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Detroit River Phosphorus Loading Determination

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Overview

In response to requests from the Lake Erie LaMP, Environment Canada undertook a nutrient study in the lower Detroit River. The primary goal of the Detroit River Phosphorus Loading Application study was to estimate phosphorus loads to Lake Erie. During the period of August to November, 2007, ISCO programmable water samplers were run at two locations on the Lower Detroit River to collect water samples automatically every two hours, 24-hours a day, in order to provide a better estimate of phosphorus loads to Lake Erie. Sub samples from each ISCO sample collected on a common day were combined to comprise a 24-hour (daily) composite sample. These samples were subsequently analyzed to determine total phosphorus (TP) concentrations. Grab samples were also taken periodically at these and several other locations along the Detroit River. The grab samples were analyzed for TP and total soluble reactive phosphorus (SRP). It was intended that relationships would first be developed between the measured TP concentrations from grab samples taken at the ISCO station(s) and grab samples taken at other locations. Using these relationships, the 24-hour (daily) composite data generated from the ISCO samplers could then be related to the grab sample locations to estimate near-continuous phosphorus loading concentrations. An existing two-dimensional hydrodynamic model of the St. Clair-Detroit River system was modified specifically for this study. It was used to estimate flow distributions across each channel and at each sampling location, so that the total loading of phosphorus entering Lake Erie over the study period could be estimated.

Study Area

The Detroit River connects Lake St. Clair and Lake Erie in the Great Lakes Basin, and forms part of the international boundary between Canada and the United States (Figure 1). The Detroit River is approximately 51 km long and has a mean flow of approximately 5,270 m3/s. Nearly 98% of the Detroit River flow enters from Lake Huron via Lake St Clair with 2% entering through a number of additional tributaries, the most significant of which being the Rouge River, located in Michigan, USA. The flow in the Detroit River is complicated by the many branches around islands and through navigation channels, particularly in the Lower Detroit River near Lake Erie (Figure 2). The Fleming Channel, north of Peche Island, accounts for 74% of the total flow into the Detroit River (Holtschlag and Koschik, 2002b). In 2006 Environment Canada (EC) used USCG Buoy R-114 as an upstream monitoring site located north of Peche Island in the Fleming Channel. Samples collected from this site were intended to characterize the general water quality conditions of the waters exiting Lake St. Clair. However, inputs that discharge into the east and south shores of Lake St Clair may not be well captured at this upstream reference site. In 2007 a site south of Peche Island was added to capture the near shore contaminants originating along the east and south shores of Lake Clair that persist in the water column.

Much of the Detroit River shoreline is highly urbanized and is one of the world's most heavily industrialized areas (UGLCCS, 1988). The average flushing time for the Detroit River is 19 hours (UGLCCS (2)).

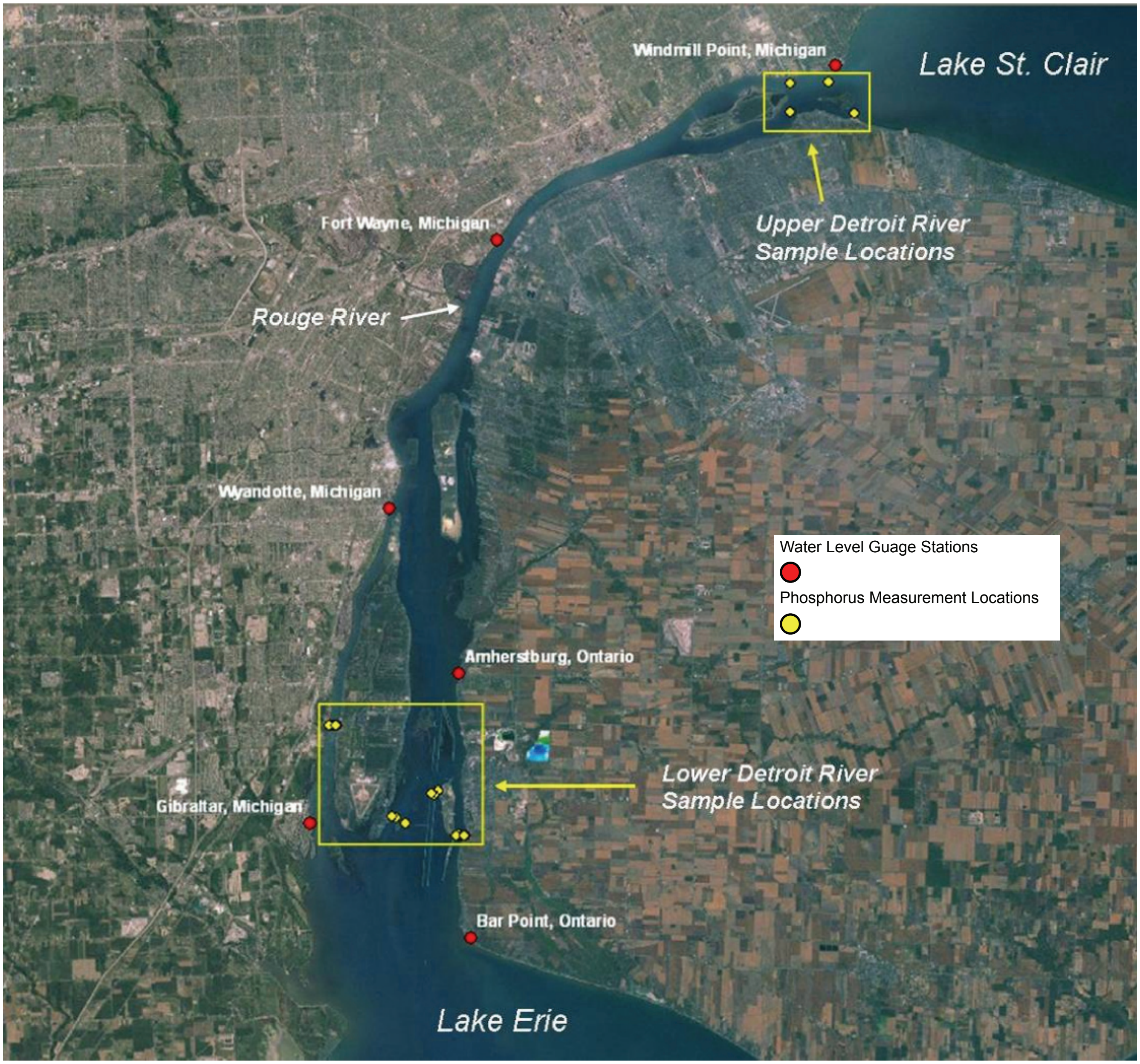

Figure 1: Detroit River study area.

- **Lower Detroit River – Near Fighting Island**

Generally, the distinction between the Upper and Lower Detroit River begins at Fighting Island where the river flow is separated into three channels: two of the channels flow along the US and Canadian shoreline, and the other channel flows midstream in the river. Various sections of these three channels have specific names:

1) The "Trenton Channel," flows entirely along the US shore;

2) The “La Salle Channel” is located between Fighting Island and the Canadian shoreline. Historically this channel was identified as “Fighting Channel”, however, on current navigational charts it is un-named;
3) “Fighting Island Channel” is the busy commercially-dredged navigational channel in the river’s midstream;
4) The “Ballards Reef Channel” extends the Fighting Island Channel navigational channel some 5 km south. The flow of the Ballards Reef Channel at its southern end is physically bisected at Stony Island by rock berms locally known as the “Crystal Bay Compensating Dike”, creating two additional channels known as the “Amerherstburg Channel” and, “Livingstone Channel”.

- **Lower Detroit River – Amherstburg Channel**

As compared to the Livingstone Channel, which runs close to the mid-stream of the river, the Amherstburg Channel flows directly along the Canadian shoreline. The Amhurstberg Ch. is expected to have higher concentrations of suspended sediments and contaminants due to the sediment plume that flows along the shoreline in addition to the on-shore contaminant sources that directly impact its waters. Therefore, Environment Canada positioned one of the monitoring sites in the Amherstburg Channel such that it would be near-shore and directly downstream of Canadian inputs to the River.

- **Lower Detroit River – Midstream**

Above Stony Island, between Ballards Reef Channel and Grosse Ile, are shallow, slow moving waters where sedimentation is likely to occur. Flow of water into the “Grosse Ile to Livingstone Ch. Berm” midstream channel either passes through a shallow passage located between Grosse Ile and Stony Island, or through an opening in the Livingstone Channel located at the upstream end of Bois Blanc (Boblo) Island. To the south of Stony Island, these lower midstream waters are partially contained by natural and man-made structures, which also provide suitable conditions for sedimentation; these structures include the following:

(1) to the north, Stony Island and associated man-made structures;
(2) to the west, Grosse Ile and smaller islands;
(3) to the east, Livingstone Channel berm; and
(4) to the south, Sugar Island, Sugar Island Compensating Dike, as well as Meso and Hickory Islands.

- **Lower Detroit River – Trenton Channel**

The Trenton Channel is located on the west side of the Detroit River along the US shoreline. It originates near the upstream end of Fighting Island and over much of its length flows between Grosse Ile and the U.S. mainland in a straight and well-defined channel. As well the Detroit STP empties into the Trenton Channel increasing suspended sediment load. Environment Canada placed a station here to capture inputs into this channel.

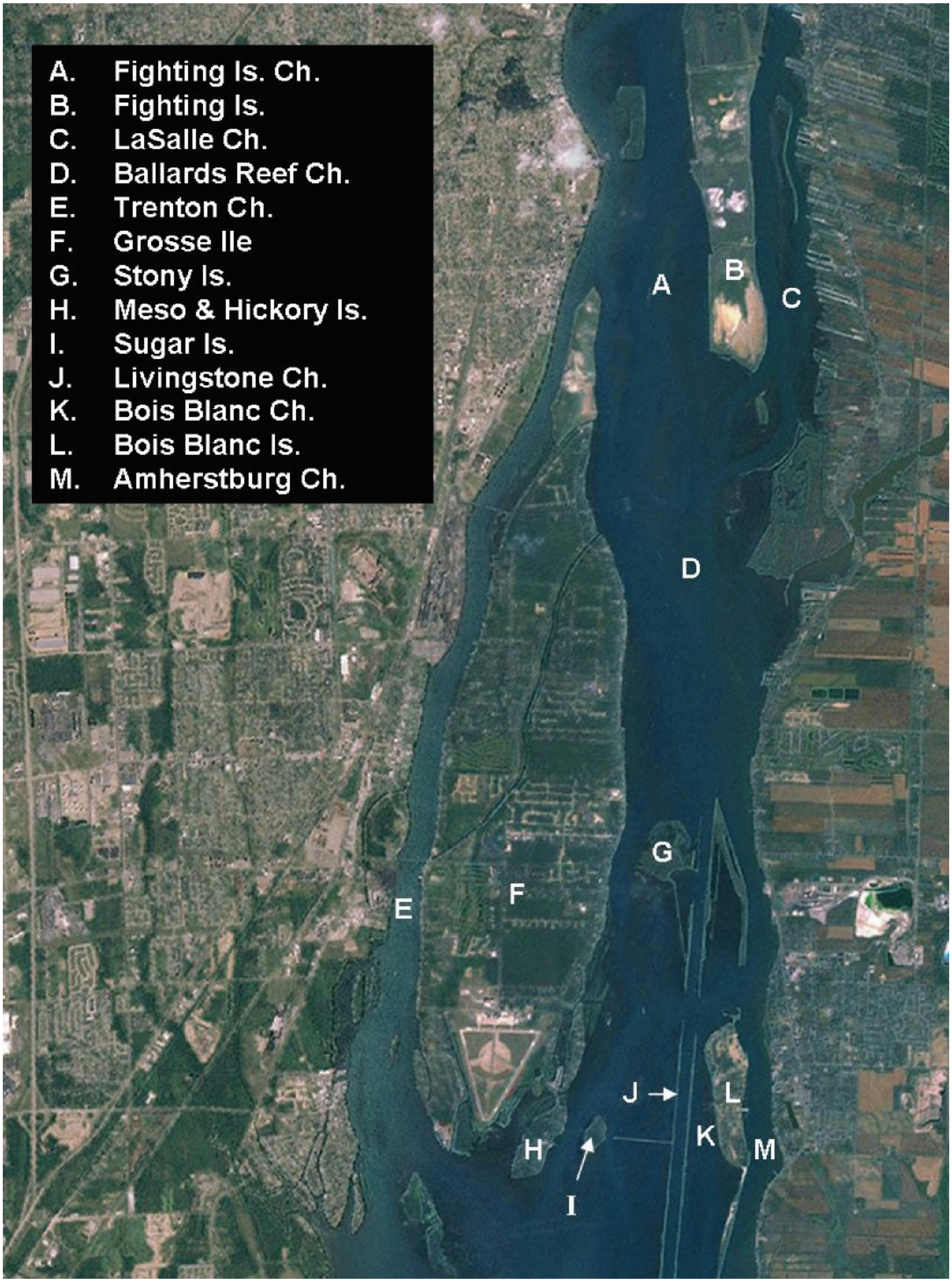

Figure 2: Lower Detroit River features and channels.

Preliminary Studies

In 2004, Environment Canada completed a preliminary surveillance study. A total of 17 surveys were conducted in the Detroit River from May to October by staff of EC's Water Quality Monitoring and Surveillance Office (WQM&S), in partnership with staff of the Great Lakes Institute for Environmental Research (GLIER). Whole-water surface grab samples (62) were collected to characterize TP concentrations at locations throughout the St. Clair-Detroit R. corridor with greater resolution focusing in the Lower Detroit River. The results of the study were used to characterize TP concentrations and to estimate the TP loading and discharge through each of the channels (Trenton, Sugar Island, Livingstone and Amherstburg) in the Lower Detroit River. These values would then be used to estimate the TP loading into Lake Erie from the Detroit River for the survey period (Figure 3). The TP load entering Lake Erie from the Detroit River was estimated from this data to be 5,850 kg/day from April 19/2004-November 1/2004.

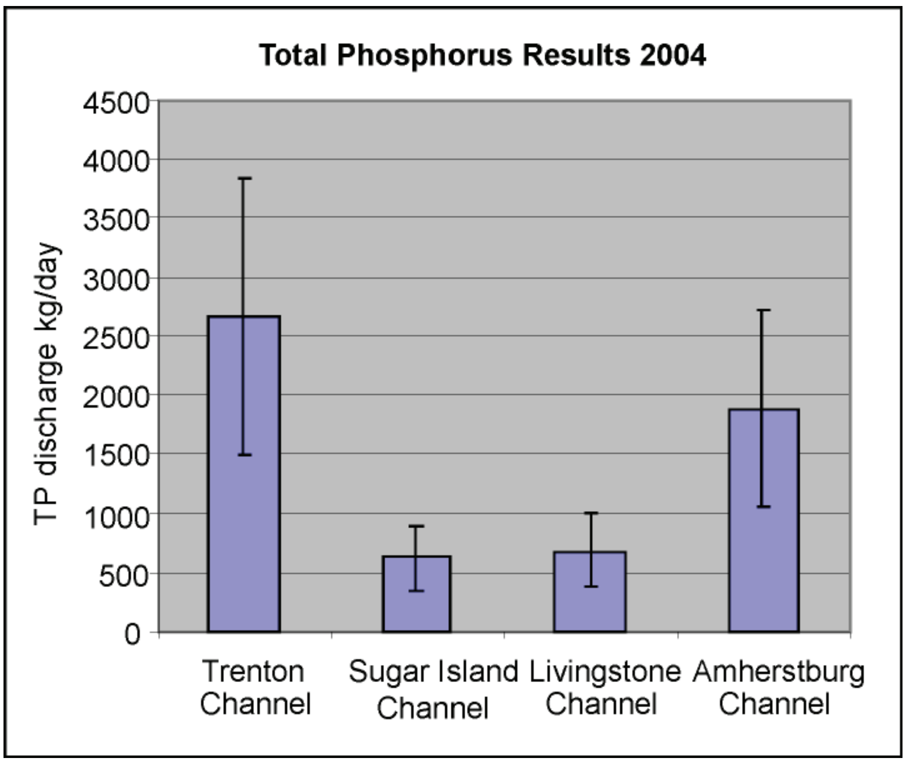

Figure 3: Total phosphorus 2004 results: discharge in channels in the Lower Detroit R.

As well as the loading estimates, the 2004 study provided key information which help in understanding the dynamics of TP concentration in the system. Key points from the 2004 study were:

1) There were no significant differences in TP concentration between the water exiting the St. Clair R. and from the water exiting Lake St. Clair, even though high concentrations of TP entered Lake St. Clair

from major tributaries during the study period (Sydenham R. TP=22 ± 3 ug/L, n=6; Thames R. TP= 159±47 ug/L, n=7 (Ontario Ministry of the Environment). Note: As mentioned previously, the location of the upstream site in 2004 was on the north side of Fleming Ch. and may not have been influenced by the local Canadian inputs;
2) There were no significant changes in TP concentrations from water entering the Detroit R. and the concentration found in the middle channels of the lower Detroit R;
3) Significant increases in TP concentration were found in both the Amherstburg and Trenton channel water.

Due to the limited number of grab samples collected from each site during the 2004 survey, estimates for both concentration and loadings were considered to have large errors and provided general information only.

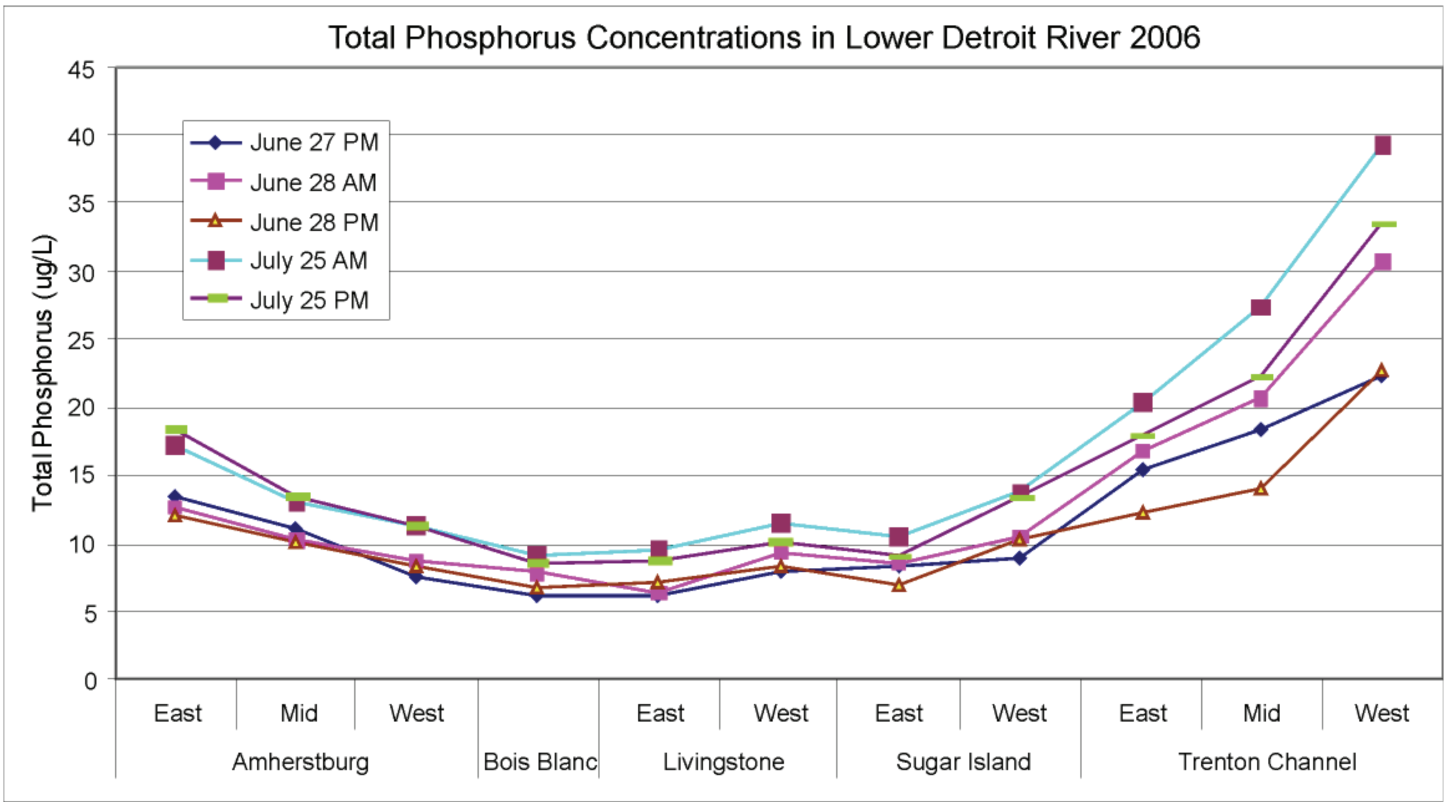

Figure 4: Variation of total phosphorus concentrations temporally and horizontally in Lower Detroit River in June and July, 2006.

Environment Canada conducted a nutrient pilot study in 2006 to examine the spatial patterns of TP concentrations in the Detroit R. and to provide key information for the 2007 study. Discrete samples were collected at various times in each of the channels of the Lower Detroit River. Sample sites were spaced both horizontally and vertically over the channel. Temporal, spatial and depth variation of TP and SRP concentrations were subsequently assessed. With the exception of the Trenton Channel, temporal variations were found to be small during the course of this study. Results indicated that spatial variation (surface water) of phosphorus concentrations varied between the different channels (Amherstburg, Bois Blanc, Livingstone, Sugar Island and Trenton), and also across each individual channel, with the greatest spatial variation observed within the Trenton and Amherstburg Channels. Temporal and spatial variations are shown graphically in Figure 4. The spatial variation of the data also indicated that the Amherstburg and Trenton Channels were impacted most by point and non point sources upstream. There was little vertical variation in phosphorus concentrations in the water column at any of the sites.

A series of 24 hourly samples were collected in the Trenton Channel in 2006 from 12:30 am on August 31st to 11:30 am on September 1st and analyzed for TP in order to assess the temporal variability at a fixed site. A sampler was located on the Grosse Ile free bridge at the bridge pivot on the downstream footing. The results indicated that the TP concentration in the Trenton Channel is highly variable over a 24 hour period (Figure 5). The study indicated a greater range of TP concentrations than previously (2004) observed. As a result a temporal component that incorporated hourly and day-to-day variability would be required to generate a more accurate estimation of loadings.

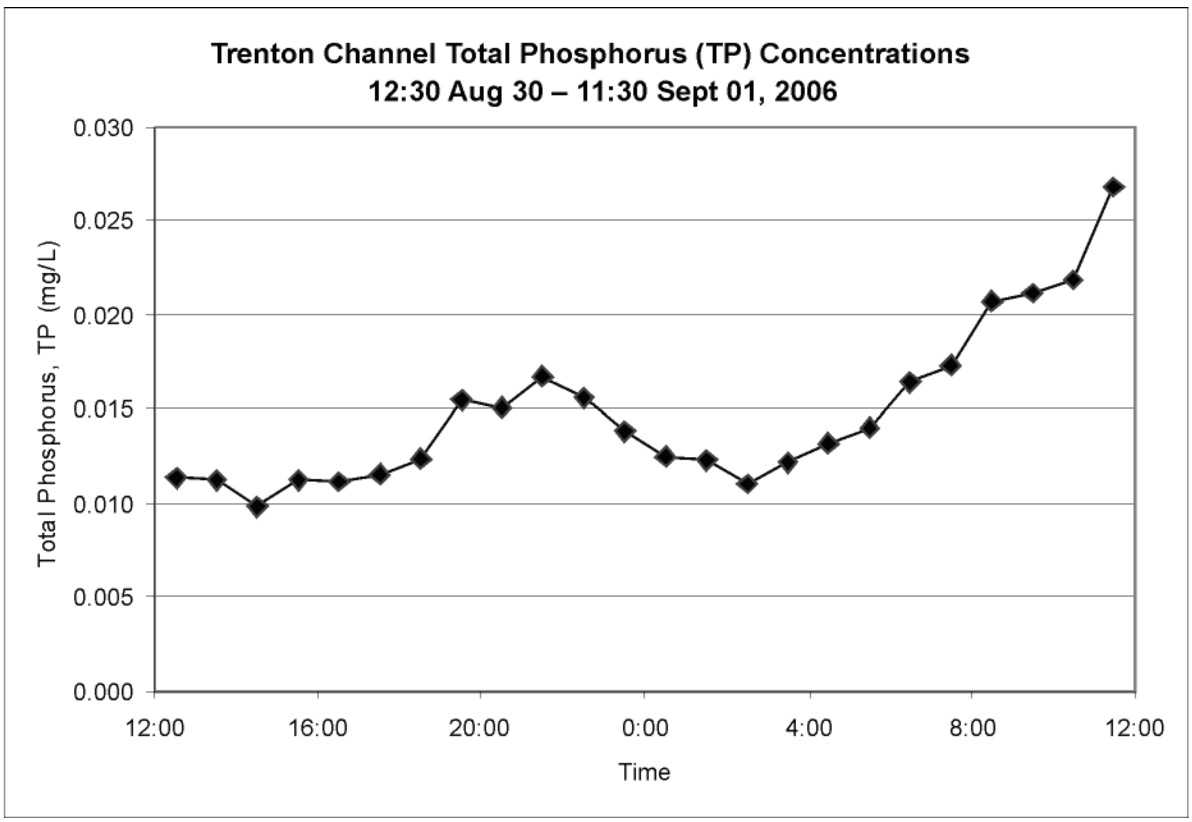

Figure 5: Trenton Channel total phosphorus concentrations taken hourly Aug 30- Sept. 01, 2006.

While the design of the 2006 study provided only general concentration and loading estimates for a snap shot in time due to the limited number of samples, key points of the 2006 study were:

1) There was a large temporal variation in the Trenton Channel;
2) At all times during the investigation there was large horizontal variation across the Trenton Ch., Amherstburg Ch., and Lower Detroit R.;
3) Throughout the study there was minimal horizontal variation across the Bois Blanc, Livingstone and Sugar Is. Channels; these channels were minimally impacted by TP sources within the Detroit R.;
4) There was minimal vertical variation in TP at all sites, for all times investigated;.
5) Trenton Ch. had the highest TP concentrations, greatest cross-channel (horizontal) variation and the greatest temporal variation.

These earlier results helped with the strategy for the 2007 Detroit R. corridor nutrient monitoring program. Perhaps the most useful information provided by the 2004 and 2006 preliminary studies was that they demonstrated that temporal and spatial variation in TP concentrations can be significant in the Lower Detroit River, with the Trenton Channel having the highest TP concentrations, greatest cross-channel variation and the greatest temporal variation. Nonetheless a fairly consistent spatial pattern emerged. It was hypothesized that this pattern may allow for effective monitoring from a single shore based site, beyond any near shore influences, if a relationship could be established with samples collected from across the channel. Also since variability in the discharge regime of the sewage treatment plants (point sources of TP to the Detroit R.) may increase the temporal variations of TP concentrations in the river, future sampling efforts need to include time-integrated sampling to incorporate variability within the day. Collection of daily time-integrated samples would mitigate the need to interpolate data between surveys.

Overview of 2007 Detroit R. Nutrient Monitoring Program

In the summer and fall of 2007, Environment Canada's Water Quality Monitoring and Surveillance Ontario Section undertook a four-month phosphorus sampling program on the Detroit River. The objectives of the 2007 study design were to:
1) Characterize Detroit River water concentrations across the river with samples from all the major channels just above the river mouth, downstream of all major inputs and across the river inlet.
2) Characterize mean daily concentrations in Amherstburg and Trenton Channels for the duration of the study period.
3) Characterize temporal variation in TP concentrations over two day sampling periods.
4) Estimate daily TP discharge into Lake Erie for open water conditions.

Firstly, an assessment of the relationship between grab samples taken at sites across the individual channels and grab samples taken at one of the sites where the ISCO sampler was established (ISCO site) was determined where appropriate. Secondly, sources of phosphorus to the Detroit River were investigated. This work was then used to determine the TP loadings from the Detroit River to Lake Erie. To best calculate these loadings an existing two dimensional hydrodynamic model was adapted to estimate flow factors in each of the channels investigated. The flow factors from this model were then applied to the grab sample mean TP concentrations at each of the sampling locations. The 24-hour (daily) composite data collected using the ISCO samplers were then used, where relationships could be established, to determine loadings for each channel. The sum of the TP loading from each channel, determined using either grab sample data alone (where no relationship with ISCO site could be established) or by using grab sample and the 24-hour (daily) composite sample (where relationship could be established) provided the current estimate for loadings of TP from the Detroit River into Lake Erie.

Methods

The 2007 sampling program involved two types of sample collection methods: ISCO programmable water samplers and discrete grab samples. The programmable ISCO samplers collected a water sample every two hours over 24-hours. ISCO sample locations were identified in the Amherstburg Channel (ACISCO) and Trenton Channel (TCISCO). In addition, discrete grab samples were collected manually during 14 two-day surveys performed approximately biweekly from July 30th to November 1st, 2007. For each day of the survey in the Lower Detroit River, single grab samples were collected at a number of locations spaced across each channel in order to spatially capture the majority of the flow before entering Lake Erie (Figure 6). Also included in these surveys were triplicate grab samples collected at each of the ISCO stations. Grab samples in the Lower Detroit River were collected in the order given in Table 1. Each survey took approximately two hours to complete. Upper Detroit River grab samples were also collected during each survey (Figure 7). The specific locations, site identifiers and geographic coordinates of all samples collected are shown in Table 2.

Figure 6: Phosphorus sample locations in the Lower Detroit River in 2007.

Figure 7: Phosphorus sample locations in the Upper Detroit River in 2007.

Table 1: Lower Detroit River sampling order.

Order	Channel	Sample
1	Trenton	TCISCO #1
2		TC1
3		TC2
4		TC3
5		TCISCO #2
6		TC4
7		TC5
8		TCISCO #3
9	West Sugar Island	WS2
10		WS1
11	East Sugar Island	ES
12	Livingstone	LC2
13		LC1
14	Boise Blanc	BB
15	Amherstburg	ACISCO #1
16		AC2
17		AC3
18		ACISCO #2
19		AC4
20		AC5
21		ACISCO #5

Table 2: Sampling locations in the Detroit River.

River Location	Specific Location	Site ID	Type	Latitude	Longitude
Lower Detroit River	Amherstburg Channel	AC2	Grab	42.08627	-83.11425
Lower Detroit River	Amherstburg Channel	AC3	Grab	42.08645	-83.11537
Lower Detroit River	Amherstburg Channel	AC4	Grab	42.08663	-83.11628
Lower Detroit River	Amherstburg Channel	AC5	Grab	42.08662	-83.11703
Lower Detroit River	Boise Blanc	BB	Grab	42.10267	-83.12557
Lower Detroit River	East Sugar Island	ES	Grab	42.09083	-83.14151
Lower Detroit River	Livingston Channel	LC1	Grab	42.10131	-83.12758
Lower Detroit River	Livingston Channel	LC2	Grab	42.10141	-83.12874
Lower Detroit River	Trenton Channel	TC1	Grab	42.12659	-83.17348
Lower Detroit River	Trenton Channel	TC2	Grab	42.12660	-83.17438
Lower Detroit River	Trenton Channel	TC3	Grab	42.12660	-83.17528
Lower Detroit River	Trenton Channel	TC4	Grab	42.12662	-83.17619
Lower Detroit River	Trenton Channel	TC5	Grab	42.12662	-83.17707
Lower Detroit River	West Sugar Island	WS1	Grab	42.09288	-83.14593
Lower Detroit River	West Sugar Island	WS2	Grab	42.09338	-83.14778
Lower Detroit River	Trenton Channel	TCISCO	composite/Grab	42.12635	-83.17360
Lower Detroit River	Amherstburg Channel	ACISCO	composite/Grab	42.08623	-83.11336
Upper Detroit River	Cdn. side Peche Is	DP5	Grab	42.34162	-82.92109
Upper Detroit River	Fleming Ch Cdn. side	D110	Grab	42.34207	-82.95177
Upper Detroit River	Fleming Ch US side	R114	Grab	42.35282	-82.93292
Upper Detroit River	North Belle Is US side	R2	Grab	42.35245	-82.95125

Two ISCO samplers (Figure 8) were employed for the collection of daily composite samples. An ISCO sampler is a battery operated or AC powered whole water sampler. From August 1st to November 30th the ISCO samplers collected whole water samples every two hours, 24 hours a day. Samples were recovered within two days and acidified with 8 mL of 30% sulfuric acid in the field. Samples were acid soaked for five days, shaken, then sub-sampled (100 mL) into pre-cleaned 125 mL glass bottles. In the Trenton Channel the ISCO was operated on AC power and samples were retrieved by the U.S. Environmental Protection Agency (USEPA) staff. In the Amherstburg channel, samples were collected by the Town of Amherstburg Water Filtration Plant staff whose field notes identified that the battery operated ISCO located in this channel was prone to missed sampling events. The ISCO samples were later sub-sampled and combined to form a single integrated sample; the combined sub-samples represented a 24-hour (daily) composite sample for TP.

Whole water grab samples were collected using a 4 L Van Dorne water sampler and the collected water drained into 125 mL glass bottles. Samples were preserved with 1 mL-30% sulfuric acid. Analysis was done at the National Laboratory for Environmental Testing in Burlington, ON. On the biweekly sampling days, where the cross-channel samples were collected, the ISCO samples were not composited and discrete samples collected over the 24 hour period were analyzed in order to improve the temporal relationship between biweekly samples and the ISCO samples.

For replicate sampling, any remaining water in the Van Dorne bottle was emptied and then submerged again to fill. Blank samples were generated by filling sample bottles with phosphorus free water in the laboratory and uncapping during sampling. Blank samples were treated the same as all other samples.

All samples that were collected for soluble reactive phosphorus (SRP) were kept cold and shipped back to the lab within 24-hours. Samples were filtered and analyzed at the laboratory within the two day holding period.

- ISCO programmable sampler
- Amherstburg Ch. Site located at abandoned pier to Boise Blanc (Boblo) Is.
- Trenton Ch. Site located at the end of first dock just below swing bridge at the Grosse Ile Township marina
- Samples collected every 2 hours, 24 hours/day
- Samples recovered every one or two days
- ISCO samples are acidified with 8 mL of 30% sulfuric acid.
- ISCO samples sub-sampled and combined to create 24-hour (daily) composite samples

Figure 8: ISCO programmable sampler

Grab Sample Relationships

One of the objectives of the 2007 monitoring program was to estimate the daily TP discharge to Lake Erie. The monitoring program was designed to achieve these goals by establishing relationships between grab samples collected at the various locations in the Lower Detroit River and the grab samples collected at one of the ISCO stations. These relationships could then be used to estimate continuous phosphorus loading to Lake Erie from August to November, 2007, based on the 24-hour (daily) composite samples collected at the ISCO stations. The results of this initiative are described in the following sections. While there are a variety of approaches in developing relationships the authors chose to pursue an investigation into a linear relationship between the grab sample sites including the ISCO site

- **Amherstburg Channel TP Relationships**

The Amherstburg Channel grab sample locations (AC2 to AC5) and the Amherstburg Channel ISCO station are shown in Figure 9. On the second day of every two-day grab sample survey run, triplicate samples were collected at AC3. Resultant mean values for the triplicates samples had low standard deviations (SD) and therefore were representative of single AC3 measurement for these days. The low SD provides evidence that the QA sampling, field processing and analytical protocols were appropriate for this application.

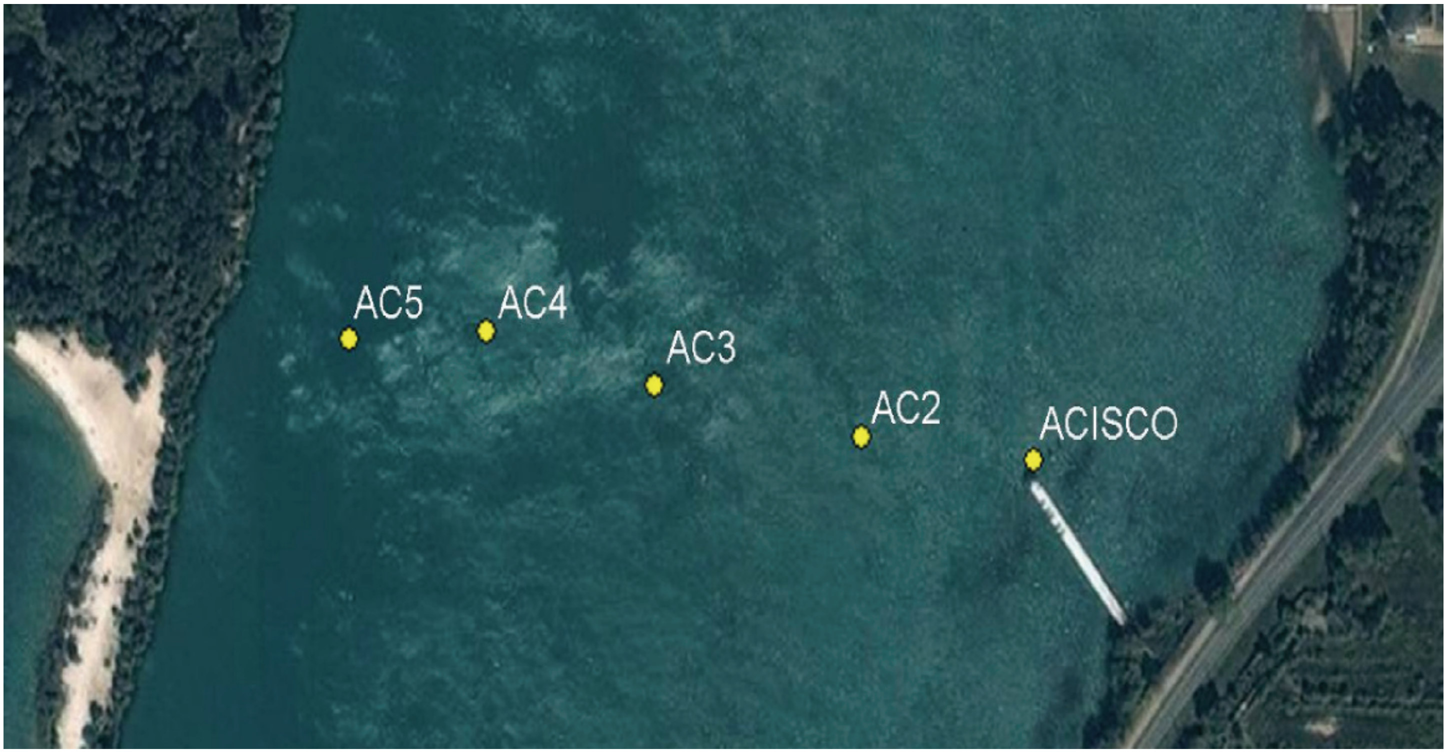

Figure 9: Amherstburg Channel sample locations

As indicated in Table 1, grab samples were taken at each ISCO site three times each day for each two day survey. For the ACISCO grab samples, the TP concentrations with mean and SDs are shown in Table 3. Only one measurement was collected on July 30th. Many of the SDs are large in relation to the mean, indicating the grab samples varied significantly during each sample run at this location. This contrasts with the results from the triplicate samples collected at AC3. The variability with the ACISCO grab sample data may be a result of transient effects in the river, or with the ACISCO site location. The ACISCO site may have been influenced by nearby point sources or it may also be influenced by variable current due to the irregular shoreline directly upstream of the site. Another possible factor is the periodic discharge from the upstream Amherstburg STP. Regardless of the cause, the variability makes developing a relationship between the ACISCO location and the other (AC2-AC5) grab sample locations difficult.

Table 3: Grab sample data collected at ACISCO.

Date	Grab Sample Concentration (mg/L)				
	ACISCO-1	ACISCO-2	ACISCO-3	Mean	SD
Jul-30-2007	0.0191	--	--	0.0191	--
Jul-31-2007	0.0166	0.0163	0.0173	0.0167	0.0005
Aug-13-2007	0.0147	0.0153	0.0188	0.0163	0.0022
Aug-14-2007	0.0172	0.0244	0.0184	0.0200	0.0039
Sep-04-2007	0.0171	0.0493	0.0152	0.0272	0.0192
Sep-05-2007	0.0182	0.0213	0.0163	0.0186	0.0025
Sep-25-2007	0.0198	0.0189	0.0184	0.0190	0.0007
Sep-26-2007	0.0148	0.0146	0.0139	0.0144	0.0005
Oct-10-2007	0.0259	0.0146	0.0135	0.0180	0.0069
Oct-11-2007	0.0151	0.0339	0.0352	0.0281	0.0112
Oct-23-2007	0.0217	0.0204	0.0217	0.0213	0.0008
Oct-24-2007	0.0186	0.0198	0.0215	0.0200	0.0015
Oct-31-2007	0.0337	0.0278	0.0303	0.0306	0.0030
Nov-01-2007	0.0617	0.0306	0.0333	0.0419	0.0172

The TP concentrations from the ACISCO grab samples showed poor correlation with grab samples collected at other AC locations (AC2-AC5). The results are shown in Table 4. The correlation coefficients were low in all cases. Linear models were fit to the data using least squares regression. Theoretically the intercept should not be less than zero as a negative phosphorus concentration does not exist; however, given the range of samples collected, a better fit to the data may include an intercept term; neither model however provided a good fit to the data (Figure 10).

Table 4: Amherstburg Channel grab sample relationship results.

Date	Grab Sample Concentration (mg/L)				
	ACISCO Mean	AC2	AC3	AC4	AC5
Jul-30-2007	0.0191	0.0164	0.0156	0.0163	0.0122
Jul-31-2007	0.0167	0.0237	0.0183	0.0155	0.0127
Aug-13-2007	0.0163	0.0189	0.0175	0.0156	0.0139
Aug-14-2007	0.0200	0.0195	0.0161	0.0159	0.0143
Sep-04-2007	0.0272	0.0214	0.0174	0.0146	0.0108
Sep-05-2007	0.0186	0.0200	0.0158	0.0148	0.0121
Sep-25-2007	0.0190	0.0186	0.0120	0.0121	0.0083
Sep-26-2007	0.0144	0.0196	0.0138	0.0121	0.0102
Oct-10-2007	0.0180	0.0168	0.0165	0.0107	0.0085
Oct-11-2007	0.0281	0.0284	0.0160	0.0122	0.0101
Oct-23-2007	0.0213	0.0255	0.0169	0.0146	0.0139
Oct-24-2007	0.0200	0.0300	0.0270	0.0262	0.0270
Oct-31-2007	0.0306	0.0190	0.0147	0.0138	0.0138
Nov-01-2007	0.0419	0.0206	0.0151	0.0137	0.0127
MEAN	0.0222	0.0213	0.0166	0.0149	0.0129
SD	0.0074	0.0041	0.0034	0.0037	0.0045
CORREL	--	0.1304	-0.1179	-0.1154	-0.0106
SLOPE	--	0.0730	-0.0544	-0.0576	-0.0065
INTERCEPT	--	0.0197	0.0178	0.0161	0.0130
SLOPE (b=0)	--	0.8773	0.6740	0.6018	0.5260

In general mean TP concentrations did tend to decrease across the Amherstburg Channel, from east (ACISCO) to west (AC5). This relationship however was not consistent, resulting in poor relationships between grab samples taken at the ACISCO and the grab samples collected across the Amherstburg channel. While different approaches in developing relationships between sites could be investigated, the variability in the TP data at the ACISCO site precludes any success in realizing a relationship between these sites. For future studies the location of the intake for a fixed sampling site in the Amherstburg channel would need to be moved further into the middle of the channel.

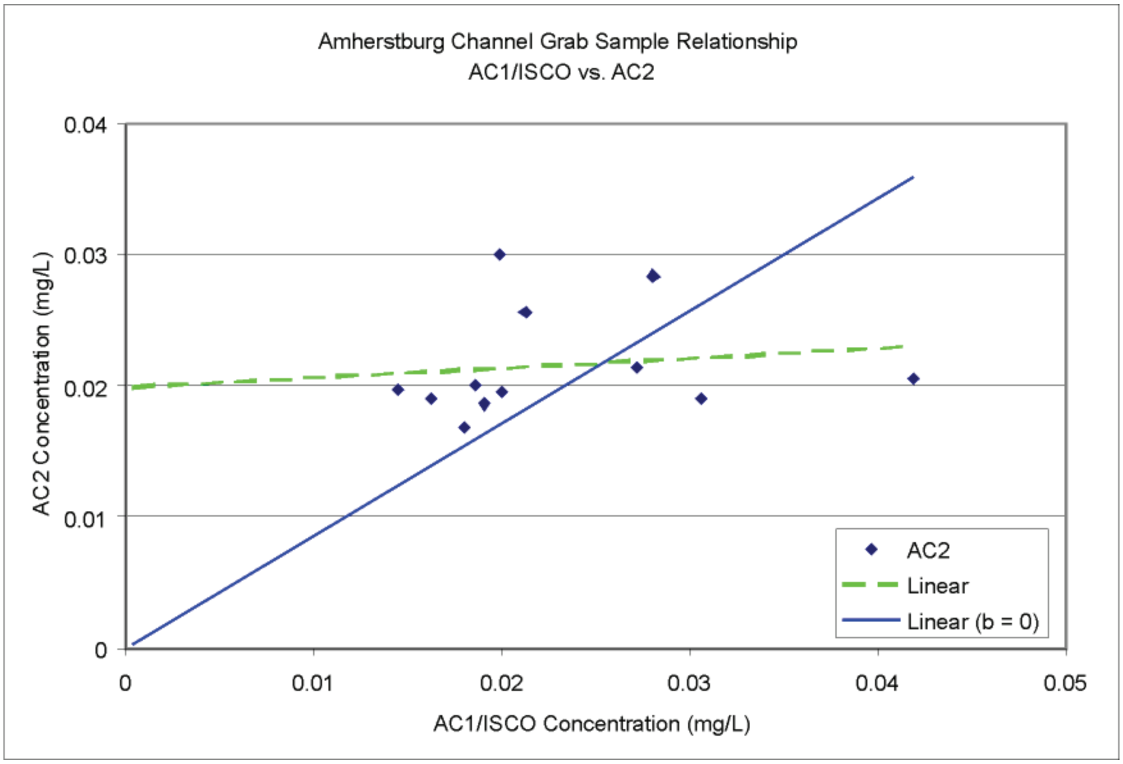

Figure 10: Linear relationships between TP measured from grab samples collected at ACISCO and AC2 locations.

The results however did show that a correlation between the grab sample locations (AC2-AC5) was better than the correlation observed between the ACISCO and the other grab sample data. This observation suggests that the ACISCO location was potentially impacted by one or more of the factors discussed earlier. A correlation coefficient matrix is given in Table 5. The coefficients between samples collected at AC2 through AC5 ranged from 0.528 to 0.959 suggesting that while a relationship in TP concentration may exist between stations on the Amherstburg Channel, the data collected at the ACISCO station does not maintain such a relationship.

Table 5: Correlation coefficient matrix for Amherstburg Channel.

Location	ACISCO	AC2	AC3	AC4	AC5
ACISCO	1.000	0.216	-0.119	-0.114	0.039
AC2	--	1.000	0.659	0.528	0.582
AC3	--	--	1.000	0.887	0.883
AC4	--	--	--	1.000	0.959
AC5	--	--	--	--	1.000

While temporal effects exist in the river, it is unlikely these affected the data relationships as sample collection time for the entire Lower Detroit River was less than two hours, and in addition, the other grab sample locations in the Amherstburg Channel had good correlation. Problems with sample/data collection are also unlikely, given the high quality of all other data collected in the river. Logistically speaking, the ACISCO station was located in an ideal location on the Canadian shore in that it was shore based, accessible and extended out from the near shore into the river; however, a shallow bend in the river coupled with a deeper, dredged navigation channel closer to the U.S. shoreline may cause the velocities to be much slower at the ACISCO station. Variation in the TP concentration at the ACISCO location was the greatest (41%) within all the AC sites. Much of this variability, even within the replicate sets, is due to relatively high concentrations. The greatest differences as seen at the ACISCO site occurred in surveys on Oct 31st and Nov 1st, when the ACISCO TP concentrations were at their highest for the year, whereas, concentrations at AC2, AC3 were below the annual mean. The elevated TP concentrations may have been caused by a nearby source. The closest is the Amherstburg STP, which is upstream (1.2 km) of the sampling transect.
Discharges from the Amherstburg STP into the shallow and sluggish near shore waters would appear to be having, at times, a greater impact on the TP concentrations at the ACISCO site. Any flow issues at this site would also compound the effects. It is apparent that the ACISCO site did not extend outside the near shore influences.

Overall the results from the Amherstburg Channel suggest that TP concentrations at the ACISCO station were not highly correlated with the TP concentrations measured at the other grab site locations in the Amherstburg Channel. There does, however, appear to be strong correlation between the grab site locations AC2-AC5, which indicated that mean TP concentrations tended to increase, from west to east, across the river, suggesting that TP relationships across the Amherstburg Channel may exist.

- **Trenton Channel TP Relationships**

The locations of the five Trenton Channel (TC) grab sample locations (TC1 to TC5) and the Trenton Channel ISCO station (TCISCO) are shown in Figure 11. The mean daily (n=3) TP concentrations for grab samples taken at TCISCO (Table 6) were used to build the TP relationships between sites. Note the SDs of the TCISCO station samples were much less than those for the ACISCO station with no noticeable outliers.

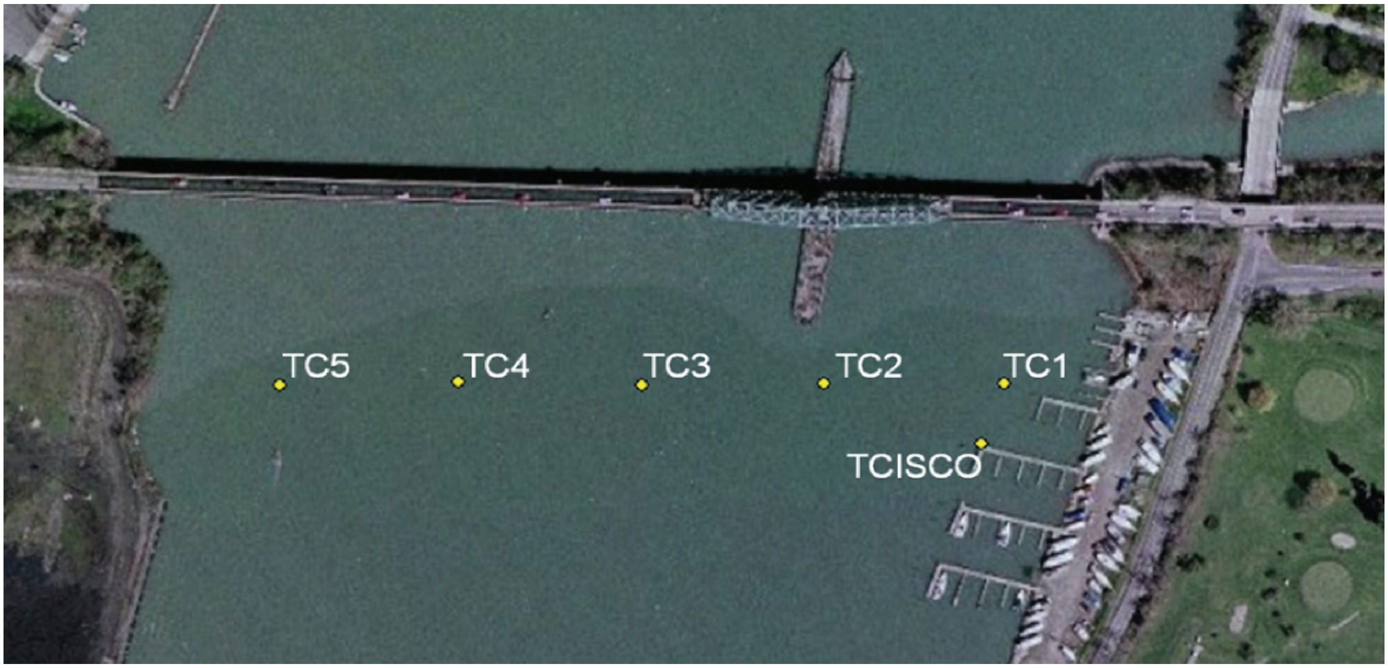

Figure 11: Trenton Channel sample locations.

Table 6: TC ISCO grab sample data with calculated mean and SD.

Date	Sample TP Concentration (mg/L)			TCISCO	
	TCISCO 1	TCISCO 2	TCISCO 3	Mean	SD
Jul-30-2007	0.0180	0.0174	0.0185	0.0180	0.00055
Jul-31-2007	0.0196	0.0195	0.0200	0.0197	0.00026
Aug-13-2007	0.0258	0.0255	0.0253	0.0255	0.00025
Aug-14-2007	0.0238	0.0235	0.0244	0.0239	0.00046
Sep-04-2007	0.0372	0.0285	0.0265	0.0307	0.0057
Sep-05-2007	0.0254	0.0254	0.0249	0.0252	0.00029
Sep-25-2007	0.0174	0.0150	0.0150	0.0158	0.0014
Sep-26-2007	0.0154	0.0155	0.0157	0.0155	0.00015
Oct-10-2007	0.0243	0.0215	0.0245	0.0234	0.0017
Oct-11-2007	0.0220	0.0234	0.0248	0.0234	0.0014
Oct-23-2007	0.0271	0.0282	0.0286	0.0280	0.00078
Oct-24-2007	0.0197	0.0200	0.0194	0.0197	0.00030
Oct-31-2007	0.0201	0.0193	0.0182	0.0192	0.00095
Nov-01-2007	0.0232	0.0221	0.0233	0.0229	0.00055

TP concentrations for the TCISCO grab samples were related to other TC grab samples (TC1-TC5) using a linear relationship, with the y-intercept again both variable and set to zero. A plotted example is shown in Figure 12. The TCISCO grab sample concentrations showed fairly strong linear relationships with each of the other TC grab samples (Table 7). The correlation coefficients are greater than 0.82 at all locations, indicating that the linear relationships in the Trenton Channel were generally fairly strong.

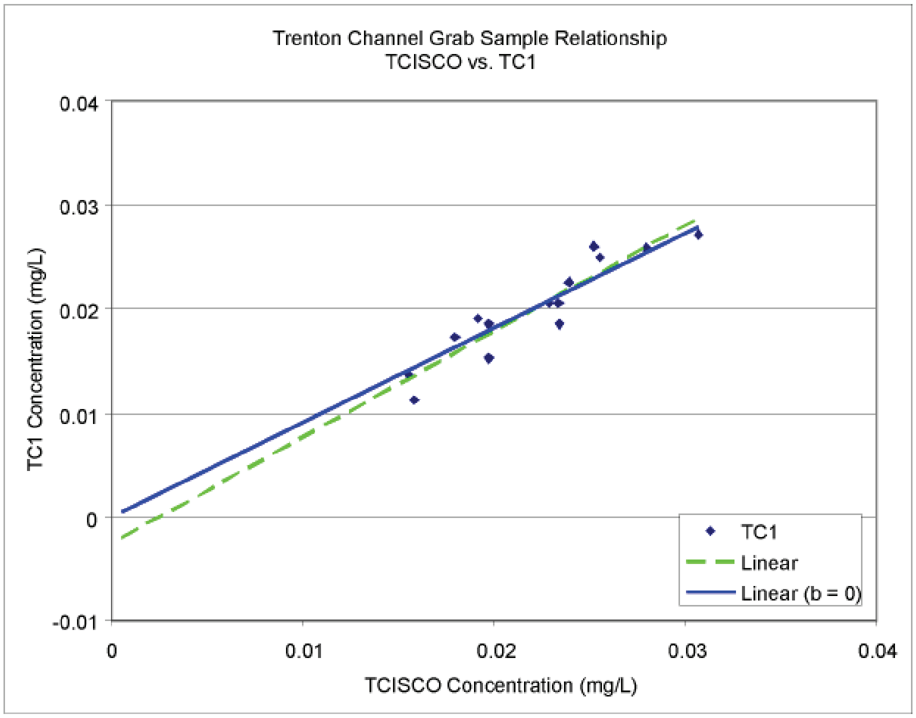

Figure 12: Linear relationships between grab samples TP concentration measured TCISCO and TC1 locations.

Table 7: Trenton Channel linear relationship results.

Date	TP Concentration (mg/L)					
	TCISCO Mean	TC1	TC2	TC3	TC4	TC5
Jul-30-2007	0.0180	0.0173	0.0216	0.0260	0.0293	0.0333
Jul-31-2007	0.0197	0.0185	0.0250	0.0272	0.0327	0.0353
Aug-13-2007	0.0255	0.0250	0.0294	0.0334	0.0453	0.0510
Aug-14-2007	0.0239	0.0226	0.0242	0.0302	0.0347	0.0444
Sep-04-2007	0.0307	0.0271	0.0416	0.0488	0.0545	0.0588
Sep-05-2007	0.0252	0.0260	0.0329	0.0396	0.0472	0.0501
Sep-25-2007	0.0158	0.0112	0.0139	0.0215	0.0165	0.0202
Sep-26-2007	0.0155	0.0136	0.0146	0.0175	0.0213	0.0264
Oct-10-2007	0.0234	0.0185	0.0216	0.0237	0.0277	0.0376
Oct-11-2007	0.0234	0.0206	0.0216	0.0235	0.0267	0.0299
Oct-23-2007	0.0280	0.0259	0.0291	0.0313	0.0386	0.0499
Oct-24-2007	0.0197	0.0152	0.0172	0.0183	0.0201	0.0252
Oct-31-2007	0.0192	0.0190	0.0230	0.0233	0.0256	0.0281
Nov-01-2007	0.0229	0.0205	0.0245	0.0265	0.0289	0.0329
MEAN	0.0222	0.0201	0.0243	0.0279	0.0321	0.0374
SD	0.0045	0.0049	0.0073	0.0084	0.0110	0.0116
CORREL	--	0.9316	0.8823	0.8235	0.8511	0.8961
SLOPE	--	1.0185	1.4537	1.5618	2.0990	2.3422
INTERCEPT	--	-0.0026	-0.0080	-0.0068	-0.0145	-0.0147
SLOPE (b=0)	--	0.9078	1.1069	1.2677	1.4677	1.7059

The TP concentrations tended to increase east (TC1) to west (TC5) across the channel. This suggests a significant source of phosphorus loading located upstream of this section on the western bank of the river.

A sample plot of the residuals for the Trenton Channel is shown in Figure 13. The linear models developed to relate TCISCO to TC1 were used to generate the fitted data, which was compared to the observed data at this location. Both models show the residuals to be fairly evenly scattered around zero, and fall within an absolute range of 0.004 mg/L. There are no apparent trends in the residuals, indicating that the linear models are suitable for the range of TP concentrations measured.

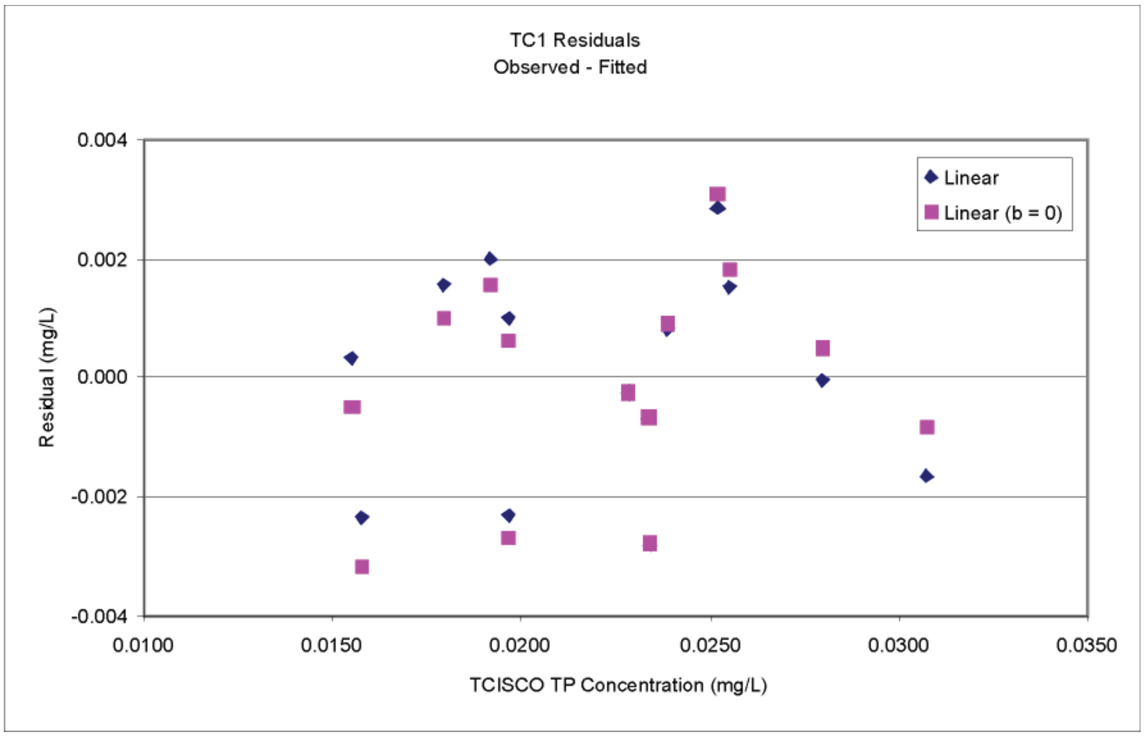

Figure 13: Example plot of observed total phosphorus concentration minus model fitted for Trenton Channel TC1.

- **Middle Channel TP Relationships**

The grab sample locations in the middle channels of the Detroit River, which included East Sugar Island (ES), West Sugar Island (WS), Livingstone Channel (LC) and the Boise Blanc (Boblo) Channel (BB), are shown in Figure 14. The preliminary studies and the results from this study indicated little change in the TP concentration between the upstream sites and the middle channel sites. This implies that a relationship between the mid-channel and ISCO site grab samples is unlikely. A positive relationship between samples from these sites, however, would allow for better estimates across the channel while monitoring a shore based (ISCO) site. Therefore, an attempt to relate the grab sample TP concentrations from the mid-channel sites to the ACISCO and/or TCISCO grab sample data was done. The results for TP are shown in Table 8. Neither ISCO station showed a strong relationship with the data from any of the additional channel stations. These results agree with the results from the 2004 survey, which showed that the middle channels were less impacted by direct TP sources to the Lower Detroit River than the Amherstburg or Trenton Channels. The middle channels were also shown to have less temporal variation than the outer channels, and hence the likely cause of the poor relationships between the middle channels and the ACISCO and TCISCO stations' TP grab sample data. Given that the TP concentrations in the mid-channels had less variability, the daily phosphorus load could therefore be established with less temporal and spatial monitoring than the other channels.

Figure 14: Location of additional grab sample locations at West Sugar Island (WS), East Sugar Island (ES), Livingstone Channel (LC) and Boise Blanc Channel (BB).

Table 8: Amherstburg Channel and Trenton Channel linear relationship results with mid channel grab sample locations.

	Mean TP Concentration (mg/L)							
	ACISCO	TCISCO	WS1	WS2	ES	LC1	LC2	BB
MEAN	0.0210	0.0222	0.0123	0.0132	0.0105	0.0110	0.0105	0.0121
SD	0.0059	0.0045	0.0024	0.0022	0.0021	0.0048	0.0027	0.0048
ACISCO Relationship Results								
CORREL	--	--	0.141	-0.0489	-0.657	0.0713	-0.0836	0.133
SLOPE	--	--	0.0602	-0.020	-0.241	0.0627	-0.0418	0.117
INTERCEPT	--	--	0.0113	0.0136	0.0153	0.0097	0.0114	0.0097
SLOPE (b=0)	--	--	0.563	0.584	0.440	0.494	0.465	0.550
TCISCO Relationship Results								
CORREL	--	--	0.0614	0.424	0.195	-0.0814	-0.0290	-0.0828
SLOPE	--	--	0.0333	0.212	0.0926	-0.0877	-0.0177	-0.0891
INTERCEPT	--	--	0.0116	0.0085	0.0084	0.0130	0.0109	0.0141
SLOPE (b=0)	--	--	0.535	0.582	0.457	0.476	0.455	0.521

- **Soluble Reactive Phosphorus Relationships**

Soluble reactive phosphorus (SRP) is the fraction of TP that is taken up directly by plants, including algae. In addition to the TP samples, SRP samples were collected on the second day of each bi-weekly grab sampling survey. Since SRP samples have only a 24 hour holding time, only Lower Detroit River locations could be sampled.

While the sampling plan was not designed specifically to model SRP across the Amherstburg and Trenton Channels, the study did give an opportunity to collect SRP samples in an effort to improve our understanding of the proportion of SRP in the Lower Detroit River. The data was used to model the SRP concentration. The size of the data set, however, was found inadequate for developing similar relationships as was done for the TP data. Instead, the ratio of SRP to TP for each sample was calculated as a percentage and then averaged for each location (Table 9). The SRP ratios were found to be greatest in the Trenton Channel, ranging from 44.9 to 51-percent SRP. Also of note is that, similar to the TP concentrations in the Trenton Channel, the percent-SRP increased moving across the channel from east (Canadian) shore to the western (U.S.) shore, indicating that SRP makes up a greater percentage of the higher TP concentrations in this channel. The SRP ratios were less in the other Lower Detroit River channels. In the Amherstburg Channel, percent-SRP ranged between only 11.0 and 13.1-percent. Similar to the Trenton Channel, the percent-SRP increased across the Amherstburg Channel, from east to west. SRP ratios in the middle channels did not show any obvious patterns, and ranged from 11.4 to 25.9-percent.

Table 9: Ratio of soluble reactive phosphorus (SRP) to total phosphorus (TP) in Lower Detroit River channels.

Site ID	Percent-SRP (SRP/TP, %)	
	MEAN	SD
AC1/ISCO	11.0	3.8
AC2	11.4	2.2
AC3	12.5	2.5
AC4	13.0	4.6
AC5	13.1	4.1
BB	16.7	13.4
ES	25.9	6.3
LC1	18.1	9.3
LC2	20.8	9.6
TCISCO	44.9	13.4
TC1	47.1	17.2
TC2	48.3	19.3
TC3	49.2	21.2
TC4	50.3	19.2
TC5	51.0	20.7
WS1	11.4	2.2
WS2	11.4	2.2

- **Summary**

There was a poor correlation between the ACISCO and all other grab sample sites. The ACISCO grab sample TP concentrations had relatively large SDs associated with the data indicating large variations in the water concentrations at this site. While it is likely that the location of the ACISCO site suffered due to the relatively shallow water and physical characteristics of the shoreline, effects of TP inputs upstream at the Amherstburg STP certainly contributed to the higher SDs. The lack of a relationship with the middle channels was predictable and probably would not improve with a change in the Amherstburg or Trenton Channel ISCO sites. Data from 2004 and this study show little change in TP concentrations from the upstream stations and the Lower Detroit middle channel sites, indicating that the water from the middle channels are not significantly affected by TP sources along the Detroit River. It should also be noted that significant rain events increase the discharge of point sources temporarily and therefore would not be captured properly in the grab sampling regime. While it is true that the grab sample surveys were not designed to capture the significance of any rain event, and that these rain events may have influenced relationships between sites, 24-hour (daily) composite samples were also collected simultaneously during these surveys. The 24-hour (daily) composite sampling regime would capture all significant phosphorus loading events, whatever the cause, in proportion to their duration and extent. The 24-hour (daily) composite samples were logistically necessary to decrease the analytical laboratory load to a manageable level and to facilitate in calculating TP loads to the river.

The relationships developed at the TCISCO station would benefit from additional data. Additional data at the current Amherstburg site would likely not help with the relationships between the AC sites due to the ACISCO location. If however a shore based site could be found in the Amherstburg Channel outside, of the near shore influences, then relationships between the other grab sample locations could likely be developed. The grab sample data from both ISCO stations does not encompass the full range of TP concentrations observed in the 24-hour (daily) composite samples collected at the ISCO stations (Figure 15). For example, TP concentrations for grab samples collected at the Trenton Channel location ranged from 0.0150 to 0.0372 mg/L, whereas 24-hour total phosphorus concentrations collected at this location had a much greater range of 0.0173 to 0.1820 mg/L. Similarly, grab sample concentrations ranged from 0.0135 to 0.0352 mg/L at the ACISCO station, whereas 24-hour concentrations ranged from 0.0052 to 0.0988 mg/L. While it would be impossible to capture all water events that may influence TP concentrations (i.e. transient effects, storm events, STP discharges, etc.) using a grab sample regime, a higher frequency of sampling would certainly help reflect the concentration ranges better and help in the calibration of the ISCO sites.

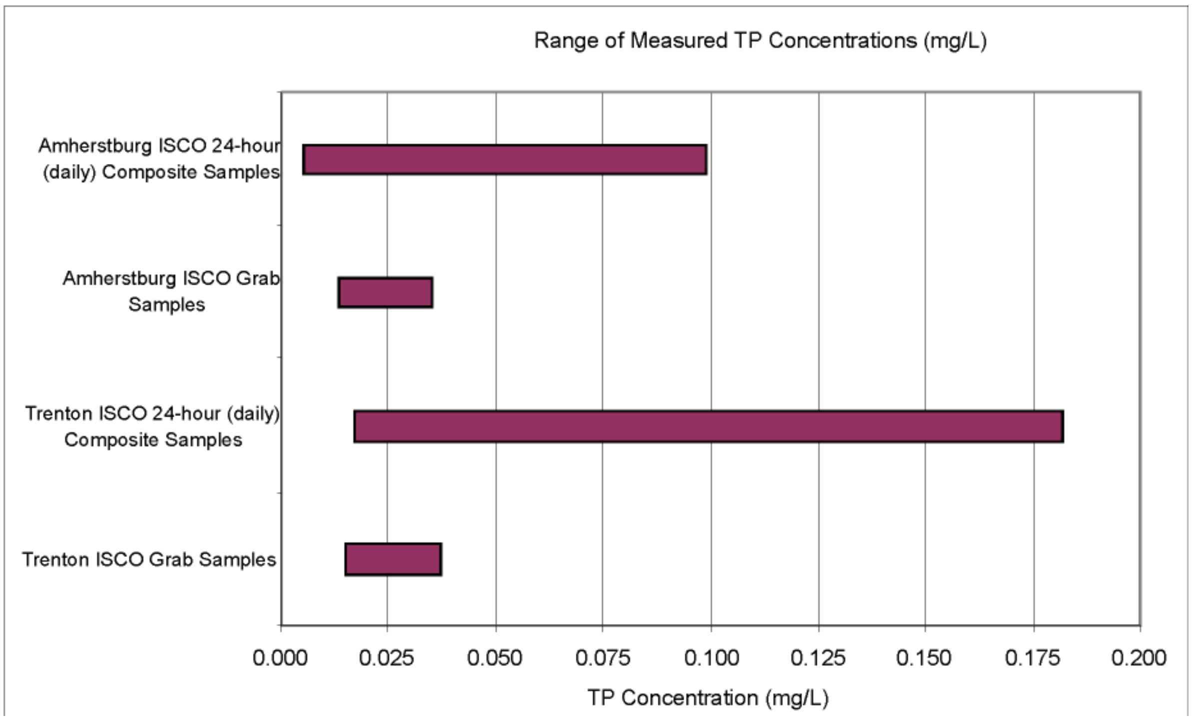

Figure 15: Range of total phosphorus concentrations measured at ISCO stations (grab sample versus 24-hour (daily) composite measurements).

Sources of Phosphorus Loadings

- **Inputs from Upstream**

In addition to grab samples collected in the Lower Detroit River, samples were also collected in the Upper Detroit River (Figure 7). The results are shown in Table 10. The TP mean concentration was calculated at each site to include: a) all samples collected during the survey; and b) samples with common sample dates only. Note that the travel time from upstream to downstream in the Detroit River is roughly one day, but data was not available to account for this lag. Each of the upstream sites provided different information about the water system. Data (Environment Canada, unpublished data) for this time period taken at Port Lambton, at the mouth of the St. Clair R., from the Environment Canada Upstream/Downstream program indicated the concentration of TP in whole water exiting the St. Clair River was 0.010 mg/L. The TP concentration in water entering the Detroit River at the Fleming Channel site (U.S. side) was 0.0111 mg/L. This station represents approximately 74% of the flow entering the Detroit R. There is little change in TP concentration as the water passes out of the St. Clair R., through Lake St. Clair and into the Detroit R. along the American side. This would suggest that the tributaries and other sources of TP on the American side of Lake St. Clair had little influence in the TP concentration of the water. The Canadian side of Peche Island has 26% of the flow entering the Detroit R. The TP concentration of 0.0177 mg/L for this site represents a >75% increase in TP concentration in the water as it flowed through Lake St. Clair suggesting that the concentration was heavily influenced by tributary inputs along the Canadian side of Lake St. Clair. The Ministry of the Environment reported the concentration of the Thames R. during the study period to be 0.174 mg/L (n=7) (Ontario Ministry of the Environment). While the relatively low flow (in relation to the total flow) from this tributary may not significantly influence the TP load entering the Detroit R. (calculated using North Belle Is. and Fleming Ch. Canadian side), it does appear to have a significant localized affect on the TP concentration on the Canadian side at the head of the Detroit R.

Table 10: Measured TP concentration comparison at Upper and Lower Detroit River locations.

Location(s)	Measured TP Concentration (mg/L)	
	Mean (all dates)	Mean (common dates)
Peche Isl. (Can. Side)	*0.0167*	*0.0177*
Fleming Ch. (Can. Side)	*0.0143*	*0.0145*
Fleming Ch. (U.S. Side)	*0.0107*	*0.0111*
North Belle Isl. (U.S. Side)	*0.0074*	*0.0077*
Amherstburg Channel	*0.0191*	*0.0173*
Livingstone & Boise Blanc Channels	*0.0112*	*0.00970*
East and West Sugar Island Channels	*0.0118*	*0.0120*
Trenton Channel	*0.0260*	*0.0282*

The TP load entering the Detroit River at the upper boundary located at Lake St. Clair can be estimated using the TP concentration from each Upper River grab sample site multiplied by the total water volume passing that site. Holtschlag and Koschik (2002b) estimated the proportion of the total river flow that passes through each channel of the St. Clair and Detroit Rivers from regression analysis of ADCP measurements. The total volume of water that passed through the Detroit River from August through November, 2007, was determined from stage-fall-discharge equations to be 50.47 x 109 m3. This volume was divided for each channel using the flow proportions as described, and these divided volumes were multiplied by the mean grab sample concentrations to estimate the TP load in the Upper Detroit River (Table 11). Note that the names of the channels used by Environment Canada and Holtschlag and Koschik differ and are indicated as such. The TP load from the combined flows on either side of Peche Island (i.e. Fleming Channel (U.S. Side) and Peche Island (Can. Side)) was estimated as 620.3 metric tonnes for the four month period from August through November, or 1861 metric tonnes per annum (mta). Just downstream of this location, the TP load from the combined flows on either side of Belle Island (North Belle Isl. (U.S. Side) and Fleming Ch. (Can. Side)) gave estimates of 614.4 metric tonnes (August through November) or 1843 mta. These two estimates of TP load entering from the Upper Detroit River agree quite well.

Table 11: Estimated TP loading from the Upper Detroit River from grab sample data.

EC Sampling Location *(Corresponding Holtschlag and Koschik, 2002b, Flow Proportion Location)*	Fleming Ch. (U.S. Side) *(Peche Island North)*	Peche Isl. (Can. Side) *(Peche Island South)*	North Belle Isl. (U.S. Side) *(Scott Middle Ground)*	Fleming Ch. (Can. Side) *(Fleming Channel)*
Flow Proportion (Holtschlag and Koschik, 2002b)	0.7350	0.2650	0.3085	0.6916
Total Volume Aug-Nov (10^9 m^3)	37.10	13.37	15.57	34.91
Mean TP Concentration Aug-Nov (mg/L)	0.0107	0.0167	0.00740	0.0143
TP Load Aug-Nov (1000 kg)	397.0	223.3	115.2	499.2
TP Load Upper River Aug-Nov (1000 kg)	620.3		614.4	
TP Load Upper River (mta)	1861		1843	

- **Inputs from Tributaries**

The differences in measured TP concentrations from upstream to downstream in the Detroit R. and the differences in the various channels in the Lower Detroit River indicate that sources of TP loadings exist along the length of the River. The Friends of the Detroit River conducted an additional phosphorus sampling program in 2007 at significant Detroit R. tributaries. Samples were collected on 15 separate days from August to November at Little River, Turkey Creek and Canard River, in Ontario, and Rouge River, Conners Creek, Ecorse Creek, Brownstown and Frank and Poet Creeks (combined), in Michigan. An additional sample was collected at Sand Point Beach in Lake St. Clair, near the Canadian shore. The TP concentrations of the samples ranged from 0.0077 to 0.2660 mg/L, with mean concentrations ranging from 0.0176 to 0.1259 mg/L. A portion of the TP load in the Detroit River must therefore result from tributary flow. This information was used to estimate the loading contribution from the tributaries.

On average even the largest tributary, the Rouge River, MI, provides a relatively insignificant amount of additional discharge to the Detroit River. The average discharge of the Rouge River is approximately 8.8 m3/s, whereas the mean discharge of the Detroit River is approximately 5,270 m3/s (Holtschlag and Koschik, 2002a). It follows that for Detroit R. tributaries to have a significant impact on the TP load to Lake Erie then their concentrations would have to be orders of magnitude higher then the concentration found in the water entering the Upper Detroit River from Lake St. Clair. Table 12 gives the mean

TP concentrations for each tributary sampled, the mean discharge from both Lake St. Clair (measured at Sand Point Beach) and the Rouge R. The phosphorus loading (kg/day) to Lake Erie from Lake St. Clair and the Rouge R. were calculated using mean discharge and TP concentrations measured at both locations. Mean discharge estimates for the other tributaries were not found, but it can be assumed that the mean discharge in these would be less than that of the largest tributary, the Rouge River. Subsequently, by using the mean flow from the Rouge R. as the basis to estimate TP load from the other tributaries the TP load at each of the other monitored tributary sites was highly overestimated (Table 12). The sum of phosphorus loading to Lake Erie via the Detroit R., from the tributaries under these assumptions was found to be only 397 kg/day, or 3-percent of the total load from Lake St. Clair, estimated at Sand Point Beach, to be 12600 kg/day. Therefore, in terms of overall TP loading to the Detroit R. the contribution from the tributaries is negligible.

Table 12: Locations and estimated TP loadings of major Detroit River tributaries.

Location No.	Location Name	Lat	Long	Location	Mean Q (m^3/s)	Mean TP (mg/L)	TP Load (kg/day)	Over est. TP Load* (kg/day)
1	Sand Pt. Beach (Lake St. Clair Outflow)	42.3379	-82.9137	Lake St. Clair, Can. Shore, near mouth of Detroit River	*5270*	*0.0276*	*12600*	--
2	Little River	42.3401	-82.9307	Can. shore, near mouth of Detroit River	NA	0.126	NA	96
3	Conners Creek	42.3548	-82.9541	US shore, near mouth of Detroit River	NA	0.0176	NA	13
4	Rouge River	42.2736	-83.1101	US shore, approx. halfway between St. Clair and Erie	8.8	0.0415	32	32
5	Turkey Creek	42.2439	-83.1088	Can. shore, approx. halfway between St. Clair and Erie	NA	0.0982	NA	75
6	Ecorse Creek	42.2349	-83.148	US shore, approx. halfway between St. Clair and Erie	NA	0.114	NA	87
7	Brownstown & Frank and Poet Creeks	42.0812	-83.1942	US shore, near Lake Erie	NA	0.086	NA	66
8	Canard River	42.1601	-83.1085	Can. shore, across from Grosse Island	NA	0.0371	NA	28
* Estimated using average discharge of Rouge R.				Max	*5270*	*0.126*	*12600*	*96*
** The mean and sum include only the tributaries, and not Sand Point Beach				Min	NA	0.0176	32	13
				Mean**	NA	0.0685	--	57**
NA- Not Available/Not applicable				Sum**	NA	--	--	397**

Lower Detroit River Hydrodynamic Model Overview

Given that grab sample data collected varied in TP concentration across the Lower Detroit River and having developed acceptable relationships between grab sample data in the Trenton Channel, an estimate of the variation in flow across the Lower Detroit River channels was needed to calculate the TP load entering Lake Erie. A hydrodynamic model of the Lower Detroit River was used for this purpose.

The Lower Detroit River hydrodynamic model used in this application was derived from the RMA2 model of the full St. Clair-Detroit River system developed by the United States Geological Survey (USGS) (Holtschlag and Koschik, 2002a). The original full-system model covers the connecting channel system between Lakes Huron and Erie in its entirety, including the St. Clair River, Lake St. Clair, and the Detroit River. The Lower Detroit River model used in this application characterizes only the lower portion of the Detroit River, from approximately Fort Wayne, Michigan, to Bar Point, Ontario, which is at the downstream boundary of the Detroit River and the western end of Lake Erie (Figure 16). The total length of the modeled reach is approximately 27.8 kilometers (17.3 miles). In addition to shortening the original model domain, the model mesh density was increased by a factor of four. This was done to improve model convergence and flow continuity in the various channels making up the Lower Detroit River. The modified model was kept in the original imperial units for simplicity since most of the supporting data used by the model is in imperial units. All conversions into metric quantities were made after the model was executed.

The original USGS model was extensively calibrated and validated during development using measured water levels, flows and flow distributions. The Lower Detroit River model as adapted for this study is substantially different than the original RMA2 model. The modified model was assessed for performance to ensure that it maintained adequate estimates of water levels and flows in the Detroit River. Details on the adapted model validation are found in Appendix A.

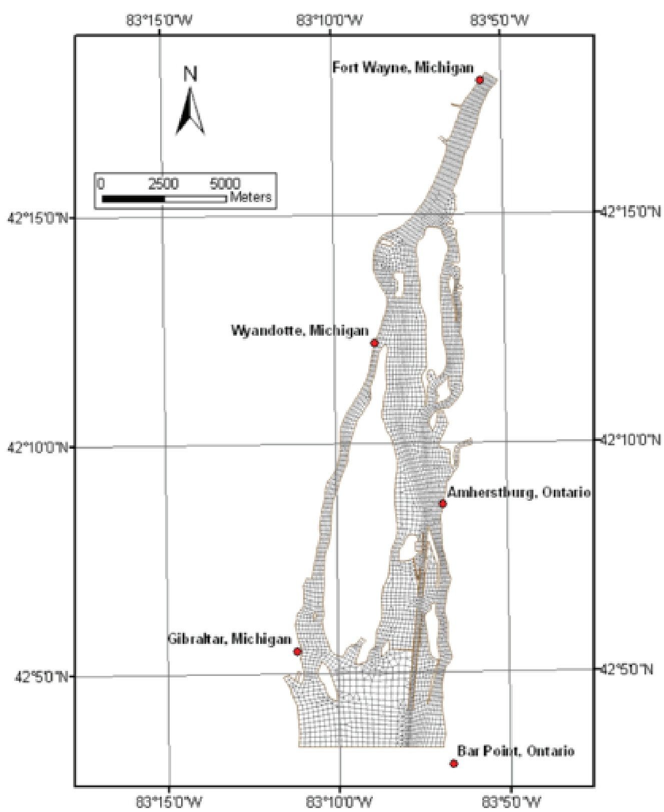

Figure 16: Lower Detroit River RMA2 model mesh extent, boundaries and water level gauge locations.

Channel Flow Factors

The validated Lower Detroit River RMA2 model adapted for this study was used to develop flow factors for each grab sample location since TP concentrations varied horizontally across each channel as did channel velocity and water depth. The flow factors developed are estimates of the proportion of the total discharge in the Detroit River occurring in a 24-hour period that passes through a specific part of a cross-section in each channel. More specifically, the flow factors indicate the proportion of the total flow to be applied to the TP concentration at each grab sample location.

The flow factors were estimated from the simulated results of the twelve steady-state scenarios from 2007. Continuity check lines were used in the RMA2 model to determine the flow distribution across each channel. In this case the continuity check lines were located at the approximate locations of the grab samples for the Trenton Channel (Figure 17). The flow passing through each continuity check line was calculated using the RMA2 model and then divided by the total flow in the Lower Detroit River to determine the proportion of the total flow passing each location for each scenario. The flow factors were determined at each location as the mean calculated flow proportion from all scenarios. The 95-percent confidence levels were calculated as the mean plus or minus two times the SD. The results are given in Appendix B, Table B-1.

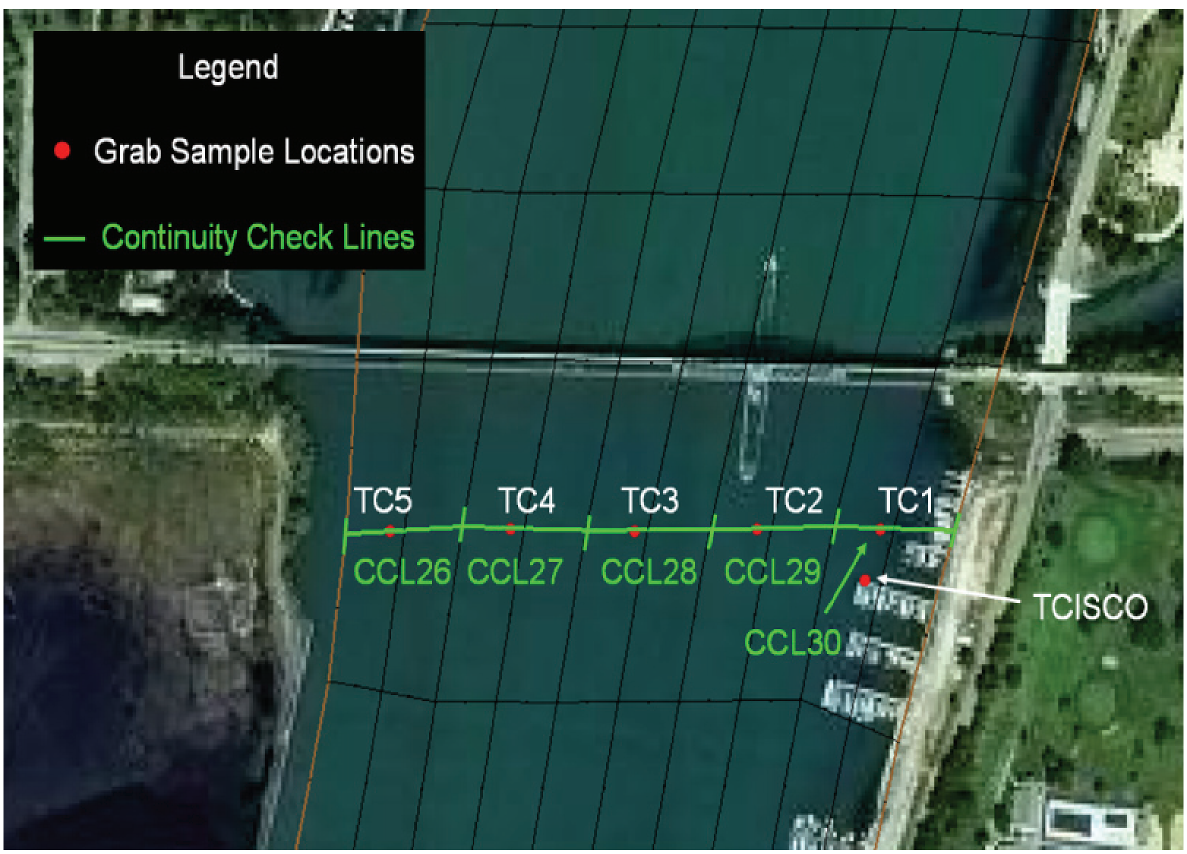

Figure 17: Example of continuity check lines (CCL) located at Trenton Channel grab sample locations.

An informal sensitivity analysis was also performed on the flow factors. Additional calculations of the flow factors were made, first with the original, unrefined model mesh, and second with Manning's roughness increased and decreased by one and five percent throughout the model domain. It was determined that neither the mesh density nor changes in the roughness coefficients had a significant impact on the calculated flow factors. The original calculated flow factors were used for the remaining analysis.

Phosphorus Loading Estimates to Lake Erie

The flow factors were used with the TP and SRP concentrations from the grab samples to estimate the TP and SRP load by mass to Lake Erie. Two methods were employed, each specific to the channel investigated.

- **Phosphorus Loading Estimates using Grab Sample Data**

Since relationships between the grab samples taken at the ISCO stations and the grab sample locations could be developed for only the Trenton Channel, the mean grab sample TP concentrations were first used to estimate the TP load to Lake Erie. Due to the temporal variability of the TP concentrations measured in both the Trenton and Amherstburg Channels, the TP load to Lake Erie as determined from this method is likely highly underestimated.

The flow factors developed for each grab sample location were multiplied by the mean 24-hour total flow in the Lower Detroit River to estimate the mean daily flow passing each grab sample location as given by Equation 1:

$$Q_n = FF_n \cdot Q_{LowerDetroit} \qquad \text{(Eq. 1)}$$

Where = the discharge (m3/s) passing through each location, n; = the flow factor calculated for each location; = the total discharge (m3/s) in the Lower Detroit River.

The grab sample mean TP concentrations were multiplied by the total volume passing each location from August to November, 2007. The TP load (kg) at each location was then calculated, and these were summed to estimate the TP load to Lake Erie from each channel as well as the entire Lower Detroit River as given by Equation 2:

$$TP_{channel} = \sum_{n=1}^{k} V_n \cdot tp_n \qquad \text{(Eq. 2)}$$

Where = the 24-hour total phosphorus loading (kg) for a given channel; = the volume (m3) of water flowing through each location, n, over a 24-hour period; = the grab sample mean total phosphorus concentration (mg/L); n = specific grab sample site; k = the total number of locations in the channel.

The results (Table 13) showed a TP load from each channel of between approximately 24.2-312.9 metric tonnes. The total TP load to Lake Erie from the Lower Detroit River was approximately 852.4 tonnes over the four-month period from August to November, 2007, or approximately 2557 mta. This is similar to the 2135 mta estimated from the 2004 data. With the TP load estimate from the Upper River approximately 1850 mta the 2007 results indicate an estimated increase of 707 mta between the head and mouth of the Detroit R.

However, earlier studies have shown that the TP concentrations measured in the Lower Detroit River channels varied significantly over time. TP concentrations in the Trenton Channel in 2006 varied significantly over a 24-hour period (Figure 5). The ISCO station data collected in 2007 for this study showed greater range of TP concentrations than did the grab sample data. Therefore, it is possible that the TP load as calculated from the grab sample data underestimates the TP loading to Lake Erie, and that a more continuous measure of TP concentrations is needed to obtain an accurate estimate.

Table 13: Total phosphorus (TP) loading results using grab sample TP concentrations.

Location	Mean TP Conc. (mg/L)	MEAN			UPPER 95			LOWER 95		
		Mean Q (m^3/s)	Total Volume (10^6 m^3)	TP Load (1000 kg)	Mean Q (m^3/s)	Total Volume (10^6 m^3)	TP Load (1000 kg)	Mean Q (m^3/s)	Total Volume (10^6 m^3)	TP Load (1000 kg)
TC1	0.0201	86	909	18.3	99	1040	20.9	74	777	15.6
TC2	0.0243	243	2564	62.3	250	2635	64.0	237	2493	60.6
TC3	0.0279	267	2816	78.6	273	2877	80.3	261	2756	76.9
TC4	0.0321	207	2185	70.1	216	2276	73.1	199	2095	67.2
TC5	0.0374	158	1665	62.3	168	1766	66.1	148	1565	58.5
TC Total	--	961	10139	291.6	1006	10593	304.4	919	9685	278.8
WS1	0.0123	393	4138	50.9	419	4421	54.4	366	3856	47.4
WS2	0.0132	229	2412	31.8	259	2725	36.0	199	2100	27.7
WS Total	--	622	6551	82.7	678	7146	90.4	565	5955	75.1
ES	0.0105	266	2801	29.4	300	3164	33.2	231	2438	25.6
ES Total	--	266	2801	29.4	300	3164	33.2	231	2438	25.6
LC1	0.0110	439	4623	50.9	466	4916	54.1	411	4330	47.6
LC2	0.0105	549	5784	60.7	580	6117	64.2	517	5451	57.2
LC Total	--	988	10407	111.6	1046	11032	118.3	928	9781	104.8
BB	0.0121	190	1999	24.2	222	2342	28.3	157	1655	20.0
BB Total	--	190	1999	24.2	222	2342	28.3	157	1655	20.0
ACISCO	0.0229	39	414	9.5	50	525	12.0	29	303	6.9
AC2	0.0215	484	5102	109.7	503	5304	114.0	465	4901	105.4
AC3	0.0166	399	4204	69.8	429	4517	75.0	369	3891	64.6
AC4	0.0147	488	5143	75.6	532	5607	82.4	444	4678	68.8
AC5	0.0130	352	3715	48.3	379	3997	52.0	326	3432	44.6
AC Total	--	1762	18577	312.9	1893	19950	335.4	1633	17205	290.3
Lower Detroit Total	--	4789	50474	852.4	5145	54228	910.0	4433	46719	794.6

- **Trenton Channel Phosphorus Loading Estimates from ISCO vs. Grab Sample Relationships**

Strong linear relationships existed between the grab samples taken at the Trenton Channel grab sample (TC1-TC5) and TCISCO station locations. Since the TP concentration in the Trenton and other channels varied both spatially and temporally the relationships developed between the grab sample data collected for the Trenton Channel were used to give a time-varying estimate of TP concentration. These concentrations were used with the flow factors to produce a more continuous estimate of TP load to Lake Erie from the Trenton Channel.

It was assumed that the 24-hour (daily) composite samples from the ISCO station for the Trenton Channel could be related to the grab sample locations using the same relationship as that developed for the grab samples. One significant limitation of this analysis relates to the range of grab sample concentrations observed. TP concentrations for grab samples collected in the Trenton Channel ranged from 0.0150 to 0.0372 mg/L, whereas 24-hour (daily) composite TP concentrations collected at this location had a much greater range of 0.0173 and 0.182 mg/L. Given this range, it seems likely that grab samples were collected during periods of relatively low TP concentrations whereas the 24-hour continuous ISCO station measurements included periods of high concentrations.

The discharge passing by each grab sample location was used to calculate the total volume passing through each location over a 24-hour period, which was multiplied by the 24-hour (daily) composite TP concentration at each location as determined from the linear fitted model developed from the grab sample data. These sub-loadings were then summed to provide an estimate for the TP load for the entire Trenton Channel over a 24-hour period as given by Equation 3:

$$TP_{TC} = \sum_{n=1}^{k=5} V_n \cdot tp'_n \qquad \text{(Eq. 3)}$$

Where = the 24-hour total phosphorus loading (kg) from the Trenton Channel; = the volume (m3) of water flowing through each location in the Trenton Channel over a 24-hour period; = the estimated 24-hour total phosphorus concentration (mg/L) at each location in the Trenton Channel as derived from the model-fitted relationships. In this case k = 5 as there are five grab sample locations in the Trenton Channel.

Due to the uncertainty in the model-fitted relationships, three relationships were used to relate the ISCO station data to the grab sample locations data; first, a linear model was fitted to the data, with the intercept allowed to vary; second, a linear model with the intercept assumed to be zero; lastly, a one-to-one relationship between the Trenton Channel ISCO station concentrations and the grab sample locations was assumed. Since the grab sample data collected at the ISCO station was shown to have lower TP concentrations then at the other locations on average (see Table 7), a one-to-one relationship can be assumed to provide the minimum TP loading estimate, and without the added uncertainty resulting from the use of a linear relationship between the different locations.

A plotted comparison of the 24-hour Trenton Channel results from August to November, 2007, for each of the relationships used is given in Figure 18. Note there were a total of 13 days for which TCISCO data was missing, and therefore TP concentrations within the Trenton Channel could not be estimated directly on these days. Instead, the total phosphorus load from the missing days was estimated as the mean load for the channel from all other days for which data was available. The mean 24-hour phosphorus load per day was 7200 kg, 6100 kg and 4600 kg for the linear model with intercept, linear model without intercept, and one-to-one relationship, respectively.

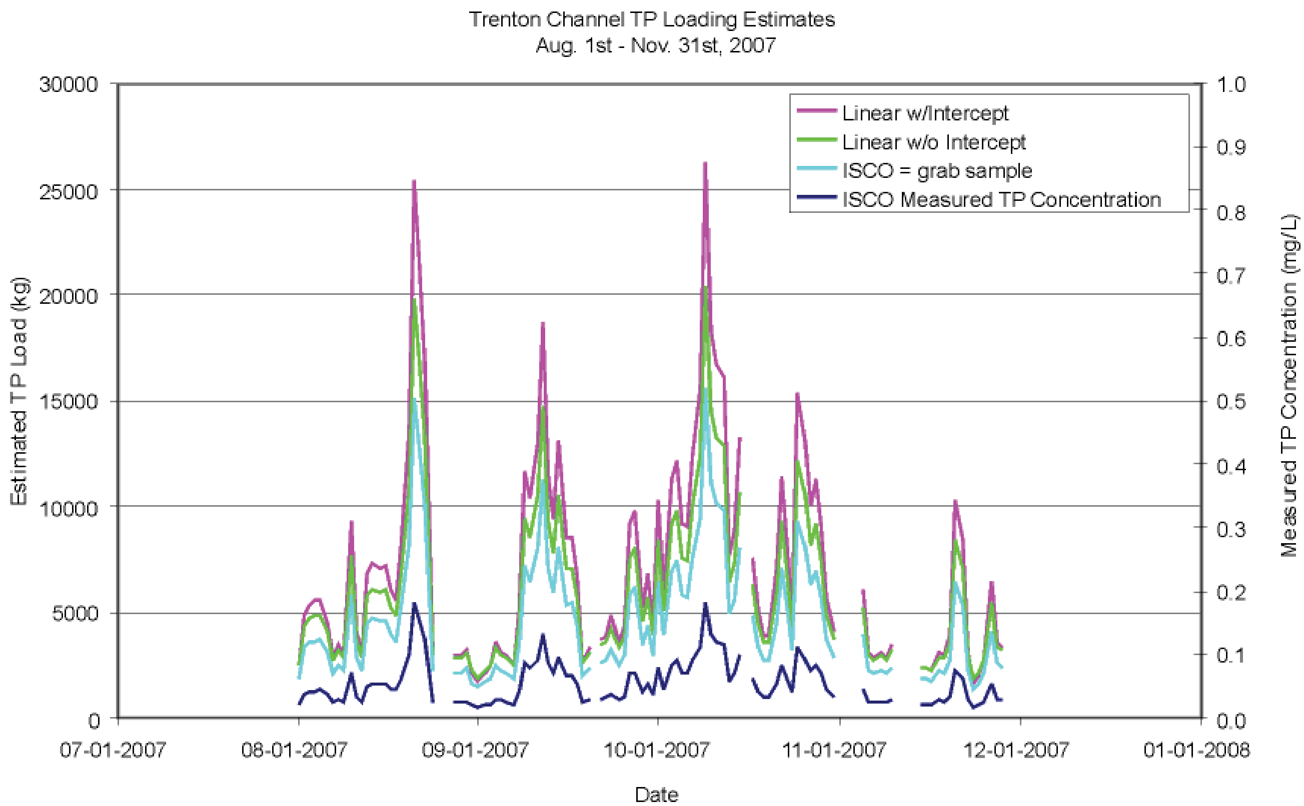

Figure 18: Comparison of Trenton Channel 24-hour total phosphorus (TP) loading results using different relationships between ISCO station and grab sample locations.

A summary of the TP load estimates for the Trenton Channel from August to November, 2007, is given in Table 14. Using the methods outlined, the total load of phosphorus to Lake Erie from the Trenton Channel was estimated to be between approximately 540,200 and 918,400 kg for the period of August to November 2007 or 1621 and 2755 mta. Since the one-to-one relationship method (ISCO = grab sample) is likely an absolute minimum estimated load (given the increase in measured TP concentration across the channel), an estimated TP load of between 2000 and 2500 mta is likely more realistic.

Table 14: Summary of total phosphorus loading estimates for Trenton Channel

Method	Linear w/Intercept			Linear w/o Intercept			ISCO = grab sample		
Flow Factor	Mean	Upper 95%	Lower 95%	Mean	Upper 95%	Lower 95%	Mean	Upper 95%	Lower 95%
TP: Sampled (1000 kg)	786.8	820.9	752.7	662.3	691.2	633.4	505.6	528.3	483.0
Total Days	122	122	122	122	122	122	122	122	122
Days Sampled	109	109	109	109	109	109	109	109	109
Mean Sampled TP/day (1000 kg)	7.2	7.5	6.9	6.1	6.3	5.8	4.6	4.8	4.4
TP Aug. – Nov. (1000 kg)	880.4	918.4	842.4	741.6	773.1	708.8	565.4	590.7	540.2
TP (mta)	2641	2755	2527	2225	2319	2126	1696	1772	1621

This estimate of TP load is subject to uncertainties resulting primarily from uncertainties in the ISCO station relationships. Uncertainties in the model-simulated flow factors were accounted for to some degree using the upper and lower 95-percent confidence levels, but additional uncertainties in the total river flow as estimated from the stage-fall-discharge equations were not accounted for. Seasonality effects may also cause errors in the estimated flow values.

That being said, given the temporal variability observed in the TP concentrations as measured in the Trenton Channel, the TP load estimated above using the 24-hour (daily) composite data from the Trenton Channel ISCO station should be considered a more accurate estimate than that obtained from the grab sample data, regardless of the relationship used. The estimated load for the Trenton Channel using the grab sample data ranged between 836 and 913 mta, much less than the estimated 2000 to 2500 mta estimated from the 24- hr (daily) composite ISCO data. This underestimation is likely true to some degree for the other channels in the Lower Detroit River, in particular the Amherstburg Channel, which was found to be impacted by TP point sources in a 2006 study. However, a similar analysis as was done in the Trenton Channel could not be conducted in the Amherstburg Channel due to the poor relationships developed between the grab sample data at this ISCO station and other locations in the Amherstburg Channel, likely resulting from various factors that influenced the location of the Amherstburg ISCO sampler.

- **Soluble Reactive Phosphorus Loading Estimates**

The total soluble reactive phosphorus (SRP) loadings were estimated using the TP loads as calculated from the grab sample data and percent SRP (Table 15). The total SRP load for the Lower Detroit was found to be approximately 226.2 tonnes for the period from August 1st to November 31st, 2007, or 679 mta.

Table 15: Total soluble reactive phosphorus (SRP) as estimated from grab sample data.

Location	TP Load (1000 kg)	Percent-SRP (SRP/TP, %)		Total SRP (1000 kg)	Total SRP (mta)
		mean	SD		
TC1	18.3	47.1	17.2	8.6	26
TC2	62.3	48.3	19.3	30.1	90
TC3	78.6	49.2	21.2	38.7	115
TC4	70.1	50.3	19.2	35.3	105
TC5	62.3	51	20.7	31.8	95
TC Total	291.6	--	--	144.4	431
WS1	50.9	11.4	2.2	5.8	17
WS2	31.8	11.4	2.2	3.6	11
WS Total	82.7	--	--	9.4	28
ES	29.4	25.9	25.9	7.6	23
ES Total	29.4	--	--	7.6	23
LC1	50.9	18.1	9.3	9.2	27
LC2	60.7	20.8	9.6	12.6	38
LC Total	111.6	--	--	21.8	65
BB	24.2	16.7	13.4	4.0	12
BB Total	24.2	--	--	4.0	12
ACISCO	9.5	11	3.8	1.0	3
AC2	109.7	11.4	2.2	12.5	37
AC3	69.8	12.5	2.5	9.2	26
AC4	75.6	13	4.6	9.8	29
AC5	48.3	13.1	4.1	6.3	19
AC Total	312.9	--	--	38.9	115
Lower Detroit Total	852.4	--	--	226.2	674

For the Trenton Channel specifically, the total SRP load determined from the grab sample data was found to be 433 mta, or 64-percent of the total SRP load from the Lower Detroit River. The TP loading estimate for the Trenton Channel using the grab sample data is likely significantly underestimated. If the TP loading estimates from the ISCO station data are instead used (i.e. between 2000 and 2500 mta), and a percent-SRP value of 50-percent is assumed for the entire Trenton Channel, the estimated total SRP load from this channel alone would increase to approximately 1000-1250 mta, or almost twice the amount estimated for the entire Lower Detroit River from the grab sample data alone.

Uncertainty in the percent-SRP exists as a result of the smaller range of TP values observed in the grab sample data. The percent-SRP may be affected by the higher TP concentrations captured by the ISCO sampler, especially if they represent a different source of TP.

Conclusions

Overall the use of programmable ISCO samplers provided a more robust estimate of the TP loads for the Detroit R. compared to grab sampling alone. This study demonstrated that the temporal variability in TP concentrations necessitates a continuous sampling approach.

The flow factors determined from the adapted flow model were used to estimate the total flow to be applied to each grab sample location over the study period. This total flow was used with the measured TP and SRP concentrations to estimate the TP and SRP load to Lake Erie. Using the grab sample concentrations with the calculated flows gave a TP load of approximately 2557 mta for the entire Lower Detroit River, with 836 to 913 mta coming from the Trenton Channel alone. This TP load estimate for the Lower Detroit River was close to the 2135 mta estimated in 2004. The estimated TP concentration determined to be entering the Upper Detroit River from the 2007 data was 1850 mta. However, using the relationships derived from the Trenton Channel grab sample data and the ISCO station data, the estimated TP load from the Trenton Channel was found to be significantly underestimated. Results using this data showed the TP load from the Trenton Channel to be at least 1600 mta, and more likely between 2000 and 2500 mta. Similarly, SRP loading estimates from the grab sample data alone were 679 mta for the entire Lower Detroit, with 433 mta from the Trenton Channel. When using the Trenton Channel grab sample relationships the total SRP load from the Trenton Channel increased to greater than 1000 mta.

The current estimates for the loading of TP to Lake Erie via the Detroit River were calculated by assessing the best method for each individual channel, calculating the load per channel, and then summing the individual channels (Table 16).

Table 16: Current estimate of total phosphorus load to Lake Erie.

Channel	Data Used For Estimate	Current Estimate Range (mta)	
		Low	High
Trenton Ch. (TC)	grab sample relationships and ISCO 24 hour (daily) composite data	2000	2500
West Sugar Is. (WS)	grab sample data	225.3	271.2
East Sugar Is. (ES)	grab sample data	76.8	99.6
Livingstone Ch. (LC)	grab sample data	314.4	354.9
Bois Blanc Ch. (BB)	grab sample data	60.0	84.9
Amherstburg Ch. (AC)*	grab sample data	870.9	1006.2
Total Load	--	3547	4317

* estimate of Amherstburg Ch. is estimated low as grab samples do not capture full range of data

The study results indicate that there is temporal variability of TP loading, and show that the TP and SRP loads to Lake Erie can be severely underestimated depending on the method employed. The current best estimates for total phosphorus to Lake Erie via the Detroit River range from roughly 3500 mta to 4300 mta, a significant increase from previous estimates.

Recommendations

The following recommendations are given for consideration in future studies:

- Additional grab sample data should be collected in order to improve the relationships between grab sample locations and the ISCO stations. In particular, this should include the development of a grab sampling strategy able to measure higher concentrations of TP and SRP in the Lower Detroit River, since the range of grab sample data measured in this study is far smaller than the range observed in the ISCO sample data.

- Analysis of the ISCO sample concentrations against STP discharges and precipitation and storm event records to determine peak concentration causality.

- Sampling over a 12 month period to ascertain seasonal variability.

- Missing data at the ISCO stations should be reduced, perhaps with the use of a redundant sampler at these locations.

- Investigate alternative locations, outside of the near shore influence, for the placement of future ISCO stations on the Amherstburg Channel.

- Results from the middle channels suggest a less intensive monitoring regime may suffice in these locations; however, further study is needed to confirm this hypothesis.

- The two-dimensional hydrodynamic model of the Lower Detroit River should be modified further to improve model accuracy in terms of simulating measured water levels, velocities and flows.

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Appendix A: Validation of the Adapted Lower Detroit RMA2 Hydrodynamic Model

The Lower Detroit RMA2 hydrodynamic model was adapted from a model for the full St. Clair-Detroit River corridor developed by Holtschlag and Koschik (2002a). The adapted two-dimensional model is used to simulate water levels, depth-averaged velocities and flows in the river. The original model was extensively calibrated and validated during development using measured water levels, flows and flow distributions. The Lower Detroit River model as adapted for this study is substantially different than the original RMA2 model, and therefore needed to be assessed for performance to ensure that it maintained adequate estimates of water levels and flows in the Detroit River.

The adapted model's roughness parameters and viscosity parameters, specified as Manning's roughness coefficients and Peclet number respectively, were retained from the original model. Two types of validation scenario were examined; a simulation using: 1) a subset of twelve mean daily discharge and daily water levels from the August to November, 2007, period under steady-state boundary conditions; and 2) unsteady-state boundary conditions using a 24-hour time step for the period from April to November, 2006. Daily means were used to negate wind effects, which can have a significant influence on water levels, especially at shorter time steps. For the purposes of this study, a daily time step of computation is sufficient.

The boundary conditions for the Lower Detroit RMA2 model are the discharge upstream at Fort Wayne, and the water level at the downstream boundary located at Bar Point. Measured mean daily water levels were obtained from the internet database of the Department of Fisheries and Oceans, Canada (http://www.meds-sdmm.dfo-mpo.gc.ca/). Measured mean daily flows were computed by Environment Canada staff from mean daily water levels and stage-fall-discharge equations developed for the Detroit

River by the U.S. Army Corps of Engineers. The twelve scenarios for the steady-state model runs were chosen semi-arbitrarily from the 2007 measured data to cover a full range of possible flow conditions observed during this period. The complete list of scenarios used is given in Table A-1.

Table A-1: Scenarios used for calculation of flow factors.

Scenario Number	Date (M/D/Y)	Daily Mean Discharge (m^3/sec)	Bar Point Water Level (m)
1	10/25/07	4451	174.14
2	11/10/07	4661	173.84
3	5/6/07	4736	174.51
4	9/16/07	4772	174.08
5	7/24/07	4818	174.20
6	7/29/07	4861	174.18
7	4/23/07	4888	174.30
8	6/9/07	4920	174.34
9	11/29/07	4942	173.44
10	5/10/07	4977	174.38
11	6/8/07	5034	174.28
12	4/5/07	5305	173.91

The Lower Detroit River RMA2 model's performance was validated by comparing computed (observed) versus actual (measured) water levels and discharge. For the twelve daily mean, steady-state simulations, the simulated daily mean water levels at gauges located at Gibraltar, Amherstburg, Wyandotte and Fort Wayne (Figure 16) were compared to the observed daily mean water levels at these locations. The results are given in Table A-2. The largest errors (differences between actual and computed) ranged from -10 to 7 cm for all scenarios, with absolute mean errors ranging from 2 to 4 cm at all gauges. The combined root mean squared error (RMSE) was only 4 cm, and the combined mean absolute error was only 3 cm. It should be noted that Bar Point errors were necessarily zero as this was the downstream boundary condition specified as a water level.

Table A-2: Steady-state model results using Lower Detroit River model with refined model mesh density.

Scenario	Date (M/D/Y)	Observed-measured Water Level (m)				
		Gibraltar	Amherstburg	Wyandotte	Fort Wayne	Combined
1	10/25/2007	0.03	0.04	0.04	0.01	--
2	11/10/2007	-0.02	0.01	-0.01	-0.03	--
3	5/6/2007	0.02	0.02	0.03	0	--
4	9/16/2007	0.07	0.05	0.05	0.03	--
5	7/24/2007	0.05	0.04	0.04	0.01	--
6	7/29/2007	0.05	0.05	0.05	0.02	--
7	4/23/2007	-0.02	-0.01	-0.02	-0.05	--
8	6/9/2007	0.01	0.03	0.02	0	--
9	11/29/2007	-0.1	-0.02	-0.05	-0.07	--
10	5/10/2007	-0.01	0.01	0.01	-0.01	--
11	6/8/2007	-0.01	0.01	0	-0.02	--
12	4/5/2007	-0.08	-0.01	-0.04	-0.06	--
MEAN		0	0.02	0.01	-0.01	0
MAX POSITIVE		0.07	0.05	0.05	0.03	0.07
MAX NEGATIVE		-0.1	-0.02	-0.05	-0.07	-0.1
RMSE		0.05	0.03	0.03	0.03	0.04
SUM Absolute Error		0.5	0.3	0.4	0.3	1.4
Mean Absolute Error		0.04	0.02	0.03	0.03	0.03

In addition, the refined model mesh was compared to the results from the original model mesh density. The refined mesh was found to give similar or even slightly improved results in terms of model performance as were obtained using the original model mesh density. Table A-3 shows a comparison of the two models. Note that the RMSE values and mean absolute errors are similar, and that while the maximum positive errors increased slightly, the maximum negative errors were improved with the refined mesh.

Table A-3: Steady-state model results using Lower Detroit River model with refined model mesh density.

Model Mesh	Statistic	Observed- Measured Water Level (m)				
		Gibraltar	Amherstburg	Wyandotte	Fort Wayne	Combined
Refined	MEAN	0.0	0.02	0.01	-0.01	0.00
	MAX POSITIVE	0.07	0.05	0.05	0.03	0.07
	MAX NEGATIVE	-0.10	-0.02	-0.05	-0.07	-0.10
	RMSE	0.05	0.03	0.03	0.03	0.04
	SUM Absolute Error	0.47	0.3	0.36	0.32	1.45
	Mean Absolute Error	0.04	0.02	0.03	0.03	0.03
Original	MEAN	0.0	0.01	0.0	-0.03	-0.01
	MAX POSITIVE	0.07	0.04	0.04	0.01	0.07
	MAX NEGATIVE	-0.11	-0.04	-0.07	-0.1	-0.11
	RMSE	0.05	0.03	0.04	0.05	0.04
	SUM Absolute Error	0.47	0.26	0.36	0.42	1.52
	Mean Absolute Error	0.04	0.02	0.03	0.04	0.03
Difference	MEAN	0.0	0.01	0.01	0.02	0.01
	MAX POSITIVE	0.0	0.01	0.01	0.02	0.0
	MAX NEGATIVE	0.0	0.02	0.02	0.03	0.0
	RMSE	0.0	0.0	0.0	-0.01	0.0
	SUM Absolute Error	0.0	0.03	0.0	-0.1	-0.07
	Mean Absolute Error	0.0	0.0	0.0	-0.01	0.0

The second validation analysis performed involved an unsteady-state model simulation for the period of April 1st to October 31st, 2006. The model was simulated on a 24-hour time step, again using daily mean water levels and flows as the model boundary conditions. Simulated results were again compared to the observed daily mean water levels at gauge stations located throughout the Lower Detroit River. Similar to the steady-state simulation results, the model performed well during the unsteady simulation. An example comparison of modeled versus observed water levels is shown at Fort Wayne in Figure A-1. At this gauge, water level differences ranged from approximately -5 to 5 cm.

Of special note is the obvious trend in the residuals. A similar trend was also observed at other gauge stations along the river. The simulated values from the model tended to overestimate the water level at each gauge station near the beginning and end of the model simulation, while the simulated values tended to underestimate the values during the middle of the simulation. This is most likely due to the seasonal growth and decay of vegetation in the river and its related effects on channel resistance. Vegetation begins to grow in the spring and increases throughout the summer. It subsequently dies off and decays in the late fall and winter. As vegetation grows the amount of flow resistance in the channel increases. Therefore at a given downstream water level, an increase in vegetation growth results in an increase in upstream water level. This effect is more pronounced in wide, shallow river cross-sections (such as the Lower Detroit River), than narrow, deep river cross-sections (such as other areas of the St. Clair and Detroit Rivers), because wide, shallow sections have more volume of water in contact with vegetation compared to the narrower, deeper sections of a river. Shallower depths also allow greater light penetration, which can increase vegetation growth.

The Lower Detroit River model's roughness parameters were established using an optimization process with the objective to match the observed water levels in the river over the entire ice-free season using a single set of Manning's roughness coefficients. As such, in general, the model tends to over-predict water levels during times of reduced vegetation growth (spring/late fall) because the model's roughness parameters are too high, whereas the model will tend to underestimate water levels during times of increased vegetation growth (summer/early fall) because the model's roughness parameters are too low. Therefore, sacrifices in the performance of the model during specific periods of the year result from the choice of a single set of roughness coefficients. A seasonally varying calibration of the model would improve the performance of the model, but this added precision was believed to be unnecessary for this application.

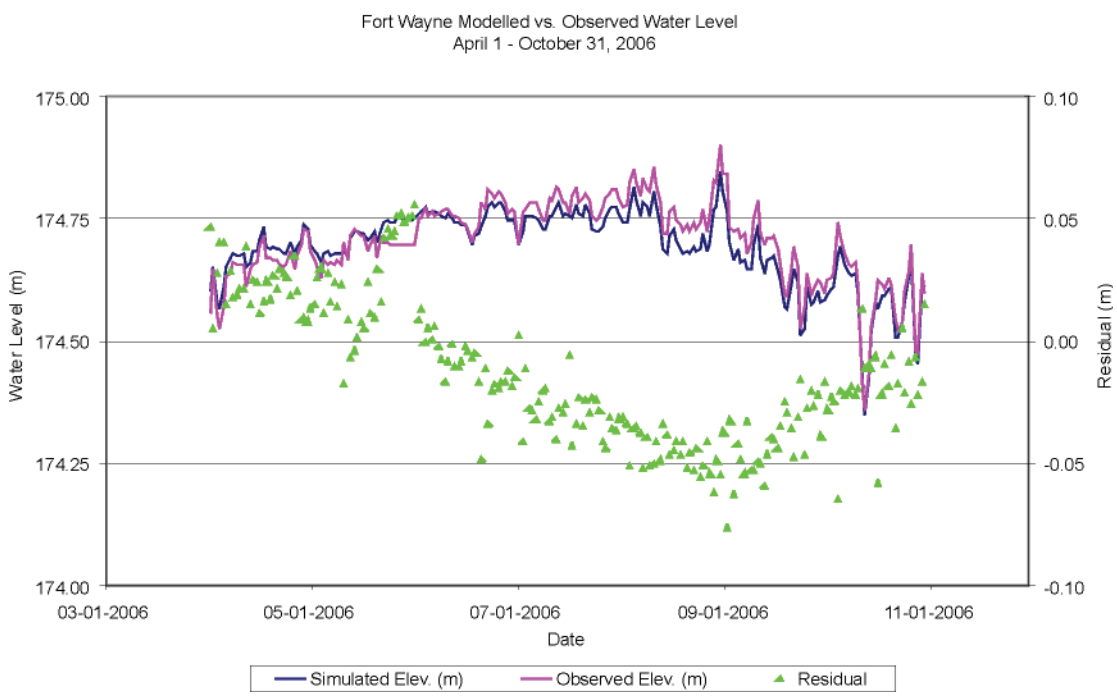

Figure A-1: Modeled versus observed results for April 1st to October 31st, 2006, at Fort Wayne for unsteady-state simulation using daily means as boundary conditions.

Lastly, continuity check lines were used in the model to compare simulated flows in the channel to flow proportions as estimated by Holtschlag and Koschik, 2002b. Holtschlag and Koschik estimated the proportion of the total river flow that passes through each channel of the St. Clair and Detroit Rivers from regression analysis of ADCP measurements. These were compared to flow proportions for the different channels estimated using the revised Lower Detroit River RMA2 model. The mean discharge value of the continuity lines for each of the twelve steady-state simulation results were divided by the total flow in the channel to estimate the flow proportion. In addition, the 95-percent confidence levels were calculated as two times the SD. A comparison of the results is shown in Table A-4. The modeled results compared fairly well to those obtained by Holtschlag and Koschik, with both similar mean expected values and overlapping confidence limits of the estimates for all channels.

Table A-4: Flow proportion comparison estimated by Holtschlag and Koshik (2002b) and revised RMA2 model.

Flow Proportion	Holtschlag and Koschik (2002b)			Modeled		
Channel	Expected	Lower 95%	Upper 95%	Expected	Lower 95%	Upper 95%
Trenton	0.222	0.201	0.243	0.201	0.192	0.209
West Sugar Island	0.122	0.115	0.128	0.132	0.120	0.143
East Sugar Island	0.053	0.046	0.060	0.055	0.048	0.062
Livingstone	0.210	0.186	0.235	0.206	0.193	0.218
Boise Blanc	0.045	0.024	0.065	0.039	0.032	0.047
Amherstburg	0.349	0.331	0.367	0.367	0.345	0.390

In general, the simulated results from the Lower Detroit River model compared well to the observed data, and more favorably to observed data than simulated results from the original full-system model. This is likely due to the reduced distance between the model boundaries and the refined estimates of the flow in the Detroit River obtained by using the Detroit River stage-fall-discharge relationships rather than the St. Clair River relationships. It may also partially be the result of other minor model variations, such as the refined model mesh density used in this analysis.

Appendix B: Flow Proportions and Flow Factor Results

Table B-1: Scenario flow proportions and flow factor results.

Location		Flow Proportions in Divided Channels															
		Trenton Channel					West Sugar		East Sugar	Livingstone Channel		Boise Blanc	Amherstburg Channel				
Grab Sample		TC5	TC4	TC3	TC2	TC1	WS2	WS1	ES	LC2	LC1	BB	AC5	AC4	AC3	AC2	ACISCO
CCL #		26	27	28	29	30	31	32	33	34	35	36	37	38	39	40 + 41	42
SCENARIO	1	0.0330	0.0434	0.0560	0.0509	0.0178	0.0476	0.0820	0.0555	0.1146	0.0916	0.0395	0.0736	0.1019	0.0833	0.1010	0.0081
	2	0.0320	0.0425	0.0555	0.0502	0.0165	0.0445	0.0793	0.0519	0.1179	0.0946	0.0361	0.0765	0.1066	0.0864	0.1027	0.0069
	3	0.0342	0.0442	0.0563	0.0514	0.0197	0.0516	0.0852	0.0594	0.1107	0.0881	0.0438	0.0704	0.0965	0.0796	0.0992	0.0096
	4	0.0329	0.0432	0.0559	0.0508	0.0177	0.0472	0.0816	0.0551	0.1151	0.0920	0.0390	0.0740	0.1026	0.0837	0.1014	0.0079
	5	0.0333	0.0436	0.0561	0.0510	0.0183	0.0485	0.0827	0.0564	0.1138	0.0909	0.0404	0.0729	0.1007	0.0825	0.1007	0.0084
	6	0.0333	0.0435	0.0560	0.0510	0.0182	0.0483	0.0825	0.0562	0.1139	0.0910	0.0402	0.0731	0.1010	0.0826	0.1008	0.0083
	7	0.0337	0.0438	0.0561	0.0511	0.0188	0.0496	0.0836	0.0575	0.1127	0.0899	0.0416	0.0720	0.0992	0.0815	0.1002	0.0088
	8	0.0338	0.0439	0.0562	0.0512	0.0190	0.0500	0.0839	0.0579	0.1123	0.0895	0.0421	0.0717	0.0987	0.0811	0.0999	0.0090
	9	0.0304	0.0409	0.0541	0.0488	0.0149	0.0401	0.0750	0.0463	0.1230	0.0988	0.0314	0.0808	0.1135	0.0910	0.1054	0.0056
	10	0.0339	0.0440	0.0562	0.0512	0.0192	0.0504	0.0842	0.0583	0.1119	0.0892	0.0425	0.0713	0.0981	0.0807	0.0998	0.0091
	11	0.0336	0.0438	0.0561	0.0511	0.0187	0.0494	0.0834	0.0574	0.1128	0.0900	0.0415	0.0721	0.0994	0.0816	0.1002	0.0087
	12	0.0324	0.0428	0.0556	0.0504	0.0172	0.0458	0.0803	0.0535	0.1166	0.0934	0.0375	0.0753	0.1047	0.0851	0.1021	0.0074
MEAN (FLOW FACTORS)		0.0330	0.0433	0.0558	0.0508	0.0180	0.0478	0.0820	0.0555	0.1146	0.0916	0.0396	0.0736	0.1019	0.0833	0.1011	0.0082
STDEV		0.0010	0.0009	0.0006	0.0007	0.0013	0.0031	0.0028	0.0036	0.0033	0.0029	0.0034	0.0028	0.0046	0.0031	0.0017	0.0011
UPPER 95		0.0350	0.0451	0.0570	0.0522	0.0206	0.0540	0.0876	0.0627	0.1212	0.0974	0.0464	0.0792	0.1111	0.0895	0.1045	0.0104
LOWER 95		0.0310	0.0415	0.0546	0.0494	0.0154	0.0416	0.0764	0.0483	0.1080	0.0858	0.0328	0.0680	0.0927	0.0771	0.0977	0.0060

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