Watershed Studies and Lake Eutrophication Assessments in Alberta

Presented at ALMS Workshop
Sept 26, 2014

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Historical Overview (1976-2013)

- Lake P-Budgets (9 Alberta studies)
- P-Loading Information
  - Internal Loading Estimates (>28 lakes)
  - Stream Loading Estimates (108 Streams)
- BATHTUB
- River Diversion Effects

The Alberta Setting

- Geology and land use
- Relatively few high quality lakes
- Many are shallow and naturally fertile
- Most are poorly flushed
- 125+ years human impacts

Hon. William Yurko, Minister of Environment (Nov 16, 1972)

- "I think we might all agree that a *Symposium on the Lakes of Western Canada* is timely. Here in Alberta, intensifying industrial and agricultural activities have not left our lakes unaffected...problems such as fluctuating and receding lake levels, deterioration of water quality, shoreline erosion, silt deposition and competing usage are increasing in magnitude and scope. <u>These problems have gone on far too long</u> and have reached proportions which now dictate that a concerted effort by different levels of government is required to preserve the quality and character of our lakes....."

“Task Force on Shorelands” (1976)

- 630 lakes assessed
- 45 identified as being of immediate concern...overcrowding and restricted public access to major lakes
- Development of land for recreational, industrial, residential land prohibited until a lake management plan and zoning bylaw was prepared by the municipality

Development prohibited at 15 lakes

- Regulated Lake Shoreland Development Operation Regulations
  - Baptiste, Gull, Garner, Island, Isle, Lac La Biche, La la Nonne, Lac Ste Anne, Moose, Muriel, Nakamun, Sandy, Skeleton, Sturgeon and Wizard
- Regulation repealed in 1986

The Baptiste Lake Study 1976-79

- Crisis at lake: too much development already
- GOA needed a “model” to predict effects of watershed development
- Intensive study of lake and watershed nutrient sources

The Vollenweider phosphorus model (1969)

$$[TP] = \frac{L}{\bar{z}(\sigma + \rho\omega)}$$

[TP] = TP Concentration

L = Annual P-Loading

z = Mean depth

ρ_w = Flushing rate

σ = Sed. Coeff

Dillon and Rigler Model (1974)

$$[P] = \frac{L\,(1 - R_p)}{z \cdot \rho_\omega}$$

- P = Spring [TP]
- L = Areal P-load
- R_p = retention coeff.
- z = mean depth
- ρ_ω = flush. rate

Chapra Model (1975)

$$P = \frac{L}{(\upsilon + q_s)}$$

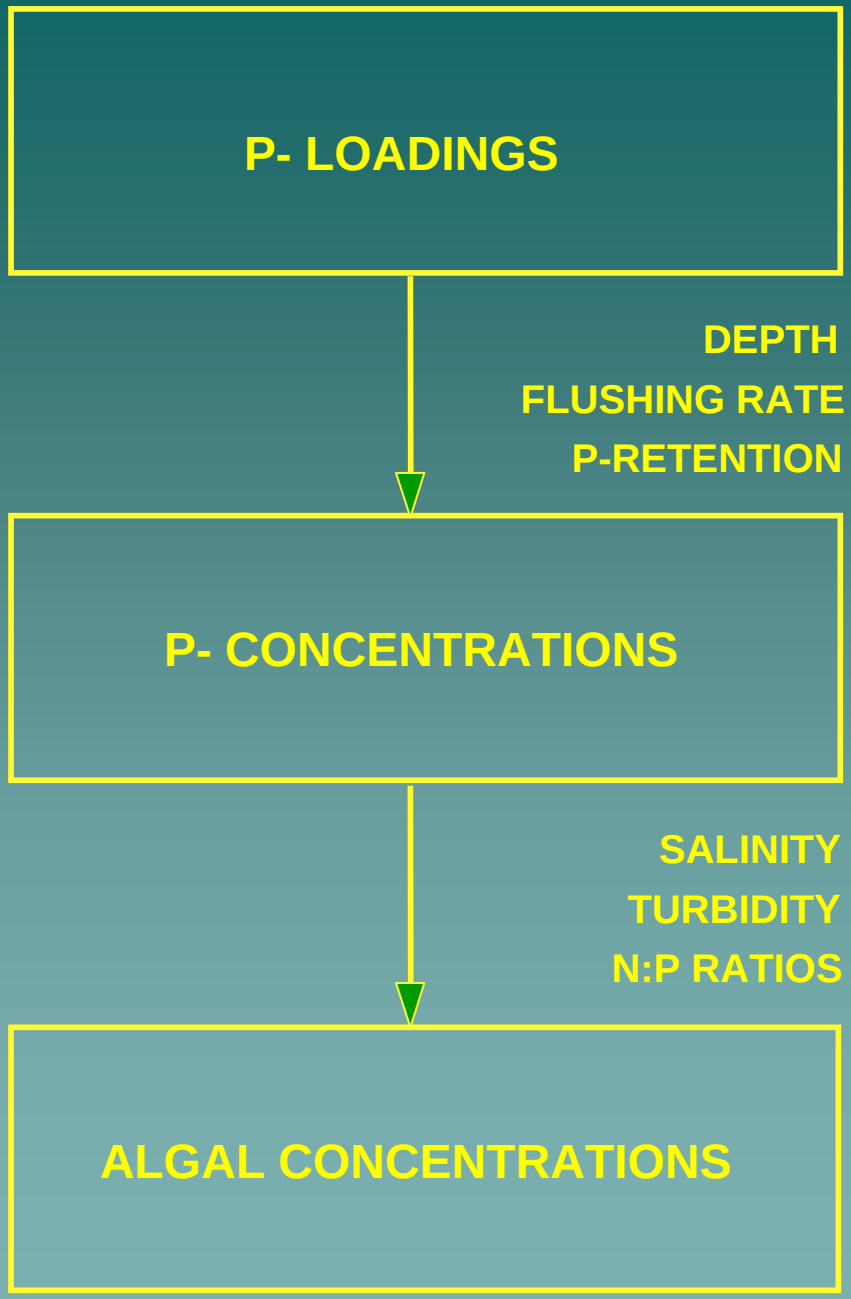
- P = Steady state [TP]
- L = areal P-load ($mg \cdot m^{-2} \cdot yr^{-1}$)
- υ = P-settling velocity
- q_s = areal water load ($m \cdot yr^{-1}$)

Rast and Lee Model (1978)

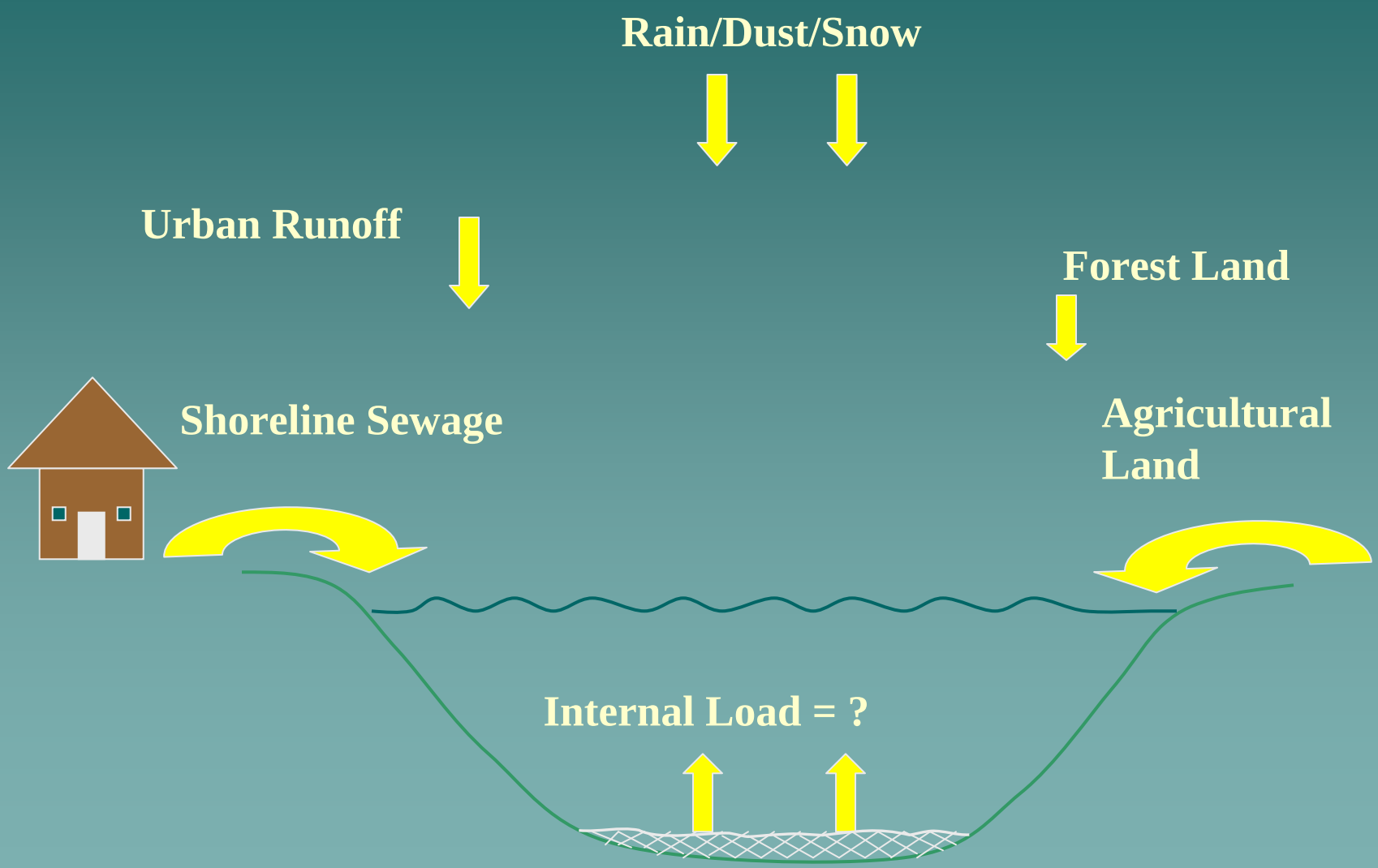
$$[P] = \frac{[P_i]}{(1 + \sqrt{\tau_w})}$$

- P = steady state [TP]
- P_i = mean influent [TP]
- τ_w = hydraulic residence time

The phosphorus modeling sequence



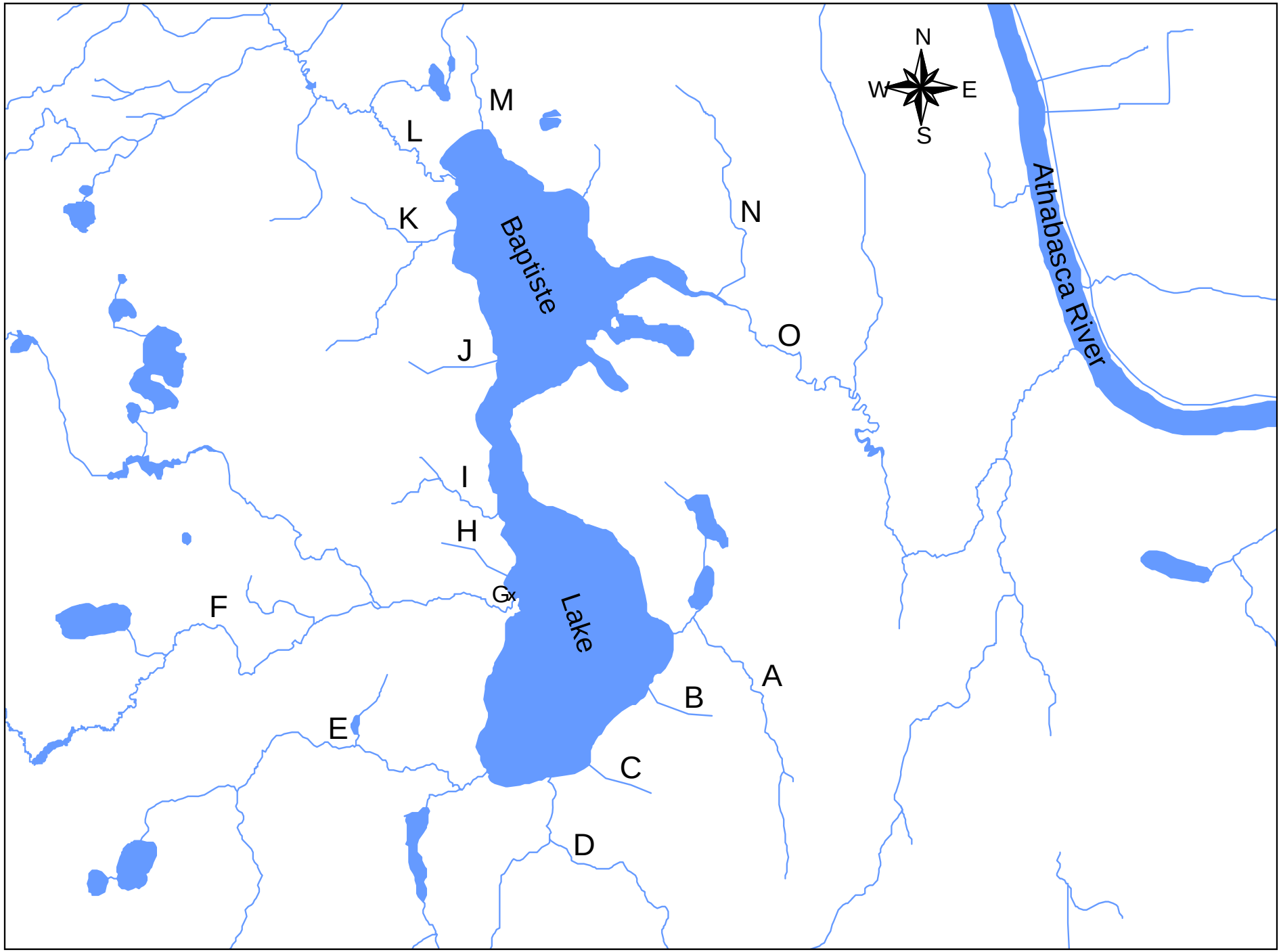
Phosphorus Sources



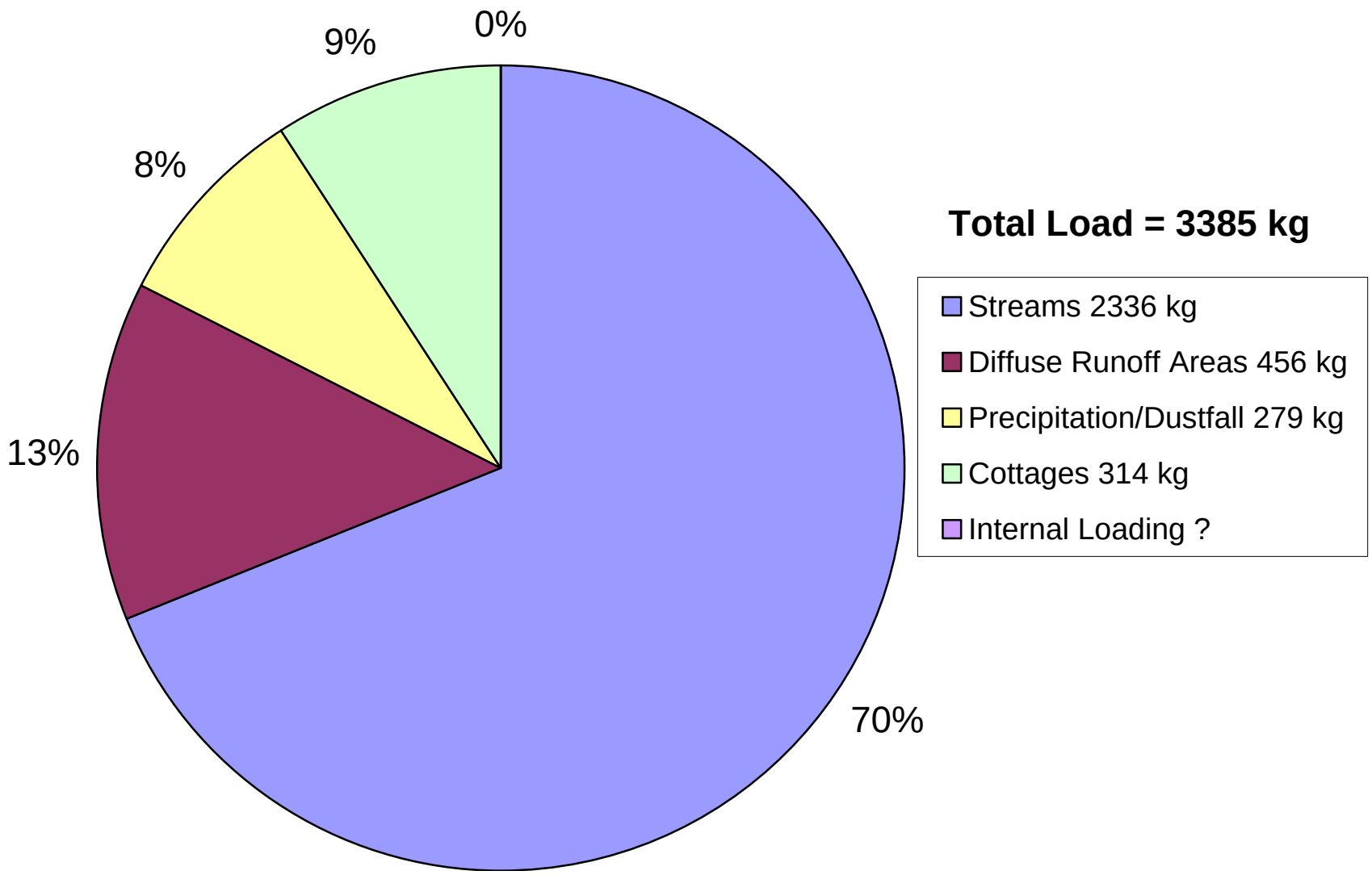
Lake Watershed Studies in Alberta

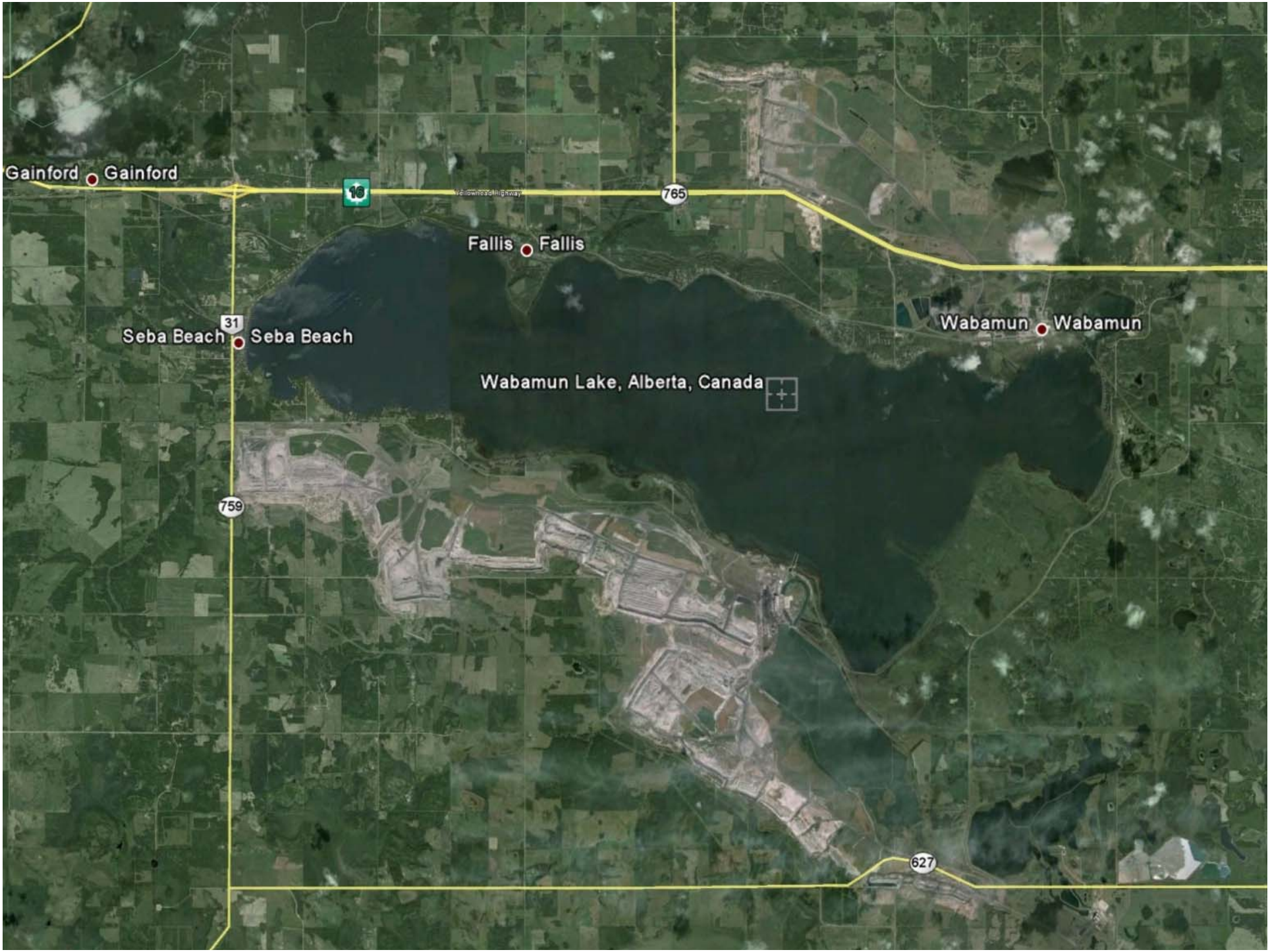
Lake Watershed Studies

1. Baptiste Lake (1976-78)
2. Wabamun Lake (1980-81)*
3. Tucker (1981)
4. Pine Lake (1992)
5. Lac Ste Anne (1997)
6. Lake Isle (1997)
7. Lesser Slave Lake (1991-93)
8. Gull Lake (1999)
9. Pigeon (2013)

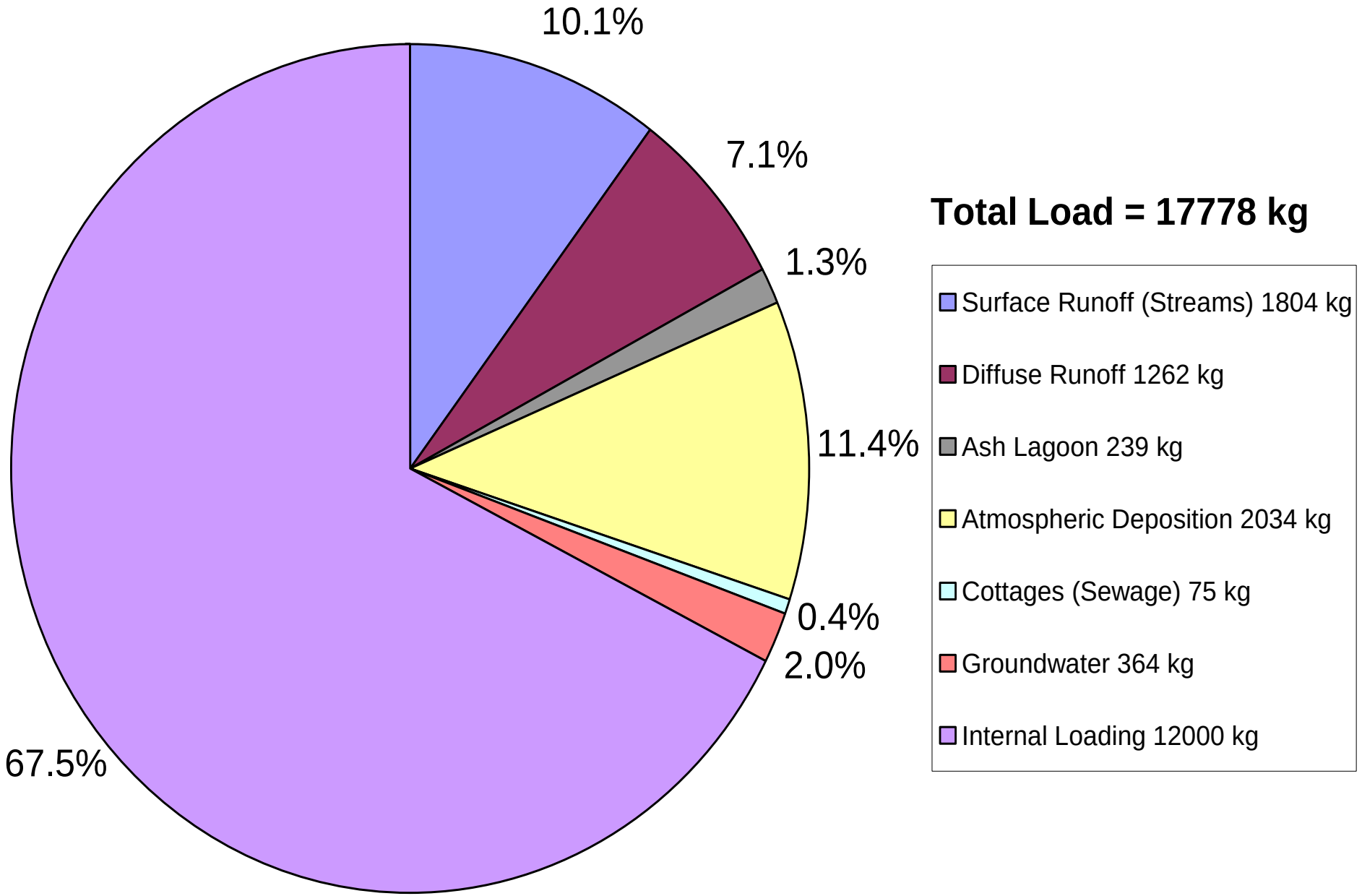

N
W
E
S
M
L
K
Baptiste
N
Athabasca River
O
J
I
H
G
Lake
F
A
B
E
C
D

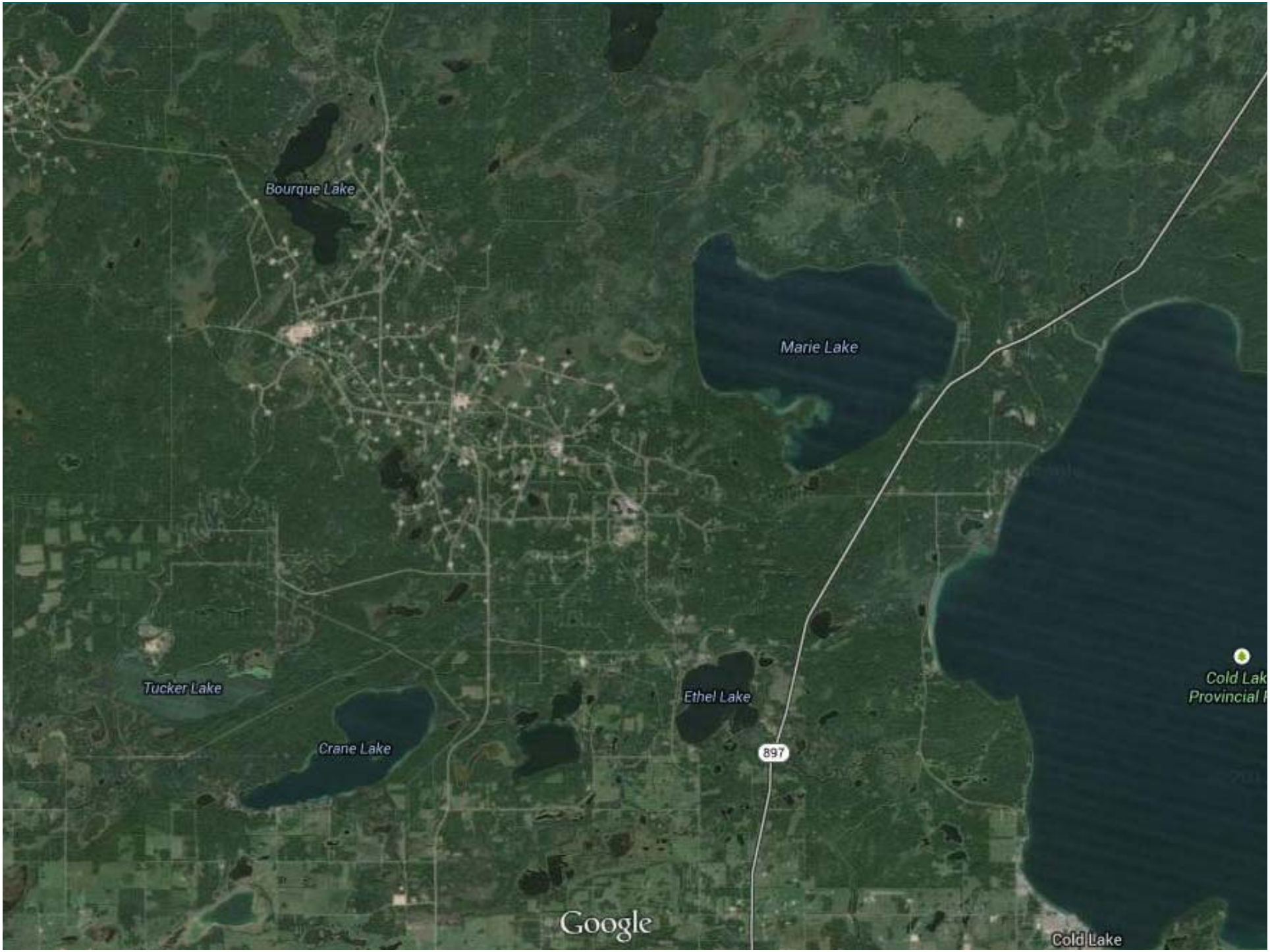
Baptiste Lake P-budget, May 11-November 8, 1977




Gainford
Gainford
16
765
Fallis
Fallis
31
Seba Beach
Seba Beach
Wabamun
Wabamun
Wabamun Lake, Alberta, Canada
759
627

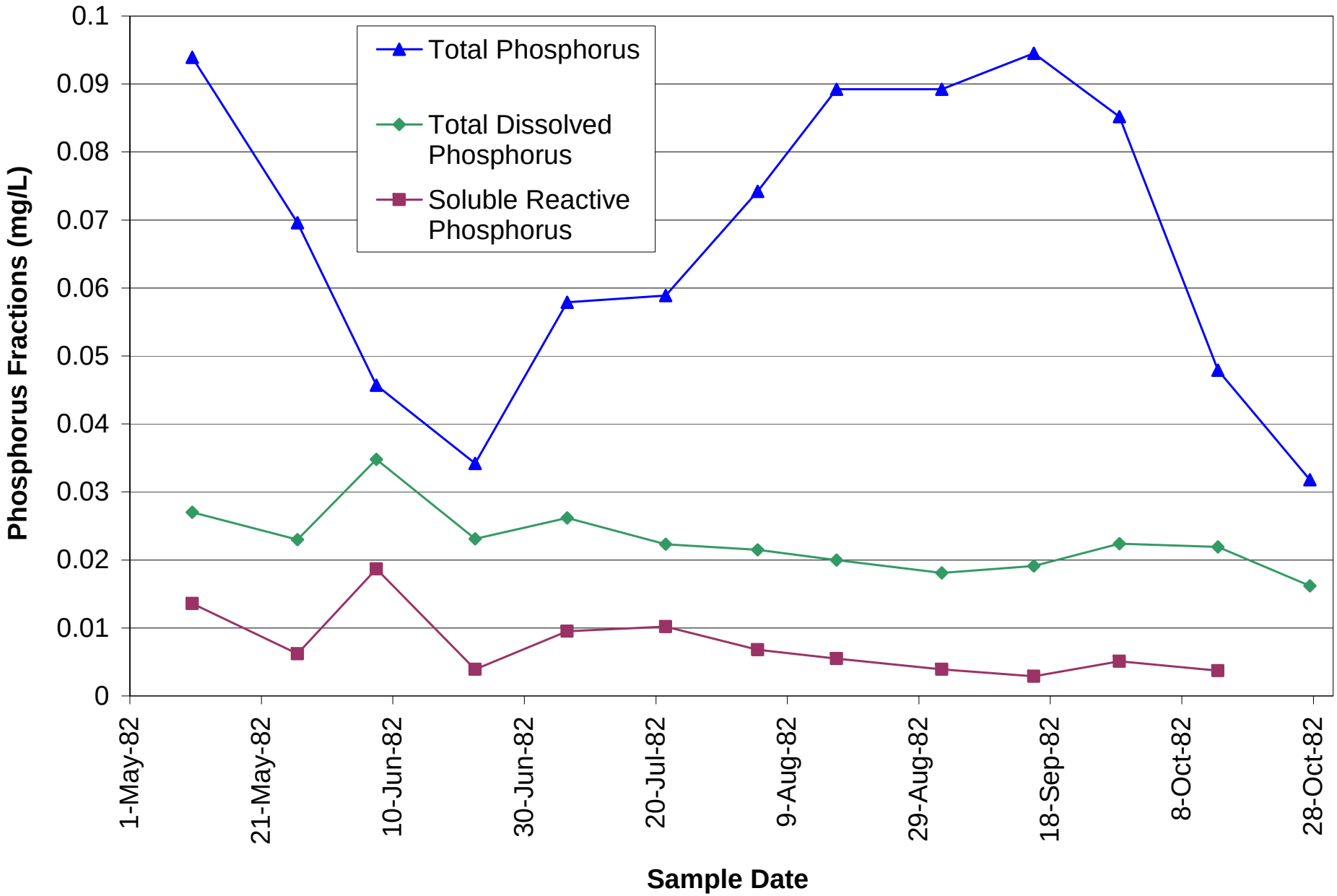
Wabamun Lake P-budget, March 4, 1981 to March 3, 1982



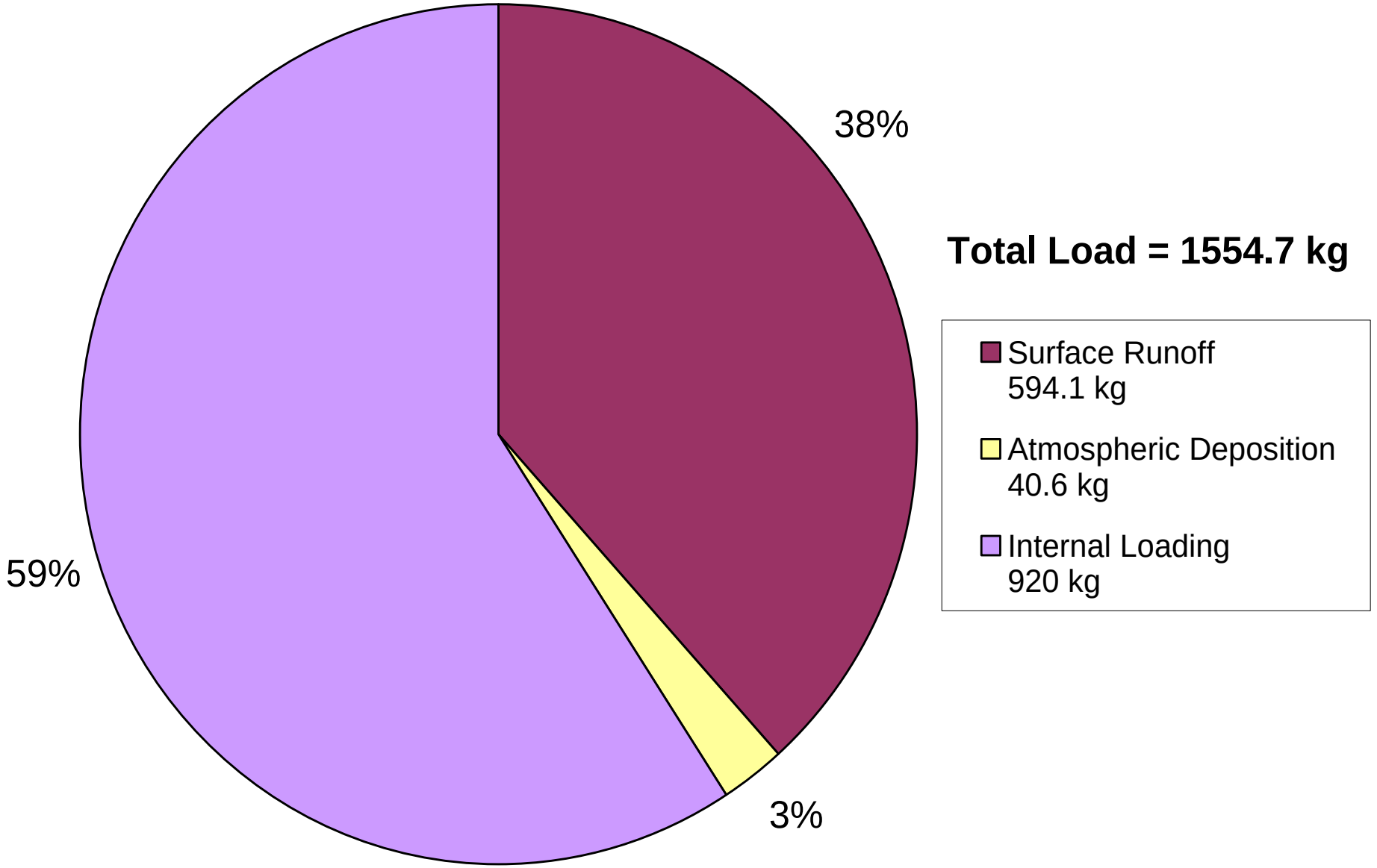

Bourque Lake
Marie Lake
Tucker Lake
Ethel Lake
Crane Lake
897
Google
Cold Lake

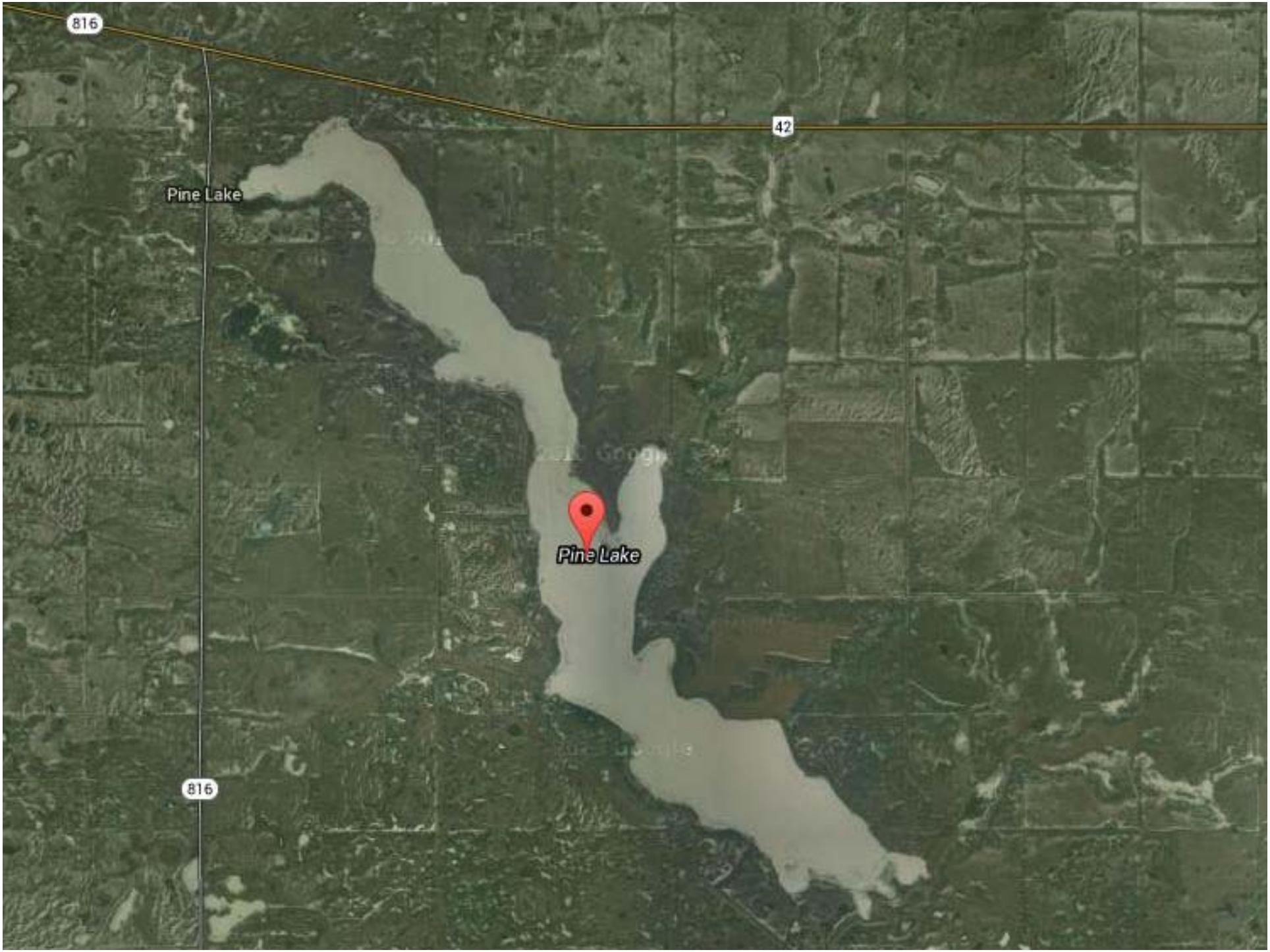

Tucker Lake
Google

Comparison of Seasonal Phosphorus Concentrations in Tucker Lake, 1982

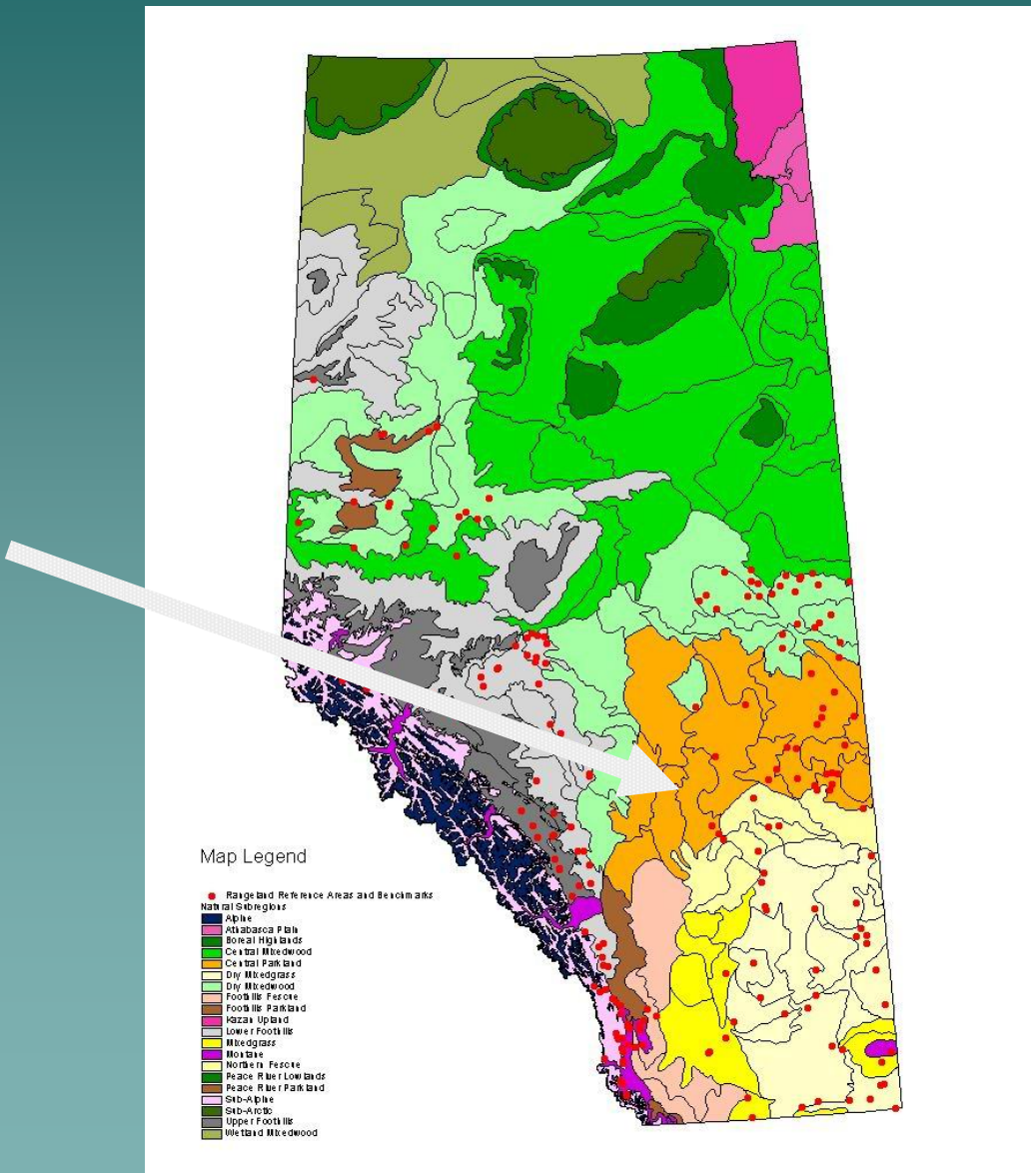


Tucker Lake P-budget, May 10-October 27, 1982

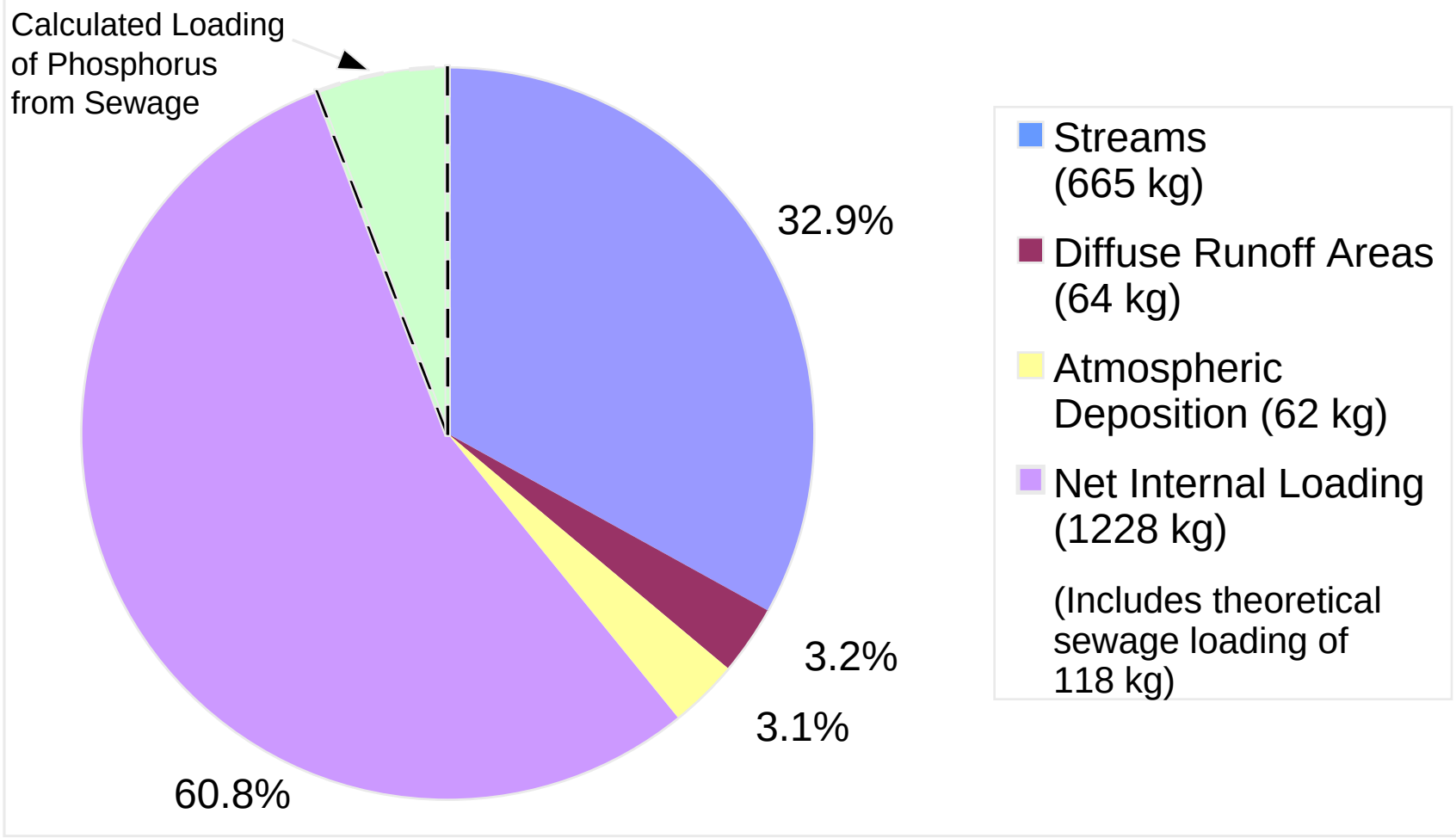



816
42
Pine Lake
Pine Lake
816

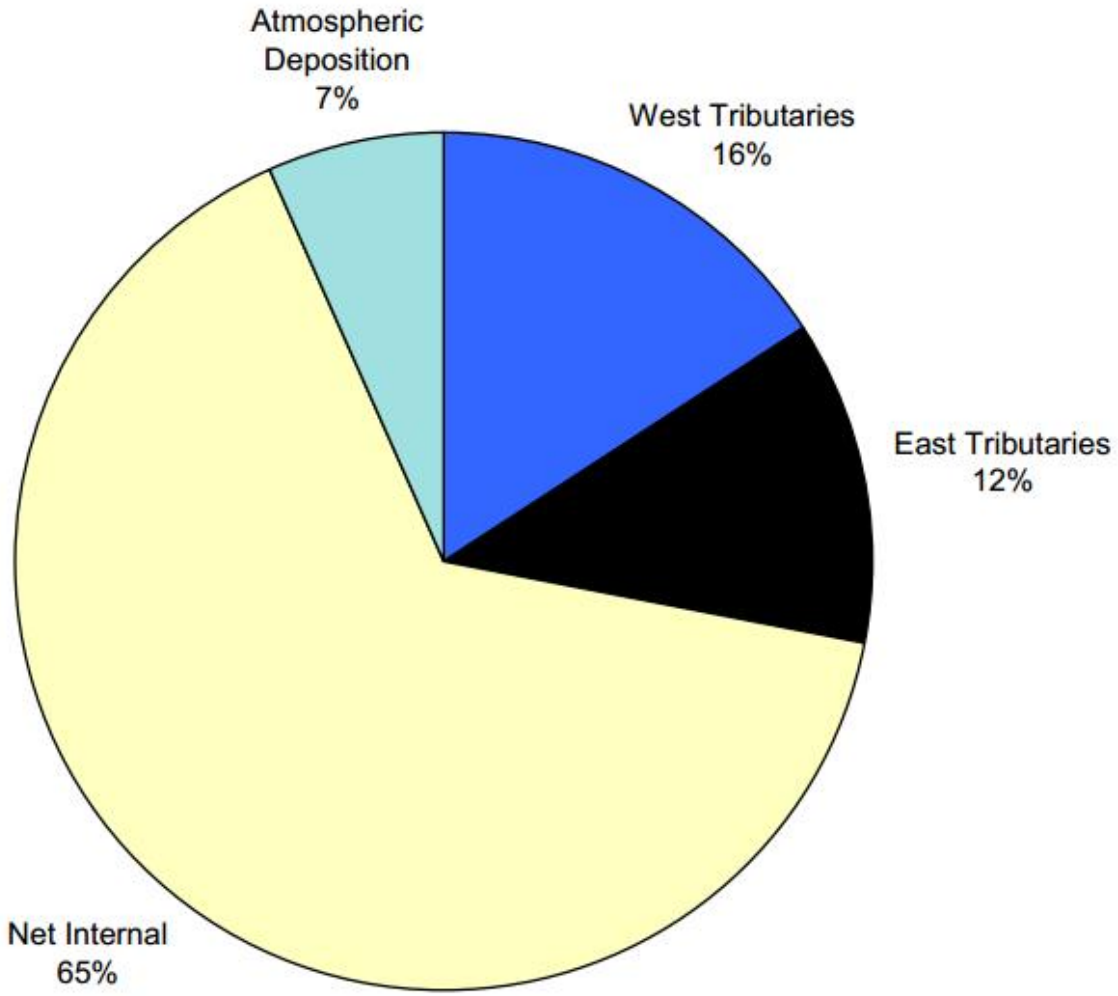
Pine Lake is in the Aspen Parkland of Central Alberta



Pine Lake Phosphorus Budget, 1992

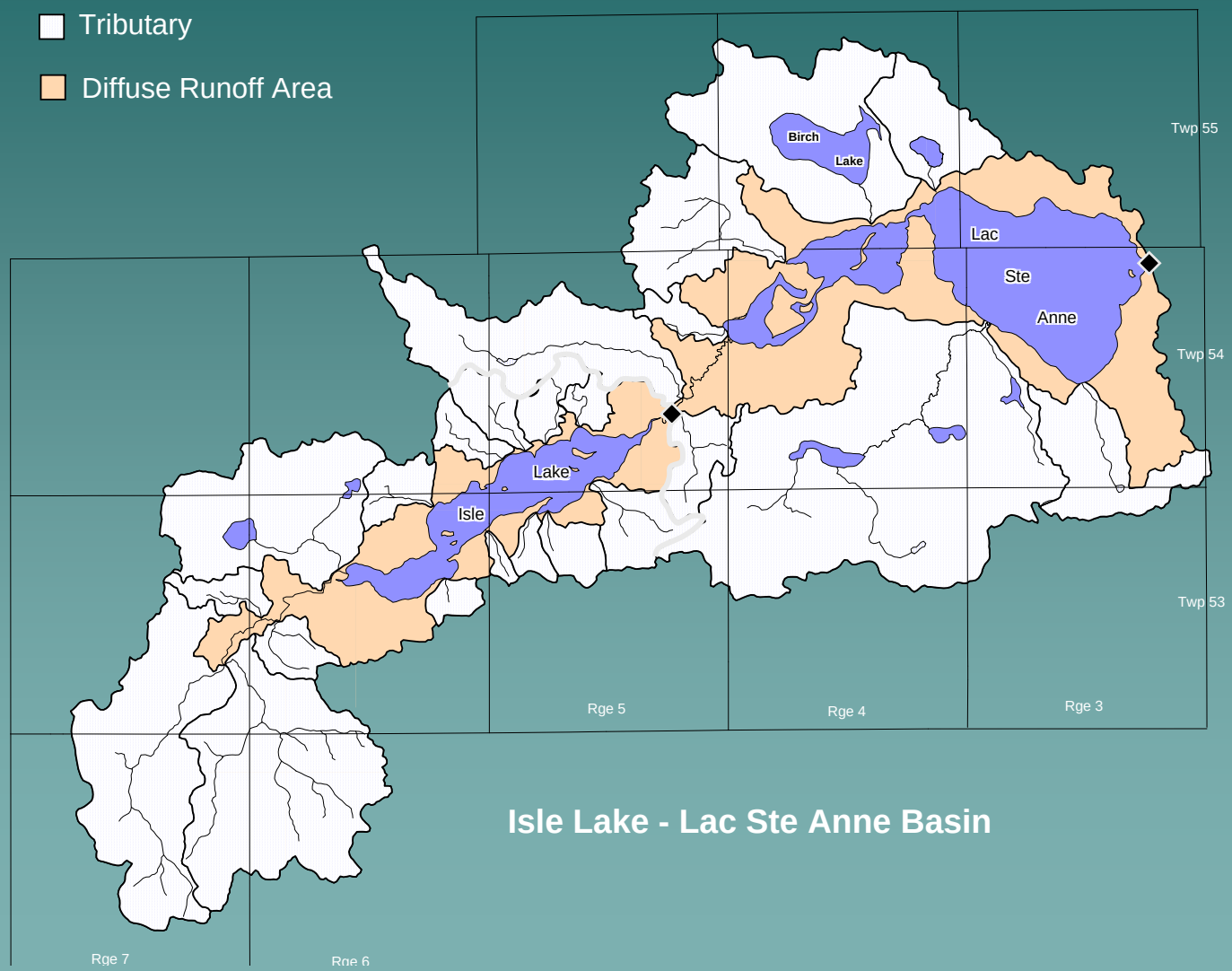


Lesser Slave Lake (1991-93)



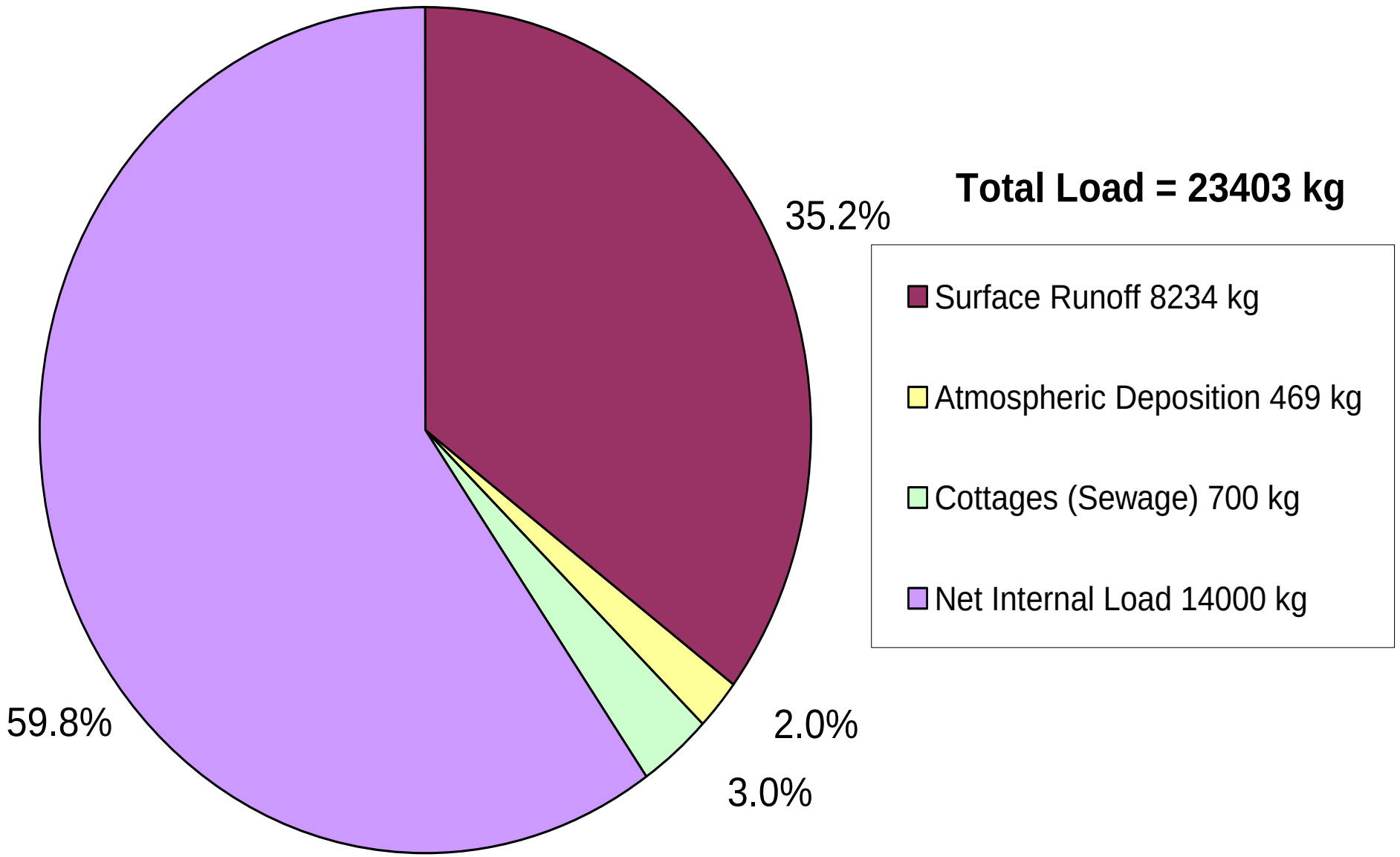
Estimated Annual Total Phosphorus Supply: 350,000 kg/yr

Lac Ste. Anne and Lake Isle

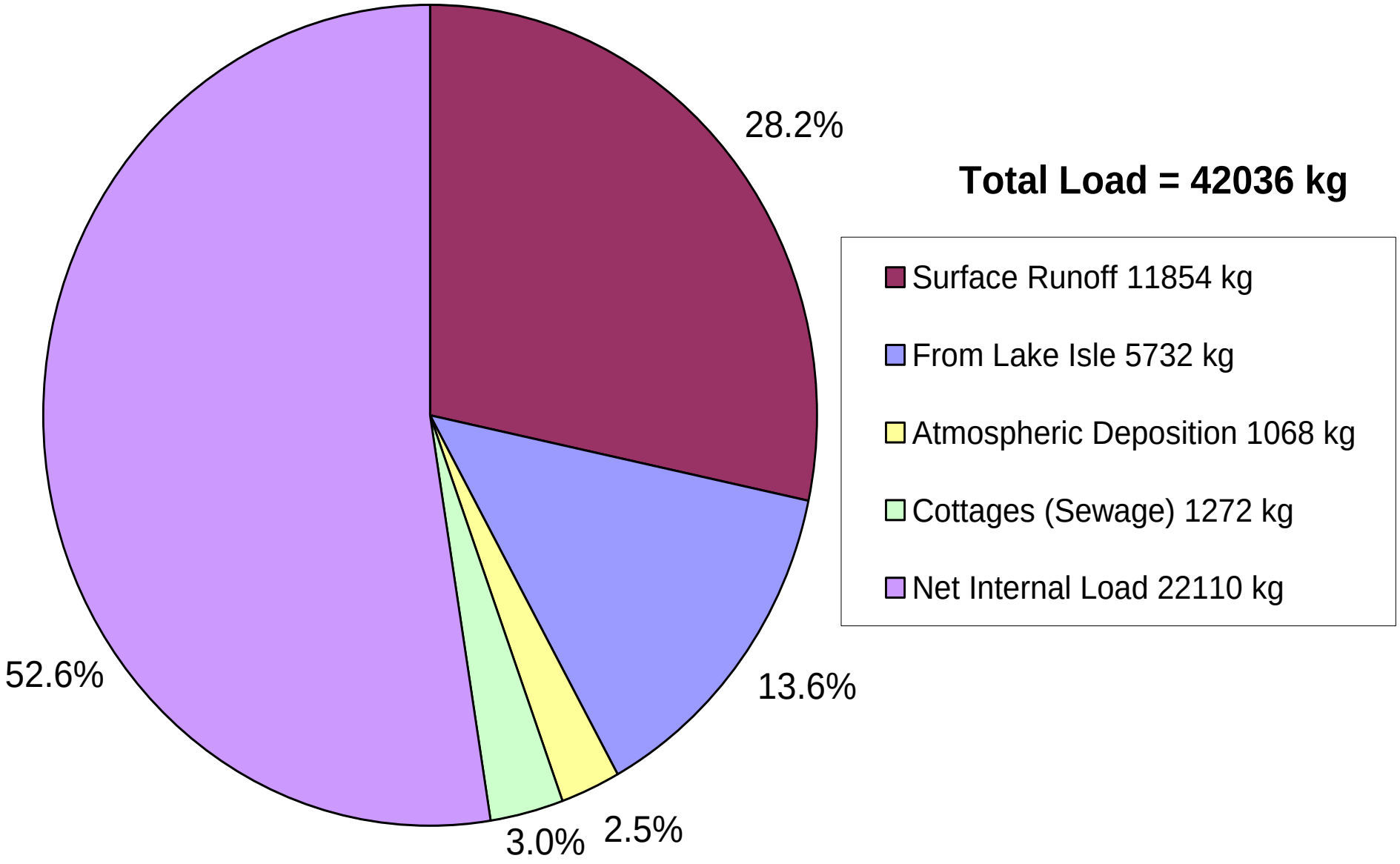


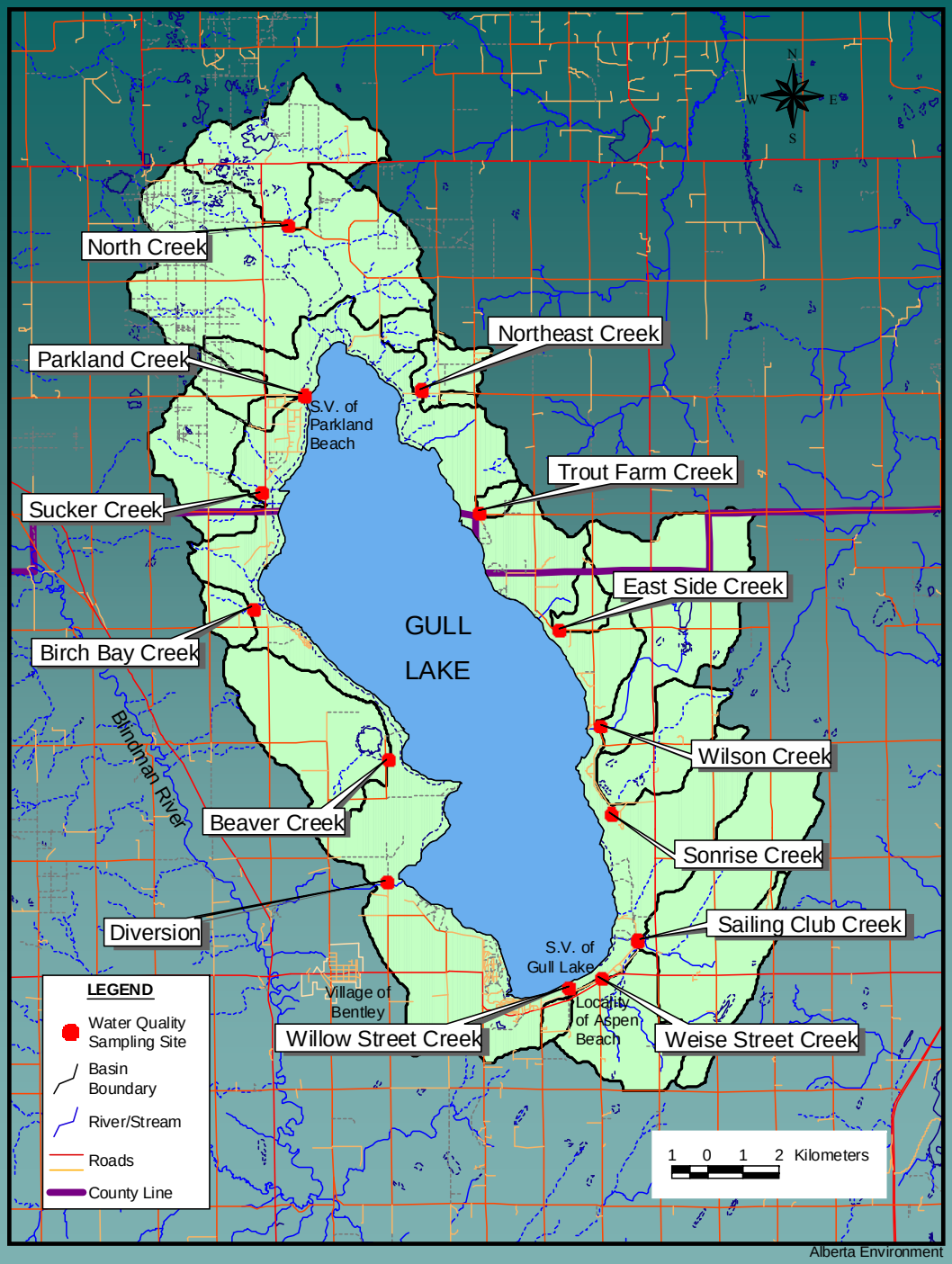
Isle Lake - Lac Ste Anne Basin

Isle Lake P-budget, March 1 to October 31, 1997



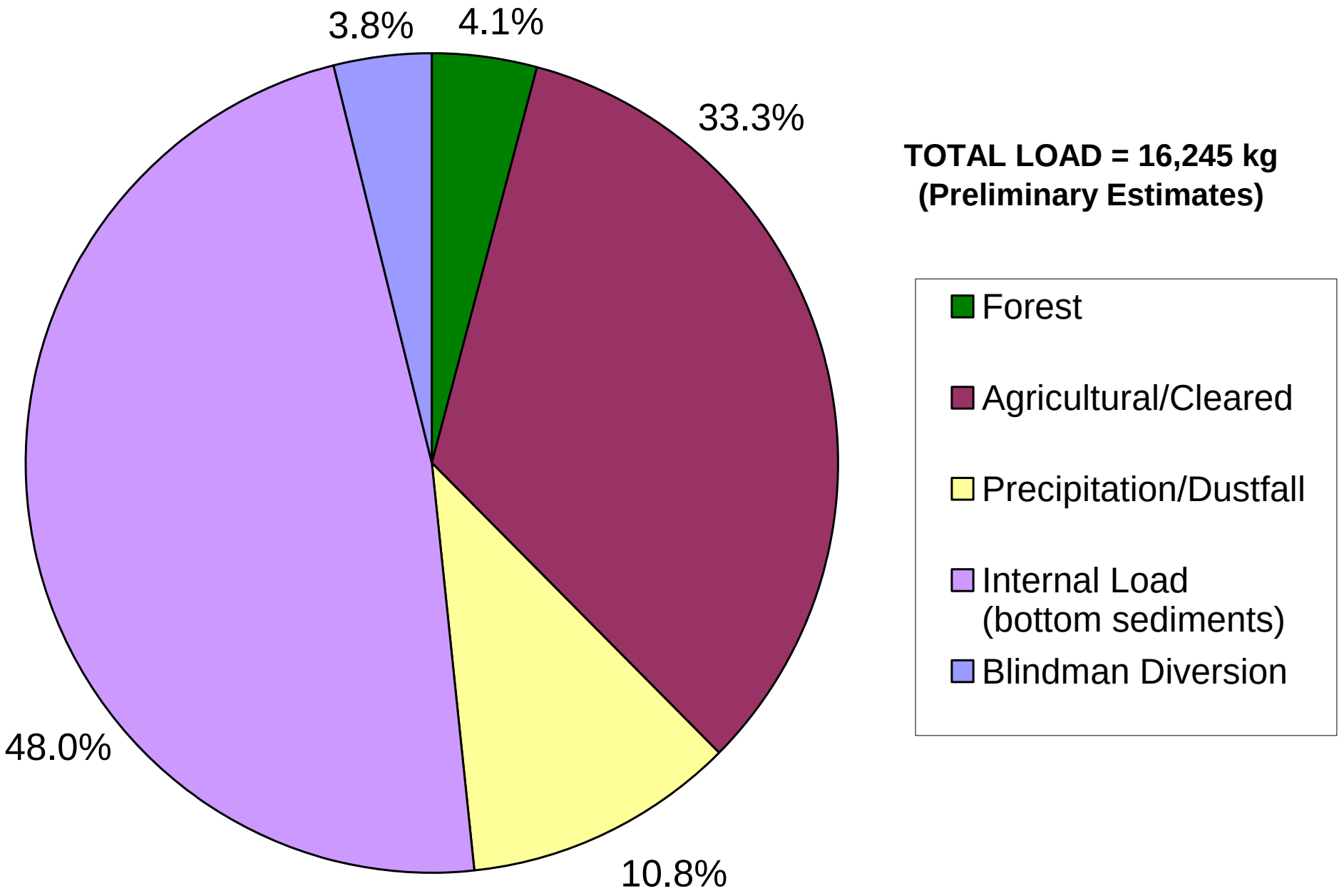
Lac Ste. Anne P-budget, March 1 to October 31, 1997

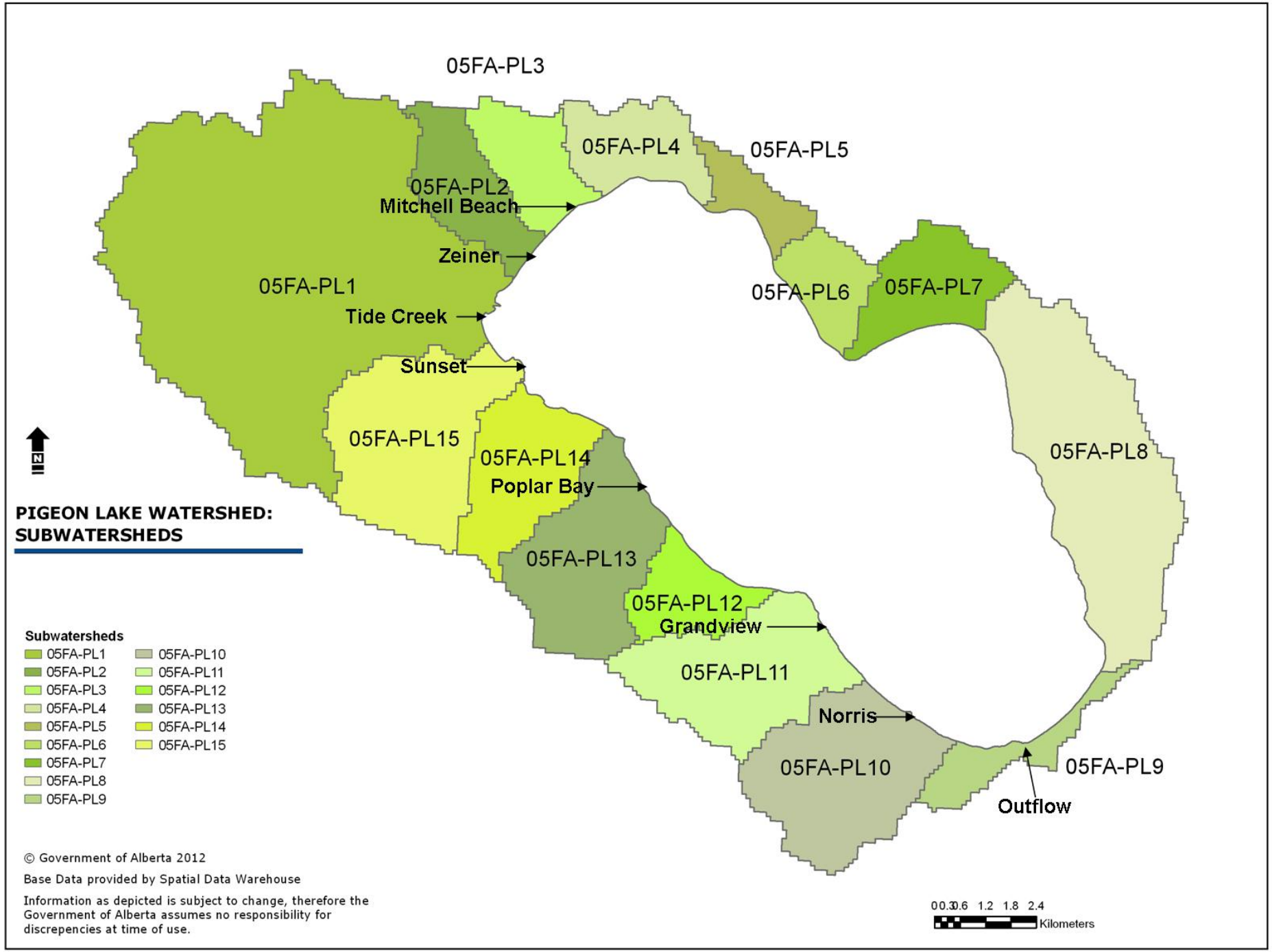


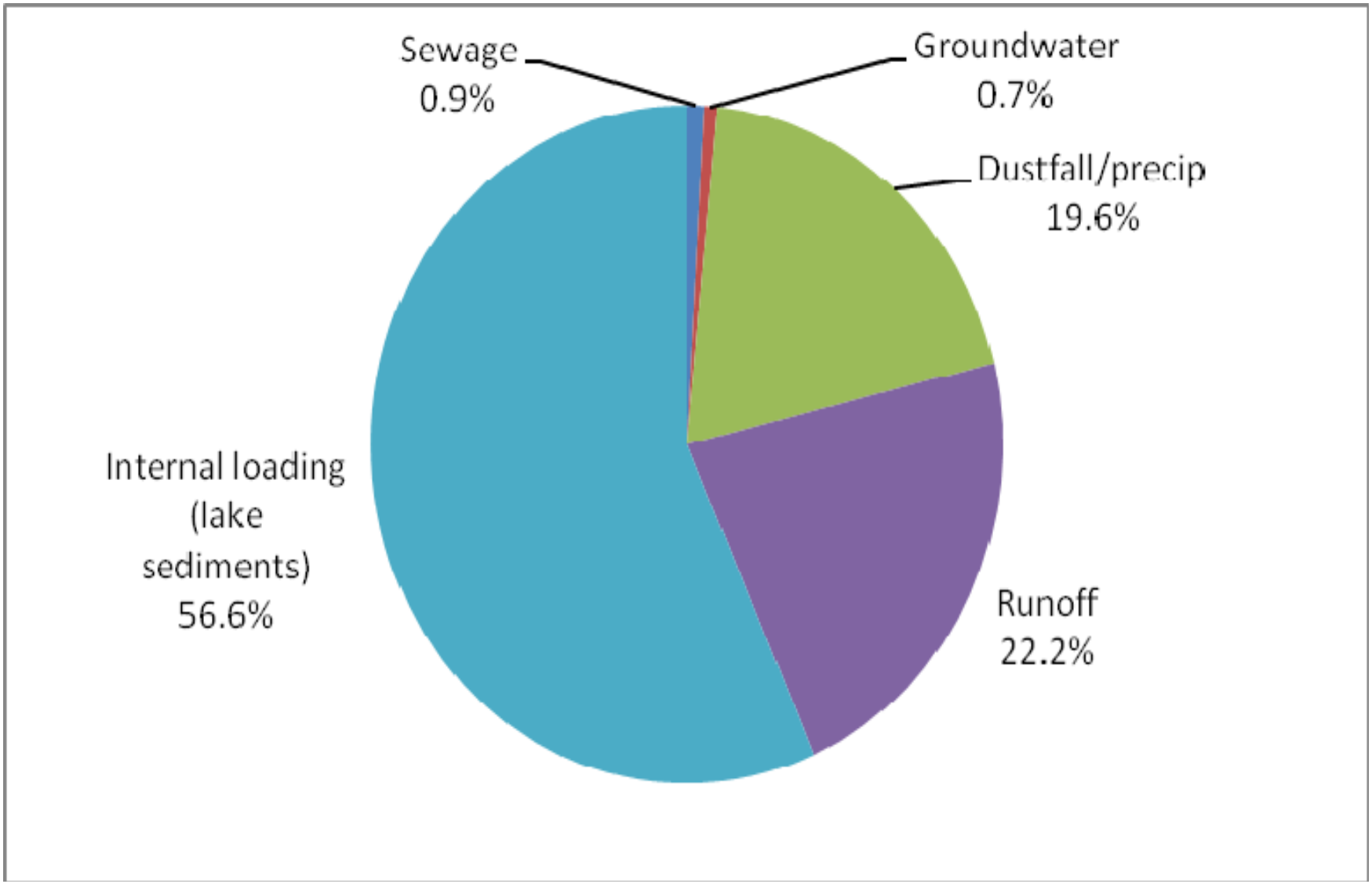


Location of Water Quality Sampling Sites on Streams in the Gull Lake Study Area, 1999-2000

Gull Lake P-Budget, 2000




05FA-PL3
05FA-PL4
05FA-PL5
05FA-PL2
Mitchell Beach
Zeiner
05FA-PL1
05FA-PL6
05FA-PL7
Tide Creek
Sunset
05FA-PL15
05FA-PL14
05FA-PL8
Poplar Bay
05FA-PL13
05FA-PL12
Grandview
05FA-PL11
Norris
05FA-PL10
05FA-PL9
Outflow
N
PIGEON LAKE WATERSHED:
SUBWATERSHEDS
Subwatersheds
05FA-PL1
05FA-PL2
05FA-PL3
05FA-PL4
05FA-PL5
05FA-PL6
05FA-PL7
05FA-PL8
05FA-PL9
05FA-PL10
05FA-PL11
05FA-PL12
05FA-PL13
05FA-PL14
05FA-PL15
© Government of Alberta 2012
Base Data provided by Spatial Data Warehouse
Information as depicted is subject to change, therefore the Government of Alberta assumes no responsibility for discrepencies at time of use.
0 0.3 0.6 1.2 1.8 2.4
Kilometers

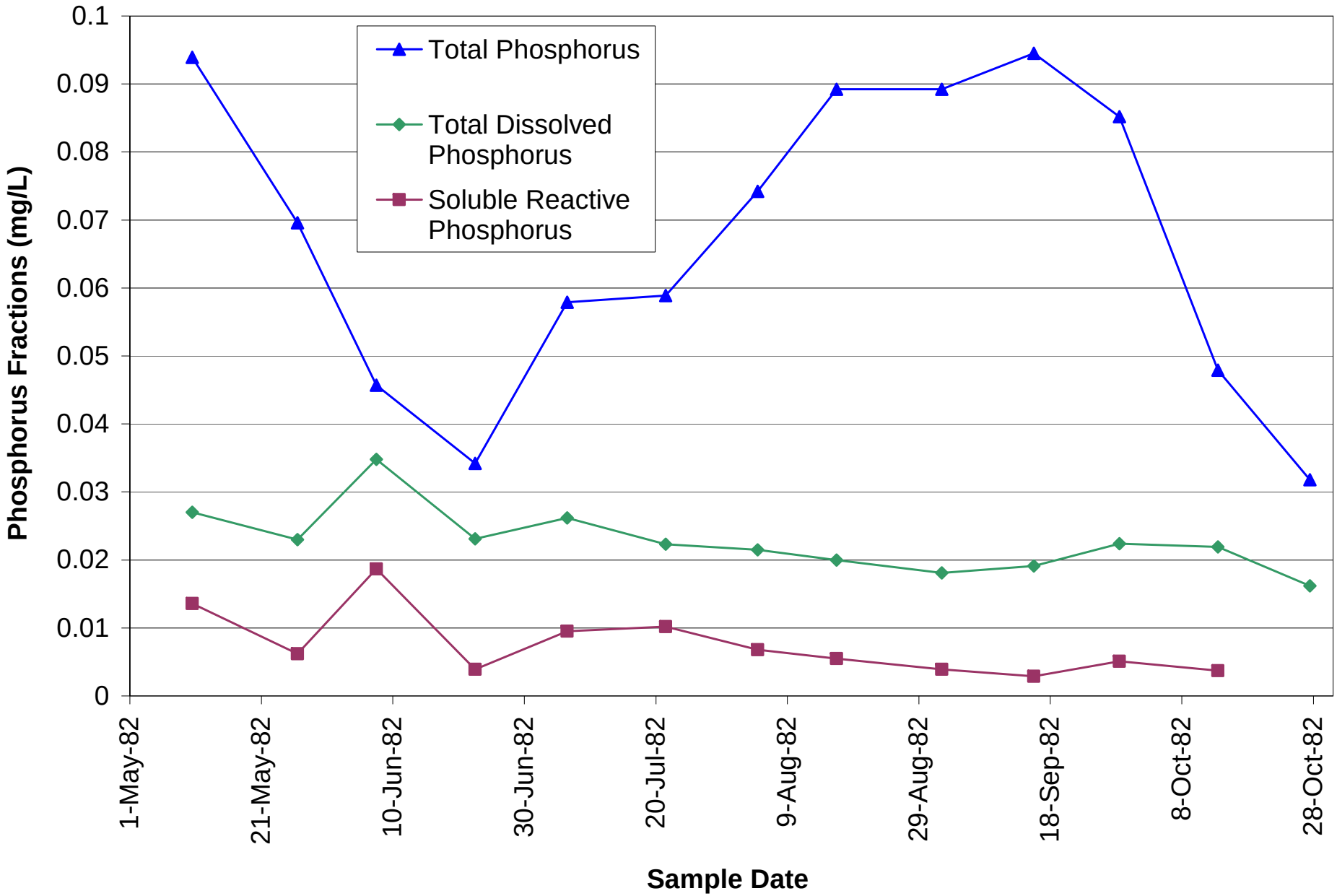

Sewage
0.9%
Groundwater
0.7%
Dustfall/precip
19.6%
Internal loading
(lake
sediments)
56.6%
Runoff
22.2%

Internal Loading Estimates for 28 Shallow Lakes

Internal P-Loading Estimates

- Sediments sampled from 17 shallow lakes
- Hydrologic and nutrient balances estimated for 34 shallow lakes (1980-90)
- First approximation: Net Internal Loading estimates for 28 lakes (1980-90)

Comparison of Seasonal Phosphorus Concentrations in Tucker Lake, 1982

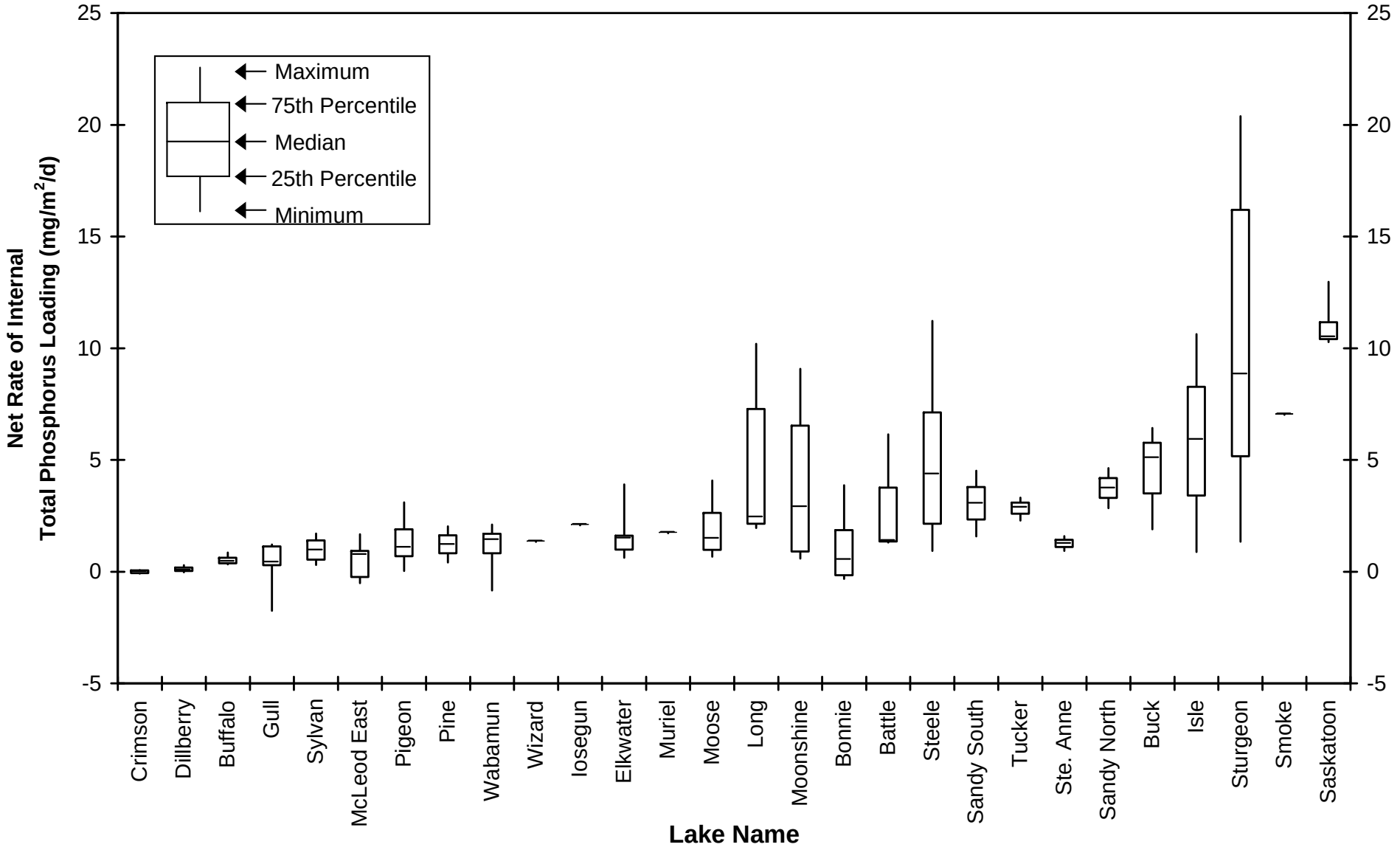


Summer TP Balances (~90 days)

Net Int. Load (kg) =

$$\Delta TP_{mass} + L_{outflow} - L_{Atmos} - L_{inflow}$$

Range of Daily Net Internal Loading Rates for 28 Shallow Alberta Lakes

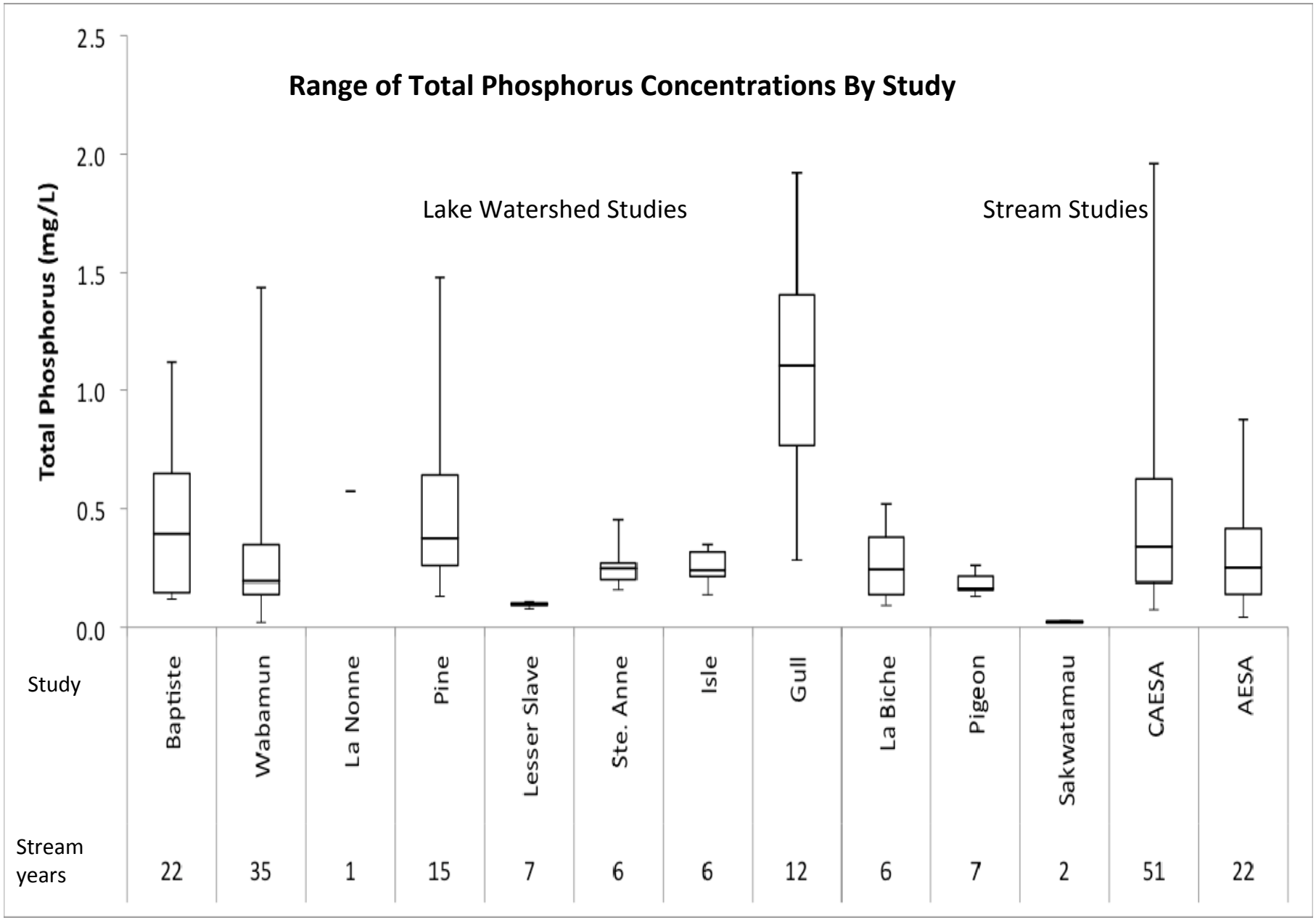


Stream Nutrient Studies in Alberta

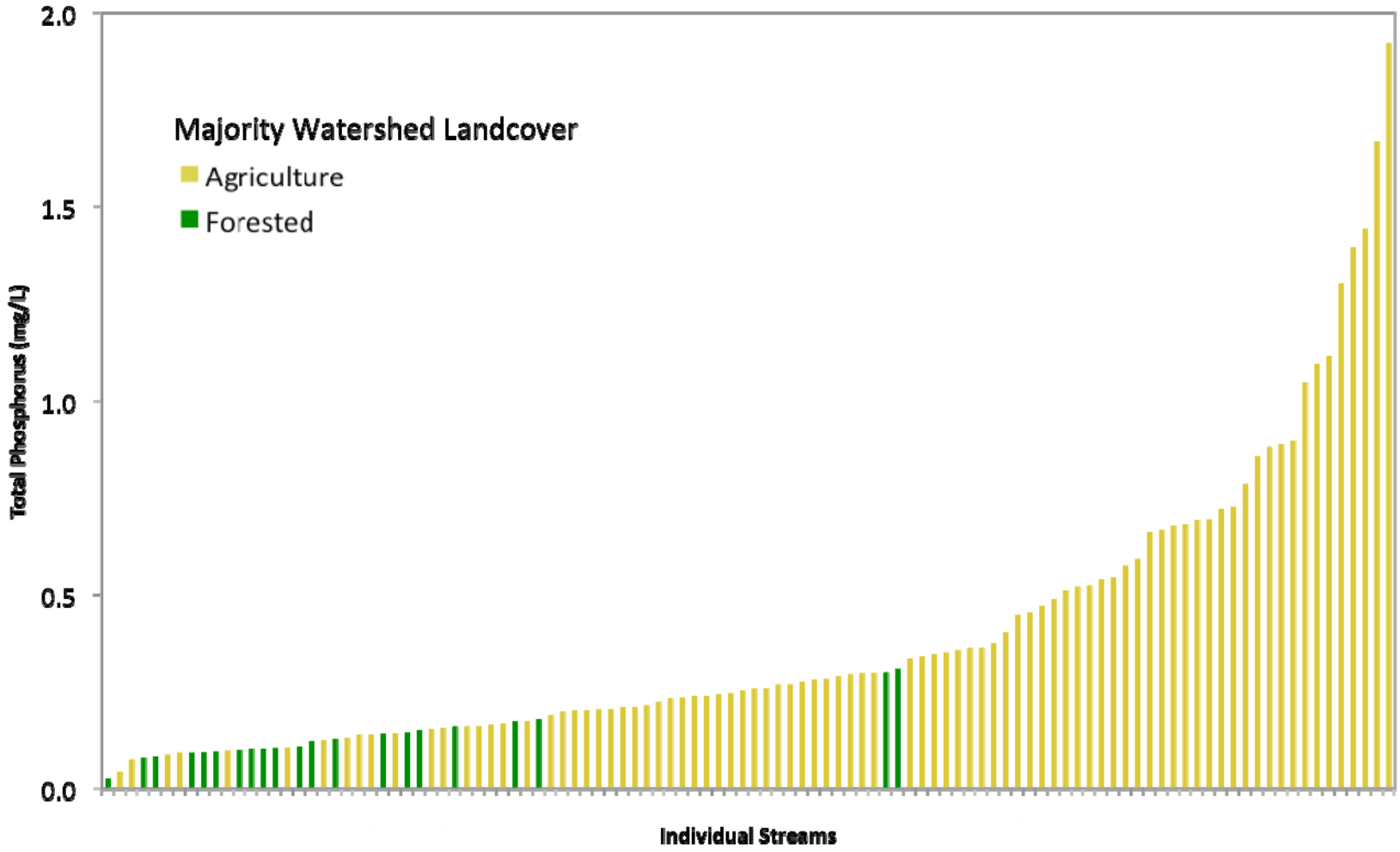
Number of Streams = 108

Studies Compiled for Alberta Stream Nutrients Report

Study	Year(s) sampled	No. streams	No. new streams
Lake Watershed Studies			
Baptiste Lake (Trew et al. 1987)	1976-1978	6	6
Wabamun Lake (Mitchell 1985)	1980-1981	14	1
Majeau Creek Lac La Nonne (Mitchell & Hamilton 1982)	1981	1	1
Pine Lake (Sosiak & Trew 1996)	1989 & 1992	8	8
Lesser Slave Lake (Noton 1998)	1991-1993	7	7
Baptiste Lake (Cooke & Prepas 1998)	1994-1995	4	0
Lac Ste. Anne & Lake Isle (Mitchell 1999)	1997	12	12
Gull Lake (Mitchell & LeClair 2003)	1999	12	12
Wabamun Lake (Emmerton 2008)	2008	7	2
Lac La Biche (Neufeld 2005)	2003-2004	6	6
Pigeon Lake (Teichreb 2014)	2013	7	7
Stream Studies			
Sakwatamau Two Creek (Munn & Prepas 1986)	1983	2	2
CAESA (Anderson et al. 1998)	1995-1996	25	24
AESA (Lorenz et al. 2008)	1999-2006	22	7
TOTAL		**133**	**108**


Range of Total Phosphorus Concentrations By Study
Total Phosphorus (mg/L)
2.5
2.0
1.5
1.0
0.5
0.0
Lake Watershed Studies
Stream Studies
Study
Baptiste
Wabamun
La Nonne
Pine
Lesser Slave
Ste. Anne
Isle
Gull
La Biche
Pigeon
Sakwatamau
CAESA
AESA
Stream years
22
35
1
15
7
6
6
12
6
7
2
51
22

Median Total Phosphorus Concentrations for 108 Alberta Streams
- Median for All Available Stream Years 1976-2013 -



Lake Nutrient Modeling

Eutrophication Modeling Projects: BATHTUB

1. Pine (1992)
2. Lac Ste Anne, Lake Isle (1998, 2014)
3. Baptiste (2006)
4. Lac St Cyr (2013)
5. Wabamun (2013)
6. Mayatan (2014)
7. Pigeon (2014)
8. Lesser Slave Lake (2013, 2014*)

BATHTUB - Calibration

- Steady state model: predicts summer averages
- TP can be simulated well
- Chlorophyll a simulated fairly well
- Secchi depth simulated fairly well
- Total nitrogen not simulated well
- Single year calibrations are difficult: runoff loads vary from year to year but observed lake TP varies less
- Best to use long term hydrologic context (Inflows over 10, 20, 40 years)

Variable	#	Selection +Description
Conservative Substance	0	Not Computed *
Total Phosphorus	8	Canfield & Bachman (1981), Natural Lakes $0.162\ (Wp/V)^{0.458}$
Total Nitrogen	4	Bachman (1980), Volumetric Load $0.0159\ (Wn/V)^{0.59}$
Chlorophyll-a	4	P, Linear B = K 0.28 P
Transparency	3	Secchi vs. Total Phosphorus, CE Reservoirs $S = K\ 17.8\ P^{-0.76}$
Longitudinal Dispersion	2	Constant-Numeric – Fixed Dispersion Rate D = 1000 KD
Phosphorus Calibration	1	Decay Rates – Apply calibration factors to sedimentation rate *
Nitrogen Calibration	1	Decay Rates – Apply calibration factors to sedimentation rate*
Error Analysis	1	Consider Model Error and Data Error *
Availability Factors	0	Ignore *
Mass Balance Tables	1	Use predicted segment concentration to calculate outflow and storage terms
Output Destination	2	Excel worksheet *

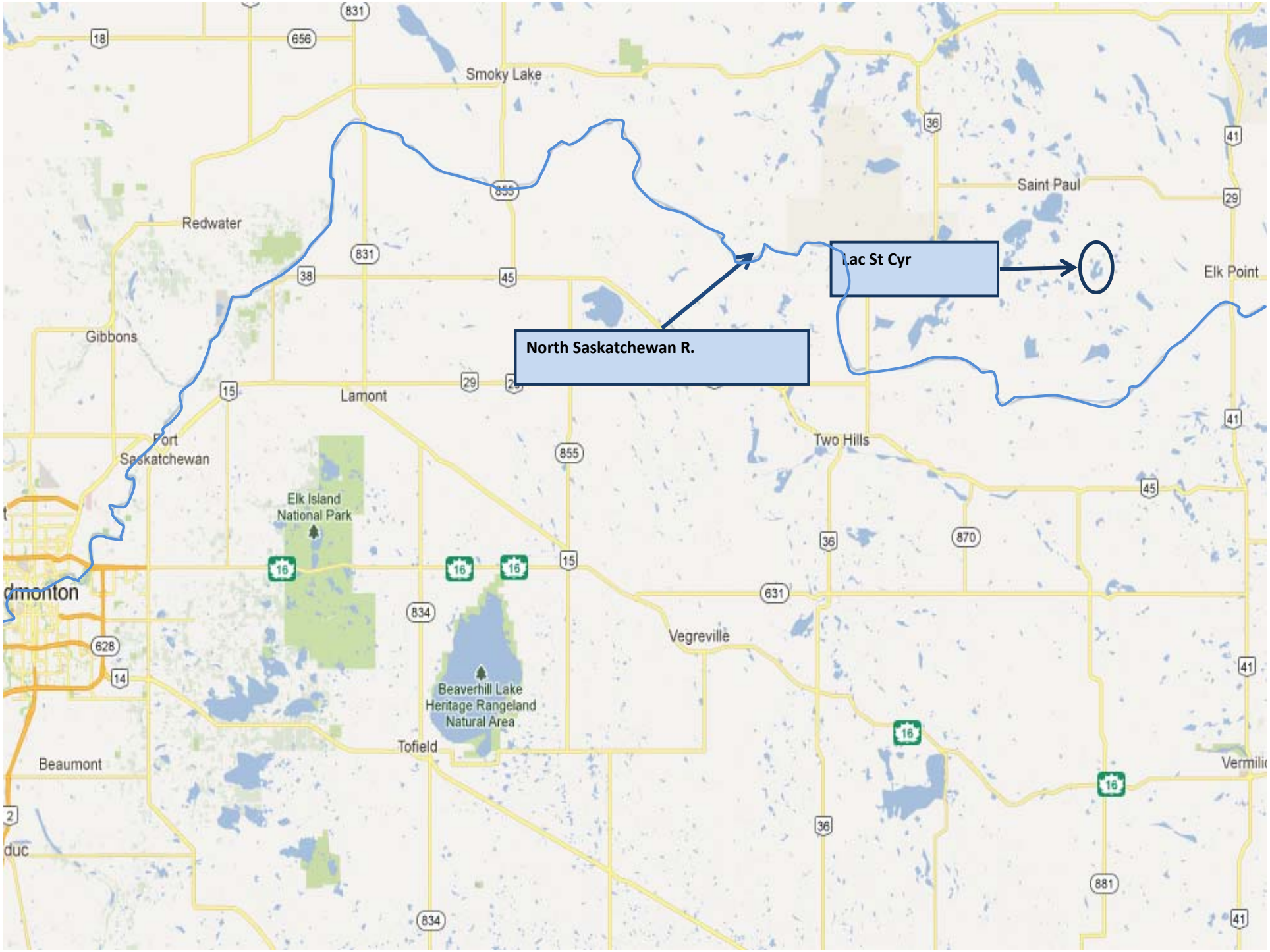
BATHTUB

- Bathtub designed for U.S. reservoirs: not all model selections and features applicable to Alberta Lakes
- Calibration process provides great educational value
- Predictive capacity is limited, caution required
- Consider developing an “Alberta Lakes Model”
- Need to develop more lake modeling expertise in Alberta

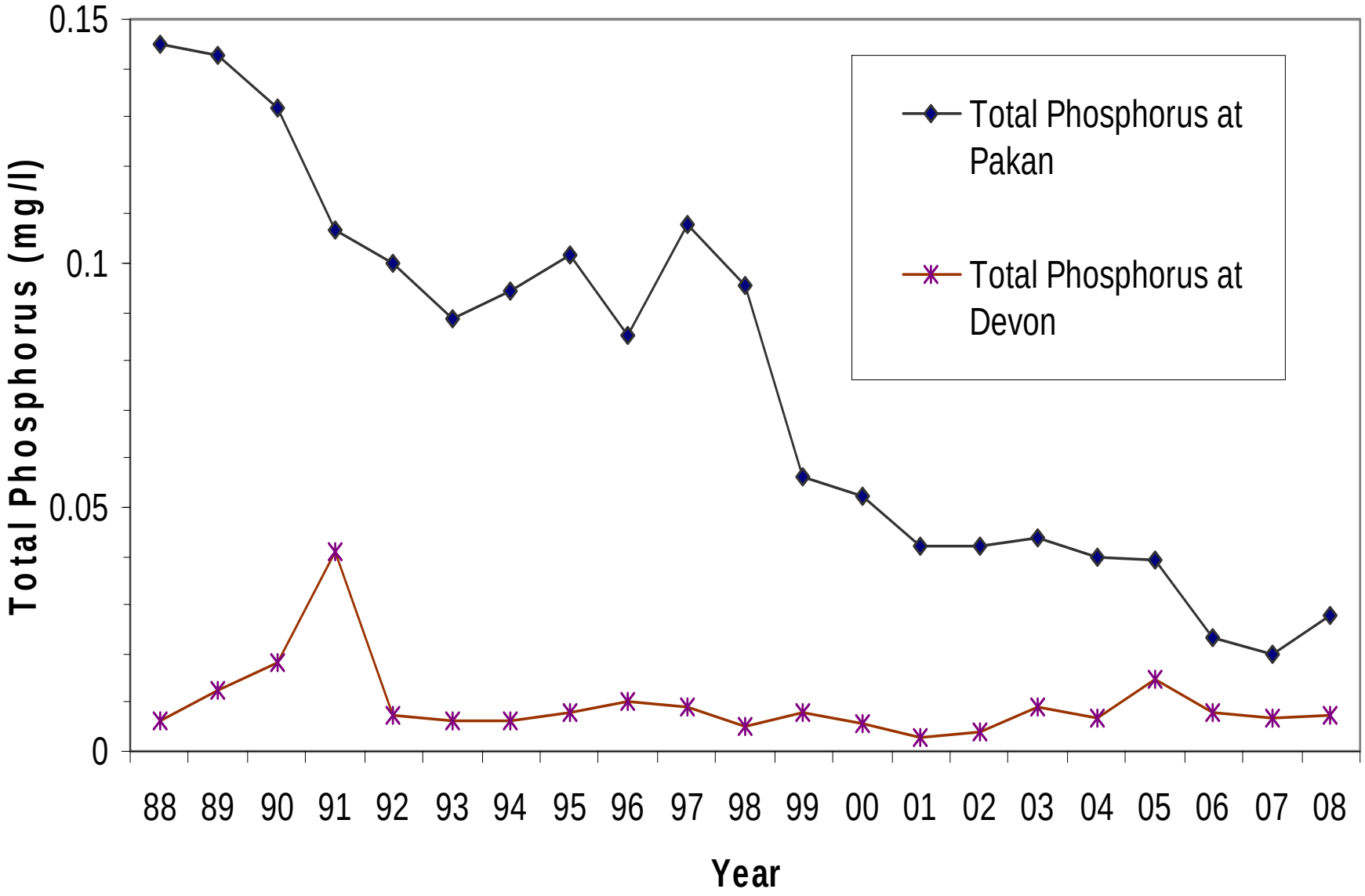
River Diversion Effects

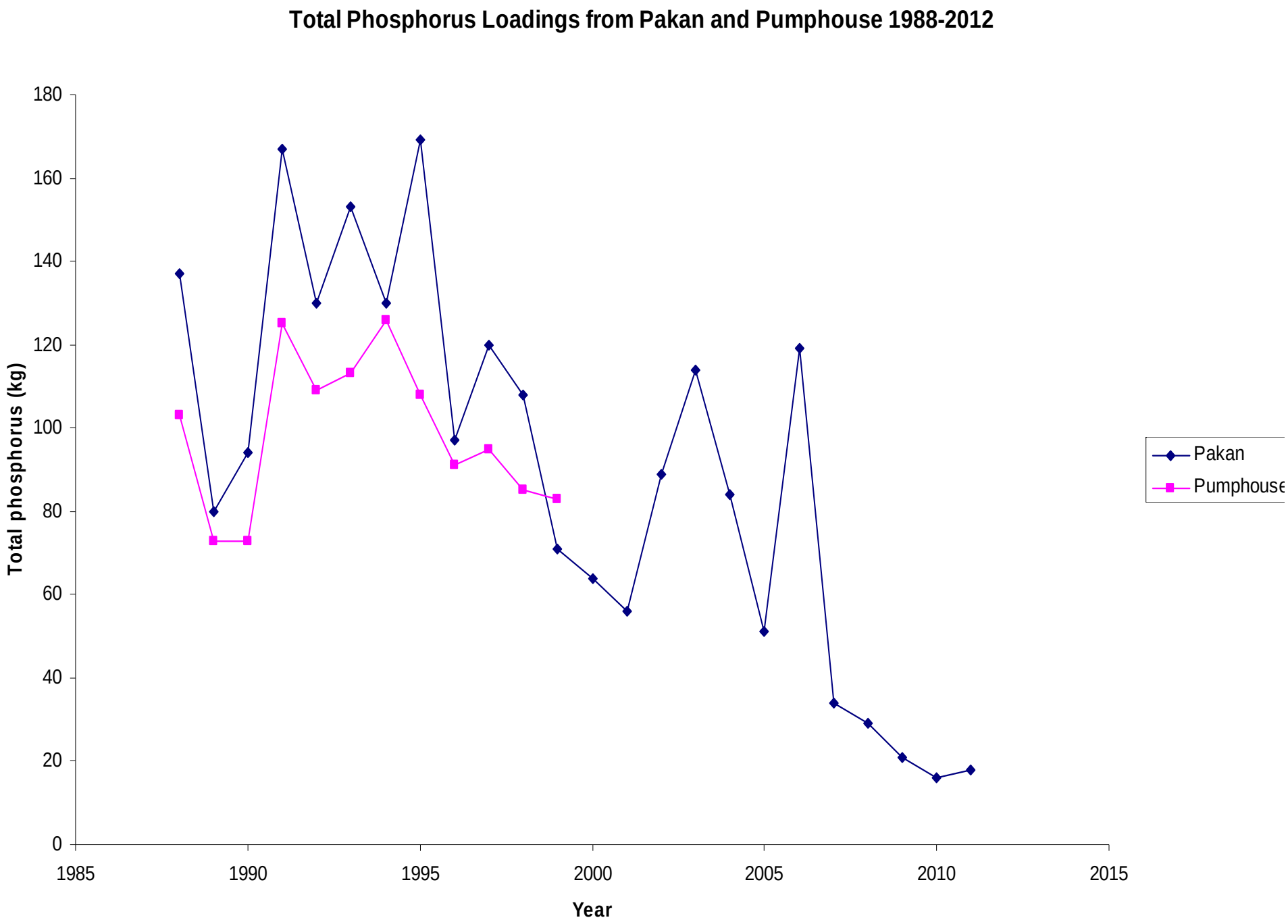
- A few lakes in Alberta have received long-term river diversions to raise lake levels
- Long-term water quality data for Lac St Cyr and Lake Wabamun suggest nutrient reductions as a result of NSR diversions
- Long-term water quality data for Lake Newell also suggest nutrient reductions as a result of Bow River diversions

Lac St Cyr Report (NSWA 2014)


Lac St Cyr
North Saskatchewan R.
Smoky Lake
Redwater
Saint Paul
Elk Point
Gibbons
Lamont
Two Hills
Fort Saskatchewan
Elk Island National Park
Vegreville
Beaverhill Lake Heritage Rangeland Natural Area
Tofield
Beaumont

Median Annual Phosphorus at Devon and Pakan




Total Phosphorus Loadings from Pakan and Pumphouse 1988-2012
Total phosphorus (kg)
180
160
140
120
100
80
60
40
20
0
1985
1990
1995
2000
2005
2010
2015
Year
Pakan
Pumphouse

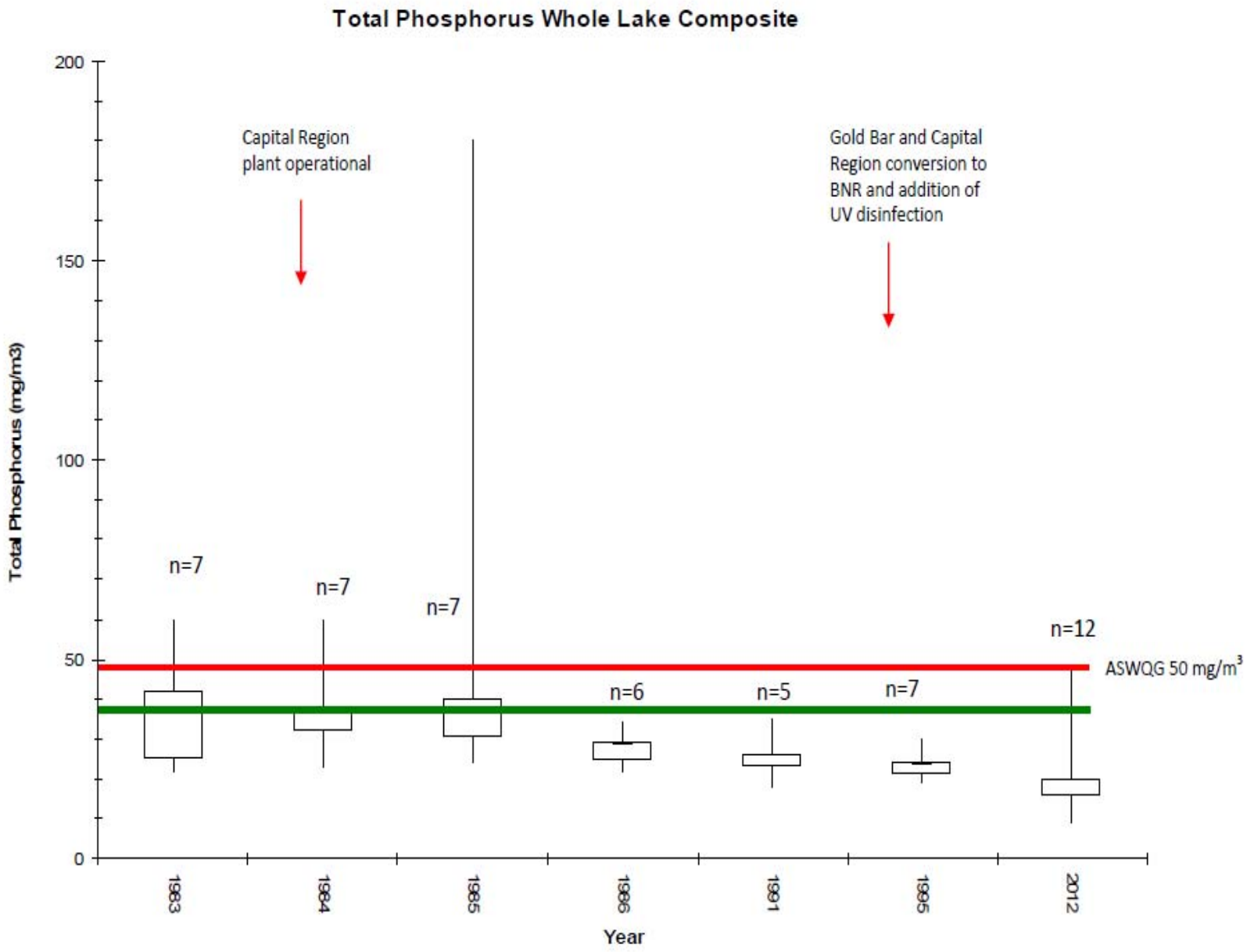


Figure 37. Total phosphorus levels in whole lake composite samples. A decreasing trend in concentrations can be seen. The Alberta Surface Water Quality Guideline for the Protection of Aquatic Life is indicated by the red line, while the green line indicates the transition concentration from mesotrophic status to eutrophic status (Vollenweider, 1982; Nurnberg, 1996). Based on TP concentration criteria the lake is now in a mesotrophic state.

Whole Lake Composite Samples

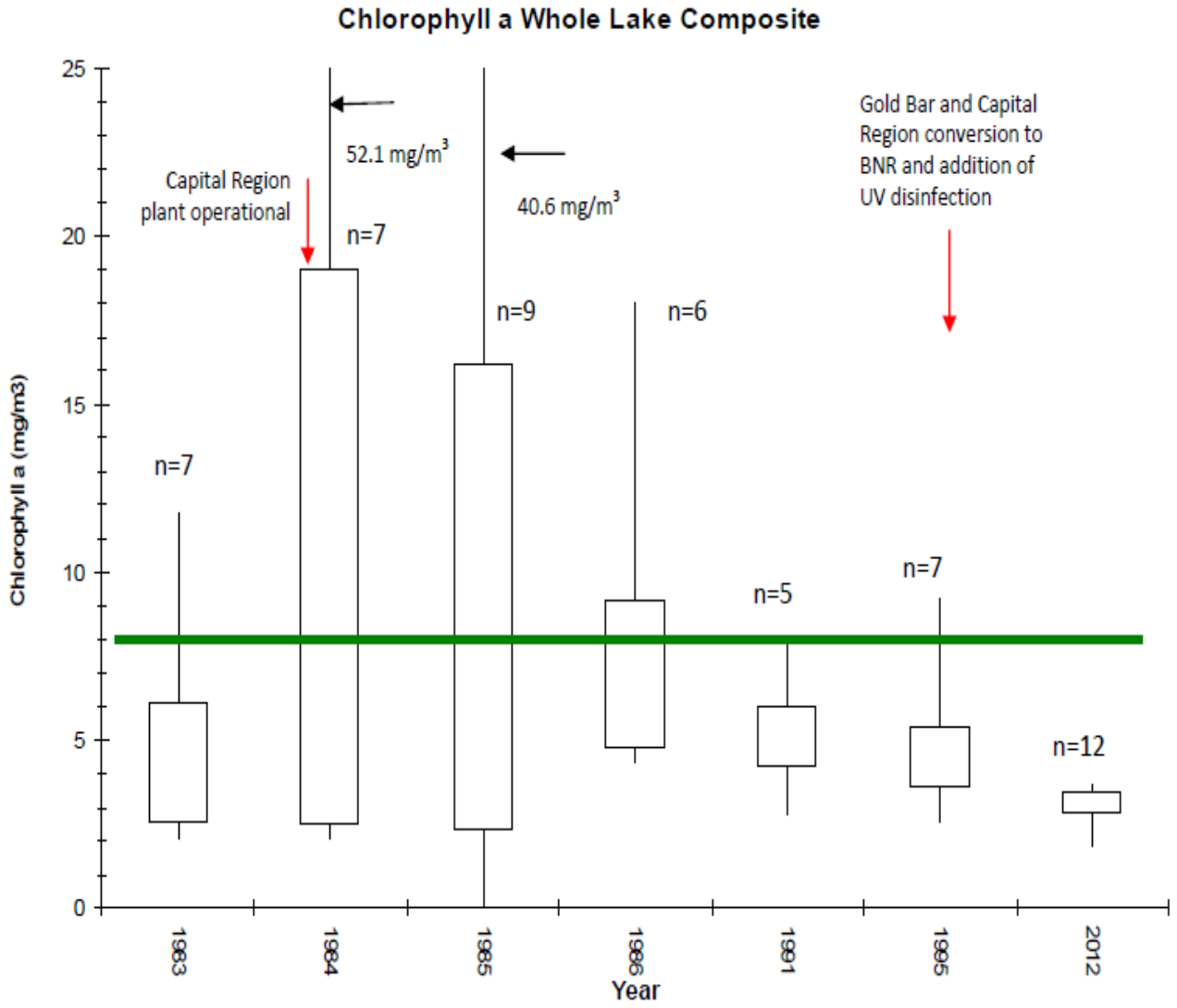
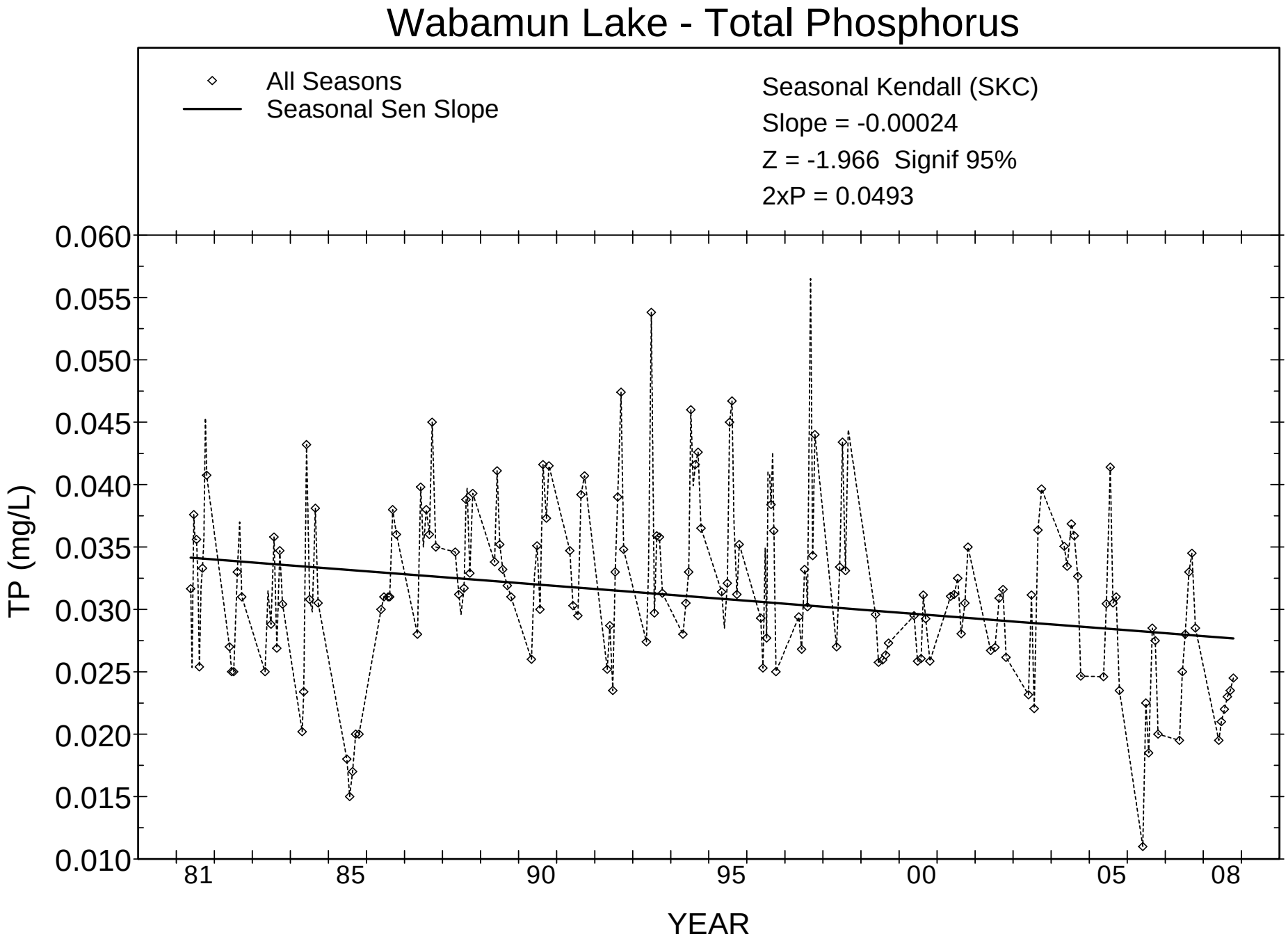
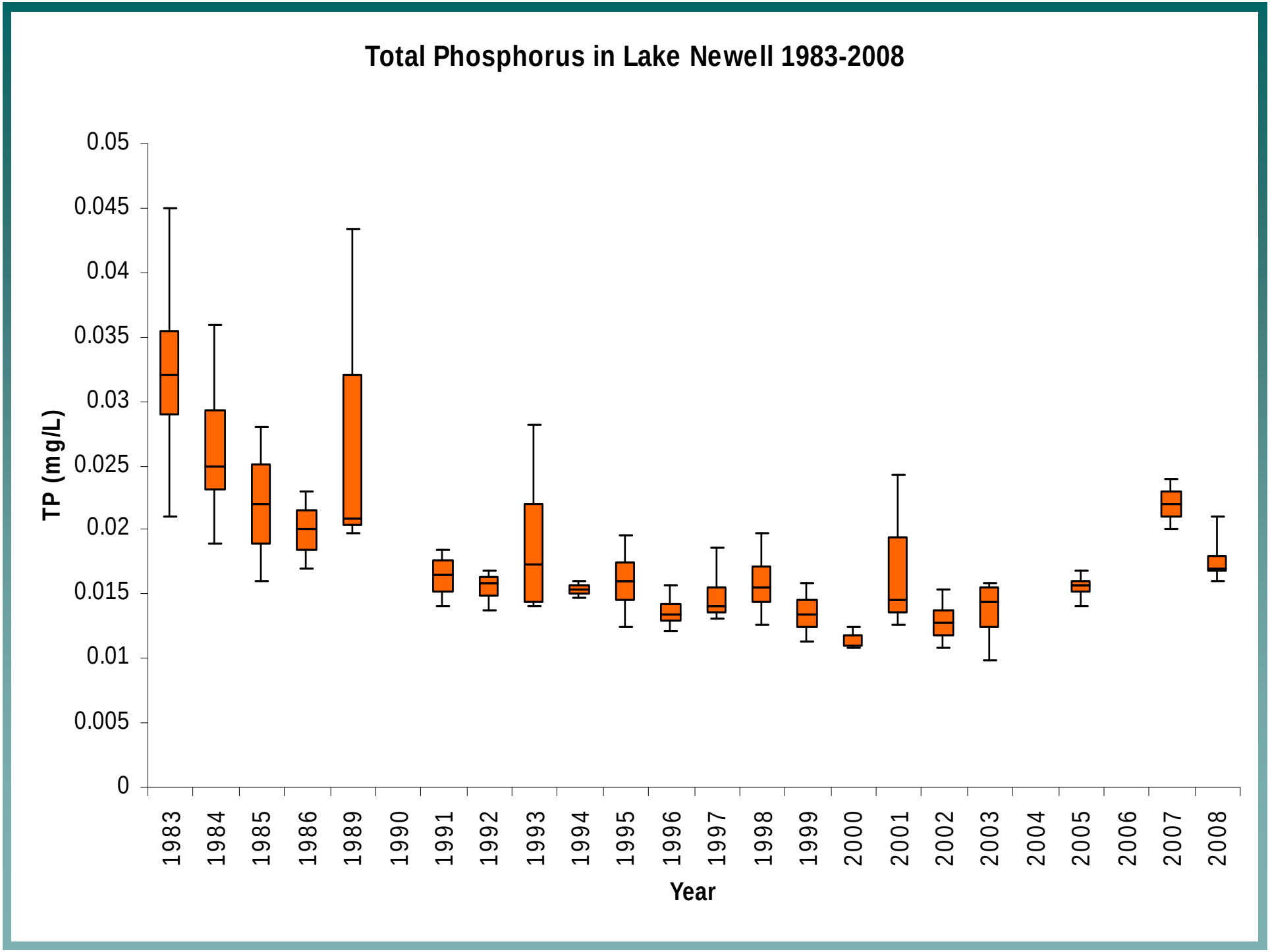


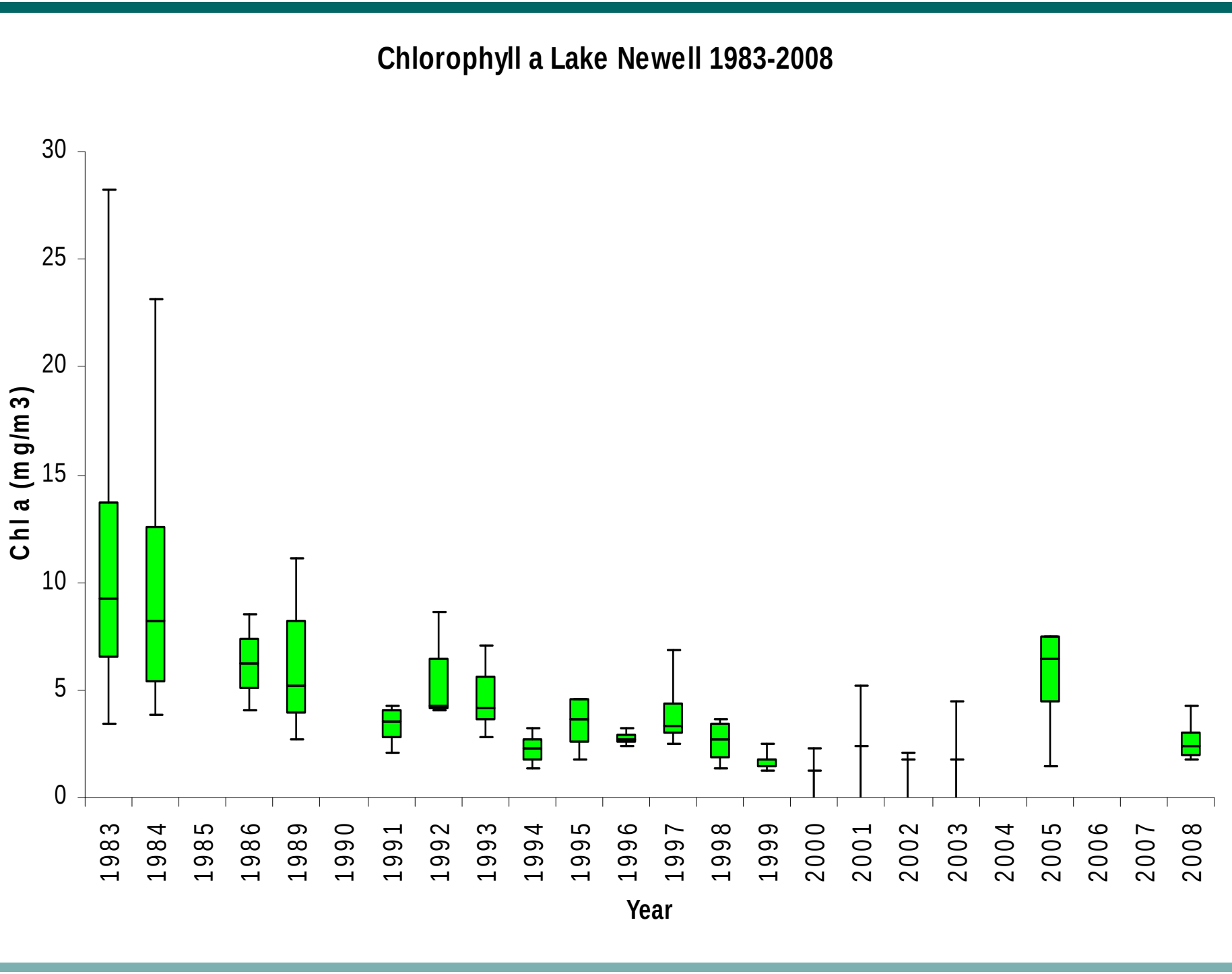
Figure 36. Chlorophyll-a levels in whole lake composite samples. Values greater than the scale are shown next to the arrows. Peak concentrations are seen in 1984 and 1985, and levels declined into 2012. The green line indicates the transition concentration from mesotrophic status to eutrophic status (Vollenweider, 1982; Nurnberg, 1996). Based on chlorophyll-a concentration criteria the lake is now in a mesotrophic state.

NSR Diversion to Lake Wabamun (Commenced 1999)


Wabamun Lake - Total Phosphorus
All Seasons
Seasonal Sen Slope
Seasonal Kendall (SKC)
Slope = -0.00024
Z = -1.966 Signif 95%
2xP = 0.0493
TP (mg/L)
0.060
0.055
0.050
0.045
0.040
0.035
0.030
0.025
0.020
0.015
0.010
81
85
90
95
00
05
08
YEAR

Historical data for Lake Newell


Total Phosphorus in Lake Newell 1983-2008
TP (mg/L)
0.05
0.045
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
1983
1984
1985
1986
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
Year


Chlorophyll a Lake Newell 1983-2008
Chl a (mg/m3)
30
25
20
15
10
5
0
1983
1984
1985
1986
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
Year

Diversions

- Alberta's long-term (~35 year) lake and reservoir data bases should be further reviewed to evaluate river diversion effects on nutrient levels
- Note:
  - Diversion proposals must be evaluated comprehensively for water quality effects, trans-faunation potential, economic implications and impacts on downstream users
  - Ongoing watershed management to reduce nutrient loads is still required for all lakes

Thank you!