Tools for Phosphorus Management in the Bay of Quinte

Dr. Ken Minns and Jim Moore
Fisheries and Oceans Canada, Burlington
JEMSys, Dundas

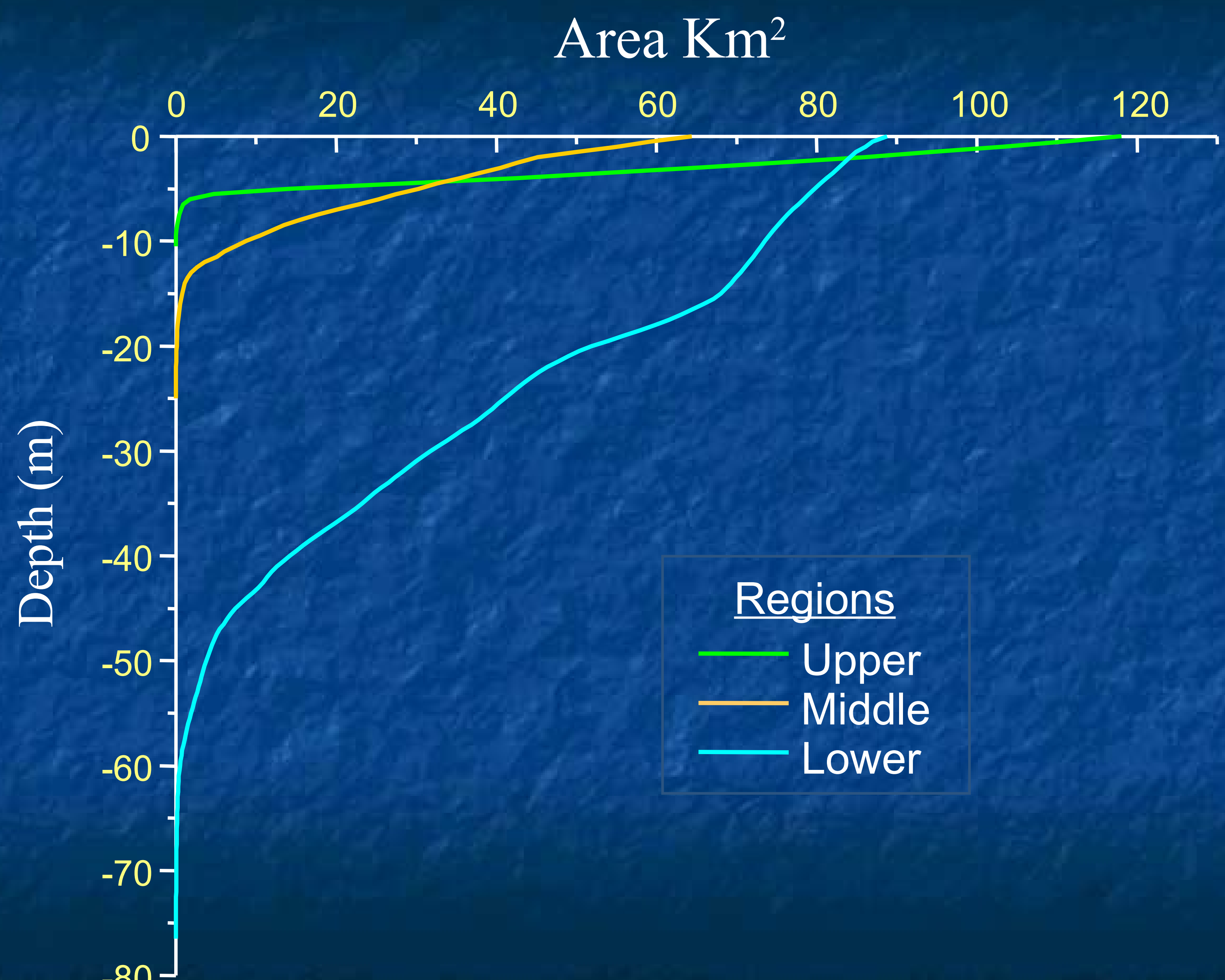
Work-Plan

- Steps
  - ➔ Nutrient Budgets 1972-2001
  - ➔ P Modelling
  - ➔ Workshop to present and review results
  - ➔ Feedback aids finalization of MS Rpts
- Products
  - ➔ MS Rpt Nutrient Budgets 1972-2001(✓)
  - ➔ Access DB of all data and programming (✓)
  - ➔ MS Rpt P Modelling (✓)
  - ➔ Stella Software (✓)
  - ➔ Temporary FTP site with all materials

Bay of Quinte

- Bay is a flooded river valley with a very large drainage area supplying runoff
- Deforestation in the 19^{th} century pre-conditioned the Bay for eutrophication by adding nutrients and fine sediments
- Urban growth near the Bay coupled with collection of sewage waste led to eutrophication from the 1930s on, peaking in the late 1960s/ early 1970s (P detergents added to the problem)

Hypsometric Relationships for the Bay of Quinte



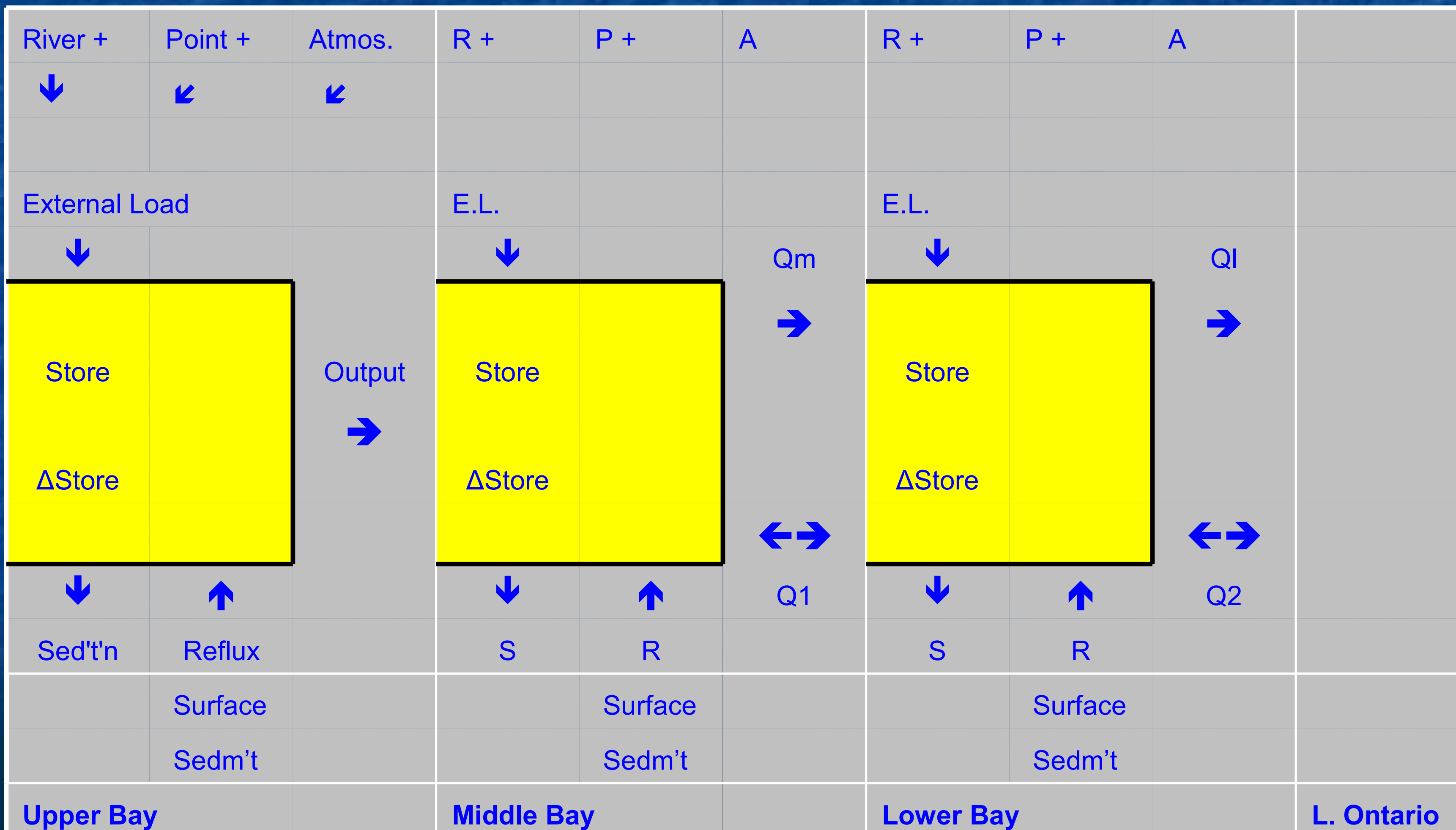
Tools

- Nutrient Budgets
  - Analysis of inputs, outputs, retention
  - Relative importance of sources
  - Understanding processes
  - Input data for model development and testing
- Models
  - Calibration with past observed conditions
  - Prediction of alternate future conditions
  - Assessment of management options
  - Confirmation of understanding

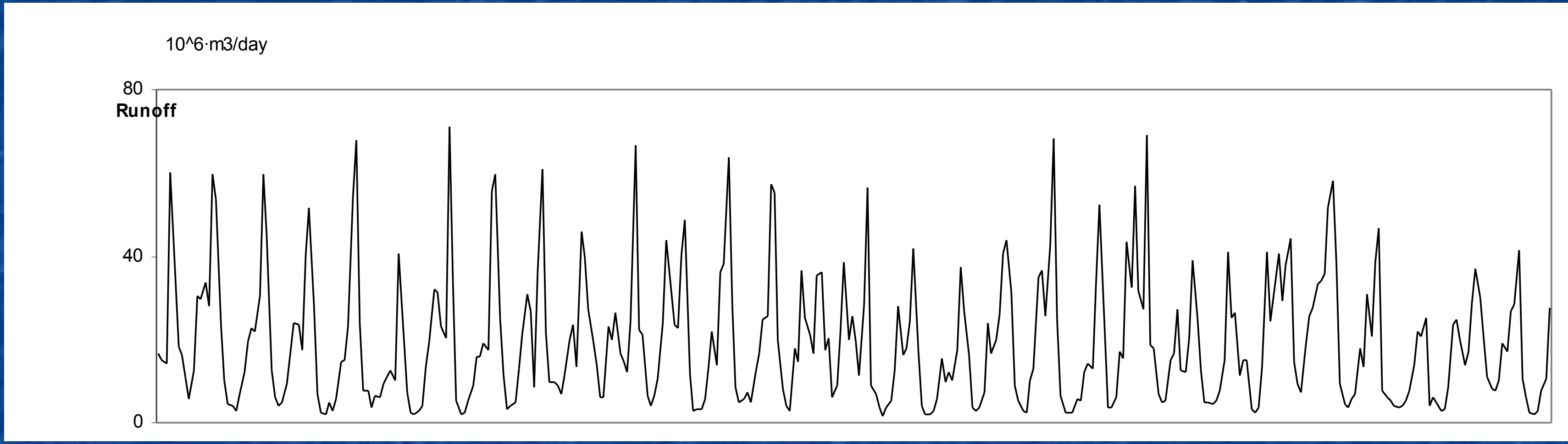
Nutrient Budgets 1972-2001

- Conceptual framework for analyses
- Water budgets
- Chemical budgets
- River loading
- Point-source loading
- Analyses

Budget Framework



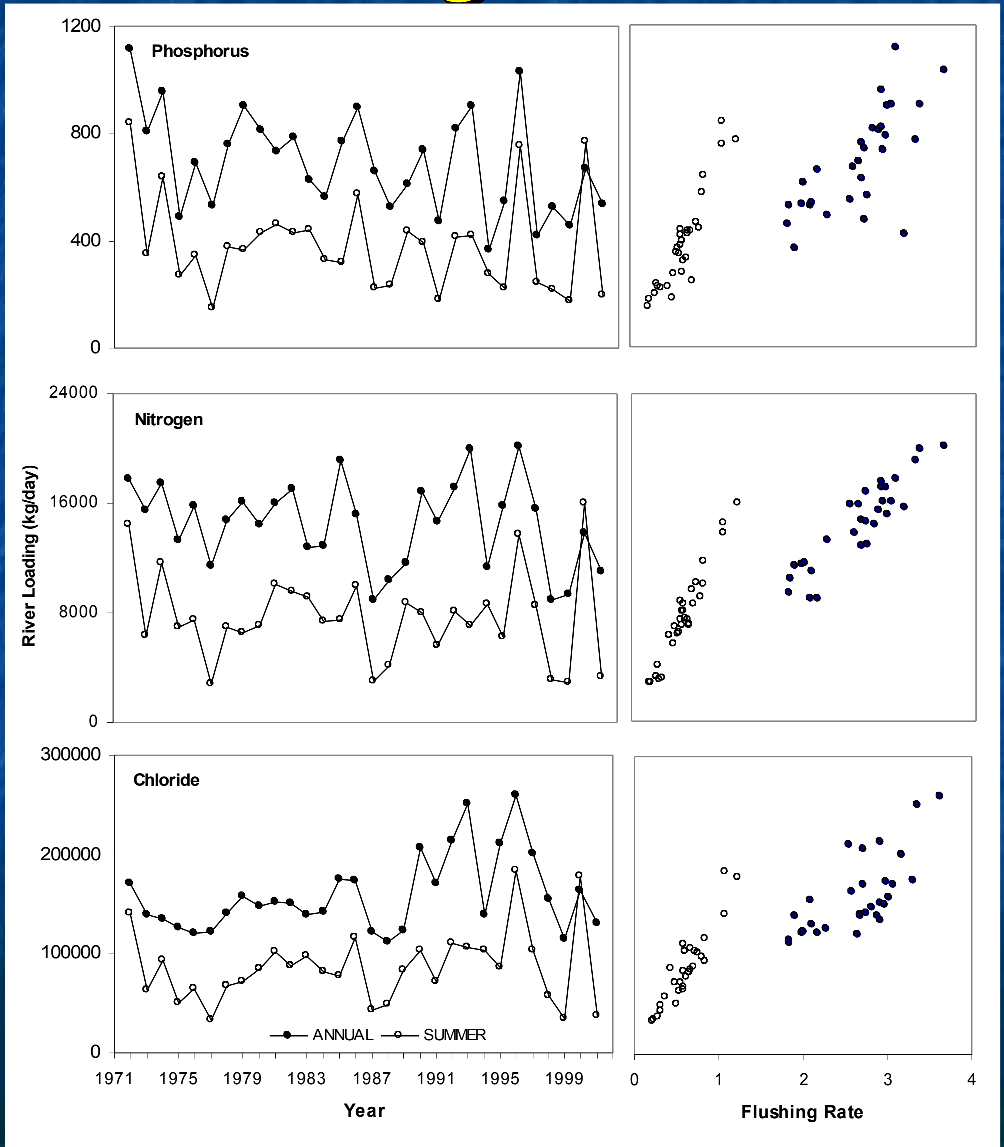
Water Budget



- River flow is the dominant feature in the upper Bay, especially from the Trent River
- Exchanges flows between Lake Ontario and the lower/middle Bay compete with upper Bay outflow, especially in summer when thermally stratified

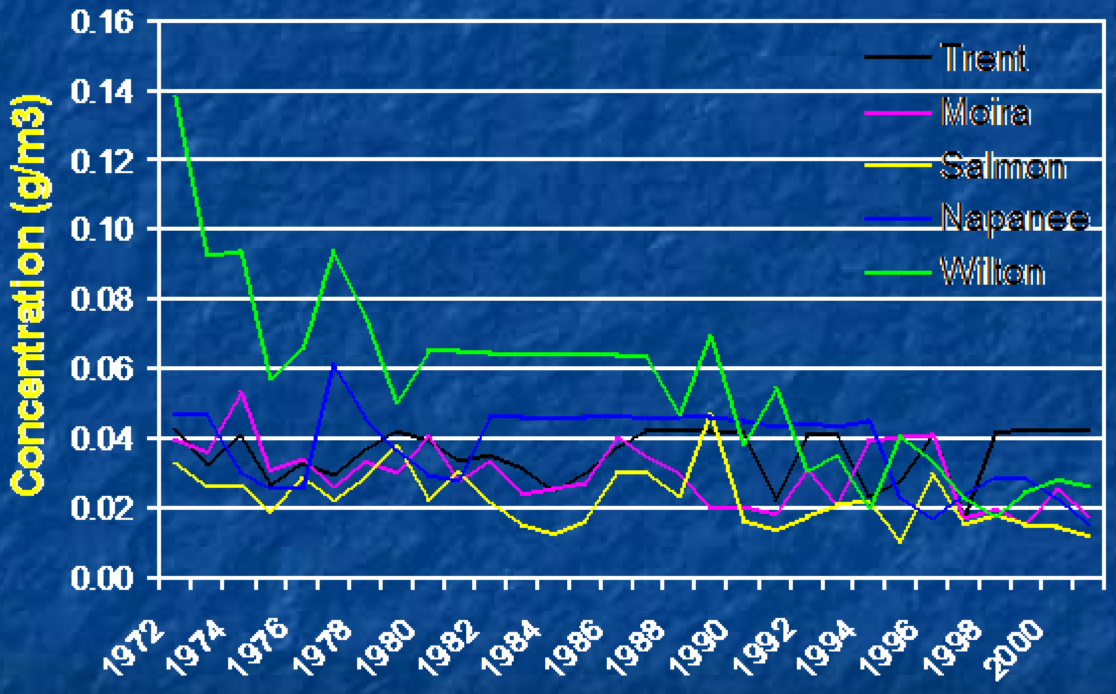
River Loading

- Loads strongly related to river flows and hence Bay flushing
- P down somewhat
- N unchanged
- Cl higher



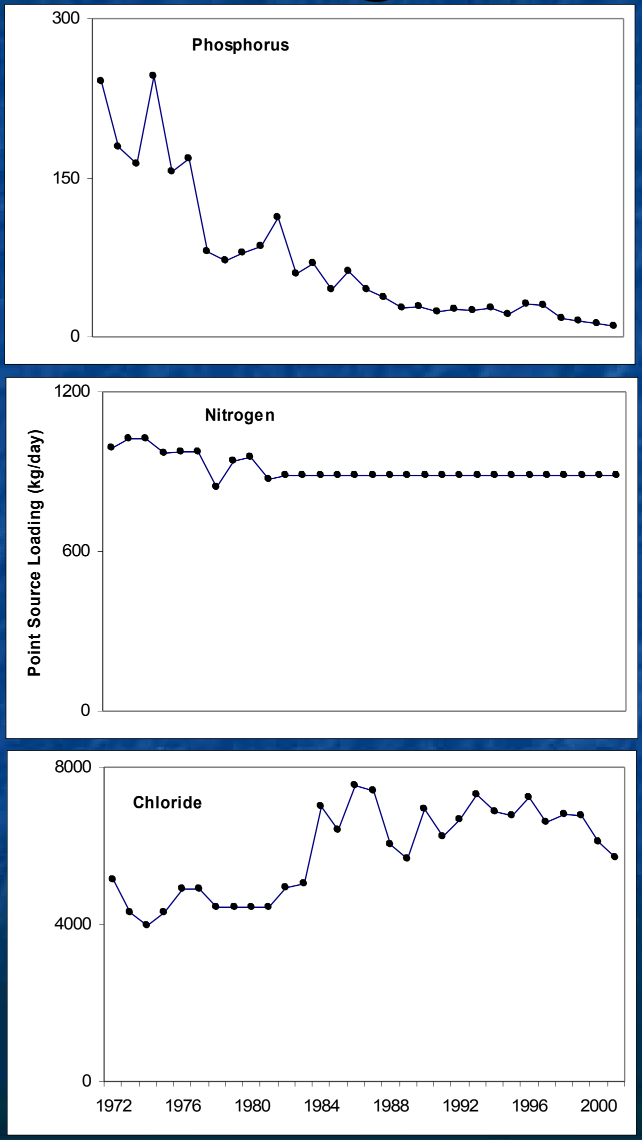
Tributary [Phosphorus]

- Biggest decline in Wilton creek
- Small declines in medium-sized rivers
- No change in Trent R., the dominant source for the upper Bay

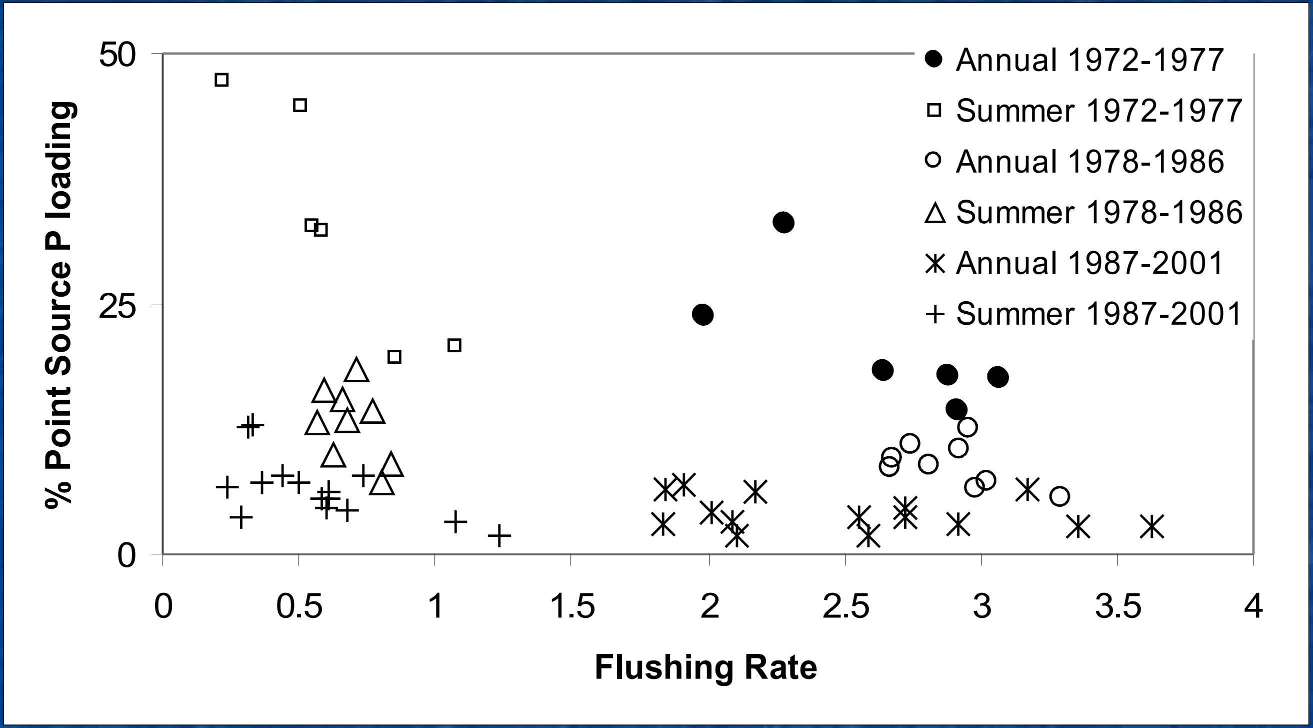


Point-Source Loadings

- Shows major decline in phosphorus
- Nitrogen loads fairly steady but poorly monitored
- Chloride loads have increased

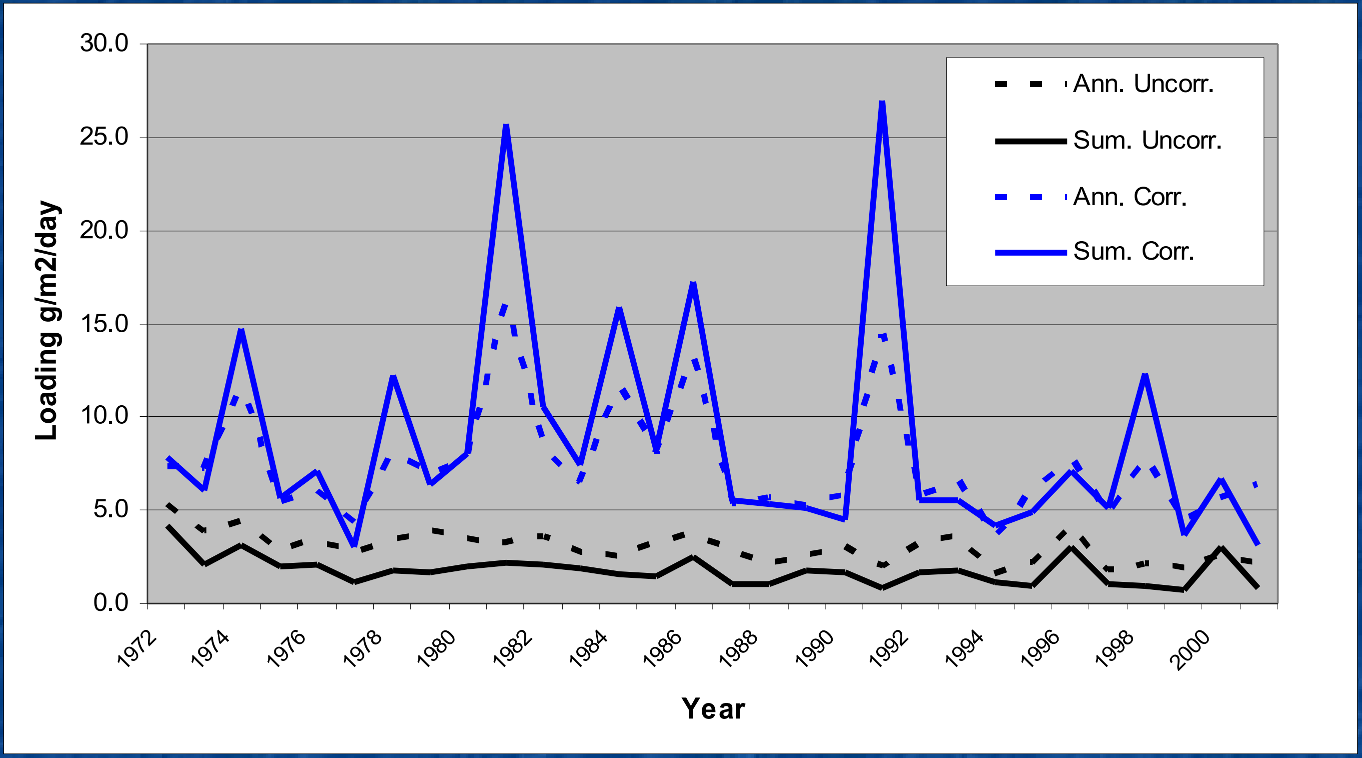


Point-source P vs. Flushing



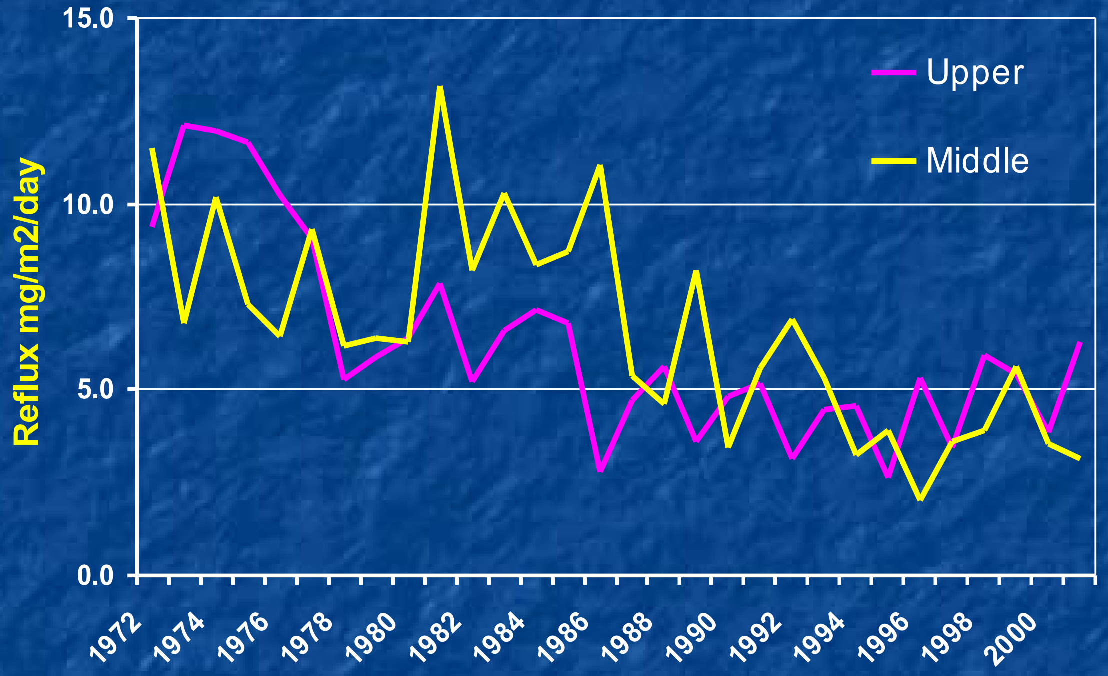
- Point-source contribution higher for low flushing
- Lower flushing rates more prevalent now

Whole-Bay P Budgets



- Chloride budgets are used to estimate exchange flows
- Exchange flows with Lake Ontario dominate in the middle and lower Bay sections

Summer Sediment P Reflux

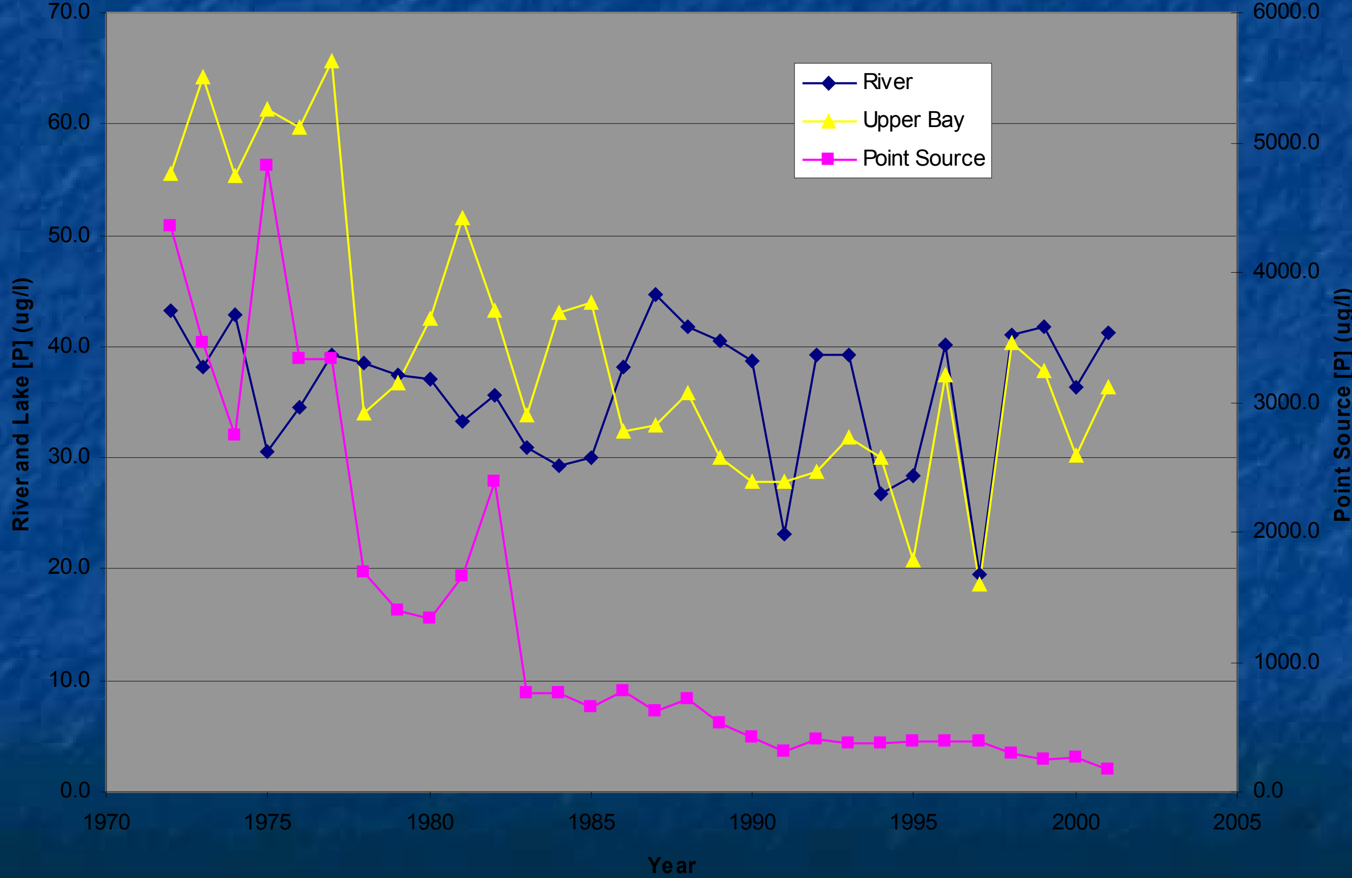


- Estimated reflux rates declined until mid-1990s
- Middle Bay response lagged behind Upper Bay as expected with slow turnover of surface sediments and movement down through the Bay and out over time

Implications

- Point-source P control has been a major success
- Tributary inputs are dominated by Trent River so WQ improvements in smaller watersheds have little impact on the Bay though clearly beneficial within those watersheds
- Water supply to Bay has declined, possibly due to climate change; Water levels are also down
- Confirms earlier finding that upper Bay [P] results from the mixing of high volume tributary flows with low [P] and low volume point-source flows with high [P]
- Low river flows in the summer allow point source inputs to increase Bay [P], ie. eutrophication

Upper Bay Summer [P]



Future Management Issues

- Safe-guarding this success will require eternal vigilance
- Future area human population growth will increase STP flows and hence point-source loads (unless effluent [P]s are further reduced with new technologies or improved efficacy)
- Lower runoff (and potentially lower water levels), likely related to climate change, will increase the impact of point-source loads, especially in summer

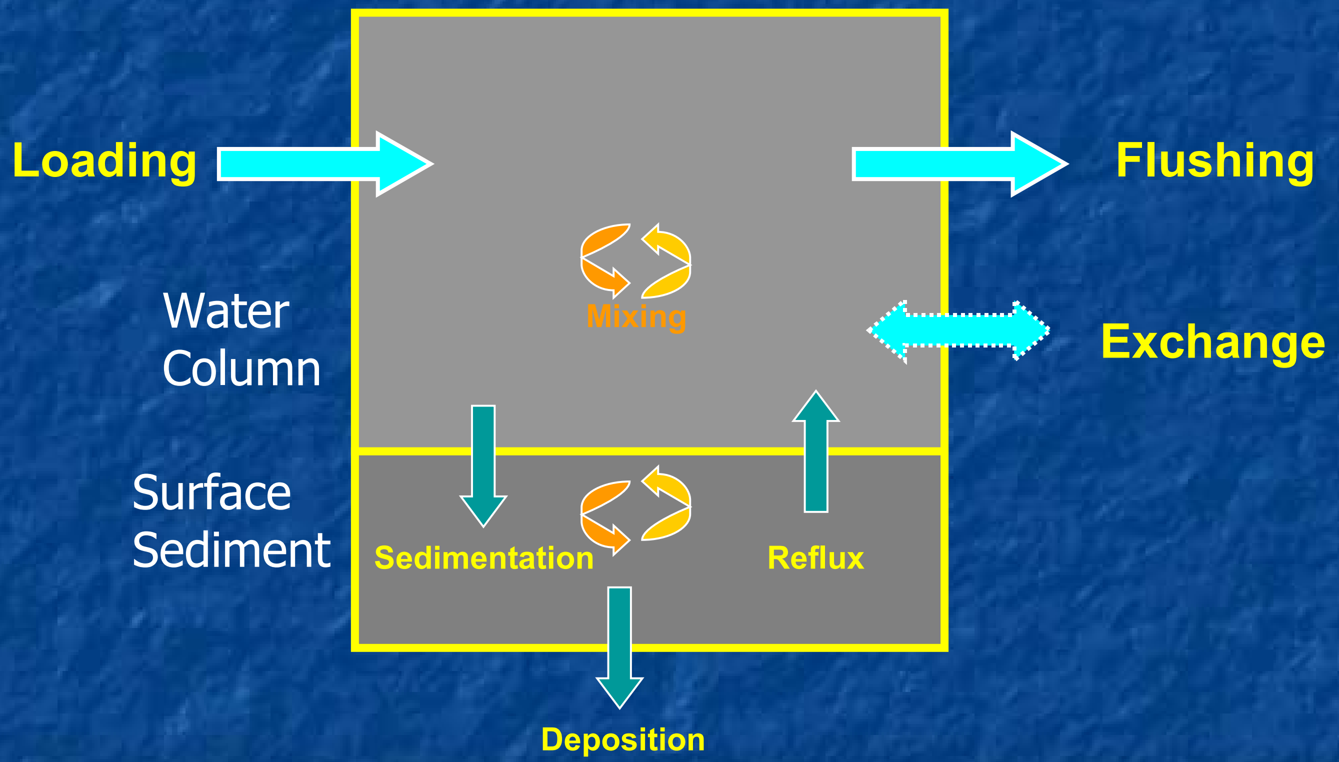
Monitoring Needs

- Enhance STP monitoring with more coverage of N and Cl
- Ensure 16-20 samples per year near mouths of major tributaries
- Maintain weekly water intake monitoring (Belleville, Kingston) and enhance elsewhere if possible (Picton, Lennox,?) (Temperature daily, P N Cl weekly)
- Maintain biweekly in-Bay sampling (May to Oct) at main stations and enhance with section boundary measures every 3 to 5 years
- Ensure tributary flows and water level monitoring is sustained

Phosphorus Modelling

- Model Concept (Minns 1986)
- Modelling Approach
- Implementation
- Scenarios
- Overview of Simulation Results
- Conclusions and Recommendations

P Model



- dPw = Loading-Sedimentation-Flushing+Reflux (+/- Exchange)
- dPs = Sedimentation-Reflux- Deposition

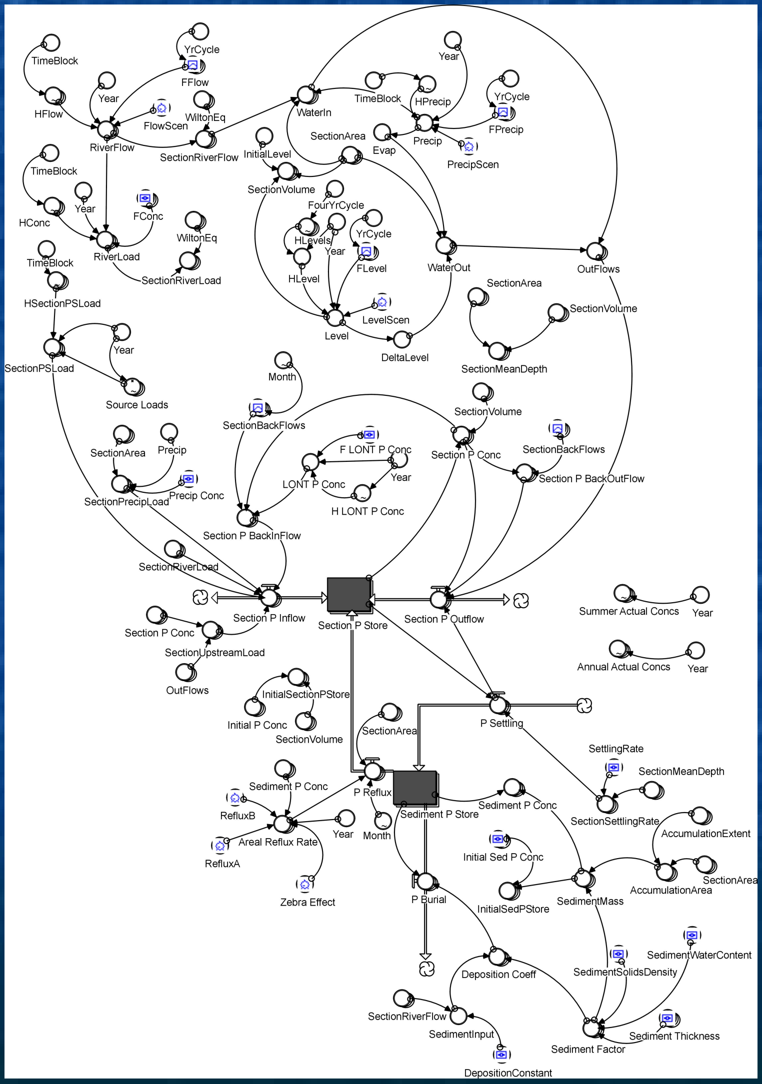
P Model Components

- Inputs (measured)
  - ➔ Loading, Flushing, Exchange
- Estimated (literature and Quinte studies)
  - ➔ Sedimentation, Deposition
- Modelled
  - ➔ Reflux
    - Minns (1986) assumed fixed proportion (γ) of sediment pool
    - Here rate function of [P] surface sediment as it gave a better fit to observations (1972-2001)

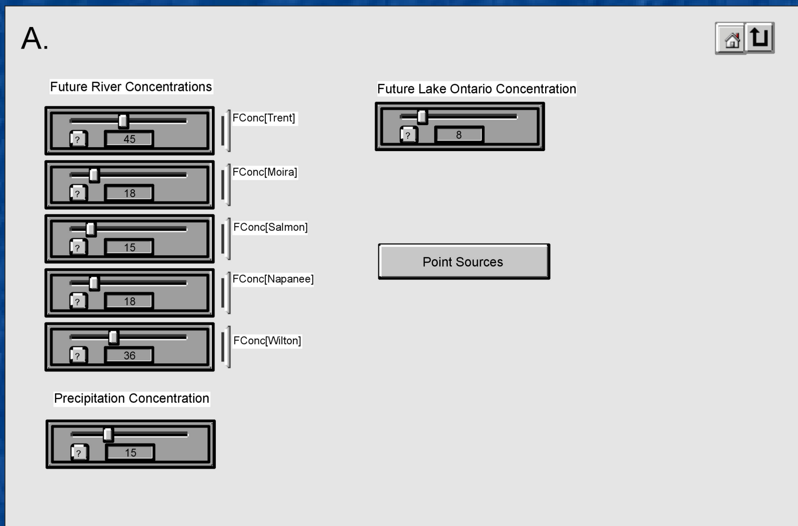
Implementation (Overview)

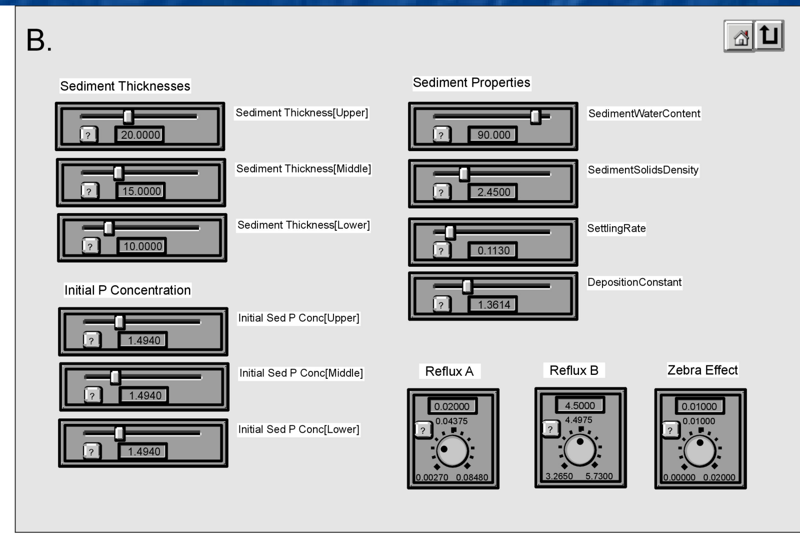
- Programmed in STELLA with EXCEL for scenario input
  - Model documentation built into program
  - User can change parameter inputs
- Statistical representation for 1972-2001
- Selection of “future” hydrology based on percentiles of past flows
- Future point source loading patterns

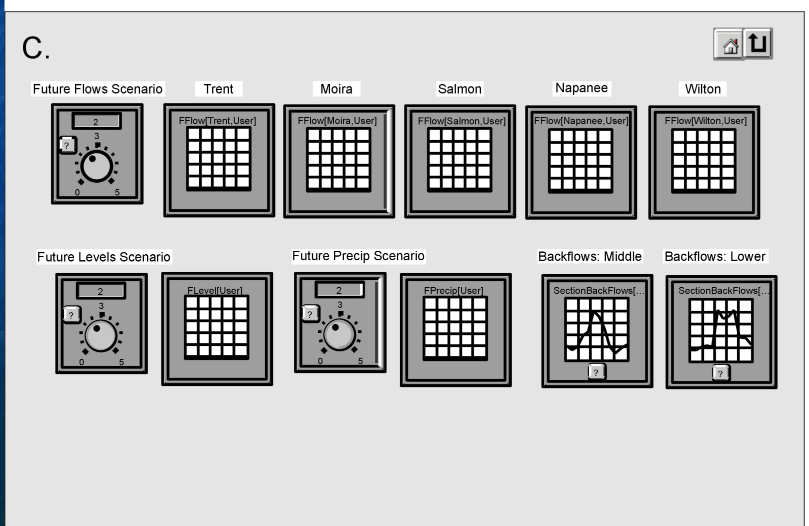
Quinte P Stella Diagram



Quinte P Control Modules







D.

Make point source parameter changes in the associated workbook "FuturePointSources.xls". This may be done in one of two ways:

1. Change STP final effluent concentrations, design capacities, or percent of capacity directly in one or more of the sheets called "Upper STPs", "Middle STPs", or "Lower STPs".

2. In the sheet "Section Loads", locate and click the "Show Controller" button to bring up a graphical interface for making the same parameter value changes.

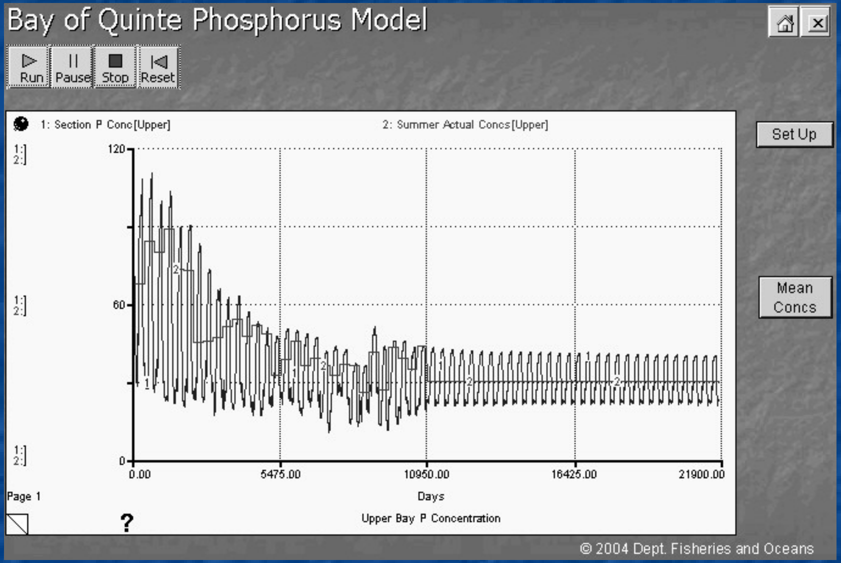
Note: The workbook must be open prior to starting the model runtime and must remain open while the model is being used.

Implementation (Details)

- Daily time step
- Input data smoothed series from budget analyses
- Graphical displays cover the past,1972-2001, and the predicted future,2002-2031
- Annual and summer mean tabular summaries

Quinte P Input/Output

- Daily time step
- Annual & Summer Means
- Save output to files



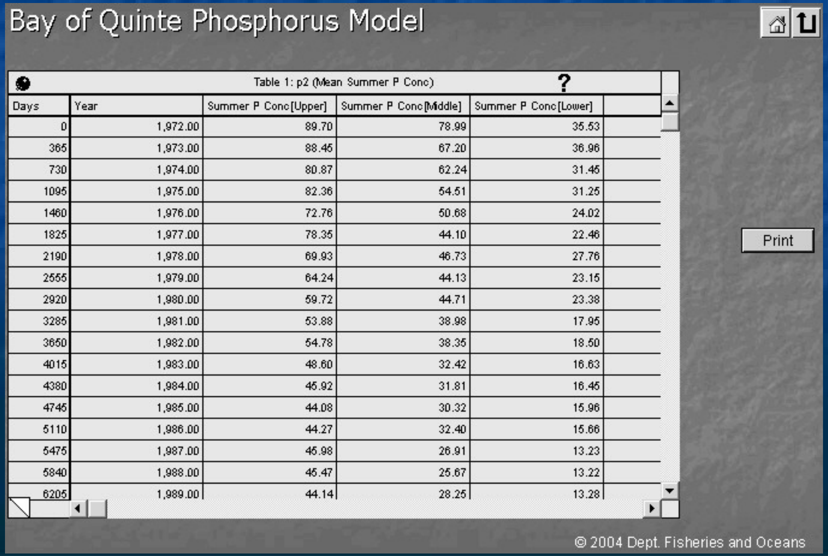
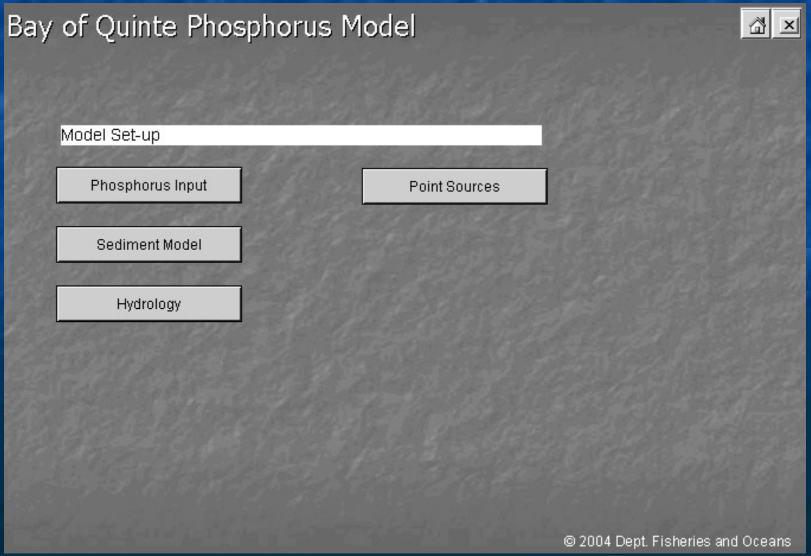


Table 1: p2 (Mean Summer P Conc)

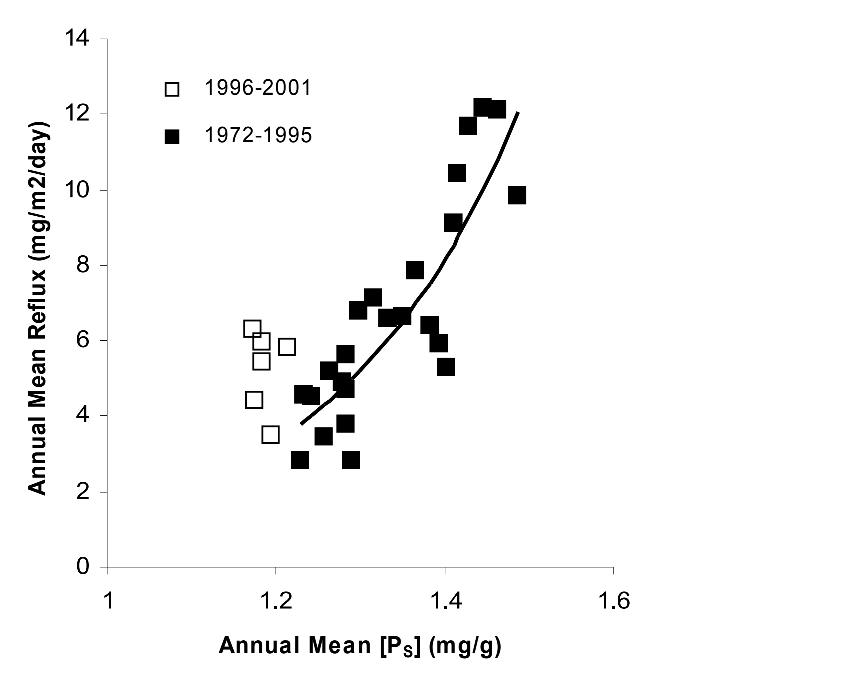
Days	Year	Summer P Conc[Upper]	Summer P Conc[Middle]	Summer P Conc[Lower]
0	1,972.00	89.70	78.99	35.53
365	1,973.00	88.45	67.20	36.96
730	1,974.00	80.87	62.24	31.45
1095	1,975.00	82.36	54.51	31.25
1460	1,976.00	72.76	50.68	24.02
1825	1,977.00	78.35	44.10	22.46
2190	1,978.00	69.93	46.73	27.76
2555	1,979.00	64.24	44.13	23.15
2920	1,980.00	59.72	44.71	23.38
3285	1,981.00	53.88	38.98	17.95
3650	1,982.00	54.78	38.35	18.50
4015	1,983.00	48.60	32.42	16.63
4380	1,984.00	45.92	31.81	16.45
4745	1,985.00	44.08	30.32	15.96
5110	1,986.00	44.27	32.40	15.66
5475	1,987.00	45.98	26.91	13.23
5840	1,988.00	45.47	25.67	13.22
6205	1,989.00	44.14	28.25	13.28



Implementation (Calibration)

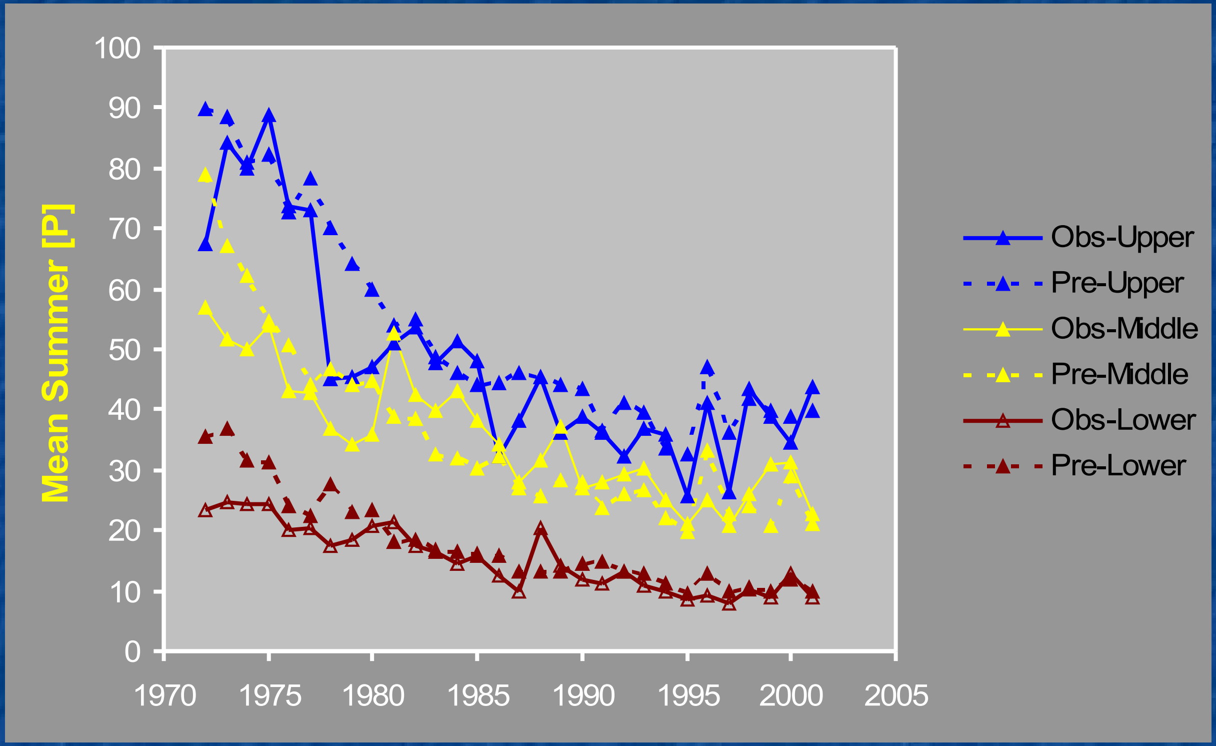
- Reflux implemented as function of surface sediment concentration using estimated reflux rates and assumed initial sediment P pool in 1972; ZM enter system in 1995
- Sensitivity analysis to maximize reflux parameters using mean summer observed vs. predicted water concentrations as test
- Base model run with best available reflux parameter estimates

Sediment P Reflux Model



- Sediment P budget computed using 1972-2001analyses
- R=.015e(4.498*[Ps])
- Note “ZM” effect after 1995; net effect in P budget

Base Model Fit 1972-2001

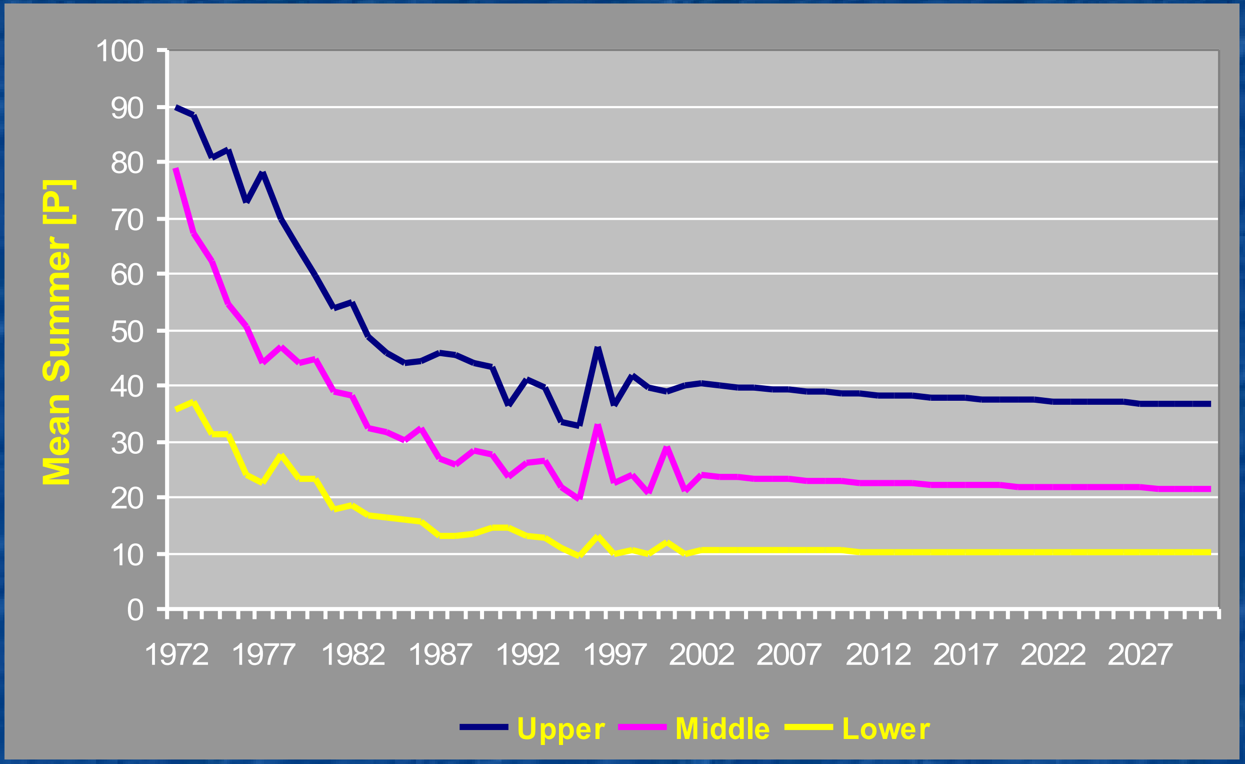


- Good agreement in all three sections
- Similar parameter values throughout

Scenarios

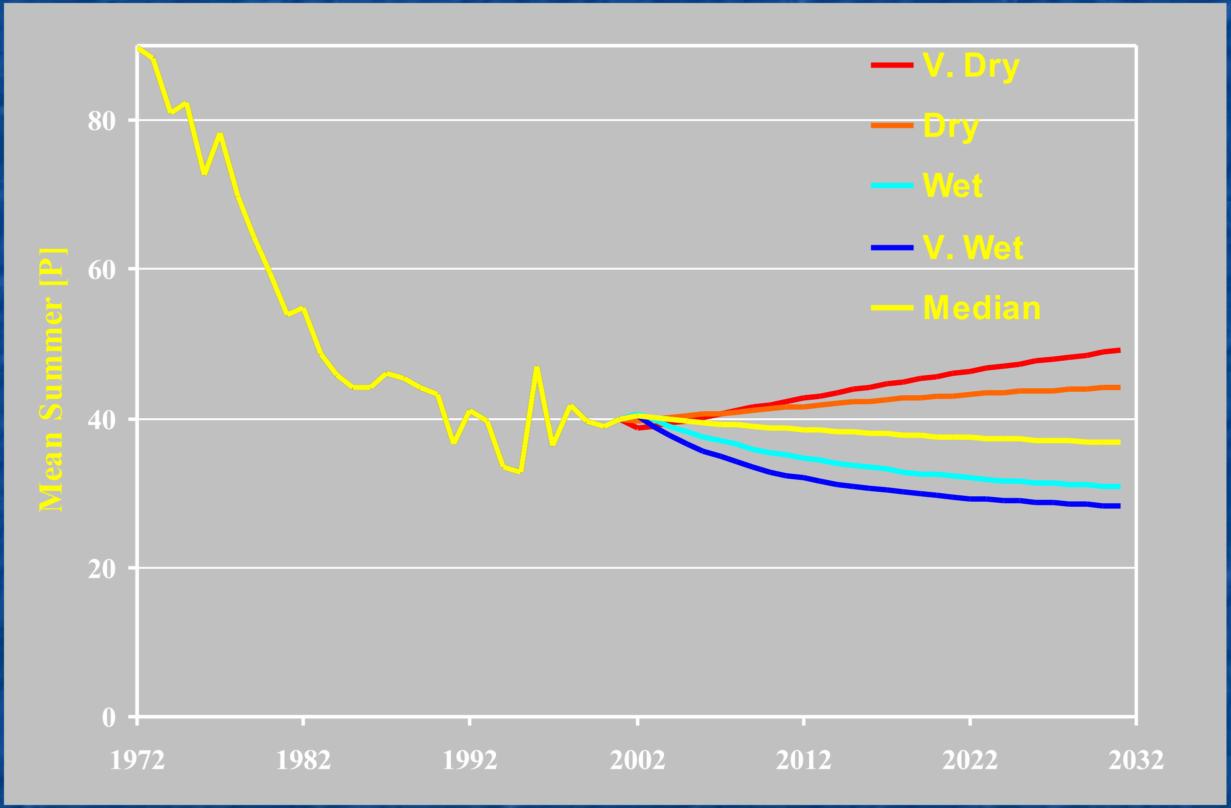
- Baseline 1972-2001 with 2001 rates persisting from 2002 to 2031 with median flows
- Hydrology effects
- “Zebra mussel” effects
- Current STP capacities
- Point vs. diffuse loading

Baseline 1972-2031



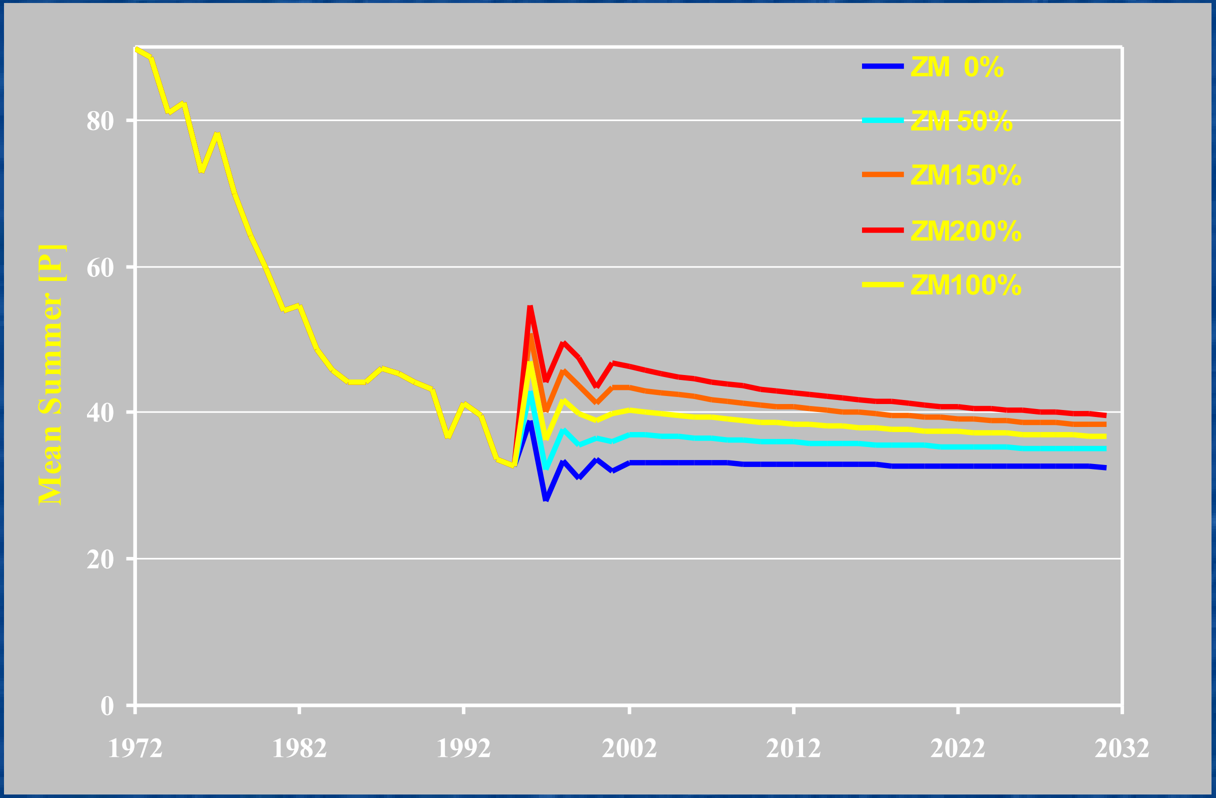
- Assumed point sources at 2001 level for 2002-31
- Flows at 50th percentile of 1972-2001 for 2002-2031

Hydrology Effects



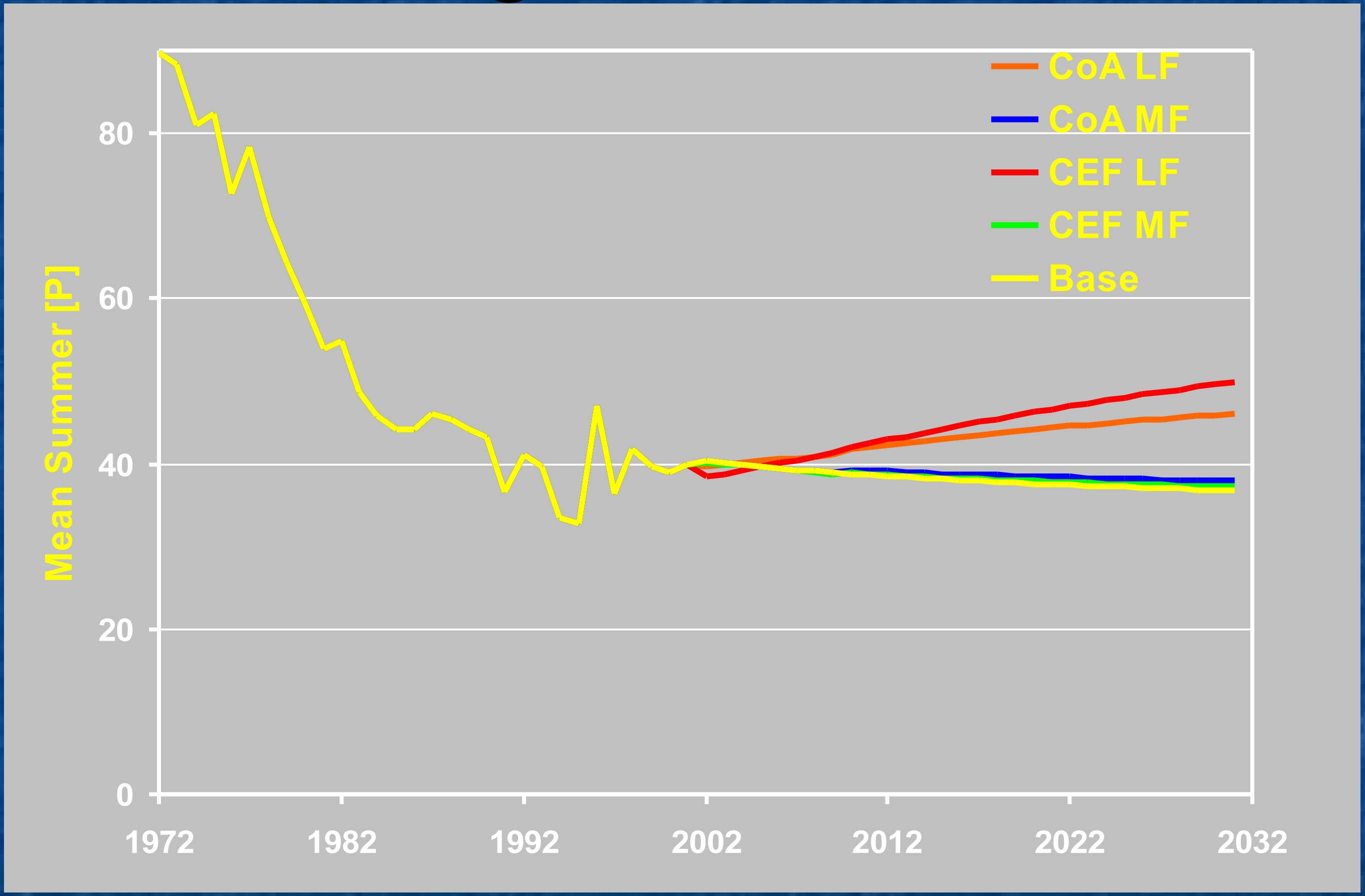
- 10, 25, 50, 75, 90 percentiles of 1972-2001 flows
- Lower flows are more prevalent in recent years

"Zebra Mussel" Effects



- Percentages of median effect 1996-2001 on reflux
- ZM rose 1994 to 2000, Future trajectory unknown

Existing STP Effects



- Using CoA or Current STP efficiencies, [P]^ at LF (25%)
- Flows have been lower in the last 15 years –Climate Change

Upper Bay Load Limit

Scenario		Upper Bay	Mean Summer [P] in 2031		% Range
Flow	STP [P] µg.L^{-1}	Load kg.d^{-1}	Low Flow (25%)	Median Flow (50%)	<43.3 µg.L^{-1}
Actual 2001	300 (CoA)	13.92	44.2	36.8	87.8
Actual 2001	circa 2001	10.06	43.5	36.4	97.2
100%	300	25.35	46.0	38.0	66.3
100%	circa 2001	18.36	44.8	37.2	80.3
80%	300	20.28	45.2	37.4	75.6
75%	300	19.01	45.0	37.3	77.9
100%	250	21.13	45.4	37.5	73.4
100%	200	16.90	44.7	37.1	81.6
100%	150	12.68	44.0	36.7	90.4

Point Vs. Diffuse Loading

Scenario	Mean summer upper Bay [P] in 2031	
	Low flow (25%)	Median flow (50%)
Baseline 2001 loading		
Trent River [P] = 45 ug/l	44.2	36.8
Trent River [P] = 44 ug/l	43.1	35.8
Trent River [P] = 43 ug/l	42.0	34.9
100% CoA 2010		
Trent River [P] = 45 ug/l	46.0	38.0
Trent River [P] = 44 ug/l	44.9	37.0
Trent River [P] = 43 ug/l	43.7	36.0

- Trent R. is dominant flow and 1 ug/l is approx 10-15 kg/d
- No evidence such a reduction is achievable over large area

Possible Future Steps

- Test model sediment [P] with a new survey revisiting sites surveyed by Thomas (1972)
- Add a dynamic model of zebra mussel P dynamics
- Update water and nutrient budgets every 5 years and recalibrate model
- Update ZM distribution and abundance data circa every 5 years to calibrate their impact on P dynamics

Conclusions

- Using 100% point source P loads will not produce deleterious in-Bay impacts at median river flows
- BUT prolonged low (25%) river flows will lead to decreased water quality
- “Zebra mussel” effect is significant raising expected [P] by 3-5 ug/l

Recommendations

- Set an upper limit for total on-Bay point source P loadings to the Bay of Quinte (circa 15 kg/day)
  - ➔ Use low flow to evaluating alternate future loadings
  - ➔ Track ZM #; if they decline, limit won't be as stringent
- Accept existing, and any additional future, flow capacities <u>but</u> require all sources to produce effluent concentration reductions if growth exceeds the load limit (Q*[P])
  - ➔ 10-15 year window for planning next steps
- Upstream point and diffuse loading reductions are not a practical alternate to on-Bay point source limits
  - ➔ Seek benefits of upstream controls upstream