Nutrient Load Estimation and Reporting

Loading Calculations Technical Symposium
NOAA GLIER, Ann Arbor
Alice Dove and Sean Backus
Water Quality Monitoring & Surveillance
Isaac Wong and Phil Fong
Watershed Hydrology and Ecosystem Research Division
April 6, 2017
Contents

• Whole Lake Loads
• Tributary Monitoring
  – Sampling Methods and Load Estimation Methods
• Connecting Channel Monitoring
  – Unique opportunity to validate corridor estimates
  – Overview of St. Clair, Detroit and Niagara Loads
• Loading Estimate Decision Support System
Mean TP Loads to Lake Erie, 2003-2013 (MTA)
Mean TP Loads to Lake Erie, 2003-2013 (MTA)
Tributary Sampling Approach

Field Program:

- Year-round, including the critical winter and early spring times
- Emphasis on rain and snow events plus low flow

- At automated sites:
  - Samples taken every 8 hours
  - On-site refrigeration
  - Samples are collected weekly
  - Retrospective analysis of the hydrograph for sample selection to target runoff events

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Major ions: Cl, F, SO₄</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total phosphorus</td>
<td>Total Kjeldahl nitrogen</td>
</tr>
<tr>
<td>Total dissolved phosphorus</td>
<td>Ammonia**</td>
</tr>
<tr>
<td>Soluble reactive phosphorus**</td>
<td>Nitrate plus nitrite**</td>
</tr>
<tr>
<td>Total suspended solids</td>
<td></td>
</tr>
</tbody>
</table>

Environment and Climate Change Canada
Environnement et Changement climatique Canada
All Season Stations

Grand River

Thames River
In-River Pumps
Flow-Through for ISCO and Sonde
Samples Achieved
Sufficient Samples?
Sample Selection Protocol

Example - Thames River at Thamesville:

- For runoff events >200 m$^3$/s – three samples will be analyzed (rising limb, peak, falling limb)
- For runoff events >100 m$^3$/s up to 200 m$^3$/s – two samples will be analyzed (rising limb, peak)
- For runoff events >80 m$^3$/s up to 100 m$^3$/s – one sample will be analyzed (peak)
- If no runoff events (flow <80 m$^3$/s) – one sample will be analyzed every two weeks (most recent sample)
- One sample on each day of Lake St. Clair survey
Current Activities – St. Clair Detroit Corridor

• Ongoing St. Clair River monitoring with enhancements
  – Increased frequency, SRP monitoring
• Ongoing Detroit River monitoring on the Canadian side ONLY
  *Debbie Burniston, Alice Dove, Sean Backus*

• Thames River and Sydenham River monitoring for loadings
• Nested monitoring in the Thames River watershed - 12 locations
• Collaborative monitoring in Lake St. Clair with MOECC
Mean TP Loads to Lake Erie, 2003-2013 (MTA)
St. Clair River Upstream-Downstream Program

Year-round (all season) monitoring

- Every 2 weeks from 2001 – 2012
- Every 4 weeks 2012 to present

Nutrients (TP, TDP, NO$_3^-$+NO$_2^-$, TN, TDN, NH$_3$)
Major Ions (Ca, Cl, Mg, K, Na, SO$_4^{2-}$, SiO$_2$)
Organic Contaminants
Trace Metals

In water and suspended sediment
Total Phosphorus Loads - LOADEST

900 MTA input from Lake Huron

1980 MTA output to Lake St. Clair
Total Phosphorus Loads - LOADEST

900 MTA input from Lake Huron

1980 MTA output to Lake St. Clair

Point Edward
Port Lambton
Detroit River 2014 and 2015 (2004 and 2007)
Detroit River 2014 and 2015 (2004 and 2007)
Detroit River 2014 and 2015 (2004 and 2007)
Hydrosim 2d and Dispersim 2d Model

Boundary Waters Issues, Meteorological Survey of Canada
## Corridor Total Phosphorus Loads

<table>
<thead>
<tr>
<th>Water year, MTA</th>
<th>2007</th>
<th>2014</th>
<th>2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lake Huron</td>
<td>877</td>
<td>933</td>
<td>1250</td>
</tr>
<tr>
<td>St. Clair River</td>
<td>1350</td>
<td>1970</td>
<td>1980</td>
</tr>
<tr>
<td>Trenton Channel</td>
<td>2000-2500</td>
<td>718</td>
<td>584</td>
</tr>
<tr>
<td>Mid River</td>
<td>810</td>
<td>1580</td>
<td>837</td>
</tr>
<tr>
<td>Amherstburg Channel</td>
<td>870-1010</td>
<td>1250</td>
<td>1190</td>
</tr>
<tr>
<td>Total Load, Detroit River</td>
<td>3680-4320</td>
<td>3550</td>
<td>2610</td>
</tr>
</tbody>
</table>
Mean TP Loads to Lake Erie, 2003-2013 (MTA)
## Corridor Total Phosphorus Loads

<table>
<thead>
<tr>
<th>Water year, MTA</th>
<th>2007</th>
<th>2014</th>
<th>2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lake Huron</td>
<td>877</td>
<td>933</td>
<td>1250</td>
</tr>
<tr>
<td>St. Clair River</td>
<td>1350</td>
<td>1970</td>
<td>1980</td>
</tr>
<tr>
<td>Trenton Channel</td>
<td>2000-2500</td>
<td>718</td>
<td>584</td>
</tr>
<tr>
<td>Mid River</td>
<td>810</td>
<td>1580</td>
<td>837</td>
</tr>
<tr>
<td>Amherstburg Channel</td>
<td>870-1010</td>
<td>1250</td>
<td>1190</td>
</tr>
<tr>
<td><strong>Total Load, Detroit River</strong></td>
<td>3680-4320</td>
<td>3550</td>
<td>2610</td>
</tr>
</tbody>
</table>

Total: 2859
What we thought we knew
Total Phosphorus Loads at Niagara-on-the-Lake
Interlaboratory Comparison
Heidelberg University and ECCC NLET

SRP
Collaborative Project between Water Quality Monitoring and Research Divisions

Purpose: an updated, more highly automated tool to estimate annual TP and SRP loadings using Dolan Method

- Monitored tributaries, unmonitored watershed areas, point sources (municipal and industrial), atmospheric deposition, upstream Great Lakes (i.e. Lake Huron)
- Loadings calculated on a water year basis
- Standard errors are provided for each estimate

Project timeline:

- April 2016: Start project
- June 2016: Receive data files for Lake Erie loads
- July 2016: Develop system design of loading estimate decision support system
- September 2016: Began implementation of Dolan Method in decision support system (DSS)
- March 2017 - present: In process of beta testing, bug fixing and verifying results

Loading Estimate Decision Support System (DSS)

Overview

- Initial beta implementation of Dolan Method
- DSS is a Windows application with a graphical user interface
- Input data (tributary flows and concentrations, point source effluent, atmospheric deposition, etc.) are stored in multiple csv-formatted text files
  - Data import function for point source data
- A “project” file is used to organize data and information
- Output results are saved in multiple csv-formatted text files
- Some input data and outputs are viewable within the DSS, others require external application (e.g., Excel)
  - Graphs generated by R software with EGRET library (Exploration and Graphics for RivEr Trends) from USGS
<table>
<thead>
<tr>
<th>Data</th>
<th>Agency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tributary Flow</td>
<td><strong>Canada</strong>&lt;br&gt;Water Survey of Canada (Environment and Climate Change Canada)</td>
</tr>
<tr>
<td></td>
<td><strong>U.S.</strong>&lt;br&gt;Water Resources Division (U.S. Geological Service)</td>
</tr>
<tr>
<td>Tributary Water Quality</td>
<td><strong>Canada</strong>&lt;br&gt;Water Quality and Monitoring and Surveillance Division (Environment and Climate Change Canada)&lt;br&gt;Provincial Water Quality Monitoring Network (Ontario Ministry of Environment and Climate Change)</td>
</tr>
<tr>
<td></td>
<td><strong>U.S.</strong>&lt;br&gt;National Center for Water Quality Research (Heidelberg University)&lt;br&gt;Water Resources Division (Michigan Department of Environmental Quality)&lt;br&gt;Division of Surface Water (Ohio Environmental Protection Agency)&lt;br&gt;STORET (U.S. Environmental Protection Agency)&lt;br&gt;Water Resources Division (U.S. Geological Survey)</td>
</tr>
<tr>
<td>Point Source</td>
<td><strong>Canada</strong>&lt;br&gt;MISA (Ontario Ministry of Environment and Climate Change)</td>
</tr>
<tr>
<td></td>
<td><strong>U.S.</strong>&lt;br&gt;Water Division-PCS/ICIS (U.S. Environment Protection Agency)</td>
</tr>
<tr>
<td>Atmospheric Deposition</td>
<td><strong>Canada</strong>&lt;br&gt;Water Quality and Monitoring and Surveillance Division (Environment and Climate Change Canada)</td>
</tr>
</tbody>
</table>
# Loading Estimate Decision Support System

## Project File

### Project File: general information for tributary

<table>
<thead>
<tr>
<th>Tributaries</th>
<th>Basin</th>
<th>Country</th>
<th>Watershed Area (km²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black-MI</td>
<td>Huron-Erie Corridor</td>
<td>US</td>
<td>1800</td>
</tr>
<tr>
<td>Belle-Pine Complex</td>
<td>Huron-Erie Corridor</td>
<td>US</td>
<td>1550</td>
</tr>
<tr>
<td>Clinton</td>
<td>Huron-Erie Corridor</td>
<td>US</td>
<td>1901</td>
</tr>
<tr>
<td>Rouge</td>
<td>Huron-Erie Corridor</td>
<td>US</td>
<td>1890</td>
</tr>
<tr>
<td>Thames</td>
<td>Huron-Erie Corridor</td>
<td>CAN</td>
<td>5706</td>
</tr>
<tr>
<td>Sydenham</td>
<td>Huron-Erie Corridor</td>
<td>CAN</td>
<td>3038</td>
</tr>
<tr>
<td>Canard</td>
<td>Huron-Erie Corridor</td>
<td>CAN</td>
<td>347</td>
</tr>
<tr>
<td>Turkey</td>
<td>Huron-Erie Corridor</td>
<td>CAN</td>
<td>28</td>
</tr>
</tbody>
</table>

### Example of tributary sections in project file

#### Flow Data for Black-MI

<table>
<thead>
<tr>
<th>Date</th>
<th>Flow (cfs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>01/10/2008</td>
<td>409.4</td>
</tr>
<tr>
<td>02/10/2008</td>
<td>407.456</td>
</tr>
<tr>
<td>03/10/2008</td>
<td>331.058</td>
</tr>
<tr>
<td>04/10/2008</td>
<td>281.624</td>
</tr>
<tr>
<td>05/10/2008</td>
<td>229.194</td>
</tr>
<tr>
<td>06/10/2008</td>
<td>191.744</td>
</tr>
<tr>
<td>07/10/2008</td>
<td>164.78</td>
</tr>
<tr>
<td>08/10/2008</td>
<td>164.78</td>
</tr>
<tr>
<td>09/10/2008</td>
<td>187.25</td>
</tr>
<tr>
<td>10/10/2008</td>
<td>203.728</td>
</tr>
<tr>
<td>11/10/2008</td>
<td>185.752</td>
</tr>
<tr>
<td>12/10/2008</td>
<td>167.776</td>
</tr>
<tr>
<td>13/10/2008</td>
<td>142.31</td>
</tr>
<tr>
<td>14/10/2008</td>
<td>137.816</td>
</tr>
<tr>
<td>15/10/2008</td>
<td>130.326</td>
</tr>
<tr>
<td>16/10/2008</td>
<td>134.82</td>
</tr>
<tr>
<td>17/10/2008</td>
<td>146.804</td>
</tr>
<tr>
<td>18/10/2008</td>
<td>133.322</td>
</tr>
<tr>
<td>19/10/2008</td>
<td>127.33</td>
</tr>
<tr>
<td>20/10/2008</td>
<td>122.836</td>
</tr>
<tr>
<td>21/10/2008</td>
<td>115.366</td>
</tr>
</tbody>
</table>

#### Concentration Data for Black-MI

<table>
<thead>
<tr>
<th>Date</th>
<th>TP (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>21/10/2008</td>
<td>0.046</td>
</tr>
<tr>
<td>14/04/2009</td>
<td>0.035</td>
</tr>
<tr>
<td>15/06/2009</td>
<td>0.071</td>
</tr>
<tr>
<td>05/08/2009</td>
<td>0.059</td>
</tr>
<tr>
<td>08/10/2009</td>
<td>0.035</td>
</tr>
<tr>
<td>21/05/2010</td>
<td>0.076</td>
</tr>
<tr>
<td>19/07/2010</td>
<td>0.08</td>
</tr>
<tr>
<td>11/08/2010</td>
<td>0.055</td>
</tr>
<tr>
<td>12/10/2010</td>
<td>0.042</td>
</tr>
<tr>
<td>29/03/2011</td>
<td>0.06</td>
</tr>
<tr>
<td>20/06/2011</td>
<td>0.047</td>
</tr>
<tr>
<td>01/09/2011</td>
<td>0.059</td>
</tr>
</tbody>
</table>

### Project File: monitored tributary data

<table>
<thead>
<tr>
<th>Mon Tributary Loads</th>
<th>Parameter</th>
<th>Flow Data File</th>
<th>Concentration Data File</th>
<th>Loading Estimate Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black-MI</td>
<td>TP</td>
<td>Inputs\Black-MI flow.csv</td>
<td>Inputs\Black-MI TP.csv</td>
<td>Beale</td>
</tr>
<tr>
<td>Black-MI</td>
<td>SRP</td>
<td>Inputs\Black-MI flow.csv</td>
<td>Inputs\Black-MI SRP.csv</td>
<td>Beale</td>
</tr>
<tr>
<td>Clinton</td>
<td>TP</td>
<td>Inputs\Clinton flow.csv</td>
<td>Inputs\Clinton TP.csv</td>
<td>Beale</td>
</tr>
<tr>
<td>Clinton</td>
<td>SRP</td>
<td>Inputs\Clinton flow.csv</td>
<td>Inputs\Clinton SRP.csv</td>
<td>Beale</td>
</tr>
<tr>
<td>Rouge</td>
<td>TP</td>
<td>Inputs\Rouge flow.csv</td>
<td>Inputs\Rouge TP.csv</td>
<td>Beale</td>
</tr>
<tr>
<td>Rouge</td>
<td>SRP</td>
<td>Inputs\Rouge flow.csv</td>
<td>Inputs\Rouge SRP.csv</td>
<td>Beale</td>
</tr>
<tr>
<td>Huron-MI</td>
<td>TP</td>
<td>Inputs\Huron-MI flow.csv</td>
<td>Inputs\Huron-MI TP.csv</td>
<td>Beale</td>
</tr>
<tr>
<td>Huron-MI</td>
<td>SRP</td>
<td>Inputs\Huron-MI flow.csv</td>
<td>Inputs\Huron-MI SRP.csv</td>
<td>Beale</td>
</tr>
</tbody>
</table>
Loading Estimate Decision Support System
Schematic Diagram

**INPUTS**
- Monitored Tributary Data
- Point Source Data
- Project File
- Unmonitored Watershed Data
- Atmospheric Deposition Data

**DATA IMPORT UTILITY**

**LOADING ESTIMATE DSS**

**DOLAN METHOD LOADING ESTIMATOR**

**VISUALIZATION**

**OUTPUTS**
- Monitored tributary loads
- Point source loads
- Unmonitored watershed loads
- Atmospheric deposition loads
- Basin and lake total loads

Dolan Method calculates the following:
- Monitored tributary loads
- Point source loads
- Unmonitored watershed loads
- Atmospheric deposition loads
- Basin and lake total loads

Data (will be limited to specific formats)
Loading Estimate Decision Support System

Current Status

• Implemented loading calculations for:
  – monitored tributaries (Stratified Beale Ratio Estimator, Heidelberg data)
  – unmonitored watershed areas
  – point sources
  – atmospheric deposition
  – basin, country and lake totals

• In the process of beta testing, bug fixing and verifying results
Loading Estimate Decision Support System Demo

Choose project file
Loading Estimate Decision Support System Demo
Loading Estimate Decision Support System
Monitored Tributaries (Stratified Beale Ratio)

**Inputs**
- Grand-ON flow data
- Grand-ON concentration data

**Program Execution**
- View input data
- Flow for Grand-ON
- Calculate monitored tributary loads and view results
- Graphs: R software with EGRET library

**Outputs**
- Annual loads for tributaries (csv file)
- Details of results (free form text file)

Data files converted into csv format using external program such as Excel

Environment and Climate Change Canada
Loading Estimate Decision Support System
Monitored Tributaries (Heidelberg)

**Inputs**

- Maumee daily loads
- Original data file
- Maumee daily loads
- Data files converted into csv format using external program such as Excel
- csv file for DSS
- Program Execution

**View input data**

- Convert
- View input data
- Sum up daily loads of monitored tributaries in water year and view results

**Outputs**

- Annual loads from tributaries (csv file)
- Monitored Tributary loads.csv - Notepad
- Maumee TP loads
- Details of results (free form text file)
- Maumee

**Program Execution**

- Program Execution
- Graphs: R software with EGRET library

**Data files converted into csv format using external program such as Excel**
Loading Estimate Decision Support System

**Point Sources**

- **Inputs**
  - Point source effluents (monthly average flows and concentrations or loads)

- **Program Execution**
  - Convert
  - Calculate point source loads and view results

- **Outputs**
  - Annual loads from all point sources for each tributary (csv file)
  - Average daily loads at individual point sources (csv file)

Original data file (multiple facilities)

Industry: Sulco Chemicals Ltd.

Function available in DSS to import point source data into required csv format.

Grand-ON TP loads

Sulco Chemicals
Loading Estimate Decision Support System
Unmonitored Watershed Areas (Unit Area Load)

**Inputs**
- Annual loads for monitored tributaries calculated by DSS
- Black-MI TP loads
- Annual loads from indirect point sources calculated by DSS
- TP point source loads for Black-MI
- Areas of monitored and unmonitored watersheds

**Program Execution**
- Calculate unmonitored watershed area loads

**Outputs**
- Annual loads for unmonitored watershed areas (csv file)

Canada
Environment and Climate Change Canada
Environnement et Changement climatique Canada
Loading Estimate Decision Support System

Atmospheric Deposition

**Inputs**

- Monthly precipitation volumes and TP concentrations

**Program Execution**

- Calculate atmospheric deposition loads

**Outputs**

- Annual loads for basins (csv file)
- Annual loads at monitoring stations (csv file)

**Data files converted into csv format using external program such as Excel**

- Original data file
- Point Pelee
- Lake Erie basins

- csv file for DSS
- Point Pelee

Climate Change Canada

Environnement et Changement climatique Canada
Loading Estimate Decision Support System

Basin and Lake Total Loads

**Inputs**
- Monitored tributaries
- Unmonitored watershed areas
- Atmospheric Deposition
- Point sources

**Program Execution**
- All annual loads calculated by DSS
- Basins, parameters, water year, load (MTA), SE (MTA^2)

**Outputs**
- Basin and lake total annual loads from all sources (csv file)
- Basin and lake annual loads from each individual source (csv file)

- Huron-Erie Corridor, CP, 2008, 2025, 174.86
- Huron-Erie Corridor, SRP, 2008, 1221.361, 56.394
- Huron-Erie Corridor, TP, 2008, 2425, 174.86
- Huron-Erie Corridor, TP, 2009, 2701.691, 56.394
- Huron Erie Corridor, SRP, 2009, 486, 18.56
- Central, TP, 2009, 1952.451, 315.49
- Central, SRP, 2009, 554.287, 35.287
- Eastern, TP, 2009, 838.422, 114.04
- Eastern, SRP, 2009, 219.275, 62.198
- Huron-Erie Corridor, TP, 2010, 1755.05, 49.052
- Huron-Erie Corridor, SRP, 2010, 7902.173, 32.181
- Western, TP, 2010, 1926.779, 39.815
- Western, SRP, 2010, 540.251, 11.881
- Central, TP, 2010, 1417.276, 71.401
- Central, SRP, 2010, 473.923, 23.293
- Eastern, TP, 2010, 479.95, 43.012
- Eastern, SRP, 2010, 130.168, 15.525
- Huron-Erie Corridor, TP, 2011, 2984.121, 415.342

**Example Data**
- Basin: Huron-Erie Corridor
- Year: 2008
- Water Year: 2007
- Load (MTA): 2425
- SE (MTA^2): 174.86

**Additional Information**
- Basin and lake annual loads from each individual source
- Sum up loads from all sources by basin, country, lake

**Environment and Climate Change Canada**

**Environnement et Changement climatique Canada**
Loading Estimate Decision Support System

Implementation Issues

- After initial round of beta testing of DSS, discrepancies in some results were discovered
- Implementation is our interpretation of Dolan Method based on Maccoux et al., (2016)

1. **Monitored tributaries:** When calculating loads using Stratified Beale Ratio Estimator, there were cases where the DSS used different flow cutoff values and/or number of strata compared to Maccoux et al., (2016).

**Examples: Black-MI in 2013**

<table>
<thead>
<tr>
<th># of strata</th>
<th>TP Load (MTA)</th>
<th>MSE (MTA^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maccoux</td>
<td>49</td>
<td>709</td>
</tr>
<tr>
<td>DSS</td>
<td>44 (-10%)</td>
<td>637 (-10%)</td>
</tr>
</tbody>
</table>

**Sydenham in 2013**

<table>
<thead>
<tr>
<th># of strata</th>
<th>Flow cutoff (cfs)</th>
<th>TP Load (MTA)</th>
<th>MSE (MTA^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maccoux</td>
<td>400</td>
<td>90</td>
<td>1100</td>
</tr>
<tr>
<td>DSS</td>
<td>300 (-2%)</td>
<td>88 (-1%)</td>
<td>1085 (-1%)</td>
</tr>
</tbody>
</table>

If we have detail information on the algorithms from Dolan program used by Maccoux et al., (2016) to compute flow cutoff values and to choose number of strata, then issue can be resolved.
2. **Point sources:** Differences in assigning point sources to tributaries and/or categorizing them as indirect or direct. This process was performed manually using a GIS by visual inspecting point source locations in relation to tributaries and water quality monitoring stations.

Example: Huron-MI in 2011

<table>
<thead>
<tr>
<th></th>
<th>Indirect Municipal (MTA)</th>
<th>Indirect Industrial (MTA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maccoux</td>
<td>27.95</td>
<td>0.17</td>
</tr>
<tr>
<td>DSS</td>
<td>33.06 (18%)</td>
<td>0.13 (-23%)</td>
</tr>
</tbody>
</table>

Note that differences in aggregated loads from multiple point sources can be large. If the same tributary and indirect/direct assignments from Maccoux *et al.*, (2016) were used, then differences can be resolved.

2. **Heidelberg data:** Annual mean square errors (MSEs) were not computed by DSS, but were obtained from Maccoux *et al.*, (2016) data files. For future years, MSEs need to be provided or calculation method needs to be known. Also for future years, daily loads need to be provided since these were not calculated by the DSS.
Loading Estimate Decision Support System

Next Steps

• Refine implementation of Dolan Method in DSS to reduce differences in results
• Implement visualization of results
  – Tables: annual loads from individual sources (or all aggregated) by tributary, basin, lake, country
  – Maps and graphs
• Implement data import utilities as required
Summary

- ECCC is monitoring in the Huron-Erie corridor, priority Canadian tributaries to Lake Erie, nested monitoring in the Thames River watershed, Lake St. Clair with MOECC, and in the Great Lakes.
- Loadings estimates based on Dolan approach, with 50-100 samples collected per location per water year.
- LEDSS will be a publically available tool, modernizing the Dolan approach using AI and a user-friendly interface.
- ECCC is working with partners to ensure data comparability and is supporting watershed and lake modeling initiatives with enhanced data.