D. Phosphorus Bioavailability and Loads

importance, recent history, and variability
Outline

1. Phosphorus importance and forms
2. Runoff events, phosphorus loading, and variability
3. Bioavailability: Background and results
4. Applying the bioavailability concept to phosphorus loads
5. Point source reductions to the shelf
6. Bioavailable loads to Cayuga Lake: LSC context
7. Summary

* see attached slides for added information on estimates of variability and uncertainty
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Importance of phosphorus (P) loads to lakes

- Cultural eutrophication and associated water quality problems continue to be an important issue.
- P is the limiting nutrient for algae growth in most inland waters, least available constituent necessary to support growth.
  - Cayuga Lake is P-limited.
- Control of the supply of P ($P_L$; loads e.g., kg) is a primary management approach for lakes with excessive algal growth, described as culturally eutrophic.
- Earlier this was based on the concentration of total P (TP), and the development of TP loading rates ($TP_L = Q \cdot TP$; where Q is the flow rate of the input).
- Focus here:
  - The evolution to the development of bioavailable P loads ($BAP_L$).
Forms of phosphorus (P)

- Total phosphorus (TP)
  - TP = PP + TDP (m)
- Particulate P (PP) (m)
  - organic PP (PP$_o$)
  - minerogenic PP (PP$_m$)
  - PP$_m$ = PP$_{m/u}$ + PP$_{m/a}$
- Total dissolved P (TDP) (m)
  - TDP = SRP + SUP (m)
    - Soluble reactive P (SRP) (m)
    - Soluble unreactive P (SUP) (m)

(m) – directly, or indirectly from measurement
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Inclusion of runoff-event based sampling was critical to support development of representative loading estimates and the overall P-eutrophication modeling initiative

- Figure 3 (Fall Cr.) from Prestigiacomo et al., 2015

- strong dynamics in concentrations of forms of P are observed in most tributaries during runoff events
- these need to be resolved and parameterized to support credible loading estimates and related modeling
  - as promoted by NYSDEC (automated sampling equipment, and program support)
- \( P_L \) as a major model driver has important management implications
  - apportionment according to sources is critical

- [Diagram showing flow, biweekly observations, event observations, estimated and observed concentrations of forms of P (SRP, SUP, PP) over time from April to October 2013]
Sixmile Creek during high flow
Approach used for phosphorus load estimation: Independently for each stream

\[ TP_L = PP_L + SUP_L + SRP_L \]

- **PP**
  - PP-driver expression
  - PP$_L$

- **SUP**
  - SUP-driver expression
  - SUP$_L$

- **SRP**
  - SRP-driver expression
  - SRP$_L$

**TP**
- long-term Q records
- concentrations runoff event based sampling
- conc. -driver relationships (Q, T)
- non-point interannual variability
- loading rate calculations (kg·d$^{-1}$)

Upstate Freshwater Institute
Loading estimates for the Cayuga Lake system: Context, importance of runoff event tributary monitoring

- tributary P loading methods and quantification – reported in Prestigiacomo et al. (2015), previous presentations
- $P_L$ strongly dependent on P/Q relationships (stream, P-form dependent)
  - developed from 2013 program
- P/Q relationships were the sole basis for estimates for previous years
  - interannual differences in P loading – driven by interannual variations in Q
- support from CSI program (Community Science Institute)
  - based on monitoring since early 2000s, no systematic changes in TP/Q relationships indicated, supporting the approach for historic $P_L$ estimation
  - other historic $P_L$ validations ongoing
Sources of uncertainty in the estimation of P loads ($P_L$)

1. methods of load estimation
   - numerous protocols available
   - daily estimates required
2. dependencies of tributary P concentrations (various forms) stream flow rate ($Q$)
   - other environmental conditions, i.e., season
3. monitoring coverage adjoining tributary mouths
   - number, frequency of sample collection
4. application of bioavailability results

- uncertainty and variability common to loading analyses

Detailed treatment of variability (uncertainty) for Fall Cr. available at end of presentation and for all tribus in Prestigiacomo et al. 2015
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1. established bioassay protocol
   a. review by Auer 2015, others
2. applications in New York
   a. NYC – reservoir tributaries
   b. Onondaga Lake – NYSDEC
      • Metro/Actiflo
      • tributaries
3. Cayuga Lake (NYSDEC)
   • 4 main tributaries
   • IAWWTP/Actiflo
   • CHWWTP
   • LSC
Importance of the bioavailability of phosphorus loads delivered to lakes

- A major problem has emerged for the simple approach of focusing strictly on TP.
  - P exists in multiple chemical forms that differ substantially in their availability to support algal growth.

- Differences in availability according to P forms:
  - TP = PP + TDP (PP – particulate P; TDP – total dissolved P)
  - TDP = SRP + SUP (SRP – soluble reactive P; SUP – soluble unreactive P)
  - PP = PP\textsubscript{o} and PP\textsubscript{m} (PP\textsubscript{o} – organic PP; PP\textsubscript{m} – minerogenic PP)

<table>
<thead>
<tr>
<th>P form</th>
<th>Bioavailability</th>
</tr>
</thead>
<tbody>
<tr>
<td>SRP</td>
<td>~ completely</td>
</tr>
<tr>
<td>SUP</td>
<td>mostly</td>
</tr>
<tr>
<td>PP</td>
<td>low</td>
</tr>
<tr>
<td>PP\textsubscript{o}</td>
<td>intermediate, variable</td>
</tr>
<tr>
<td>PP\textsubscript{m}</td>
<td>low (&lt;&lt; PP\textsubscript{o})</td>
</tr>
</tbody>
</table>
Consideration of bioavailability causes the effective external P loads ($BAP_L$) to be diminished relative to the TP load ($TP_L$)

- the failure to consider bioavailability in most contemporary mechanistic P-eutrophication models is problematic
  - TP loads overestimate the amount of P that grow algae and that leads to compensating by misrepresentation of source and/or sink processes for P as part of model calibration

- key examples of the importance of appropriate representation of $BAP_L$ are emerging for prominent cases
  - re-eutrophication of western Lake Erie
  - Onondaga Lake – Metro discharge and rehabilitation
  - Cayuga Lake – emerging in these analyses, based on related NYSDEC recommendations
Phosphorus (P) associated with clay particles: Simple concepts

1. such P would not be mobilized following delivery to the lake and thus is uncoupled from trophic state
   - not bioavailable

2. adsorption/desorption processes
   - driven by ambient SRP
   - potential bioavailability

   a. adsorption – in tributaries where SRP is higher

   b. desorption, low SRP – in lakes, bioavailable P released, where SRP is lower
      - giving up the green layer
The $\text{BAP}_L$ initiative for Cayuga Lake

- supporting components
  - monitoring forms of P in critical inputs
  - development of empirical concentration-Q relationships, supported by runoff event sampling
  - bioassay-based bioavailability (fraction $f_{\text{BAP}}$) assessments of PP, SUP, and SRP – multiple sources
- estimates and apportionment of $\text{BAP}_L$
- estimates of interannual variation in loads associated with variations in stream flow

- importance
  - apportionment of $\text{BAP}_L$ according to sources
  - model credibility
  - management deliberations/transferability
April through October, 2013

- tributaries
  - Fall Cr.
  - Cayuga Inlet mouth
    - Cayuga Inl. Cr.
    - Sixmile Cr.
    - Cascadilla Cr. (estimates)

- point sources
  - IAWWTP
  - CHWWTP
  - LSC
  - minors (estimates)
Methods for assessing P-bioavailability: Soluble phase assays

Adopts the procedure of **W.E. Miller and J.C. Greene. 1978.**

Methods for assessing P-bioavailability: Particulate phase assays

Adopts the procedure of **J.V. DePinto. 1982.**


**PP\textsubscript{initial} = 871 \mu gP/L**

**Dual Culture Diffusion Apparatus**

Precision: <4%, n=3
Application of P-bioavailability assays

89 bioassays performed on 13 systems
Range in P-bioavailability: Soluble unreactive phosphorus (SUP)
Range in P-bioavailability: Particulate phosphorus (PP)
P-bioavailability: Particulate phosphorus (PP), by discharge type

Fraction Bioavailable, $f_{\text{bio}}$ (d’less)

- WWTP Effluents
- Tributaries

Cayuga

Other Sites
Cayuga Lake and tributaries: Sediment loading and bioavailability information

<table>
<thead>
<tr>
<th>Tributary</th>
<th>Watershed (%)</th>
<th>$\text{PAV}_m$ Load (%)&lt;sup&gt;1&lt;/sup&gt;</th>
<th>ISPM Load (%)&lt;sup&gt;1&lt;/sup&gt;</th>
<th>ISPM:SPM (%)&lt;sup&gt;1&lt;/sup&gt;</th>
<th>PP Load (%)&lt;sup&gt;1&lt;/sup&gt;</th>
<th>$f_{\text{BAP PP}}$ (%)&lt;sup&gt;2&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fall Cr.</td>
<td>17.7</td>
<td>94</td>
<td>96</td>
<td>90</td>
<td>85</td>
<td>9</td>
</tr>
<tr>
<td>Inlet</td>
<td>22.0</td>
<td>89</td>
<td>87</td>
<td>90</td>
<td>78</td>
<td>-</td>
</tr>
<tr>
<td>Cayuga Inlet Cr.</td>
<td>12.9</td>
<td>96</td>
<td>99</td>
<td>93</td>
<td>98</td>
<td>6</td>
</tr>
<tr>
<td>Six Mile Cr.</td>
<td>7.20</td>
<td>97</td>
<td>90</td>
<td>97</td>
<td>89</td>
<td>6</td>
</tr>
<tr>
<td>Salmon Cr.</td>
<td>12.5</td>
<td>98</td>
<td>98</td>
<td>87</td>
<td>95</td>
<td>21</td>
</tr>
<tr>
<td>Unmonitored&lt;sup&gt;3&lt;/sup&gt;</td>
<td>49.7</td>
<td>96</td>
<td>95</td>
<td>91</td>
<td>90</td>
<td>-</td>
</tr>
</tbody>
</table>

1 fraction received during high runoff intervals  
2 fraction of PP bioavailable, average of three bioassays (Prestigiacomo et al., 2015)  
3 estimated, based on monitored portion

minerogenic particles dominate in runoff event samples
### Bioavailability assay results ($f_{\text{BAP}}$) for P forms from multiple sources to Cayuga Lake

<table>
<thead>
<tr>
<th>Source</th>
<th>PP</th>
<th>SUP</th>
<th>SRP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fall Cr.</td>
<td>9</td>
<td>77</td>
<td>94</td>
</tr>
<tr>
<td>Cayuga Inl. Cr.</td>
<td>6</td>
<td>64</td>
<td>89</td>
</tr>
<tr>
<td>Salmon Cr.</td>
<td>21</td>
<td>84</td>
<td>98</td>
</tr>
<tr>
<td>Sixmile Cr.</td>
<td>6</td>
<td>62</td>
<td>94</td>
</tr>
<tr>
<td>IAWWTP</td>
<td>1</td>
<td>72</td>
<td>93</td>
</tr>
<tr>
<td>CHWWTP</td>
<td>26</td>
<td>63</td>
<td>98</td>
</tr>
<tr>
<td>LSC</td>
<td>not avail</td>
<td>10</td>
<td>97</td>
</tr>
<tr>
<td>shelf</td>
<td>2</td>
<td>95</td>
<td>97</td>
</tr>
</tbody>
</table>

- **noteworthy features**
  - **tributary PP** $f_{\text{BAP}}$ - low, Salmon highest on average
    - some limited evidence that PP $f_{\text{BAP}}$ correlated with land-use
  - **LSC SUP** - low
    - in-lake processing effect, enzymatic activity
  - **IAWWTP PP** $f_{\text{BAP}}$ – low
    - Actiflo (similar to Syracuse Metro)
  - **shelf, post event** $f_{\text{BAP}}$ – low
    - dominated by mineral particles
Bioavailability results for Cayuga Lake system: Context

1. Salmon Cr. vs shelf tributaries
   a. Salmon Cr. SRP ~ 25 µg/L
   b. shelf tribs SRP ~ 5-10 µg/L
   c. lake SRP ~ 1 µg/L

2. important implications of low shelf $f_{\text{BAP}}$ (~ 1.7%), following the major runoff event of early July 2013
   PP = 368 µg/L; i.e., not related to trophic state
   TP = 387 µg/L

PP received by the shelf from major runoff events is nearly completely unavailable
Salmon Creek during high flow
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Application of the bioavailability concept

\[ TP_L = PP_L + SUP_L + SRP_L \]

\[ BAP_L = PP_{L/B} + SUP_{L/B} + SRP_{L/B} \]

**Concentrations**
- Runoff event-based sampling

**Conc.-driver relationships**
- \((Q,T)\)

**Loading rate calculations**
- \((kg \cdot d^{-1})\)

**Bioavailable loads, \(P\) fractions**
- Bioavailability assays
Phosphorus and bioavailability results for Cayuga Lake system: Context

- Tributary P loading – totals, according to forms
  - TP = PP + SUP + SRP
    - PP dominant (~84%)

- 2013 study results (Apr.-Oct.)
  - Documented in Prestigiacomo et al. (2015)
    - Scope, NYSDEC input, event sampling
  - Daily loads generated
    - Summaries for different intervals (e.g., summer)

- \( \text{BAP}_L \sim 26\% \) of \( \text{TP}_L \)
  - \( \text{PP}_{L/B} \sim 40\% \)
  - \( \text{SRP}_{L/B} \sim 41\% \)
  - \( \text{SUP}_{L/B} \sim 19\% \)
Comparison of total ($TP_L$) and bioavailable ($BAP_L$) load estimates to Cayuga Lake: Entire lake vs. shelf

* includes point and non-point sources

- dominant contribution of $PP_L$ to $TP_L$, received mostly during runoff events
- $BAP_L << TP_L$; ~25% due to low $f_{BAP}$ of PP
- caution for related local interpretations, because of rapid flushing of shelf (subsequently)
- $BAP_L$ remains much smaller (~22%) than $TP_L$ locally
Comparison of $\text{BAP}_L$ to the shelf and lake as a whole, 2013 conditions

$\text{BAP}_L$ Shelf
- tributaries ~87%
- LSC ~6%
- IA, CH ~7%

$\text{BAP}_L$ to Whole Lake
- tributaries ~95.5%
- LSC ~1.6%
- other PtS ~2.9%

Legend:
- Non-point source
- IAWWTP + CHWWTP
- LSC
### Apportionment of BAP loads, 2013

<table>
<thead>
<tr>
<th>Source</th>
<th>BAP$_L$ (mt)</th>
<th>Percent Contribution to total BAP$_L$ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fall Cr.</td>
<td>2.10</td>
<td>15</td>
</tr>
<tr>
<td>Cayuga In.</td>
<td>0.79</td>
<td>5.6</td>
</tr>
<tr>
<td>Salmon Cr.</td>
<td>2.18</td>
<td>15.6</td>
</tr>
<tr>
<td>Six Mile Cr.</td>
<td>0.47</td>
<td>3.4</td>
</tr>
<tr>
<td>Taugh. Cr.</td>
<td>1.10</td>
<td>7.9</td>
</tr>
<tr>
<td>Unmon. Tribs.</td>
<td>6.75</td>
<td>48.1</td>
</tr>
<tr>
<td>summed (%)</td>
<td><strong>13.4</strong></td>
<td><strong>95.5</strong></td>
</tr>
<tr>
<td>IAWWTP</td>
<td>0.21</td>
<td>1.5</td>
</tr>
<tr>
<td>CHWWTP</td>
<td>0.08</td>
<td>0.5</td>
</tr>
<tr>
<td>minor WWTP</td>
<td>0.14</td>
<td>1.0</td>
</tr>
<tr>
<td>LSC</td>
<td><strong>0.22</strong></td>
<td><strong>1.6</strong></td>
</tr>
<tr>
<td>summed (%)</td>
<td><strong>0.64</strong></td>
<td><strong>4.5</strong></td>
</tr>
<tr>
<td>summed (%)</td>
<td><strong>14.0</strong></td>
<td><strong>100</strong></td>
</tr>
</tbody>
</table>
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Reductions in P loading to the shelf from point sources

April-October loads

LSC (blue bar)
- initiated in 2000
- notable point source contributor in 2013
- small relative to the overall decrease in point source inputs

* 1990s point source assumptions detailed in Prestigiacomo et al. 2015
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Representation of interannual variations in whole lake $\text{BAP}_L$, results

Prestigiacomo et al. 2015 (Figure 8)

- $\text{BAP}_L$ variations according to source ($\pm$ 1 std. dev.)

1. $\pm$ 1 std. dev. $\sim$ 4.5 % of LSC load
2. $\pm$ 3.6 % of total PtS load
3. $\pm$ 0.07 % of total local 2013 load
4. $\pm$ 0.04 % of total estimated variability in $\text{BAP}_L$

Comparative features of LSC variability

- Variations in tributary loading dominate; potential climate change effects should be considered.

Different y-axis scaling for tribs vs. PtS.
Representation of interannual variations in local lake $\text{BAP}_L$, results

Prestigiacomo et al. 2015 (Figure 8)

- $\text{BAP}_L$ variations according to source ($\pm$ 1 std. dev.)

$\pm$ std. dev. annual ests. (estimate of interannual availability)

<table>
<thead>
<tr>
<th>Year</th>
<th>Tribs</th>
<th>PtS*</th>
<th>LSC</th>
</tr>
</thead>
<tbody>
<tr>
<td>'00-'12</td>
<td>5.0 ± 3.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>'13</td>
<td>3.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>'09-'12</td>
<td>0.46 ± 0.11</td>
<td>0.28</td>
<td>0.23 ± 0.01</td>
</tr>
<tr>
<td>'13</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

comparative features of LSC variability

1. $\pm$ 1 std. dev. $\sim$ 4.5 % of LSC load
2. $\pm$ 3.6 % of total PtS load
3. $\pm$ 0.3 % of total local 2013 load
4. $\pm$ 0.3 % of total estimated variability in $\text{BAP}_L$

variations in tributary loading dominate; potential climate change effects should be considered

*summation of point sources
Representation of interannual variations in local lake BAP_{L}, results

- local BAP_{L} for the April – October interval
  - 1998-2013 period
- systematic decrease in the WWTP BAP_{L} (IA nd CH) in ~ 2006
- increase in LSC BAP_{L} starting 2004-2005 evident

- no significant trends in Chl-a (or TP) despite those in point source BAP_{L}
Representation of interannual variations in local lake BAP$_l$, results

- local BAP$_l$ for the April – October interval
  - 1998-2013 period
- systematic decrease in the WWTP BAP$_l$ (IA nd CH) in 2006
- increase in LSC BAP$_l$ starting 2004-2005 evident
- the tributary usually dominates overall loading
  - exceptions, dry years, 2012
  - highly variable, dependent on hydrology
- Prestigiacomo et al. 2015

- no significant trends in Chl-a (or TP) despite those in point source BAP$_l$
The increase in the LSC SRP levels: A limnological signature, but only a small increase in BAP$_L$

- distinct increase in 2004
  - SRP concentration was 4-6 µg/L, now 8-10 µg/L
- current conditions represent, on average, an increase in the LSC BAP$_L$ of ~0.1 mt
  - ~2.7% increase in BAP$_L$ to shelf
- small component of overall load (all trib, non-point sources)

- indicative of shift in system metabolism
- zebra to quagga mussels?
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Summary: Phosphorus bioavailability and loads

- runoff event monitoring and P concentration-flow (P/Q) relationships critical to support loading estimates
- bioavailability concept (f_{BAP}) integrated into P loading analysis for Cayuga Lake
- components
  - multiple fractions of P monitored
  - algal bioassays of PP, SUP, and SRP – multiple sources and events
  - development of load estimates (TP_L and BAP_L)
    - including historic estimates (~late 1990s) and contemporary
- bioavailability findings for tributary inputs
  - PP (mostly minerogenic particles) – low (6-21%)
  - SUP – mostly (60-85%)
  - SRP – ~ completely (>90%)
  - other contrasting conditions – LSC/SUP, Actiflo/PP, Salmon Cr./PP, shelf post events/PP
Summary: Phosphorus bioavailability and loads

• tributary sources of $BAP_L$ dominate the overall $BAP_L$ to the entire lake and shelf
  • ~ 95% on a lake-wide basis
  • ~ 87% on the shelf
• April-October 2013 $BAP_L$ was substantially lower than $TP_L$
  • ~ 26% of $TP_L$
  • received mostly during runoff events
  • large interannual variations anticipated from variations in hydrology - complications
• point source upgrades reduced $BAP_L$ contributions lake-wide from ~20% (late 1990s) to ~5% (2013)
  • obvious benefits, quantification of benefits difficult due to tribs dominance
Questions
Detailed uncertainty and variability analyses

1. methods of load estimation
   - numerous protocols evaluated
   - results for Fall Creek

2. dependencies of tributary P concentrations (various forms)
   - stream flow rate (Q)
     - loading calculations, FLUX32 Jackknifing

3. monitoring coverage adjoining tributary mouths
   - loading calculations, FLUX32 Jackknifing

4. application of bioavailability results
   - temporal, site specific variability in bioavailability
     - Monte Carlo analysis

5. estimates of interannual variations in tributary $BAP_L$
1. Variability in Fall Creek $P_L$ estimation: Calculation protocol

<table>
<thead>
<tr>
<th>Method</th>
<th>PP Load (kg)</th>
<th>SUP Load (kg)</th>
<th>SRP Load (kg)</th>
<th>TP Load (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>F32 method 6 C/Q interpolated, seasonal</td>
<td>8,032</td>
<td>741</td>
<td>876</td>
<td>9,649</td>
</tr>
<tr>
<td>F32 method 6 C/Q interpolated, flow</td>
<td>8,010</td>
<td>742</td>
<td>855</td>
<td>9,607</td>
</tr>
<tr>
<td>F32 method 6 C/Q</td>
<td>11,289</td>
<td>770</td>
<td>1,202</td>
<td>13,261</td>
</tr>
<tr>
<td>F32 method 5 C/Q adj.</td>
<td>8,156</td>
<td>755</td>
<td>893</td>
<td>9,804</td>
</tr>
<tr>
<td>F32 method 4 C/Q flow wtd. adj.</td>
<td>8,300</td>
<td>759</td>
<td>907</td>
<td>9,966</td>
</tr>
<tr>
<td>F32 Rising/Falling limb</td>
<td>8,008</td>
<td>739</td>
<td>850</td>
<td>9,597</td>
</tr>
<tr>
<td>Manual regr.</td>
<td>10,251</td>
<td>746</td>
<td>1,108</td>
<td>12,105</td>
</tr>
<tr>
<td>Manual regr. with events</td>
<td>10,223</td>
<td>645</td>
<td>1,153</td>
<td>12,021</td>
</tr>
<tr>
<td>Multiple Linear Regression</td>
<td>8,896</td>
<td>784</td>
<td>971</td>
<td>10,651</td>
</tr>
<tr>
<td><strong>range (regression methods)</strong></td>
<td><strong>8,008-11,289</strong></td>
<td><strong>645-784</strong></td>
<td><strong>850-1,202</strong></td>
<td><strong>9,597-13,261</strong></td>
</tr>
</tbody>
</table>

- demonstration of some dependence of load estimates on the specifics of the loading calculation protocol adopted
1. Variability in Fall Creek $P_L$ estimation: Calculation protocol

- Best estimate Fall Cr. $TP_L = 9.6$ mt
  - $PP_L = 8.0$ mt;
  - $SRP_L = 0.88$ mt;
  - $SUP_L = 0.74$ mt
- Range in estimates from regression protocols is typical
  - $TP_L$ range = 3.7 mt (38% of best estimate $TP_L$)
    - $PP_L = 3.3$ mt;
    - $SRP_L = 0.35$ mt;
    - $SUP_L = 0.14$ mt
- Protocol uncertainty due to:
  - Uncertainty in C/Q
  - Assumptions embedded in individual protocols
  - Methodological uncertainty similar for other tributaries
2-3. Uncertainty in Fall Creek load estimation associated with adopted method: Jackknife analysis

**Jackknife procedure (FLUX32)**

1. calculates the best estimate load using all observed concentration data
2. excludes one measured concentration one at a time, and recalculates the loads
3. repeated for n-1 number of iterations, where n is the total number of concentration observations
4. uncertainty statistics calculated on the n-1 number of load estimates

± 2 standard deviations of jackknife analysis

- unavoidable, associated with variability in the C/Q relationships and number of observations
- greatest uncertainty associated with PP, the dominant P component
- magnitudes of jackknife uncertainty
  - \( TP_L = 2.2 \text{ mt} \)
  - \( PP_L = 2.7 \text{ mt} \)
  - \( SRP_L = 0.23 \text{ mt} \)
  - \( SUP_L = 0.06 \)
4. Uncertainty in BAP$_L$ estimates: Monte Carlo analysis

- fully summarized in Prestigiacomo et al. 2015
- associated with temporal variations in f$_{BAP}$ in the tributaries
  - beta distribution (StatSoft, 2003) was established for f$_{BAP}$ for each tributary based on the three observations for each P form
  - values of f$_{BAP}$ were selected randomly from these distributions for each day over the April-October interval of 2013 for each tributary (and P form) and associated loads were calculated (summed to BAP$_L$), as conducted for the original overall best estimate
  - process repeated for 2000 simulated April-October intervals
  - uncertainty in P$_{L/B}$ for each tributary and together is represented by 95% confidence limits of the calculated 2000 seasonal distributions
4. Uncertainty in \( \text{BAP}_L \) estimates: Monte Carlo analysis

- Fall Cr. results
- greatest uncertainty associated with PP,
- magnitudes of Monte Carlo uncertainty
  - \( \text{BAP}_{L/B} = 0.24 \text{ mt} \)
  - \( \text{PP}_{L/B} = 0.24 \text{ mt} \)
  - \( \text{SRP}_{L/B} = 0.04 \text{ mt} \)
  - \( \text{SUP}_{L/B} = 0.003 \text{ mt} \)
5. Representation of interannual variations in local $P_L$ and $BAP_L$, methods (2000-2012)

1. analyses of loads for tributaries
   a. evaluation of concentration-flow ($C/Q$) relationships
      - logarithmic relationships
      - positive, reasonably strong
      - “power law” format
      - important support for position that these dependencies have not systematically changed in recent years (historical CSI, UFI monitoring)
   b. FLUX32 calculations of $P_L$
      a. application of bioassay $f_{BAP}$ results to daily $P_L$ estimates
   c. enhanced credibility of load estimates from NYSDEC’s call for event-based tributary monitoring
   d. uncertainty in estimates unavoidable, from real variations in $P/Q$ relationships

2. point sources – discharge monitoring
3. uncertainty – estimates, real variations

- Prestigiacomo et al., 2015

![Graph of $PP_{BAP}$ vs $Q$ (m$^3$/s)](image)

- e.g., high flow years will have higher concentrations and associated loads
Potential for interannual variations in local $\text{BAP}_L$ to mask systematic benefits from reductions in point source loads

- the executed experiment:
  - Prestigiacomo et al. 2015

“Point source contributions to the total bioavailable P load ($\text{BAP}_L$) are minor (5%), reflecting the benefit of reductions from recent treatment upgrades. The $\text{BAP}_L$ represented only about 26% of the total P load, because of the large contribution of the low bioavailable PP component. Most of $\text{BAP}_L$ (> 70%) is received during high flow intervals. Large interannual variations in tributary flow and coupled $\text{BAP}_L$ will tend to mask future responses to changes in individual inputs.”