Regression-based loading estimates applied in small, agricultural watersheds

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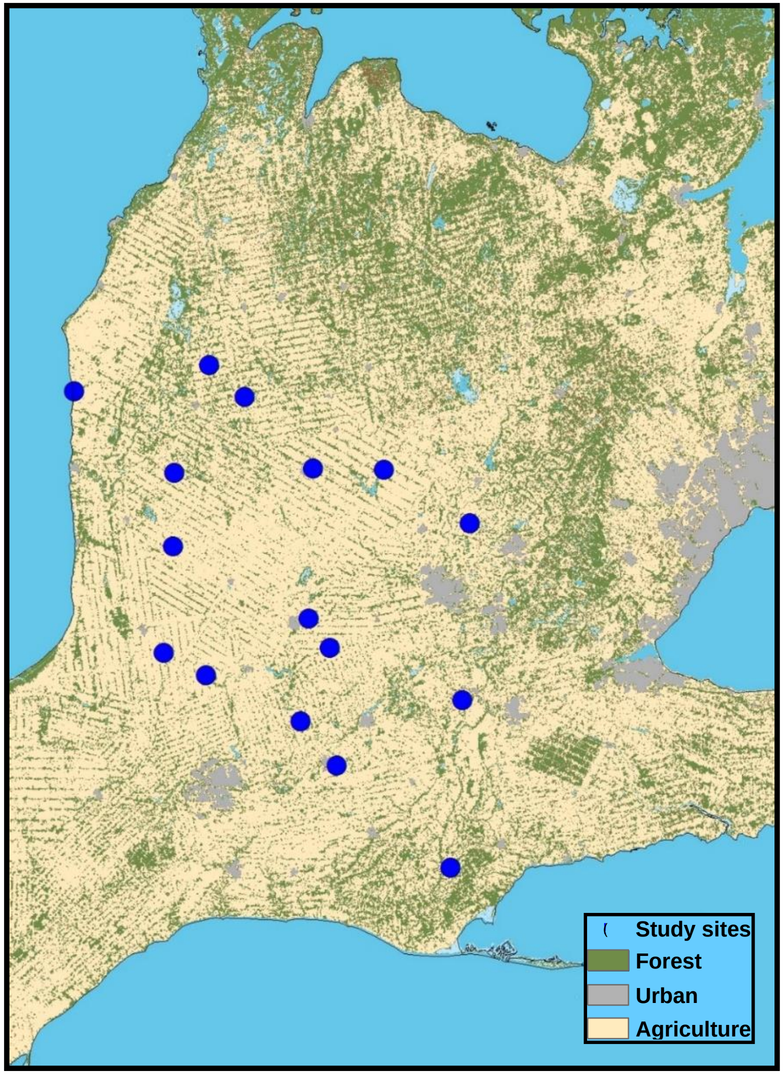
Project objectives

MOECC Nutrient Monitoring Programme:

- Examine water quality in 15 small streams draining agricultural watersheds
- Study period 2004-2009*
- Measure concentrations of nutrients (N and P), *E. coli*, and suspended solids



*MOECC 2012 report

Project objectives…

- Observe seasonal trends in loads and concentrations
- Consider:
  - potential in-stream consequences by examining concentrations
  - potential impacts to receiving waters by examining loading
- Compare concentration and load estimates to previous studies (PLUARG)
- Relationships between land use and water quality
  - Relationship between Nutrient Management Act (NMA) and stream water quality

Description of data used

- Mix of study specific and available data
- Water quality:
  - Discrete grab samples
  - Shipped to MOECC lab (Toronto) for analyses
    - TP, NO_2, NO_3, susp. solids, *E. coli* etc.
  - One station (Nissouri) with ISCO automated sampler
- Discharge:
  - Wading discharge during WQ collection
  - Combined with Water Survey of Canada (WSC) downstream data

Description of approach for:

a) Site selection

- SW ON
- No point sources
- Minimal urban
- Variety of soil types and geology
- 'Goldilocks' size watersheds (12-70km^2)
- Outlet easily and publicly accessible

Description of approach for:

b) Sample collection

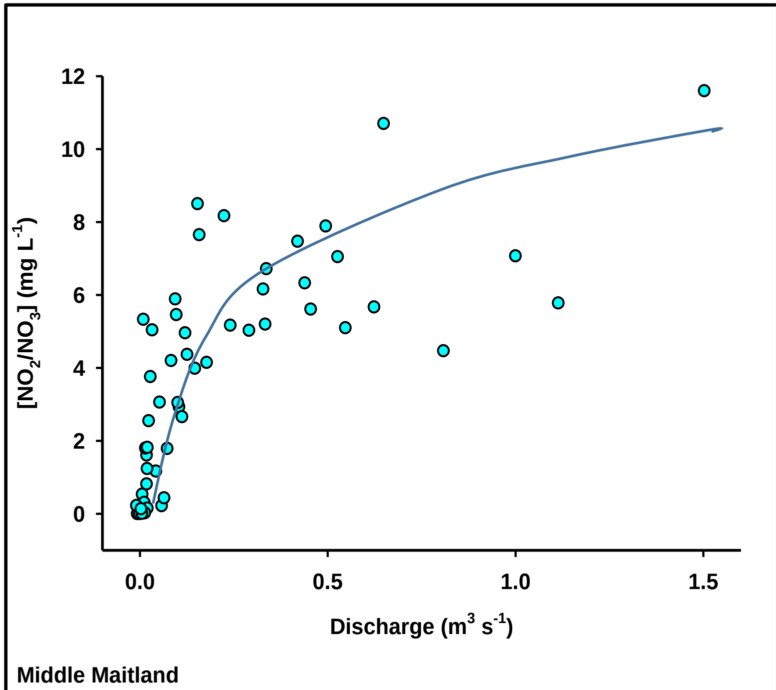
- ~12-14 discrete samples per year (primarily by CA partners)
- Sampled all seasons
- Attempt to sample through event flows
- Nissouri sampled more frequently (with ISCO)
- Wading discharge during sample collection

Description of approach for:

c) Loading estimation

- Regression-based method
    1. Construct empirical relationship between
        a) Discharge- collected frequently ('continuously')
        b) Stream [constituent]- collected infrequently

    2. Use discharge-concentration relationship to infer concentration from discharge

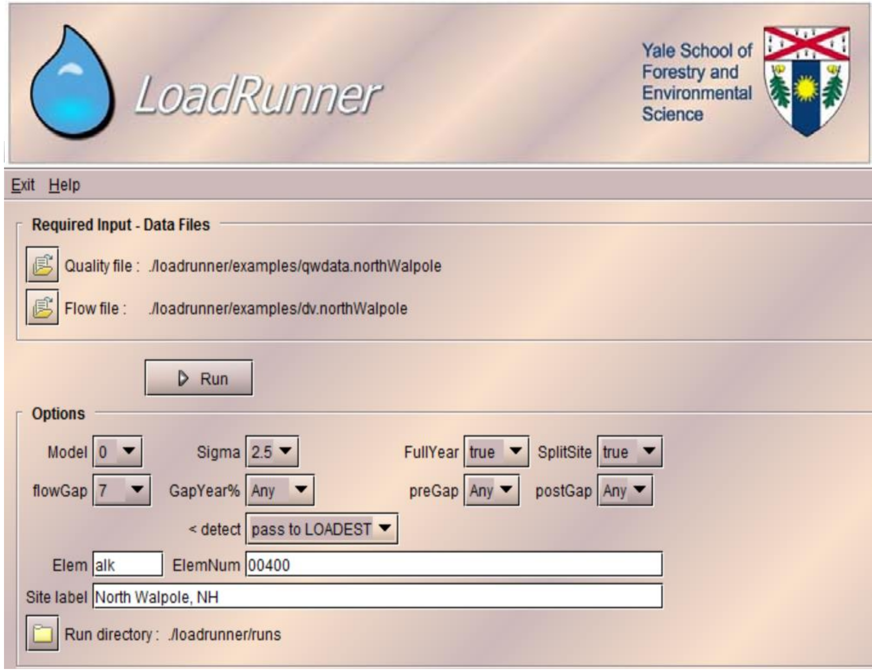


Description of approach for:

c) Loading estimation

- **Load Estimator (Loadest)**
  - USGS
  - Fortran
  - Open source
  - (Mar 2013 update)

- **LoadRunner**
  - GUI interface for Loadest
  - Serves files to Loadest and produces additional output files



http://water.usgs.gov/software/loadest/

http://environment.yale.edu/loadrunner/

Description of approach for:

c) Loading estimation

- **Loadest data requirements**
  - Mean daily* discharge
  - Paired concentration data

- **Data processing**
  - Fits regressions of varying complexity
  - Summary statistics provided to assess model fits
  - Provides both parametric and non-parametric estimates (when normality and equal variance assumptions not met)
  - Error estimates provided (*within model fit)

Specified value	Regression model
0	automatically select best model from models 1-9.
1	$a_0 + a_1 \ln Q$
2	$a_0 + a_1 \ln Q + a_2 \ln Q^2$
3	$a_0 + a_1 \ln Q + a_2 dtime$
4	$a_0 + a_1 \ln Q + a_2 \sin(2\pi dtime) + a_3 \cos(2\pi dtime)$
5	$a_0 + a_1 \ln Q + a_2 \ln Q^2 + a_3 dtime$
6	$a_0 + a_1 \ln Q + a_2 \ln Q^2 + a_3 \sin(2\pi dtime) + a_4 \cos(2\pi dtime)$
7	$a_0 + a_1 \ln Q + a_2 \sin(2\pi dtime) + a_3 \cos(2\pi dtime) + a_4 dtime$
8	$a_0 + a_1 \ln Q + a_2 \ln Q^2 + a_3 \sin(2\pi dtime) + a_4 \cos(2\pi dtime) + a_5 dtime$
9	$a_0 + a_1 \ln Q + a_2 \ln Q^2 + a_3 \sin(2\pi dtime) + a_4 \cos(2\pi dtime) + a_5 dtime + a_6 dtime^2$
10	$a_0 + a_1 per + a_2 \ln Q + a_3 \ln Q \, per$
11	$a_0 + a_1 per + a_2 \ln Q + a_3 \ln Q \, per + a_4 \ln Q^2 + a_5 \ln Q^2 \, per$
99	user defined

Rationale for choosing method:

a) Sample collection

- Several years of samples already collected
- Sample collection straightforward and minimal processing of samples (no compositing etc.)
- Discharge data not required at time of sampling (qualitative assessment of stream level sufficient)
- Retain granularity of original data
  - Compositing would lose original samples
  - Loss of single sample in a hydrograph less critical

Rationale for choosing method:

b) Loading estimation

- Availability of data
- Many events missed but wanted seasonal and annual loads
- Want to estimate concentrations at base flow

Other approaches considered:

- Beale Ratio
  - Assumes linear relationship between variables
  - Best with random sampling

What did the results look like?

- Loadest/Loadrunner output several files:
  - Model file
    - Selected model, data issues, CI, std. error
    - Recommended estimation method (MLE, AMLE, LAD)
  - Files with annual, monthly, and daily estimates of
    - Load
    - Time-weighted mean conc. (TWMC)
    - Error estimates
  - Residual and homogeneity of variance analyses done graphically using Excel templates

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Model and Data Issues

Model #	AIC	SPPC
1	2.024	-65.912
2	2.057	-68.000
3	2.021	-66.883
4	1.703	-57.917
5	2.054	-68.983
6	1.696	-58.792
7	1.728	-59.799
8	1.726	-60.792
9	1.755	-62.79

Akaike Information Criterion (AIC) and Schwarz Posterior Probability

Criteria (SPPC) did not select same best fit model. Model # 6

selected on basis of AIC. (Model # 4 would have been selected based on SPPC)

Selected Model:

Ln(Load) = a0 + a1 LnQ + a2 LnQ^2 + a3 Sin(2 pi dtime) + a4 Cos(2 pi dtime)

What did the results look like?

Some problems:

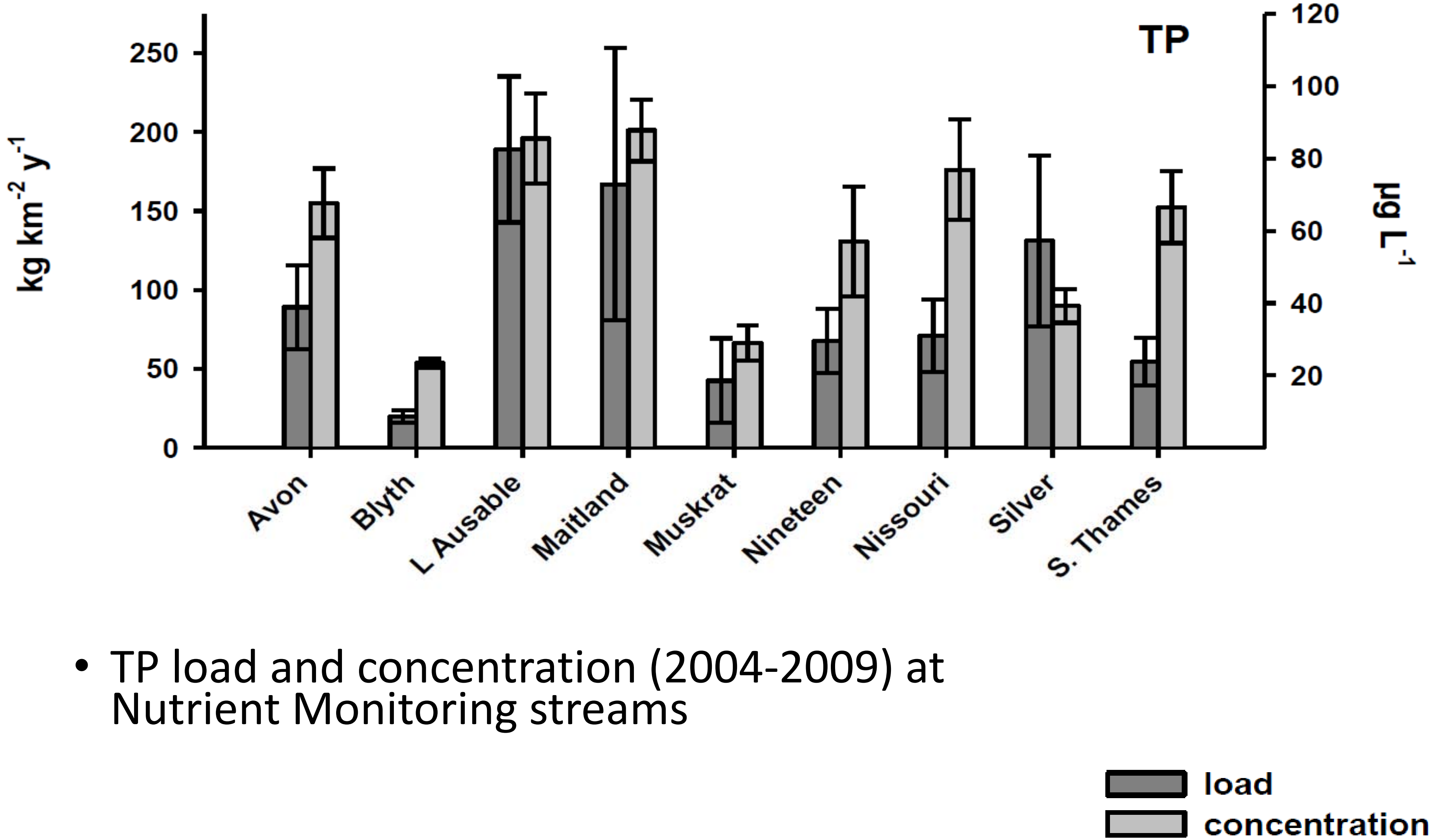
1) Gauging data not sufficient to generate reliable rating curves

   → Generated empirical relationship with downstream WSC gauge where possible (10 of 15 sites)

2) 12-14 samples per stream per year not enough data to generate annual loading model

   → rolled up 5y of samples to generate a single loading model

What did the results look like?

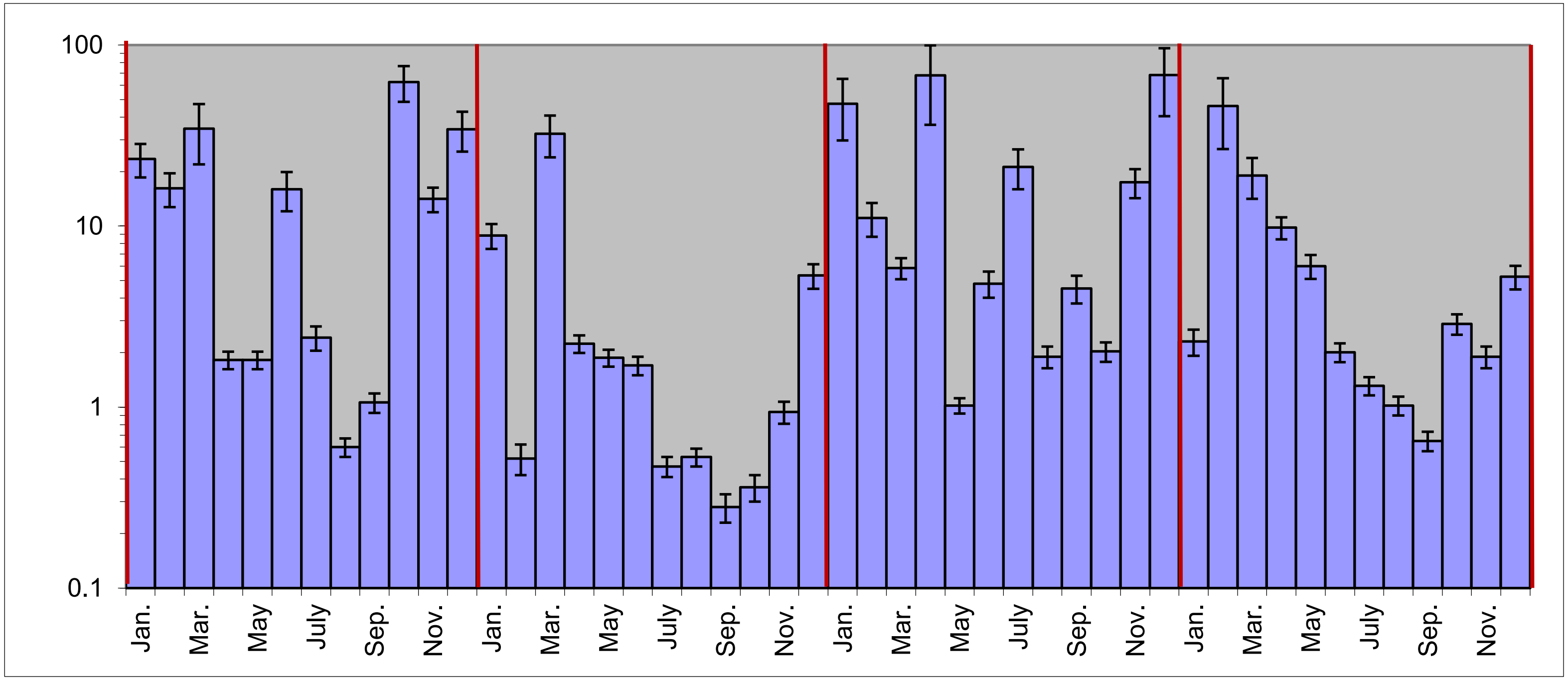


- TP load and concentration (2004-2009) at Nutrient Monitoring streams

What did the results look like?

Another ‘problem’:

- Monthly variability in loading/concentration high at any particular stream

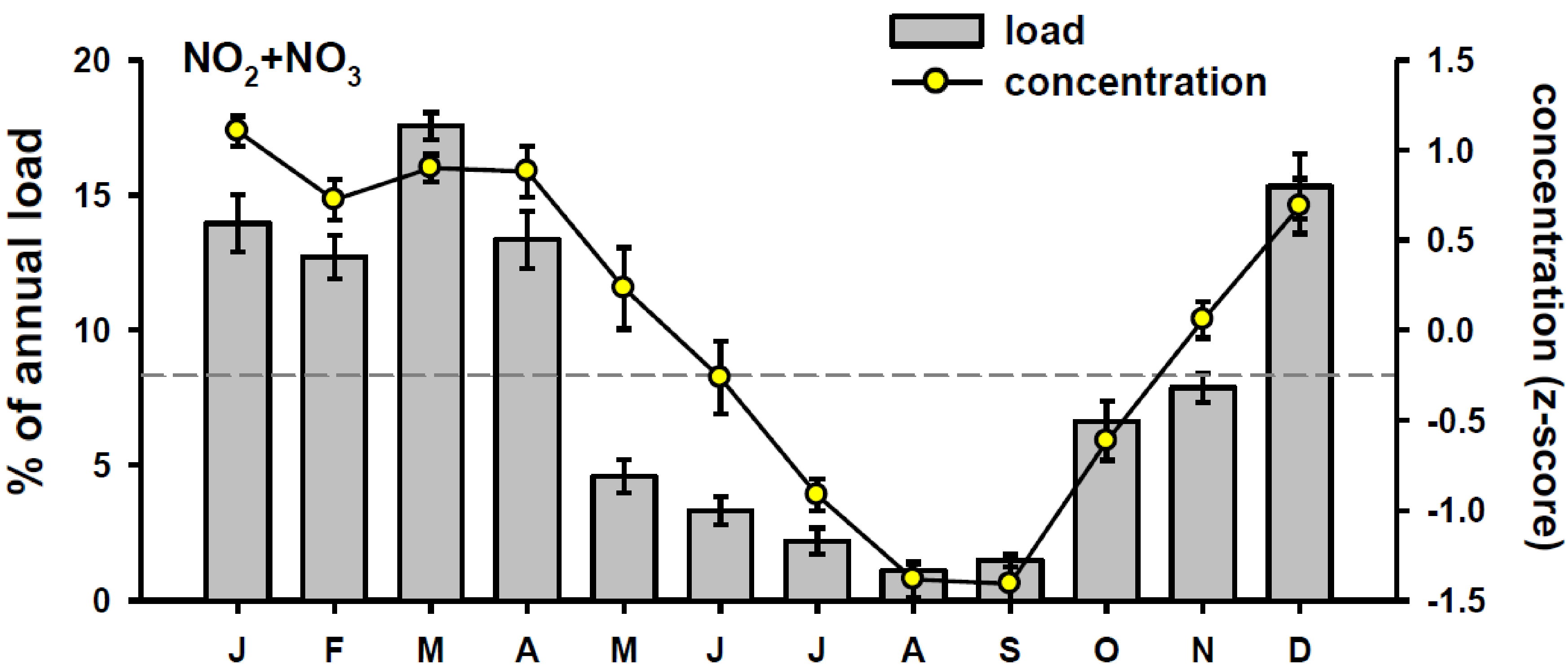


Monthly TP loading at Avon River at Stratford

What did the results look like?

→Rolled up all streams into a, ‘meta-stream’

- Expressed loads as monthly % of annual load
- Normalised concentration across streams (z-score)



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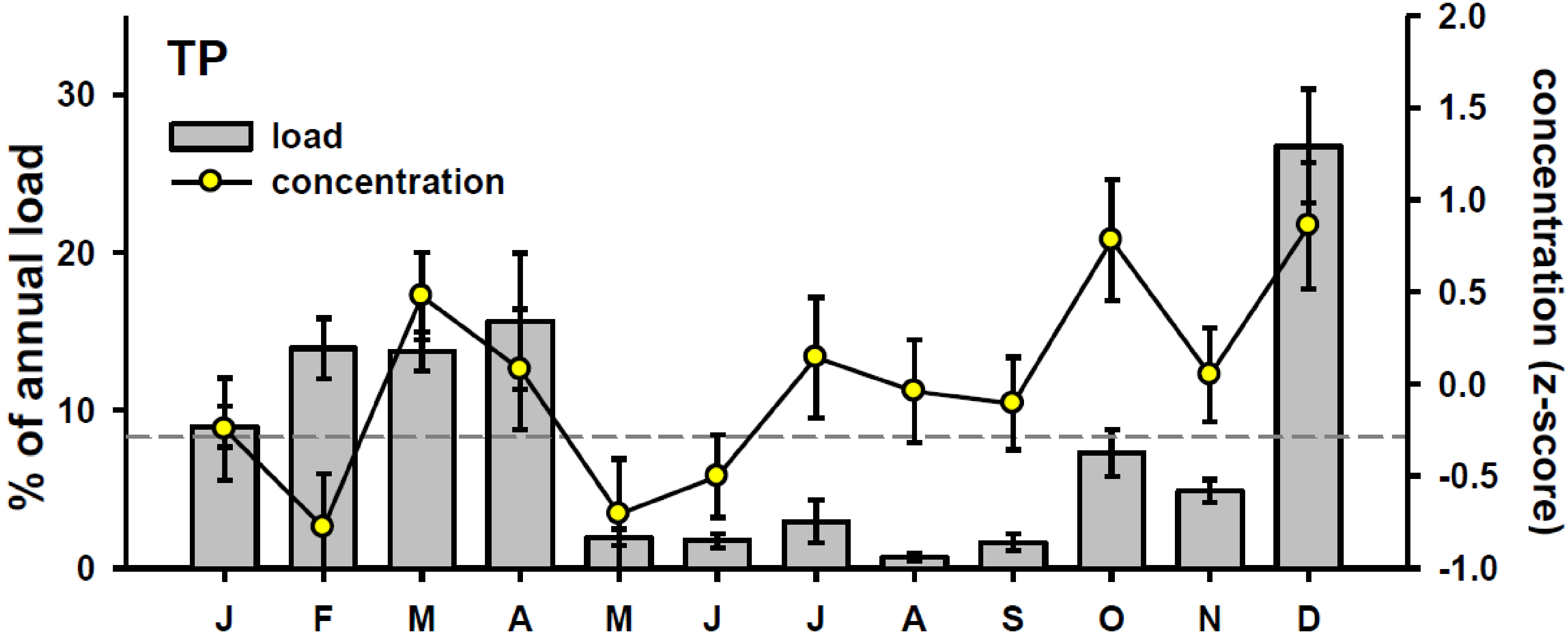

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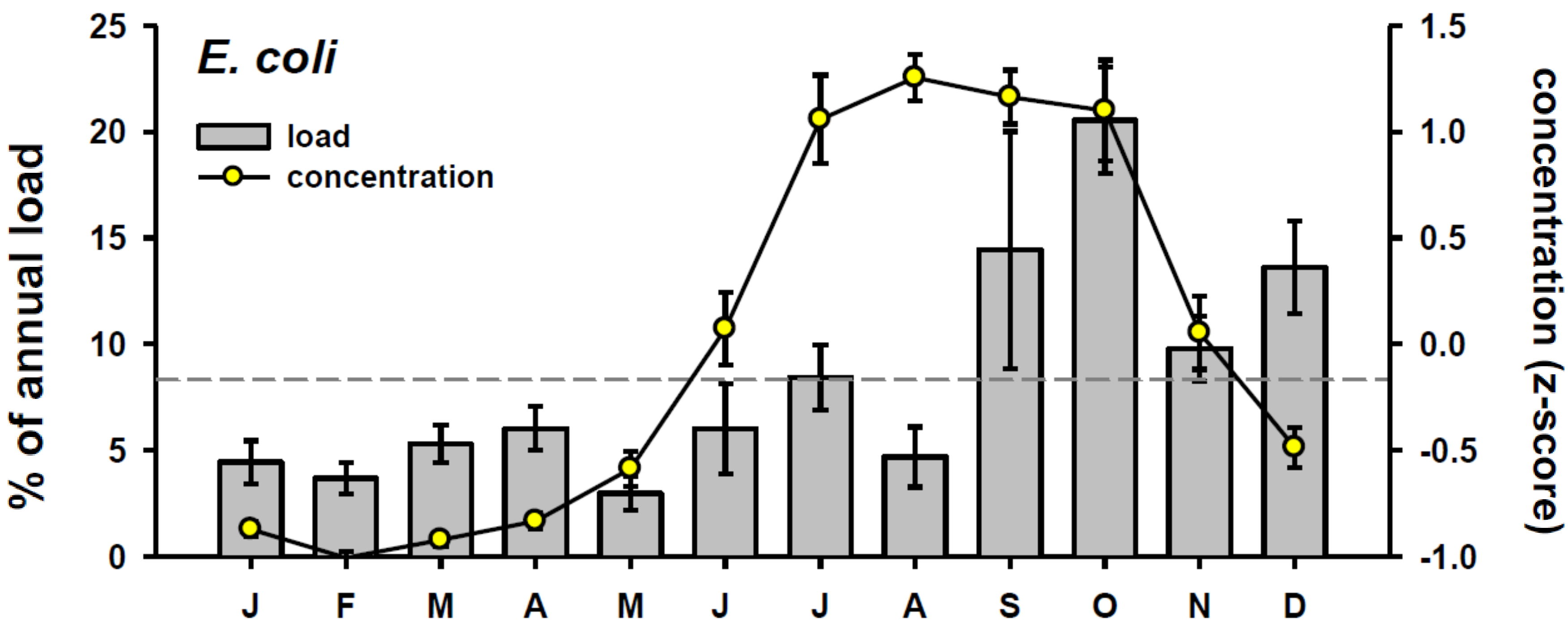

How were the results compared to other studies?

Comparison to PLUARG loading estimates:

	NO_2+NO_3 (10^3 kg km^{-2} y^{-1})	TP (kg km^{-2} y^{-1})	SS (10^3 kg km^{-2} y^{-1})
Little Ausable:			
1975 - 76	2.6	77	20
2006 - 09 (grab)	2.5	189	52
Nissouri:			
1975 - 76	2.3	81	27
2006 - 09 (grab)	3.8	71	13

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2006 - 09 (grab)	3.8	71	13
2006 - 09 (ISCO)	3.9	149	28

Expertise and effort required to collect data and obtain results

Data collection:

- Water sample collection straightforward
  - Depth or horizontally-integrated samples improve estimates*
- No compositing of samples (but requires more samples)
- All events don’t have to be captured
- ‘event’ doesn’t have to be defined
- Reliable discharge information important*
- Requires sampling through all flow regimes (especially high flows)*

Expertise and effort required to collect data and obtain results

Obtaining results:

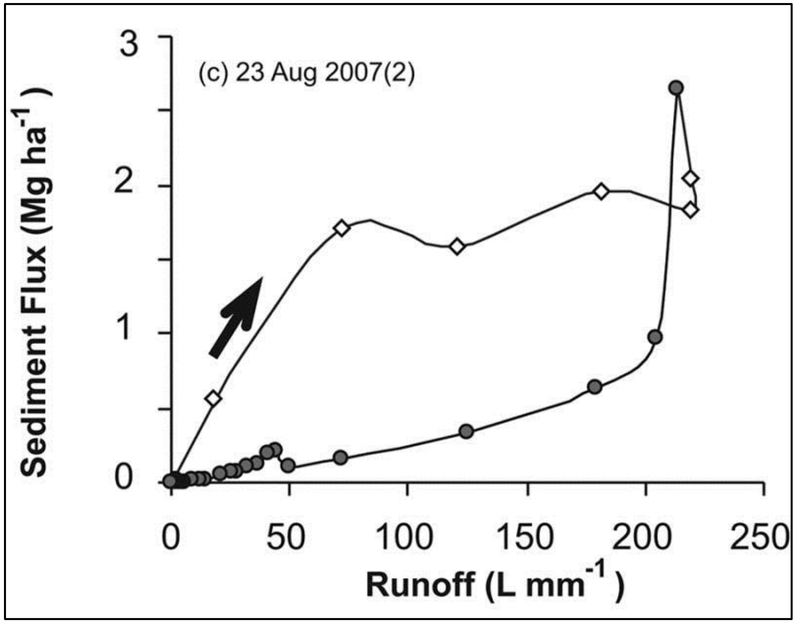
- Loadest and LoadRunner learning curve
  - Massaging of files can be tedious (but could be automated)
  - Assessment of data quality requires some stats knowledge
- Designed for large streams/rivers
  - Tweaking files to, ‘trick’ Loadest adds some complication (could be done by adjusting program code… any takers?)
- Once data are processed, easy to generate:
  - Loading for any period of interest (annual, seasonal)
  - Time-weighted mean concentrations
  - Combine with numerical base flow separation to determine proportion of load in base vs. event flows, base flow enrichment etc.

Project outcomes

- Detection of WQ response to potential land use change (e.g. from NMA)
  - Difficult with available data
- Improved understanding of:
  - water quality in ag streams
  - seasonal timing of loads and concentrations
  - preliminary comparison to past loading estimates
    - TP loadings still likely underestimates
    - Inter annual comparisons of loading comes with caveats
- Informing future studies (e.g. MWNS)

Challenges and limitations

- Need WQ samples throughout flow regime (esp. high flows)*
- Discharge info critical*
- Require adequate data to generate regression model
  - Separate models needed for comparing periods where Q vs. conc. relationship may have changed
- Hysteresis not accounted*
  - Covariate (e.g. turbidity) could improve relationship



Sidle and Ziegler JEQ 2009

Knowing what you know now, what would you have done differently?

- Ensure robust gauging data*
  - Site selection
  - Adequate development and maintenance of rating curves
  - Co-locate with existing gauge
- Use automated samplers to collect through hydrograph*
- Preliminary work to assess required sample frequency
- Explore other proxies to improve load estimates (e.g. turbidity)
- Modify/use program that accepts frequent (e.g. hourly) data
- Stayed in limnology ☺

Thank you!

Acknowledgements:

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- Ausable Bayfield, Grand River, Long Point Region, Maitland Valley, Saugeen Valley, Upper Thames River

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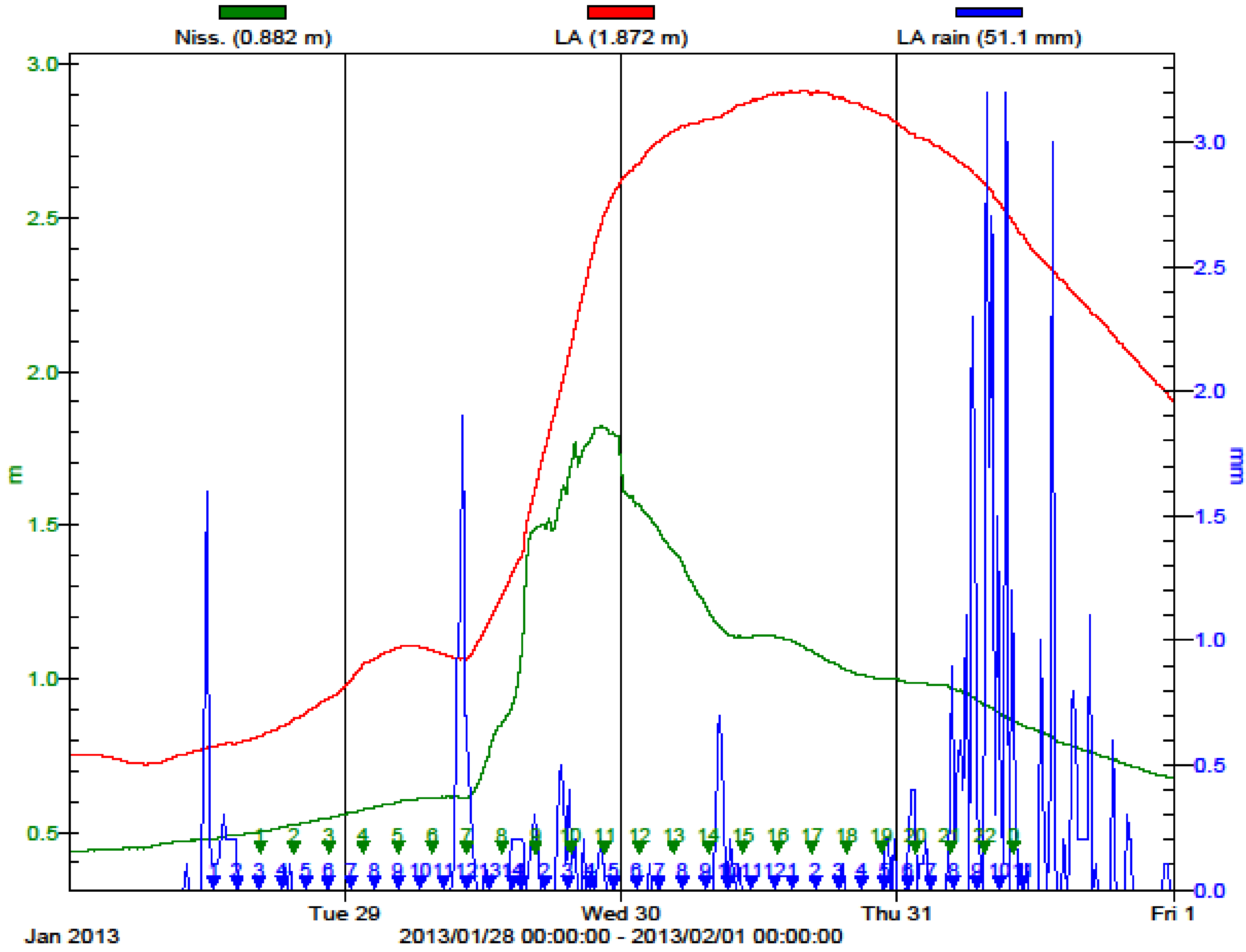
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