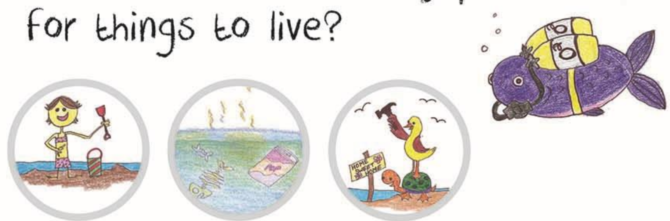
Contaminant Loadings and Concentrations to Hamilton Harbour: 2008-2016 Update

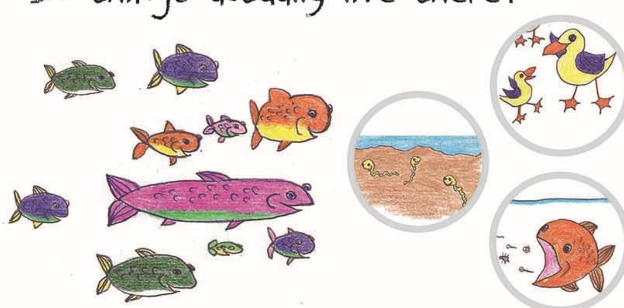
April 2018

Hamilton Harbour Remedial Action Plan

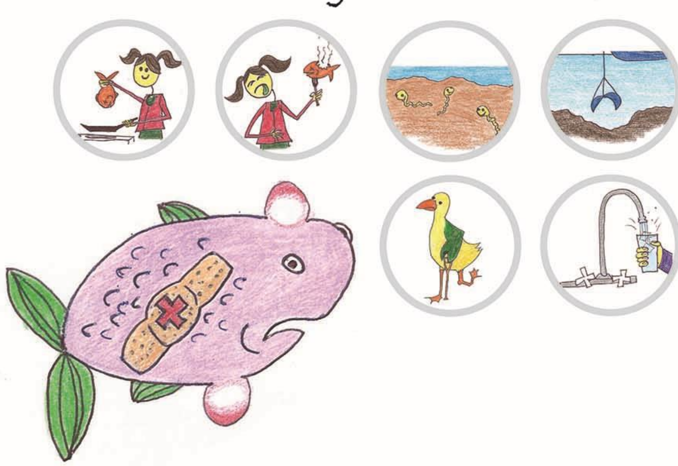
Is the harbour a healthy place for things to live?



Do things actually live there?



Are those things contaminated?



Contaminant Loadings and Concentrations to Hamilton Harbour: 2008-2016 Update

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Contaminant Loadings and Concentrations to Hamilton Harbour: 2008-2016 Update

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Executive Summary

The Hamilton Harbour Remedial Action Plan (RAP) Stage 2 Update 2002 Report set out the initial water quality goals for the Harbour necessary for delisting. It also supplied initial and final net loading targets for sources of contaminant discharge into the Harbour. Both the water quality goals and net loading targets were updated in 2012. The final loading targets are estimated to be necessary and sufficient conditions for achieving the Harbour water quality goals based on the historically observed relationship between reductions in contaminant mass loadings and reductions in Harbour water contaminant concentrations.

To track loadings to the Harbour, the RAP produced the "1990-1996 Contaminant Loadings and Concentrations to Hamilton Harbour" in 1998. In 2004, the Hamilton Harbour Technical Team continued this work and the report covered the period from 1996 to 2002. The 2010 update covered years 2003 to 2007. This update provides data for 2008 to 2016.

A loading is the total mass (kg) of a substance discharged to a receiving water body over a specified time (a day). A contaminant mass loading is the product of a contaminant concentration (mg/L) and a flow (m^3/day) and hence can be affected by changes in either term.

Section 6 reports measured loadings data (wastewater treatment plants, steel mills) and modeled loadings data (combined sewer overflows, creeks, and Cootes Paradise) by source. Section 7 repackages the data to try to provide a "total loading" to the Harbour or Cootes Paradise. Readers need to keep in mind that this total is in itself only an estimate.

Many improvements were made with this update to increase the report's accuracy and utility. Principal changes include (limited to years 2008-2016):

a. inclusion of error estimates for contaminant loadings,
b. inclusion of seasonal loads for Total Phosphorus and Total Suspended Solids,
c. addition of Total Nitrate (nitrate + nitrite) as a contaminant of interest,
d. improvements in the creek and Cootes Paradise loadings calculation methods, and
e. addition of Indian Creek as a source of contaminants to Hamilton Harbour.

The purpose of this report is to show the relative contributions of contaminants from known sources. It is not a trend analysis. The report does not provide an interpretation of the concentration and loading results. Interpretation of results is a follow-up activity to be conducted by the RAP Technical Team and others and will be published from time to time in separate reports.

The Hamilton Harbour RAP is assisted by: the Bay Area Implementation Team (BAIT), the Bay Area Restoration Council (BARC), and Hamilton Harbour scientists. The Hamilton Harbour RAP relies on BAIT for implementation of initiatives, BARC for public input, and scientists for ongoing scientific and technical advice. Participants on the RAP Technical Team assisting with this report were representatives of Environment and Climate Change Canada, Ontario Ministry of the Environment and Climate Change, City

of Hamilton, Region of Halton, Conservation Halton, Hamilton Conservation Authority, Royal Botanical Gardens, Stelco (formerly U. S Steel Canada), ArcelorMittal Dofasco, and the University of Toronto. The contributions from these groups cannot be understated. The Hamilton Harbour RAP has met the expectations of the public-at-large and incorporated an ecosystem approach because of these organizations.

Acknowledgements

Thank you to the various Hamilton Harbour RAP Technical Team Members and others who provided assistance in the preparation of this 2008-2016 update. In particular:

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1. Background

In the late 1980s, the International Joint Commission (IJC) identified 43 Areas of Concern in the Great Lakes basin where the beneficial uses of the water were considered impaired. Hamilton Harbour was designated as one of 17 Canadian Areas of Concern under Annex 2 of the Canada - United States Great Lakes Water Quality Agreement (GLWQA) (1978 – as amended 1987). The Agreement identifies the 14 beneficial use impairments as:

- i. Restriction on fish and wildlife consumption
- ii. Tainting of fish and wildlife flavour
- iii. Degraded fish and wildlife populations
- iv. Fish tumours or other deformities
- v. Bird or animal deformities or reproductive problems
- vi. Degradation of benthos
- vii. Restrictions on dredging activities
- viii. Eutrophication or undesirable algae
- ix. Restrictions on drinking water consumption or taste and odour problems
- x. Beach closings (Water contact sports)
- xi. Degradation of aesthetics
- xii. Added cost to agriculture or industry
- xiii. Degradation of phytoplankton and zooplankton populations
- xiv. Loss of fish and wildlife habitat

For each Area of Concern, the Governments committed to locally developing and implementing a Remedial Action Plan (RAP) to restore and protect environmental quality and beneficial uses. In Canada, the RAP program is a joint federal-provincial initiative under the Canada-Ontario Agreement respecting the Great Lakes Ecosystem (COA).

The RAP process involves: identifying environmental problems, determining sources and causes of problems (Stage 1); involving the public to establish community and stakeholder goals and objectives and reaching consensus on recommended actions, implementation plans and monitoring strategies (Stage 2); and implementing actions, and monitoring progress (Status Assessment Reports for individual beneficial use redesignations).

For the Hamilton Harbour Area of Concern (AOC), Stage 1 was completed in 1989 with a second edition produced in 1992. Stage 2 was completed in 1992, with an update finished in 2002. Status assessment reports will be written periodically to assess progress in restoring individual beneficial uses.

The Hamilton Harbour RAP is assisted by: the Bay Area Implementation Team (BAIT), the Bay Area Restoration Council (BARC), and Hamilton Harbour scientists. The RAP relies on BAIT for implementation of initiatives, BARC for public input, and scientists for ongoing scientific and technical advice. The contributions from these groups cannot be understated. The Hamilton Harbour RAP has met the expectations of the public-at-large and incorporated an ecosystem approach because of these organizations.

BAIT members represent the following 18 agencies and organizations: ArcelorMittal Dofasco, Bay Area Restoration Council, City of Burlington, City of Hamilton, Conservation Halton, Fisheries and Oceans Canada, Environment and Climate Change Canada, Hamilton Conservation Authority, Hamilton Harbour RAP Office, Hamilton Halton Home Builders' Association, Hamilton Port Authority, Hamilton Waterfront Trust, McMaster University, Ministry of the Environment and Climate Change, Ministry of Natural Resources and Forestry, Regional Municipality of Halton, Royal Botanical Gardens, and Stelco (formerly U. S. Steel Canada).

2. Description of the Area

Hamilton Harbour is a 2,150-hectare (ha) embayment of Lake Ontario connected to the lake by a single ship canal across the sandbar that forms the bay. The conditions in the Harbour reflect natural inputs, human activities, land uses, and drainage from the watershed of 49,400 ha (Figure 1). Cootes Paradise Marsh is a 250 ha, shallow area of both marsh and open water, discharging at an artificial opening into the west end of the Harbour called the Desjardins Canal.

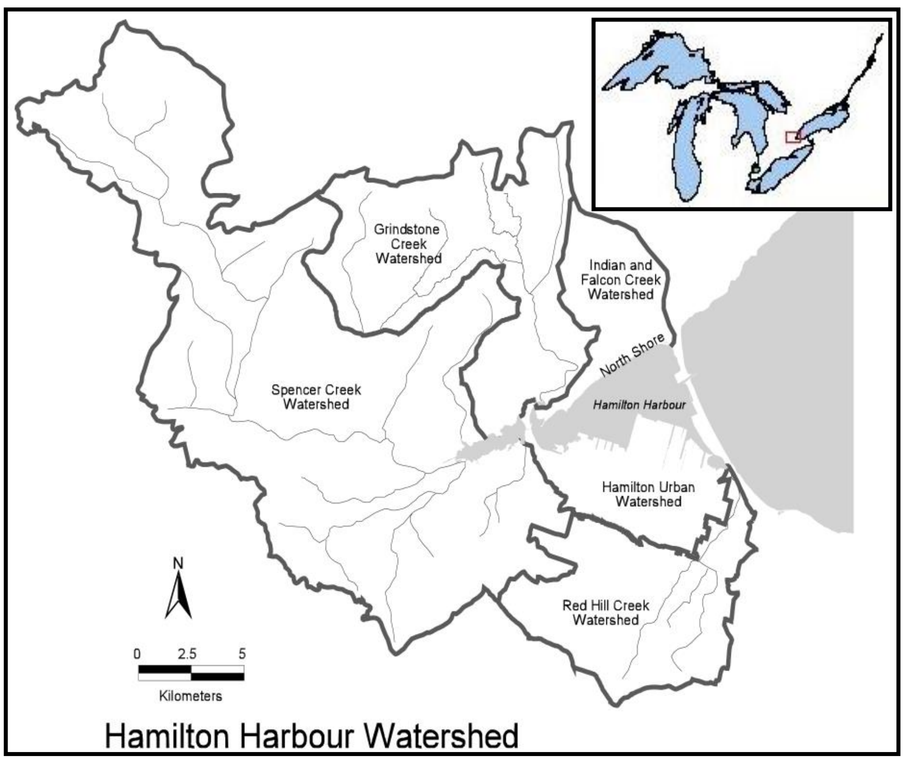

Figure 1. Hamilton Harbour Watershed Map

3. Purpose and Scope of a Loadings Report

The purpose of this report is to show the relative contributions of contaminants from known sources. It is not a trend analysis.

A loading is the total mass (kg) of a substance discharged to a receiving water body over a specified time (a day). A contaminant mass loading is the product of a contaminant concentration (mg/L) and a flow (m^3/day) and hence can be affected by changes in either term.

This report provides loadings estimates that were created with varying levels of accuracy. Some estimates were created using samples (wastewater treatment plants and steel mills) and others with models (combined sewer overflows, creeks, and Cootes Paradise). As both types of loadings are used to try to provide a “total loading” to the Harbour and Cootes Paradise, readers need to keep in mind this total is in itself only an estimate. Error bars are provided, when available, to demonstrate accuracy.

Mass loading reductions can be achieved through reducing contaminant concentrations, reducing flows, or reducing both flow and concentration. This becomes significant when identifying where potential mass loading reductions may be achievable, since those flows which are principally a function of rainfall may be either difficult or impossible to control (e.g. non-point sources such as creeks). It is also important to keep this in mind when comparing year-to-year average contaminant mass loadings from non-point sources where flow is driven by rainfall. Not only will contaminant mass loadings vary directly as a result of changes in the flow term, but for many contaminants (e.g. Total Suspended Solids, Total Phosphorus, metals) concentrations will also vary as a function of flow. This relationship increases the tendency for wet years to result in significantly higher non-point source mass loadings than dry years.

Although not attempted in this report, meaningful analysis of trends in non-point source (e.g., creek) contaminant mass loading to the Harbour is best accomplished by normalizing the results to diminish the year-to-year variability associated with wet and dry years. This increases the potential to discern any underlying trends that are (largely) independent of flow and which may be attributable to changes in factors such as land use or the adoption of improved management practices. This is a method that may be examined by the Technical Team for future reports.

The Stage 2 Update 2002 Report set out the initial water quality goals for the Harbour necessary for delisting. It also supplied initial and final net loading targets for sources of contaminant discharge into the Harbour. Both the water quality goals and net loading targets were updated in 2012 (Tables 1, 2, and 3). The final loading targets are estimated to be necessary and sufficient conditions for achieving the Harbour water quality goals based on the historically observed relationship between reductions in contaminant mass loadings and reductions in Harbour water contaminant concentrations.

It is important to note that water quality goals are of primary significance whereas the loadings targets are merely a means to this end.

Table 1. Final water quality goals for Hamilton Harbour.

	Final Goals	Compliance Criteria
Phosphorus concentration	< 20 μg/L	15 of 17 epilimnetic integrated samples analyzed weekly* at Centre Station from June to September are at or better than the targeted goal * Although weekly sampling is recommended at only one location, there will be periodic sampling of a larger number of locations Harbour-wide to confirm representativeness of Centre Station.
Chlorophyll a concentration	< 10 μg/L	
Secchi Disk Transparency	> 2.5 m	
Un-ionized Ammonia concentration	< 0.02 mg/L	Biweekly epilimnetic integrated samples from ice-out to the end of May, and weekly epilimnetic integrated samples in June at Centre Station do not exceed the targeted goal
Minimum DO concentration	> 6 ppm, but > 3 ppm during allowable exceedance period	During June to September inclusive, the water column at centre station should have a minimum 4 metre thick layer of water with a temperature <20°C and a DO >6 mg/L. Compliance with this goal is to occur in at least 15 of 17 profiles measured weekly, and during any exceedance episode, the water column at centre station should still have a minimum 2 metre thick layer of water with a temperature <20°C and a DO >3 mg/L.

Source: 2012 Summary Fact Sheet

Table 2. Interim water quality goals for Cootes Paradise and Grindstone Marsh area.

	Cootes Paradise	Grindstone Marsh Area
Phosphorus concentration[1]	60-70 μg/L	60-70 μg/L
Chlorophyll a concentration[1]	< 20 μg/L	< 20 μg/L
Secchi Disk Transparency[1]	> 1.5 m	> 1 m
Un-ionized Ammonia concentration	< 0.02 mg/L	< 0.02 mg/L
Minimum DO concentration[1]	> 5 ppm	> 5 ppm
Submergent/emergent aquatic plant area[1]	240 ha	50 ha
Suspended Solids[1]	25 ppm	25 ppm

Source: 2012 Summary Fact Sheet
[1]Cootes-Grindstone Water Quality Targets Sub-Committee is working to develop final goals

Table 3. Net loading targets in kilograms per day (kg/day).

	Total Phosphorus	Total Ammonia	Total Suspended Solids
Woodward WWTP + CSOs	82	1048	2,193
Skyway WWTP	17	115	280
Dundas WWTP[1]	TBD	TBD	TBD
Streams[2]	TBD	--	--
Industry (combined)	--	270	--
Stelco (U. S. Steel)	--	--	1500
Dofasco (ArcelorMittal)	--	--	1500

Source: 2012 Summary Fact Sheet
[1]Cootes-Grindstone Water Quality Targets Sub-Committee is working to develop final goals
[2]Stream loadings work ongoing by Water Quality Technical Team

In the context of the Hamilton Harbour RAP, contaminant mass loading summaries have two fundamental uses:

1) to guide management decisions as to where reductions in contaminant concentrations (or associated flows) will have the greatest relative effect on Harbour water quality; and
2) to illustrate those situations where regulated effluent discharges achieve and maintain effluent concentration limits, but where ongoing flow increases would lead to increased contaminant mass loadings and hence a corresponding reduction in receiving water quality.

The first of these is to guide management decisions as to where reductions in contaminant concentrations (or associated flows) will have the greatest relative effect on Harbour water quality by apportioning the approximate loads from various types of sources (e.g. municipal and industrial point sources versus watershed inputs). This is a deliberately Harbour-centric perspective which views creeks only as channels which influence water quality in the Harbour by delivering water and contaminants from watersheds to it. Clearly, this perspective is very limited in that it does not consider creeks as water bodies in their own right and hence cannot be used to guide management decision-making for water quality improvements within watersheds themselves. It is entirely possible to achieve enormously significant water quality improvements in a small creek that will result in virtually no improvement to Harbour water quality merely because the flows from this tributary are a trivial component of total flows into the Harbour. This does not mean that such water quality improvements are not worthwhile from a local perspective, just that such local improvements cannot be expected to show measurable improvements to water quality in the Harbour as a whole. It should be remembered, however, that the cumulative improvements from numerous individual sites may make a measurable difference to the Harbour.

The other principal function of mass loading summaries is to illustrate those situations where regulated effluent discharges achieve and maintain effluent concentration limits, but where ongoing flow increases would lead to increased contaminant mass loadings and hence a corresponding reduction in receiving water quality. An obvious example of this would be a municipal WWTP which maintains effluent concentrations at a specific level, but which discharges increased volumes of treated wastewater as the result of population growth, and which consequently, has an adverse effect on Harbour water quality without efforts to change the treatment practices.

This report was initiated by the RAP Office with assistance from the Technical Team to:

- Obtain and summarize annual average loadings for 2008-2016.
- Update long-term trend graphs of contaminant loadings using available 2008-2016 data and estimates.
- Identify and document concerns or problems related to the reliability, consistency, and accuracy of loading estimates.

Improvements were made with this update to increase the report's accuracy and utility. Principal changes include (limited to years 2008-2016):

a. inclusion of error estimates (standard error of the mean and confidence intervals),
b. inclusion of seasonal loads for Total Phosphorus and Total Suspended Solids,
c. addition of Total Nitrate (nitrate + nitrite) as a contaminant of interest,
d. improvements in the creek and Cootes Paradise loadings calculation methods, and
e. addition of Indian Creek as a source of contaminants to Hamilton Harbour.

The data sources, methods for obtaining and reporting the data and procedure for estimating loadings are described in this report. Limitations in the approach or gaps in the data are identified. Results are presented in the form of updated tables and graphs of loadings to Hamilton Harbour and Cootes Paradise.

The report does not provide an interpretation of the concentration and loading results. Interpretation of results would be follow-up activities to be conducted by the RAP Technical Team and others.

For the remainder of this report "contaminant mass loading" will be shortened to "loading" or "contaminant loading" for convenience purposes. Likewise, "standard error of the mean" will be shortened to "SE" or "error".

In some cases, the concentrations provided were listed as < MDL or less than method detection limit. Due to the variety of techniques and agencies, it is not practical to list all of the method detection limits in the body of the report. As < MDL causes problems when trying to calculate loadings, for the purposes of the 1996-2007 data in this report, no attempt to calculate a loading was made. The change in methodology for the 2008-2016 calculations (obtaining raw data) resolved this issue.

4. Contaminants of Concern for Hamilton Harbour

The 1992 Stage 2 Report of the Hamilton Harbour RAP presents annual concentrations and loadings of selected contaminants to Hamilton Harbour and Cootes Paradise for the period from the mid-1970s to 1989. Table 4 lists the contaminants which were plotted as trend and pie charts in that report and briefly describes their environmental significance.

Mirex and DDT were among the organochlorine compounds identified as a local concern in the 1992 Stage 2 Report, but the report does not provide loadings or trends. The 1989 Status Report stated: “There is no source of mirex in the Hamilton Harbour watershed. Sources are in Niagara Falls and Oswego, New York. There is likely no source of DDT in the Hamilton Harbour watershed.” (p. 26). Hence, this report does not include either of these compounds.

PCBs were among the trace contaminants identified in the 1992 Stage 2 Report. There was a request that PCBs be added to the next iteration of the Loadings Report; however, the Technical Team decided that PCBs in Hamilton Harbour will be tracked elsewhere (as it relates to fish consumption). More information can be found in the following reports:

> Labencki, T. 2008. An Assessment of Polychlorinated Biphenyls (PCBs) in the Hamilton Harbour Area of Concern (AOC) in Support of the Beneficial Use Impairment (BUI): *Restrictions on Fish and Wildlife Consumption*. ISBN: 978-0-9810874-0-5
>
> Labencki, T. 2009. 2007 Field Season in the Hamilton Harbour Area of Concern. PCB and PAH water monitoring undertaken by the Ontario Ministry of the Environment to support mass balance work by the Hamilton Harbour Remedial Action Plan (RAP) on PAH contamination at Randle Reef and PCB contamination in Windermere Arm. ISBN: 978-0-9810874-2-9
>
> Labencki, T. 2011. 2008 Field Season in the Hamilton Harbour Area of Concern Hamilton Harbour PCB Assessment. ISBN: 978-0-9810874-5-0 (Print Version) ISBN: 978-0-9810874-6-7 (Online Version)

There are concerns about the concentration levels of copper in the sediments of Cootes Paradise and the Grindstone Creek Estuary. The Technical Team hypothesized that sources could include copper pipes and roofs in the area or residue from copper now used in brake pads instead of asbestos. The Technical Team will review the possibility of including copper in the next reiteration of this report.

For this update, the Technical Team requested that data on different nitrogen species be included. Nitrogen can be found in many forms: inorganic nitrogen [ammonia (NH_3), nitrite (NO^{2-}), nitrate (NO^{3-}), and ammonium (NH^{4+})], and organic nitrogen. Each has its own characteristics and reason for being tracked. Total Kjeldahl Nitrogen (TKN) is the sum of ammonia and organic nitrogen. Total Nitrogen is the sum of all nitrogen forms in the water (organic + ammonia + nitrite + nitrate), including those that are not immediately available for biological uptake. In this update we provide data on Total Ammonia (ammonium + ammonia), Total Nitrate (nitrate + nitrite), and TKN. It was felt by the Technical Team that these combinations would provide a better picture of nitrogen loadings to the Harbour.

Table 4. Environmental significance of contaminants of concern for Hamilton Harbour

Contaminant and Common Abbreviation	Environmental Significance
Total Phosphorus (TP)	Stimulates nuisance algal growths, reducing water clarity and dissolved oxygen levels.
Total Suspended Solids (TSS)	High concentrations create sludge deposits and contribute to turbidity and colour. Many specific contaminants are carried with the solids. High concentrations bury and choke out aquatic life and accelerate infilling in marshes.
Total Ammonia and Total Nitrate	Depletes oxygen in the receiving water. Toxic to fish at high levels depending on the pH and temperature of receiving water. Enhances algal growth.
Total Kjeldahl Nitrogen (TKN)	The TKN test measures ammonia and organic nitrogen. In many wastewaters and effluents, organic nitrogen will convert to ammonia.
Iron (Fe)	Toxic to sensitive aquatic life at high levels.
Lead (Pb)	Toxic to aquatic life at high levels.
Zinc (Zn)	Toxic to fish, aquatic life at high levels.
Cyanide	Toxic to fish, aquatic life at high levels.
Phenolics	Measures total phenols. May taint fish flavour. Chlorination during water treatment may produce taste and odour. May have a detrimental effect on human health at high concentrations.
Polycyclic Aromatic Hydrocarbons (PAHs)	A class of organic compounds, some of which are carcinogens and are known to have other impacts on ecological receptors. Benzo(a)pyrene has been selected to represent heavy PAHs and Naphthalene represents more volatile PAHs. These are the two PAHs of primary interest for this report.

5. Sources of Contaminants

The loading sources (or "pathways") to Hamilton Harbour and Cootes Paradise identified in the 1992 Stage 2 Report, as well as a brief description of the nature of the source and the individual contributors to each source, are listed in Tables 5 and 6, respectively. With this update, Indian Creek was added as a source of contaminants to Hamilton Harbour. Air deposition, while certainly a pathway for contaminants into the Harbour, is not dealt with in this report and is not within the scope of the RAP. The RAP relies on organizations such as Clean Air Hamilton to provide the community with information on air deposition.

Lake Ontario was listed as a loading source in the 1992 Stage 2 Report, but it was dropped from the 1990-1996 Loadings Report by the RAP Technical Team. The flow of water that enters the Harbour from Lake Ontario through the Burlington Ship Canal is difficult to measure. In the winter there is a surging of the currents back-and-forth in the Canal. In the summer there is an exchange of water with the Lake by a distinct inflow of cold water along the bottom of the Canal into the Harbour and an outflow of warm water from the Harbour into the Lake. These and other flow related phenomena are studied by researchers at Environment and Climate Change Canada to create models in order to better understand flows in the Harbour, the Canal, and out into Lake Ontario. The Technical Team was of the opinion that a net increase in contaminants through flows from Lake Ontario to Hamilton Harbour was unlikely. Further, collecting information to better address the issue would be costly and of little benefit since the lake is not a controllable source.

Table 5. Hamilton Harbour loading sources.

Source	Source Description	Individual Contributors
Wastewater Treatment Plants (WWTPs)	Effluents from treatment plants following biological and chemical treatment	City of Hamilton (Woodward WWTP, Waterdown WWTP) Region of Halton (Skyway WWTP)
Steel Mills	Process and cooling waters discharged during production of steel	ArcelorMittal Dofasco Stelco
Combined Sewer Overflows (CSOs)	Intermittent discharges from older sewer systems conveying both sanitary sewage and storm runoff	City of Hamilton
Creeks	Discharges from main creeks in the Hamilton Harbour watershed	Indian Creek Grindstone Creek Red Hill Creek
Cootes Paradise	A shallow area of marsh and open water discharges via a canal to the Harbour	See Table 5

Table 6. Cootes Paradise loading sources.

Source	Individual Contributors
Wastewater Treatment Plants (WWTPs)	City of Hamilton (Dundas WWTP)
Combined Sewer Overflows (CSOs)	City of Hamilton
Tributaries	All creeks discharging to Cootes Paradise including Spencer, Ancaster, Borers, and Chedoke Creeks

6. Loading Sources Data Summaries

6.1 Wastewater Treatment Plants (WWTPs)

This report estimates contaminant loadings from three wastewater treatment plants (WWTPs): two of which outlet to Hamilton Harbour and one to Cootes Paradise.

The Region of Halton provides the RAP Office with data on the Burlington Skyway WWTP. It discharges into Hamilton Harbour in the northeast corner. The nominal design flow of the WWTP is 140 MLD (1 megalitre per day = 1000 m^3/day). In January 2016, the WWTP was upgraded to tertiary treatment (sand filtration).

The City of Hamilton provides the RAP Office with data on two WWTPs: Woodward and Dundas. The Woodward WWTP provides secondary treatment and discharges into Red Hill Creek with a nominal design flow of 400 MLD. Upgrades to modernize Woodward WWTP began in 2016 and will raise treatment to a superior tertiary level. The Dundas (King St) WWTP provides tertiary treatment (sand filtration) and discharges into Cootes Paradise with a nominal design flow of 18 MLD. All loadings for the Dundas WWTP are captured by the Cootes Paradise loading for the purposes of calculating a total loading to the Harbour. The Dundas WWTP is near end of life and the fate of this facility will be determined in the coming years. The City of Hamilton also provided data on Waterdown (Main St) WWTP discharges prior to its decommissioning in August 2010. All loadings for Waterdown WWTP are captured by the Grindstone Creek loadings for purposes of calculating a total loading to the Harbour.

For each of the WWTPs, The City of Hamilton and Region of Halton provides: a daily flow, concentration, and loading. Some parameters are not measured daily, but weekly, monthly, or intermittently. The "n" or sample size in the tables below gives an indication of how often a contaminant is measured in a year at a given WWTP. An annual average is calculated using the raw loading data provided. In previous updates, data were provided on a monthly scale and the annual average was calculated using the 12 data points per year. Tables 7-16 and Figures 2-9 provide summaries of contaminant loadings to Cootes Paradise or Hamilton Harbour from the WWTPs.

Some results prior to 2008 in the below tables are reported as "less than" MDL (< MDL); this indicates that the concentrations for at least one sample that year was below the method detection limit used at that time. This causes problems when trying to calculate loadings, so for the purposes of this report, no attempt to calculate a loading was made in these cases.

Note that a change in sampling location at Woodward WWTP in 2001 affects the ability to compare data collected before and after this year (T. Long, MOECC, personal communication).

Table 7. Total Phosphorus loadings (kg/day) from Wastewater Treatment Plants releasing to Hamilton Harbour (Skyway, Waterdown, and Woodward) and Cootes Paradise Marsh (Dundas).

Total Phosphorus																
Year	Dundas WWTP				Skyway WWTP				Waterdown WWTP				Woodward WWTP			
	Daily Average Load (kg/d)	n	SE	95% CI	Daily Average Load (kg/d)	n	SE	95% CI	Daily Average Load (kg/d)	n	SE	95% CI	Daily Average Load (kg/d)	n	SE	95% CI
1996	5.7	Error could only be estimated for years 2008-2016			48	Error could only be estimated for years 2008-2016			0.6	Error could only be estimated for years 2008-2016			143.2	Error could only be estimated for years 2008-2016		
1997	3.9				24				0.7				159.9			
1998	5.3				20				1.1				168.5			
1999	6.8				18				1.7				165.6			
2000	5.5				19				1.0				261.0			
2001	5.0				15				1.0				239.4			
2002	3.6				17				0.6				197.7			
2003	3.1				13				0.7				164.9			
2004	2.7				8				0.4				217.2			
2005	3.7				11				0.4				238.6			
2006	3.9				12				0.6				175.9			
2007	3.5				20				1.8				142.8			
2008	3.6	42	0.3	0.7	18.6	56	1.3	2.5	0.8	41	0.1	0.2	189.3	255	3.9	7.6
2009	2.7	52	0.2	0.3	18.7	54	1.9	3.7	0.5	52	0.0	0.1	171.9	260	3.5	6.8
2010	1.9	52	0.1	0.2	16.3	53	1.0	1.9	0.8	33	0.1	0.1	143.4	255	3.6	7.0
2011	2.6	53	0.1	0.3	19.7	52	1.1	2.1	WWTP Decommissioned				124.9	258	3.0	5.9
2012	3.5	51	0.2	0.4	17.8	52	1.0	2.0					143.4	260	2.5	5.0
2013	1.8	51	0.2	0.4	20.7	54	1.5	2.9					152.6	257	3.9	7.7
2014	1.5	53	0.2	0.4	20.3	53	1.4	2.7					147.4	259	3.2	6.3
2015	1.8	52	0.1	0.3	21.6	52	1.7	3.3					142.2	257	3.9	7.6
2016	2.0	52	0.1	0.2	10.5	56	0.5	1.0					161.9	259	4.8	9.4

n = sample size, SE = standard error of the mean, and 95% CI = 95% confidence interval

Table 8. Total Suspended Solids loadings (kg/day) from Wastewater Treatment Plants releasing to Hamilton Harbour (Skyway, Waterdown, and Woodward) and Cootes Paradise Marsh (Dundas).

Total Suspended Solids																
	Dundas WWTP				Skyway WWTP				Waterdown WWTP				Woodward WWTP			
Year	Daily Average Load (kg/d)	n	SE	95% CI	Daily Average Load (kg/d)	n	SE	95% CI	Daily Average Load (kg/d)	n	SE	95% CI	Daily Average Load (kg/d)	n	SE	95% CI
1996	35.4	Error could only be estimated for years 2008-2016			549	Error could only be estimated for years 2008-2016			5.2	Error could only be estimated for years 2008-2016			5751	Error could only be estimated for years 2008-2016		
1997	21.5				524				6.2				6939			
1998	24.3				435				4.8				7036			
1999	18.2				554				4.3				6580			
2000	34.0				714				5.2				8312			
2001	35.4				527				7.4				8443			
2002	28.3				461				5.2				6567			
2003	17.7				567				3.2				5744			
2004	13.3				293				2.4				7766			
2005	13.9				393				2.9				7252			
2006	17.7				373				5.0				4726			
2007	14.1				420				5.6				3336			
2008	20.4	47	1.8	3.5	391.4	56	30	58	7.1	46	1.8	3.5	4950	255	188	368
2009	24.9	53	2.6	5.1	371.8	61	26	50	2.6	52	0.2	0.4	3692	260	134	262
2010	21.3	53	3.5	6.8	493.4	53	41	80	2.8	34	0.4	0.8	3549	255	144	283
2011	29.9	53	3.5	6.8	513.3	52	45	88	WWTP Decommissioned				3275	258	136	267
2012	48.9	52	4.9	9.5	356.9	52	35	69					2416	260	101	199
2013	14.3	51	0.8	1.6	413.4	156	24	47					2786	257	192	376
2014	14.2	53	1.3	2.5	432.0	157	28	56					2875	259	145	284
2015	17.5	52	1.7	3.3	421.0	158	21	40					2756	257	197	385
2016	14.7	52	0.9	1.8	116.4	157	3	7					4236	259	312	611

n = sample size, SE = standard error of the mean, and 95% CI = 95% confidence interval

Table 9. Total Ammonia loadings (kg/day) from Wastewater Treatment Plants releasing to Hamilton Harbour (Skyway, Waterdown, and Woodward) and Cootes Paradise Marsh (Dundas).

Total Ammonia																
Year	Dundas WWTP				Skyway WWTP				Waterdown WWTP				Woodward WWTP			
	Daily Average Load (kg/d)	n	SE	95% CI	Daily Average Load (kg/d)	n	SE	95% CI	Daily Average Load (kg/d)	n	SE	95% CI	Daily Average Load (kg/d)	n	SE	95% CI
1996	5.2	Error could only be estimated for years 2008-2016			720	Error could only be estimated for years 2008-2016			3.0	Error could only be estimated for years 2008-2016			3962	Error could only be estimated for years 2008-2016		
1997	5.4				878				0.6				4229			
1998	3.3				508				3.2				3857			
1999	9.7				58				9.1				4517			
2000	6.1				60				12.2				3943			
2001	13.5				133				5.4				2925			
2002	12.9				179				5.3				3175			
2003	6.2				195				3.2				2874			
2004	1.3				92				0.4				3289			
2005	1.9				64				1.1				2753			
2006	8.3				31				0.5				2062			
2007	6.1				27				3.6				1680			
2008	2.7	46	0.8	1.5	36.9	56	7.4	14.5	4.1	45	0.6	1.2	1789	255	103	203
2009	2.7	52	0.6	1.2	33.2	52	7.5	14.6	0.7	50	0.2	0.5	1100	259	82	161
2010	8.2	52	2.3	4.4	13.6	53	3.6	7.1	5.4	34	1.7	3.2	878	255	54	106
2011	8.6	53	2.4	4.7	42.4	54	9.3	18.3	WWTP Decommissioned				991	258	73	142
2012	8.0	53	2.9	5.6	19.9	52	2.3	4.4					337	260	22	43
2013	5.1	51	3.4	6.6	43.4	156	5.4	10.5					332	257	15	30
2014	3.0	53	1.1	2.2	144.1	115	20.1	39.5					651	259	37	72
2015	2.5	54	0.8	1.5	143.3	56	27.8	54.4					1072	257	69	134
2016	0.8	52	0.1	0.3	37.4	53	8.6	16.8					947	259	31	60

n = sample size, SE = standard error of the mean, and 95% CI = 95% confidence interval

Table 10. Total Nitrate loadings (kg/day) from Wastewater Treatment Plants releasing to Hamilton Harbour (Skyway, Waterdown, and Woodward) and Cootes Paradise Marsh (Dundas).

Total Nitrate																
Year	Dundas WWTP				Skyway WWTP				Waterdown WWTP				Woodward WWTP			
	Daily Average Load (kg/d)	n	SE	95% CI	Daily Average Load (kg/d)	n	SE	95% CI	Daily Average Load (kg/d)	n	SE	95% CI	Daily Average Load (kg/d)	n	SE	95% CI
1996	n/r	Error could only be estimated for years 2008-2016			n/r	Error could only be estimated for years 2008-2016			n/r	Error could only be estimated for years 2008-2016			n/r	Error could only be estimated for years 2008-2016		
1997	n/r				n/r				n/r				n/r			
1998	n/r				n/r				n/r				n/r			
1999	n/r				n/r				n/r				n/r			
2000	n/r				n/r				n/r				n/r			
2001	n/r				n/r				n/r				n/r			
2002	n/r				n/r				n/r				n/r			
2003	n/r				n/r				n/r				n/r			
2004	n/r				n/r				n/r				n/r			
2005	n/r				n/r				n/r				n/r			
2006	n/r				n/r				n/r				n/r			
2007	n/r				n/r				n/r				n/r			
2008	255	46	5	11	2436	53	40	79	n/r	—	—	—	2871	252	71	139
2009	256	52	4	7	2615	51	32	63	n/r	—	—	—	3206	260	66	130
2010	253	52	5	10	2471	53	58	114	n/r	—	—	—	3624	255	53	104
2011	218	53	4	9	2674	52	39	77	WWTP Decommissioned				3635	258	57	111
2012	239	52	7	13	2438	52	42	83					4266	260	48	95
2013	242	52	7	13	2481	52	38	74					4419	256	49	95
2014	212	53	4	8	2386	53	55	108					3866	259	41	80
2015	183	52	7	15	2348	49	83	162					3299	258	62	122
2016	271	51	6	12	2592	52	34	67					3105	259	45	88

n = sample size, SE = standard error of the mean, 95% CI = 95% confidence interval, and n/r = not requested

Table 11. Total Kjeldahl Nitrogen loadings (kg/day) from Wastewater Treatment Plants releasing to Hamilton Harbour (Skyway, Waterdown, and Woodward) and Cootes Paradise Marsh (Dundas).

Total Kjeldahl Nitrogen																
Year	Dundas WWTP				Skyway WWTP				Waterdown WWTP				Woodward WWTP			
	Daily Average Load (kg/d)	n	SE	95% CI	Daily Average Load (kg/d)	n	SE	95% CI	Daily Average Load (kg/d)	n	SE	95% CI	Daily Average Load (kg/d)	n	SE	95% CI
1996	22.2	Error could only be estimated for years 2008-2016			839	Error could only be estimated for years 2008-2016			4.9	Error could only be estimated for years 2008-2016			5030	Error could only be estimated for years 2008-2016		
1997	22.8				1014				4.2				5174			
1998	22.3				644				7.1				4759			
1999	26.0				190				12.8				5249			
2000	24.4				197				16.2				4971			
2001	34.5				272				9.6				3860			
2002	33.8				330				9.3				3812			
2003	n/a				342				n/a				3338			
2004	n/a				216				n/a				3971			
2005	n/a				159				n/a				3351			
2006	n/a				137				n/a				2711			
2007	16.0				151				5.8				2036			
2008	16.7	40	1.6	3.1	172.0	55	10.2	19.9	7.2	38	1.0	1.9	2358	255	107	209
2009	13.3	52	0.9	1.7	173.3	51	181.1	355.0	2.3	47	0.3	0.6	1528	259	82	160
2010	17.2	51	2.0	3.9	153.0	53	7.1	14.0	7.0	34	1.6	3.2	1266	255	51	100
2011	16.9	53	2.4	4.6	179.9	52	10.6	20.8	WWTP Decommissioned				1388	258	71	139
2012	20.6	52	3.2	6.2	143.4	52	4.9	9.6					670	260	25	50
2013	12.9	51	3.5	6.9	188.5	52	13.3	26.0					732	257	22	42
2014	9.2	53	1.2	2.4	292.7	53	31.8	62.4					1051	259	43	84
2015	9.4	52	1.0	1.9	248.3	49	39.0	76.5					1460	257	72	142
2016	8.2	52	0.6	1.2	103.0	52	9.9	19.5					1452	259	43	85

n = sample size, SE = standard error of the mean, 95% CI = 95% confidence interval, and n/a = data not available

Table 12. Iron loadings (kg/day) from Wastewater Treatment Plants releasing to Hamilton Harbour (Skyway, Waterdown, and Woodward) and Cootes Paradise Marsh (Dundas).

Iron																
Year	Dundas WWTP				Skyway WWTP				Waterdown WWTP				Woodward WWTP			
	Daily Average Load (kg/d)	n	SE	95% CI	Daily Average Load (kg/d)	n	SE	95% CI	Daily Average Load (kg/d)	n	SE	95% CI	Daily Average Load (kg/d)	n	SE	95% CI
1996	3.7	Error could only be estimated for years 2008-2016			no data	Error could only be estimated for years 2008-2016			0.4	Error could only be estimated for years 2008-2016			472	Error could only be estimated for years 2008-2016		
1997	4.1				50.2				0.6				483			
1998	2.1				65.8				0.4				1186			
1999	9.1				97.8				0.4				580			
2000	6.6				156.4				0.6				527			
2001	5.9				53.2				1.2				553			
2002	4.4				135.0				0.7				501			
2003	n/a				64.9				n/a				339			
2004	n/a				53.2				n/a				690			
2005	n/a				55.7				n/a				357			
2006	n/a				47.7				n/a				279			
2007	2.0				56.8				0.6				195			
2008	1.9	5	0.7	1.5	54.5	11	3.8	7.5	1.5	12	0.5	1.1	365.4	5.0	128.0	250.9
2009	2.8	12	0.7	1.3	59.0	12	9.8	19.1	0.2	12	0.1	0.1	184.3	12.0	22.6	44.3
2010	3.8	12	0.7	1.5	74.4	12	10.0	19.7	0.8	8	0.6	1.2	217.3	12.0	35.2	69.0
2011	3.2	12	0.5	1.0	60.3	12	10.1	19.8	WWTP Decommissioned				237.6	12.0	40.6	79.5
2012	2.6	12	0.4	0.8	54.1	12	5.9	11.5					177.4	12.0	22.1	43.2
2013	1.1	12	0.2	0.3	60.1	12	4.8	9.5					151.4	12.0	25.0	49.0
2014	1.6	12	0.3	0.6	55.8	12	5.0	9.8					260.8	12.0	56.9	111.6
2015	4.0	12	1.2	2.4	52.4	12	9.6	18.9					139.6	12.0	14.0	27.4
2016	2.7	12	0.2	0.5	31.1	12	3.3	6.5					205.6	12.0	30.9	60.5

n = sample size, SE = standard error of the mean, 95% CI = 95% confidence interval, and n/a = data not available

Table 13. Lead loadings (kg/day) from Wastewater Treatment Plants releasing to Hamilton Harbour (Skyway, Waterdown, and Woodward) and Cootes Paradise Marsh (Dundas).

Lead																
Year	Dundas WWTP				Skyway WWTP				Waterdown WWTP				Woodward WWTP			
	Daily Average Load (kg/d)	n	SE	95% CI	Daily Average Load (kg/d)	n	SE	95% CI	Daily Average Load (kg/d)	n	SE	95% CI	Daily Average Load (kg/d)	n	SE	95% CI
1996	1.3				<MDL				0.10				27.1			
1997	<MDL				0.1				<MDL				34.1			
1998	<MDL				<MDL				<MDL				<MDL			
1999	<MDL				<MDL				<MDL				14.5			
2000	<MDL				<MDL				<MDL				6.9			
2001	<MDL	Error could only be estimated for years 2008-2016			<MDL	Error could only be estimated for years 2008-2016			<MDL	Error could only be estimated for years 2008-2016			<MDL	Error could only be estimated for years 2008-2016		
2002	<MDL				<MDL				<MDL				<MDL			
2003	n/a				<MDL				n/a				1.3			
2004	n/a				<MDL				n/a				1.8			
2005	n/a				<MDL				n/a				1.1			
2006	n/a				<MDL				n/a				<MDL			
2007	0.01				<MDL				0.00				0.30			
2008	0.02	5	0.00	0.01	0.15	12	0.02	0.04	0.00	12	0.00	0.00	0.92	5	0.57	1.12
2009	0.02	12	0.00	0.00	0.11	12	0.00	0.01	0.00	12	0.00	0.00	0.30	12	0.03	0.06
2010	0.02	12	0.00	0.00	0.11	12	0.01	0.02	0.00	8	0.00	0.00	0.31	12	0.02	0.04
2011	0.02	12	0.00	0.00	0.13	12	0.01	0.02					0.36	12	0.04	0.07
2012	0.02	12	0.00	0.00	0.07	12	0.01	0.02					0.29	12	0.01	0.03
2013	0.01	12	0.00	0.00	0.05	12	0.00	0.00	WWTP Decommissioned				0.28	12	0.01	0.03
2014	0.01	12	0.00	0.00	0.05	12	0.00	0.00					0.58	12	0.14	0.27
2015	0.01	12	0.00	0.00	0.04	12	0.00	0.00					0.27	12	0.01	0.02
2016	0.01	12	0.00	0.00	0.08	12	0.02	0.05					0.29	12	0.02	0.05

n = sample size, SE = standard error of the mean, 95% CI = 95% confidence interval, n/a = data not available, and < MDL = concentrations were less than the method detection limit

Table 14. Zinc loadings (kg/day) from Wastewater Treatment Plants releasing to Hamilton Harbour (Skyway, Waterdown, and Woodward) and Cootes Paradise Marsh (Dundas).

Zinc																
Year	Dundas WWTP				Skyway WWTP				Waterdown WWTP				Woodward WWTP			
	Daily Average Load (kg/d)	n	SE	95% CI	Daily Average Load (kg/d)	n	SE	95% CI	Daily Average Load (kg/d)	n	SE	95% CI	Daily Average Load (kg/d)	n	SE	95% CI
1996	<MDL	Error could only be estimated for years 2008-2016			2.29	Error could only be estimated for years 2008-2016			<MDL	Error could only be estimated for years 2008-2016			34.9	Error could only be estimated for years 2008-2016		
1997	1.00				1.56				0.30				32.8			
1998	0.30				1.62				0.10				12.4			
1999	0.80				<MDL				0.10				14.9			
2000	0.80				1.91				0.10				17.3			
2001	0.70				2.16				0.10				11.8			
2002	0.50				3.14				0.09				15.3			
2003	n/a				3.57				n/a				20.2			
2004	n/a				2.80				n/a				17.9			
2005	n/a				3.60				n/a				17.8			
2006	n/a				2.02				n/a				16.8			
2007	0.43				2.82				0.07				11.4			
2008	0.28	5	0.03	0.05	3.15	12	0.22	0.44	0.07	12	0.01	0.02	13.11	5	3.07	6.01
2009	0.42	12	0.04	0.07	2.38	12	0.13	0.25	0.06	12	0.01	0.02	10.46	12	1.38	2.70
2010	0.47	12	0.11	0.22	2.70	12	0.24	0.46	0.07	8	0.01	0.02	9.04	12	0.90	1.76
2011	0.43	12	0.05	0.10	3.06	12	0.23	0.46	WWTP Decommissioned				9.79	12	1.29	2.53
2012	0.45	12	0.04	0.08	2.10	12	0.10	0.20					8.29	12	0.72	1.40
2013	0.50	12	0.05	0.10	2.46	12	0.10	0.19					9.36	12	0.76	1.49
2014	0.47	12	0.04	0.08	2.61	12	0.16	0.32					14.11	12	1.63	3.19
2015	0.43	12	0.05	0.09	2.78	12	0.19	0.37					12.69	12	1.34	2.63
2016	0.43	12	0.03	0.05	2.75	12	0.20	0.38					10.84	12	1.29	2.53

n = sample size, SE = standard error of the mean, 95% CI = 95% confidence interval, n/a = data not available, and < MDL = concentrations were less than the method detection limit

Table 15. Cyanide loadings (kg/day) from Wastewater Treatment Plants releasing to Hamilton Harbour (Skyway, Waterdown, and Woodward) and Cootes Paradise Marsh (Dundas).

Cyanide																
Year	Dundas WWTP				Skyway WWTP				Waterdown WWTP				Woodward WWTP[1]			
	Daily Average Load (kg/d)	n	SE	95% CI	Daily Average Load (kg/d)	n	SE	95% CI	Daily Average Load (kg/d)	n	SE	95% CI	Daily Average Load (kg/d)	n	SE	95% CI
1996	no data	Error could only be estimated for years 2008-2016			no data	Error could only be estimated for years 2008-2016			no data	Error could only be estimated for years 2008-2016			no data	Error could only be estimated for years 2008-2016		
1997	no data				no data				no data				44.8			
1998	no data				no data				no data				26.6			
1999	no data				no data				no data				14.0			
2000	no data				no data				no data				23.1			
2001	no data				no data				no data				29.5			
2002	no data				no data				no data				27.5			
2003	no data				no data				no data				30.9			
2004	no data				no data				no data				22.7			
2005	no data				no data				no data				25.6			
2006	no data				no data				no data				25.3			
2007	no data				no data				no data				30.9			
2008	no data	—	—	—	no data	—	—	—	no data	—	—	—	19.7	12	3.0	5.9
2009	no data	—	—	—	no data	—	—	—	no data	—	—	—	14.8	12	1.6	3.2
2010	no data	—	—	—	no data	—	—	—	no data	—	—	—	11.2	12	2.0	3.9
2011	no data	—	—	—	no data	—	—	—	WWTP Decommissioned				5.7	1	—	—
2012	no data	—	—	—	no data	—	—	—					no data	—	—	—
2013	no data	—	—	—	no data	—	—	—					no data	—	—	—
2014	no data	—	—	—	no data	—	—	—					no data	—	—	—
2015	no data	—	—	—	no data	—	—	—					no data	—	—	—
2016	no data	—	—	—	no data	—	—	—					no data	—	—	—

n = sample size, SE = standard error of the mean, and 95% CI = 95% confidence interval

[1]1999-2002 Cyanide values are estimates using a non-weighted average of plant flows

Table 16. Phenolics and Polycyclic Aromatic Hydrocarbon loadings (Benzo(a)pyrene and Naphthalene; kg/day) from Wastewater Treatment Plants releasing to Hamilton Harbour (Skyway, Waterdown, and Woodward) and Cootes Paradise Marsh (Dundas).

	Phenolics				PAH - Benzo(a)pyrene				PAH - Naphthalene			
	Dundas	Skyway[1]	Waterdown	Woodward[2]	Dundas	Skyway	Waterdown	Woodward	Dundas	Skyway	Waterdown	Woodward
Year	Daily Average Load (kg/d)	Daily Average Load (kg/d)	Daily Average Load (kg/d)	Daily Average Load (kg/d)	Daily Average Load (kg/d)	Daily Average Load (kg/d)	Daily Average Load (kg/d)	Daily Average Load (kg/d)	Daily Average Load (kg/d)	Daily Average Load (kg/d)	Daily Average Load (kg/d)	Daily Average Load (kg/d)
1996	no data	<MDL	no data	no data	no data	<MDL	no data	no data	no data	0.08	no data	no data
1997	no data	<MDL	no data	no data	no data	<MDL	no data	no data	no data	<MDL	no data	no data
1998	no data	<MDL	no data	no data	no data	<MDL	no data	no data	no data	<MDL	no data	no data
1999	no data	no data	no data	no data	no data	no data	no data	no data	no data	no data	no data	no data
2000	no data	<MDL	no data	no data	no data	<MDL	no data	no data	no data	<MDL	no data	no data
2001	no data	<MDL	no data	no data	no data	<MDL	no data	no data	no data	<MDL	no data	no data
2002	no data	<MDL	no data	no data	no data	<MDL	no data	no data	no data	<MDL	no data	no data
2003	no data	<MDL	no data	no data	no data	<MDL	no data	no data	no data	<MDL	no data	no data
2004	no data	no data	no data	1.7	no data	no data	no data	no data	no data	no data	no data	no data
2005	no data	no data	no data	2.0	no data	no data	no data	no data	no data	no data	no data	no data
2006	no data	no data	no data	1.6	no data	no data	no data	no data	no data	no data	no data	no data
2007	no data	no data	no data	no data	no data	no data	no data	no data	no data	no data	no data	no data
2008	no data	no data	no data	no data	no data	no data	no data	no data	no data	no data	no data	no data
2009	no data	no data	no data	no data	no data	no data	no data	no data	no data	no data	no data	no data
2010	no data	no data	no data	no data	no data	no data	no data	no data	no data	no data	no data	no data
2011	no data	no data	WWTP Decommissioned	no data	no data	no data	WWTP Decommissioned	no data	no data	no data	WWTP Decommissioned	no data
2012	no data	no data		no data	no data	no data		no data	no data	no data		no data
2013	no data	no data		no data	no data	no data		no data	no data	no data		no data
2014	no data	no data		no data	no data	no data		no data	no data	no data		no data
2015	no data	no data		no data	no data	no data		no data	no data	no data		no data
2016	no data	no data		no data	no data	no data		no data	no data	no data		no data

< MDL = concentrations were less than the method detection limit
Note that error is not shown for these compounds as the data are supplied as yearly averages, when available.

[1]Skyway data is for strictly phenol not phenolics, which could be a variety of compound variations
[2]For 1996-2002 there were only two months for which data was provided – not enough to include in this report. The two concentrations given for phenol were ≤ 0.003 mg/L.

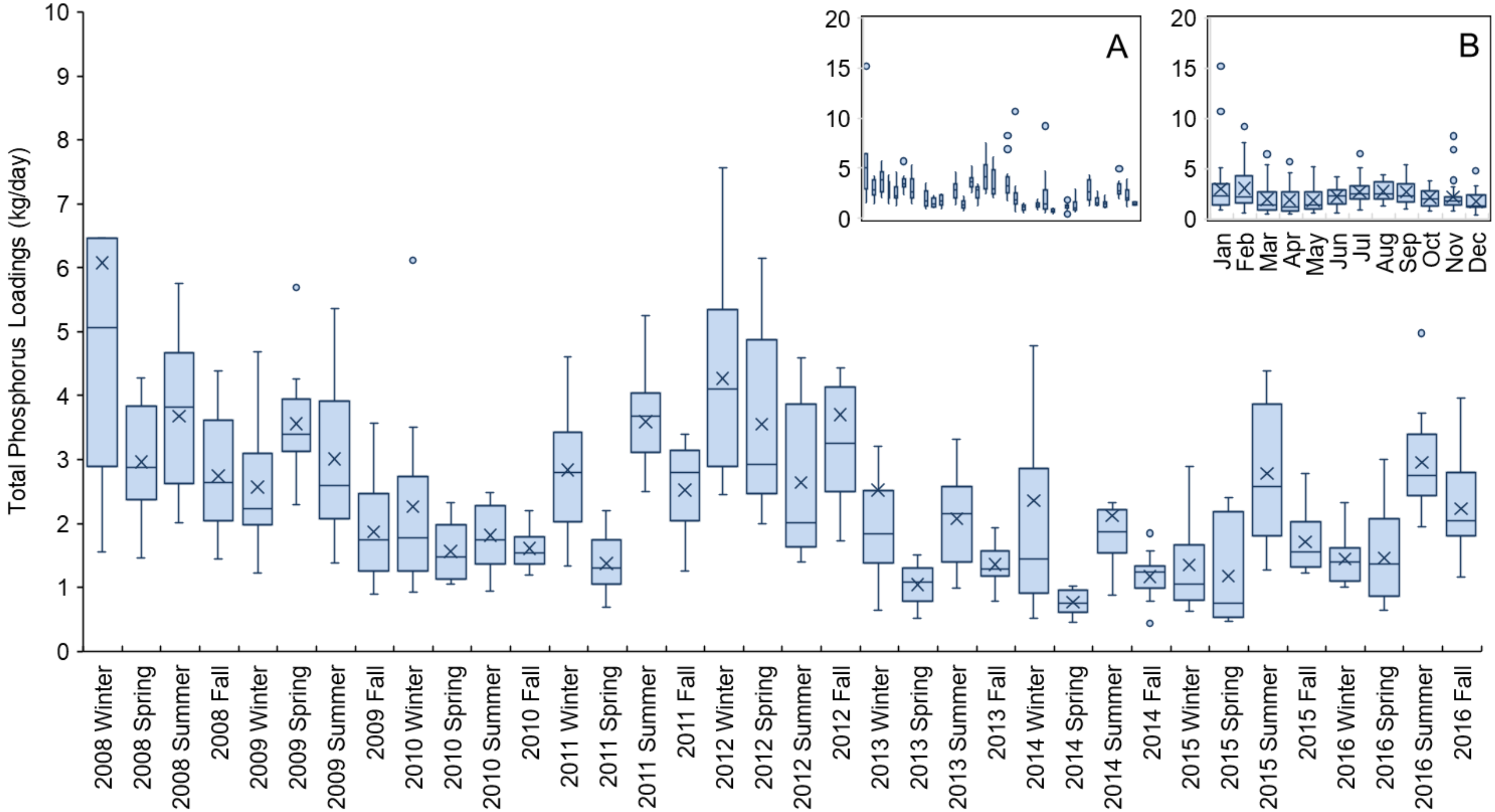

Figure 2. Dundas WWTP seasonal Total Phosphorus loadings (kg/day). Seasonal mean loading is represented by an X. Inset A shows the same data at full scale and inset B shows the data redistributed by month.

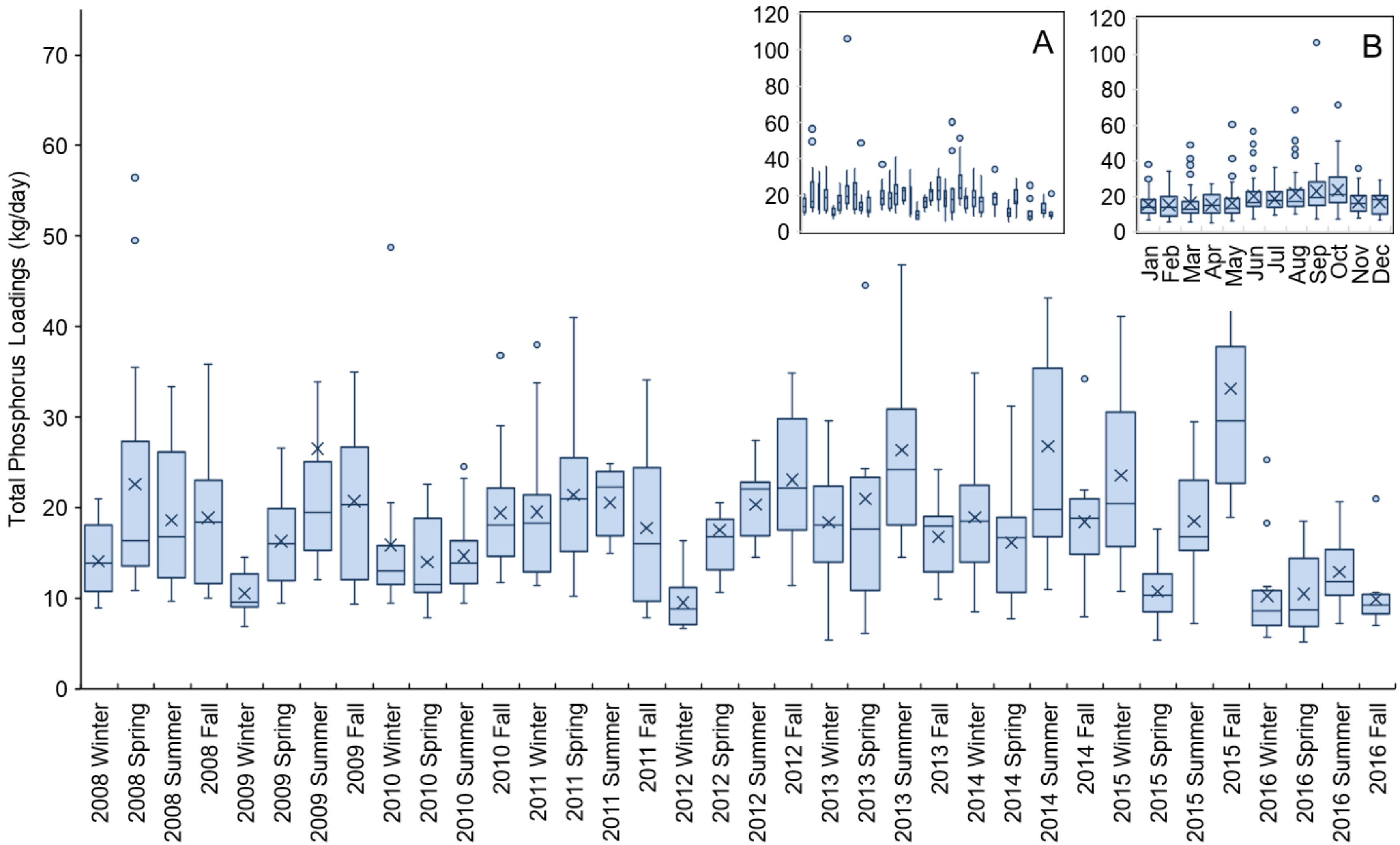

Figure 3. Skyway WWTP seasonal Total Phosphorus loadings (kg/day). Seasonal mean loading is represented by an X. Inset A shows the same data at full scale and inset B shows the data redistributed by month.

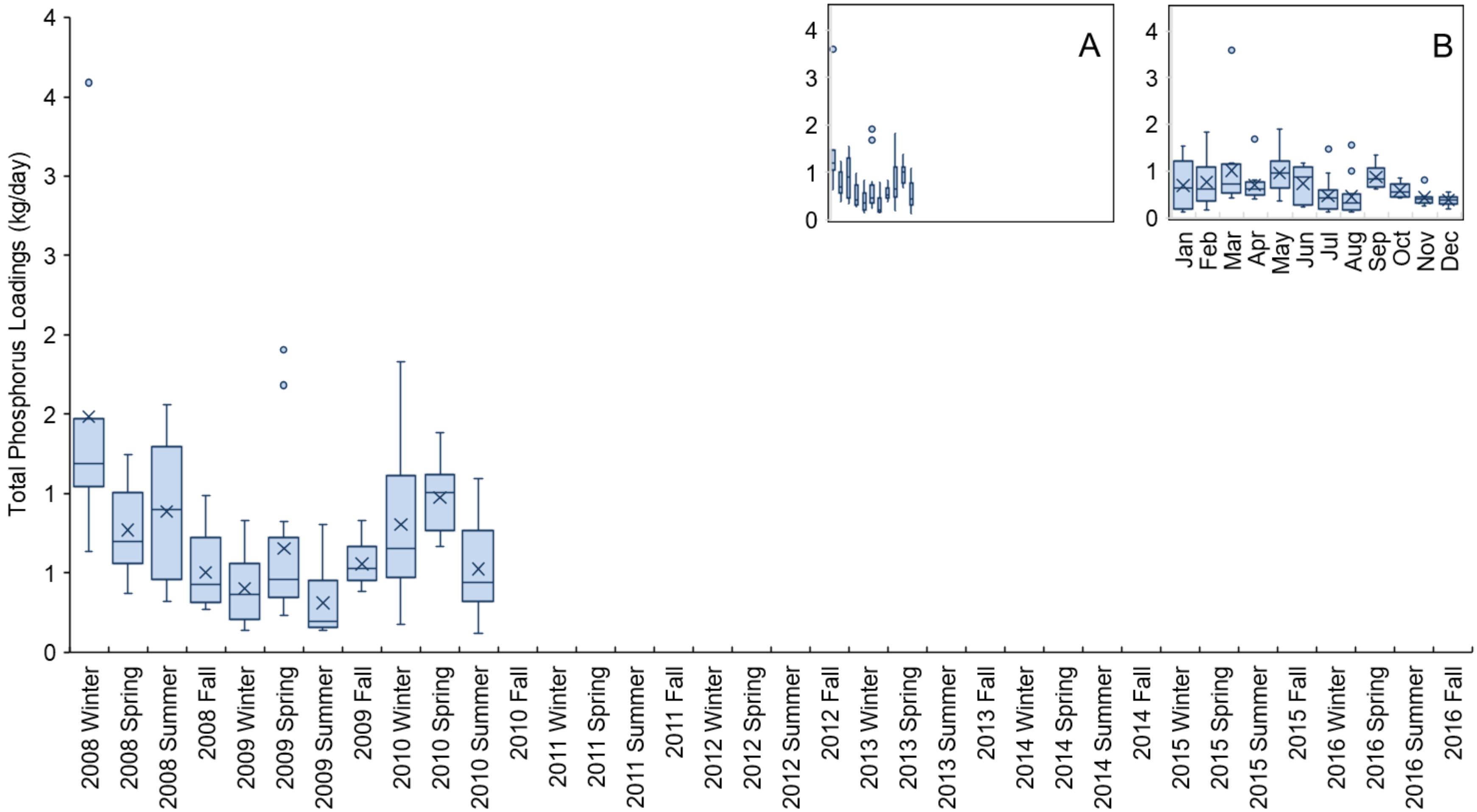

Figure 4. Waterdown WWTP seasonal Total Phosphorus loadings (kg/day). Seasonal mean loading is represented by an X. Inset A shows the same data at full scale and inset B shows the data redistributed by month. The WWTP was decommissioned in August 2010.

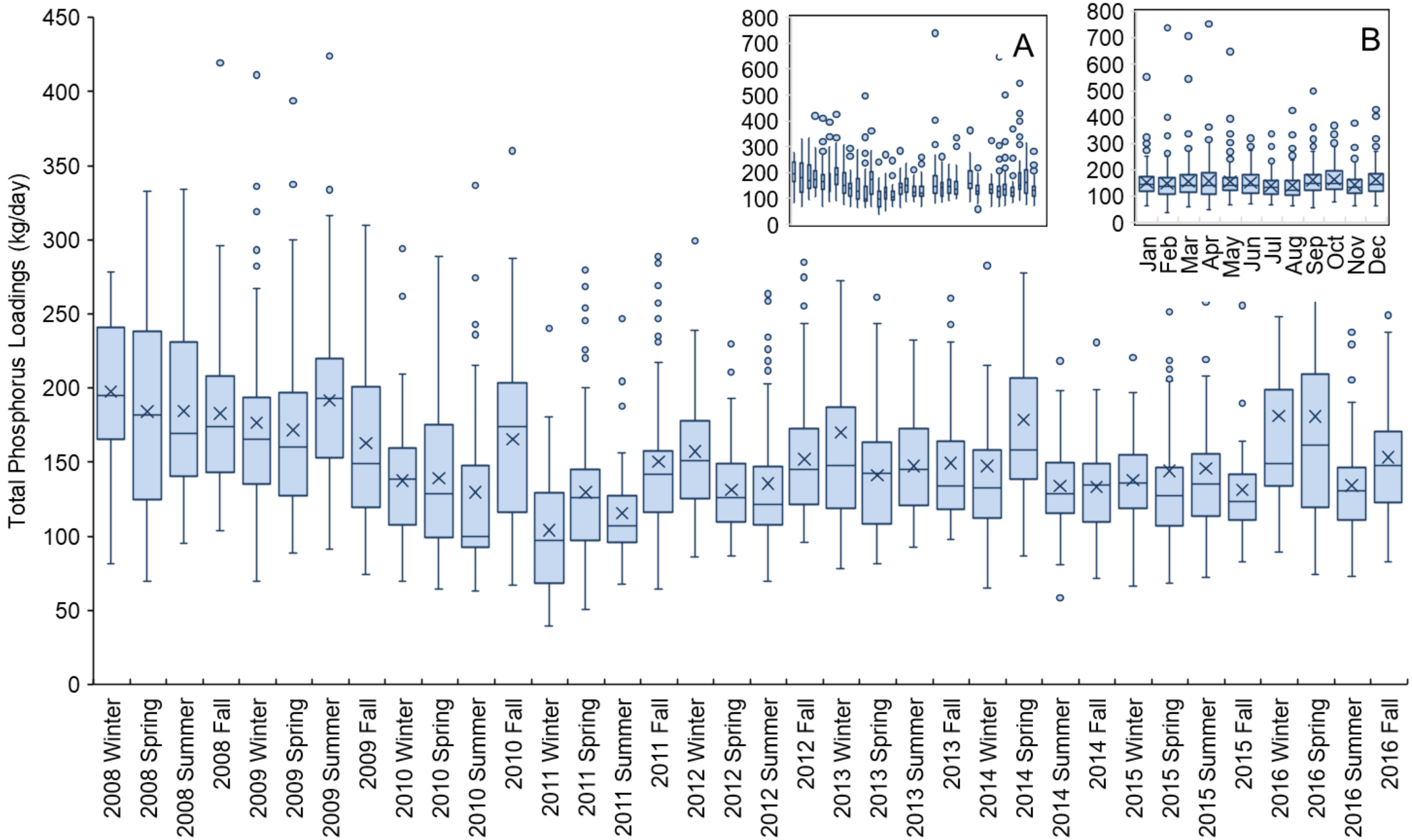

Figure 5. Woodward WWTP seasonal Total Phosphorus loadings (kg/day). Seasonal mean loading is represented by an X. Inset A shows the same data at full scale and inset B shows the data redistributed by month.

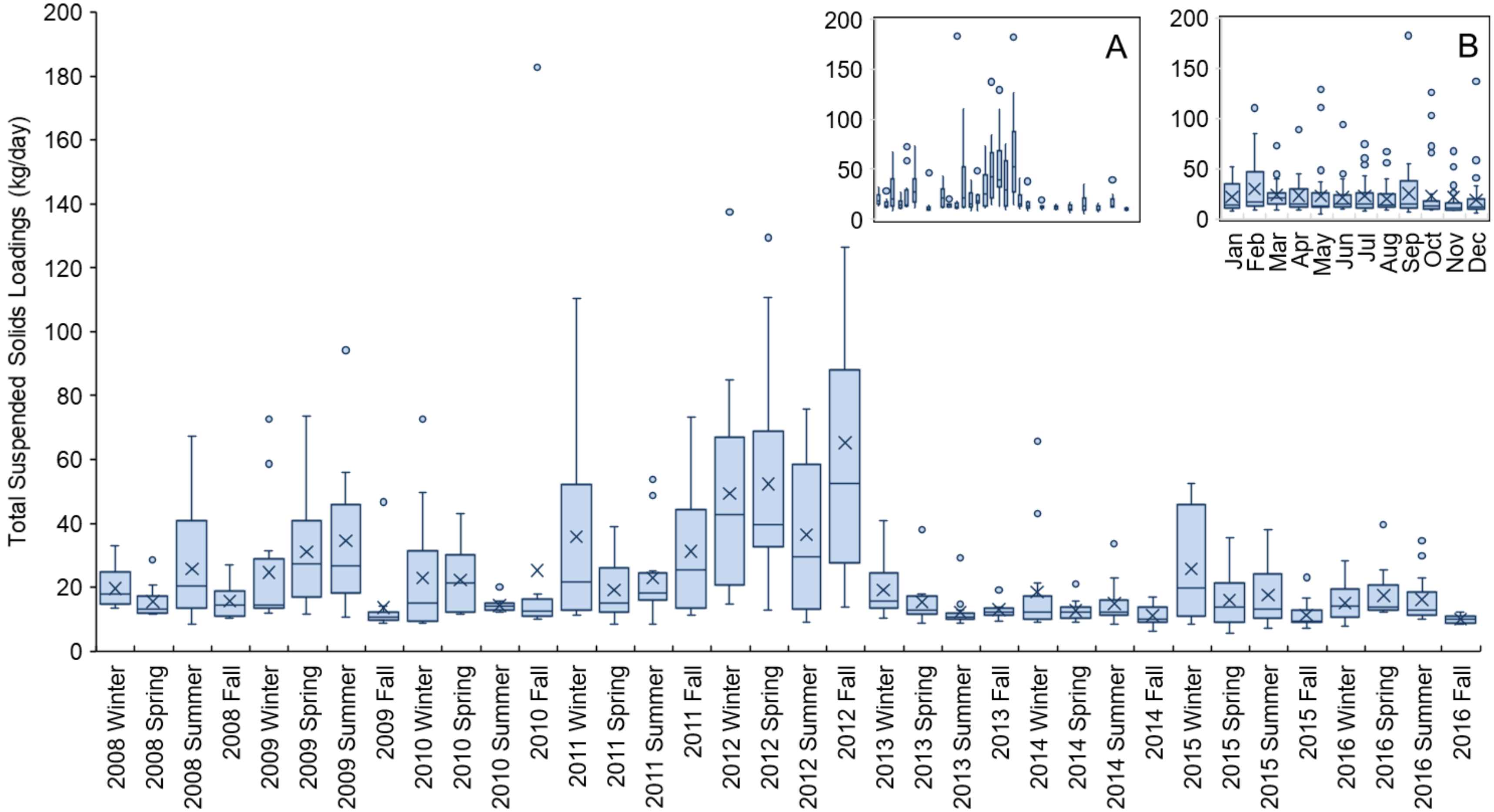

Figure 6. Dundas WWTP seasonal Total Suspended Solids loadings (kg/day). Seasonal mean loading is represented by an X. Inset A shows the same data at full scale and inset B shows the data redistributed by month.

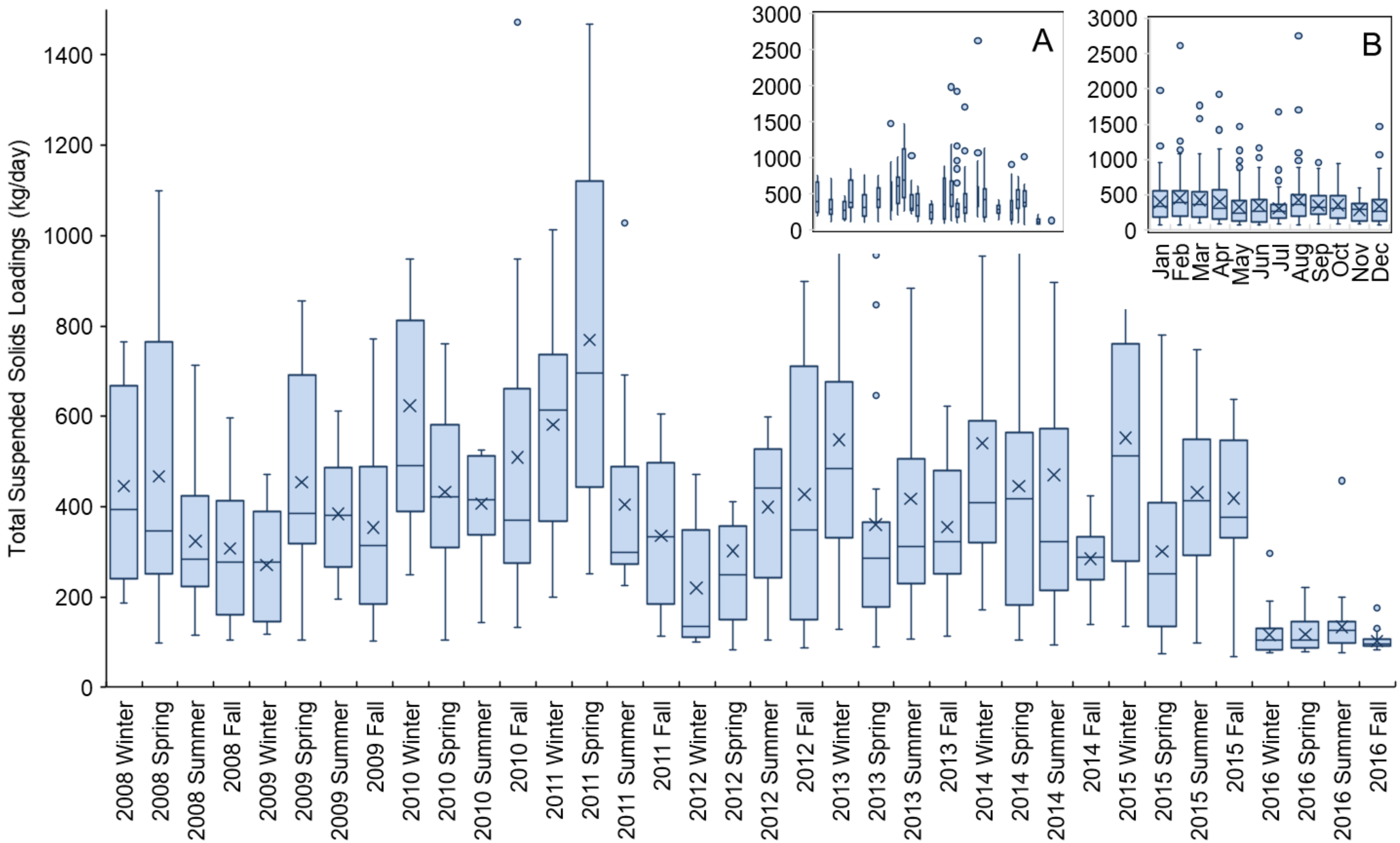

Figure 7. Skyway WWTP seasonal Total Suspended Solids loadings (kg/day). Seasonal mean loading is represented by an X. Inset A shows the same data at full scale and inset B shows the data redistributed by month.

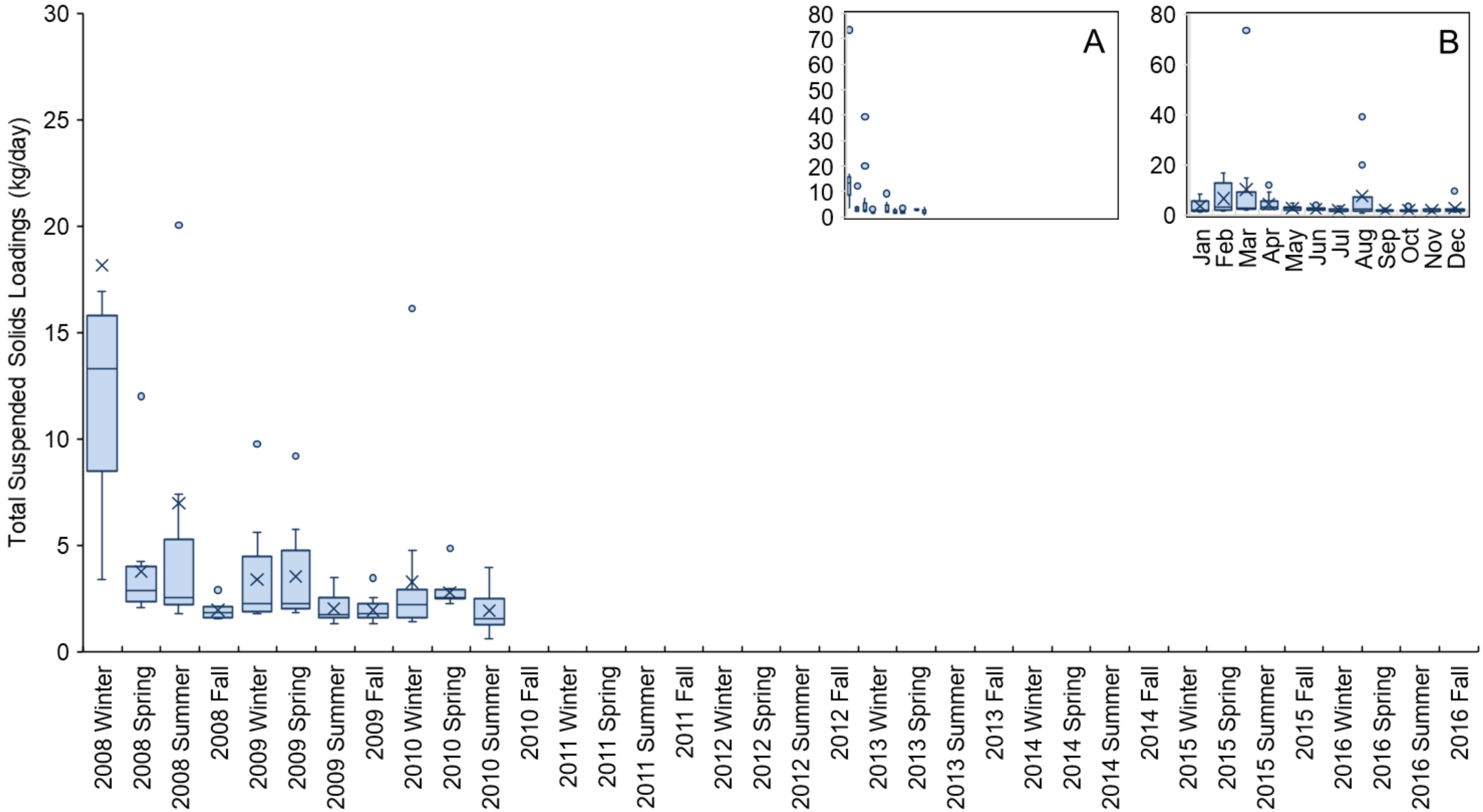

Figure 8. Waterdown WWTP seasonal Total Suspended Solids loadings (kg/day). Seasonal mean loading is represented by an X. Inset A shows the same data at full scale and inset B shows the data redistributed by month.

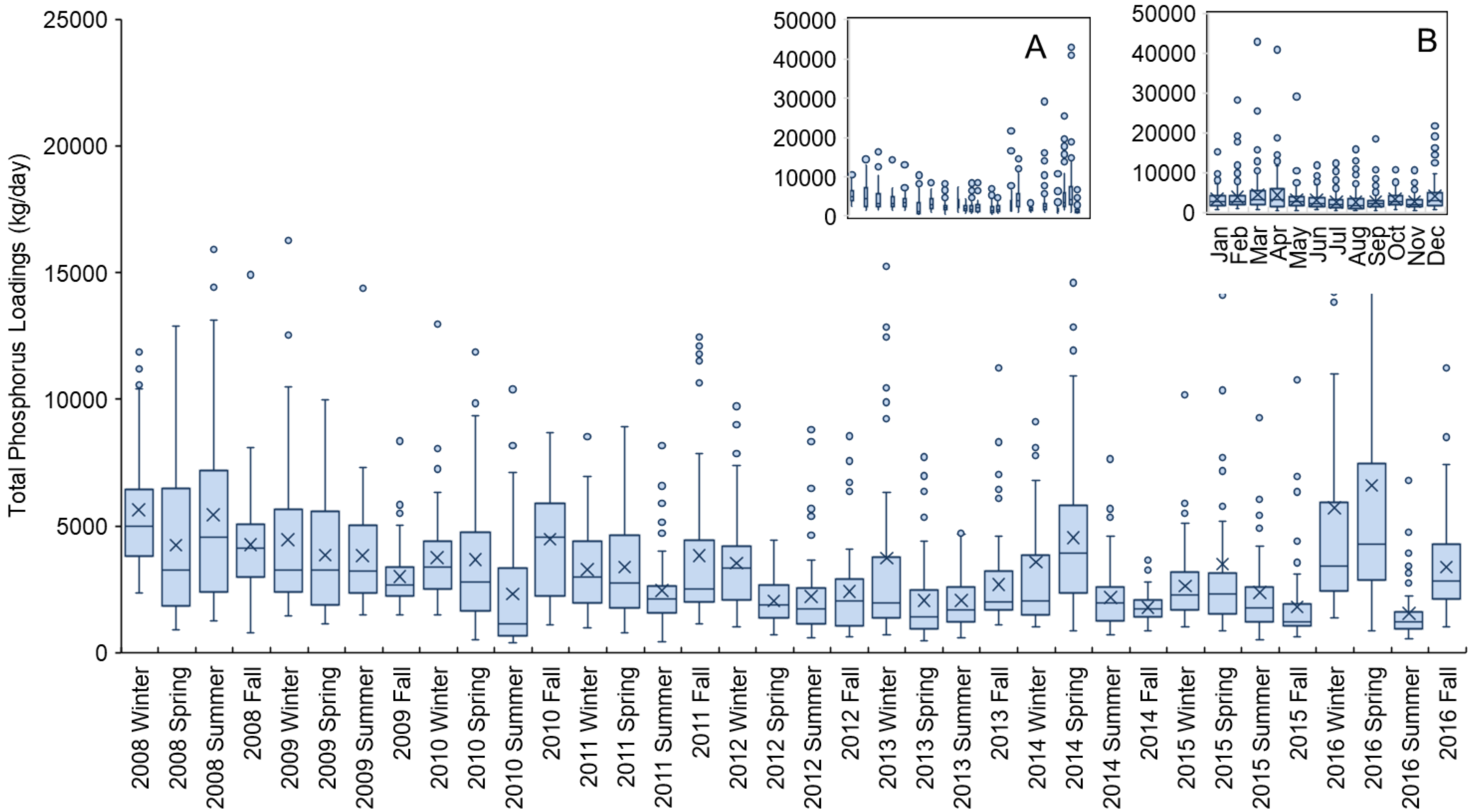

Figure 9. Woodward WWTP seasonal Total Suspended Solids loadings (kg/day). Seasonal mean loading is represented by an X. Inset A shows the same data at full scale and inset B shows the data redistributed by month.

Comments

Both Woodward and Skyway WWTPs have overflow provisions to prevent the secondary processes from washing out under high flows during wet weather periods. Plant "overflow" means a discharge to the environment from the WWTP at a location other than the plant outfall or into the plant outfall downstream of the final effluent sampling location (i.e., contaminants not captured by the WWTP loadings estimates above). A primary overflow means there has been primary treatment before release, and a secondary overflow means there has been secondary treatment. However, it was felt by the Technical Team that as these discharges represent such a small percentage of the total load to the Harbour, they will not be calculated or incorporated into this report. For information purposes only, the table below shows the number of annual primary and secondary overflow occurrences and their duration in hours; however, it should be noted that the loadings may not be proportional to their duration due to variations in concentrations and flows.

Year	Woodward WWTP # of Overflow Occurrences (duration in hours)		Skyway WWTP # of Overflow Occurrences (duration in hours)	
	Plant	Secondary	Primary	Secondary
1996	included in CSO data	34 (328 hrs)	no data	no data
1997	included in CSO data	59 (574 hrs)	no data	no data
1998	included in CSO data	68 (740 hrs)	no data	no data
1999	included in CSO data	0 (0 hrs) [1]	no data	no data
2000	included in CSO data	62 (676 hrs)	no data	no data
2001	included in CSO data	62 (1557 hrs)	no data	no data
2002	included in CSO data	31 (271 hrs)	no data	no data
2003	included in CSO data	15 (146.25 hrs)	no data	no data
2004	included in CSO data	19 (232.33 hrs)	no data	no data
2005	included in CSO data	9 (291.75 hrs)	no data	no data
2006	included in CSO data	1 (3 hrs)	no data	no data
2007	included in CSO data	1 (8.5 hrs)	no data	no data
2008	included in CSO data	0 (0 hrs)	19 (113.97 hrs)	0 (0 hrs)
2009	included in CSO data	0 (0 hrs)	19 (139.07 hrs)	0 (0 hrs)
2010	included in CSO data	0 (0 hrs)	14 (122.89 hrs)	0 (0 hrs)
2011	included in CSO data	0 (0 hrs)	25 (239.18 hrs)	0 (0 hrs)
2012	included in CSO data	0 (0 hrs)	4 (4.77 hrs)	0 (0 hrs)
2013	included in CSO data	0 (0 hrs)	12 (105.57 hrs)	0 (0 hrs)
2014	included in CSO data	0 (0 hrs)	15 (109.83 hrs)	0 (0 hrs)
2015	included in CSO data	1 (10.82 hrs)	5 (25.33 hrs)	0 (0 hrs)
2016	included in CSO data	10 (49.28 hrs)	5 (66.31 hrs)	4 (44.8 hrs)

[1]City of Hamilton confirmed this number. There were plant overflows, but no recorded secondary overflows.

6.2 Steel Mills

The Municipal-Industrial Strategy for Abatement (MISA) regulatory program, including the Iron and Steel Sector regulations, was passed to work towards the virtual elimination of toxic contaminants in industrial discharges into Ontario's waterways. The MISA effluent regulation (Environmental Protection Act, Ontario Regulation 214/95, Effluent Monitoring and Effluent Limits – Iron and Steel Manufacturing Sector) requires the reporting of gross effluent loadings. Limits were set for gross effluent loadings of: benzo[a]pyrene and naphthalene (PAHs), total cyanide, ammonia plus ammonium, total suspended solids, lead, zinc, phenolics, benzene, oil and grease, but not iron or phosphorus.

However, for the Hamilton Harbour RAP it is of interest to understand the net contribution of contaminants for each source. ArcelorMittal Dofasco (AMD) and Stelco (formerly U. S. Steel Canada) take water from the Harbour, pass it through a screening filter, use it in their facilities (some contacts the product, some doesn't contact the product (non-contact)), contact water is treated, and then both non-contact waters and the treated contact waters are discharged back to the Harbour again. Net loadings are calculated by subtracting the background loadings measured in Harbour intake water from the gross effluent loadings measured from what goes back into the Harbour. This can result in the reporting of a negative loading; it would indicate the industry removed more of the contaminant than they returned to the Harbour through their effluent stream. This approach recognizes that water withdrawn from the Harbour by the mills for steel making may be the cause of contaminants measured in the effluents they discharge. Very small positive and negative values can also be simply caused by analytical error in the measurement process, especially if the concentrations are close to the method detection limit. ArcelorMittal Dofasco and Stelco provided the RAP Office with annual net daily average loadings for 1996-2016, including iron and phosphorus, which they measure at the request of the RAP.

Net loadings are calculated from measurements at a number of sampling points. The effluent and intake sampling points used to calculate ArcelorMittal Dofasco and Stelco's contaminant loadings are listed in Tables 17 and 18, respectively. Tables 19 and 20 summarize the net daily loadings data reported by ArcelorMittal Dofasco and Stelco for 1996-2016.

Seasonal loadings and error estimates could not be calculated for the Steel Mills as only annual data could be provided.

Table 17. ArcelorMittal Dofasco effluent and intake sampling points.

MISA Control Point	Location	Description
0100	East Boat Slip Sewer	Cooling Water Effluent
0200	Ottawa Street Slip	Mixture of Dofasco and City of Hamilton discharges
0300	#1 Boiler House	Cooling Water Effluent
0400	West Bayfront Sewer	Merged Effluent
0600	Primary Wastewater Treatment Plant	Process Effluent
0800	Blast Furnace Recycle Blowdown	Process Effluent
1101	#1 Acid Regeneration Plant	Process Effluent
1200	#2 Boiler House	Cooling Water Effluent
1700	#2 Hot Mill & Melt Shop Sewer	Cooling Water Effluent
2000	#2 Hot Mill Plant Blowdown	Process Effluent
2500	Electric Arc Furnace Cooling Water	Cooling Water Effluent
2700	#6 Pickle Line Cooling Water Discharge	Cooling Water
2800	#2 Tandem Cooling Water Discharge	Cooling Water
0500	North End of property between boatslip and Ottawa Street Slip	Baywater Intake

Table 18. Stelco effluent and intake sampling points.

MISA Control Point	Location	Description
0100	West Side Open Cut	Cooling Water Effluent
0200	Northwest Outfall	Cooling Water Effluent
0400	North Outfall	Merged Effluent
0601	East Side Filter Plant	Process Effluent
0602	#1 60 Inch Sewer	Cooling Water Effluent
1100[1]	#2 Rod Mill	Process Effluent
1600	# 2 Bayshore Pumphouse	Intake

[1] Control Point 1100 discontinued with shut down of #2 Rod Mill (~ 2007)

Table 19. Annual net daily average contaminant loadings (kg/day) to Hamilton Harbour from ArcelorMittal Dofasco (AMD) and Stelco.

	Total Phosphorus (kg/day)		**Total Suspended Solids** (kg/day)		**Total Ammonia** (kg/day)		**Total Nitrate** (kg/day)		**TKN** (kg/day)		**Iron** (kg/day)		**Lead** (kg/day)		**Zinc** (kg/day)	
Year	**AMD**	**Stelco**	**AMD**	**Stelco**	**AMD**	**Stelco**	**AMD**	**Stelco**	**AMD**	**Stelco**	**AMD**	**Stelco**	**AMD**	**Stelco**	**AMD**	**Stelco**
1996	9.8	36.2	1626	6820	356	75.7	no data	no data	no data	no data	540	no data	-0.20	3.60	27.1	29.7
1997	-0.9	9.0	2191	2658	333	-10.8	no data	no data	no data	no data	371	no data	0.82	-0.97	11.1	3.4
1998	10.0	18.2	890	4175	155	-13.3	no data	no data	no data	no data	70	134.0	0.12	0.22	4.0	4.5
1999	-7.0	7.6	1168	849	152	-36.4	no data	no data	no data	no data	96	87.0	0.07	0.03	5.1	-1.5
2000	2.9	0.7	1069	314	94	-27.3	no data	no data	no data	no data	119	16.7	0.42	0.43	7.8	4.0
2001	-8.1	-3.4	812	293	54	3.6	no data	no data	no data	no data	86	2.0	0.19	-0.34	11.4	6.2
2002	-9.0	-6.5	823	-1228	34	-28.6	no data	no data	no data	no data	61	-20.4	0.42	0.20	11.0	5.3
2003	8.0	-3.5	840	-605	-118	-64.0	no data	no data	no data	no data	79	23.8	0.63	-0.01	27.0	0.2
2004	20.0	2.2	1187	-532	53	-16.9	no data	no data	no data	no data	201	78.6	0.59	0.01	9.0	6.1
2005	14.0	3.0	1857	765	46	12.5	no data	no data	no data	no data	200	138.0	1.60	0.12	8.7	18.8
2006	-12.6	6.0	1135	-25	89	28.9	no data	no data	no data	no data	7	93.2	1.50	0.06	6.5	1.3
2007	8.7	3.5	1648	-734	202	31.2	no data	no data	no data	no data	581	89.6	4.01	0.02	14.2	3.3
2008	-15.2	2.5	1521	-233	116	121.9	no data	no data	no data	no data	60	22.4	0.81	0.16	7.8	1.1
2009	-8.1	2.9	1021	246	77	-4.0	no data	no data	no data	no data	75	6.4	0.57	0.00	6.7	0.3
2010	4.0	1.5	1229	-44	99	57.8	no data	no data	no data	no data	90	5.4	1.30	-0.11	5.6	0.5
2011	6.8	1.1	2519	462	239	12.4	no data	no data	no data	no data	121	7.4	0.94	-0.04	10.6	-0.4
2012	11.2	1.5	2563	450	170	-19.5	no data	no data	no data	no data	100	7.8	0.53	-0.03	6.0	0.2
2013	4.1	1.7	1895	245	160	-7.9	no data	no data	no data	no data	74	4.5	1.84	0.00	9.9	-0.2
2014	9.2	1.5	2122	-8	140	-6.3	no data	no data	no data	no data	107	0.7	2.03	-0.01	17.4	-0.1
2015	8.9	0.5	1658	108	79	-5.7	no data	no data	no data	no data	99	1.6	1.46	-0.01	7.7	-0.1
2016	3.9	0.3	1584	101	117	-5.0	no data	no data	no data	no data	60	3.0	0.91	-0.01	6.4	-0.4

Note: As this is net data not gross, values can be reported as a negative value.
Note that error is not shown for the Steel Mills because annual data are supplied

Table 20. Annual net daily average contaminant loadings (kg/day) to Hamilton Harbour from ArcelorMittal Dofasco (AMD) and Stelco.

	Cyanide (kg/day)		**Phenolics** (kg/day)		**PAH Benzo(a)pyrene** (kg/day)		**PAH Napthalene** (kg/day)	
Year	**AMD**	**Stelco**	**AMD**	**Stelco**	**AMD**	**Stelco**	**AMD**	**Stelco**
1996	23.1	8.0	8.40	5.97	0.1000	0.0019	0.1900	-0.0136
1997	3.3	7.1	2.20	4.05	0.0000	-0.0044	-0.0020	0.0016
1998	0.1	12.1	0.78	0.32	0.0000	0.0059	-0.0120	-0.0561
1999	6.4	15.4	1.40	1.42	0.0000	-0.0213	0.0240	-0.0264
2000	5.1	12.8	1.60	-0.21	-0.0020	-0.0714	-0.0003	-0.0002
2001	7.6	6.7	1.40	1.02	0.0000	0.0056	0.0000	-0.0012
2002	0.7	0.8	1.10	-0.26	0.0000	0.0154	0.0000	-0.1410
2003	0.2	1.0	0.39	0.10	-0.0070	0.0058	-0.0070	-0.0293
2004	-2.7	2.6	0.90	1.31	0.0110	-0.0072	0.0010	0.0496
2005	0.5	1.0	1.10	0.09	0.0000	-0.0023	0.0000	0.0535
2006	0.8	1.6	2.40	-0.01	-0.0030	-0.0069	-0.0200	-0.0105
2007	1.1	1.2	0.89	-0.01	-0.0007	0.0409	-0.0060	-0.0028
2008	-0.2	1.4	0.84	-0.04	0.0840	-0.0023	0.0040	-0.0002
2009	0.2	0.2	0.81	0.01	0.0060	-0.0003	0.0000	0.0080
2010	1.0	5.1	1.28	0.05	0.0060	0.0027	0.0160	0.0005
2011	0.9	0.1	1.53	0.08	0.0090	-0.0003	0.0010	0.0039
2012	0.0	-0.4	0.37	-0.64	0.0140	0.0000	0.0130	-0.0002
2013	0.9	-0.1	0.20	-0.08	0.0100	0.0006	0.0000	-0.0050
2014	0.6	-0.1	1.80	-0.01	0.0020	0.0001	0.0250	0.0012
2015	0.4	-0.1	1.17	0.00	0.0020	-0.0002	0.0000	0.0088
2016	0.4	0.0	0.54	-0.01	0.0000	0.0002	0.0000	0.0089

Note: As this is net data not gross, values can be reported as a negative value.
Note that error is not shown for the Steel Mills because annual data are supplied

6.3 Combined Sewer Overflows (CSO)

Combined sewers in Hamilton convey both sanitary sewage and storm runoff. This is typical of older communities. As the City of Burlington has only separated sewers, there are no CSO inputs to Hamilton Harbour from their community. Originally, during rainfall events, Hamilton's 23 CSOs discharge this mixed, untreated effluent into the natural environment, either a creek or directly into the Harbour. The City of Hamilton embarked on a combined sewer overflow control program, starting with the construction of its first CSO tank at Greenhill Ave (at Rosedale Park) in 1988. Since that time, a total of eight CSO tanks have been put into service. Each of these tanks allow the untreated sewer overflow to be held during a storm event and sent to the Woodward WWTP once the plant can deal with the flows. Overflows are still possible, even in tanked locations. If the combined sewer system was ever closed off from overflows, backups into homes and businesses might occur during larger storm events. The following five paragraphs describe how CSO loadings are estimated from personal communications with Bert Posedowski, City of Hamilton.

> At present, the combined sewer systems functions with eight controlled sewer overflows (overflows with CSO tanks) and 15 uncontrolled overflows. To produce data for the HHRAP loadings report the following general process is followed.
>
> For controlled CSO locations, discharge flows and effluent quality data is measured for each wet weather event. For each location and for each reported pollutant parameter, an average parameter concentration is calculated based upon up to five years of most recent water quality data. The annual loadings at each of these outfall locations is calculated as the product of measured effluent flow volume by the average parameter concentration at that location.
>
> For uncontrolled CSO locations, the City relies on estimated flow data generated using a MIKE URBAN hydraulic computer model of the sewer collection system. Detailed rainfall data and dry weather sewer flow data is input into the model and the model provides data on overflow frequency, duration and volume at each outfall. The model provides data for the period from April 15 to November 14. Outfall flow data for the whole year is then calculated based on the April – November flow data, pro-rated based on rainfall volume between April to November and rainfall volume for the entire year.
>
> Uncontrolled CSO locations are not continuously monitored for CSO flow volume or pollutant contaminants. The City has undertaken a number of CSO characterization studies at uncontrolled CSO locations. Each study focuses on the collection of flow and pollutant loading data at a number (approximately 5 locations per study) of uncontrolled CSO locations. The City's intention is to continue to undertake CSO characterization studies on an ongoing basis with the goal of obtaining flow and pollutant concentration data at all the uncontrolled CSO sites.
>
> To estimate the annual pollutant loadings at each uncontrolled CSO location, the City multiplies the average pollutant concentration (obtained from characterization studies) with the annual flow estimated by the MIKE URBAN model.

Using the new models and monitoring program described above, the City of Hamilton provided: average measured CSO contaminant concentrations, estimated or measured CSO volumes, and daily loadings. Equation 1 shows how contaminant loadings are estimated for each CSO and Table 21 summarizes CSO annual volumes.

$$L(x) = C(x) * V * 1 \text{ yr}/365 \text{ days} * 1000 \text{ L}/1 \text{ m}^3 * 1 \text{ kg}/1000000 \text{ mg} \quad \textbf{(Equation 1)}$$

where:

L(x) = contaminant loadings, kg/day
C(x) = contaminant concentration, mg/L
V = CSO annual volume, m^3/yr

Table 21. Estimated Hamilton Harbour and Cootes Paradise Total CSO volumes (m^3/yr).

Year	Rainfall Volume[1,2] mm/yr	Hamilton Harbour CSO Volume[1,4] millions of m^3/yr	Cootes Paradise CSO Volume[1,4] million of m^3/yr
1996	931.1	13.76	1.81
1997	532.3	7.38	1.04
1998 [3]	560.3	7.04	0.29
1999	624.4	8.33	0.40
2000	776.1	9.84	0.26
2001	974.2	11.78	0.47
2002	790.7	10.15	0.34
2003	902.5	7.16	0.14
2004	951.8	4.38	0.58
2005	992.9	12.56	0.90
2006	1033.3	5.88	0.50
2007	702.2	1.26	0.03
2008	1107.9	n/a	n/a
2009	1097.0	n/a	n/a
2010	971.2	n/a	n/a
2011	910.1	n/a	n/a
2012	773.0	n/a	n/a
2013	952.8	1.35	0.01
2014	559.8	2.89	0.09
2015	918.2	2.41	0.07
2016	646.4	1.09	0.02

n/a = data not available

[1] 1996-2007 values provided by the City from the combined sewer system simulations only cover the period April 1 to October 31 of each year (models were run according to OMOE F-5-5 Wet Weather criteria). Values have been increased by a factor of 365/214 to account for the whole year for the purposes of this report.

[2] 2003-2010 yearly rainfall volume obtained from Canadian Daily Climate Data Station 6153194 YHM (Hamilton Airport); however, in 2011 the Station had 5+ months of missing data so Station 6153301 XHM data was substituted (Royal Botanical Gardens). From 2012 onwards, data from Station 6153193 YHM was used (Hamilton Airport). (http://www.climate.weatheroffice.ec.gc.ca)

[3] Main-King and Eastwood Park CSO Tanks began operation in 1998.

[4] 2013-2016 CSO volumes are actual measurements using the City's SCADA system or simulated for the period April 15 to November 14 of each year. In the latter case, CSO volumes were extrapolated using the ratio of the rainfall volume recorded for Jan 1 to Dec 31 over the rainfall recorded from Apr 15 to Nov 14.

Contaminant loadings are then summed for those CSOs releasing directly to Hamilton Harbour plus those below the Red Hill Creek sampling site. Red Hill Creek loading estimates already integrate overflows from three upstream CSOs: Superpipe, Melvin, and Greenhill (see section **6.4 Creeks (+ CSOs)**), and are not included in the calculations here. Likewise, Cootes Paradise Tributaries (primarily Chedoke, Westdale, and Ancaster

Creeks) intercept all but one CSO releasing to the marsh. The Dundas Equalization Tank is the only CSO that would release directly to Cootes Paradise, but it had zero overflows in 2013-2016. Total loadings can be found in Table 22.

Seasonal loadings and error could not be estimated for the CSOs as only annual data are provided.

Table 22. Estimated annual Hamilton Harbour and Cootes Paradise CSO contaminant loadings (kg/day).

Year	Hamilton Harbour Loadings								Cootes Paradise Loadings							
	Daily Average Load (kg/d)								Daily Average Load (kg/d)							
	TP	TSS	Total Ammonia	Total Nitrate	TKN	Iron	Lead	Zinc	TP	TSS	Total Ammonia	Total Nitrate	TKN	Iron	Lead	Zinc
1996	80	4182	204	no data	388	174	1.0	5.7	10.6	551	26.8	no data	51	23	0.1	0.7
1997	43	2242	109	no data	208	93	0.5	3.0	6.0	315	15.3	no data	29	13	0.1	0.4
1998	41	2139	104	no data	199	89	0.5	2.9	1.7	89	4.3	no data	8	4	0.0	0.1
1999	49	2530	123	no data	235	105	0.6	3.4	2.3	121	5.9	no data	11	5	0.0	0.2
2000	57	2990	146	no data	278	125	0.7	4.0	1.5	79	3.8	no data	7	3	0.0	0.1
2001	69	3580	174	no data	332	149	0.9	4.8	2.7	142	6.9	no data	13	6	0.0	0.2
2002	59	3085	150	no data	287	129	0.8	4.2	2.0	105	5.1	no data	10	4	0.0	0.1
2003	71	3710	181	no data	345	155	0.9	5.0	1.4	74	3.6	no data	7	3	0.0	1.0
2004	44	2268	110	no data	211	95	0.6	3.1	5.8	301	14.6	no data	28	13	0.1	0.4
2005	125.	6507	317	no data	604	271	1.6	8.8	8.9	466	22.7	no data	43	19	0.1	0.6
2006	58.	3045	148	no data	283	127	0.7	4.1	5.0	260	12.7	no data	24	11	0.1	0.4
2007	13.	655	32	no data	61	27	0.2	0.9	0.3	14	0.7	no data	1	0.6	0.0	0.0
2008	n/a	n/a	n/a	no data	n/a	n/a	n/a	n/a	n/a	n/a	n/a	no data	n/a	n/a	n/a	n/a
2009	n/a	n/a	n/a	no data	n/a	n/a	n/a	n/a	n/a	n/a	n/a	no data	n/a	n/a	n/a	n/a
2010	n/a	n/a	n/a	no data	n/a	n/a	n/a	n/a	n/a	n/a	n/a	no data	n/a	n/a	n/a	n/a
2011	n/a	n/a	n/a	no data	n/a	n/a	n/a	n/a	n/a	n/a	n/a	no data	n/a	n/a	n/a	n/a
2012	n/a	n/a	n/a	no data	n/a	n/a	n/a	n/a	n/a	n/a	n/a	no data	n/a	n/a	n/a	n/a
2013	13.9	2129	6.2	no data	n/a	n/a	n/a	n/a	0.0	0	0.0	no data	n/a	n/a	n/a	n/a
2014	11.4	1372	3.3	no data	n/a	n/a	n/a	n/a	0.0	0	0.0	no data	n/a	n/a	n/a	n/a
2015	9.2	658	20.6	no data	n/a	n/a	n/a	n/a	0.0	0	0.0	no data	n/a	n/a	n/a	n/a
2016	2.5	215	3.6	no data	n/a	n/a	n/a	n/a	0.0	0	0.0	no data	n/a	n/a	n/a	n/a

n/a = data not available.
Note that error is not shown because data are supplied as yearly averages.

6.4 Creeks (+ Combined Sewer Overflows)

As it would be impractical to attempt to monitor every creek that enters Hamilton Harbour, the largest creeks are used to calculate contaminant loadings estimates. Grindstone Creek, Indian Creek (a new addition to the report), and Red Hill Creek discharge into Hamilton Harbour. In this update, the creek loadings to Cootes Paradise were calculated in totality (including Spencer, Borer, Chedoke, and Ancaster Creeks) and are hereafter referred to as Cootes Paradise tributary loadings.

Due to a perceived large margin of error in the former methods used to estimate contaminant loadings from the creeks (the Draper Method, Draper et al. 1993), an event-based monitoring program was undertaken in 2010-2012 to reduce uncertainty (Long et al. 2014). From this, a series of regression equations were developed to estimate Total Phosphorus (TP) loadings from each of the creeks using minimal data input (Long et al. 2015). This work on estimation of TP loads based on the 2010-2012 sampling was later expanded to include estimates for Total Suspended Solids (TSS), all nutrients, and metals (Tables 23 and 24; Appendix B, Boyd 2017).

Aside from the regression equations, input required for creek calculations include:

(1) Daily average flow from Water Survey of Canada HYDAT Flow stations 02HB012 (Grindstone Creek) and 02HA014 (Red Hill Creek)

(2) Dundas Waste Water Treatment Plant daily contaminant loadings (Section 6.1)

(3) Cootes Paradise daily contaminant loadings to the Harbour (Section 6.6)

In very simple terms, contaminant loadings increase with flow, but this relationship is specific to each contaminant and waterbody, and in some cases, is influenced by season or potential CSO overflows. There were instances where contaminants exhibited a poor relationship with flow. This was true for TKN at Grindstone Creek and TKN and Zn at Indian Creek mainly due to the irregularity of having high concentrations during low flow or dry weather (Boyd 2017). In the case of Indian Creek, the best alternative to a poor regression was using flow-weighted means to estimate loads. Likewise, this method was also the best alternative for approximating Total Ammonia and Total Nitrate loadings across waterbodies. A detailed summary and comparison of methods can be found in Boyd (2017) (Appendix B). Total loadings from the creeks can be found in Tables 25-32.

Regressions are based on having event-based, composite samples, but no such information was available for the creeks releasing to Cootes Paradise Marsh at the time of publication. The only tangible method of estimating creek loadings to the marsh was to subtract Dundas WWTP monthly average contaminant loadings (see Section **6.1 Waste Water Treatment Plants**) from that of Cootes Paradise (see Section **6.6 Cootes Paradise**) and hence a "total" tributary load is approximated for the marsh (Tables 25-32). The disadvantage of this method is that it fails to isolate processes occurring within the marsh that could contribute to loadings, but is an improvement on previous methods that were criticized for using an arbitrary factor of 1.44 to account for flows from Borer, Chedoke, and Ancaster Creeks, which are not monitored by the Water Survey of Canada. Future reports will benefit from Hamilton Conservation Authority's event-based sampling at Spencer Creek (a major tributary of Cootes Paradise), the data of which could be used to develop more accurate localized regressions and will eliminate the need to subtract WWTP loads from Cootes Paradise loads.

As decided by the Technical Team, this update will not separate the contributions of urban runoff and creeks. The inaccuracy of this method is clear as many of the creek loadings became negative numbers. As such, this approach has been discontinued. Instead, the total contaminant loading from each creek is shown in the graphs and tables, for the current years (2008-2016) and in retrospect. Note that total loadings values may be slightly off from those reported in previous updates due to the elimination of a calculation and its associated rounding error. The discrepancy between updates is especially noticeable for years 2003-2007 in which no creek data were given, but urban runoff was. Creek data are now shown for this time period (where available).

In many cases, overflow from CSOs is intercepted by creeks. The discharge from CSOs located above a creek sampling site (Long et al. 2014) will inherently be integrated into the creek loading estimates. This is true of Red Hill Creek. It integrates the loadings from the upstream Superpipe, Melvin, and Greenhill CSOs. Similarly, Cootes Paradise tributaries intercept four of five CSOs releasing to the marsh so that nearly all CSO contributions are integrated into the Cootes Paradise tributary loadings. The Dundas Equalization Tank is the only CSO that would release directly to Cootes Paradise, but it had zero overflows in 2013-2016.

Comments:

It should be noted that the regressions were developed for the years 2010-2012 and were extrapolated for 2008-2016 on the basis that no large watershed changes have occurred in the latter timeframe. If changes were to occur that alter the flow-contaminant relationships (e.g., widespread implementation of Low-Impact Development, elimination of combined sewer overflows to Cootes Paradise and to Red Hill Creek), then it would be best to repeat the event-based sampling and develop new equations to better reflect the new flow-contaminant relationships.

The distribution of flow events (and in turn, distribution of creek loadings) is highly skewed (i.e., not a normal distribution). When working with skewed (or non-normal) data, the median is a better indication of typical daily load than the mean (average); however, to be consistent with the rest of the report and historical data, the mean value is shown (and used in the totals graphs). The mean of non-normal data can be misleading because it does not represent a typical daily number – most daily loads are much lower than the daily mean and the high flow event loads are much higher. A comparison of medians and means for TP and TSS can be found in the seasonal box-and-whisker plots (Figures 10-17).

Table 23. Summary of calculation methods for estimating creek daily contaminant loadings to Hamilton Harbour and Cootes Paradise. Adapted from Boyd (2017) (Appendix B).

Contaminant	Grindstone Creek	Indian Creek	Red Hill Creek(+CSO)	Cootes Paradise Tributaries(+CSO)
Total Phosphorus	Method 2	Method 1	Method 1	Method 3
Total Suspended Solids	Method 2	Method 1	Method 1	Method 3
Total Ammonia	Method 4	Method 4	Method 4	Method 3
Total Nitrate	Method 4	Method 4	Method 4	Method 3
Total Kjeldahl Nitrogen	Method 2	Method 4	Method 1	Method 3
Iron	Method 2	Method 1	Method 1	Method 3
Lead	Method 2	Method 1	Method 1	Method 3
Zinc	Method 2	Method 4	Method 1	Method 3

Method 1	1. Estimate daily [contaminant] from log [contaminant] vs. log flow regression derived from MOECC 2010 to 2012 data 2. Multiply daily [contaminant] by daily flow to yield daily contaminant load Note: Indian Creek Flow =0.7324 (Red Hill Creek Flow (m^3/s)) $^{0.8278}$ 3. Apply Ferguson correction to adjust for bias from log-log regression. Corrected Load = Calculated Load EXP (2.651 x Standard Error^2)
Method 2	1. Partition data by season; June through October (summer) and November through May (winter) 2. Estimate seasonal daily [contaminant] from seasonal log [contaminant] vs. log flow regression derived from MOECC 2010 to 2012 data 3. Multiply daily [contaminant] by daily flow to yield daily contaminant load 4. Apply Ferguson correction to adjust for bias from log-log regression. Corrected Load = Calculated Load EXP (2.651 x Standard Error^2)
Method 3	1. Subtract the monthly average Dundas WWTP load from that of Cootes Paradise to yield monthly contaminant load (see Sections 6.1 Waste Water Treatment Plants and 6.6 Cootes Paradise for load calculations, respectively)
Method 4	1. Partition data by season; June through October (summer) and November through May (winter) Note: Indian Creek Flow =0.7324 (Red Hill Creek Flow (m^3/s)) $^{0.8278}$ 2. Multiply daily creek flow by the seasonal flow-weighted mean derived from MOECC 2010 to 2012 data to yield daily contaminant load. Note: Indian Creek TKN and Zn use yearly flow-weighted means.

Table 24. Summary of contaminant-average daily flow (ADF) log-log regression equations, as well as winter (W) and summer (S) flow-weighted mean (FWM) concentrations used to estimate creek contaminant loadings to Hamilton Harbour. The standard error of the mean is provided in brackets. Cootes Paradise Tributaries are not shown because the method was based on subtraction, not regression.

Contaminant	Grindstone Creek	Indian Creek	Red Hill Creek (+CSO)
Total Phosphorus	W: log[TP] = (0.93(log ADF))+1.74 (± 0.2825) S: log[TP] = (0.58(log ADF))+2.35 (± 0.2027)	log[TP] = (0.50(log ADF))+2.05 (± 0.1823)	log[TP] = (0.69(log ADF))+1.95 (± 0.2404)
Total Suspended Solids	W: log[TSS] = (1.3296(log ADF))+1.2369 (± 0.3479) S: log[TSS] = (0.7676(log ADF))+1.9265 (± 0.3797)	log[TSS] = (0.7631(log ADF))+1.6291 (± 0.2767)	log[TSS] = (0.9721(log ADF))+1.47 (± 0.3366)
Total Ammonia	W: FWM = 63 ug/l (± 24) S: FWM = 37ug/l (± 20)	W: FWM = 138 ug/l (± 42) S: FWM = 65 ug/l (± 26)	W: FWM = 295 ug/l (± 155) S: FWM = 193 ug/l (± 122)
Total Nitrate	W: FWM = 0.947 mg/l (± 0.174) S: FWM = 1.843mg/l (± 0.904)	W: FWM = 0.978 mg/l (± 0.195) S: FWM = 1.089mg/l (± 0.409)	W: FWM = 1.231 mg/l (± 0.456) S: FWM = 1.166 mg/l (± 0.891)
Total Kjeldahl Nitrogen	W: log[TKN] = (0.1923(log ADF))-0.1046 (± 0.1275) S: log[TKN] = (0.2765(log ADF))+0.034 (± 0.0989)	FWM = 0.972 mg/l (± 0.098)	log[TKN] = (0.316(log ADF))-0.1414 (± 0.157)
Iron	W: log[Fe] = (0.6815(log ADF))+2.456 (± 0.2083) S: log[Fe] = (0.6629(log ADF))+2.8562 (± 0.2036)	log[Fe] = (0.5806(log ADF))+2.5848 (± 0.2084)	log[Fe] = (0.7819(log ADF))+2.4474 (± 0.2682)
Lead	W: log[Pb] = (0.8789(log ADF))-0.0782 (± 0.2720) S: log[Pb] = (.6719(log ADF))+0.4952 (± 0.2926)	log[Pb] = (0.5589(log ADF))+0.4115 (± 0.2487)	log[Pb] = (0.7794(log ADF))+0.2872 (± 0.2932)
Zinc	W: log[Zn] = (0.6215(log ADF))+(log 0.8841) (± 0.1742) S: log[Zn] = (0.5621(log ADF))+(log 1.2238) (± 0.2625)	FWM = 102 ug/l (±21)	log[Zn] = (0.5711(log ADF))+1.4904 (± 0.2244)

Table 25. Total Phosphorus loadings (kg/day) from Cootes Paradise tributaries (+CSO) and Hamilton Harbour creeks (Grindstone, Indian, and Red Hill Creeks (+CSO)).

Total Phosphorus																
	Cootes Paradise Tribs (+CSO)				Grindstone Creek[2]				Indian Creek[1,3]				Red Hill Creek (+CSO)[1,3]			
Year	Daily Average Load (kg/d)	n	SE	95% CI	Daily Average Load (kg/d)	n	SE	95% CI	Daily Average Load (kg/d)	n	SE	95% CI	Daily Average Load (kg/d)	n	SE	95% CI
1996	57.2	Due to changes/improvements in calculation methods, error could only be estimated for years 2008-2016			30.2	Due to changes/improvements in calculation methods, error could only be estimated for years 2008-2016			no data	Due to changes/improvements in calculation methods, error could only be estimated for years 2008-2016			36.5	Due to changes/improvements in calculation methods, error could only be estimated for years 2008-2016		
1997	39.8				20.6				no data				17.2			
1998	28.8				17.7				no data				23.2			
1999	11.9				3.7				no data				16.6			
2000	33.0				19.2				no data				26.3			
2001	23.7				9.2				no data				21.3			
2002	17.6				7.2				no data				11.4			
2003	32.4				11.9				no data				no data			
2004	32.4				11.6				no data				no data			
2005	41.6				16.6				no data				no data			
2006	43.0				20.8				no data				no data			
2007	24.3				no data				no data				no data			
2008	63.7	12	17.3	33.9	33.4	335	5.8	11.4	no data	—	—	—	no data	—	—	—
2009	50.4	12	12.3	24.2	17.2	365	4.8	9.4	7.9	365	1.7	3.4	25.8	365	9.4	18.4
2010	41.5	12	17.5	34.2	22.2	365	9.9	19.4	6.9	365	1.5	2.9	21.7	365	7.4	14.6
2011	49.0	12	15.3	30.0	19.5	365	2.7	5.3	8.6	365	1.2	2.3	23.0	365	4.6	9.1
2012	16.3	12	3.2	6.3	3.2	366	0.3	0.7	3.5	365	0.5	0.9	6.5	365	1.5	2.9
2013	44.4	12	9.3	18.3	14.1	365	2.7	5.4	6.7	365	1.3	2.5	18.6	365	6.5	12.7
2014	38.4	12	13.0	25.5	17.6	365	3.2	6.3	4.9	365	0.6	1.2	10.2	365	1.8	3.5
2015	19.4	12	5.5	10.8	5.0	365	0.9	1.7	4.5	253	0.8	1.6	10.4	253	2.8	5.4
2016	25.9	12	10.5	20.7	7.3	366	1.4	2.7	no data	—	—	—	no data	—	—	—

n = sample size, SE = standard error of the mean, and 95% CI = 95% confidence interval

[1] No data available for 2003-2007 and 2016 as flow equipment was removed during construction in the area.
[2] No data available in 2007 due to vandalized equipment and follow-up repairs.
[3] 2015 data includes January 1 – September 15 only.

Table 26. Total Suspended Solids loadings (kg/day) from Cootes Paradise tributaries (+CSOs) and Hamilton Harbour creeks (Grindstone, Indian, and Red Hill Creeks (+CSOs)).

Total Suspended Solids																
Year	Cootes Paradise Tribs (+CSO)				Grindstone Creek[2]				Indian Creek[1,3]				Red Hill Creek (+CSO)[1,3]			
	Daily Average Load (kg/d)	n	SE	95% CI	Daily Average Load (kg/d)	n	SE	95% CI	Daily Average Load (kg/d)	n	SE	95% CI	Daily Average Load (kg/d)	n	SE	95% CI
1996	20716	Due to changes/improvements in calculation methods, error could only be estimated for years 2008-2016			12355	Due to changes/improvements in calculation methods, error could only be estimated for years 2008-2016			no data	Due to changes/improvements in calculation methods, error could only be estimated for years 2008-2016			20187	Due to changes/improvements in calculation methods, error could only be estimated for years 2008-2016		
1997	14852				8637				no data				7540			
1998	10940				7769				no data				12607			
1999	2872				854				no data				8012			
2000	11460				7576				no data				14147			
2001	6903				3038				no data				9913			
2002	4658				2403				no data				4216			
2003	11534				4870				no data				no data			
2004	11474				4308				no data				no data			
2005	15974				6844				no data				no data			
2006	14354				8167				no data				no data			
2007	8269				no data				no data				no data			
2008	27310	12	9539	18697	23598	335	5300	10387	no data	—	—	—	no data	—	—	—
2009	20872	12	6670	13072	12201	365	5082	9961	4535	365	1318	2583	20300	365	9115	17866
2010	18421	12	10458	20498	21097	365	12447	24395	3913	365	1088	2132	16448	365	6823	13373
2011	19257	12	7134	13982	11817	365	2024	3966	4567	365	762	1494	14963	365	3672	7197
2012	6098	12	1213	2377	1324	366	167	327	1548	366	273	536	3420	365	999	1959
2013	16758	12	4414	8652	9036	365	2290	4488	3578	365	935	1833	13104	365	6060	11877
2014	14167	12	5969	11699	11316	365	2376	4658	2305	365	341	669	5586	365	1132	2219
2015	6811	12	2187	4286	2552	365	544	1066	2224	253	500	981	6127	253	1905	3734
2016	10359	12	4806	9420	4119	366	1048	2055	no data	—	—	—	no data	—	—	—

n = sample size, SE = standard error of the mean, and 95% CI = 95% confidence interval

[1] No data available for 2003-2007 and 2016 as flow equipment was removed during construction in the area.
[2] No data available in 2007 due to vandalized equipment and follow-up repairs.
[3] 2015 data includes January 1 – September 15 only.

Table 27. Total Ammonia loadings (kg/day) from Cootes Paradise tributaries (+CSO) and Hamilton Harbour creeks (Grindstone, Indian, and Red Hill Creeks (+CSO)).

Total Ammonia																
Year	Cootes Paradise Tribs (+CSO)				Grindstone Creek[2]				Indian Creek[1,3]				Red Hill Creek (+CSO)[1,3]			
	Daily Average Load (kg/d)	n	SE	95% CI	Daily Average Load (kg/d)	n	SE	95% CI	Daily Average Load (kg/d)	n	SE	95% CI	Daily Average Load (kg/d)	n	SE	95% CI
1996	no data	Due to changes/improvements in calculation methods, error could only be estimated for years 2008-2016			no data	Due to changes/improvements in calculation methods, error could only be estimated for years 2008-2016			no data	Due to changes/improvements in calculation methods, error could only be estimated for years 2008-2016			no data	Due to changes/improvements in calculation methods, error could only be estimated for years 2008-2016		
1997	no data				no data				no data				no data			
1998	no data				no data				no data				no data			
1999	no data				no data				no data				no data			
2000	no data				no data				no data				no data			
2001	no data				no data				no data				no data			
2002	no data				no data				no data				no data			
2003	no data				no data				no data				no data			
2004	no data				no data				no data				no data			
2005	no data				no data				no data				no data			
2006	no data				no data				no data				no data			
2007	no data				no data				no data				no data			
2008	71.4	12	20.6	40.4	6.4	335	0.5	1.0	no data	—	—	—	no data	—	—	—
2009	60.9	12	17.6	34.4	4.8	365	0.4	0.8	5.3	365	0.5	1.0	19.2	365	2.5	5.0
2010	56.1	12	16.2	31.8	3.7	365	0.5	1.0	4.6	365	0.5	1.0	16.6	365	2.5	4.9
2011	73.5	12	21.2	41.6	5.5	365	0.4	0.8	6.5	365	0.6	1.1	23.1	365	2.4	4.6
2012	39.1	12	11.3	22.2	2.3	366	0.2	0.3	3.5	366	0.2	0.4	10.9	366	0.9	1.7
2013	54.8	12	16.9	33.0	4.4	365	0.4	0.7	5.4	365	0.5	1.0	18.6	365	2.4	4.8
2014	66.5	12	19.2	37.6	4.4	365	0.4	0.8	4.7	365	0.4	0.7	15.1	365	1.4	2.8
2015	39.0	12	11.2	22.0	2.1	365	0.2	0.4	3.9	253	0.4	0.8	12.8	253	1.7	3.3
2016	62.5	12	18.0	35.4	3.1	366	0.3	0.6	no data	—	—	—	no data	—	—	—

n = sample size, SE = standard error of the mean, and 95% CI = 95% confidence interval

[1] No data available for 2003-2007 and 2016 as flow equipment was removed during construction in the area.
[2] No data available in 2007 due to vandalized equipment and follow-up repairs.
[3] 2015 data includes January 1 – September 15 only.

Table 28. Total Nitrate loadings (kg/day) from Cootes Paradise tributaries (+CSO) and Hamilton Harbour creeks (Grindstone, Indian, and Red Hill Creeks (+CSO)).

Total Nitrate																
Year	Cootes Paradise Tribs (+CSO)[4,5,6]				Grindstone Creek[2]				Indian Creek[1,3]				Red Hill Creek (+CSO)[1,3]			
	Daily Average Load (kg/d)	n	SE	95% CI	Daily Average Load (kg/d)	n	SE	95% CI	Daily Average Load (kg/d)	n	SE	95% CI	Daily Average Load (kg/d)	n	SE	95% CI
1996	no data	Due to changes/improvements in calculation methods, error could only be estimated for years 2008-2016			no data	Due to changes/improvements in calculation methods, error could only be estimated for years 2008-2016			no data	Due to changes/improvements in calculation methods, error could only be estimated for years 2008-2016			no data	Due to changes/improvements in calculation methods, error could only be estimated for years 2008-2016		
1997	no data				no data				no data				no data			
1998	no data				no data				no data				no data			
1999	no data				no data				no data				no data			
2000	no data				no data				no data				no data			
2001	no data				no data				no data				no data			
2002	no data				no data				no data				no data			
2003	no data				no data				no data				no data			
2004	no data				no data				no data				no data			
2005	no data				no data				no data				no data			
2006	no data				no data				no data				no data			
2007	no data				no data				no data				no data			
2008	245.2	1	—	—	135.0	335	9.7	19.1	no data	—	—	—	no data	—	—	—
2009	160.1	1	—	—	89.9	365	6.1	12.0	49.7	365	5.0	9.8	91.0	365	12.7	25.0
2010	66.7	1	—	—	75.6	365	8.1	16.0	44.2	365	4.6	8.9	80.0	365	11.6	22.8
2011	197.1	1	—	—	99.9	365	6.8	13.4	55.0	365	4.3	8.4	103.6	365	10.5	20.5
2012	-12.1	1	—	—	40.0	366	2.4	4.6	33.4	366	2.3	4.5	52.5	365	4.7	9.2
2013	140.8	1	—	—	79.4	365	5.5	10.7	47.5	365	3.9	7.6	84.8	365	10.3	20.1
2014	122.6	1	—	—	84.0	365	7.2	14.2	40.0	365	2.8	5.4	68.2	365	6.2	12.2
2015	27.8	1	—	—	41.6	365	3.5	6.9	36.3	253	3.7	7.2	61.0	253	8.0	15.7
2016	-4.1	1	—	—	50.5	366	4.2	8.2	no data	—	—	—	no data	—	—	—

n = sample size, SE = standard error of the mean, and 95% CI = 95% confidence interval

[1] No data available for 2003-2007 and 2016 as flow equipment was removed during construction in the area.
[2] No data available in 2007 due to vandalized equipment and follow-up repairs.
[3] 2015 data includes January 1 – September 15 only.
[4] Total Nitrate loadings for Cootes Paradise Tributaries had to be estimated on a yearly scale because many values were negative when calculated on a monthly basis (weekly grab samples at the Dundas WWTP may have overestimated monthly loads, compared to the daily estimates at the Desjardins Canal).
[5] Desjardins Canal Total Nitrate estimates were less than that of the Dundas WWTP, resulting in negative numbers in 2012 and 2016. These were dry years and Cootes Paradise may have acted as a sink for Total Nitrate.
[6] Total Nitrogen estimates are available for 1996-2007 (HHRAP 2010), but are not included here.

Table 29. Total Kjeldahl Nitrogen loadings (kg/day) from Cootes Paradise tributaries (+CSO) and Hamilton Harbour creeks (Grindstone, Indian, and Red Hill Creeks (+CSO)).

Total Kjeldahl Nitrogen																
Year	Cootes Paradise Tribs (+CSO)				Grindstone Creek[2]				Indian Creek[1,3]				Red Hill Creek (+CSO)[1,3]			
	Daily Average Load (kg/d)	n	SE	95% CI	Daily Average Load (kg/d)	n	SE	95% CI	Daily Average Load (kg/d)	n	SE	95% CI	Daily Average Load (kg/d)	n	SE	95% CI
1996	no data	Due to changes/improvements in calculation methods, error could only be estimated for years 2008-2016			no data	Due to changes/improvements in calculation methods, error could only be estimated for years 2008-2016			no data	Due to changes/improvements in calculation methods, error could only be estimated for years 2008-2016			no data	Due to changes/improvements in calculation methods, error could only be estimated for years 2008-2016		
1997	no data				no data				no data				no data			
1998	no data				no data				no data				no data			
1999	no data				no data				no data				no data			
2000	no data				no data				no data				no data			
2001	no data				no data				no data				no data			
2002	no data				no data				no data				no data			
2003	no data				no data				no data				no data			
2004	no data				no data				no data				no data			
2005	no data				no data				no data				no data			
2006	no data				no data				no data				no data			
2007	no data				no data				no data				no data			
2008	472.1	12	85.2	167.0	123.8	335	12.0	23.6	no data	—	—	—	no data	—	—	—
2009	385.6	12	68.1	133.5	78.4	365	8.3	16.3	47.3	365	4.6	9.1	89.1	365	21.6	42.2
2010	294.6	12	78.3	153.5	66.6	365	12.1	23.7	41.8	365	4.3	8.5	77.6	365	18.3	35.8
2011	383.8	12	94.2	184.6	93.6	365	7.8	15.3	53.1	365	4.2	8.2	94.9	365	13.8	27.1
2012	168.7	12	32.5	63.8	31.4	366	2.3	4.5	31.7	366	2.1	4.2	36.5	365	5.4	10.5
2013	355.8	12	59.8	117.3	70.0	365	7.0	13.8	45.5	365	3.8	7.5	74.4	365	15.7	30.7
2014	315.2	12	80.3	157.4	76.7	365	8.7	17.0	38.5	365	2.7	5.3	52.1	365	6.8	13.3
2015	180.8	12	40.5	79.3	32.5	365	3.6	7.0	34.5	253	3.4	6.7	48.9	253	9.6	18.9
2016	25.9	12	10.4	20.4	45.5	366	4.8	9.5	no data	—	—	—	no data	—	—	—

n = sample size, SE = standard error of the mean, and 95% CI = 95% confidence interval

[1] No data available for 2003-2007 and 2016 as flow equipment was removed during construction in the area.
[2] No data available in 2007 due to vandalized equipment and follow-up repairs.
[3] 2015 data includes January 1 – September 15 only.

Table 30. Iron loadings (kg/day) from Cootes Paradise tributaries (+CSO) and Hamilton Harbour creeks (Grindstone, Indian, and Red Hill Creeks (+CSO)).

Iron																
Year	Cootes Paradise Tribs (+CSO)[5]				Grindstone Creek[2,4]				Indian Creek[1,3]				Red Hill Creek (+CSO)[1,3]			
	Daily Average Load (kg/d)	n	SE	95% CI	Daily Average Load (kg/d)	n	SE	95% CI	Daily Average Load (kg/d)	n	SE	95% CI	Daily Average Load (kg/d)	n	SE	95% CI
1996	581.0	Due to changes/improvements in calculation methods, error could only be estimated for years 2008-2016			865.0	Due to changes/improvements in calculation methods, error could only be estimated for years 2008-2016			no data	Due to changes/improvements in calculation methods, error could only be estimated for years 2008-2016			284.0	Due to changes/improvements in calculation methods, error could only be estimated for years 2008-2016		
1997	428.0				605.0				no data				121.0			
1998	320.0				544.0				no data				179.0			
1999	43.0				60.0				no data				121.0			
2000	308.0				530.0				no data				202.0			
2001	150.0				213.0				no data				153.0			
2002	86.0				168.0				no data				74.0			
2003	318.0				341.0				no data				no data			
2004	315.0				302.0				no data				no data			
2005	472.0				479.0				no data				no data			
2006	370.0				572.0				no data				no data			
2007	218.0				no data				no data				no data			
2008	239.2	5	61.3	120.1	106.4	335	16.3	31.9	no data	—	—	—	no data	—	—	—
2009	211.6	12	50.4	98.8	54.2	365	11.4	22.3	30.0	365	7.2	14.1	105.6	365	41.7	81.7
2010	166.6	12	65.6	128.6	59.5	365	21.2	41.6	26.2	365	6.1	12.0	88.0	365	32.4	63.4
2011	205.8	12	61.1	119.8	67.0	365	8.6	16.8	32.1	365	4.6	9.1	88.7	365	19.2	37.5
2012	82.0	12	16.0	31.3	13.4	366	1.3	2.6	12.4	366	1.8	3.5	23.3	365	5.8	11.3
2013	186.1	12	38.5	75.4	46.1	365	7.5	14.8	25.1	365	5.2	10.3	73.2	365	28.3	55.5
2014	159.8	12	52.1	102.1	58.9	365	11.0	21.6	17.7	365	2.3	4.5	37.1	365	6.8	13.4
2015	83.4	12	23.5	46.1	18.1	365	3.0	5.8	16.6	253	3.2	6.3	38.7	253	10.9	21.4
2016	113.9	12	43.2	84.6	26.3	366	4.2	8.3	no data	—	—	—	no data	—	—	—

n = sample size, SE = standard error of the mean, and 95% CI = 95% confidence interval

[1] No data available for 2003-2007 and 2016 as flow equipment was removed during construction in the area.
[2] No data available in 2007 due to vandalized equipment and follow-up repairs.
[3] 2015 data includes January 1 – September 15 only.
[4] 1996-2006 Iron loadings were obtained by multiplying the TSS loading by 0.07 as outlined in HHRAP (2010).
[5] 2008 Iron loadings are for August to December only.

Table 31. Lead loadings (kg/day) from Cootes Paradise tributaries (+CSO) and Hamilton Harbour creeks (Grindstone, Indian, and Red Hill Creeks (+CSO)).

Lead																
Year	Cootes Paradise Tribs (+CSO)[4]				Grindstone Creek[2]				Indian Creek[1,3]				Red Hill Creek (+CSO)[1,3]			
	Daily Average Load (kg/d)	n	SE	95% CI	Daily Average Load (kg/d)	n	SE	95% CI	Daily Average Load (kg/d)	n	SE	95% CI	Daily Average Load (kg/d)	n	SE	95% CI
1996	2.4	Due to changes/improvements in calculation methods, error could only be estimated for years 2008-2016			0.4	Due to changes/improvements in calculation methods, error could only be estimated for years 2008-2016			no data	Due to changes/improvements in calculation methods, error could only be estimated for years 2008-2016			0.6	Due to changes/improvements in calculation methods, error could only be estimated for years 2008-2016		
1997	1.6				0.3				no data				0.4			
1998	1.2				0.2				no data				0.4			
1999	0.7				0.2				no data				0.4			
2000	1.5				0.3				no data				0.4			
2001	1.2				0.3				no data				0.5			
2002	1.0				0.2				no data				0.4			
2003	1.4				0.3				no data				no data			
2004	1.4				0.3				no data				no data			
2005	1.6				0.3				no data				no data			
2006	2.0				0.4				no data				no data			
2007	1.1				no data				no data				no data			
2008	1.1	5	0.3	0.6	0.5	335	0.1	0.2	no data	—	—	—	no data	—	—	—
2009	1.0	12	0.2	0.5	0.2	365	0.1	0.1	0.2	365	0.0	0.1	0.8	365	0.3	0.6
2010	0.8	12	0.3	0.6	0.3	365	0.1	0.2	0.2	365	0.0	0.1	0.6	365	0.2	0.5
2011	1.0	12	0.3	0.6	0.3	365	0.0	0.1	0.2	365	0.0	0.1	0.6	365	0.1	0.3
2012	0.4	12	0.1	0.2	0.0	366	0.0	0.0	0.1	366	0.0	0.0	0.2	365	0.0	0.1
2013	0.9	12	0.2	0.4	0.2	365	0.0	0.1	0.2	365	0.0	0.1	0.5	365	0.2	0.4
2014	0.8	12	0.3	0.5	0.3	365	0.1	0.1	0.1	365	0.0	0.0	0.3	365	0.0	0.1
2015	0.4	12	0.1	0.2	0.1	365	0.0	0.0	0.1	253	0.0	0.0	0.3	253	0.1	0.2
2016	0.6	12	0.2	0.4	0.1	366	0.0	0.0	no data	—	—	—	no data	—	—	—

n = sample size, SE = standard error of the mean, and 95% CI = 95% confidence interval

[1] No data available for 2003-2007 and 2016 as flow equipment was removed during construction in the area.
[2] No data available in 2007 due to vandalized equipment and follow-up repairs.
[3] 2015 data includes January 1 – September 15 only.
[4] 2008 Lead loadings include August to December only.

Table 32. Zinc loadings (kg/day) from Cootes Paradise tributaries (+CSO) and Hamilton Harbour creeks (Grindstone, Indian, and Red Hill Creeks (+CSO)).

Zinc																
Year	Cootes Paradise Tribs (+CSO)[4]				Grindstone Creek[2]				Indian Creek[1,3]				Red Hill Creek (+CSO)[1,3]			
	Daily Average Load (kg/d)	n	SE	95% CI	Daily Average Load (kg/d)	n	SE	95% CI	Daily Average Load (kg/d)	n	SE	95% CI	Daily Average Load (kg/d)	n	SE	95% CI
1996	16.1	Due to changes/improvements in calculation methods, error could only be estimated for years 2008-2016			0.8	Due to changes/improvements in calculation methods, error could only be estimated for years 2008-2016			no data	Due to changes/improvements in calculation methods, error could only be estimated for years 2008-2016			6.9	Due to changes/improvements in calculation methods, error could only be estimated for years 2008-2016		
1997	11.7				0.6				no data				3.3			
1998	8.7				0.4				no data				4.4			
1999	1.7				0.2				no data				3.1			
2000	8.7				0.5				no data				5.0			
2001	4.7				0.4				no data				4.0			
2002	3.0				0.3				no data				2.2			
2003	8.9				0.4				no data				no data			
2004	8.8				0.4				no data				no data			
2005	12.7				0.5				no data				no data			
2006	10.7				0.6				no data				no data			
2007	6.2				no data				no data				no data			
2008	8.2	5	2.9	5.6	2.5	335	0.4	0.7	no data	—	—	—	no data	—	—	—
2009	8.1	12	2.2	4.2	1.3	365	0.3	0.5	5.0	365	0.5	1.0	6.7	365	2.2	4.3
2010	5.9	12	2.4	4.7	1.4	365	0.5	0.9	4.4	365	0.5	0.9	5.7	365	1.8	3.5
2011	7.8	12	2.5	4.9	1.6	365	0.2	0.4	5.6	365	0.4	0.9	6.4	365	1.2	2.3
2012	3.4	12	0.9	1.8	0.3	366	0.0	0.1	3.3	366	0.2	0.4	2.0	365	0.4	0.8
2013	6.9	12	1.7	3.4	1.1	365	0.2	0.3	4.8	365	0.4	0.8	5.1	365	1.5	3.0
2014	5.9	12	2.2	4.2	1.4	365	0.2	0.5	4.0	365	0.3	0.6	3.0	365	0.5	1.0
2015	3.2	12	1.1	2.2	0.4	365	0.1	0.1	3.6	253	0.4	0.7	3.0	253	0.7	1.4
2016	4.6	12	1.9	3.7	0.6	366	0.1	0.2	no data	—	—	—	no data	—	—	—

n = sample size, SE = standard error of the mean, and 95% CI = 95% confidence interval

[1] No data available for 2003-2007 and 2016 as flow equipment was removed during construction in the area.
[2] No data available in 2007 due to vandalized equipment and follow-up repairs.
[3] 2015 data includes January 1 – September 15 only.
[4] 2008 Zinc loadings include August to December only.

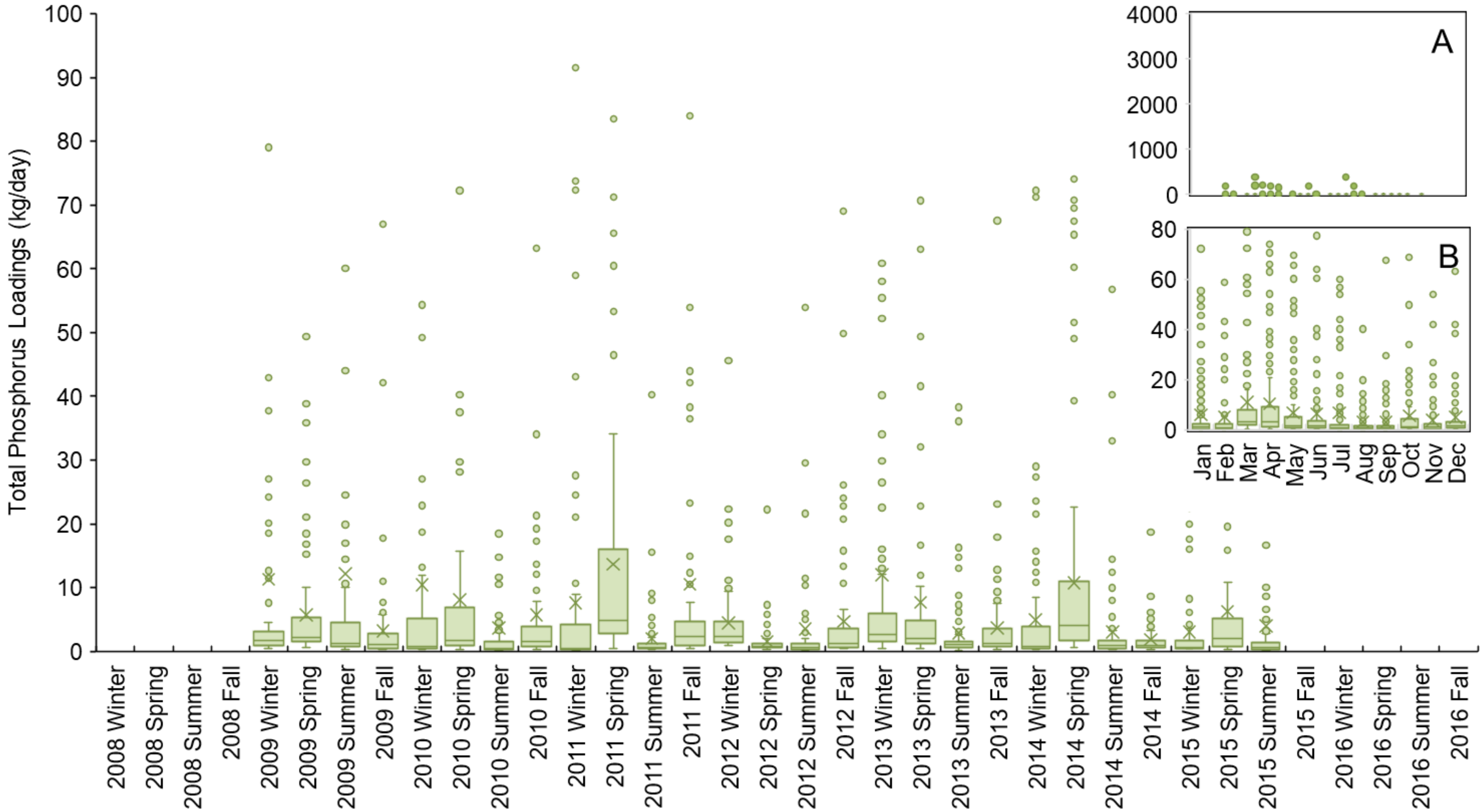

Figure 10. Indian Creek seasonal Total Phosphorus loadings (kg/day). Seasonal mean loading is represented by an X. Inset A shows the same data at full scale and inset B shows the data redistributed by month.

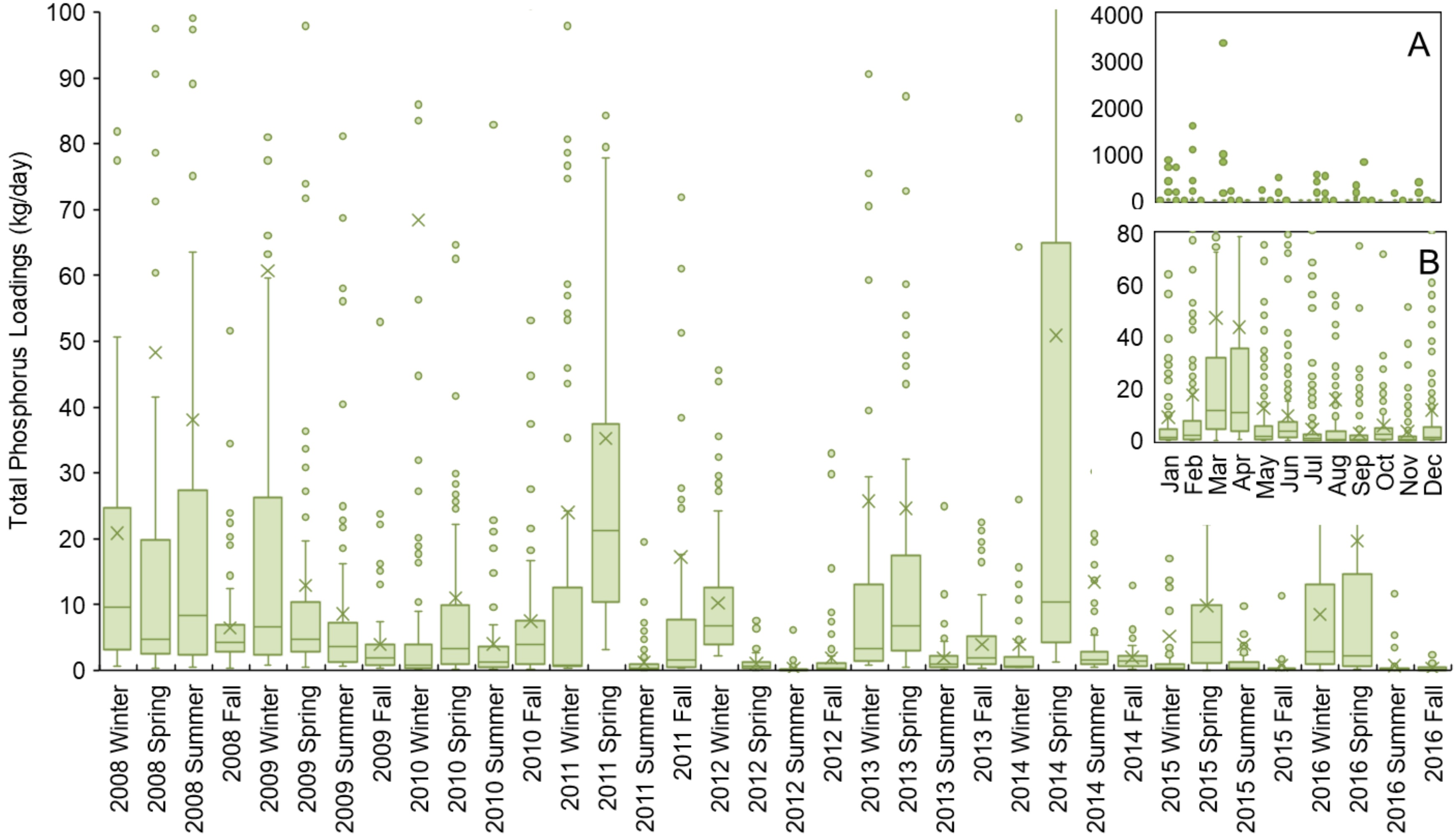

Figure 11. Grindstone Creek seasonal Total Phosphorus loadings (kg/day). Seasonal mean loading is represented by an X. Inset A shows the same data at full scale and inset B shows the data redistributed by month.

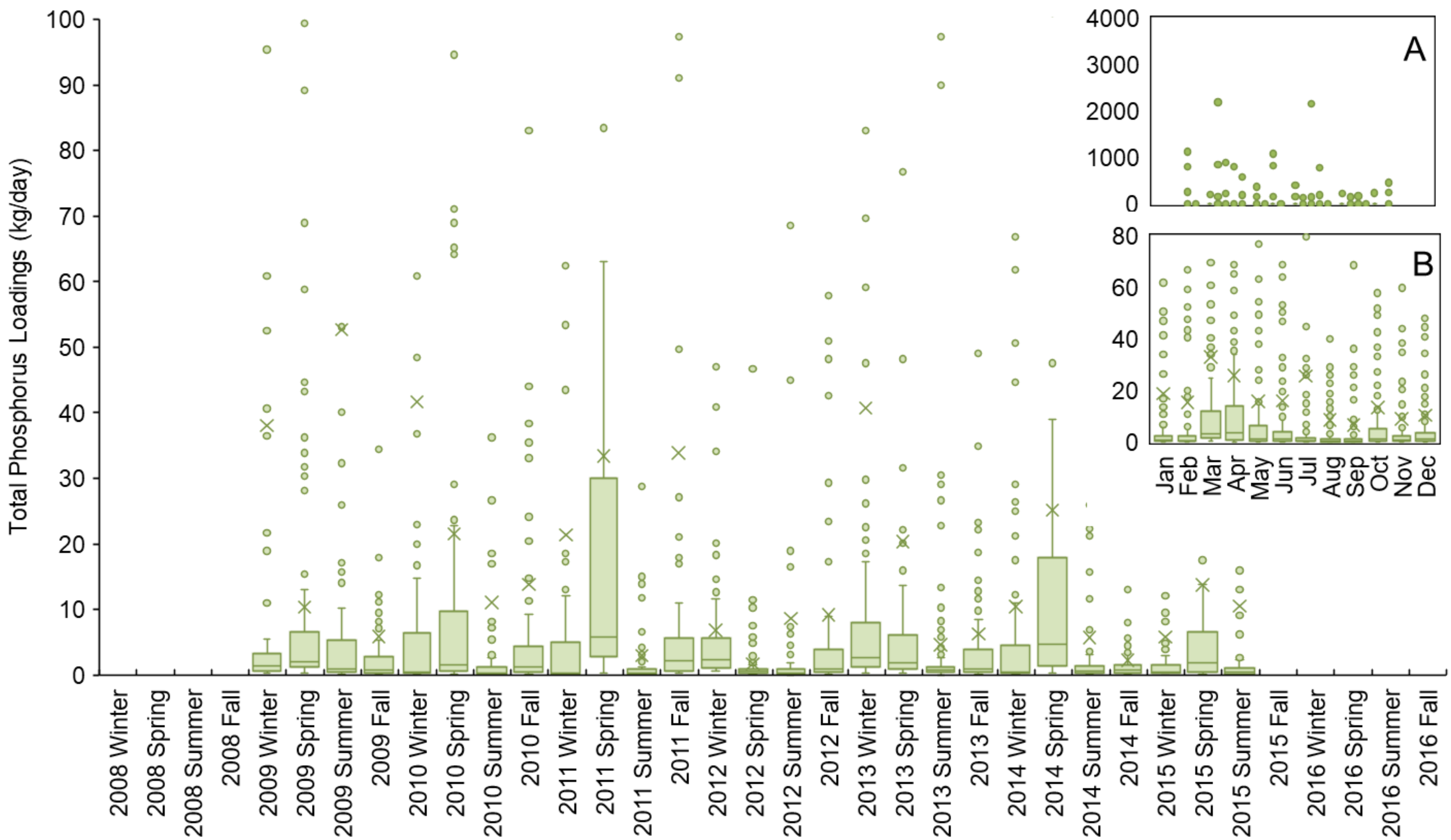

Figure 12. Red Hill Creek (+CSO) seasonal Total Phosphorus loadings (kg/day). Seasonal mean loading is represented by an X. Inset A shows the same data at full scale and inset B shows the data redistributed by month.

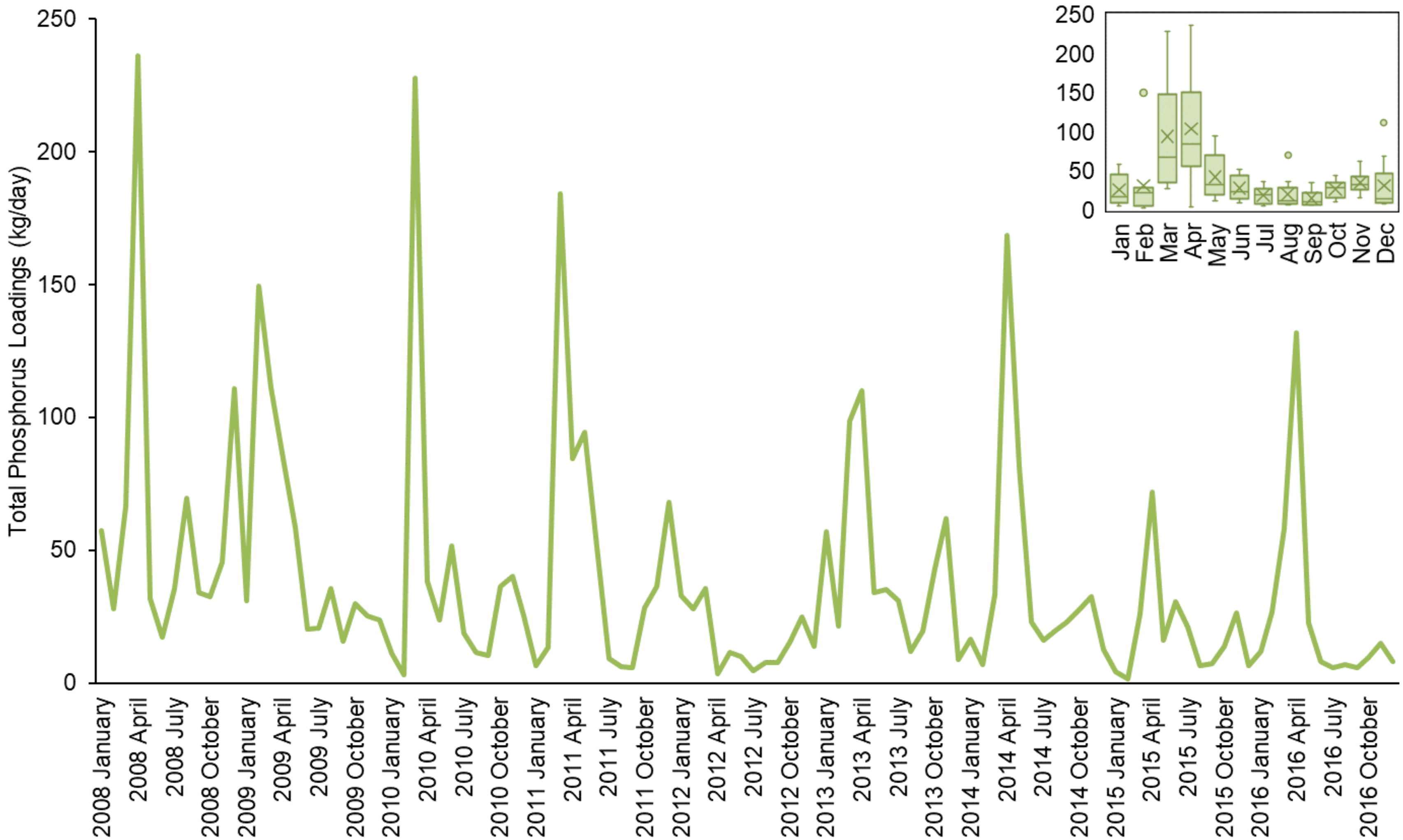

Figure 13. Cootes Paradise Tributaries (+CSO) seasonal Total Phosphorus loadings (kg/day). Seasonal mean loading is represented by an X. The inset shows the same data redistributed by month.

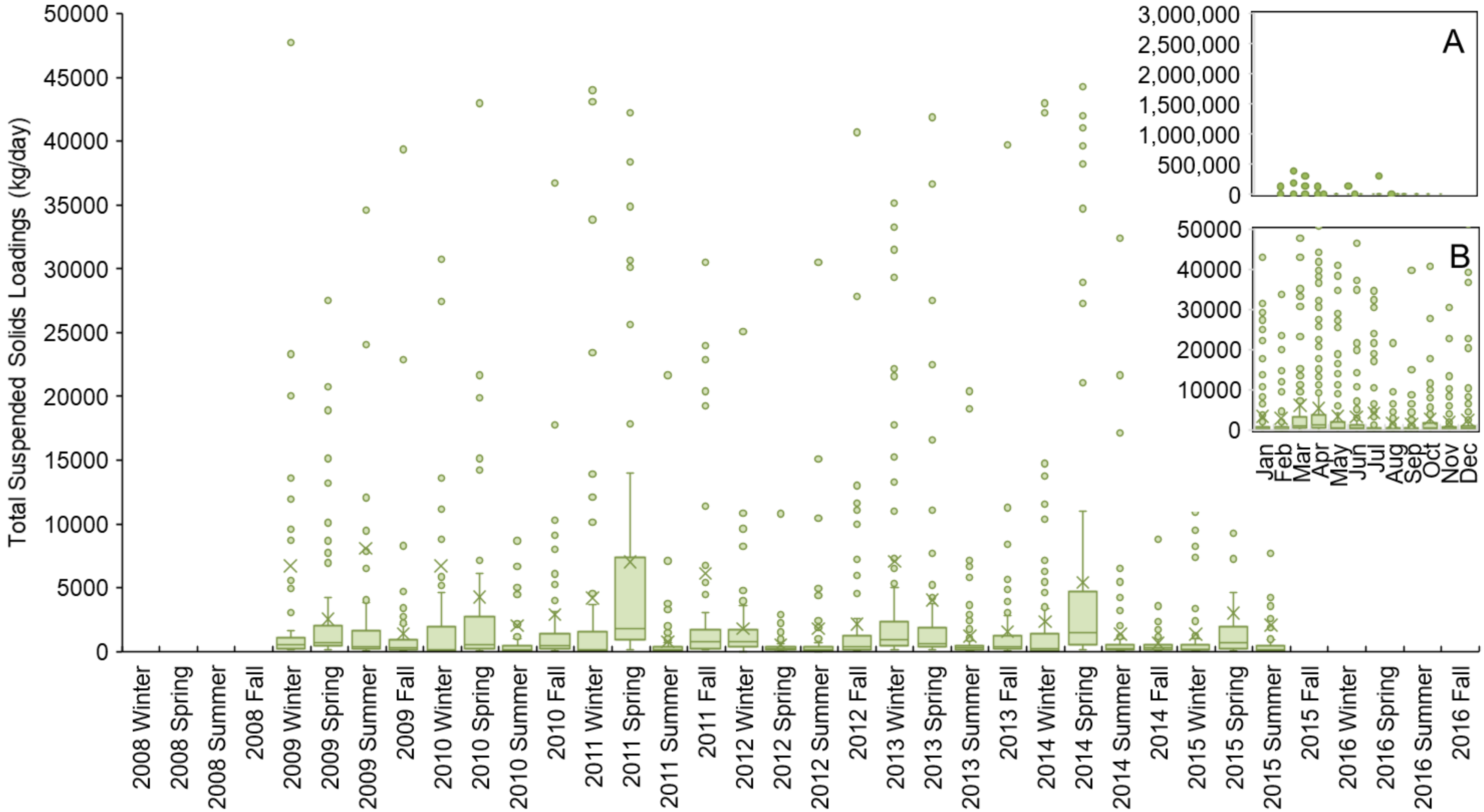

Figure 14. Indian Creek seasonal Total Suspended Solids loadings (kg/day). Seasonal mean loading is represented by an X. Inset A shows the same data at full scale and inset B shows the data redistributed by month.

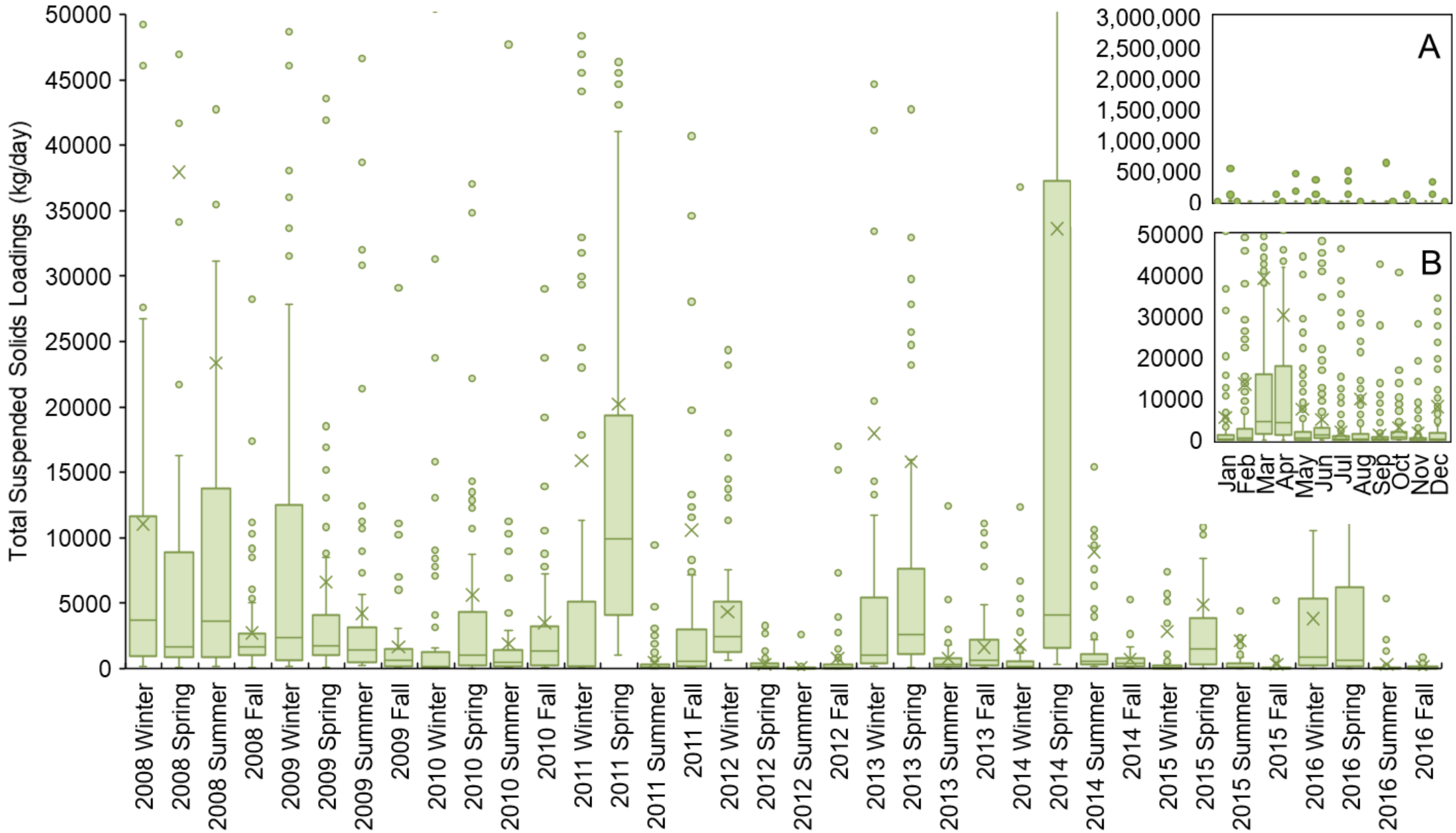

Figure 15. Grindstone Creek seasonal Total Suspended Solids loadings (kg/day). Seasonal mean loading is represented by an X. Inset A shows the same data at full scale and inset B shows the data redistributed by month.

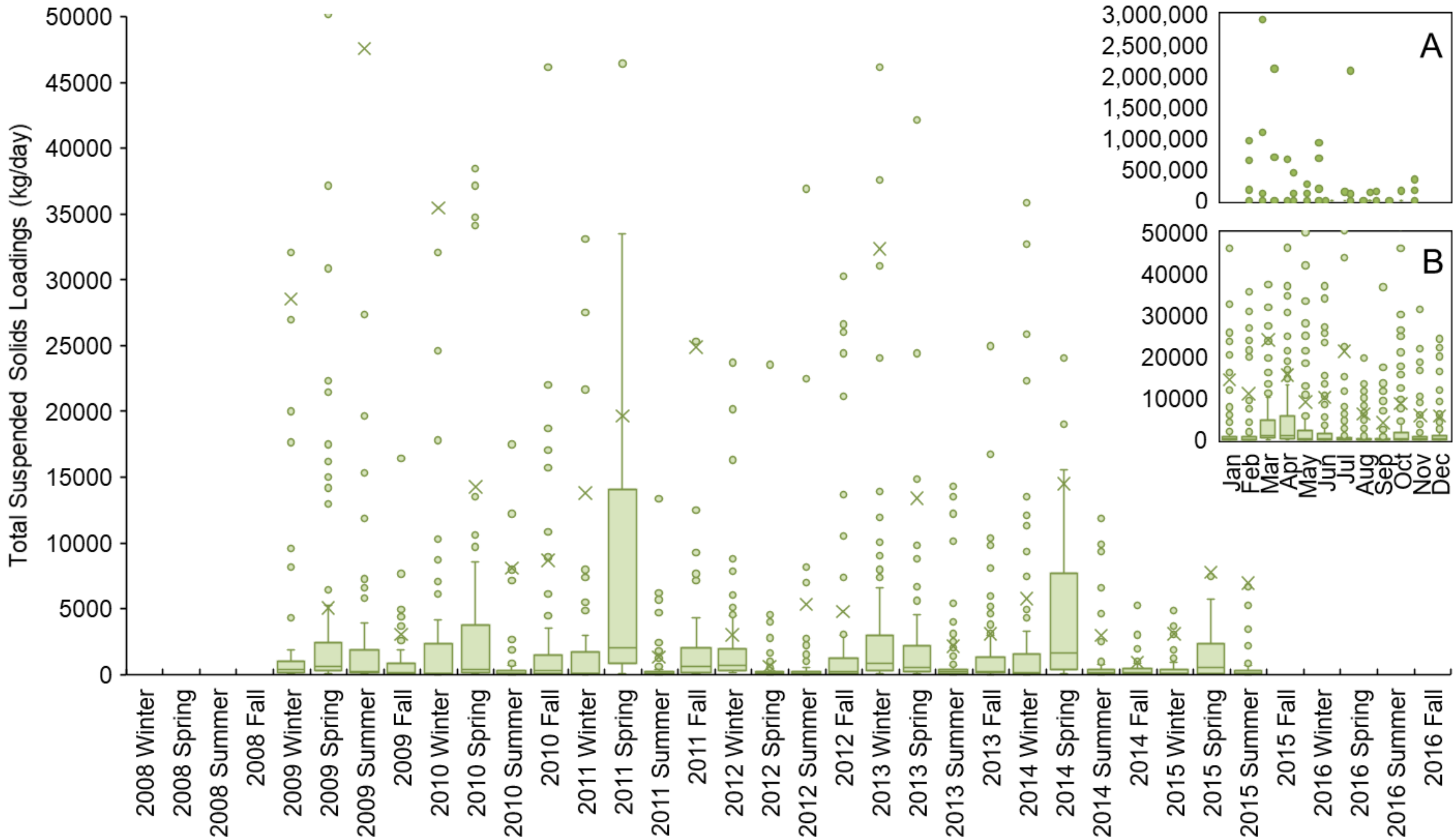

Figure 16. Red Hill Creek (+CSO) seasonal Total Suspended Solids loadings (kg/day). Seasonal mean loading is represented by an X. Inset A shows the same data at full scale and inset B shows the data redistributed by month.

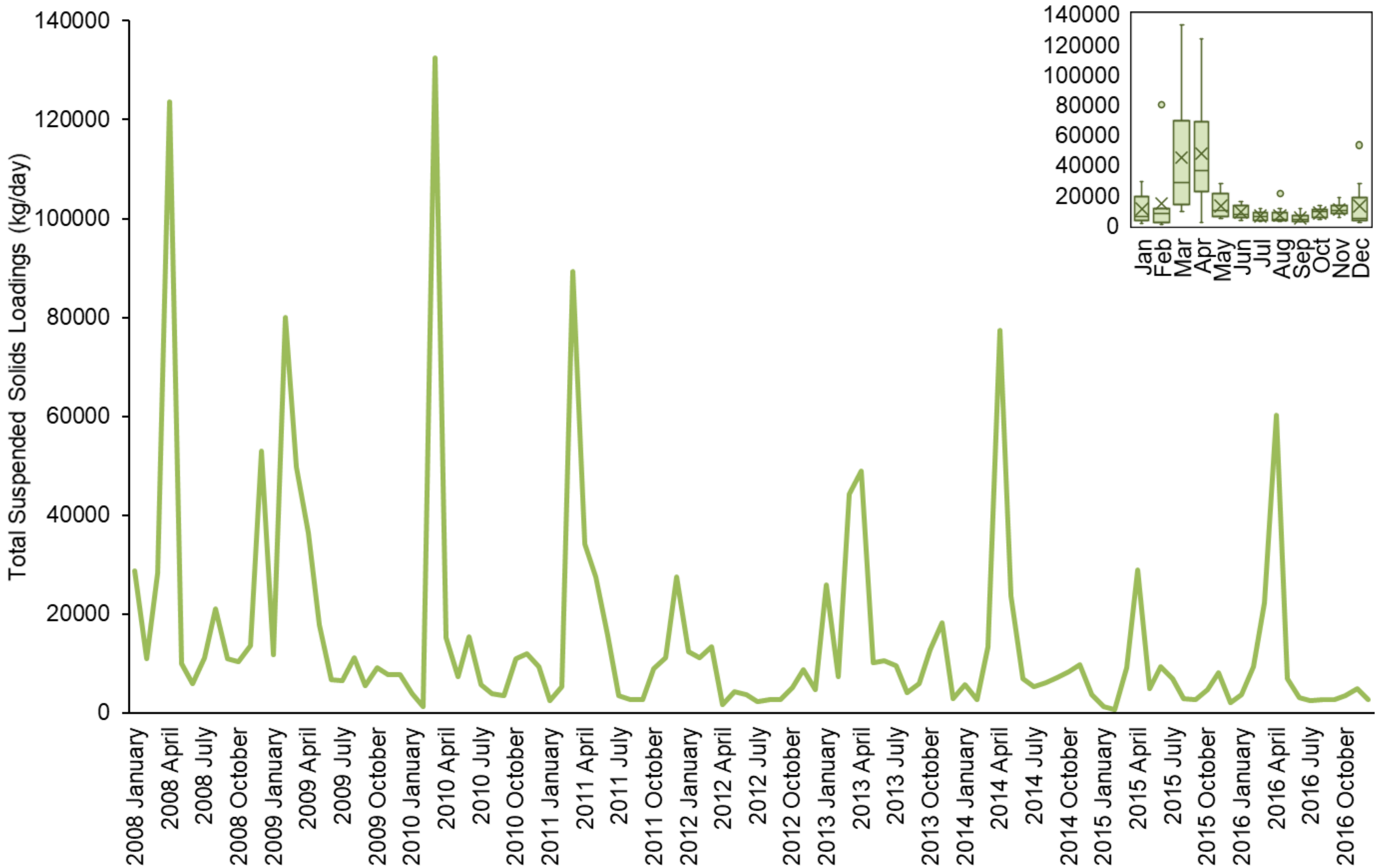

Figure 17. Cootes Paradise Tributaries (+CSO) seasonal Total Suspended Solids loadings (kg/day). The inset shows the same data redistributed by month. Seasonal mean loading is represented by an X.

6.5 Urban Runoff

Urban runoff is a non-point source of pollution produced as rainwater washes off surfaces in urban areas during a storm event. In communities with a separated system, sanitary sewers take sewage to wastewater treatment plants, and storm sewers deliver untreated urban runoff directly into natural water bodies (i.e., creeks). In the Hamilton Harbour watershed, separated systems are used in Burlington (Aldershot and the Hager-Rambo Creek diversion channel) and parts of Hamilton (including Ancaster, Dundas, Stoney Creek, and Waterdown).

In previous reports, loadings from urban runoff were estimated and subtracted from creek loadings. However, with this update, urban runoff will not be calculated and instead will be left integrated in the creek loadings estimates. This was decided by the Technical Team in order to avoid the criticisms of double counting and negative loadings that were often calculated for the creeks after urban loading was subtracted (indicating inaccuracy). Please refer to previous reports to see calculations.

It should be noted that there are instances where urban runoff will not be inherently captured in the creek estimates. This includes direct sheet flow to the Harbour that would occur in low-lying areas in Hamilton and Burlington. Piers 5-8 are being redeveloped by the City of Hamilton and have been proposed to include Low Impact Development (LID) features that would capture direct runoff from this area. The Aldershot area in Burlington sometimes has sheet flow and mostly relies on its sandy soils to infiltrate runoff. These loadings cannot be estimated.

6.6 Cootes Paradise

Contaminants flow from Cootes Paradise to Hamilton Harbour through the eastern Desjardins Canal. Similar to the creeks, a MOECC monitoring station was installed at the Desjardins Canal from 2010-2012 in order to develop predictive equations for loadings to the Harbour based on measured, event-based contaminant concentrations and flow. However, unlike the regression methods of the creeks, the Desjardins Canal had a complicated three-factor sine curve model to predict contaminant concentrations (Long et al. 2014); in Boyd (2017) (Appendix B), a simplified approach was developed requiring:

1. Pooled 2010-2012 MOECC and 2008-2016 RBG datasets (Stations 1&2),

2. Daily average flow from Water Survey of Canada HYDAT Flow station 02HB007 (Spencer Creek),

The new simplified method employs a blend of methods 2 (seasonal regressions) and 4 (flow-weighted means) found in Table 23:

TP, TSS, TKN, Fe, Pb, Zn:

1. Estimate the daily average flow from Spencer Creek vs. Desjardins Canal flow regression derived from MOECC and Water Survey of Canada data

   Desjardins Canal Flow = 1.45 x Spencer Creek Flow + 0.44 **(Equation 2)**

2. Partition data by season; May through November (summer) and December through April (winter)
3. Estimate winter daily [contaminant] from seasonal [contaminant] vs. flow regression derived from pooled MOECC 2010 to 2012 and RBG 2008 to 2016 data
4. Multiply winter daily [contaminant] by winter daily flow to yield winter daily contaminant load and apply Ferguson correction to adjust for bias from log-log regression. Corrected Load = Calculated Load EXP (2.651 x Standard Error^2)
5. Multiply summer daily creek flow by the summer flow-weighted mean derived from pooled data to yield summer daily contaminant load.

Total Ammonia:

1. Estimate the daily average flow from Spencer Creek vs. Desjardins Canal flow regression derived from MOECC and Water Survey of Canada data
2. Multiply daily creek flow by the yearly flow-weighted mean derived from MOECC 2010 to 2012 data to yield daily contaminant load

Total Nitrate:

1. Estimate the daily average flow from Spencer Creek vs. Desjardins Canal flow regression derived from MOECC and Water Survey of Canada data
2. Partition data by season; May through November (summer) and December through April (winter)
3. Multiply daily creek flow by the seasonal flow-weighted mean derived from MOECC 2010 to 2012 data to yield daily contaminant load.

Summaries of the total loadings can be found in Tables 33-34 and Figures18-19.

Previously, the average estimated flows into Cootes Paradise were multiplied by the average concentrations at RBG stations 1 and 2 to produce loadings estimates. However, the flow from Cootes Paradise to Hamilton Harbour was not measured and made assumptions that flow into Cootes Paradise (from tributaries and WWTPs) was equal to the flow out, which does not capture lake seiche effects and concentration changes due to mixing of Cootes Paradise and Harbour waters. The new calculation improves upon this because it is based upon event-based measurements and eliminates the need for a factor of 1.44 to account for flows from Borer, Chedoke, and Ancaster Creeks, which are not monitored by the Water Survey of Canada.

Comments:

The 1990-1996 Loadings Report appears to contain a mathematical error in the Cootes Paradise section of Attachment # 2 (p. 38). The calculation of the total flow into Cootes Paradise in 1996 should be 414,765 m^3/day instead of 387,600 m^3/day. This error has been carried through all of the loadings estimates for Cootes Paradise in 1996 in that report. This needs to be kept in mind when looking at the old report.

Table 33. Estimated Total Phosphorus, Total Suspended Solids, Total Ammonia, and Total Nitrate loadings from Cootes Paradise to Hamilton Harbour (kg/day).

	Total Phosphorus				Total Suspended Solids				Total Ammonia				Total Nitrate			
Year	Daily Average Load (kg/d)	n	SE	95% CI	Daily Average Load (kg/d)	n	SE	95% CI	Daily Average Load (kg/d)	n	SE	95% CI	Daily Average Load (kg/d)	n	SE	95% CI
1996	76.4	Due to changes/improvements in calculation methods, error could only be estimated for years 2008-2016			26493	Due to changes/improvements in calculation methods, error could only be estimated for years 2008-2016			29.8	Due to changes/improvements in calculation methods, error could only be estimated for years 2008-2016			no data	Due to changes/improvements in calculation methods, error could only be estimated for years 2008-2016		
1997	26.0				5892				28.2				no data			
1998	36.4				8294				7.7				no data			
1999	35.2				8076				7.7				no data			
2000	33.2				9687				21.4				no data			
2001	45.5				12737				14.1				no data			
2002	25.9				10015				9.6				no data			
2003	42.3				10809				6.8				no data			
2004	36.6				12450				15.7				no data			
2005	56.3				15569				7.2				no data			
2006	51.4				16836				17.0				no data			
2007	43.7				11917				7.0				no data			
2008	67.7	366	5.8	11.4	27297	366	3260	6390	119.7	366	5.9	11.6	495	366	28	54
2009	52.5	365	5.0	9.8	20485	365	2915	5713	99.8	365	5.1	9.9	416	365	24	47
2010	43.7	365	7.4	14.4	18658	365	4750	9310	77.7	365	5.5	10.9	318	365	26	50
2011	52.0	365	4.0	7.9	19437	365	2067	4051	100.8	365	5.3	10.3	415	365	23	46
2012	19.8	366	0.8	1.7	6139	366	309	605	53.9	366	2.2	4.3	228	366	11	21
2013	46.3	365	3.4	6.7	16804	365	1777	3482	93.5	365	4.2	8.2	382	365	20	39
2014	39.9	365	3.0	5.8	14155	365	1395	2735	82.7	365	4.1	8.0	335	365	19	37
2015	21.2	365	1.4	2.8	6820	365	623	1221	51.6	365	2.5	4.9	211	365	12	23
2016	27.7	366	2.6	5.1	10299	366	1266	2482	61.7	366	3.8	7.5	267	366	18	36

Note numbers may be slightly different from 1996-2002 report as no longer rounded during calculations

Table 34. Estimated Total Kjeldahl Nitrogen, Iron, Lead, and Zinc loadings from Cootes Paradise to Hamilton Harbour (kg/day).

	Total Kjeldahl Nitrogen				Iron				Lead				Zinc			
Year	Daily Average Load (kg/d)	n	SE	95% CI	Daily Average Load (kg/d)	n	SE	95% CI	Daily Average Load (kg/d)	n	SE	95% CI	Daily Average Load (kg/d)	n	SE	95% CI
1996	938	Due to changes/improvements in calculation methods, error could only be estimated for years 2008-2016			no data	Due to changes/improvements in calculation methods, error could only be estimated for years 2008-2016			no data	Due to changes/improvements in calculation methods, error could only be estimated for years 2008-2016			no data	Due to changes/improvements in calculation methods, error could only be estimated for years 2008-2016		
1997	313				no data				no data				no data			
1998	304				no data				no data				no data			
1999	202				no data				no data				no data			
2000	241				no data				no data				no data			
2001	386				no data				no data				no data			
2002	268				no data				no data				no data			
2003	342				no data				no data				no data			
2004	395				no data				no data				no data			
2005	450				no data				no data				no data			
2006	543				no data				no data				no data			
2007	352				no data				no data				no data			
2008	489.5	366	27.8	54.5	270.0	366	22.1	43.4	1.3	366	0.1	0.2	10.4	366	0.8	1.6
2009	396.2	365	23.4	45.8	211.9	365	18.9	37.1	1.0	365	0.1	0.2	8.4	365	0.7	1.3
2010	313.0	365	28.8	56.4	171.7	365	26.5	51.9	0.8	365	0.1	0.2	6.5	365	0.9	1.7
2011	402.2	365	23.1	45.2	210.3	365	15.7	30.8	1.0	365	0.1	0.1	8.3	365	0.6	1.2
2012	187.8	366	7.1	14.0	84.5	366	3.7	7.3	0.4	366	0.0	0.0	3.8	366	0.2	0.4
2013	369.1	365	18.3	35.9	187.3	365	13.4	26.3	0.9	365	0.1	0.1	7.4	365	0.5	1.0
2014	324.6	365	17.9	35.0	161.4	365	11.9	23.2	0.8	365	0.1	0.1	6.3	365	0.5	0.9
2015	190.1	365	9.7	19.0	87.4	365	5.9	11.6	0.4	365	0.0	0.1	3.6	365	0.3	0.5
2016	225.5	366	15.4	30.1	115.9	366	10.6	20.8	0.6	366	0.1	0.1	5.0	366	0.4	0.9

Note numbers may be slightly different from 1996-2002 report as no longer rounded during calculations

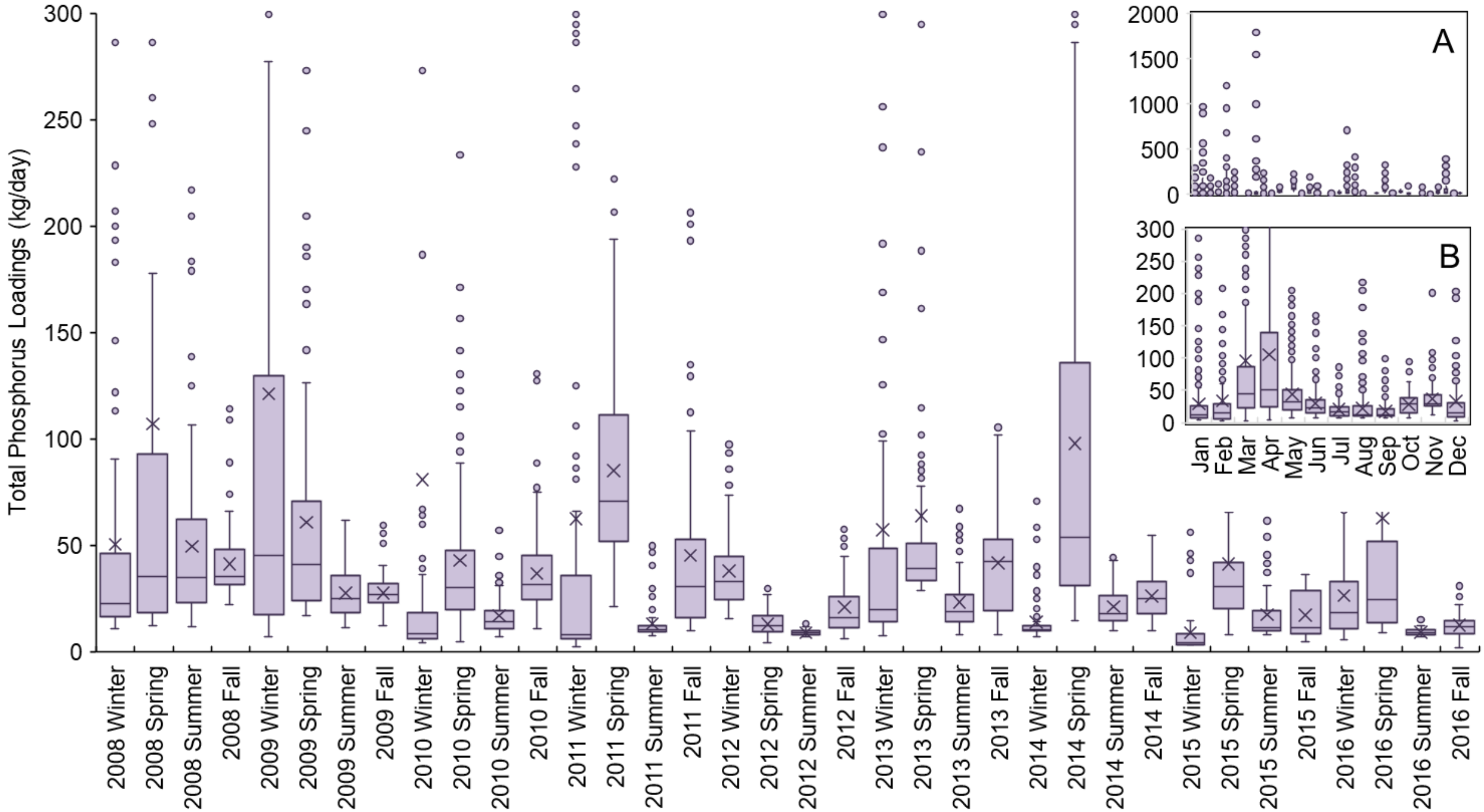

Figure 18. Cootes Paradise seasonal Total Suspended Solids loadings (kg/day). Seasonal mean loading is represented by an X. Inset A shows the same data at full scale and inset B shows the data distributed by month.

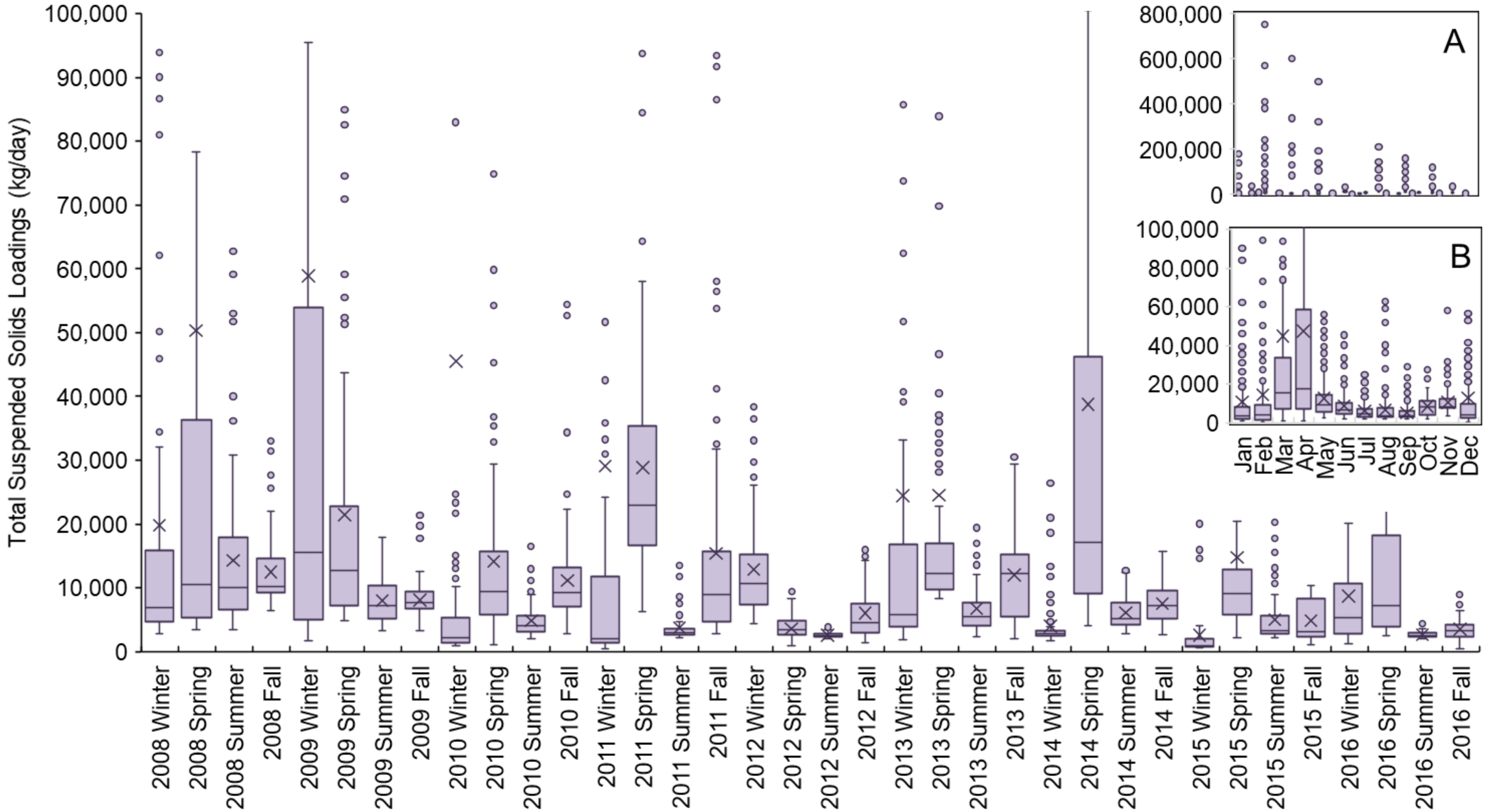

Figure 19. Cootes Paradise seasonal Total Suspended Solids loadings (kg/day). Seasonal mean loading is represented by an X. Inset A shows the same data at full scale and inset B shows the data distributed by month.

6.7 Ambient Monitoring

Contaminant levels in Hamilton Harbour are measured through ambient monitoring. It is this type of monitoring that will show if Hamilton Harbour has been able to meet the water quality goals set out in Table 1.

Every year Environment and Climate Change Canada researchers monitor the environmental conditions at Centre Station (Station 1001) throughout the year by taking weekly (June-September), biweekly (April-May and October-November), or monthly samples (December- March) (Figures 20-23). In order to confirm representativeness of Centre Station, the same researchers monitor three additional stations (9030, 9033, and 9031) systematically every other year starting in 2007 and irregularly prior to that.

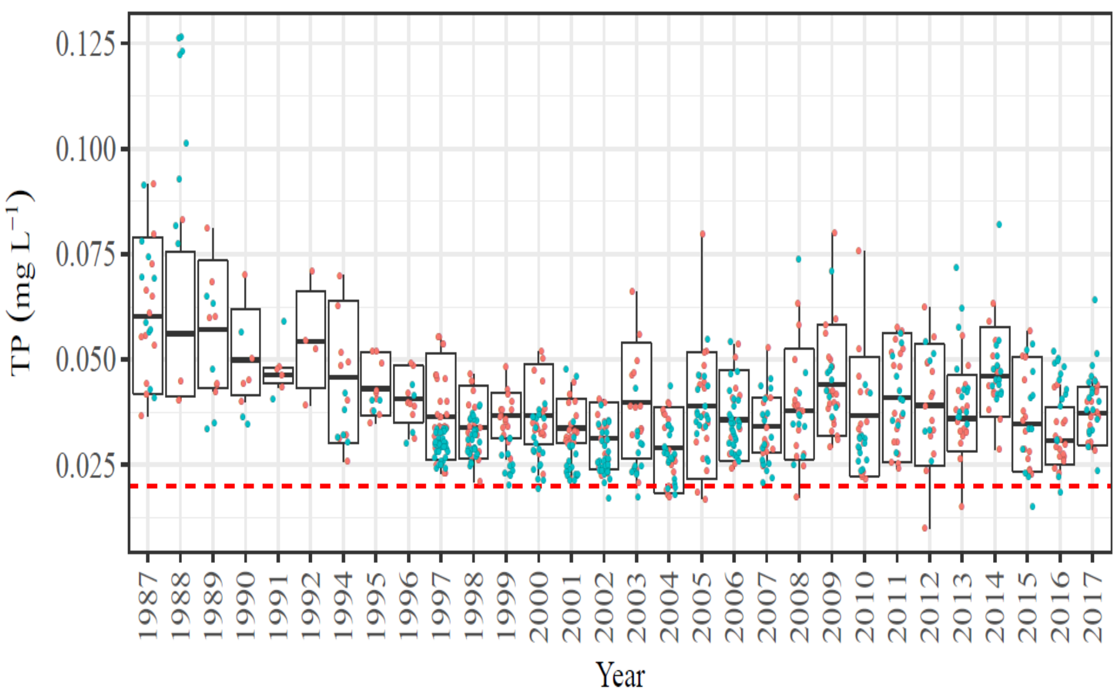

Figure 20. Boxplots of Total Phosphorus (mg/L) from 1 m below surface at Centre Station (1001) in Hamilton Harbour from 1987 – 2017. The top and bottom of the boxes indicate the 90th and 10th percentiles, whiskers represent the minimum and maximum and the solid bar represents the mean of samples collected during the delisting period (June – end of September), represented by orange dots. Blue dots indicate samples collected outside the delisting period. The dashed red line represents the final water quality objective of 0.020 mg/L. (Source: David Depew, ECCC).

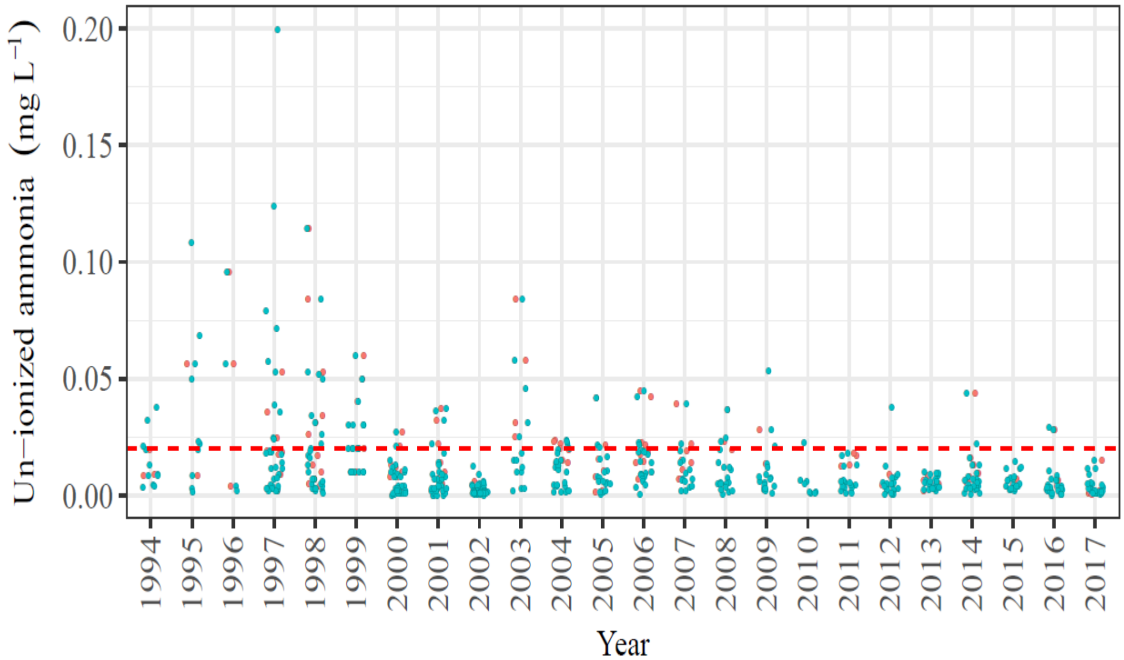

Figure 21. Scatterplot of Un-ionized Ammonia (mg/L) from 1 m below surface at Centre Station (1001) in Hamilton Harbour from 1994 – 2017. Orange dots represent samples collected during the delisting period (ice out to end of June) while blue dots indicate samples collected outside the delisting period. The dashed red line indicates the final water quality goal of 0.02 mg/L. (Source: David Depew, ECCC).

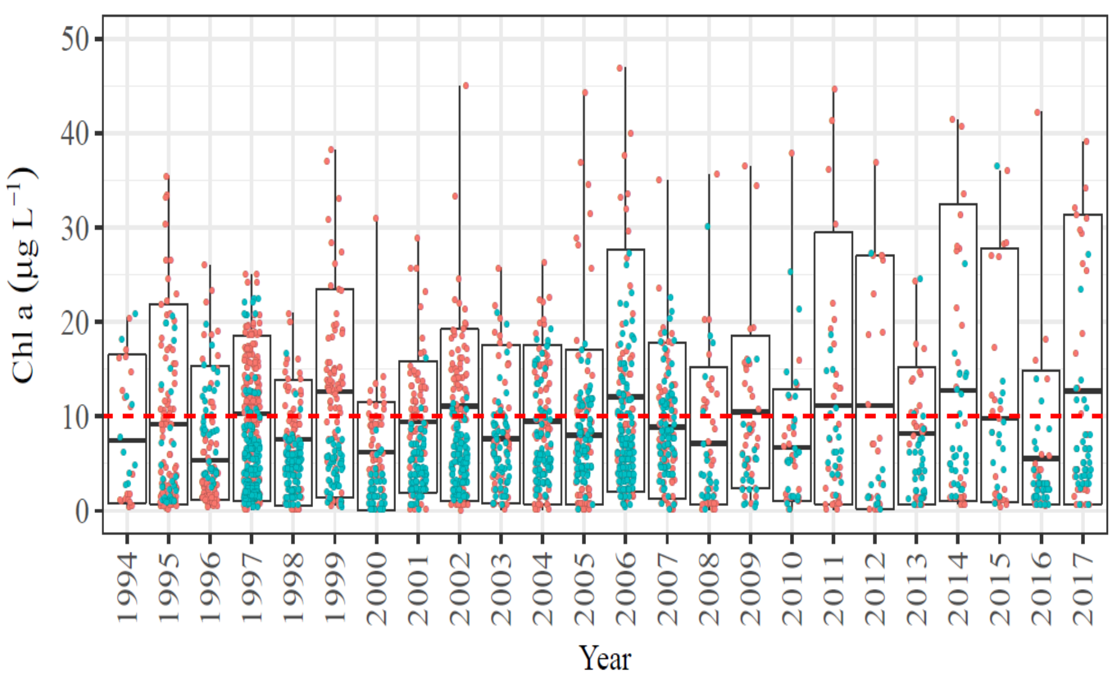

Figure 22. Boxplots of Chlorophyll a (µg/L) from 1 m below surface at Centre Station (1001) in Hamilton Harbour from 1987 – 2017. The top and bottom of the

boxes indicate the 90th and 10th percentiles, whiskers represent the minimum and maximum and the solid bar represents the mean of samples collected during the delisting period (June – end of September), represented by orange dots. Blue dots indicate samples collected outside the delisting period. The dashed red line represents the final water quality objective of 10 µg/L). (Source: David Depew, ECCC).

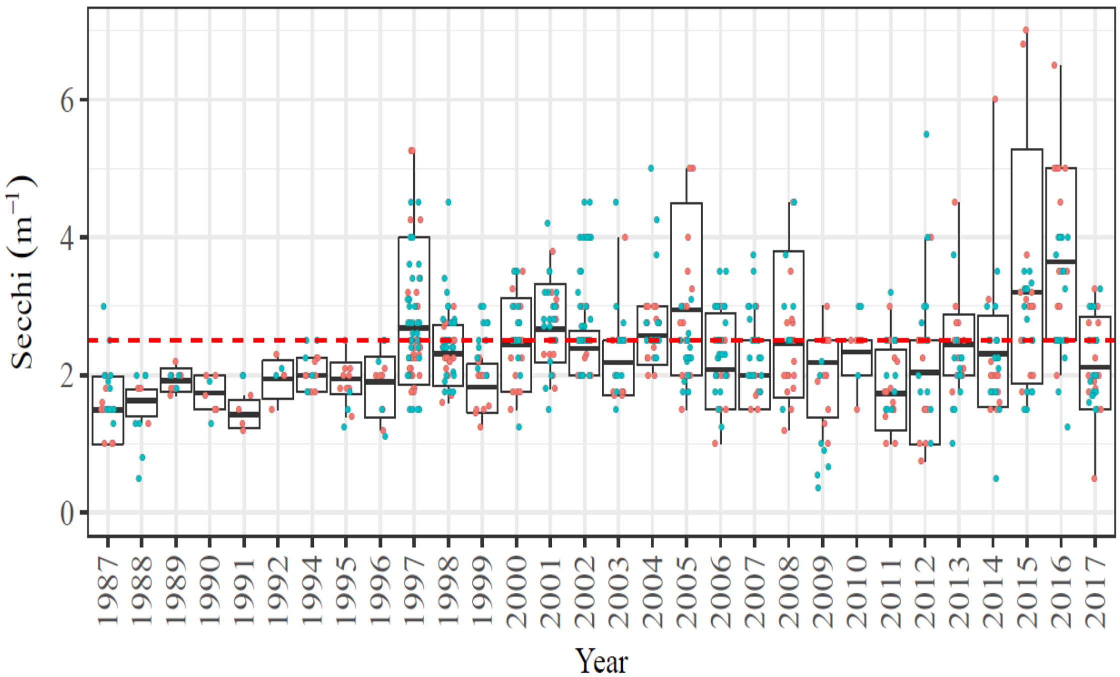

Figure 23. Boxplots of Secchi Disc depth (m) at Centre Station (1001) in Hamilton Harbour from 1987 – 2017. The top and bottom of the boxes indicate the 90th and 10th percentiles, whiskers represent the minimum and maximum and the solid bar represents the mean of samples collected during the delisting period (June – end of September), represented by orange dots. Blue dots indicate samples collected outside the delisting period. The dashed red line represents the final water quality objective of 2.5 m. (Source: David Depew, ECCC).

The Ontario Ministry of the Environment and Climate Change (MOECC) generally monitors Hamilton Harbour on a three-year cycle as part of the Great Lakes Index Station sampling program. In a monitoring year, samples are collected three times (spring, summer, fall). MOECC has historically sampled at many stations in Hamilton Harbour, although only Station 258 at the centre of Harbour is sampled regularly as part of the Index Sampling Program. Table 35 presents the data collected between 1992 and 2016 at Stations 258, 252, and 270.

MOECC data are not directly comparable to that of ECCC. ECCC data are based on samples collected at 1 m depth, whereas the MOECC data are based on upper and lower-water column samples: three samples from the epilimnion and one sample from 1m above the bottom surface during each survey.

Table 35. MOECC annual median concentrations (using pooled upper and lower water column samples).

Station	Year	TKN (mg/L)	TP (µg/L)	TSS (ppm)	Lead (mg/L)	Iron (mg/L)	Zinc (mg/L)
258	1992	1.580	45	4.0	<0.005	0.090	0.0070
	1994	0.860	37	4.3	<0.005	0.060	0.0058
	1997	0.960	32	3.0	0.0007	0.095	0.0066
	2000	0.730	32	2.5	0.0003	0.023	0.0050
	2003	0.800	31	2.8	0.0003	0.040	0.0066
	2006	0.720	33	5.4	0.0004	0.040	0.0051
	2007	no data		4.4	no data		
	2008	no data		4.0	no data		
	2009	0.710	44	3.8	0.0002	0.007	0.0040
	2012	0.730	44	5.0	0.0002	0.020	0.0045
252	1992	1.575	58	5.2	<0.005	0.135	0.0070
	1997	1.100	36	3.5	0.0006	0.100	0.0068
	2000	0.920	32	2.0	0.0003	0.067	0.0061
270	1992	1.540	47	4.1	<0.005	0.093	0.0060
	2000	1.040	32	4.0	0.0003	0.065	0.0047

7. Contaminant Summaries

This section presents the same data shown in Section 6, but are rearranged by the contaminants of concern leading into either Hamilton Harbour or Cootes Paradise. As estimated loadings are used to try to provide a “total loading”, readers need to keep in mind this total is in itself only an estimate, and is calculated in order to give a sense of the big picture.

It should also be noted that the yearly total error presented in the following tables and graphs was calculated by summing the individual standard error of the means for the respective year presented in Section 6. The total error will be an underestimate because raw data for several sources were not provided (e.g., Steel Mills) and therefore individual standard error of the mean could not be computed or included in the total error estimate.

No attempt was made to interpret the results, and consequently, comments are not provided in this section as to the significance of loading sources. The focus of this report was to present the loading data and estimates for the period 1996-2016. The intention is for the RAP Technical Team to analyse various sections, topics to vary from year to year, and to produce supplementary reports providing their interpretation and recommendations for follow-up.

NOTE: Due to extenuating circumstances (flow gauges removed due to construction or vandalism) there is no data for some of the creeks inletting to Hamilton Harbour during 2003-2008 and 2016 on any of the following graphs. This omission is unfortunate, but discussions around how to calculate an appropriate substitute value concluded stating “no data” was the appropriate course of action.

7.1 Total Phosphorus (TP)

Table 36. Total Phosphorus loadings to Hamilton Harbour (kg/day).

Total Phosphorus (kg/day)											
Year	Skyway WWTP	Woodward WWTP	AMD	Stelco	CSOs	Indian Creek	Grindstone Creek	Red Hill Creek	Cootes Paradise	Total	SE
1996	48	143	9.8	36.2	80	no data	30.2	36.5	76.4	460	no data
1997	24	160	-0.9	9.0	43	no data	20.6	17.2	26.0	299	no data
1998	20	169	10.0	18.2	41	no data	17.7	23.2	36.4	335	no data
1999	18	166	-7.0	7.6	49	no data	3.7	16.6	35.2	289	no data
2000	19	261	2.9	0.7	57	no data	19.2	26.3	33.2	419	no data
2001	15	239	-8.1	-3.4	69	no data	9.2	21.3	45.5	388	no data
2002	17	198	-9.0	-6.5	59	no data	7.2	11.4	25.9	303	no data
2003	13	165	8.0	-3.5	71	no data	11.9	no data	42.3	308	no data
2004	8	217	20.0	2.2	44	no data	11.6	no data	36.6	340	no data
2005	11	239	14.0	3.0	125	no data	16.6	no data	56.3	464	no data
2006	12	176	-12.6	6.0	58	no data	20.8	no data	51.4	312	no data
2007	20	143	8.7	3.5	13	no data	no data	no data	43.7	232	no data
2008	19	189	-15.2	2.5	n/a	no data	33.4	no data	67.7	296	16.8
2009	19	172	-8.1	2.9	n/a	7.9	17.2	25.8	52.5	289	26.3
2010	16	143	4.0	1.5	n/a	6.9	22.2	21.7	43.7	260	30.7
2011	20	125	6.8	1.1	n/a	8.6	19.5	23.0	52.0	256	16.6
2012	18	143	11.2	1.5	n/a	3.5	3.2	6.5	19.8	207	6.7
2013	21	153	4.1	1.7	13.9	6.7	14.1	18.6	46.3	279	19.3
2014	20	147	9.2	1.5	11.4	4.9	17.6	10.2	39.9	265	13.1
2015	22	142	8.9	0.5	9.2	4.5	5.0	10.4	21.2	226	11.5
2016	10	162	3.9	0.3	2.5	no data	7.3	no data	27.7	216	9.3

As industries report net data instead of gross, a negative loading indicates the removal of more contaminant from the intake water than is put back through the effluent stream.
SE = standard error of the mean

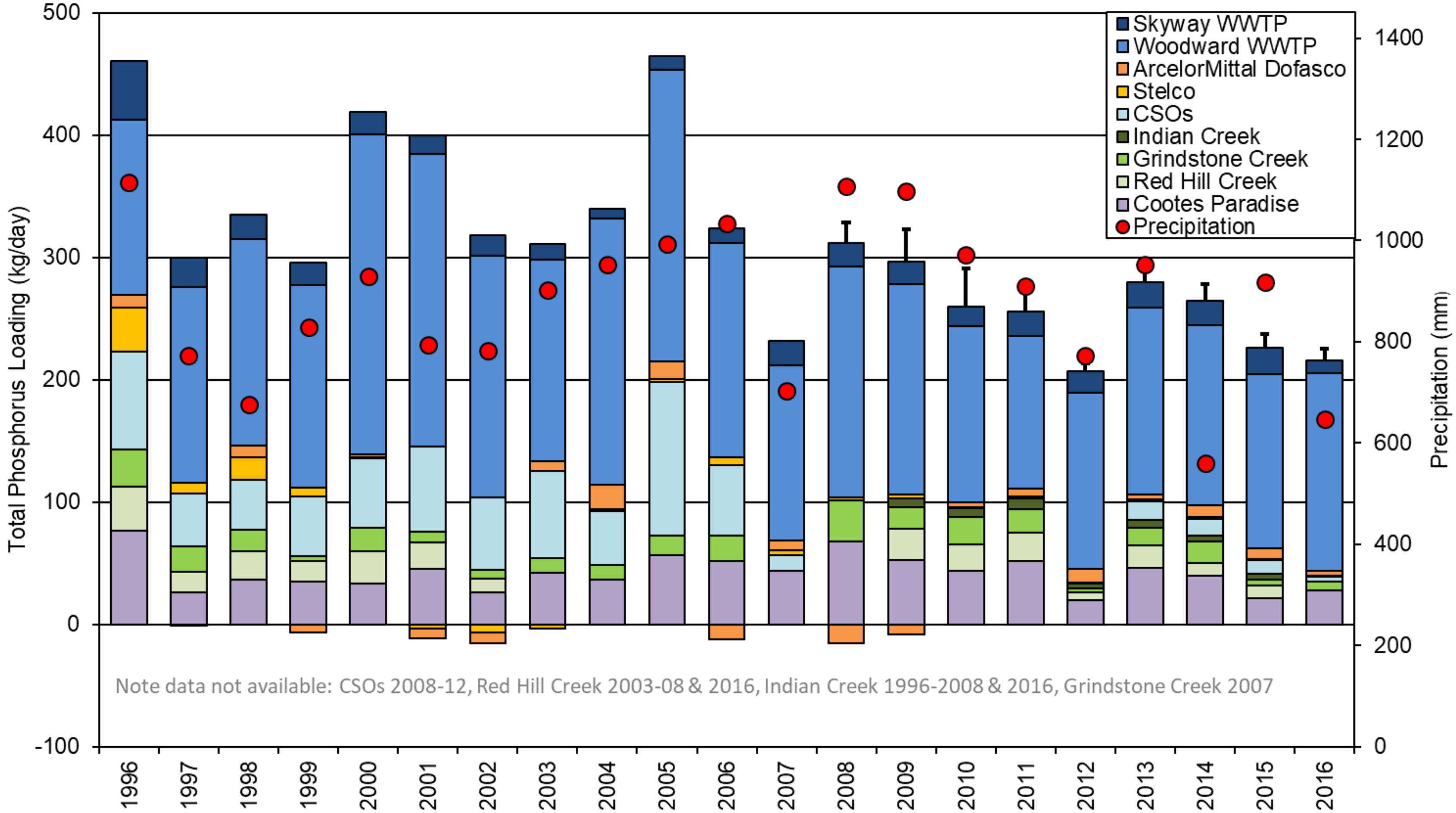

Figure 24. Total Phosphorus loadings to Hamilton Harbour (kg/day).

Table 37. Total Phosphorous Loadings to Cootes Paradise (kg/day).

Total Phosphorus (kg/day)					
Year	Dundas WWTP	CSOs	Tributaries	Total	SE
1996	5.7	10.6	57.2	73.5	no data
1997	3.9	6.0	39.8	49.7	no data
1998	5.3	1.7	28.8	35.8	no data
1999	6.8	2.3	11.9	21.0	no data
2000	5.5	1.5	33.0	40.0	no data
2001	5.0	2.7	23.7	31.4	no data
2002	3.6	2.0	17.6	23.2	no data
2003	3.1	1.4	32.4	36.9	no data
2004	2.7	5.8	32.4	40.9	no data
2005	3.7	8.9	41.6	54.2	no data
2006	3.9	5.0	43.0	51.9	no data
2007	3.5	0.3	24.3	28.1	no data
2008	3.63	n/a	63.7	67.3	17.6
2009	2.69	n/a	50.4	53.1	12.5
2010	1.86	n/a	41.5	43.4	17.6
2011	2.62	n/a	49.1	51.7	15.4
2012	3.51	n/a	16.3	19.8	3.4
2013	1.80	0.0	44.4	46.3	9.6
2014	1.51	0.0	38.4	40.2	13.2
2015	1.78	0.0	19.4	21.4	5.7
2016	2.02	0.0	25.9	28.0	10.7

n/a = data not available, SE = standard error of the mean

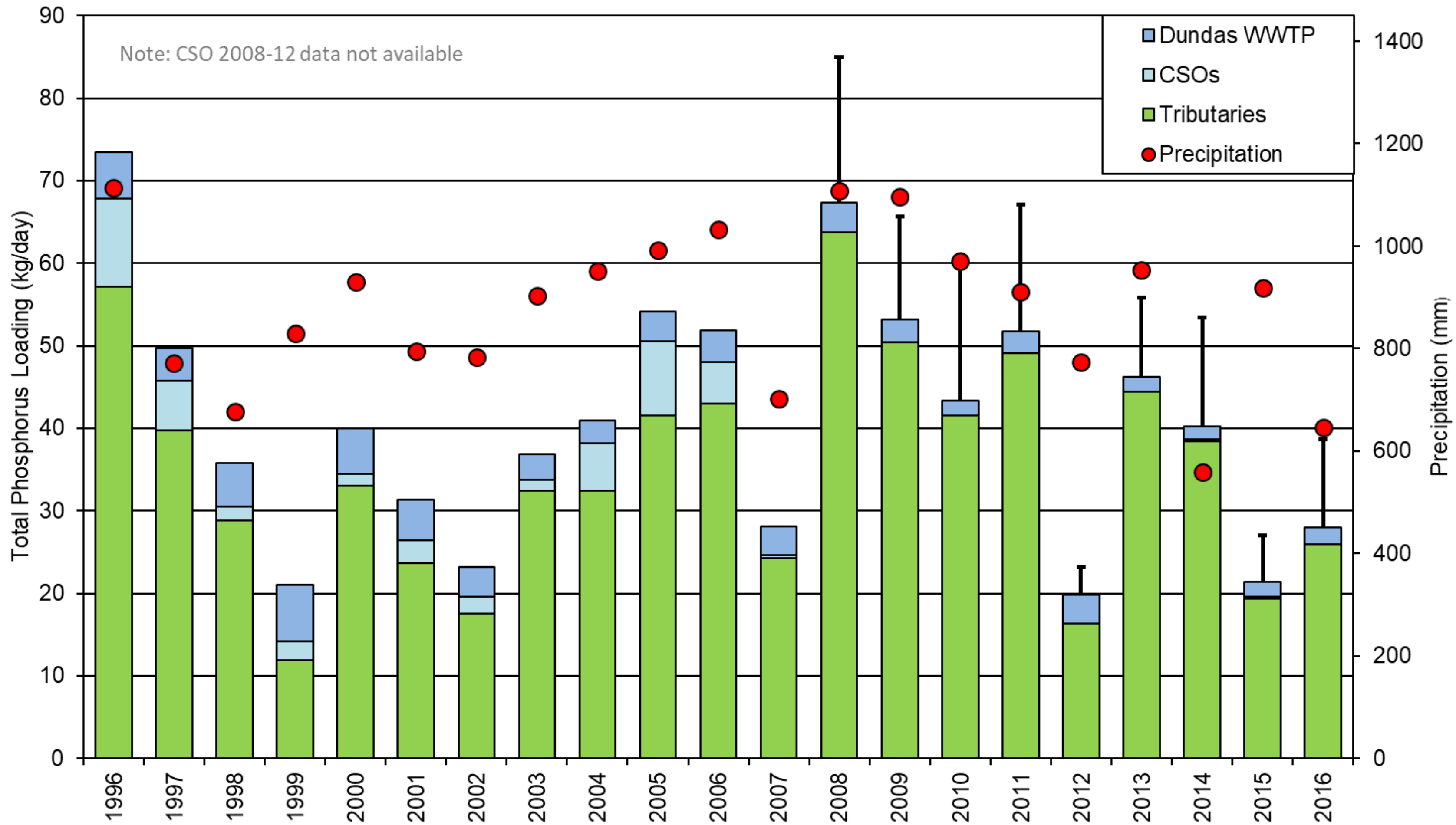

Figure 25. Total Phosphorus loadings to Cootes Paradise (kg/day).

7.2 Total Suspended Solids (TSS)

Table 38. Total Suspended Solids loadings to Hamilton Harbour (kg/day).

Total Suspended Solids (kg/day)											
Year	**Skyway WWTP**	**Woodward WWTP**	**AMD**	**Stelco**	**CSOs**	**Indian Creek**	**Grindstone Creek**	**Red Hill Creek**	**Cootes Paradise**	**Total**	**SE**
1996	549	5751	1626	6820	4182	no data	12355	20187	26493	77963	no data
1997	524	6939	2191	2658	2242	no data	8637	7540	5892	36623	no data
1998	435	7036	890	4175	2139	no data	7769	12607	8294	43345	no data
1999	554	6580	1168	849	2530	no data	854	8012	8076	28623	no data
2000	714	8312	1069	314	2990	no data	7576	14147	9687	44808	no data
2001	527	8443	812	293	3580	no data	3038	9913	12737	39342	no data
2002	461	6567	823	-1228	3085	no data	2403	4216	10015	26342	no data
2003	567	5744	840	-605	3710	no data	4870	no data	10809	25935	no data
2004	293	7766	1187	-532	2268	no data	4308	no data	12450	27740	no data
2005	393	7252	1857	765	6507	no data	6844	no data	15569	39187	no data
2006	373	4726	1135	-25	3045	no data	8167	no data	16836	34257	no data
2007	420	3336	1648	-734	655	no data	no data	no data	11917	17242	no data
2008	391	4950	1521	-233	n/a	no data	23598	no data	27297	57524	8777
2009	372	3692	1021	246	n/a	4535	12201	20300	20485	60447	18590
2010	493	3549	1229	-44	n/a	3913	21097	16448	18658	65343	25294
2011	513	3275	2519	462	n/a	4567	11817	14963	19437	57553	8706
2012	357	2416	2563	450	n/a	1548	1324	3420	6139	18217	1885
2013	413	2786	1895	245	2129	3578	9036	13104	16804	50023	11277
2014	432	2875	2122	-8	1372	2305	11316	5586	14155	40327	5418
2015	421	2756	1658	108	658	2224	2552	6127	6820	23486	3790
2016	116	4236	1584	101	215	no data	4119	no data	10299	20791	2630

As industries report net data instead of gross, a negative loading indicates the removal of more contaminant from the intake water than is put back through the effluent stream.
SE = standard error of the mean

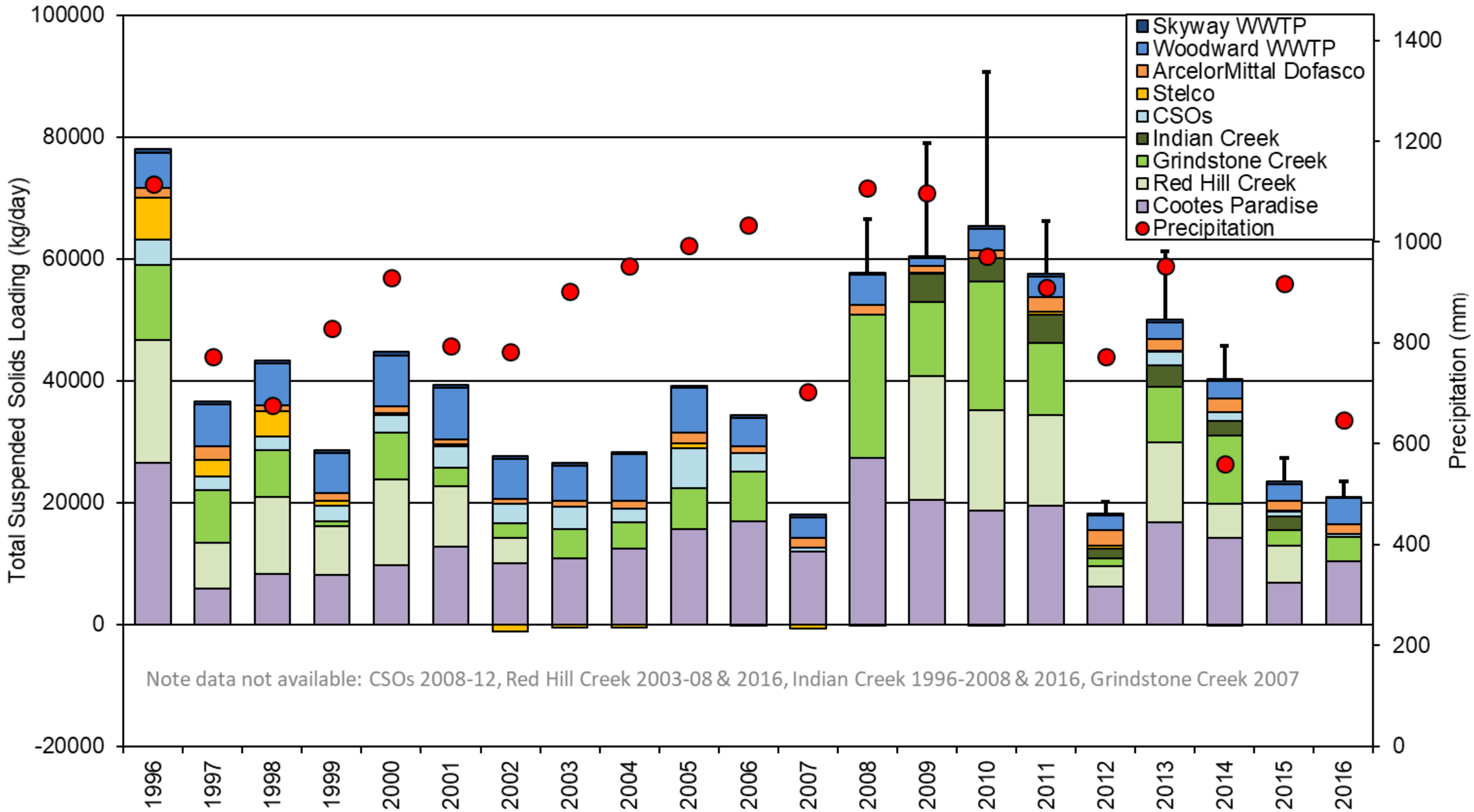

Figure 26. Total Suspended Solids loadings to Hamilton Harbour (kg/day).

Table 39. Total Suspended Solids loadings to Cootes Paradise (kg/day).

Total Suspended Solids (kg/day)					
Year	Dundas WWTP	CSOs	Tributaries	Total	SE
1996	35.4	551	20716	21302	no data
1997	21.5	315	14852	15189	no data
1998	24.3	89	10940	11053	no data
1999	18.2	121	2872	3011	no data
2000	34.0	79	11460	11573	no data
2001	35.4	142	6903	7080	no data
2002	28.3	105	4658	4791	no data
2003	17.7	74	11534	11626	no data
2004	13.3	301	11474	11788	no data
2005	13.9	466	15974	16454	no data
2006	17.7	260	14354	14632	no data
2007	14.1	14	8269	8297	no data
2008	20.4	n/a	27328	27348	9541
2009	24.9	n/a	20893	20918	6673
2010	21.3	n/a	18439	18460	10463
2011	29.9	n/a	19282	19312	7137
2012	48.9	n/a	6139	6188	1218
2013	14.3	0	16771	16786	4416
2014	14.2	0	14180	14224	5970
2015	17.5	0	6827	6894	2188
2016	14.7	0	10371	10403	4807

n/a = data not available, SE = standard error of the mean

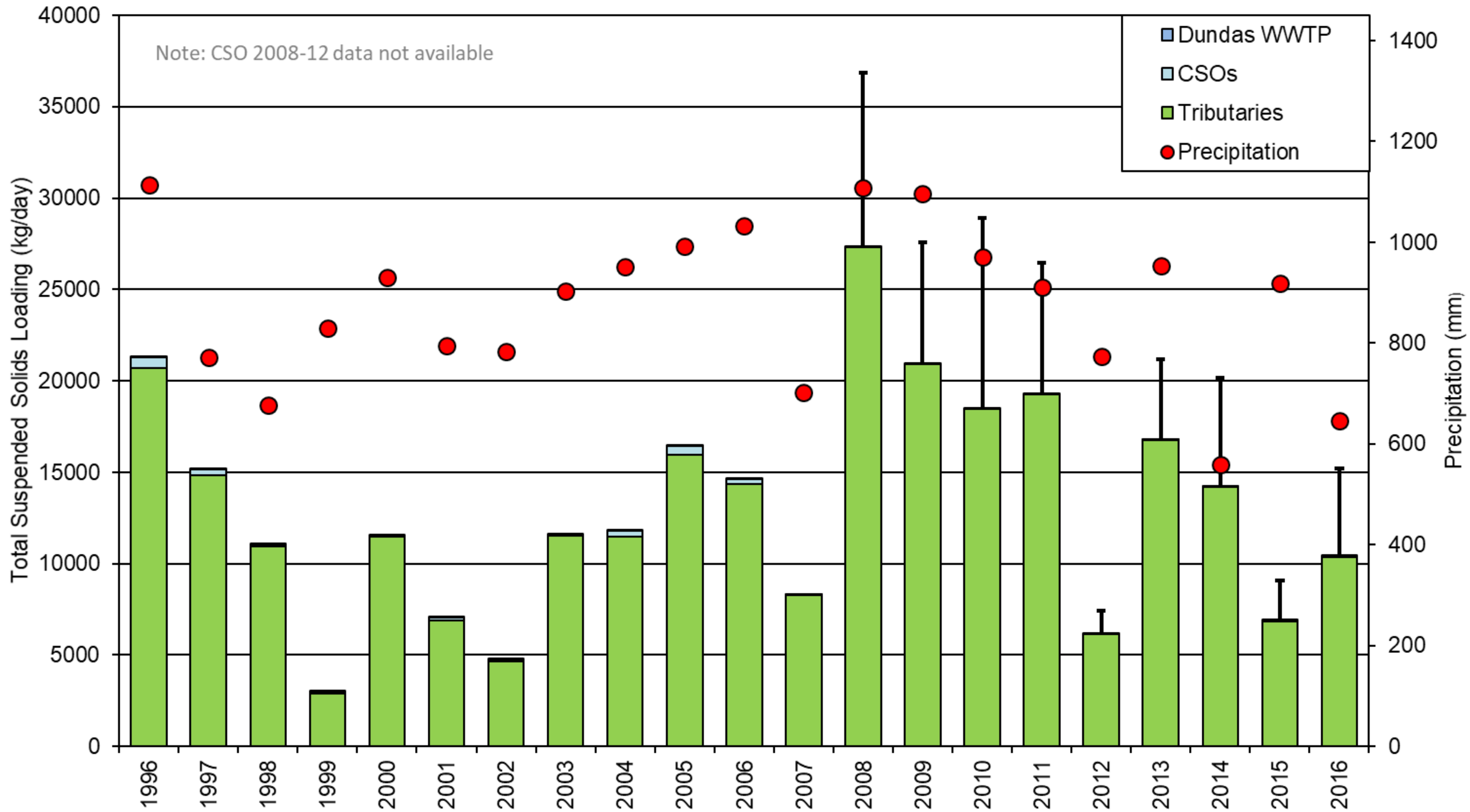

Figure 27. Total Suspended Solids loadings to Cootes Paradise (kg/day).

7.3 Total Ammonia

Table 40. Total Ammonia loadings to Hamilton Harbour (kg/day).

Total Ammonia (kg/day)											
Year	Skyway WWTP	Woodward WWTP	AMD	Stelco	CSOs	Indian Creek	Grindstone Creek	Red Hill Creek	Cootes Paradise	Total	SE
1996	720	3962	356	75.7	204	no data	no data	no data	29.8	5348	no data
1997	878	4229	333	-10.8	109	no data	no data	no data	28.2	5566	no data
1998	508	3857	155	-13.3	104	no data	no data	no data	7.7	4618	no data
1999	58	4517	152	-36.4	123	no data	no data	no data	7.7	4821	no data
2000	60	3943	94	-27.3	146	no data	no data	no data	21.4	4237	no data
2001	133	2925	54	3.6	174	no data	no data	no data	14.1	3304	no data
2002	179	3175	34	-28.6	150	no data	no data	no data	9.6	3519	no data
2003	195	2874	-118	-64.0	181	no data	no data	no data	6.8	3075	no data
2004	92	3289	53	-16.9	110	no data	no data	no data	15.7	3543	no data
2005	64	2753	46	12.5	317	no data	no data	no data	7.2	3199	no data
2006	31	2062	89	28.9	148	no data	no data	no data	17.0	2376	no data
2007	27	1680	202	31.2	32	no data	no data	no data	7.0	1979	no data
2008	36.9	1789	116	121.9	n/a	no data	6.4	no data	119.7	2189	117
2009	33.2	1100	77	-4.0	n/a	5.3	4.8	19.2	99.8	1335	98
2010	13.6	878	99	57.8	n/a	4.6	3.7	16.6	77.7	1151	67
2011	42.4	991	239	12.4	n/a	6.5	5.5	23.1	100.8	1421	91
2012	19.9	337	170	-19.5	n/a	3.5	2.3	10.9	53.9	578	28
2013	43.4	332	160	-7.9	6.2	5.4	4.4	18.6	93.5	659	28
2014	144.1	651	140	-6.3	3.3	4.7	4.4	15.1	82.7	1047	63
2015	143.3	1072	79	-5.7	20.6	3.9	2.1	12.8	51.6	1387	101
2016	37.4	947	117	-5.0	3.6	no data	3.1	no data	61.7	1171	43

As industries report net data instead of gross, a negative loading indicates the removal of more contaminant from the intake water than is put back through the effluent stream.
SE = standard error of the mean

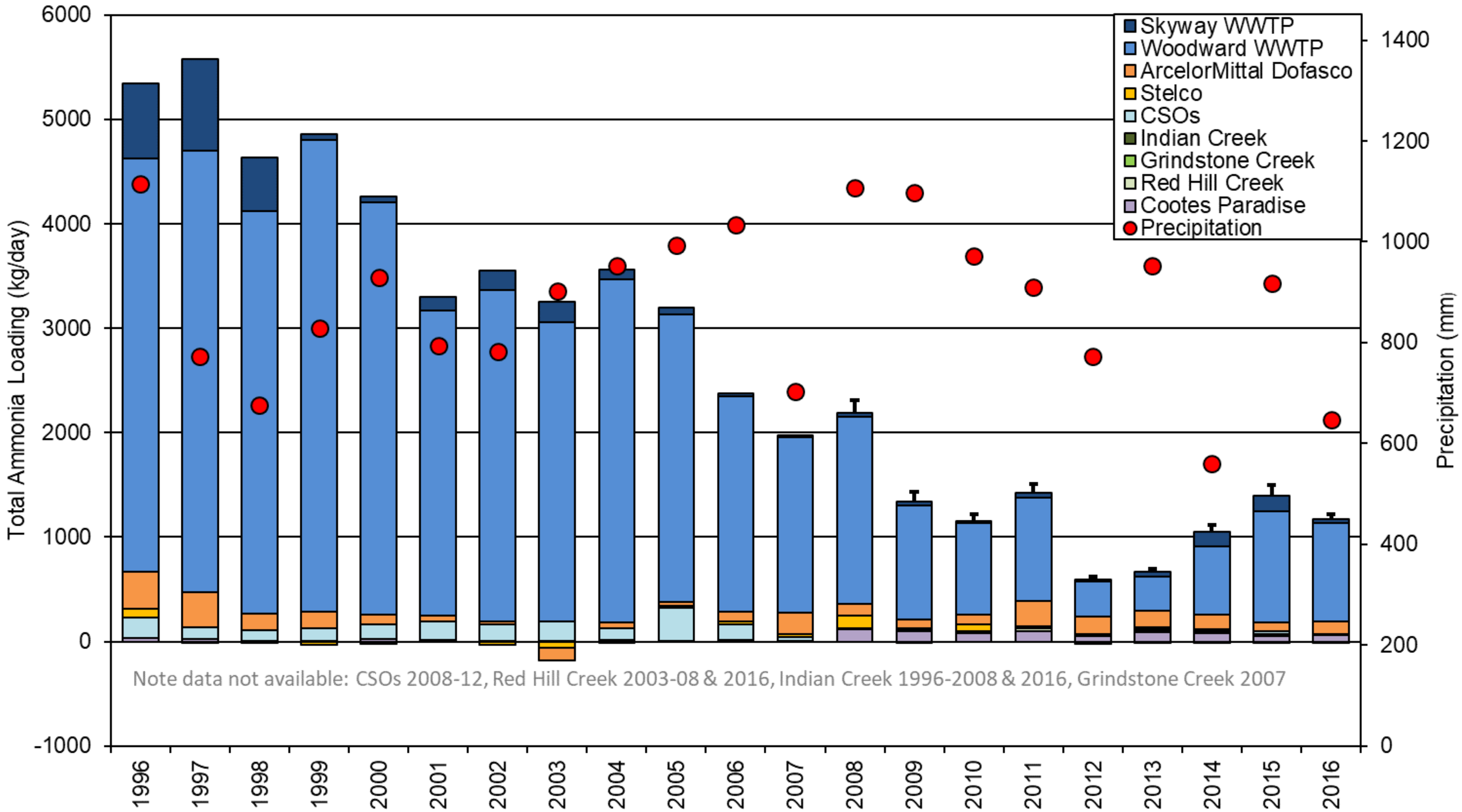

Figure 28. Total Ammonia loadings to Hamilton Harbour (kg/day).

Table 41. Total Ammonia loadings to Cootes Paradise (kg/day).

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Total Ammonia (kg/day)					
Year	**Dundas WWTP**	**CSOs**	**Tributaries**	**Total**	**SE**
1996	5.2	26.8	no data	32.0	no data
1997	5.4	15.3	no data	20.7	no data
1998	3.3	4.3	no data	7.6	no data
1999	9.7	5.9	no data	15.6	no data
2000	6.1	3.8	no data	9.9	no data
2001	13.5	6.9	no data	20.4	no data
2002	12.9	5.1	no data	18.0	no data
2003	6.2	3.6	no data	9.8	no data
2004	1.3	14.6	no data	15.9	no data
2005	1.9	22.7	no data	24.6	no data
2006	8.3	12.7	no data	21.0	no data
2007	6.1	0.7	no data	6.8	no data
2008	2.69	n/a	116.8	119.5	21.4
2009	2.74	n/a	97.7	100.4	18.2
2010	8.20	n/a	69.5	77.7	18.5
2011	8.63	n/a	92.4	101.0	23.6
2012	8.03	n/a	46.9	54.9	14.2
2013	5.14	0.0	88.2	93.4	20.2
2014	3.01	0.0	79.7	83.5	20.3
2015	2.54	0.0	49.1	51.8	12.0
2016	0.82	0.0	61.2	62.0	18.2

SE = standard error of the mean

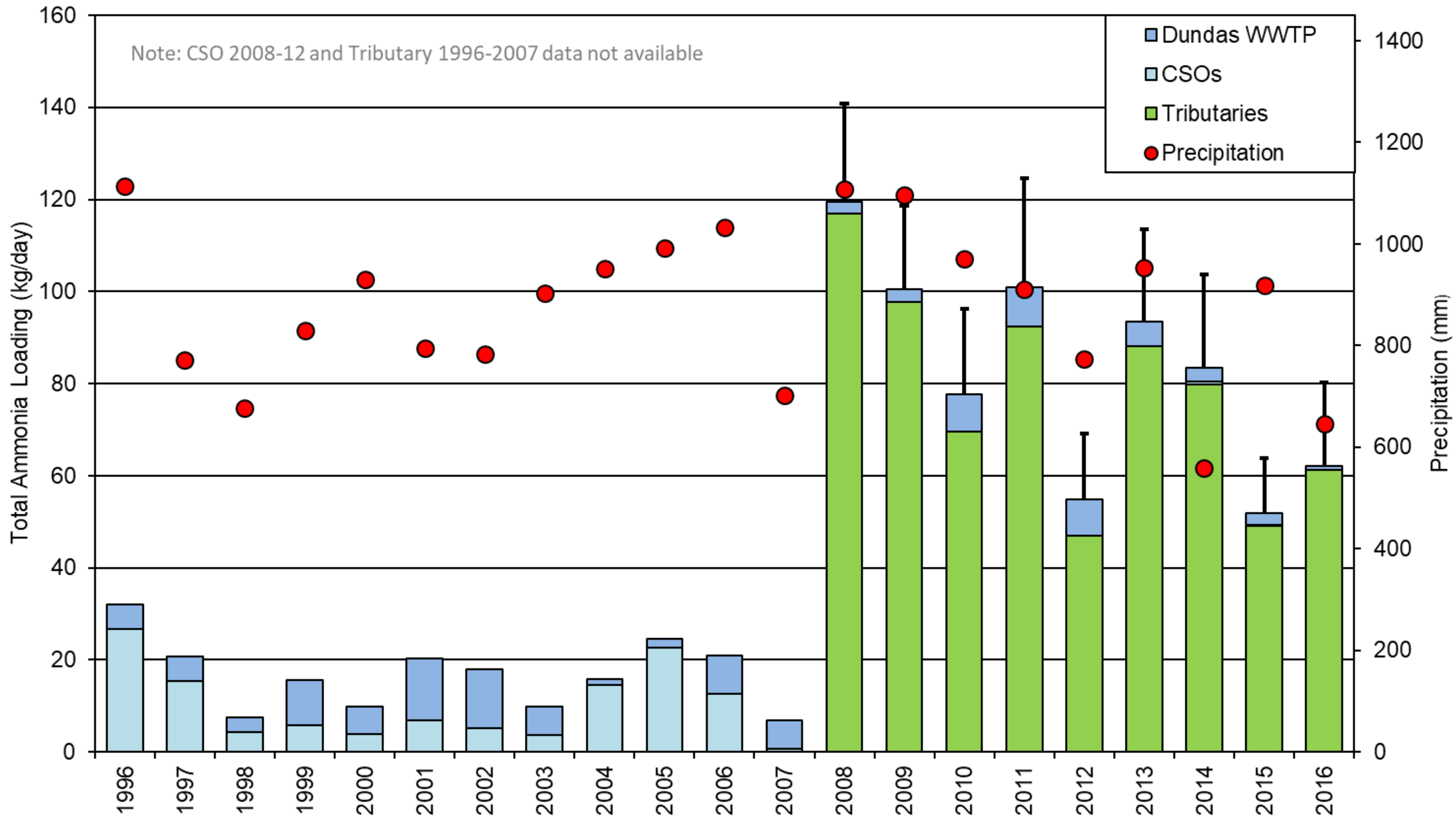

Figure 29. Total Ammonia loadings to Cootes Paradise (kg/day).

7.4 Total Nitrate

Table 42. Total Nitrate loadings to Hamilton Harbour (kg/day).

Total Nitrate (kg/day)											
Year	**Skyway WWTP**	**Woodward WWTP**	**AMD**	**Stelco**	**CSOs**	**Indian Creek**	**Grindstone Creek**	**Red Hill Creek**	**Cootes Paradise**	**Total**	**SE**
1996	n/a	n/a	no data	no data	no data	no data	no data	no data	no data	no data	no data
1997	n/a	n/a	no data	no data	no data	no data	no data	no data	no data	no data	no data
1998	n/a	n/a	no data	no data	no data	no data	no data	no data	no data	no data	no data
1999	n/a	n/a	no data	no data	no data	no data	no data	no data	no data	no data	no data
2000	n/a	n/a	no data	no data	no data	no data	no data	no data	no data	no data	no data
2001	n/a	n/a	no data	no data	no data	no data	no data	no data	no data	no data	no data
2002	n/a	n/a	no data	no data	no data	no data	no data	no data	no data	no data	no data
2003	n/a	n/a	no data	no data	no data	no data	no data	no data	no data	no data	no data
2004	n/a	n/a	no data	no data	no data	no data	no data	no data	no data	no data	no data
2005	n/a	n/a	no data	no data	no data	no data	no data	no data	no data	no data	no data
2006	n/a	n/a	no data	no data	no data	no data	no data	no data	no data	no data	no data
2007	n/a	n/a	no data	no data	no data	no data	no data	no data	no data	no data	no data
2008	2608	5197	no data	no data	no data	no data	135.0	no data	495	8435	159
2009	2789	4730	no data	no data	no data	49.7	89.9	91.0	416	8164	144
2010	2624	4890	no data	no data	no data	44.2	75.6	80.0	318	8032	151
2011	2854	5023	no data	no data	no data	55.0	99.9	103.6	415	8551	140
2012	2581	4936	no data	no data	no data	33.4	40.0	52.5	228	7871	111
2013	2670	5134	no data	no data	no data	47.5	79.4	84.8	382	8397	141
2014	2678	4917	no data	no data	no data	40.0	84.0	68.2	335	8123	135
2015	2597	4779	no data	no data	no data	36.3	41.6	61.0	211	7725	150
2016	2699	4557	no data	no data	no data	no data	50.5	no data	267	7574	118

n/a = data not available
SE = standard error of the mean

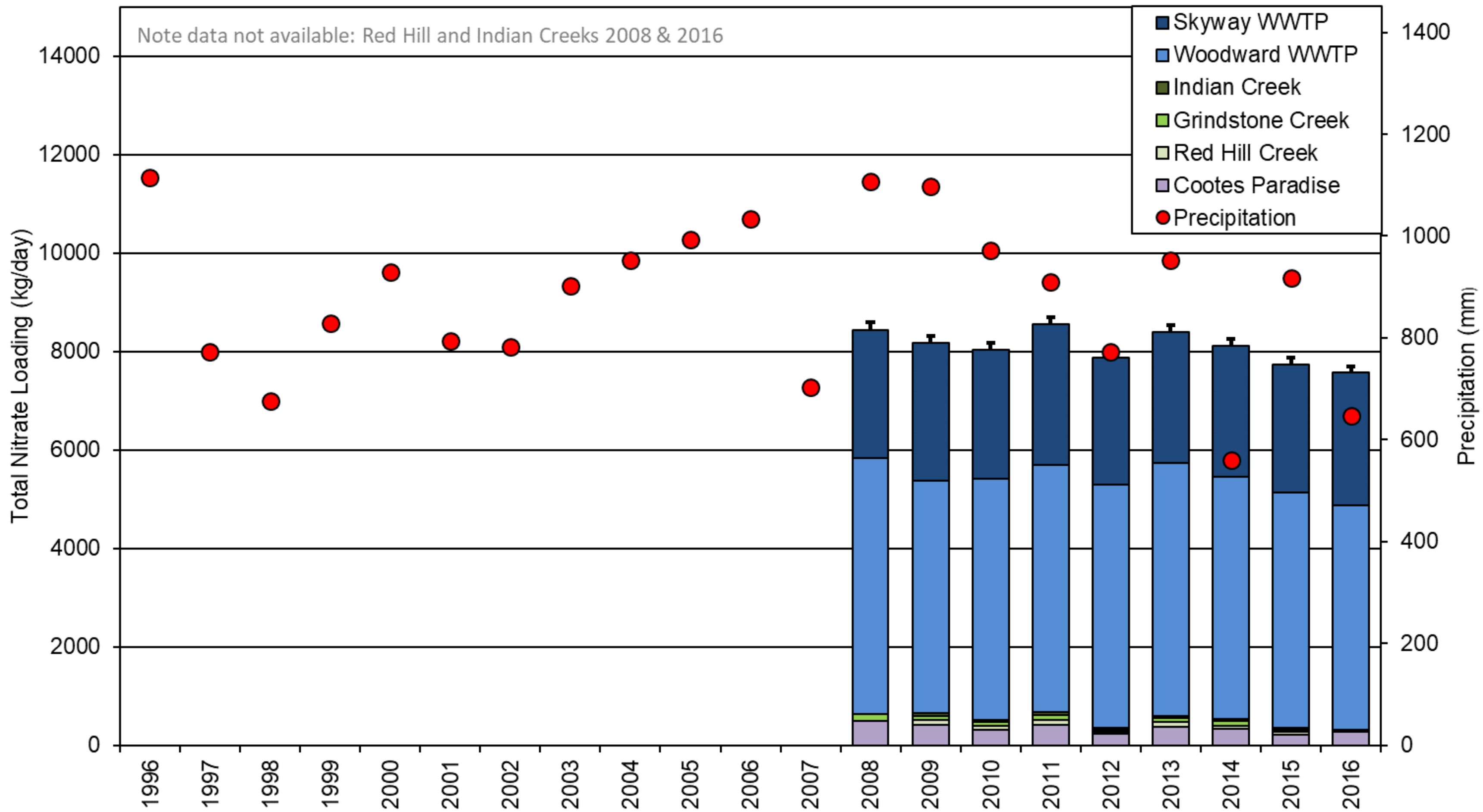

Figure 30. Total Nitrate loadings to Hamilton Harbour (kg/day).

Table 43. Total Nitrate loadings to Cootes Paradise (kg/day).

Total Nitrate (kg/day)					
Year	**Dundas WWTP**	**CSOs**	**Tributaries**	**Total**	**SE**
1996	n/a	no data	no data	no data	no data
1997	n/a	no data	no data	no data	no data
1998	n/a	no data	no data	no data	no data
1999	n/a	no data	no data	no data	no data
2000	n/a	no data	no data	no data	no data
2001	n/a	no data	no data	no data	no data
2002	n/a	no data	no data	no data	no data
2003	n/a	no data	no data	no data	no data
2004	n/a	no data	no data	no data	no data
2005	n/a	no data	no data	no data	no data
2006	n/a	no data	no data	no data	no data
2007	n/a	no data	no data	no data	no data
2008	255	no data	245	500	5
2009	256	no data	160	416	4
2010	253	no data	67	319	5
2011	218	no data	197	415	4
2012	239	no data	-12	227	7
2013	242	no data	141	383	7
2014	212	no data	123	335	4
2015	183	no data	28	211	7
2016	271	no data	-4	267	6

n/a = data not available, SE = standard error of the mean

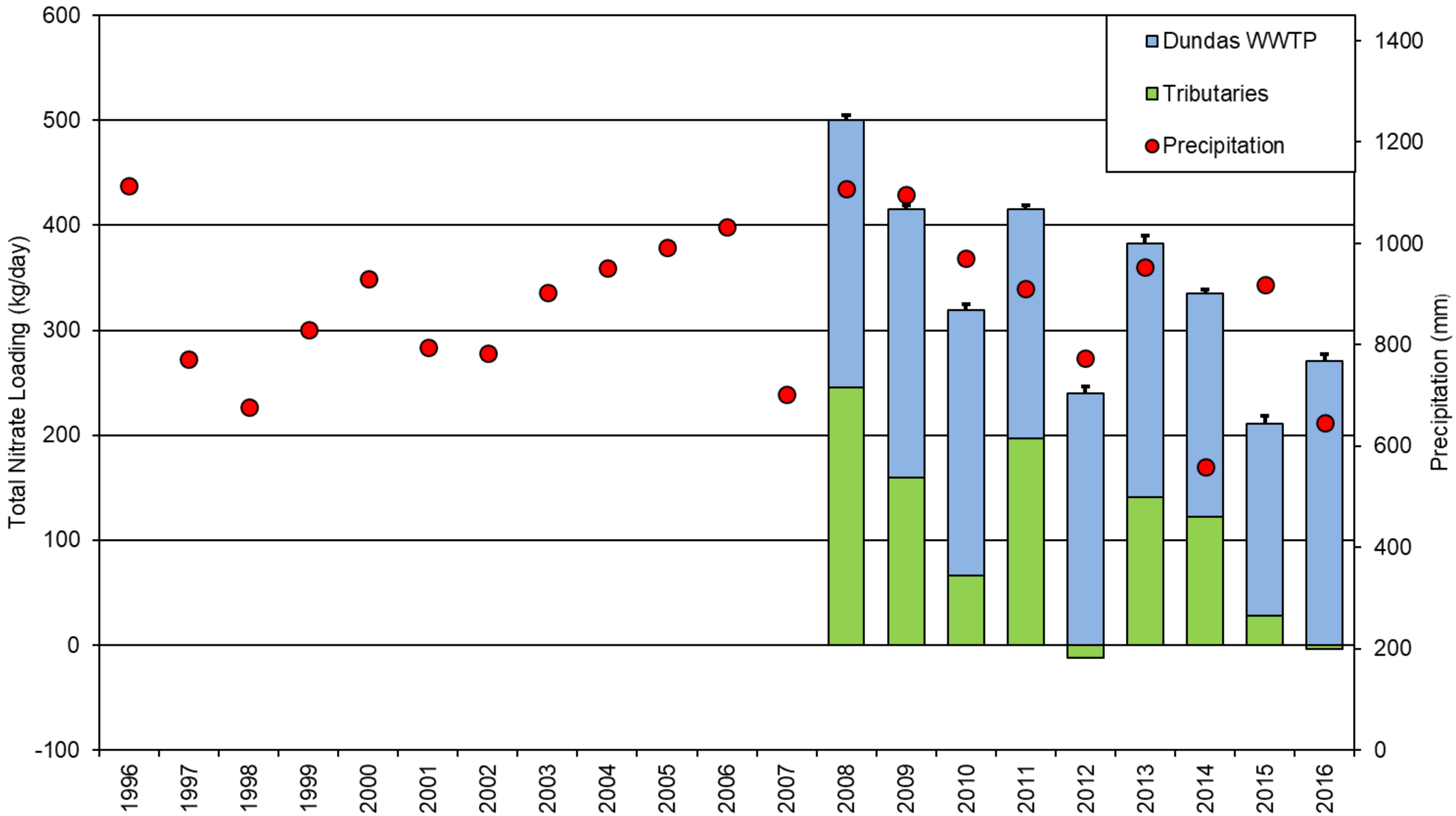

Figure 31. Total Nitrate loadings to Cootes Paradise (kg/day).

7.5 Total Kjeldahl Nitrogen (TKN)

Table 44. Total Kjeldahl Nitrogen loadings to Hamilton Harbour (kg/day).

Total Kjeldahl Nitrogen (kg/day)											
Year	Skyway WWTP	Woodward WWTP	AMD	Stelco	CSOs	Indian Creek	Grindstone Creek	Red Hill Creek	Cootes Paradise	Total	SE
1996	839	5030	no data	no data	388	no data	no data	no data	938	7195	no data
1997	1014	5174	no data	no data	208	no data	no data	no data	313	6708	no data
1998	644	4759	no data	no data	199	no data	no data	no data	304	5906	no data
1999	190	5249	no data	no data	235	no data	no data	no data	202	5876	no data
2000	197	4971	no data	no data	278	no data	no data	no data	241	5687	no data
2001	272	3860	no data	no data	332	no data	no data	no data	386	4850	no data
2002	330	3812	no data	no data	287	no data	no data	no data	268	4697	no data
2003	342	3338	no data	no data	345	no data	no data	no data	342	4367	no data
2004	216	3971	no data	no data	211	no data	no data	no data	395	4793	no data
2005	159	3351	no data	no data	604	no data	no data	no data	450	4564	no data
2006	137	2711	no data	no data	283	no data	no data	no data	543	3674	no data
2007	151	2036	no data	no data	61	no data	no data	no data	352	2600	no data
2008	172	2358	no data	no data	n/a	no data	123.8	no data	489	3143	157
2009	173	1528	no data	no data	n/a	47.3	78.4	89.1	396	2312	321
2010	153	1266	no data	no data	n/a	41.8	66.6	77.6	313	1918	121
2011	180	1388	no data	no data	n/a	53.1	93.6	94.9	402	2212	130
2012	143	670	no data	no data	n/a	31.7	31.4	36.5	188	1101	47
2013	188	732	no data	no data	n/a	45.5	70.0	74.4	369	1480	80
2014	293	1051	no data	no data	n/a	38.5	76.7	52.1	325	1836	111
2015	248	1460	no data	no data	n/a	34.5	32.5	48.9	190	2014	138
2016	103	1452	no data	no data	n/a	no data	45.5	no data	225	1826	74

n/a = data not available, SE = standard error of the mean

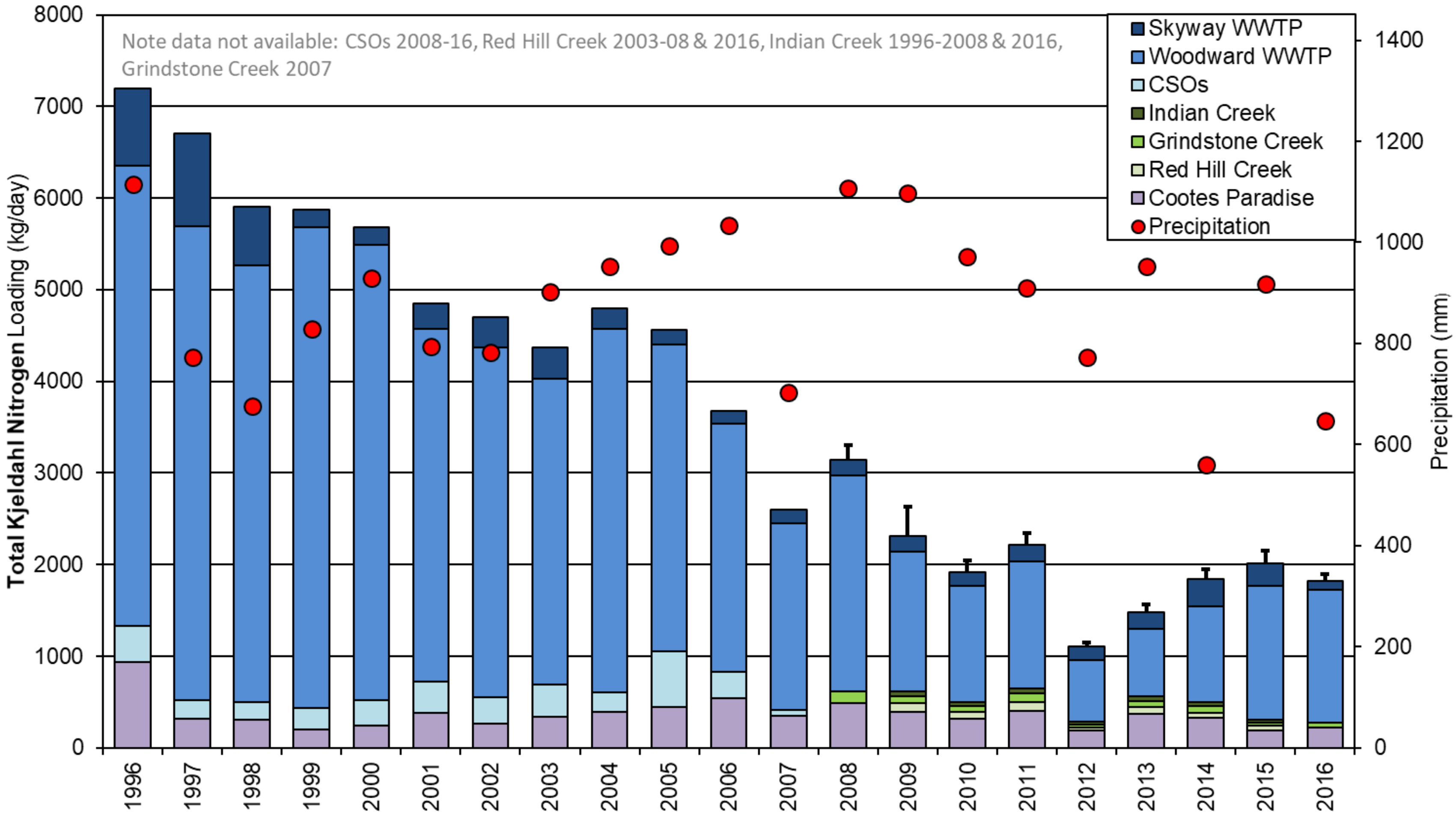

Figure 32. Total Kjeldahl Nitrogen loadings to Hamilton Harbour (kg/day).

Table 45. Total Kjeldahl Nitrogen loadings to Cootes Paradise (kg/day).

Total Kjeldahl Nitrogen (kg/day)					
Year	**Dundas WWTP**	**CSOs**	**Tributaries**	**Total**	**SE**
1996	22.2	51	no data	73.2	no data
1997	22.8	29	no data	51.8	no data
1998	22.3	8	no data	30.3	no data
1999	26.0	11	no data	37.0	no data
2000	24.4	7	no data	31.4	no data
2001	34.5	13	no data	47.5	no data
2002	33.8	10	no data	43.8	no data
2003	n/a	7	no data	7.0	no data
2004	n/a	28	no data	28.0	no data
2005	n/a	43	no data	43.0	no data
2006	n/a	24	no data	24.0	no data
2007	16.0	1	no data	17.0	no data
2008	16.7	n/a	472	489	86.8
2009	13.3	n/a	386	399	69.0
2010	17.2	n/a	295	312	80.3
2011	16.9	n/a	384	401	96.5
2012	20.6	n/a	169	189	35.7
2013	12.9	n/a	356	369	63.4
2014	9.2	n/a	315	324	81.5
2015	9.4	n/a	181	190	41.5
2016	8.2	n/a	28	36	11.0

n/a = data not available, SE = standard error of the mean

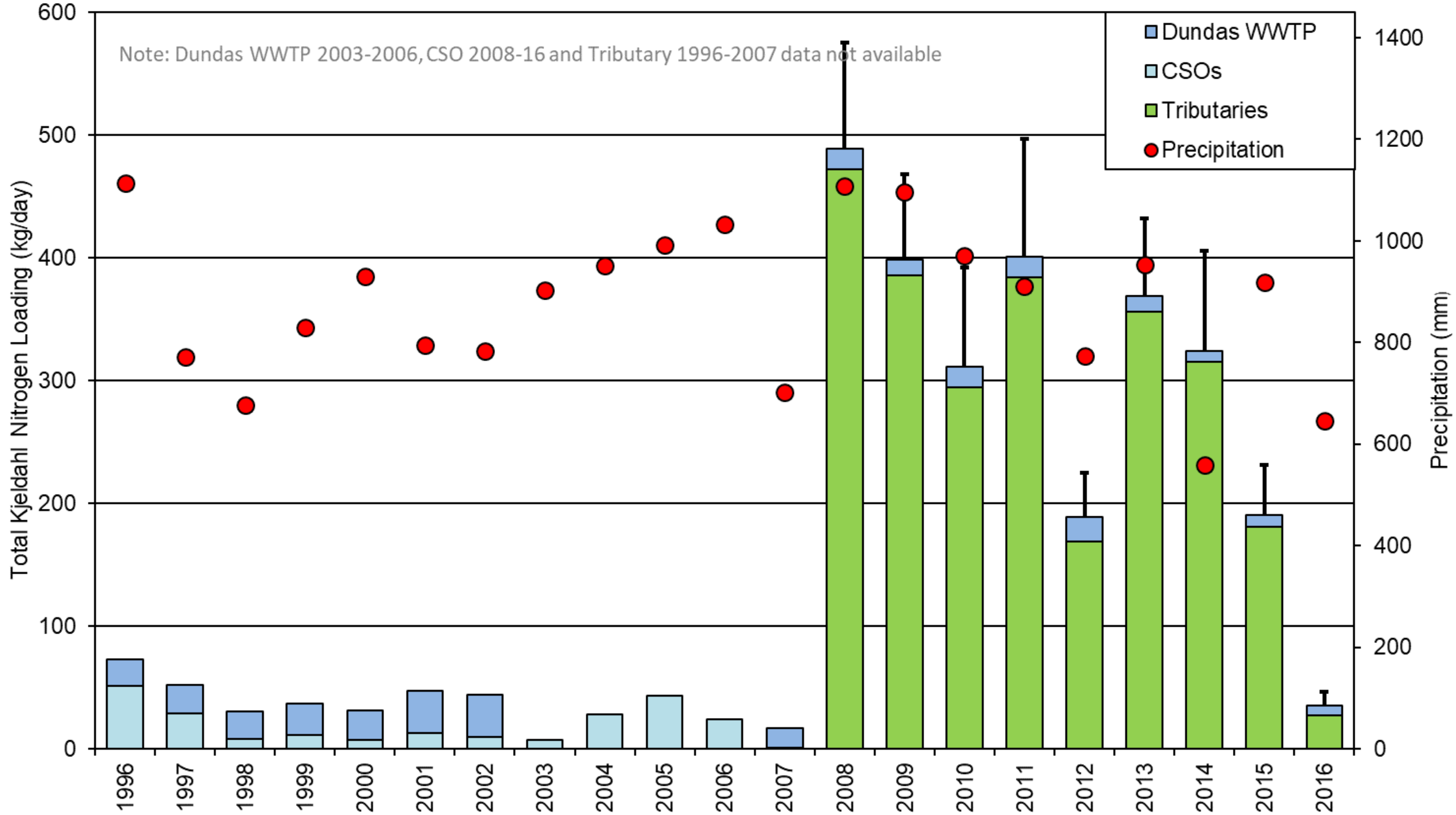

Figure 33. Total Kjeldahl Nitrogen loadings to Cootes Paradise (kg/day).

7.6 Iron (Fe)

Table 46. Iron loadings to Hamilton Harbour (kg/day).

Iron (kg/day)											
Year	**Skyway WWTP**	**Woodward WWTP**	**AMD**	**Stelco**	**CSOs**	**Indian Creek**	**Grindstone Creek**	**Red Hill Creek**	**Cootes Paradise**	**Total**	**SE**
1996	no data	472	540	no data	174	no data	865	284	no data	2335	no data
1997	50	483	371	no data	93	no data	605	121	no data	1723	no data
1998	66	1186	70	134.0	89	no data	544	179	no data	2268	no data
1999	98	580	96	87.0	105	no data	60	121	no data	1147	no data
2000	156	527	119	16.7	125	no data	530	202	no data	1676	no data
2001	53	553	86	2.0	149	no data	213	153	no data	1209	no data
2002	135	501	61	-20.4	129	no data	168	74	no data	1047	no data
2003	65	339	79	23.8	155	no data	341	no data	no data	1003	no data
2004	53	690	201	78.6	95	no data	302	no data	no data	1420	no data
2005	56	357	200	138.0	271	no data	479	no data	no data	1501	no data
2006	48	279	7	93.2	127	no data	572	no data	no data	1127	no data
2007	57	195	581	89.6	27	no data	no data	no data	no data	949	no data
2008	55	365	60	22.4	n/a	no data	106.4	no data	270	879	170
2009	59	184	75	6.4	n/a	30.0	54.2	105.6	212	726	112
2010	74	217	90	5.4	n/a	26.2	59.5	88.0	172	732	131
2011	60	238	121	7.4	n/a	32.1	67.0	88.7	210	824	99
2012	54	177	100	7.8	n/a	12.4	13.4	23.3	84	473	41
2013	60	151	74	4.5	n/a	25.1	46.1	73.2	187	622	84
2014	56	261	107	0.7	n/a	17.7	58.9	37.1	161	699	94
2015	52	140	99	1.6	n/a	16.6	18.1	38.7	87	453	47
2016	31	206	60	3.0	n/a	no data	26.3	no data	116	442	49

n/a = data not available, SE = standard error of the mean
As industries report net data instead of gross, a negative loading indicates the removal of more contaminant from the intake water than is put back through the effluent stream.

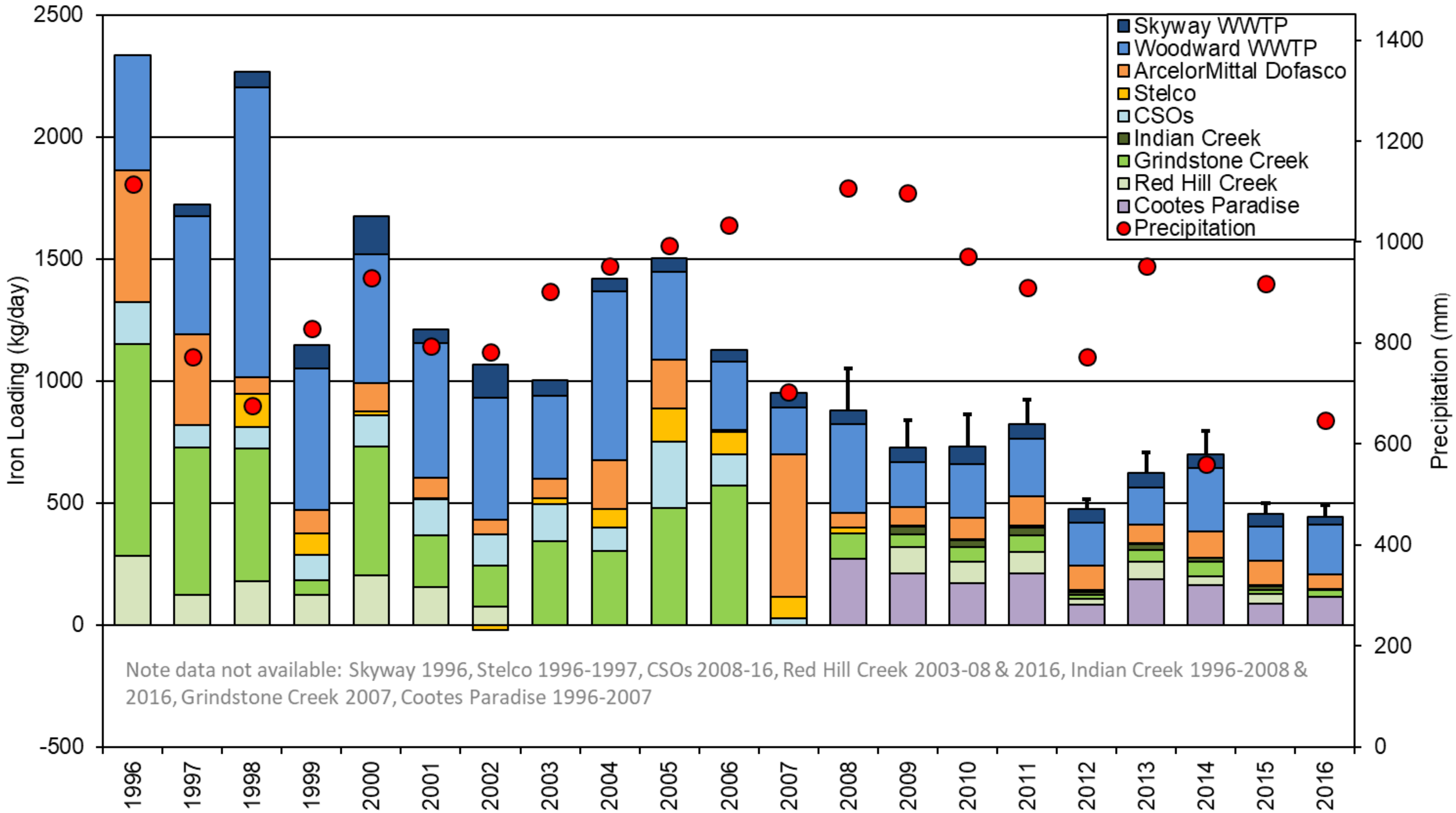

Figure 34. Iron loadings to Hamilton Harbour (kg/day).

Table 47. Iron loadings to Cootes Paradise (kg/day).

Iron (kg/day)					
Year	**Dundas WWTP**	**CSOs**	**Tributaries**	**Total**	**SE**
1996	3.7	23	581	608	no data
1997	4.1	13	428	445	no data
1998	2.1	4	320	326	no data
1999	9.1	5	43	57	no data
2000	6.6	3	308	318	no data
2001	5.9	6	150	162	no data
2002	4.4	4	86	94	no data
2003	n/a	3	318	321	no data
2004	n/a	13	315	328	no data
2005	n/a	19	472	491	no data
2006	n/a	11	370	381	no data
2007	2.03	1	218	221	no data
2008	1.94	n/a	239	241	62.0
2009	2.79	n/a	212	214	51.1
2010	3.75	n/a	167	170	66.4
2011	3.23	n/a	206	209	61.6
2012	2.64	n/a	82	85	16.4
2013	1.06	n/a	186	187	38.6
2014	1.63	n/a	160	161	52.4
2015	4.04	n/a	83	87	24.7
2016	2.68	n/a	114	117	43.4

n/a = data not available, SE = standard error of the mean

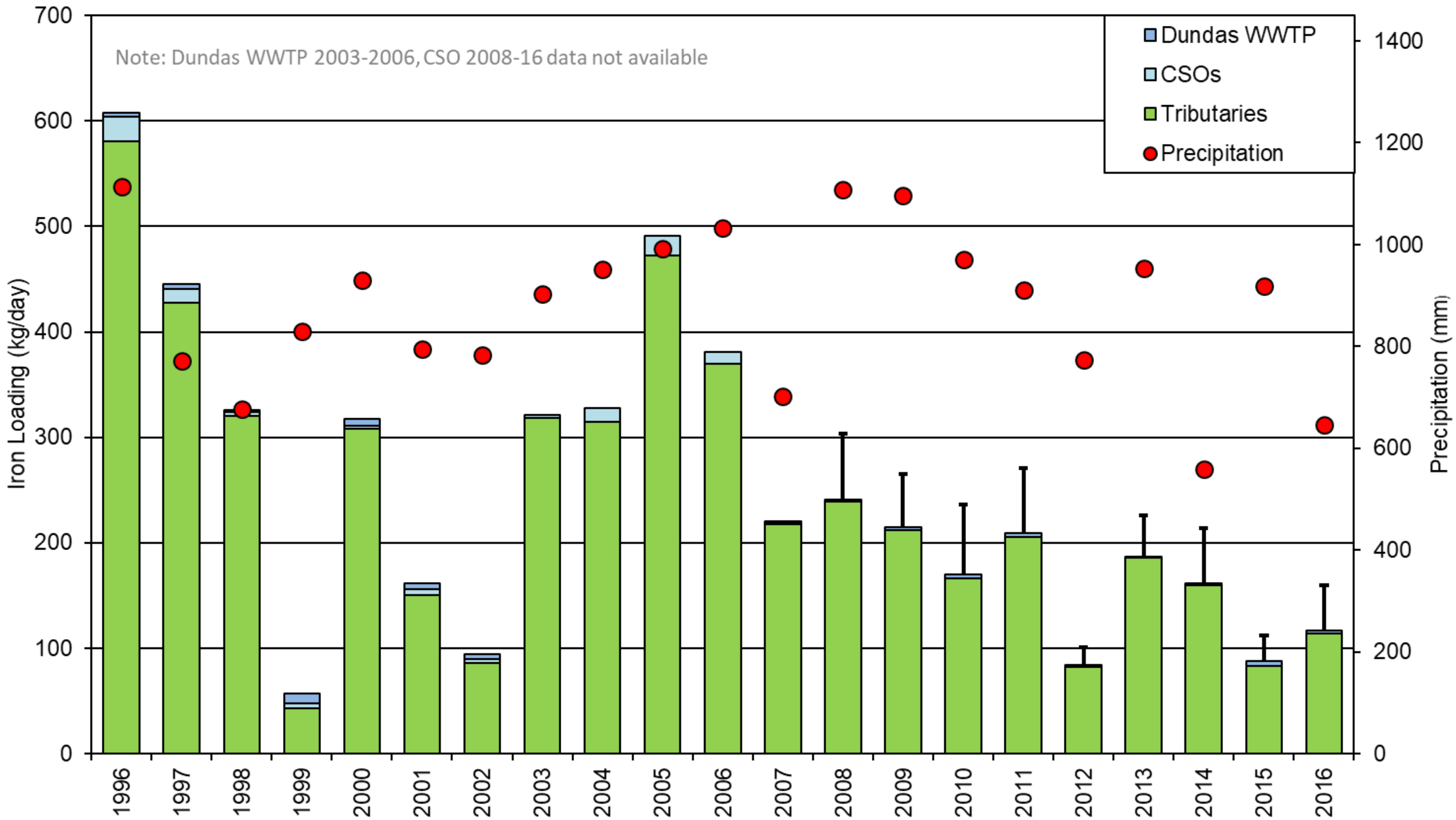

Figure 35. Iron loadings to Cootes Paradise (kg/day).

7.7 Lead (Pb)

Table 48. Lead loadings to Hamilton Harbour (kg/day).

Lead (kg/day)											
Year	Skyway WWTP	Woodward WWTP	AMD	Stelco	CSOs	Indian Creek	Grindstone Creek	Red Hill Creek	Cootes Paradise	Total	SE
1996	<MDL	27.1	-0.20	3.60	1.0	no data	0.40	0.60	no data	32.50	no data
1997	0.10	34.1	0.82	-0.97	0.5	no data	0.30	0.40	no data	35.25	no data
1998	<MDL	<MDL	0.12	0.22	0.5	no data	0.20	0.40	no data	1.44	no data
1999	<MDL	14.5	0.07	0.03	0.6	no data	0.20	0.40	no data	15.80	no data
2000	<MDL	6.9	0.42	0.43	0.7	no data	0.30	0.40	no data	9.15	no data
2001	<MDL	<MDL	0.19	-0.34	0.9	no data	0.30	0.50	no data	1.55	no data
2002	<MDL	<MDL	0.42	0.20	0.8	no data	0.20	0.40	no data	2.02	no data
2003	<MDL	1.3	0.63	-0.01	0.9	no data	0.30	no data	no data	3.12	no data
2004	<MDL	1.8	0.59	0.01	0.6	no data	0.30	no data	no data	3.30	no data
2005	<MDL	1.1	1.60	0.12	1.6	no data	0.30	no data	no data	4.72	no data
2006	<MDL	<MDL	1.50	0.06	0.7	no data	0.40	no data	no data	2.66	no data
2007	<MDL	0.30	4.01	0.02	0.2	no data	no data	no data	no data	4.53	no data
2008	0.15	0.92	0.81	0.16	n/a	no data	0.49	no data	1.30	3.83	0.78
2009	0.11	0.30	0.57	0.00	n/a	0.21	0.24	0.75	1.02	3.20	0.53
2010	0.11	0.31	1.30	-0.11	n/a	0.18	0.30	0.63	0.82	3.54	0.55
2011	0.13	0.36	0.94	-0.04	n/a	0.22	0.29	0.63	1.01	3.54	0.33
2012	0.07	0.29	0.53	-0.03	n/a	0.09	0.05	0.17	0.41	1.56	0.10
2013	0.05	0.28	1.84	0.00	n/a	0.17	0.20	0.52	0.90	3.96	0.35
2014	0.05	0.58	2.03	-0.01	n/a	0.12	0.26	0.27	0.77	4.06	0.32
2015	0.04	0.27	1.46	-0.01	n/a	0.12	0.07	0.28	0.42	2.65	0.16
2016	0.08	0.29	0.91	-0.01	n/a	no data	0.10	no data	0.56	1.94	0.12

n/a = data not available, SE = standard error of the mean, < MDL = concentrations were less than the method detection limit used
As industries report net data instead of gross, a negative loading indicates the removal of more contaminant from the intake water than is put back through the effluent stream.

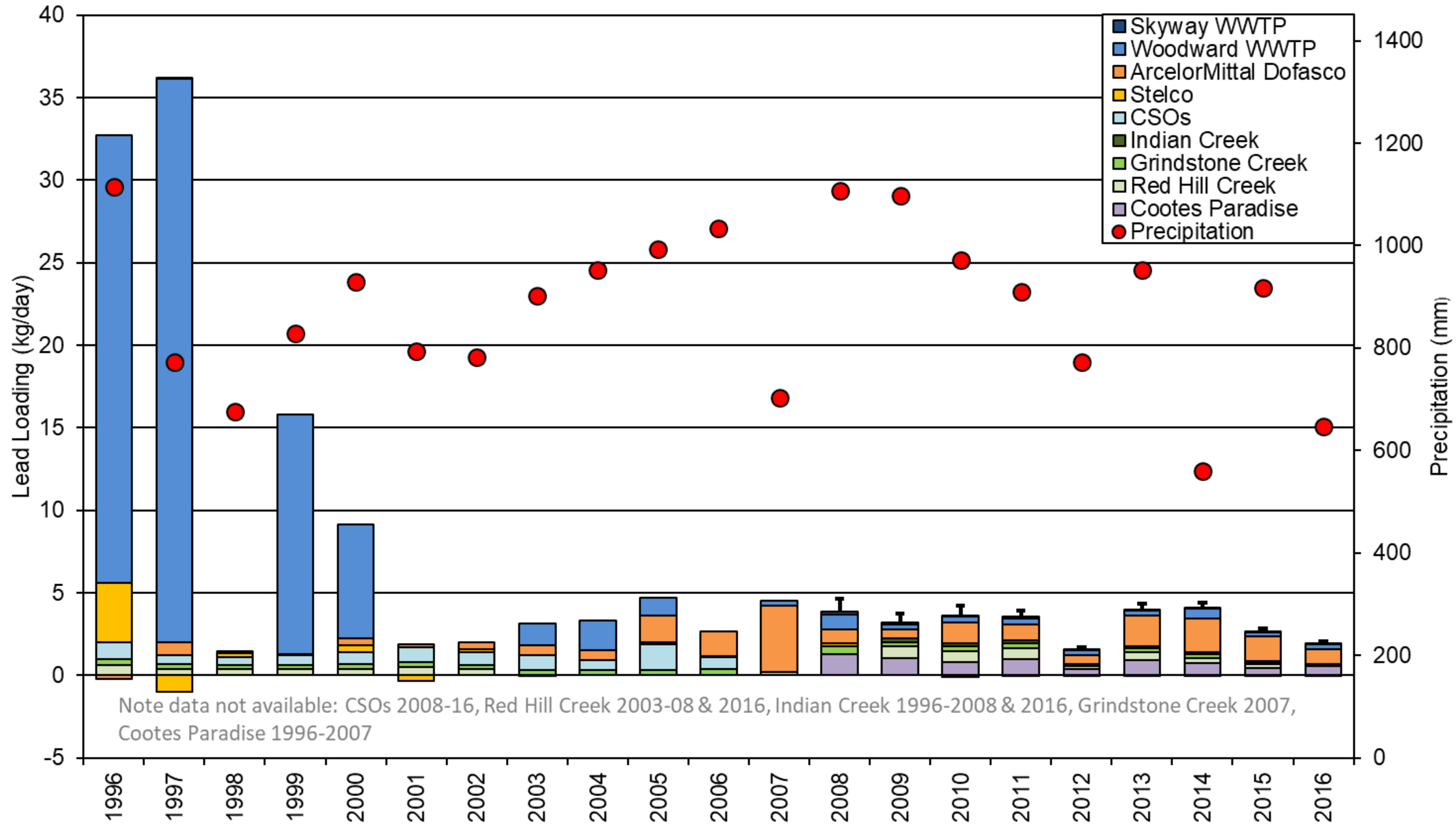

Figure 36. Lead loadings to Hamilton Harbour (kg/day).

Table 49. Lead loadings to Cootes Paradise (kg/day).

Lead (kg/day)					
Year	Dundas WWTP	CSOs	Tributaries	Total	SE
1996	1.30	0.10	2.40	3.8	no data
1997	<MDL	0.10	1.60	1.7	no data
1998	<MDL	0.02	1.20	1.2	no data
1999	<MDL	0.03	0.70	0.7	no data
2000	<MDL	0.02	1.50	1.5	no data
2001	<MDL	0.03	1.20	1.2	no data
2002	<MDL	0.03	1.00	1.0	no data
2003	n/a	0.02	1.40	1.4	no data
2004	n/a	0.07	1.40	1.5	no data
2005	n/a	0.11	1.60	1.7	no data
2006	n/a	0.06	2.00	2.1	no data
2007	0.01	0.00	1.10	1.1	no data
2008	0.02	n/a	1.12	1.1	0.3
2009	0.02	n/a	1.01	1.0	0.2
2010	0.02	n/a	0.80	0.8	0.3
2011	0.02	n/a	0.99	1.0	0.3
2012	0.02	n/a	0.39	0.4	0.1
2013	0.01	n/a	0.88	0.9	0.2
2014	0.01	n/a	0.76	0.8	0.3
2015	0.01	n/a	0.41	0.4	0.1
2016	0.01	n/a	0.55	0.6	0.2

n/a = data not available, SE = standard error of the mean
< MDL = concentrations were less than the method detection limit used

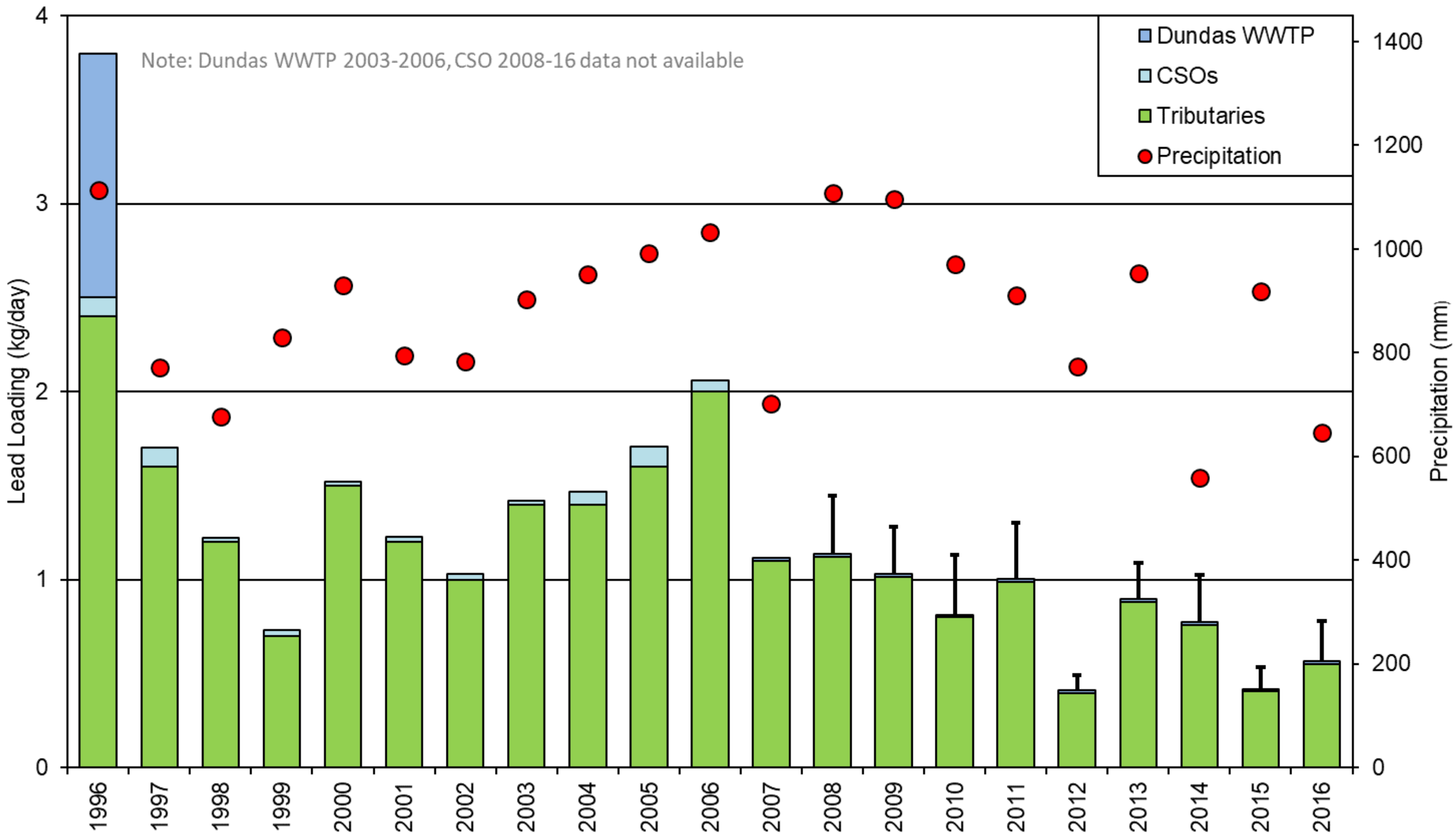

Figure 37. Lead loadings to Cootes Paradise (kg/day).

7.8 Zinc (Zn)

Table 50. Zinc loadings to Hamilton Harbour (kg/day).

Zinc (kg/day)											
Year	Skyway WWTP	Woodward WWTP	AMD	Stelco	CSOs	Indian Creek	Grindstone Creek	Red Hill Creek	Cootes Paradise	Total	SE
1996	2.29	34.9	27.1	29.70	5.7	no data	0.8	6.9	no data	107.4	no data
1997	1.56	32.8	11.1	3.44	3.0	no data	0.6	3.3	no data	55.8	no data
1998	1.62	12.4	4.0	4.51	2.9	no data	0.4	4.4	no data	30.2	no data
1999	<MDL	14.9	5.1	-1.54	3.4	no data	0.2	3.1	no data	25.2	no data
2000	1.91	17.3	7.8	3.95	4.0	no data	0.5	5.0	no data	40.5	no data
2001	2.16	11.8	11.4	6.17	4.8	no data	0.4	4.0	no data	40.7	no data
2002	3.14	15.3	11.0	5.25	4.2	no data	0.3	2.2	no data	41.4	no data
2003	3.57	20.2	27.0	0.21	5.0	no data	0.4	no data	no data	56.4	no data
2004	2.80	17.9	9.0	6.14	3.1	no data	0.4	no data	no data	39.3	no data
2005	3.60	17.8	8.7	18.85	8.8	no data	0.5	no data	no data	58.2	no data
2006	2.02	16.80	6.5	1.26	4.1	no data	0.6	no data	no data	31.3	no data
2007	2.82	11.40	14.2	3.28	0.9	no data	no data	no data	no data	32.6	no data
2008	3.15	13.11	7.8	1.13	n/a	no data	2.47	no data	10.41	38.1	4.5
2009	2.38	10.46	6.7	0.33	n/a	4.96	1.30	6.72	8.40	41.3	5.1
2010	2.70	9.04	5.6	0.49	n/a	4.39	1.37	5.74	6.45	35.8	4.7
2011	3.06	9.79	10.6	-0.44	n/a	5.57	1.60	6.41	8.30	44.9	3.9
2012	2.10	8.29	6.0	0.23	n/a	3.32	0.34	1.98	3.80	26.1	1.7
2013	2.46	9.36	9.9	-0.21	n/a	4.78	1.12	5.07	7.39	39.9	3.5
2014	2.61	14.11	17.4	-0.09	n/a	4.04	1.38	3.03	6.33	48.8	3.3
2015	2.78	12.69	7.7	-0.08	n/a	3.62	0.45	3.00	3.61	33.8	3.0
2016	2.75	10.84	6.4	-0.37	n/a	no data	0.65	no data	5.02	25.3	2.0

SE = standard error of the mean, < MDL = concentrations were less than the method detection limit used
As industries report net data instead of gross, a negative loading indicates the removal of more contaminant from the intake water than is put back through the effluent stream.

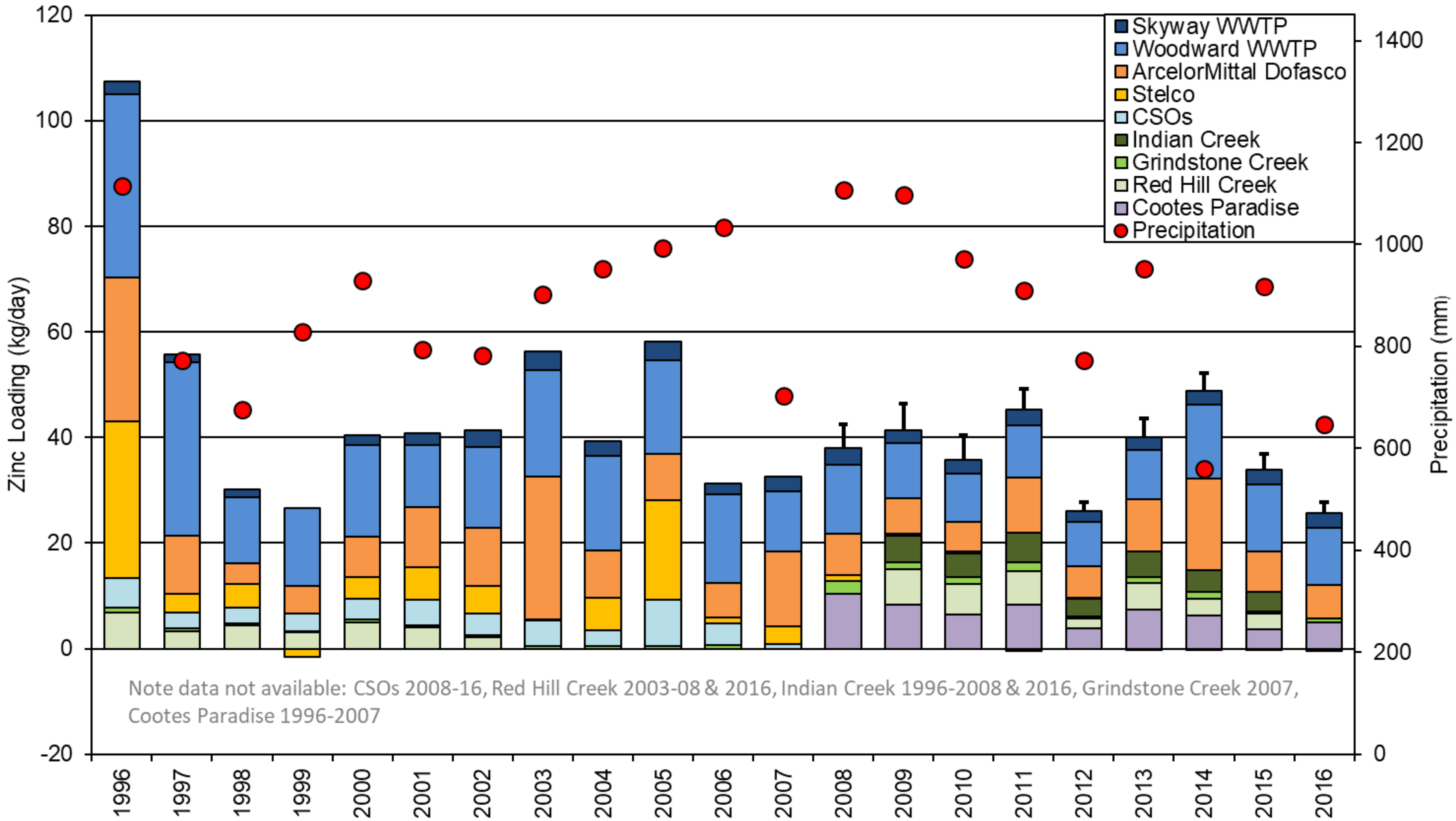

Figure 38. Zinc loadings to Hamilton Harbour (kg/day).

Table 51. Zinc loadings to Cootes Paradise (kg/day).

Zinc (kg/day)					
Year	Dundas WWTP	CSOs	Tributaries	Total	SE
1996	<MDL	0.7	16.1	16.8	no data
1997	1.0	0.4	11.7	13.1	no data
1998	0.3	0.1	8.7	9.1	no data
1999	0.8	0.2	1.7	2.7	no data
2000	0.8	0.1	8.7	9.6	no data
2001	0.7	0.2	4.7	5.6	no data
2002	0.5	0.1	3.0	3.6	no data
2003	n/a	1.0	8.9	9.9	no data
2004	n/a	0.4	8.8	9.2	no data
2005	n/a	0.6	12.7	13.3	no data
2006	n/a	0.4	10.7	11.1	no data
2007	0.43	0.02	6.20	6.6	no data
2008	0.28	n/a	8.24	8.5	2.9
2009	0.42	n/a	8.08	8.5	2.2
2010	0.47	n/a	5.93	6.4	2.5
2011	0.43	n/a	7.82	8.3	2.6
2012	0.45	n/a	3.35	3.8	0.9
2013	0.50	n/a	6.89	7.4	1.8
2014	0.47	n/a	5.87	6.3	2.2
2015	0.43	n/a	3.18	3.6	1.1
2016	0.43	n/a	4.62	5.1	1.9

n/a = data not available, SE = standard error of the mean
< MDL = concentrations were less than the method detection limit used

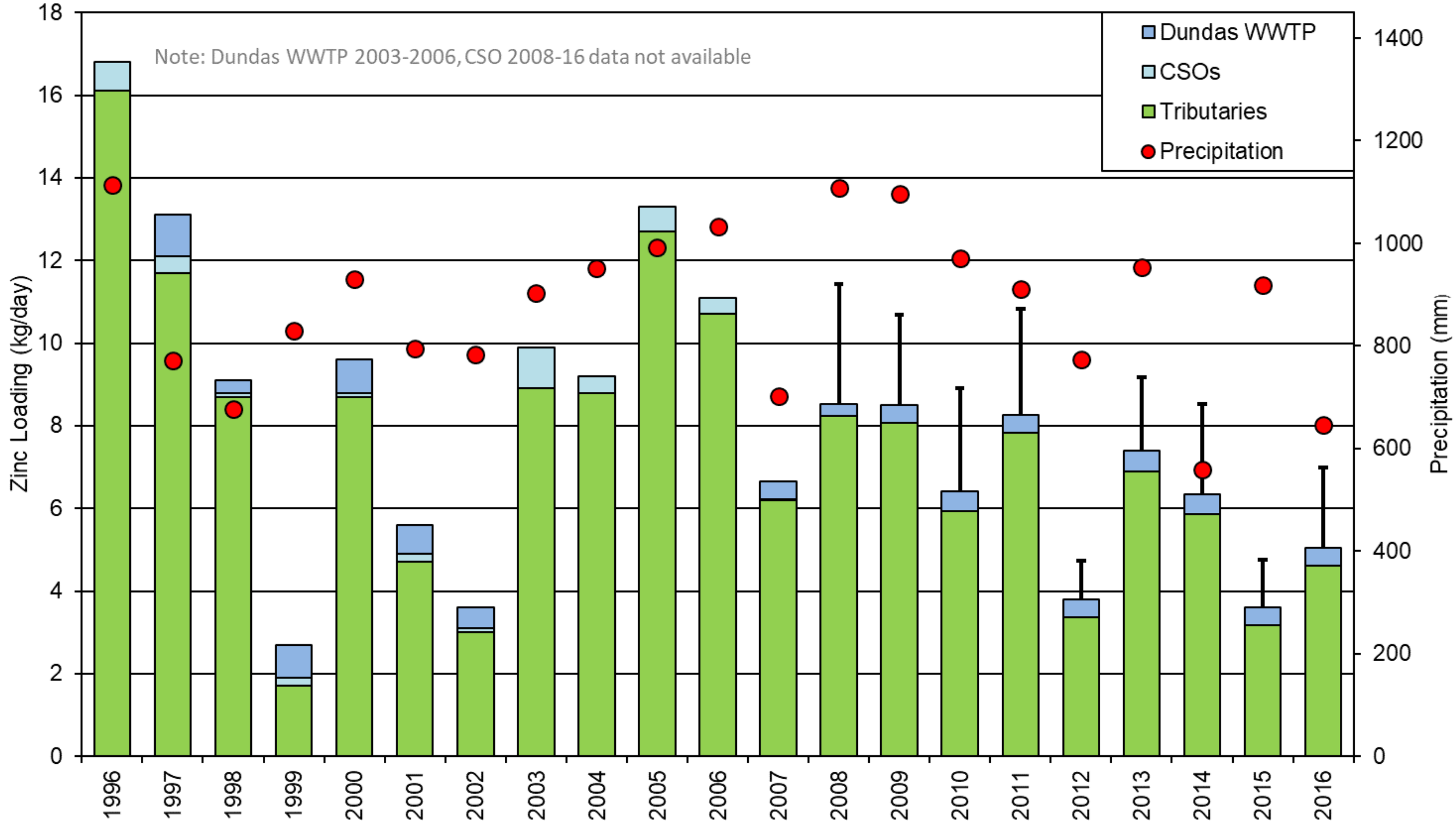

Figure 39. Zinc loadings to Cootes Paradise (kg/day).

7.9 Cyanide

No graphs are presented for Cyanide as there are not enough data to accurately estimate loadings.

In the 1990-1996 Loadings Report, three sources of Cyanide were reported: Dofasco, Stelco, and Cootes Paradise. The RAP Technical Team discussed the value of including Cootes Paradise estimates as a source, and decided that it should not be included in this report as there are no obvious inputs of Cyanide into Cootes Paradise.

Table 52. Cyanide loadings to Hamilton Harbour (kg/day).

Cyanide (kg/day)											
Year	**Skyway WWTP**	**Woodward WWTP**	**AMD**	**Stelco**	**CSOs**	**Indian Creek**	**Grindstone Creek**	**Red Hill Creek**	**Cootes Paradise**	**Total**	**SE**
1996	no data	no data	23.1	8.00	no data	no data	no data	no data	no data	31.1	no data
1997	no data	44.8	3.3	7.11	no data	no data	no data	no data	no data	55.2	no data
1998	no data	26.6	0.1	12.10	no data	no data	no data	no data	no data	38.8	no data
1999	no data	14.0	6.4	15.40	no data	no data	no data	no data	no data	35.8	no data
2000	no data	23.1	5.1	12.78	no data	no data	no data	no data	no data	41.0	no data
2001	no data	29.5	7.6	6.67	no data	no data	no data	no data	no data	43.8	no data
2002	no data	27.5	0.7	0.85	no data	no data	no data	no data	no data	29.1	no data
2003	no data	30.9	0.2	1.03	no data	no data	no data	no data	no data	32.2	no data
2004	no data	22.7	-2.7	2.57	no data	no data	no data	no data	no data	22.6	no data
2005	no data	25.6	0.5	0.98	no data	no data	no data	no data	no data	27.1	no data
2006	no data	25.31	0.8	1.61	no data	no data	no data	no data	no data	27.7	no data
2007	no data	30.90	1.1	1.24	no data	no data	no data	no data	no data	33.2	no data
2008	no data	19.71	-0.2	1.42	no data	no data	no data	no data	no data	20.9	3.0
2009	no data	14.85	0.2	0.16	no data	no data	no data	no data	no data	15.2	1.6
2010	no data	11.16	1.0	5.07	no data	no data	no data	no data	no data	17.2	2.0
2011	no data	5.68	0.9	0.10	no data	no data	no data	no data	no data	6.7	no data
2012	no data	no data	0.0	-0.45	no data	no data	no data	no data	no data	-0.4	no data
2013	no data	no data	0.9	-0.11	no data	no data	no data	no data	no data	0.8	no data
2014	no data	no data	0.6	-0.05	no data	no data	no data	no data	no data	0.5	no data
2015	no data	no data	0.4	-0.14	no data	no data	no data	no data	no data	0.3	no data
2016	no data	no data	0.4	-0.04	no data	no data	no data	no data	no data	0.4	no data

As industries report net data instead of gross, a negative loading indicates the removal of more contaminant from the intake water than is put back through the effluent stream.
SE = standard error of the mean

7.10 Phenolics

No graphs are presented for Phenolics as there are not enough data to accurately estimate loadings.

In the 1990-1996 Loadings Report, three sources of phenolics were reported: Dofasco, Stelco, and Cootes Paradise. The RAP Technical Team discussed the value of including Cootes Paradise estimates as a source, and decided that it should not be included in this report as there are no obvious inputs of phenolics into Cootes Paradise.

Table 53. Phenolics loadings to Hamilton Harbour (kg/day).

Phenolics (kg/day)											
Year	Skyway WWTP	Woodward WWTP	AMD	Stelco	CSOs	Indian Creek	Grindstone Creek	Red Hill Creek	Cootes Paradise	Total	SE
1996	<MDL	no data	8.40	5.97	no data	no data	no data	no data	no data	14.37	no data
1997	<MDL	no data	2.20	4.05	no data	no data	no data	no data	no data	6.25	no data
1998	<MDL	no data	0.78	0.32	no data	no data	no data	no data	no data	1.10	no data
1999	no data	no data	1.40	1.42	no data	no data	no data	no data	no data	2.82	no data
2000	<MDL	no data	1.60	-0.21	no data	no data	no data	no data	no data	1.39	no data
2001	<MDL	no data	1.40	1.02	no data	no data	no data	no data	no data	2.42	no data
2002	<MDL	no data	1.10	-0.26	no data	no data	no data	no data	no data	0.84	no data
2003	<MDL	no data	0.39	0.10	no data	no data	no data	no data	no data	0.49	no data
2004	no data	1.7	0.90	1.31	no data	no data	no data	no data	no data	3.91	no data
2005	no data	2.0	1.10	0.09	no data	no data	no data	no data	no data	3.19	no data
2006	no data	1.6	2.40	-0.01	no data	no data	no data	no data	no data	3.99	no data
2007	no data	no data	0.89	-0.01	no data	no data	no data	no data	no data	0.88	no data
2008	no data	no data	0.84	-0.04	no data	no data	no data	no data	no data	0.80	no data
2009	no data	no data	0.81	0.01	no data	no data	no data	no data	no data	0.82	no data
2010	no data	no data	1.28	0.05	no data	no data	no data	no data	no data	1.33	no data
2011	no data	no data	1.53	0.08	no data	no data	no data	no data	no data	1.61	no data
2012	no data	no data	0.37	-0.64	no data	no data	no data	no data	no data	-0.27	no data
2013	no data	no data	0.20	-0.08	no data	no data	no data	no data	no data	0.12	no data
2014	no data	no data	1.80	-0.01	no data	no data	no data	no data	no data	1.79	no data
2015	no data	no data	1.17	0.00	no data	no data	no data	no data	no data	1.17	no data
2016	no data	no data	0.54	-0.01	no data	no data	no data	no data	no data	0.53	no data

SE = standard error of the mean, < MDL = concentrations were less than the method detection limit used
As industries report net data instead of gross, a negative loading indicates the removal of more contaminant from the intake water than is put back through the effluent stream.

7.11 Polycyclic Aromatic Hydrocarbons (PAHs)

No graphs are presented for PAHs as there are not enough data to accurately estimate PAH loadings.

ArcelorMittal Dofasco and Stelco have provided the RAP Office with loadings data for two prominent PAHs, Naphthalene and Benzo(a)pyrene. As they both report net loadings resulting from the treatment of Harbour intake water, some of the values are negative. This would indicate the industry removed more of the contaminant from the water than they put back through their effluent stream. The fluctuation of values around zero may represent error in the sampling method more than an actual change in loading.

Table 54. Benzo(a)pyrene loadings to Hamilton Harbour (kg/day).

PAH - Benzo(a)pyrene											
Year	Skyway WWTP	Woodward WWTP	AMD	Stelco	CSOs	Indian Creek	Grindstone Creek	Red Hill Creek	Cootes Paradise	Total	SE
1996	<MDL	no data	0.1000	0.0019	no data	no data	no data	no data	no data	0.1019	no data
1997	<MDL	no data	0.0000	-0.0044	no data	no data	no data	no data	no data	-0.0044	no data
1998	<MDL	no data	0.0000	0.0059	no data	no data	no data	no data	no data	0.0059	no data
1999	no data	no data	0.0000	-0.0213	no data	no data	no data	no data	no data	-0.0213	no data
2000	<MDL	no data	-0.0020	-0.0714	no data	no data	no data	no data	no data	-0.0734	no data
2001	<MDL	no data	0.0000	0.0056	no data	no data	no data	no data	no data	0.0056	no data
2002	<MDL	no data	0.0000	0.0154	no data	no data	no data	no data	no data	0.0154	no data
2003	<MDL	no data	-0.0070	0.0058	no data	no data	no data	no data	no data	-0.0012	no data
2004	no data	no data	0.0110	-0.0072	no data	no data	no data	no data	no data	0.0038	no data
2005	no data	no data	0.0000	-0.0023	no data	no data	no data	no data	no data	-0.0023	no data
2006	no data	no data	-0.0030	-0.0069	no data	no data	no data	no data	no data	-0.0099	no data
2007	no data	no data	-0.0007	0.0409	no data	no data	no data	no data	no data	0.0402	no data
2008	no data	no data	0.0840	-0.0023	no data	no data	no data	no data	no data	0.0817	no data
2009	no data	no data	0.0060	-0.0003	no data	no data	no data	no data	no data	0.0057	no data
2010	no data	no data	0.0060	0.0027	no data	no data	no data	no data	no data	0.0087	no data
2011	no data	no data	0.0090	-0.0003	no data	no data	no data	no data	no data	0.0087	no data
2012	no data	no data	0.0140	0.0000	no data	no data	no data	no data	no data	0.0140	no data
2013	no data	no data	0.0100	0.0006	no data	no data	no data	no data	no data	0.0106	no data
2014	no data	no data	0.0020	0.0001	no data	no data	no data	no data	no data	0.0021	no data
2015	no data	no data	0.0020	-0.0002	no data	no data	no data	no data	no data	0.0018	no data
2016	no data	no data	0.0000	0.0002	no data	no data	no data	no data	no data	0.0002	no data

SE = standard error of the mean, < MDL = concentrations were less than the method detection limit used
As industries report net data instead of gross, a negative loading indicates the removal of more contaminant from the intake water than is put back through the effluent stream.

Table 55. Naphthalene loadings to Hamilton Harbour (kg/day).

PAH - Napthalene											
Year	**Skyway WWTP**	**Woodward WWTP**	**AMD**	**Stelco**	**CSOs**	**Indian Creek**	**Grindstone Creek**	**Red Hill Creek**	**Cootes Paradise**	**Total**	**SE**
1996	0.0820	no data	0.1900	-0.0136	no data	no data	no data	no data	no data	0.2584	no data
1997	<MDL	no data	-0.0020	0.0016	no data	no data	no data	no data	no data	-0.0004	no data
1998	<MDL	no data	-0.0120	-0.0561	no data	no data	no data	no data	no data	-0.0681	no data
1999	no data	no data	0.0240	-0.0264	no data	no data	no data	no data	no data	-0.0024	no data
2000	<MDL	no data	-0.0003	-0.0002	no data	no data	no data	no data	no data	-0.0005	no data
2001	<MDL	no data	0.0000	-0.0012	no data	no data	no data	no data	no data	-0.0012	no data
2002	<MDL	no data	0.0000	-0.1410	no data	no data	no data	no data	no data	-0.1410	no data
2003	<MDL	no data	-0.0070	-0.0293	no data	no data	no data	no data	no data	-0.0363	no data
2004	no data	no data	0.0010	0.0496	no data	no data	no data	no data	no data	0.0506	no data
2005	no data	no data	0.0000	0.0535	no data	no data	no data	no data	no data	0.0535	no data
2006	no data	no data	-0.0200	-0.0105	no data	no data	no data	no data	no data	-0.0305	no data
2007	no data	no data	-0.0060	-0.0028	no data	no data	no data	no data	no data	-0.0088	no data
2008	no data	no data	0.0040	-0.0002	no data	no data	no data	no data	no data	0.0038	no data
2009	no data	no data	0.0000	0.0080	no data	no data	no data	no data	no data	0.0080	no data
2010	no data	no data	0.0160	0.0005	no data	no data	no data	no data	no data	0.0165	no data
2011	no data	no data	0.0010	0.0039	no data	no data	no data	no data	no data	0.0049	no data
2012	no data	no data	0.0130	-0.0002	no data	no data	no data	no data	no data	0.0128	no data
2013	no data	no data	0.0000	-0.0050	no data	no data	no data	no data	no data	-0.0050	no data
2014	no data	no data	0.0250	0.0012	no data	no data	no data	no data	no data	0.0262	no data
2015	no data	no data	0.0000	0.0088	no data	no data	no data	no data	no data	0.0088	no data
2016	no data	no data	0.0000	0.0089	no data	no data	no data	no data	no data	0.0089	no data

SE = standard error of the mean, < MDL = concentrations were less than the method detection limit used
As industries report net data instead of gross, a negative loading indicates the removal of more contaminant from the intake water than is put back through the effluent stream.

Appendix A. References

*NOTE: Reports available in the Hamilton Harbour RAP Library are given a catalogue number, these numbers appear in brackets after the reference (e.g. HH-****)*

Boyd, D. 2017. Recommended Approaches for Estimating Hamilton Harbour Tributary Loadings: Nutrients, Suspended Solids, and Metals. (Final Report to the Hamilton Harbour Remedial Action Plan).

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Hamilton Harbour RAP. September 1998. Remedial Action Plan for Hamilton Harbour. 1998 Status Report. Third Printing, March 1999. ISBN 0-662-27238-2 *(HH-1554)*

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Labencki, T. August 2008. An Assessment of Polychlorinated Biphenyls (PCBs) in the Hamilton Harbour Area of Concern (AOC) in Support of the Beneficial Use Impairment (BUI): *Restrictions on Fish and Wildlife Consumption*. ISBN: 978-0-9810874-0-5

Labencki, T. December 2009. 2007 Field Season in the Hamilton Harbour Area of Concern. PCB and PAH water monitoring undertaken by the Ontario Ministry of the Environment to support mass balance work by the Hamilton Harbour Remedial Action Plan (RAP) on PAH contamination at Randle Reef and PCB contamination in Windermere Arm. ISBN: 978-0-9810874-2-9

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Appendix B.

RECOMMENDED APPROACHES FOR ESTIMATING HAMILTON HARBOUR TRIBUTARY LOADINGS: NUTRIENTS, SUSPENDED SOLIDS, AND METALS

Prepared for the Hamilton Harbour Remedial Action Plan

Duncan Boyd

DECEMBER 2017

1. INTRODUCTION

This report documents the analysis of 2010 to 2012 water quality and flow data to estimate tributary loadings of nutrients (Total Phosphorus, Total Kjeldahl Nitrogen[1], Total Ammonia[2], Total Nitrate[3]), Total Suspended Solids, and metals (Iron, Lead and Zinc) into Hamilton Harbour. Sample collection and analysis were undertaken as part of a comprehensive event-based water quality monitoring study undertaken by MOECC in partnership with Conservation Halton, Royal Botanical Gardens and the City of Hamilton. Sampling was undertaken over the period July 2010 through May 2012 at three tributaries flowing into Hamilton Harbour (Red Hill Creek, Indian Creek, Grindstone Creek) as well as at the Desjardins Canal which connects the Cootes Paradise Marsh to the harbour. These data have previously been analyzed to evaluate the significance of wet-weather events and seasonality on nutrient dynamics in these watersheds as well as to estimate tributary loads of Total Phosphorus (TP) (Long et al. 2014, Long et al. 2015).

A key application of this previous work was the development of a regression-based approach for estimation of TP loads that evaluated the relationship between log-transformed average 24-hour event flows and the log-transformed 24-hour level-weighted TP concentration. These regressions were found to be highly statistically significant ($p < 0.001$) with coefficients of determination (r^2 representing the proportion of the variance in the dependent variable that is predictable from the independent variable) generally greater than 0.50. The regression equations allowed the use of daily flow data to estimate corresponding daily TP concentrations which were in turn used to compute annual and seasonal loads. At Grindstone Creek evaluation of the data by Long et al. (2015) led to the calculation of separate seasonal regression equations for summer (June through October) and winter (November through May) since these yielded higher r^2 results than the pooled annual data. This seasonal improvement in the r^2 was not observed at other tributary locations.

Unlike the other tributaries, TP regression analysis for the Desjardins Canal did not yield any reliable relationship between flow and concentration so the authors derived a three-factor model that combined a time series sinusoidal TP concentration function with a precipitation-TP concentration regression (to estimate CSO flow events) and a winter flow-TP concentration regression that captured snow melt. The sine-wave model was empirically derived to account for a general pattern of lower winter and higher summer TP concentrations and was hypothesized to reflect ecological processes in the Cootes Paradise marsh rather than seasonal variation in loads to the marsh from the Dundas WWTP or tributary inputs. The authors acknowledged that this model would require updating following the completion of urban stormwater retention infrastructure which would greatly diminish CSO flows into the Cootes Paradise marsh and which has been operational since 2012 and thus would affect the estimation of more recent loadings.

Long et al. (2015) compared the regression-based daily loading estimates for tributaries with those derived in previous RAP Loadings Reports and estimates based on the use of PWQMN data and showed that these other methods significantly underestimated loads associated with high flow events but also tended to over-estimate loads associated with base-flows. The paper recommended application of a regression-based methodology for TP loading estimates in future RAP Loadings Report updates since it would require availability of only flow data and would yield superior estimates for high flow event loads and seasonal distributions than the previous approach.

Long et al. (2014) noted a positive relationship between flow and Total Suspended Solids (TSS) and Total Kjeldahl Nitrogen (TKN). The RAP Loadings Report includes results for these substances as well as Iron (Fe), Lead (Pb) and Zinc (Zn) and since it is well-established that metals can be strongly associated with TSS due to particulate adsorption, it is reasonable to surmise that the regression methodology may be applicable for them also. Long et al. (2014) also examined flow-concentration relationships for Total Ammonia and Total Nitrate

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[1] *Total Organic Nitrogen plus Ammonia*
[2] *The sum of un-ionized Ammonia and Ammonium*
[3] *The sum of Nitrite and Nitrate*

and noted no consistent relationships across tributaries with a range of regression slopes and r^2 values. Although tributary loadings for these substances have not been included in previous iterations of the RAP Loadings Report the RAP Technical Team has recommended that they be added for future reports since they will be useful for assessing nutrient dynamics through application of the harbour eutrophication model developed by University of Toronto.

Given the work undertaken to date and the Technical Team recommendation to expand the list of substances considered when estimating tributary loading estimates, the following analysis seeks to:

(a) Assess the *log [flow]* versus *log [contaminant]* regressions using the 2010-2012 data for TP, TSS, TKN, Total Ammonia, Total Nitrate, Pb, Fe and Zn for Red Hill Creek, Indian Creek, Grindstone Creek and Desjardins Canal;

(b) Evaluate the regression approach using available data for Spencer Creek from the Hamilton Conservation Authority; and

(c) Review and recommend alternative load estimation methodologies for parameters and tributaries where the regression approach is not suitable due to the lack of a statistically significant relationship between flow and contaminant concentration or where the flow accounts for less than 50% of the variance in the concentration (i.e. $r^2 < 0.50$).

2. METHODS

Background

Depending on location, water quality samples were collected on 80 to 87 days during the July 2010 to May 2012 period with at least 75% of samples taken during rain or snow melt events[4].The current exercise seeks to use the July 2010 to May 2012 data set to interpolate loadings for days where only flow data are available during this period as well as to extrapolate loadings for days prior to July 2010 and after May 2012 based solely on flow data. Estimation of loads in 2010 and 2012 requires both interpolation and extrapolation since sampling was not undertaken throughout the entire year. Extrapolated loading estimates for years prior to 2010 and after 2012 are undertaken with the realization that these estimates cannot account for any factors that would alter the flow or water quality, or the relationship between them. For example, it is possible that changing land use through urbanization, or improved nutrient management and erosion control, will occur during the period of extrapolated loading estimates and hence such an extrapolation can only be sustained for so long before the cumulative influence of such factors requires updated water quality information. Although future event-based sampling results should be undertaken at some point, even best-case sampling efforts incorporate large relative error terms for loadings (see Results section) and will yield widely diverging seasonal and annual loading estimates due to differences in the amount and distribution of precipitation. Any systematic bias for the period prior to 2010 and since 2012 based on 2010 to 2012 data will be small relative to the error term and variability in loads attributable to wet and dry years[5].

Load Estimation Approaches

The most commonly used approaches to estimating contaminant loads are averaging estimators, regression methods and ratio estimators. Combinations of these approaches were evaluated in this study. A very brief summary is provided here since there are numerous descriptions and comparisons of these approaches

[4] *Typically eight additional "duplicate" samples were taken during the period*

[5] *There is no analytical methodology with sufficient statistical power to discern such systematic bias through typical ongoing monitoring efforts. A decision as to when future intensive, event-based sampling needs to be undertaken to avoid extrapolating from obsolete data will require a review of land use change and aggregate implementation of stewardship programs within the watersheds of interest.*

available (for example Dolan et al. 1981, Preston et al. 1989, Richards 1998, Fox et al. 2005, Quilbe et al. 2006, Zamyadi et al. 2007).

Averaging
Averaging estimators generate annual estimates by using averages for a given time interval as representative measures of flow and concentration to yield load and then summing over the year. A best-case example would involve the calculation of daily loads from daily average flows and daily contaminant concentrations and summing these to derive the annual total. Although this approach is flexible and easy to apply, most sampling programs do not collect data at a sufficient frequency to characterize the entire range of flow and concentration values and violations of implicit assumptions such as independent and identically distributed data result in biased estimates. Typically loads will be underestimated in instances where there is a positive correlation between flow and concentration and overestimated when the correlation is negative (Fox et al. 2005). This method is recommended in situations where there is no correlation between contaminant concentration and flow since the best estimate of concentration over time is the mean, and the best estimate of load values is the mean concentration times the total flow (Dickinson and Rudra, 2015).

Regression
Regression methods quantify the regression relationship between concentration and flow (and other variables if desired) based on the days on which water quality samples are obtained. Once the regression relationship is established, it is used to estimate concentrations for each day on which a sample was not taken, based on the flow (usually the mean daily flow) for the day. The total load is calculated as the sum of the daily loads, obtained by multiplying the measured or concentration by the flow. In most applications, both concentration and flow are log-transformed due to the highly skewed distribution of both flow and concentration measurements and the tendency for the variability of both measures to increase for higher values. When log transformations are applied, the inverse transformation (exponentiation) is required to obtain estimated concentrations, since the regression model yields estimates of log-concentration rather than concentration. This transformation creates a bias in the loads, and further assumptions must be made (and validated) about the distribution of the residuals of the estimated concentrations to correct the bias (Richards 1998).

The regression relationship is frequently based on samples for a single year so that the relationship primarily serves to interpolate concentration results for unsampled days, but it can also be based on samples gathered over several years (as in this study). Incorporating several years of data has the obvious advantage of increasing the sample size and accounting for interannual variability resulting from wet and dry years. This provides a more robust basis for extrapolating beyond the sampled period although the correlation between flow and concentration may not be as strong as for any single year results. Calculation of separate seasonal regressions is sometimes warranted where there is a consistent change in the nature of the relationship due to factors other than flow (e.g. temperature or differing land use activity).

Load-Flow Ratio
The basis of ratio estimators is the assumption that the ratio of load to flow (dimensionally equivalent to the flow-weighted mean concentration) for the entire year is the same as the ratio of load to flow on the days concentration was measured. The daily load is calculated as the product of concentration and flow on days on which samples are taken and the mean of these loads is also calculated. The mean daily load is then adjusted by multiplying it by a flow ratio, which is derived by dividing the average flow for the year as a whole by the average flow for the days on which chemical samples were taken. A bias correction factor is included in the calculation, to compensate for the effects of correlation between discharge and load. The adjusted mean daily load is multiplied by 365 to obtain the annual load. In situations where there is an observable relationship between flow and concentration or season and concentration, the ratio estimator approach can be improved by stratifying the data. Separate calculations within each data stratum can then be combined to produce an annual total load estimate with less statistical error. When used in a stratified mode, the same process is applied within each stratum, and the stratum load is calculated by multiplying the mean daily load for the stratum by the

number of days in the stratum. The stratum loads are then summed to obtain the total annual load.

The most commonly applied version of this approach to Great Lakes data has been the Beale Ratio Estimator recommended by Dolan (1981) which applies a specific bias correction term. The expected bias of the Beale Ratio Estimator varies inversely as a function of n^2 and approaches zero very quickly as the sampling frequency increases. The approach has been generally applied to daily results for a single year and available computer applications such as AUTOBEALE (Richards 1998) and FLUX32[6] are designed accordingly. There is, however, no intrinsic reason why results for multiple years cannot be used to determine single or stratified load to flow ratios (or flow-weighted means), particularly since this can increase n and consequently reduce the bias.
Although the typical approach is to determine annual daily mean loads and multiply the result by 365 (or by the number of days within stratified periods), if daily mean loads are calculated individually by multiplying the overall observed load to flow ratio by individual daily flows, then the total annual load can be calculated by summing these 365 separate estimates. These are arithmetically equivalent and although the latter approach has not been widely applied it has been used in this analysis since these daily loading estimates can be used to generate annual or seasonal loads with a variance term that illustrates variability attributable to flow.

In this analysis, all water quality parameters at the five locations of interest (Red Hill Creek, Indian Creek, Grindstone Creek, Desjardins Canal, Spencer Creek) were first evaluated using the *log [flow]* versus *log [concentration]* regression approach used for TP by Long et al. (2015). Spencer Creek data were not collected as part of the 2010 to 2012 MOECC sampling effort but preliminary results from the Hamilton Conservation Authority (HCA) 24-hour time composite sampling were available for the period 2011 through 2013. Following Long et al. (2015), separate summer and winter regressions were applied at Grindstone Creek. Following this initial assessment based on the MOECC 2010 to 2012 data, the Desjardins Canal results were also evaluated separately to see if the winter flow-concentration regression recommended by Long et al. (2015) could be utilized. They were also assessed to seek a more straightforward means of estimating daily loads than the three-factor model used in Long et al. (2015). This was undertaken not only to simplify the calculations, but to alleviate concerns that extrapolation of the three-factor model past the 2010-2012 sampling period would be problematic due to storm water infrastructure upgrades at Dundas that have significantly reduced CSO discharges resulting in over estimation of loads associated with summer wet weather events. Also, a sinusoidal relationship that reflects summer maximum and winter minimum TP concentrations attributable to nutrient cycling processes within the marsh cannot be assumed to apply to other parameters.

In those situations where the concentration versus flow regression was poor several other approaches were evaluated. These included the Beale Ratio Estimator (BRE) and the use of seasonal flow-weighted and arithmetic averages. Segmented regression analysis using the shareware SegReg application[7] was used to evaluate quantitatively the existence of flow breakpoints that could be used to identify flow strata for these alternative loading calculation approaches. An additional special case of segmented regression analysis plotting flow as a function of concentration was undertaken separately[8] to evaluate concentration break points and fit separate regression equations at Indian Creek to see if this could be used to generate a useful relationship for TKN and Zn which did not yield good flow-concentration regressions due to dry weather high-concentration anomalies.

Since there is no flow monitoring station for Indian Creek, the regression relationship described in Long et al. (2014) between Indian Creek and Red Hill Creek was used to predict Indian Creek flows. Similarly, since there is no routine flow monitoring for the Desjardins Canal, the Spencer Creek flow vs. Desjardins Canal

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6 *Ver. 4.0 2016.Load Estimation software developed by U.S. Army Corps of Engineers and Minnesota Pollution Control Agency*

7 *www.waterlog.info*

8 *Dr. G. Arhonditsis at University of Toronto*

flow regression identified in Long et al. (2014) was used to estimate Desjardins Canal flows during the July 2010 to May 2012 sampling period.

Evaluation of Model Error

Evaluation of load estimation model effectiveness requires some quantitative comparison of estimated and measured values. Several authors have noted inconsistent and sub-optimal approaches and made recommendations to rectify this (e.g. Smith and Rose 1995, Kobayashi and Salam 2000, Gauch et al. 2003, Schunn and Wallach 2005, Pineiro et al. 2008). The most frequent concern is the use of predicted versus observed regressions to determine the coefficient of determination (r^2) and to check whether the intercept is near 0 and the slope is near 1. This frequently fails to quantify directly the predictive accuracy of a model since the error is based on the best-fit regression line and does not directly compare observed results with the 1:1 line (i.e. the regression line that represents a perfect fit between observed and predicted results). Similarly, the root mean square error (RMSE) often reported for regressions uses deviations around the best-fit regression line rather than deviations around the 1:1 line.

The analysis in this report follows recommendations from Pineiro et al. (2008) and evaluates loading model effectiveness through linear regression of observed values (x axis) and predicted values (y axis) with the regression forced to pass through the intercept. The corresponding r^2 is used to illustrate the proportion of variance in observed values that is explained by the predicted values, and the root mean square deviation (RMSD) from the 1:1 line is calculated rather than RMSE for the best-fit regression line. Although this approach tends to yield slightly smaller r^2 values and RMSD values are necessarily greater than RMSE values, it has the advantage of providing a direct measure of the model's predictive accuracy. The Nash-Sutcliffe Efficiency (NSE) is also computed to complement the r^2 since unlike r^2 it penalizes for bias and can be negative for a model which predicts more poorly than the average of the observations.

For any situation where there is a stable, non-random relationship between flow and contaminant concentration (i.e. a positive or negative correlation, or constant concentration) the regressions for observed versus predicted loads will yield a high r^2 value since in most cases the same flow data will be used to both predict loads and calculate observed loads. Since the flow term generally dominates a loading calculation regressing *[flow x concentration]* against *[flow]* guarantees a reasonable correlation, departures from the 1:1 line will be solely the result of error in estimating concentration results. It could be argued that assessment of regression-based estimates that seek to predict “missing” concentration data should be made through comparison of predicted versus observed concentrations rather than loads. This form of evaluation is not included in this report, however, since this type of analysis is not well suited to ratio estimator or averaging estimator approaches which do explicitly seek to estimate daily concentrations.

A final observation regarding assessment of regression model uncertainty is that the relative error in a *log [flow]* versus *log [concentration]* relationship increases with higher concentrations but is functionally disguised until the results have been inversely transformed. The relative error for a log-log plot that yields predicted $\log_{10}$ concentration values of 1.0 and 2.0 with a regression 95% confidence limit of +/- 0.5 translates into predicted concentrations of 10 +21.6/-6.8 and 100 +216/-68.4. High flow events account for a significant proportion of annual loads (hence the need for event-based monitoring to yield realistic estimates) so it is apparent that for parameters of concern that demonstrate a strong positive flow-concentration relationship, the most important flow events will also exhibit the greatest relative error in predicted load. Furthermore, the greatest relative error on a linear scale will be associated with over-predictions of concentrations for high flow events. This does not render these estimates of no value, but it is worth keeping in mind that there are intrinsic limitations to this approach to load prediction when undertaking subsequent analysis of annual or seasonal loading estimates such as attempting to discern temporal trends.

The relative error arising from log transformed regression methods for estimating concentrations based on flow (and flow estimations at Indian Creek and Desjardins Canal) is not incorporated in the annual loading estimates derived from the analysis undertaken in this report since a similar analysis cannot be undertaken for averaging estimator or flow-weighted mean/ratio estimator approaches. Flow, however, is reliably measured daily at Red Hill Creek, Grindstone Creek and Spencer Creek and is generally the dominant term in loading calculations so statistical error associated with variability in flow can be applied to all approaches and, in most cases, will represent the greatest single source of variance in the loading estimates.

3. RESULTS AND DISCUSSION

3.1 Regression Equations

Table 1 summarizes the results of all *log [flow]* versus *log [concentration]* regressions for all substances at all locations including the regression equations. As shown, strong positive *log [flow]* versus *log [concentration]* regressions with $r^2 > 0.50$ were observed for TP, TSS, TKN, Fe, Pb and Zn at Red Hill Creek, Indian Creek, and Grindstone Creek. The exceptions were TKN and Zn anomalies at Indian Creek and a winter TKN anomaly at Grindstone Creek where the regressions were weak or poor. Total Ammonia exhibited no strong relationship with flow at any location, and Total Nitrate showed variable results with strong negative *log [flow]* versus *log [concentration]* regressions at Indian Creek and Grindstone Creek (winter only) with all other regressions being weak or poor. It is unsurprising that Total Ammonia and Total Nitrate exhibited a different relationship with flow than TP, TSS, TKN, Fe, Pb and Zn since, unlike these latter substances which are generally present with a significant particulate phase, they are primarily present in the dissolved phase.

If an $r^2 > 0.50$ is used as the threshold to determine the applicability of the regression-based approach then the findings summarized in Table 1 support the use of the listed regression equations to estimate daily concentrations based on flow for TP, TSS, Fe and Pb at Red Hill Creek, Indian Creek, Grindstone Creek (summer and winter). Regression equations can also be used for TKN at Red Hill Creek and Grindstone Creek (summer) and for Zn at Red Hill Creek and Grindstone Creek (summer and winter). These estimated daily concentrations may then be summed to provide annual and seasonal loading results.

For an r^2 threshold of 0.50 the analysis does not support the use of regression equations for estimation of daily loads of TKN and Zn at Indian Creek, TKN at Grindstone Creek in the winter, or any substance of interest at Spencer Creek or Desjardins Canal. The results also indicated that in general the regression-based approach is not well suited for Total Nitrate or Total Ammonia at any location. Although Total Nitrate exhibited a strong negative relationship between flow and concentration at Indian Creek ($r^2 = 0.71$) and Grindstone Creek in the winter ($r^2 = 0.56$), a weak positive correlation was observed at Red Hill Creek ($r^2 = 0.15$) and there was no significant correlation for Grindstone Creek in the summer ($r^2 = 0.06$). The inconsistent flow versus Total Nitrate concentration relationship observed between Red Hill Creek, Indian Creek and Grindstone Creek, and the poor TKN and Total Ammonia regressions at the latter two locations suggest that flow is not a consistently reliable basis for estimating concentrations of nitrogen related compounds. Alternative methods will require evaluation for Total Ammonia and Total Nitrate at all locations of interest.

The TKN and Zn anomalies at Indian Creek are driven by elevated dry-weather concentrations of these substances which do not follow the expected positive relationship with flow and TSS that is evident at Red Hill Creek and Grindstone Creek. This anomaly suggests a dry weather source of soluble TKN and Zn at Indian Creek, but no obvious candidate can be suggested by local municipal and Conservation Authority staff. Further dry weather sampling will be needed to confirm whether this pattern of dry weather anomalies persists, but since the general regression approach is not currently applicable the use of segmented regression, ratio estimator and averaging approaches have been evaluated for these substances at this location.

Alternative approaches have also been evaluated for winter TKN at Grindstone Creek and all substances at Spencer Creek and the Desjardins Canal. Unlike Indian Creek, the regression for winter TKN at Grindstone Creek was statistically significant at $p < 0.001$. The diminished r^2 of 0.25 for winter TKN compared with summer TKN r^2 of 0.72 was driven by a wider range of wet weather concentrations for a given range of wet weather flows.

TABLE 1: Summary of *log [average event flow]* vs. *log [24-hour level-weighted concentration]* regression equations for Hamilton Harbour Tributaries using MOECC 2010 to 2012 data (unless otherwise noted); *"y" represents log [concentration] and "x" represents log [flow]*

Tributary	TP	TSS	TKN	Pb	Fe	Zn	Total NO_3/NO_2	Total NH_4/NH_3
Red Hill Creek	N= 92 r^2 = 0.75 SE = 0.24 p < 0.001 *y = .69x+1.95*	N = 91 r^2 = 0.75 SE = 0.34 p < 0.001 *y = .97x+1.47*	N = 91 r^2 = 0.60 SE = 0.16 p < 0.001 *y = .32x-0.14*	N = 90 r^2 = 0.72 SE = 0.29 p < 0.001 *y = .78x+0.29*	N = 92 r^2 = 0.76 SE = 0.27 p < 0.001 *y = .78x+2.45*	N = 92 r^2 = 0.70 SE = 0.22 p < 0.001 *y = .57x+1.49*	N = 89 r^2 = 0.15 SE = 0.30 p < 0.001 *y = .21x - 0.05*	N = 89 r^2 = 0.27 SE = 0.43 p < 0.001 *y = .45x+0.89*
Indian Creek	N = 97 r^2 = 0.72 SE = 0.18 p < 0.001 *y = .50x+2.05*	N = 95 r^2 = 0.72 SE = 0.28 p < 0.001 *y = .76x+1.63*	N = 96 r^2 = 0.04 SE = 0.24 N.S. *y = .06x-0.06*	N = 96 r^2 = 0.63 SE = 0.25 p < 0.001 *y = .56x+0.41*	N = 96 r^2 = 0.73 SE = 0.21 p < 0.001 *y = .58x+2.58*	N = 96 r^2 = 0.03 SE = 0.33 N.S. *y = .11x+1.92*	N= 93 r^2 = 0.71 SE = 0.12 p < 0.001 *y = -.31x+0.06*	N = 93 r^2 = 0.007 SE = 0.47 N.S. *y = -.07x+1.95*
Grindstone Creek summer data*	N = 34 r^2 = 0.73 SE = 0.20 p < 0.001 *y = .58x+2.35*	N = 34 r^2 = 0.57 SE = 0.38 p < 0.001 *y = .77x+1.93*	N = 34 r^2 = 0.72 SE = 0.10 p < 0.001 *y = .28x+0.03*	N = 34 r^2 = 0.63 SE = 0.29 p < 0.001 *y = .67x+0.50*	N = 34 r^2 = 0.77 SE = 0.20 p < 0.001 *y = .66x+2.86*	N = 34 r^2 = 0.60 SE = 0.26 p < 0.001 *y = .56x+1.22*	N = 32 r^2 = 0.06 SE = 0.35 N.S. *y = -.16x+0.21*	N = 32 r^2 = 0.06 SE = 0.41 N.S. *y = .17x+1.46*
Grindstone Creek winter data**	N = 55 r^2 = 0.61 SE = 0.28 p < 0.001 *y = .93x+1.74*	N = 54 r^2 = 0.69 SE = 0.35 p < 0.001 *y = 1.33x+1.24*	N = 54 r^2 = 0.25 SE = 0.13 p < 0.001 *y = .19x-0.10*	N = 55 r^2 = 0.60 SE = 0.27 p < 0.001 *y = .88x-0.08*	N = 55 r^2 = 0.61 SE = 0.21 p < 0.001 *y = .68x+2.46*	N = 55 r^2 = 0.65 SE = 0.17 p < 0.001 *y = .62x+0.88*	N = 55 r^2 = 0.56 SE = 0.15 p < 0.001 *y = -.45x+0.11*	N = 55 r^2 = 0.09 SE = 0.35 N.S. *y = .28x+1.55*
Spencer Creek *(Hamilton CA data)*	N = 19 r^2 = 0.06 SE = 0.30 N.S. *y = -.12x+2.02*	N = 19 r^2 = 0.14 SE = 0.57 N.S. *y = -.38x+1.14*	N = 19 r^2 = 0.04 SE = 0.16 N.S. *y = .05x-0.17*	N = 19 r^2 = 0.06 SE = 0.43 N.S. *y = -.17x+0.41*	N = 19 r^2 = 0.001 SE = 0.53 N.S *y = -.03x+2.81*	N = 19 r^2 = 0.03 SE = 0.28 N.S. *y = -.07x+1.58*	N = 19 r^2 = 0.35 SE = 0.17 p < 0.01 *y = .21x - 0.15*	N = 19 r^2 = 0.21 SE = 0.24 N.S. *y = .21x - 1.41*
Desjardins Canal	N = 94 r^2 = 0.02 SE = 0.29 N.S. *y = -.05x+0.01*	N = 93 r^2 = 0.07 SE = 0.38 p < 0.01 *y = .18x+0.20*	N = 94 r^2 = 0.01 SE = 0.18 N.S. *y = -.05x+0.01*	N = 94 r^2 = 0.07 SE = 0.25 p < 0.01 *y = .27x+1.30*	N = 94 r^2 = 0.10 SE = 0.24 p < 0.01 *y = .18x+0.20*	N = 94 r^2 = 0.34 SE = 0.18 p < 0.001 *y = .21x+2.51*	N = 93 r^2 = 0.01 SE = 0.25 N.S. *y =.07x - 0.03*	N = 93 r^2 = 0.07 SE = 0.26 N.S. *y =.18x+2.17*
Desjardins Canal winter data***	N = 38 r^2 = 0.47 SE = 0.25 p < 0.001 *y = .71x+1.38*	N = 37 r^2 = 0.48 SE = 0.37 p < 0.001 *y = 1.03x+0.59*	N = 39 r^2 = 0.23 SE = 0.16 p < 0.01 *y = .26x-0.28*	N = 39 r^2 = 0.40 SE = 0.24 p < 0.001 *y = .58x-0.16*	N = 38 r^2 = 0.47 SE = 0.22 p < 0.001 *y = .59x+2.14*	N = 38 r^2 = 0.43 SE = 0.14 p < 0.001 *y = .36x+1.05*	N = 38 r^2 = 0.19 SE = 0.12 p < 0.01 *y = -.17x+0.24*	N = 38 r^2 = 0.19 SE = 0.22 p < 0.01 *y = .31x-0.95*

(green)	Highly Significant Regression p < 0.001, High r^2 > 0.50
(olive)	Highly Significant Regression p < 0.001, Medium r^2 > 0.25 < 0.50
(yellow)	Significant Regression p < 0.01 or <0.001, Low r^2 < 0.25
(red)	Regression not significant at p < 0.01
SE	Standard Error of the regression calculated for the y value

**** Grindstone Creek Summer data: June to October***
***** Grindstone Creek Winter data: November to May***
****** Desjardins Canal Winter data: December to April***

3.2 Indian Creek TKN and Zn: Segmented Regression Analysis

The lack of a statistically significant *log [flow]* versus *log [concentration]* regression for TKN and Zn at Indian Creek resulted in exploration of a more sophisticated statistical approach to analysing the data (Arhonditsis 2017). Application of Segmented Regression was used to identify a breakpoint determined by the response variable (concentration) instead of the predictor variable (flow). For TKN, a breakpoint of 0.90 mg/l was identified yielding regression equations:

1) ln(TKN) = -0.331 + 0.139 · ln(Flow) when TKN < 0.90 mg/l

and

2) ln(TKN) = 0.176 - 0.080 · ln(Flow) when TKN > 0.90 mg/l

Similarly, for Zn, a breakpoint of 51.9 µg/l was identified yielding regression equations:

1) ln(Zn) = 3.482 + 0.360 · ln(Flow) when Zn < 51.9 µg/l

and

2) ln(Zn) = 4.606 - 0.085 · ln(Flow) when Zn > 51.9 µg/l

In both cases there is a positive slope below the concentration thresholds and a slight negative slope above them. Although selection of a concentration breakpoint allows a better regression with flow, there is no apparent process or mechanism that would cause a switch from a positive to a negative relationship between concentration and flow above a certain concentration threshold for these substances. Plotting these functions for 2011 TKN data (Figure 1) demonstrates that Equation 1 (TKN <0.90 mg/l) seldom predicts a concentration greater than the threshold and Equation 2 (TKN >0.90) never predicts a concentration less than the threshold. This means that for any given flow during the study period there are always two predicted TKN concentrations on either side of the threshold value. For days when only flow data are available both functions need to be applied for each substance and the most appropriate result is then selected by implicitly interpolating between the dates for which there are data following the trajectory projected by the piecewise model (Arhonditsis 2017). This necessary interpolation restricts the use of this statistical model to periods for which there are observed concentration data and hence this approach cannot be used to extrapolate for periods outside the 2010 to 2012 sampling period and must be considered descriptive rather than predictive (Arhonditsis 2017).

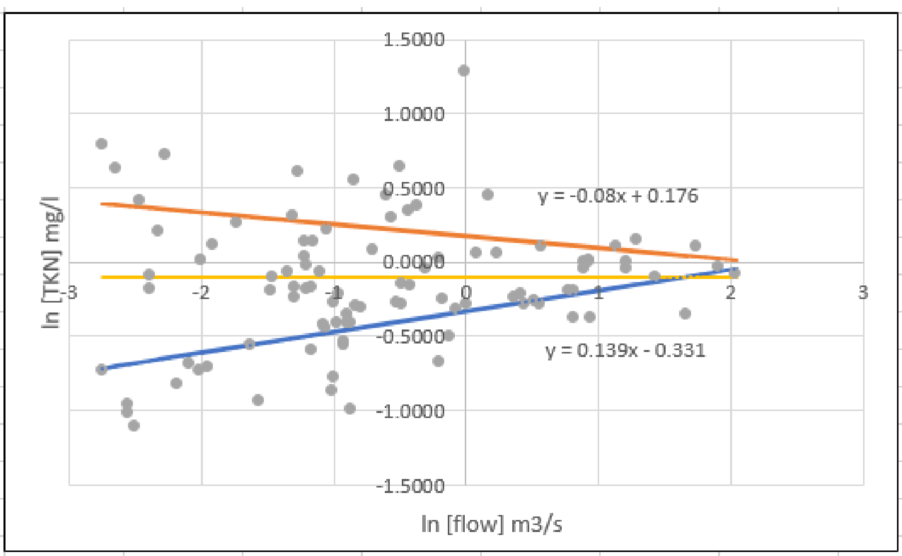


Figure 1: Indian Creek 2010 to 2012 TKN Concentration vs Flow showing concentration threshold and Segmented Regression Equations

When combined, these regression equations yielded good r^2 values for predicted versus observed TKN concentrations ($r^2 = 0.72$) and Zn concentrations ($r^2 = 0.67$) (Arhonditsis 2017). However, the lack of an underlying explanation for the breakpoints at threshold concentrations and the inability of this approach to estimate loads outside the July 2010 to May 2012 sampling period renders this descriptive approach of limited value for updating the RAP Loadings Report since only annual results for 2011 can be estimated.

3.3 Indian Creek TKN and Zn: Beale Ratio Estimator (Flow-weighted Mean)

The Beale Ratio Estimator (BRE) was applied as an alternative for calculating daily loads from the 2010 to 2012 event-based results for TKN and Zn. Segmented regression analysis of the *log[TKN]* and *log [Zn]* versus *log[flow]* confirmed that there was no quantitative basis for flow-based stratification (i.e. no breakpoints in the flow versus concentration relationship) and comparison of seasonal arithmetic and flow-weighted means indicated no basis for seasonal stratification. As a result, application of the single stratum BRE amounted to scaling the observed load:flow ratio (dimensionally equivalent to the flow-weighted mean) for the entire 2010 to 2012 sampling period by actual average daily flows for each year and applying the Beale correction factor. Since these calculations were based on the pooled data for the entire sampling period, *n* was large (97) yielding relatively trivial Beale correction factors of 1.02 for both TKN and Zn. Since an error of 2% is trivial, future loading calculations can be greatly simplified by multiplying the 2010 to 2012 flow-weighted mean concentration (FWM) for TKN (0.972 mg/l; 95% C.I = 0.098 mg/l) and Zn (102 ug/l; 95% C.I = 21 ug/l) at Indian Creek by the observed or estimated daily flows.

A comparison of the 2011 TKN annual loading estimates for the Arhonditsis (2017) segmented regression analysis and the simple BRE (FWM) is summarized in Table 2 and the observed versus predicted results for both approaches are illustrated in Figure 2.

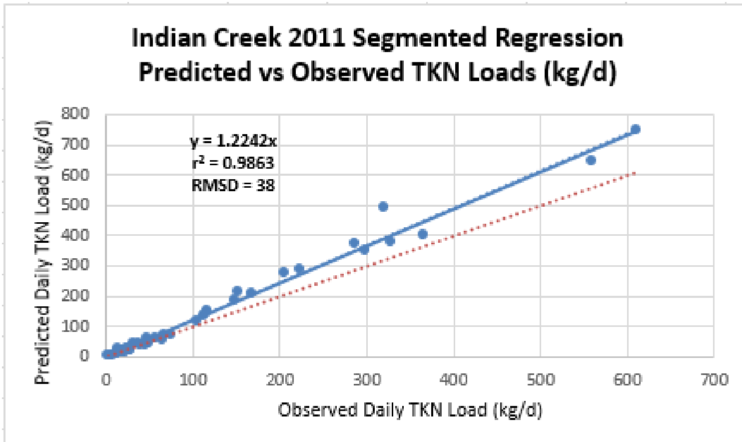
TABLE 2: Comparison of Segmented Regression and FWM (simple BRE) 2011TKN Loading Estimates for Indian Creek

Method	Annual Total (kg/year)	Annual Daily Average (kg/d)	STD	95% CI
Segmented Regression	20,992	57.5	94.4	9.7
FWM (simple BRE)	19,438	53.3	79.9	8.2

This comparison demonstrates that although the segmented regression approach provided a better estimate of observed daily TKN concentrations than using the flow-weighted mean of 0.972 mg/l for all days, the improvement was marginal since loading calculations are dominated by flow. The FWM (simple BRE) yielded an r^2 that was almost as good and a slope that was actually closer to the 1:1 line resulting in a slightly better RMSD (27 kg/d versus 38 kg/d). The FWM approach also yielded a predicted mean concentration that was closer to the observed mean concentration of 105 kg/d (110 kg/d versus 127 kg/d). This comparison supports the application of the FWM (simple BRE) approach to estimating annual loads of TKN at Indian Creek.

Given the lack of a statistically significant *log [flow]* versus *log [concentration]* regression, and the extremely low r^2 of 0.03, the FWM approach can also be applied for Zn at Indian Creek since the segmented regression developed by Arhonditsis (2017) cannot be applied for years other than 2011. Zn exhibited a similar pattern of elevated dry weather concentrations as TKN albeit with a greater relative variance in observed concentration data (101% coefficient of variation for Zn versus 51% for TKN). This resulted in greater departures between observed daily Zn concentrations and the flow-weighted mean of 102 ug/l, a larger difference between the 2011 predicted mean daily load (14.9 kg/d) and the observed mean daily load (10.8 kg/d) as well as a relatively larger RMSD from the 1:1 line of 21.6 ug/l.

Future dry weather sampling results for both TKN and Zn at Indian Creek should be compiled and compared with the 2010 to 2012 results to see if the dry weather anomalies persist. If they do not, it will become possible to recalculate the *log [flow]* versus *log [concentration]* regressions to see whether they are sufficiently improved to apply the regression methodology currently applied at Red Hill Creek and Grindstone Creek.



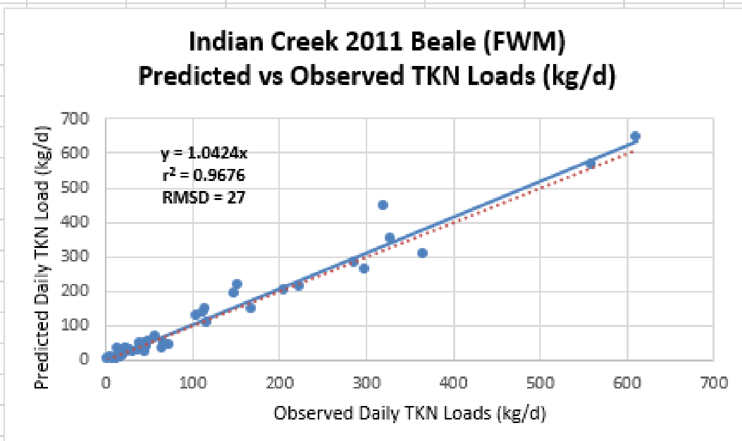


Figure 2: Observed versus predicted TKN Daily Loads for Indian Creek; Dashed line delineates 1:1; n = 48; Observed mean = 105 kg/d; Top: Segmented Regression Method (Arhonditsis 2017) predicted mean = 127 kg/d; Bottom: FWM (simple Beale Ratio Estimator)predicted mean = 110 kg/d

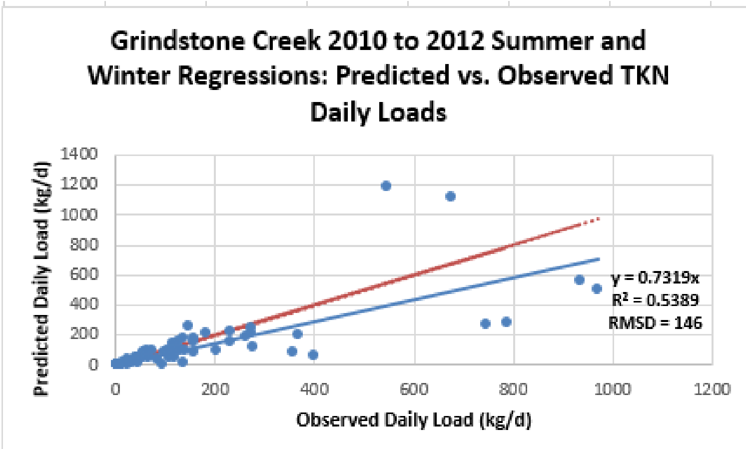
3.4 Grindstone Creek Winter TKN: Summer-Winter Regression and Summer Regression-Winter Flow-weighted Mean (FWM) Results

Although the r^2 of 0.25 for winter *log [TKN]* versus *log [flow]* regression was well below the desired threshold of 0.50 (see Table 1), the regression was statistically significant ($p < 0.001$). Segmented regression analysis of the winter data did identify a flow breakpoint at *log[flow]* = 0.03 (i.e. flow = 1.07 m3/s) but the r^2 values for the resulting two regressions were both less than 0.25 due to the diminished sample sizes and consequently conferred no real improvement over the original single *log [TKN]* versus *log [flow]* regression for winter data. Since the winter regression could not be improved, the alternative approach was to apply a simplified BRE method using the winter flow-weighted mean TKN concentration rather than the winter regression to estimate winter daily loads.

A comparison of the original summer and winter regression-based estimates with those derived from application of the summer regression and winter FWM (i.e. simplified BRE) method is shown in Table 3. The observed versus predicted results for both approaches are illustrated in Figure 3.

TABLE 3: Comparison of 2010 to 2012: (a) Summer-Winter Regression and (b) Summer Regression-Winter FWM TKN Loading Estimates for Grindstone Creek

Year	Method	Annual Total (kg/year)	Annual Daily Average (kg/d)	STD	95% CI
2010	**Regression**	24,326	66.6	231.0	23.7
	FWM	*24,729*	*67.8*	*168.2*	*17.3*
2011	**Regression**	34,159	93.6	149.5	15.3
	FWM	*35,905*	*98.4*	*140*	*14.4*
2012	**Regression**	12,152	33.2	44.1	4.5
	FWM	*15,048*	*41.1*	*49.2*	*5.1*



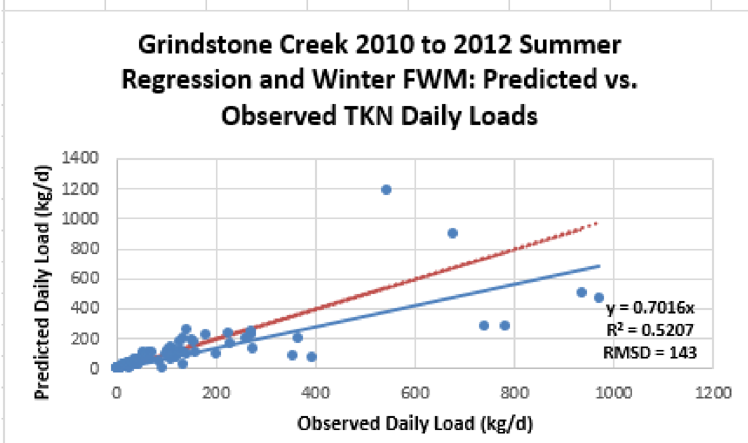


Figure 3: Observed versus predicted TKN Daily Loads for Grindstone Creek; Dashed line delineates 1:1; n = 81; Observed mean = 139 kg/d; Top: Summer and Winter regression method predicted mean = 111 kg/d; Bottom: Summer regression and Winter FWM predicted mean = 116 kg/d

This comparison demonstrates that although the winter TKN *log [flow]* versus *log [concentration]* regression r^2 is less than the desired threshold of 0.50, the anomaly at Grindstone Creek is less problematic than for Indian Creek. Both the "Summer - Winter regression" and "Summer regression -Winter FWM" methods yield similar annual loading estimates for the period 2010 to 2012 (Table 3) and similar observed versus predicted regressions (Figure 3). Both methods tend to underestimate observed loads by approximately the same amount and have similar RMSD values relative to the 1:1 line. This comparison suggests that although the Summer regression and Winter FWM approach yields a RMSD and predicted mean concentration that are marginally better than the Summer and Winter regression-based approach, the original winter regression can be applied without greatly biasing the estimates. Adopting this approach will simplify calculations since it will involve applying the same method for TP, TSS, TKN, Fe, Pb and Zn.

3.5 Spencer Creek

The extremely poor regression results for Spencer Creek 2011 to 2013 data (Table 1) may be partially attributable to the small number of samples (n = 19) and might improve once more up-to-date event-based sampling results become available. The complete absence of a statistically significant relationship between flow and concentrations of TP, TSS, TKN, Fe, Pb and Zn, however, suggests that there may be other factors involved. These might include the flow control imposed by the Christie Lake dam and the influence of local urban sources in Dundas below the escarpment. For now, loads into Cootes Paradise marsh from Spencer Creek, Borer Creek, Chedoke Creek and Ancaster Creek will have to be estimated by subtracting Dundas WWTP loads from Desjardins Canal loads (see following section). This approximation intrinsically assumes that flow out of Cootes equals the flow into Cootes. Although this fails to account for nutrient cycling and evapotranspiration in the marsh it is the same reasonable initial approximation made in previous loadings reports and will have to suffice until better event-based sampling and data analysis have been completed at Spencer Creek as part of the current TP mass balance and eutrophication modelling study being undertaken by U. of T. (Kim et al. 2016).

3.6 Desjardins Canal: Summer Flow-weighted Mean (FWM) - Winter Regression and Summer - Winter FWM Results

Additional analysis for the Desjardins Canal applied the Long et al. (2014) regression equation between flow at Spencer Creek and the Desjardins Canal based 2009 data collected at the Desjardins Canal:

$$\mathbf{Flow_{D.C.} = 1.45\ Flow_{S.C.} + 0.44; \quad (r^2 = 0.66)}$$

Applying this regression to the downloaded Water Survey of Canada HYDAT daily flow summary for Spencer Creek in Dundas (Station 02HB007) for the RAP Loadings Report period of interest will provide reasonable estimates of daily Desjardins Canal flows to Hamilton Harbour. These can be combined with estimated daily concentrations for substances of interest to yield daily loads.

As summarized in Table 1, the *log[flow]* and *log[concentration]* r^2 values for TP, TSS, TKN, Fe, Pb and Zn were all less than the desirable threshold of 0.50 (in fact all but Zn had r^2 values of 0.10 or less) for whole-year data. Long et al. (2015), however, found a significant relationship between flow and TP concentration for December through April data ($r^2 = 0.47$) which was assumed to capture the effects of snow melt. A finer analysis shows this to have differed significantly between the two years sampled with the "cold" winter of 2010/2011 having a very strong relationship ($r^2 = 0.66$) and the "warm" winter of 2011/2012 exhibiting no significant relationship ($r^2 = 0.01$). This confirms the Long et al. (2015) snow melt hypothesis but highlights the sensitivity of this winter partitioning of the data to differences between "cold" and "warm" winters. Results of *log[concentration]* versus *log[flow]* for winter (December through April) partitioning of TSS, TKN, Fe, Pb and Zn data are shown in Table 1 and illustrate that although none of the winter r^2 for these substances quite achieved the desired threshold of 0.50, they were generally close (except for TKN) and the results were all statistically significant at $p < 0.001$. Long et al. (2015) supported use of the December through April TP regression r^2 of 0.47 as being sufficiently close to the desired threshold of 0.50 to be used which suggests that the same may also apply for the other five substances. As with TP, these regressions represent a blend of results for both warm and cold winters which make them a more robust estimator for non-sampled years, but which will tend to infer a stronger positive flow versus concentration relationship than really exists in warm years and a weaker one in cold years.

Given the complexity and limited future applicability of the three-factor model used for TP by Long et al. (2015) it would be helpful to develop and evaluate a simpler and more robust approach that can be applied to substances which would not be expected to exhibit the seasonal pattern as TP. An initial comparison of alternative approaches for TP was undertaken since the Long et al. (2015) TP estimates provide a useful benchmark. Since the December through April winter period was the only portion of the year yielding good *log [flow]* versus *log [concentration]* regressions, the first alternative approach used this winter regression and the May through November FWM[9] value for TP (152 ug/l +/- 22 ug/l 95% CI) as an estimate of spring-summer-fall concentrations rather than employing the sine function and rainfall regression method used in the three-factor model. The winter, December to April winter FWM for TP (150 ug/l +/- 40 ug/l 95% CI) was essentially identical to the non-winter FWM[10] so a third, even simpler approach was also evaluated using the winter (December through April) FWM TP value as a substitute for the winter regression TP concentration predictions to see if this was worth pursuing for other substances. The resulting loading estimates from these three approaches are compared in Table 4 and the observed versus predicted results are shown in Figure 4.

Figure 4 demonstrates that the Long et al. (2015) three-factor model provides the best overall fit between predicted and observed 2010 to 2012 TP daily loads (regression $r^2 = 0.91$ and RMSD from 1:1 line of 31.3 kg/d). This is not surprising given the effort that went into selecting model components to fit observed data. Both the three-factor model and the winter regression and non-winter FWM method tend to slightly over-predict the observed daily loads below the 75th percentile (48.3 kg/d) by an average of 4.4 kg/d and 5.4 kg/d respectively. Although both methods under-predict observed daily loads above the 75th percentile the three-factor model performed better with an average under prediction of -9.4 kg/d compared with -25.9 kg/d for the winter regression and non-winter FWM method. This superior performance at high loads reflects the Long et al. (2015) model's ability to incorporate additional loads associated with CSO inputs as estimated by the rainfall regression component.

The alternative method regression $r^2 = 0.83$ and RMSD = 41.8 kg/d were not quite as good as for the three-factor model, but were still highly significant. The alternative approach increases annual total loading estimates relative to the three-factor model (Table 4) and these estimates turn out to be just about as accurate on an annual scale since the average difference between predicted and observed concentrations is only -2.4 kg/d for the winter regression and non-winter FWM method compared with 1.0 kg/d for the three-factor model. In effect, the over-prediction of the winter regression non-winter FWM approach for high-frequency lower loading events (i.e. < 75th percentile) almost negates the under-prediction for the low-frequency higher loading events (i.e. > 75th percentile).

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9 *The Beale correction factor was only 0.9% so use of this seasonal FWM represents a simplified version of the BRE for this period.*

10 *Even though the winter mean TP concentration was substantially lower than the non-winter mean (99 ug/l versus 134 ug/l), the mean winter flow of 6.42 m^3/s was much greater than the non-winter mean flow of 2.79 m^3/s*

As shown in Figure 4, attempting a further simplification by substituting a FWM concentration for both winter and non-winter periods (i.e. instead of the winter concentrations predicted by winter regression) did not yield results that were as good ($r^2 = 0.56$; RMSD = 58.8 kg/d). This approach under-predicted loads for infrequent high loading events (> 75th percentile) by a much greater amount (-48.2 kg/d) than the other methods and over-predicted loads for high-frequency low loading events (< 75th percentile) by a greater amount (14.1 kg/d). As with the winter regression and non-winter FWM approach, the larger low loading event over-predictions almost negated the high loading event under-predictions resulting in an annual mean loading estimate that was also close to the observed mean than the three-factor model. This approach is, however, not recommended for the six substances having highly significant ($p < 0.001$) winter regressions since it provides the least accurate estimate of the within-year loading distribution resulting from low flow and high flow events.

However, the simpler alternative approach using the winter regression and non-winter FWM to estimate non-winter TP concentrations (rather than fitting a sine function and a rainfall regression) performed sufficiently well to suggest that a similar approach can be used for the other substances of interest. It would also be a more robust approach for predicting TP loads since completion of the combined sewer overflow infrastructure upgrades since it was the ability to capture these flows that accounted for the superior performance of the three-factor model.

TABLE 4: Comparison of 2010 to 2012: (a) Long et al. (2015) 3-factor model, (b) winter regression and non-winter FWM and (c) winter and non-winter FWM TP Loading Estimates for Desjardins Canal

Year	Method	Annual Total (kg/year)	Annual Daily Average (kg/d)	STD (kg/d)	95% CI (kg/d)
2010	**Long et al. (2015)**	14,444	39.6	120.4	4.1
	Winter regression and summer FWM	15,967	43.7	140.6	14.4
	Simple Beale (Winter and summer FWM)	14,813	40.6	55.2	5.7
2011	**Long et al. (2015)**	17,769	48.7	77.4	5.0
	Winter regression and summer FWM	18,977	52	77.2	7.9
	Simple Beale (Winter and summer FWM)	19,208	52.6	52.4	5.4
2012	**Long et al. (2015)**	6,370	17.4	16.1	1.8
	Winter regression and summer FWM	7,239	19.8	16.1	1.7
	Simple Beale (Winter and summer FWM)	10,294	28.1	22	2.2

Table 5 shows the correlation matrix for winter (December to April) concentration data for TP, TKN, TSS, total Nitrate, total Ammonia, Pb, Fe, and Zn along with winter versus non-winter mean concentrations and winter versus non-winter FWM concentrations. It is apparent that partitioning the data to account for December to April snowmelt effects as recommended by Long et al. (2015) yields winter concentrations that are highly correlated for all substances of interest other than Total Ammonia and Total Nitrate. TP, TSS, TKN, Fe and Pb had mean concentrations that were higher for the May to November period than the December to April period. Zn and Total Nitrate showed the opposite tendency and Total Ammonia showed no real difference. However, the mean flow for the December to April period (6.42 m3/s) was much higher than for the May to November period (2.79 m3/s) so FWM concentrations did not exhibit the same seasonal pattern. Winter and non-winter FWM values were the same for TP and Total Ammonia. For TKN the winter FWM was lower than the non-winter FWM but for all other substances the winter FWM exceeded the non-winter FWM.

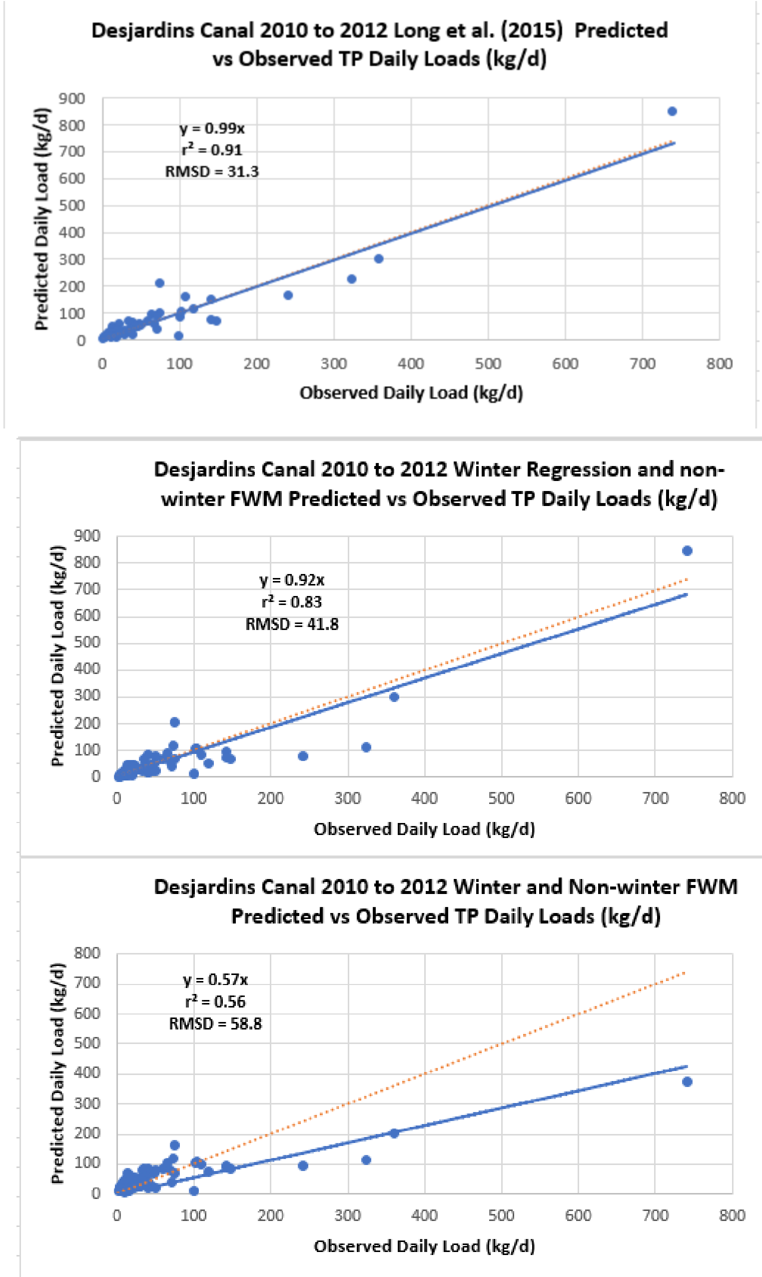


Figure 4: Observed versus predicted TP Daily Loads for Desjardins Canal; Dashed line delineates 1:1; n = 84; Observed mean = 51.7 kg/d; Top: Long et al. (2015) method predicted mean = 52.7 kg/d; Middle: Winter regression and non-winter FWM predicted mean = 49.3 kg/d; Bottom: Winter and non-winter FWM predicted mean = 50.2 kg/d

Table 5: Correlation matrix for Desjardins Canal winter (December to April) concentrations of TP, TSS, TKN, Fe, Pb, Zn, Total Ammonia and Total Nitrate; Winter and non-winter (May to November) mean concentrations and FWM

	TP	TSS	TKN	Fe	Pb	Zn	Total Ammonia	Total Nitrate
TP	1.000							
TSS	0.918	1.000						
TKN	0.922	0.779	1.000					
FE	0.849	0.914	0.697	1.000				
PB	0.936	0.959	0.825	0.848	1.000			
ZN	0.864	0.825	0.725	0.721	0.903	1.000		
Total Ammonia	0.760	0.545	0.827	0.449	0.648	0.710	1.000	
Total Nitrate	-0.355	-0.347	-0.395	-0.448	-0.316	-0.147	-0.294	1.000
May to Nov. mean (+/- 95% CI)	134 ug/l (20)	39 mg/l (7)	1.223 mg/l (0.085)	508 ug/l (62)	2.4 ug/l (0.3)	15.4 ug/l (2.7)	0.218 mg/l (0.047)	0.901 mg/l (0.099)
Dec. to April mean (+/- 95% CI)	99 ug/l (26)	33 mg/l (10)	0.854 mg/l (108)	436 ug/l (93)	2.1 ug/l (0.5)	21.9 ug/l (3.3)	0.220 mg/l (0.048)	1.397 mg/l (0.123)
May to Nov. FWM (+/- 95% CI)	142 ug/l (21)	41 mg/l (7)	1.233 mg/l (0.086)	542 ug/l (66)	2.5 ug/l (0.4)	16.7 ug/l (3.0)	0.272 mg/l (0.058)	0.912 mg/l (0.101)
Dec. to April FWM (+/- 95% CI)	142 ug/l (37)	47 mg/l (15)	1.000mg/l (0.126)	621 ug/l (133)	2.7 ug/l (0.6)	26.0 ug/l (3.9)	0.273 mg/l (0.060)	1.259 mg/l (0.111)

The highly significant ($p < 0.001$) *log [winter flow]* versus *log [winter concentration]* and the high degree of correlation between December to April concentrations of TP, TSS, Fe, Pb and Zn support the use of the winter regression and non-winter FWM approach to estimate loads for these substances. As with Total Ammonia and Total Nitrate, however, the TKN winter *log[flow]* versus *log[concentration]* regression ($r^2 = 0.23$, $p < 0.01$) fell well short of the $r^2 > 0.50$ threshold and was less significant than for TP, TSS, Fe, Pb and Zn. For this reason, the winter regression and non-winter FWM approach was compared with results obtained using the December to April FWM as an estimate of winter daily concentrations rather than that derived from the flow regression.

Results of this comparison are shown in Table 6 and Figure 5. Even though the winter *log[flow]* versus *log[concentration]* regression for TKN was not strong, Figure 5 demonstrates that the use of the winter regression to estimate daily concentrations from December to April yielded slightly better results than the use of the winter FWM. This approach had an $r^2 = 0.87$ compared with $r^2 = 0.79$ and more closely approximated the 1:1 line with an RMSD of 181 kg/d compared with 221 kg/d. Both approaches tended to slightly over-predict the observed daily loads below the 75^{th} percentile (407 kg/d) and both under-predicted observed daily loads above the 75^{th} percentile. The use of winter FWM concentrations over-predicted the high frequency low load events by an average of 47 kg/d compared with 24 kg/d for the winter regression and non-winter FWM. The all FWM approach under-predicted the low frequency high load events by an average of -158 kg/d compared with -109 kg/d for the regression approach. The use of the winter FWM approach yielded a predicted average of 380 kg/d that was very close to the observed average of 384 kg/d (closer than the regression-based predicted average 375 kg/d) because the low load over-predictions essentially compensated for the high load under-predictions. This also resulted in the FWM approach yielding annual total loading estimates that were slightly higher than those from the winter regression although the relative differences were generally slight. The better performance of the winter regression and non-winter FWM approach to estimating the seasonal distribution of TKN loads from Desjardins Canal supports its use despite falling well short of the desired $r^2 > 0.50$ threshold. This will also simplify calculations by using the same method for TP, TSS, TKN, Fe, Pb, and Zn.

Table 6: Comparison of 2010 to 2012: (a) winter regression and non-winter FWM and (b) winter and non-winter FWM TKN Loading Estimates for Desjardins Canal

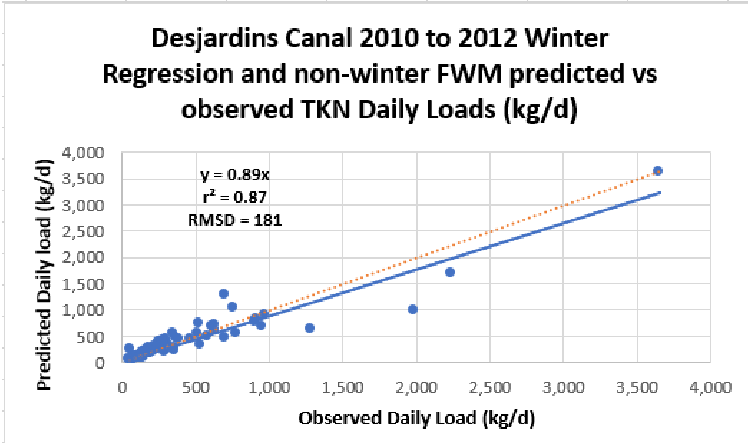
Year	Method	Annual Total (kg/year)	Annual Daily Average (kg/d)	STD	95% CI
2010	**Winter Regression and non-winter FWM**	114,258	313	549	56
	Winter and non-winter FWM	*114,528*	*314*	*393*	*40*
2011	**Winter Regression and non-winter FWM**	146,820	402	440	45
	Winter and non-winter FWM	*147,870*	*405*	*389*	*40*
2012	**Winter Regression and non-winter FWM**	68,753	188	137	14
	Winter and non-winter FWM	*77,713*	*212*	*152*	*16*

3.7 Estimating Annual Loads for Total Ammonia and Total Nitrate at all Locations

As shown in Table 1 and previously discussed, *log[flow]* versus *log[concentration]* regressions were generally poor and highly variable across locations sampled during the 2010 to 2012 period. This means that an alternative to the regression-based method is needed to estimate annual loads of these substances at Red Hill Creek, Indian Creek, Grindstone Creek and the Desjardins Canal. Rather than apply case-by-case combinations of regression-based approaches for certain substances at certain locations, it would be preferable to choose an approach that is sufficiently robust to be applied at all locations. This will not only simplify the calculations for the Loadings Report, but will ensure that whatever factors resulted in a positive *log[flow]* versus *log[concentration]* relationship for Total Nitrate at Red Hill Creek, and negative relationships at Indian Creek and Grindstone Creek (winter) do not bias future predictions (see Table 1).

Red Hill Creek, Indian Creek and Grindstone Creek

Seasonal flow-weighted mean (FWM) concentrations for Total Ammonia and Total Nitrate were calculated by applying the same "June to October" and "November to May" seasonal partitioning used for Grindstone Creek to Red Hill Creek and Indian Creek. Results are summarized in Table 7 and were used to estimate daily loads for these substances at these three locations. Summer and Winter FWM concentrations for Total Nitrate at Red Hill Creek and Indian Creek were similar but showed a marked decrease from summer to winter at Grindstone Creek. Summer FWM concentrations of Total Ammonia were higher than for winter at all three locations.



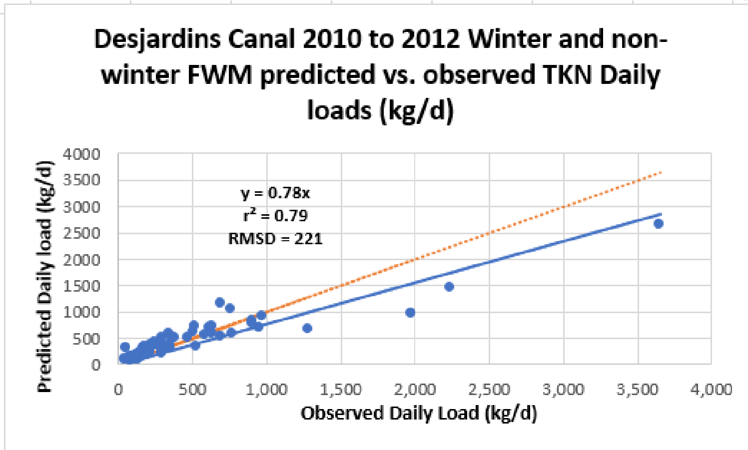


Figure 5: Observed versus predicted TKN Daily Loads for Desjardins Canal; Dashed line delineates 1:1; n = 84; Observed mean = 385 kg/d; Top: Winter regression and non-winter FWM method predicted mean = 375 kg/d; Bottom: Summer and Winter FWM predicted mean = 380 kg/d

Table 7: Seasonal Flow-weighted mean (FWM) concentrations for Total Nitrate and Total Ammonia at Red Hill Creek, Indian Creek and Grindstone Creek

		Total Nitrate (mg/l)	Total Ammonia (mg/l)
Red Hill Creek	**June to Oct. FWM (+/- 95% CI)**	1.166 (0.891)	0.193 (0.121)
	Nov. To May FWM (+/- 95% CI)	1.231 (0.456)	0.295 (0.155)
Indian Creek	**June to Oct. FWM (+/- 95% CI)**	1.089 (0.409)	0.065 (0.026)
	Nov. To May FWM (+/- 95% CI)	0.978 (0.195)	0.138 (0.042)
Grindstone Creek	**June to Oct. FWM (+/- 95% CI)**	1.843 (0.904)	0.037 (0.020)
	Nov. To May FWM (+/- 95% CI)	0.947 (0.174)	0.063 0.024

Desjardins Canal

The seasonal partitioning at Desjardins Canal differed from the other locations based on the observation that a more restricted winter period of December to April better isolated the effects of snow melt (Long et al. 2015). Although there is no strong winter flow-concentration regression for Total Ammonia or Total Nitrate at this location, this seasonal partitioning was used to provide FWM concentrations for these substances to be consistent with the approach used for other substances.

For Total Ammonia at Desjardins Canal there was virtually no seasonal difference in FWM (Table 5). The FWM for the entire sampling period was 0.272 mg/l (the same as for the May to November FWM) so this value was used as an estimate for daily concentration and used to calculate daily Total Ammonia loads. The daily load predictions (96 kg/d) were reasonably close to the observed average (98 kg/d) but this was the result of greatly under-predicting low frequency high-load events (-86 kg/d for loads greater than the 75th percentile of 91 kg/d) and over-predicting high-frequency low-load events (27 kg/d for loads less than the 75th percentile; see Figure 6). These results should be used with the understanding that although annual totals are reasonably estimated they will err on the low side in high flow years and the high side in low flow years.

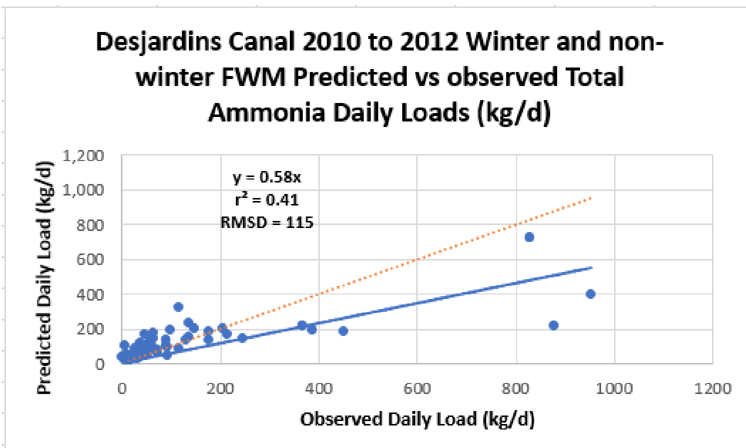


Figure 6: Observed versus predicted Total Ammonia Daily Loads for Desjardins Canal; Dashed line delineates 1:1; n = 82; Observed mean = 98 kg/d; Summer and predicted mean = 96 kg/d

Winter FWM

Total Nitrate exhibited a higher winter (December to April) FWM of 1.259 mg/l than for the remainder of the year (0.912 mg/l) so these two values were used to estimate corresponding daily concentrations and loads. The predicted mean daily load (406 kg/d) was extremely close to the observed mean (405 kg/d) and the slope of the observed versus predicted regression (1.02) was very close to the 1:1 line resulting in a RMSD of 141 kg/d. The model performed very well over the entire range of loads in that it only under-predicted low frequency high-load events by -2 kg/d for loads greater than the 75th percentile of 570 kg/d and over-predicted high-frequency low-load events by 1 kg/d for loads less than the 75th percentile (see Figure 7). The results can be used with confidence that it is providing a very good estimate of seasonal load distribution associated with high flow and low flow events.

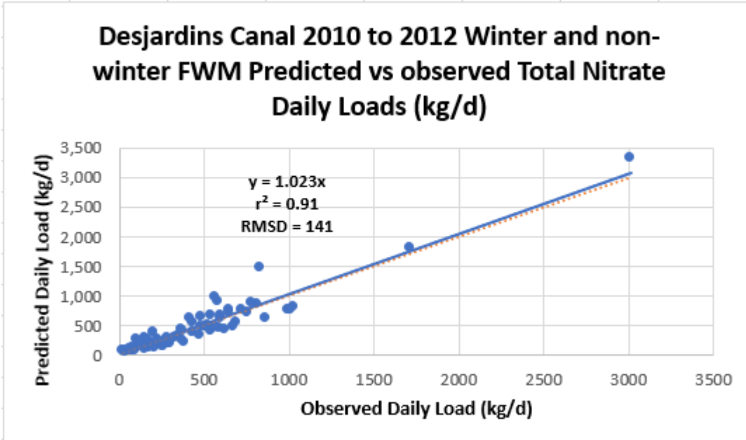


Figure 7: Observed versus predicted Total Nitrate Daily Loads for Desjardins Canal; Dashed line delineates 1:1; n = 81; Observed mean = 405 kg/d; Summer and Winter FWM predicted mean = 406 kg/d

4. RECOMMENDED METHODS AND EVALUATION OF ERROR

Table 8 summarizes the recommended loading calculation methods to use for all locations and contaminants and provides a summary of model performance. It should be noted that in many cases the HYDAT daily mean flows differed slightly from the event-mean flows used to calculate the regressions since most 24-hour sampling periods did not fall exclusively within one calendar day. The comparisons of predicted versus observed flows in this table use the same daily mean HYDAT data to calculate predicted and observed loads so the error is only attributable to differences in observed versus estimated concentrations. The Table refers to the following four methods that are recommended for estimation of Hamilton Harbour tributary loadings based on analysis of data collected over the period July 2010 to May 2012:

Method 1: Use of *log[flow]* versus *log[concentration]* regressions to estimate daily contaminant concentrations and loads;

Method 2: Use of separate seasonal *log[flow]* versus *log[concentration]* regressions to estimate November to May and June to October daily contaminant concentrations and loads;

Method 3: Use of *log[flow]* versus *log[concentration]* regressions to estimate December to April daily contaminant concentrations and loads combined with use of May to November Flow Weighted Mean (FWM) contaminant concentrations to estimate daily loads; and

Method 4: Use of seasonal FWM contaminant concentrations to estimate daily loads (December to April and May to November at Desjardins Canal; elsewhere November to May and June to October).

Table 8: Comparison of Predicted and Observed Daily for Sampled Days during the period July 2010 to May 2012 at Red Hill Creek, Indian Creek, Grindstone Cree and Desjardins Canal

Location (method)	Substance	Observed Mean (kg/d)	Predicted Mean (kg/d)	RMSD (from 1:1 line)	r^2 (for "0" intercept)	NSE (Nash-Sutcliffe Efficiency)	Regression Slope (rel. to 1:1)
Red Hill Creek							
Method 1	TP	51	57	73	0.83	0.72	1.14
Method 1	TSS	28,754	41,409	107,498	0.42	0.99	1.04
Method 1	TKN	194	199	125	0.94	0.91	1.10
Method 1	Fe	144	226	384	0.90	-0.10	1.80
Method 1	Pb	0.98	1.61	3.79	0.49	0.99	1.35
Method 1	Zn	10.2	15.0	26.3	0.69	-0.22	1.48
Method 4	Ttl. Ammon.	40	40	43	0.83	0.81	0.69
Method 4	Ttl. Nitrate	221	194	159	0.71	0.66	0.53
Indian Creek							
Method 1	TP	16	18	15	0.85	0.78	1.09
Method 1	TSS	9,064	10,655	16,147	0.64	0.99	1.03
Method 4	TKN	85	87	35	0.92	0.92	0.98
Method 1	Fe	55	69	68	0.89	0.57	1.38
Method 1	Pb	0.35	0.47	0.68	0.80	0.15	1.47
Method 4	Zn	8.3	14.8	17.1	0.72	-1.41	1.84
Method 4	Ttl. Ammon.	13	10	16	0.18	0.13	0.56
Method 4	Ttl. Nitrate	102	94	66	0.81	0.81	0.82
Grindstone Creek							
Method 2	TP	25	27	48	0.68	0.20	1.22
Method 2	TSS	11,965	17,956	51,030	0.45	0.98	1.60
Method 2	TKN	139	111	146	0.54	0.48	0.73
Method 2	Fe	82	91	147	0.70	0.33	1.20
Method 2	Pb	0.31	0.41	0.93	0.54	-1.20	1.47
Method 2	Zn	1.7	2.1	3.8	0.59	-1.41	1.34
Method 4	Ttl. Ammon.	6	6	7	0.50	0.58	0.68
Method 4	Ttl. Nitrate	121	121	51	0.91	0.89	1.04
Desjardins Canal							
Method 3	TP	52	49	42	0.83	0.82	0.92
Method 3	TSS	16,284	19,295	31,735	0.80	-0.06	1.55
Method 3	TKN	384	375	181	0.87	0.88	0.89
Method 3	Fe	212	199	113	0.94	0.93	0.86
Method 3	Pb	0.94	0.96	0.86	0.77	0.65	1.07
Method 3	Zn	8.1	7.9	4.9	0.86	0.85	0.98
Method 4	Ttl. Ammon.	98	96	115	0.41	0.57	0.58
Method 4	Ttl. Nitrate	405	406	141	0.91	0.89	1.02

Note: The observed and predicted TP results in this table differ slightly from those presented in Long et al. (2015) since in this analysis data were thinned by combining duplicate samples to yield single daily concentration results. Differences in r^2, RMSD, NSE and slope values for TP were also the result of applying alternative goodness-of-fit methods. Differences in TP results for the Desjardins Canal result from substitution of a simple winter regression and non-winter FWM model for the original 3-factor model.

Several patterns emerge from Table 8 that are worth noting when applying the recommended methods to generate annual loading estimates for these substances. There is no evidence that the loading estimates derived from FWM (simplified Beale) related methods (i.e. Methods 3 and 4) delivered results that were inferior to the exclusively regression-based estimates (i.e. Methods 1 and 2). In fact, the best results were delivered for the Desjardins Canal where only Methods 3 and 4 were used.

It is also encouraging to see that the predicted and observed mean daily loadings were within approximately 10% for half the combinations of substance and locations. The largest relative errors were for TSS at all locations and for most metals particularly at Red Hill Creek and Grindstone Creek. The most prevalent tendency where the discrepancy between observed and predicted was greater than 10% was for model estimates to exceed observed loads. This was the case for TSS and metals. The most notable under-predictions were for Total Nitrate at Red Hill Creek, Total Ammonia at Indian Creek and TKN at Grindstone Creek.

Although Total Ammonia exhibited an extremely low r^2 value at Indian Creek (0.18) as well as low regression slopes at Indian Creek and Desjardins Canal (0.56 and 0.48), the relative errors in predicted versus observed annual mean daily loads were not egregious. As previously noted, the primary message here is that although the total annual average estimates for ammonia are reasonable, the corresponding models are achieving this by over-predicting high frequency low load events and greatly under-predicting low frequency high load events. Figure 6 (on p. 20) demonstrates that this large under-prediction is largely the result of two high load events where the observed loads greatly exceed the FWM model estimates. These loading estimates should be used with the understanding that annual estimates will be biased high in dry years and biased low in wet years.

The opposite pattern is the case for TSS and metals where regression-based models tend to over-predict results for metals during low frequency high load events. Figure 8 illustrates the situation using the results for Grindstone Creek, but similar results were observed for TSS and most metals at most locations. In this case it is apparent that most of the error stems from a small number of high loading events where the regression model yields daily load estimates that greatly exceed observed loads and these outliers are driving the poor NSE scores. (removing these outliers from the analysis results in positive NSE scores). This analysis suggests that low frequency, high flow events will yield significant over-estimates of daily loading for TSS and metals and consequently annual estimates will also tend to be biased high in years with more frequent extremely high flow events. This is not necessarily surprising since (as noted at the outset) following exponentiation, regression models based on relationships between *log[flow]* versus *log [contaminant]* will always yield the greatest relative error for the high flow events.

Although the methods employed in this analysis use daily concentrations and loads, the goal of the exercise is to produce seasonal or annual estimates. Since these pooled results will be much less sensitive to extreme outliers (i.e. they will include a preponderance of high frequency, low flow events where the relative error is small) the results can be used without undue concern regarding the influence of outliers. Assessing the receiving water effects of inputs from individual extreme events is best accomplished through actual measurements rather than model based estimates.

A final observation regarding the representation of annual loads as daily averages is a reminder that these do not actually represent typical daily loads. Due to the highly skewed distribution of flows and loads, the annual arithmetic daily average will be higher than the actual load for low flow days, and much lower than the actual load on high flow days. Median or geometric mean results are a better measure of typical daily loads. This may be worth clarifying when results are presented.

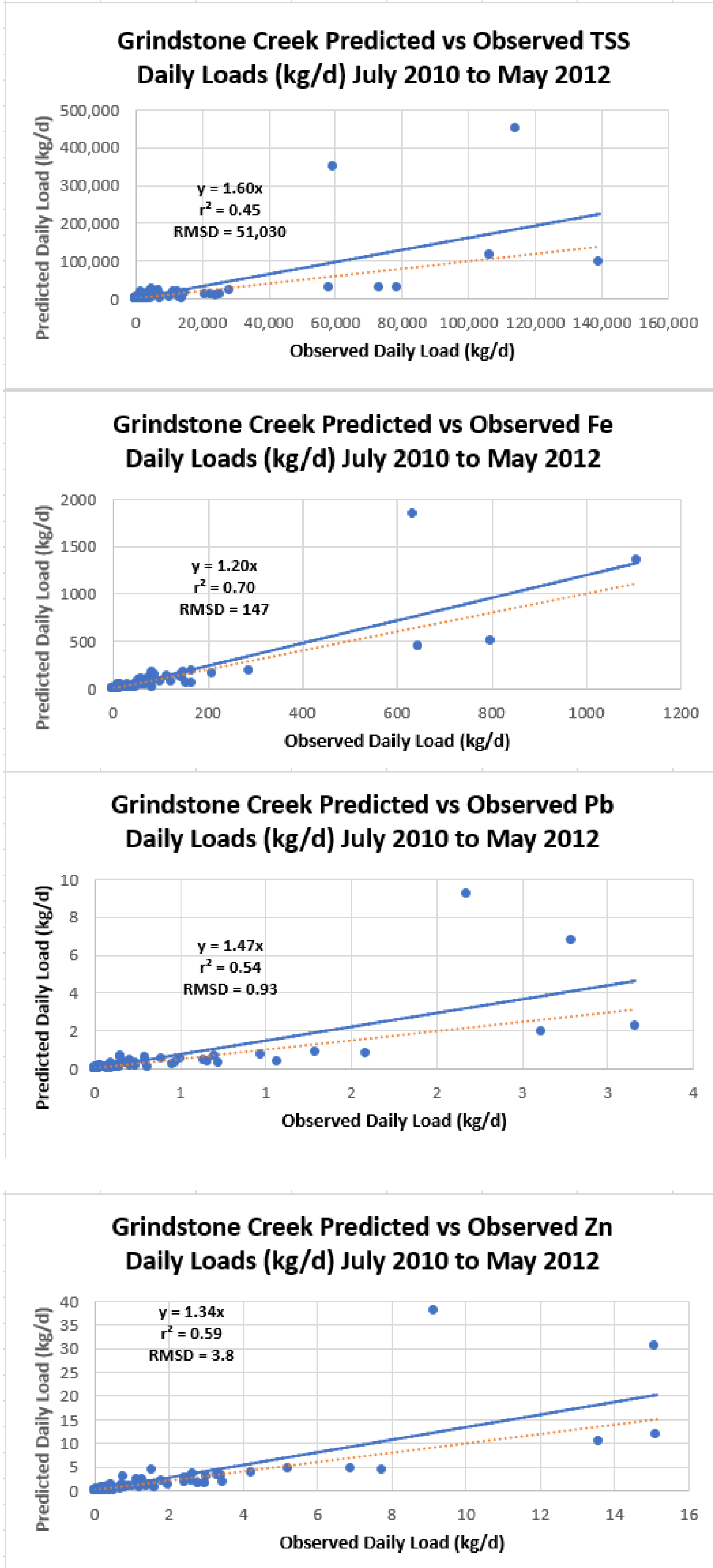


Figure 8: Observed versus predicted Daily TSS, Fe, Pb and Zn Loads for Grindstone Creek; Dashed line delineates 1:1; n = 80

5. CONCLUSIONS

Analysis of event-based flow and water quality sampling for total suspended solids, nutrients and metals at inputs to Hamilton Harbour over the period July 2010 to May 2012 support the following conclusions:

- The *log [flow]* versus *log [contaminant]* regression-based approach recommended by Long et al. (2015) for TP can also be applied to generate loading estimates for TSS, TKN, Fe, Pb and Zn at Red Hill Creek and Grindstone Creek;

- The regression-based approach is also valid at Indian Creek for TP, TSS, Fe and Pb but dry weather high concentration anomalies for TKN and Zn yield regressions that are not statistically significant and which therefore require an alternative approach;

- A comparison of alternative load estimation methodologies for TKN and Zn at Indian Creek suggests the use of seasonal FWM concentrations (equivalent to application of the Beale Ratio Estimator) will yield satisfactory loading estimates;

- A comparison of the Desjardins Canal three-factor TP model developed by Long et al. (2015) with a simplified method combining the winter flow-concentration regression with the non-winter FWM for TP suggests that the use of this simpler alternative can deliver satisfactory results for TP and also be applied to TSS, TKN, Fe, Pb and Zn;

- Use of seasonal FWM concentrations (a simple equivalent to the Beale Ratio Estimator) will yield acceptable load estimates for Total Ammonia and Total Nitrate at all locations; and

- Available data for Spencer Creek were insufficient to yield any significant flow-concentration relationship and additional data collection is necessary before contaminant loads can be estimated.

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