on water quality due to the permanent flow alterations to the Welland River has been underestimated and it was not examined in the Welland River Eutrophication Study. Binbrook Reservoir and the redirection of the Niagara River down the Welland River for hydroelectric operations may be significant contributors to the *Eutrophication and Undesirable Algae* BUI. With the Binbrook Reservoir, water is released from the bottom of the dam (i.e. the hypolimnion) where water is presumably

lower in DO and likely to cause a plume of low DO conditions downstream of the reservoir. Additionally, when water is not released from the reservoir because of needs pertaining to recreational uses of the reservoir, the resulting low flow in the headwaters exacerbates drought conditions in the river, and negatively impacts water quality. The other major flow alteration is the daily water level fluctuation to downstream portions of the Welland River due to control of flow for the production of hydroelectric power. The water level fluctuation does not allow for efficient flushing of an already low-gradient stream, resulting in flow reversal/stagnation/backwater effects and likely low DO conditions. Control of chemical inputs may improve water quality conditions, but it remains possible that no amount of loading reductions may bring about the desired change due to the physical alterations to the Welland River.

4. The TWG noted that there must be some consideration given to the receiving water (Niagara River) into which the Welland River drains. Discharge from the Ontario portion of the AOC contributes less than one percent to the total flow in the Niagara River (Environment Canada 1993). TP data from Environment Canada It is necessary to determine whether or not water quality conditions and phosphorus loads from the Welland River are significantly impacting the nearshore or main channel of the Niagara River. The Niagara River RAP Stage 1 Report (1993) states "plumes of water discharge from the Sir Adam Beck power generating station are visible in the Niagara River and likely the result of higher suspended sediment levels associated with the Welland River". However, Environment Canada's water quality monitoring stations in Niagara-on-the-Lake indicate there is no increase of phosphorus in Niagara River downstream of Queenston (1993). If the Welland River is not contributing to eutrophication or algae/macrophyte overgrowth in the Niagara River there may be sufficient reason to designate the nutrient problem as a regional issue rather than a RAP issue.

5. A number of concerns were raised by some TWG members regarding how to achieve the desired TP delisting criteria given the massive TP loading reductions needed to achieve any of the alternative delisting approaches explored above. This concern is valid but some TWG members suggest that this should not hinder the process of setting the delisting targets as targets will provide the impetus to improve water quality conditions in the Niagara River AOC.

6. TWG members suggested changing the delisting criteria of the *Eutrophication and Undesirable Algae* BUI from an ambient in-river TP concentration to generic criteria. These generic criteria could include ensuring that a certain percentage of landowners have BMPs implemented in the Niagara River AOC, or ensuring that a certain percentage of septic systems have been inspected and are thus performing as intended. These generic criteria lists would need to be investigated further but may provide an alternate to a strict TP concentration value that may not be achievable for reasons outlined above. The use of generic criteria focuses on management actions, thus ensuring that everything that can be done to improve eutrophication in the River, has been done.

7. The TWG believes it is important to begin linking water quality datasets collected through the Welland River Eutrophication Study with other Niagara River AOC BUIs. Other BUIs have collected data on fish communities and other habitat variables such as water flow, buffers and aquatic habitat. These linkages must be studied in order to develop meaningful delisting criteria.

4.0. Recommendations to RAP Coordinating Committee

Based on the results of the Welland River Eutrophication Study, the Technical Working Group (TWG) has several recommendations for the Remedial Action Plan (RAP) Coordinating Committee regarding the results of the Study.

4.1 Dissolved Oxygen Study

The TWG affirmed the need for minimum dissolved oxygen (DO) concentrations in the Welland River to be at or above the target concentration of 4 mg/L which is the current warm water biota Provincial Water Quality Objectives (PWQO) for ambient water temperatures of 20 – 25 °C (MOE, 1994). This DO concentration has been identified as factor required to attain the desirable fish community in the Niagara River Area of Concern (AOC), and due to its importance in the biological restoration of the AOC, the TWG identified the need to further examine the role of DO drivers in the Welland River. If a dominant DO driver can be identified, it would allow for a more focused management plan for the Welland River.

The main focus of the Welland River Eutrophication Study has been on phosphorus, but over the course of this study it has become clear that there are a number of items potentially impacting DO concentrations in the Welland River. These items include the potential impacts to DO by Nitrogenous Oxygen Demand (NOD), Biological Oxygen Demand (BOD), Sediment Oxygen Demand (SOD) and Chemical Oxygen Demand (COD). There is also a need to determine the effects of altered flow regimes on DO concentrations, such as the role of the Binbrook Reservoir and the flow reversal of the Welland at its output to the Niagara River. The role of benthic or periphyton algae (benthic chlorophyll-a), macrophytes and duckweed on DO concentrations in Welland River needs to be examined further with surveys of the periphyton/macrophytes to provide information on density and species composition. Finally, additional DO data collected during the winter season would be important to understanding the seasonal trends of DO in the Welland River. The TWG recommends a comprehensive DO study for the Welland River and its tributaries.

4.2 Target Specific Subwatersheds for Restoration

The Welland River Eutrophication Study identified several subwatersheds (Beaver Creek, Big Forks Creek, and Oswego Creek) that can be classified as extremely enriched with phosphorus. The TWG recommends intensively implementing Best Management Practices (BMP) works in these subwatersheds and ensuring the results are monitored. By targeting the subwatersheds that can be considered the “worst offenders” for phosphorus, it may be possible to evaluate the strength of BMPs in restoring these watersheds to a less impaired state. This is especially important since it has been suggested that using BMPs to restore non-point source stressors can be very challenging and often many of the RAPs have focused on point sources to control nutrient inputs.

4.3 TP Delisting Criteria

Combined Sewer Overflows

The TWG recommends that as a surrogate total phosphorus delisting criteria for CSOs in the City of Welland, that Ontario Ministry of the Environment Procedure F-5-5 be adopted. The key requirements of Procedure F-5-5:

- During a seven-month period commencing within 15 days of April 1, capture and treat for an average year all dry weather flow plus 90% of the volume resulting from wet weather flow that is above the dry weather flow;
- 30% carbonaceous biochemical oxygen demand removal;
- 50% total suspended solids removal;
- Total suspended solids should not exceed 90 mg/L for more than 50% of the time during the seven month period; and,
- The interim effluent quality criterion for disinfection of combined sewage during wet weather is a monthly geometric mean density of *E. coli* not exceeding 100 cfu per 100ml

There are two separate issues that cause Combined Sewer Overflows (CSOs) into the Welland River: (1) Overflows from the Regional Interceptor sewers (flow backing up and spilling out the bypass structures) and; (2) direct bypasses from our system (the water never gets into the Interceptor and just outlets directly through the outfall). The City of Welland and the Region of Niagara are currently working on a CSO project that will separate 100% of the remaining combined sewers within the next 8-10 years resulting in the capture of 75% of wet weather flows. The City of Welland staff suspects that the 75% capture rate in the CSO report (XCG Consultants LTD. 2004) was underestimated. The City of Welland recently hired AMEC to create a model of the Regional Interceptor system and based on 2010 precipitation rate, the City of Welland has met F-5-5 requirements. However, it should be noted that these are preliminary results based on assumptions of direct bypasses from the system where a direct bypass value was used from the CSO report (XCG Consultants LTD. 2004). In 2012, the City of Welland has planned more detailed flow metering of the direct bypasses and continue with sewer separation. If the City of Welland removes all of its combined sewers and still have not met the 90% capture rate, there are several courses of action that could be followed: (1) Increase the capacity of the treatment plant and add a high rate treatment facility to the plant; (2) Focus on removing “partially separated” neighbourhood which continue to have foundation drains which are still connected to the sanitary sewer. Once the requirements for met F-5-5 (90% capture) are met by the City of Welland, their intention is to pursue 100% capture as per F-5-1.

Waste Water Treatment Plant

Although the City of Welland Waste Water Treatment Plant (WWTP) does contribute nutrient loads to the Welland River, the WTTP is outside the study area of the Welland River Eutrophication Study as the final effluent is discharged downstream of the old Welland Canal. Effluent discharged from the WTTP is regulated by a Ministry of the Environment (MOE) Certificate of Approval. The Welland WWTP has primary through tertiary treatment. The primary treatment consists of mechanically-raked bar screens and aerated grit channels to initially remove bulky solids, and silt/sand. The secondary treatment consists of mechanical aeration cells, phosphorus removal using ferric chloride and settling tanks that remove settling and floating solids. The solids removed are then treated in anaerobic digesters, where bacteria digest the organics into methane and CO_2. The stabilized biosolids produced by the digestion process are removed from the facility and transported to the Garner Road Biosolids Storage Facility for further treatment in lagoons. The tertiary treatment consists of sand and anthracite filter cells. The TWG agrees that no further action is required.

Tributary Delisting Criteria

Over the course of the three-year Welland River Eutrophication Study, the TWG has carefully evaluated several delisting criteria options for total phosphorus (TP). The TWG notes that this study did not identify a strong link between phosphorus and the major BUI issues like degraded aesthetics (through algae/macrophyte overgrowth) and low DO conditions. This result makes it difficult to strongly advocate for a specific TP delisting criteria. But the consensus of the TWG was that the Welland River watershed does have very high TP concentrations and these TP concentrations have the potential to cause undesirable conditions in the watershed. Based on this the TWG has provided TP Delisting Criteria Options developed through this study below in no particular order and recommends that that RAP Coordinating Committee consider the items identified in section **3.5** before finalizing TP Delisting Criteria.

Delisting Criteria Option #1

- Continue to use the current MOE Provincial Water Quality Objective (1994) of 30 µg/L for streams and rivers as the Niagara River RAP TP delisting criteria.
- There is evidence that this concentration when reached will eliminate excessive algae growth in stream and river ecosystems. This concentration is commonly used by governmental agencies in the province to assess watershed health.
- 30 µg/L is not an achievable target for a stream in southern Ontario as it represents minimally impacted or completely forested watershed conditions and does not account for the permanent irreversible land use in southern Ontario including the Niagara River AOC.

Delisting Criteria Option #2

- Use TP Delisting Criteria and Loading Targets determined through Export Coefficient Approach #1 in section **3.4.1** as the Niagara River RAP TP delisting criteria.

- Limitations for this approach are discussed in section **3.4.1**.

Delisting Criteria Option #3

- Use TP Delisting Criteria and Loading Targets determined through Export Coefficient Approach #2 in section **3.4.2** as the Niagara River RAP TP delisting criteria.
- Limitations for this approach are discussed in section **3.4.2**.

Delisting Criteria Option #4

- Use TP Delisting Criteria and Loading Targets determined through Export Coefficient Approach #3 in section **3.4.3** as the Niagara River RAP TP delisting criteria.
- Limitations for this approach are discussed in section **3.4.3**.

Delisting Criteria Option #5

- A phased approach using all three of the Export Coefficient Approaches found in sections **3.4.1**, **3.4.2** and **3.4.3**. The TWG suggested Approach #3 can serve as 5 year, Approach #2 as a 15 year and Approach #1 as a 30 year target.
- A phased approach may be inconsistent with the structure and function of the RAP.

Delisting Criteria Option #6

- Use TP Delisting Criteria and Loading Targets determined through the 25th Percentile Approach in section **3.4.4**.
- Limitations for this approach are discussed in section **3.4.4**.

Delisting Criteria Option #7

- Use a TP concentration from a reference non-AOC area such as Twenty Mile Creek in Niagara Peninsula or the Grand River as a delisting criteria.
- It should be noted that these watersheds are not a perfect match for reference conditions as there are slight differences in watershed soil types and stream geomorphology.
- The Grand River Conservation Authority has informally adopted 78 µg/L for a TP target concentration for its water resource programs. This value represents the median TP concentration of the entire Grand River long-term monitoring dataset.
- Twenty Mile watershed has a median TP concentration of 116 µg/L that could be considered a target concentration.
- Limitations for this approach are discussed in section **3.4.5**.

Delisting Criteria Option #8

- Do not set TP concentration Delisting Criteria and Loading Targets for the Niagara River AOC.

- Use as a Delisting Criteria an ideal percentage of landowners implementing Best Management Practices (BMPs) within each sub-watershed.
- It may be difficult to quantify the percentage of BMPs within a subwatershed as there is limited data available to determine the existing percentage.
- BMPs represent a large number of activities that may or may not have phosphorus limiting benefits. Phosphorus limiting BMPs will need to be clearly defined if this option is selected.

Delisting Criteria Option #9

- Do not set TP Delisting Criteria and Loading Targets for the Niagara River AOC.
- It may not be possible to fully restore the BUI: *Eutrophication and Undesirable Algae* because of permanent man-made impacts (Welland Canals, Binbrook Reservoir, OPG and flow fluctuations).
- Additional studies on dissolved oxygen and benthic algae may be required before this option can be selected.
- In this case, there may be very logical and practical reasons why the impaired BUI: *Eutrophication and Undesirable Algae* cannot be fully restored and these reasons and rationales should be provided in a Stage 3 RAP.
- The intent here is to explicitly recognize that this BUI may not be fully restored for justifiable reasons and that this should not prohibit the possible delisting of an Area of Concern.

4.4 Continued Water Quality Monitoring in Niagara River AOC

The TWG believes it is imperative that objective #5 of the Welland River Eutrophication Study be implemented. This objective will allow the Niagara River AOC partners to track water quality improvements that have been initiated through the RAP. Water quality monitoring in the Niagara River AOC has been conducted through the NPCA Water Quality Monitoring Program since 2001. The NPCA monitors twenty-three stations in the Niagara River AOC with twelve along the main channel of the Welland River and eleven at the mouths of major subwatersheds. Currently there is no lab load and equipment to characterize wet weather events within the NPCA monitoring program. The TWG recommends that wet weather/event-based sampling be incorporated into any future water quality monitoring in the Niagara River AOC. However, without continued funding for laboratory analysis there is limited capacity by the NPCA for implementing objective #5. In the past, funding for water quality analysis has been provided through the Environment Canada's Great Lake Sustainability Fund, the MOE, the Region of Niagara, and the City of Hamilton. This funding agreement has been highly effective in providing complete water quality data for the Niagara River AOC. To maintain the existing water quality network, the TWG recommends that funding for lab analysis and sampling equipment be continued for this program.

5.0 Conclusions

The Welland River Eutrophication Study was a three-year project overseen by a TWG whose purpose was to refine and implement the Recommendations for Monitoring and Assessment which were formulated by the 2007 Technical Review Committee outlined in Appendix H *Eutrophication and Undesirable Algae*. The following summarizes the main conclusions for the Welland River Eutrophication Study based on the five study objectives.

1. The TWG was unable to fully characterize the biological response of the Welland River to high phosphorus inputs and thus solely implicate TP concentrations as the primary reason for the degraded aesthetics (through algae/macrophyte overgrowth) and low DO conditions in the Niagara River AOC. Nonetheless, the TWG affirmed that the Welland River has a significant TP problem with 99% of grab samples collected in the 2008-2010 study failing to meet the interim PWQO of 30 µg/L for TP (MOEE, 1994). Mean TP concentrations ranged from 200% to 1500% greater than the PWQO depending on the subwatershed. Although TP is likely a contributor to the status of BUI's impairment, it is not the only contributor. The TWG identified benthic algae, water flow patterns, and an expanded number of oxygen demanding substances (COD, NOD, SOD) as likely stressors to this *Eutrophication and Undesirable Algae* BUI. The TWG recommends additional studies that examine the role of these stressors to fully understand the biological responses of the Welland River.

2. The TWG was able to characterize concentrations of phosphate versus sediment-bound phosphorus along the length of the Welland River. The proportion of phosphate in the main Welland River channel ranged from 4% - 58% and concentrations generally increased as water moved downstream through the Welland River watershed; however a decrease was noted in the lower reaches where mixing occurs with the Niagara River. The proportion of phosphate observed in the Welland River tributaries ranged from 24% to 68% with most of these stations exceeding 50%. These tributaries have been identified as contributing significant amounts of potentially biologically available phosphorus to the Welland River watershed. The highest concentrations observed were found in Big Forks (BF001), Beaver Creek (BV001), Oswego Creek (OS001), and Tee Creek (TE001).

3. The TWG evaluated a number of methods for determining nutrient delisting criteria in streams. Through this process the TWG found it difficult to strongly advocate for a specific delisting criteria. The TWG agreed that achieving the current TP delisting criteria of 30 µg/L would be very difficult considering the permanent irreversible land use of the watershed. In addition there were several data gaps identified (benthic algae, water flow patterns, and DO stressors) that need to be studied. Based on these constraints the TWG developed three new sets of TP delisting criteria and loading targets based on the Export Coefficient Approach for the different subwatersheds of the Welland River upstream of the Old Welland Canal. The TWG has provided the RAP Coordinating

Committee with these three plus six additional TP Delisting Criteria Options based on the results of the Welland River Eutrophication Study. Before adopting any of the proposed Delisting Criteria and Loading Targets the RAP Coordinating Committee must consider the important items that TWG identified in **Section 3.5.** In addition, each of the TP Delisting Criteria Options required varying magnitudes of TP reduction and the TWG recommends that no matter which delisting criteria is selected that it be reviewed every five years.

4. The TWG found that Niagara River AOC tributaries carry significant phosphorus concentrations that have the potential to impair the BUI: *Eutrophication and Undesirable Algae*. The TWG recommends that water quality monitoring in the Niagara River AOC continue to ensure that evaluation of conditions against the delisting criteria can be achieved. Phosphorus must be carefully managed and the TWG identified several subwatersheds with especially high TP concentrations (Beaver Creek, Big Fork and Oswego Creek). The TWG agrees that these are likely to be the most responsive to best management practices.

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