Restoring the Health of Lake Winnipeg:

Science, Policy, and Implications for Wastewater Treatment to Remove Nitrogen and Phosphorus

December 12, 2007

Presentation to APEGM

Dwight Williamson, Director
Water Science and Management Branch
Manitoba Water Stewardship

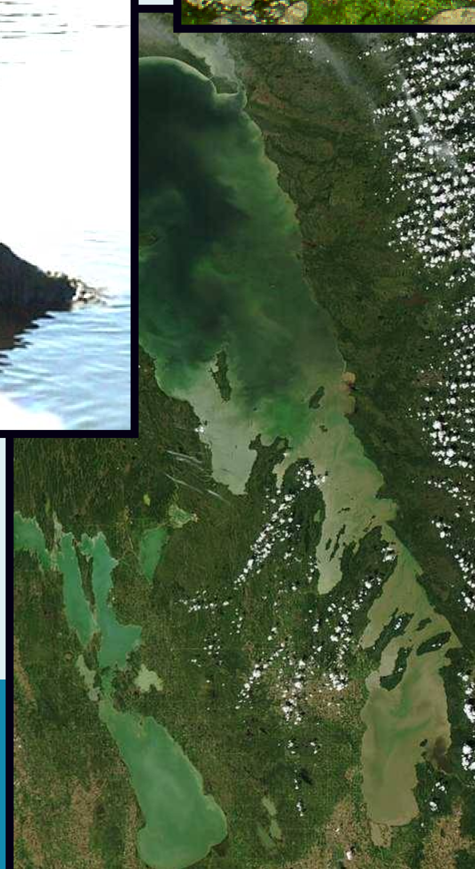
Manitoba

Eutrophication

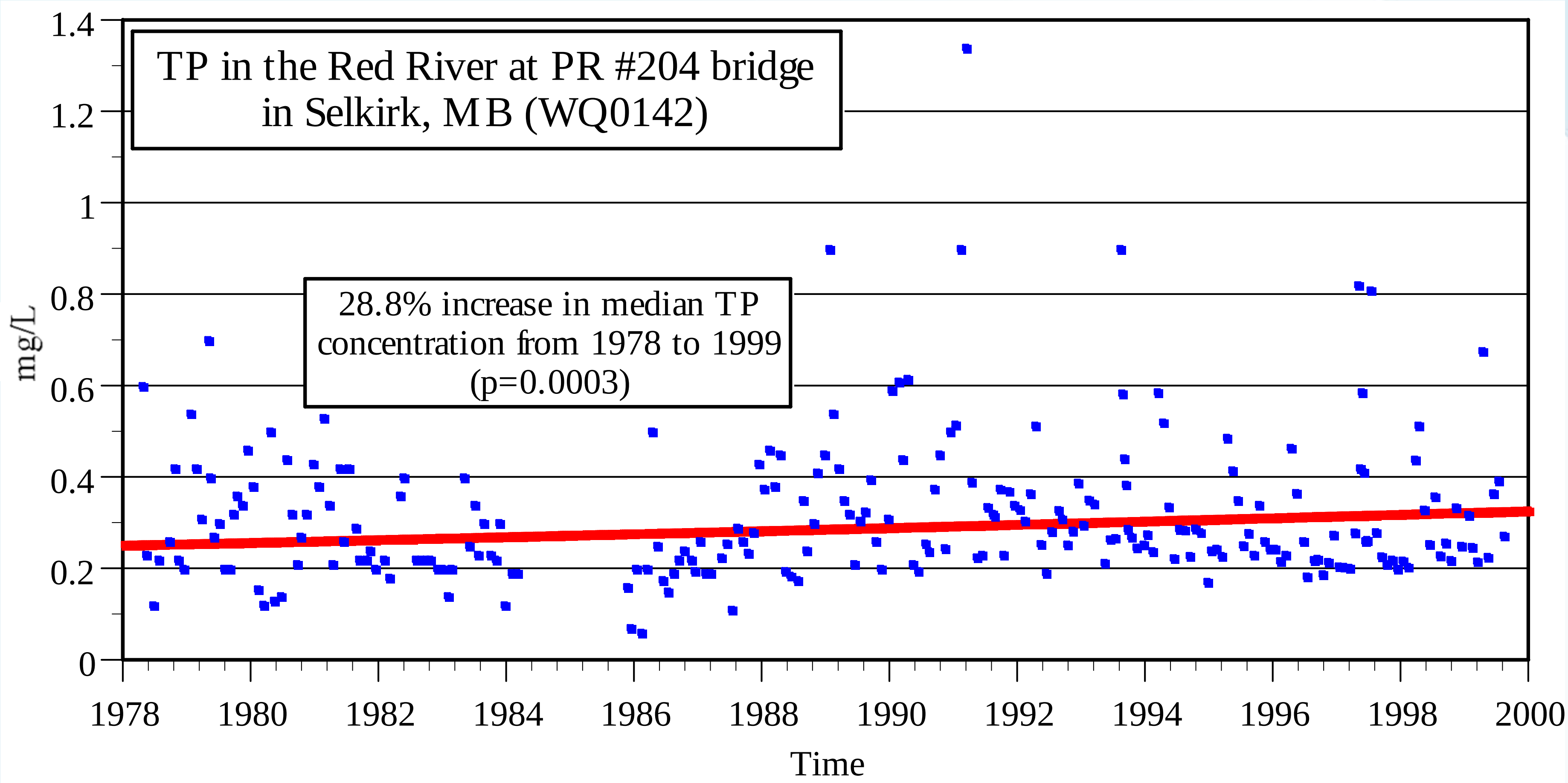
- Excessive growth of aquatic plants due to increasing supplies of nutrients
- Impacts
  - taste and odour in drinking water
  - oxygen depletion and fish kills
  - toxin production
  - degrade aquatic life habitat
  - impair recreational areas

Manitoba

Eutrophication (continued)

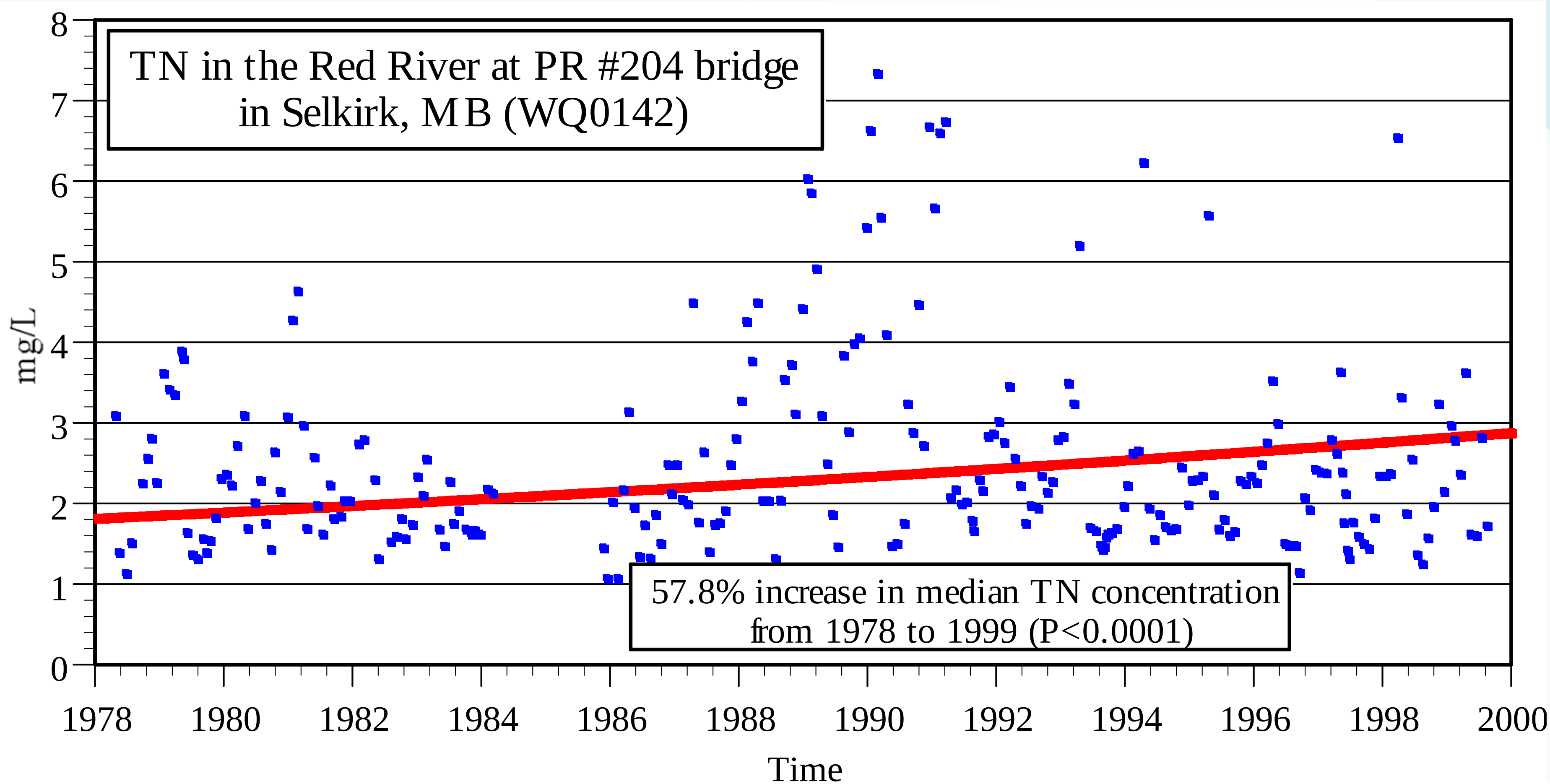


Phosphorus in Red River at Selkirk



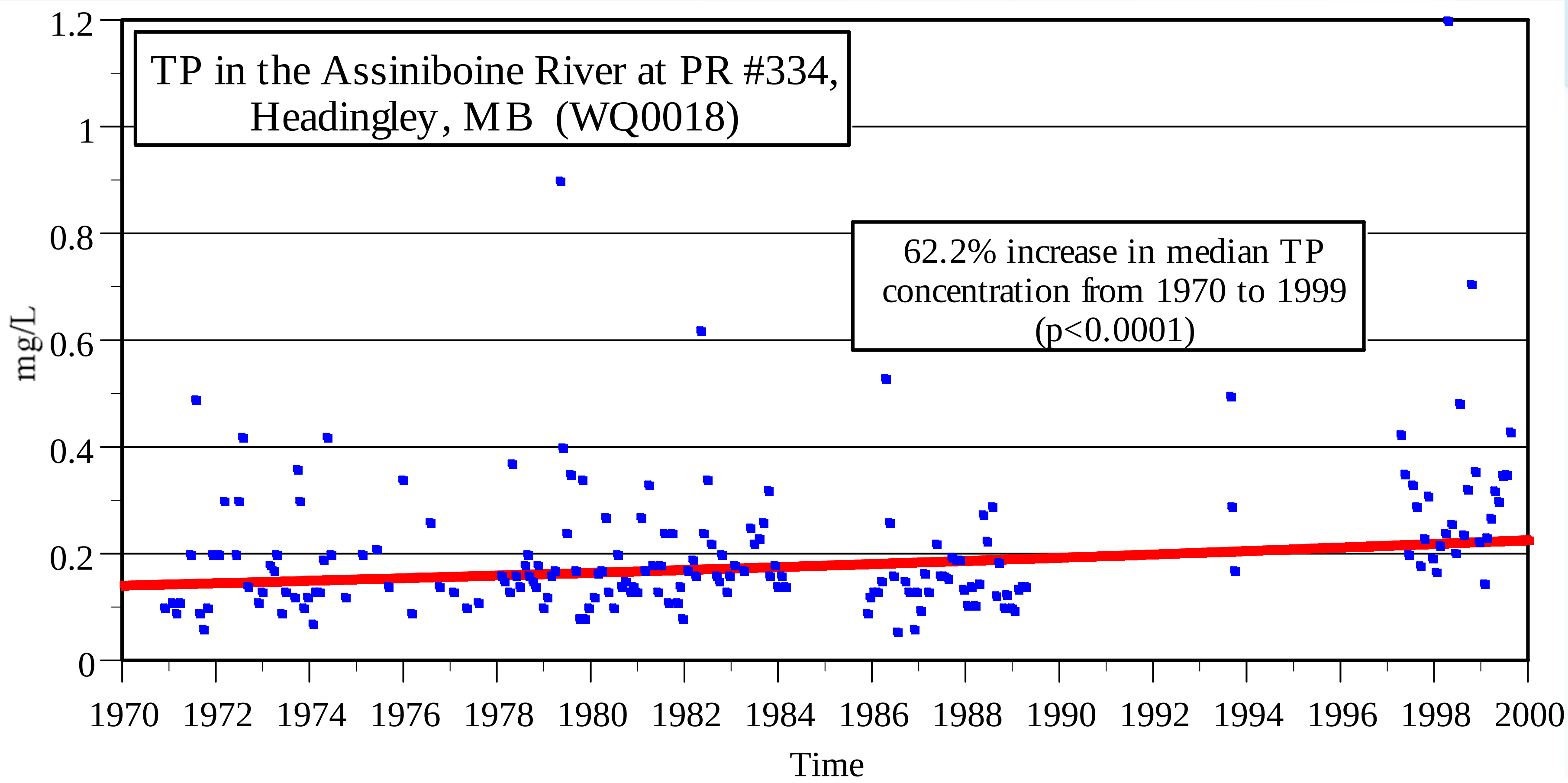
Manitoba

Nitrogen in Red River at Selkirk



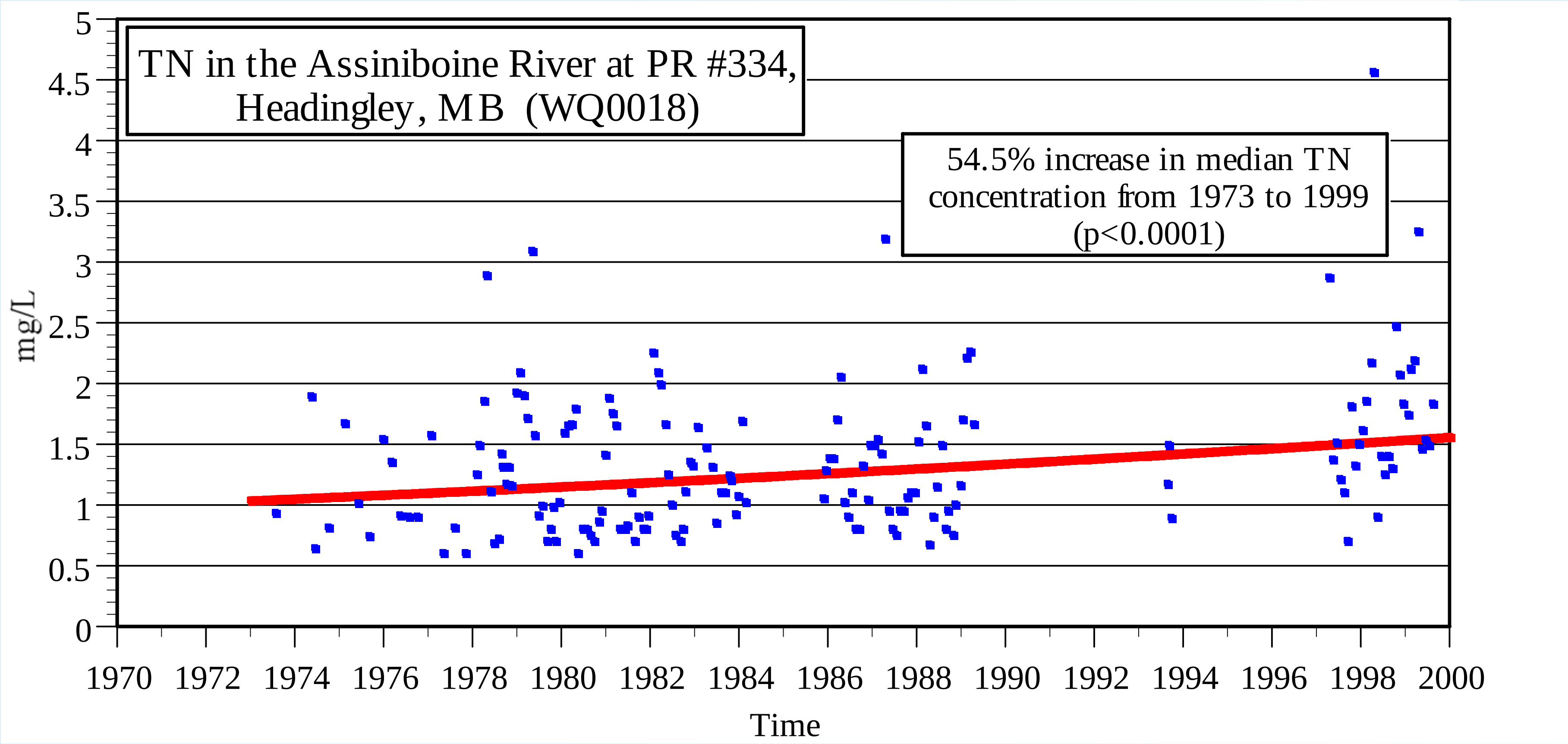
Manitoba

Phosphorus in Assiniboine River at Headingley

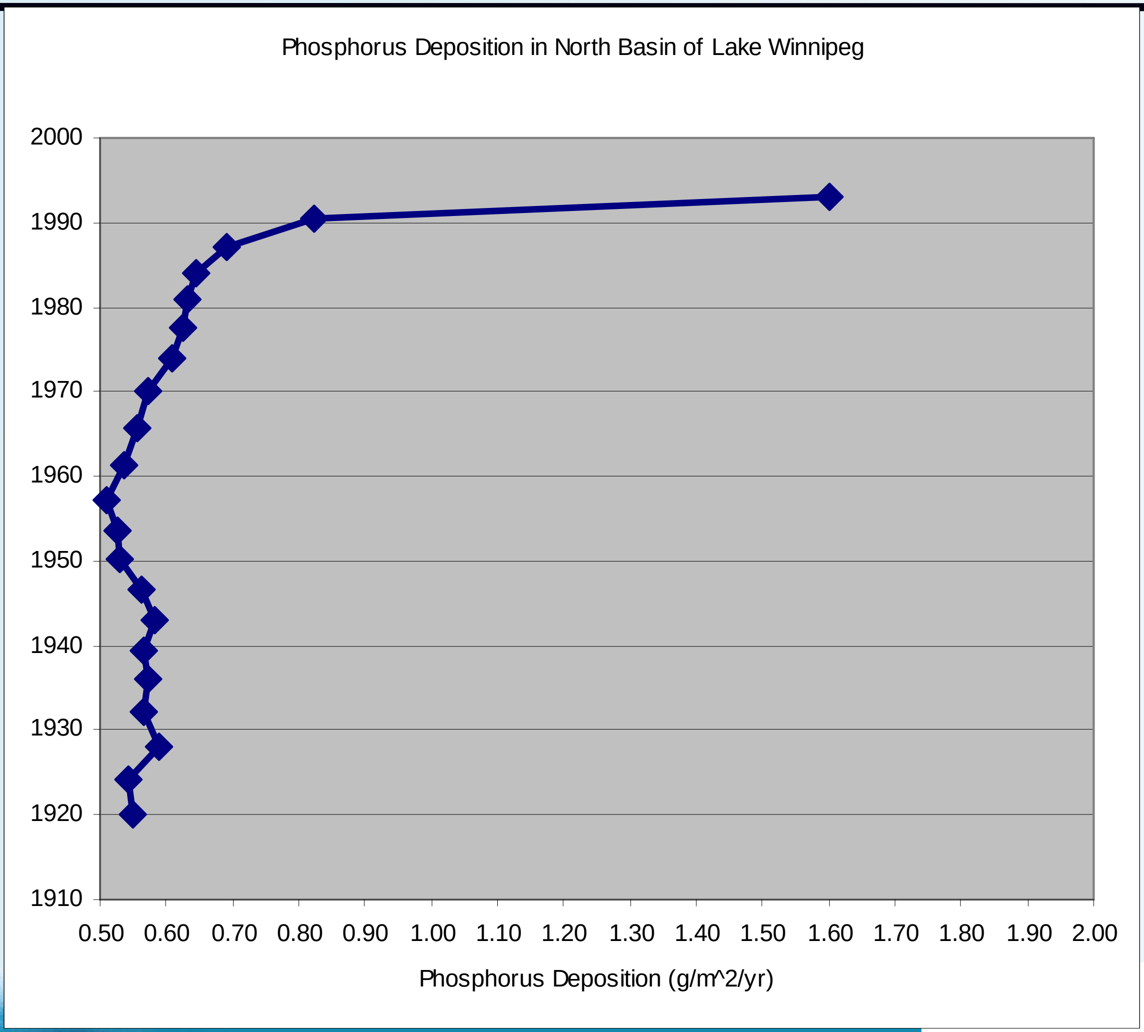


Manitoba

Nitrogen in Assiniboine River at Headingley

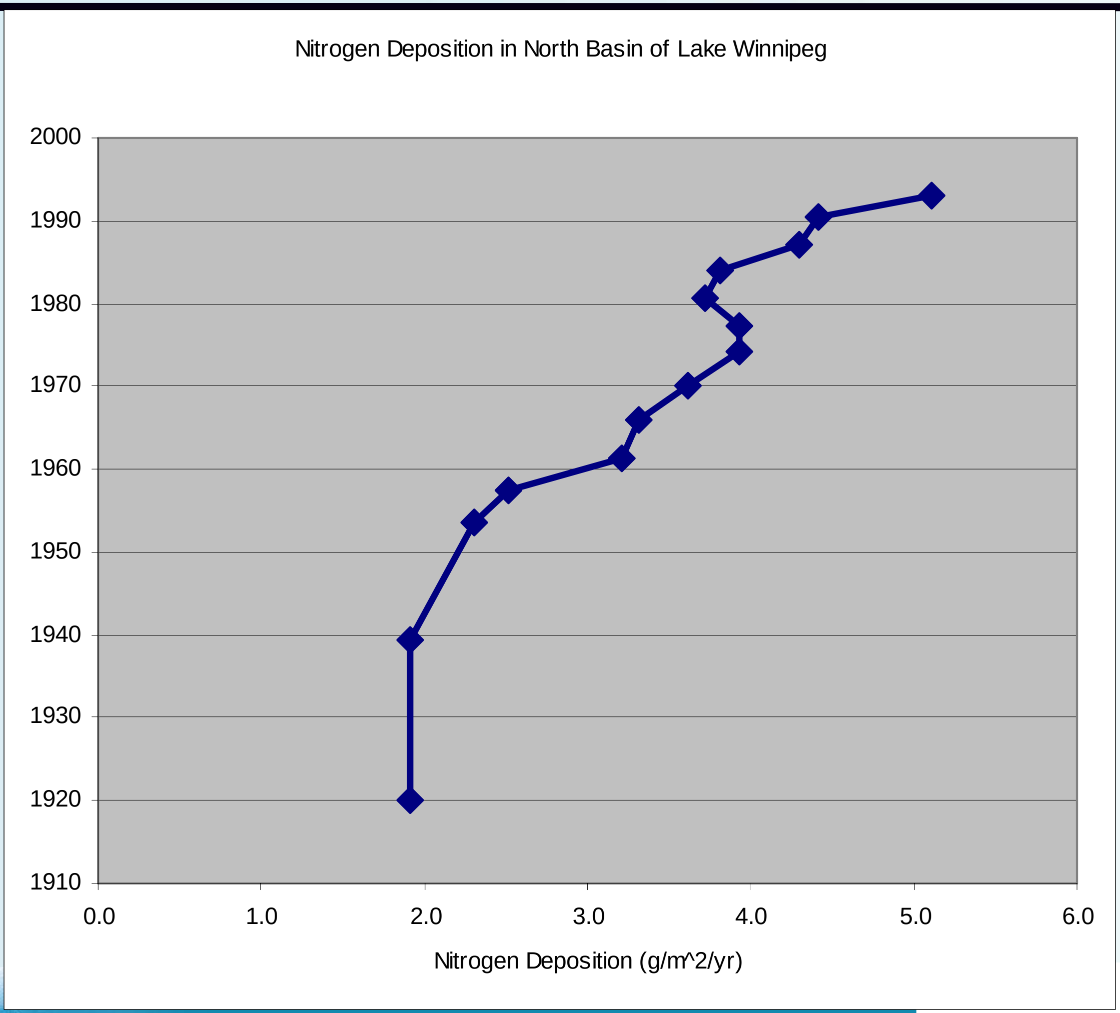


Phosphorus in North Basin Sediment Core



Manitoba

Nitrogen in North Basin Sediment Core



Manitoba

Grand Beach

Manitoba

Sources of Nutrients

Category	Nitrogen (%)	Phosphorus (%)
Overall annual nutrient load to Lake Winnipeg	96,000 tonnes / year	7,900 tonnes / year
Upstream jurisdictions	51	53
United States (Red River)	20	32
United States (Souris River)	1	3
Saskatchewan and Alberta (Assiniboine and Saskatchewan)	9	5
Ontario (East side)	4	3
Ontario (Winnipeg River)	17	10
Manitoba Sources	39	47
Manitoba Point Sources	5	9
City of Winnipeg	4	5
All others	1	4
Manitoba Watershed Processes	24	32
Estimated natural background	19	17
Present day agriculture	5	15
Atmospheric Deposition	10	6
Nitrogen Fixation	10	---

Policy

- Lake Winnipeg Action Plan
  - Phosphorus
    - reduce loadings by 10 %
  - Nitrogen
    - reduce loadings by 13 %

Scrimgeour and Chambers (2000)

- **Athabasca and Wapiti-Smoky rivers, Alberta:**
  - **18 of 33 sites were nutrient limited and of the 18**
    - **6 were limited by nitrogen**
    - **5 were limited by phosphorus**
    - **7 were co-limited (that is, limited by both nitrogen and phosphorus)**

Heiskary and Markus (2001)

- **Studied five medium to large streams in Minnesota:**

  "Strong relationships were evident among in-stream nutrients (TP and TKN in particular) and algae (expressed as total chlorophyll a) for medium to high order streams."

Dodds *et al.* (2002)

- **Examined relationships between the attached algae community at 300 stream sites across the United States and reported that:**

  "The greatest portion of variance in models for the mean and maximum biomass of benthic stream algae (about 40 %) was explained by concentrations of total N and P."

Manitoba

U.S. EPA (2000)

- Technical guidance on the development of criteria for nutrients:

  "...regional studies have demonstrated the importance of other factors regulating algal biomass in lakes. Four other factors include nitrogen ..., light limitation due to suspended solids..., lake morphometry..., and grazing by herbivores...".

- and

  "The primary factors that determine algal biomass (production) are the plant nutrients phosphorus and nitrogen."

Manitoba

U.S. EPA (2000)(continued)

- and finally

"If only one factor, such as phosphorus, was always limiting, the task of developing nutrient criteria would be a simple matter of determining limits on that single factor. Unfortunately, the factor that limits plant biomass may (1) change seasonally or over longer periods of time, (2) vary depending on the land use, or (3) vary regionally. It would make little sense to construct a single nutrient criterion when that nutrient may not necessarily limit a target lake or lakes."

Manitoba

Downing *et al.* (2001)

Table 1. Efficacy of major variables for predicting Cyanobacterial abundance in temperate zone lake plankton.

Variable	Regression equation	n	RMS	r^2
Phytoplankton biomass	BG index = –8.44 + 2.07$\log_{10}$ biomass	268	1.77	0.43
Chlorophyll *a* (chloro)	BG index = –3.10 + 1.94$\log_{10}$ chloro	157	1.84	0.43
Total nitrogen (TN)	BG index = –10.0 + 3.03$\log_{10}$ TN	204	1.85	0.42
Total phosphorus (TP)	BG index = –4.16 + 1.88$\log_{10}$ TP	268	2.06	0.34
TN/TP	BG index = 3.15 – 3.29$\log_{10}$ TN/TP	204	2.34	0.26

Downing *et al.* (2001) (continued)

- **Reported that:**

  "Despite the prevalence of P limitation in north-temperate freshwater ecosystems, total N is more strongly correlated with Cyanobacteria dominance than total P."

Manitoba

Downing *et al.* (2001) (continued)

- and

  “We show that the risk of water quality degradation by Cyanobacteria blooms is more strongly correlated with variation in total P, total N, or standing algae biomass than the ratio of N:P. Risks associated with Cyanobacteria are therefore less associated with N:P ratios than a simple increase in nutrient concentrations and algal biomass.”

Cooley *et al.* (2003)

- **In a study on the Assiniboine River done for the City of Brandon between Portage and Brandon reported that:**

  "Algal growth is potentially limited by many factors, including flow, light, temperature, and nutrients. Site-specific characteristics (e.g., appropriate substrata for attached algae) are also important."

- **and**

  "Examination of nutrient concentrations and ratios indicated that, in instances where other factors do not limit growth, nitrogen was the nutrient which would limit algal production in much of the Assiniboine River under low flow conditions."

Manitoba

Armstrong (2005)

- **In a study on the Assiniboine River upstream of Brandon reported that:**

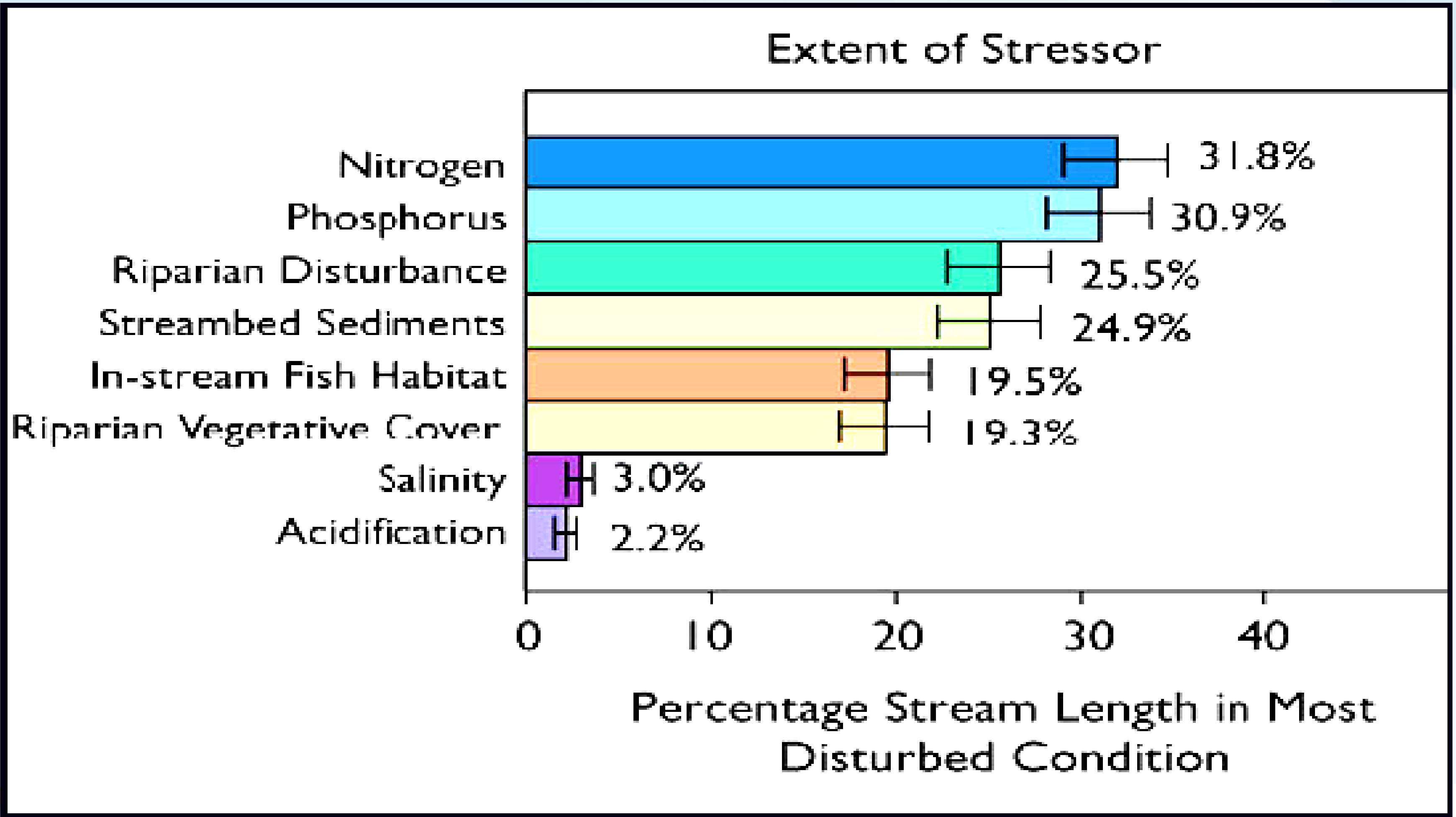
  "Algal biomass in the Assiniboine River was limited primarily by light with phosphorus as the primary nutrient limiting algal biomass during the winter and nitrogen limiting in the open water season."

U.S. EPA (2006)

- **Assessed factors contributing to the biological impairment of over 1,000,000 km of streams across the United States and reported that:**

"...excess total nitrogen is the most pervasive stressor for the nation..."

U.S. EPA (2006) (continued)



Leavitt *et al.* (2006)

- **Concluded that urban sources of nitrogen play an important role in degrading water quality in the phosphorus rich lakes in the Qu'Appelle River valley and that it requires control:**

  "...we believe that these patterns will be common to other phosphorus-sufficient lakes...".

Leavitt *et al.* (2006) (continued)

- **and**

  "...our analyses suggest that improvements in water quality are linked to reductions in nitrogen influx when lakes are replete with phosphorus from natural or anthropogenic sources".

- **and**

  "...phosphorus seems not to regulate algal production in these lakes...".

Manitoba

Leavitt *et al.* (2006) (continued)

- **and**

  "...these patterns suggest elimination of urban nitrogen sources should be the first priority for ecosystem management and that substantial improvements in water quality are expected even though Pasqua Lake is naturally eutrophic...".

- **and**

  "...we propose that sewage treatment processes should be upgraded to modern microbial methods if receiving lakes are replete with phosphorus. Such Biological Nutrient Reduction procedures remove up to 90% of total dissolved nitrogen load through denitrification...".

Leavitt *et al.* (2006) (continued)

- and finally,

  "...because Biological Nutrient Reduction processes also provide better phosphorus removal from wastewaters than do many strictly chemical approaches, improved effluent treatment is also expected to reduce production of phosphorus-limited or nitrogen-phosphorus co-limited algae".

Dodds and Paul (2007)

- Not just one nutrient limits production
- Nitrogen limits as commonly as phosphorus in streams, lakes and wetlands
- Managing for just phosphorus may miss the limiting nutrient
- Phosphorus input from sewage may be easiest to regulate, but is not necessarily the whole problem

Elser *et al.* (1990)

- **Reviewed findings of nutrient enrichment experiments in over 60 lakes in North America:**

  "...we found that combined nitrogen and phosphorus enrichment enhanced algal growth much more frequently and more substantially than did addition of nitrogen or phosphorus singly. On average, the frequency and degree of algal response did not differ for phosphorus versus nitrogen enrichment."

Manitoba

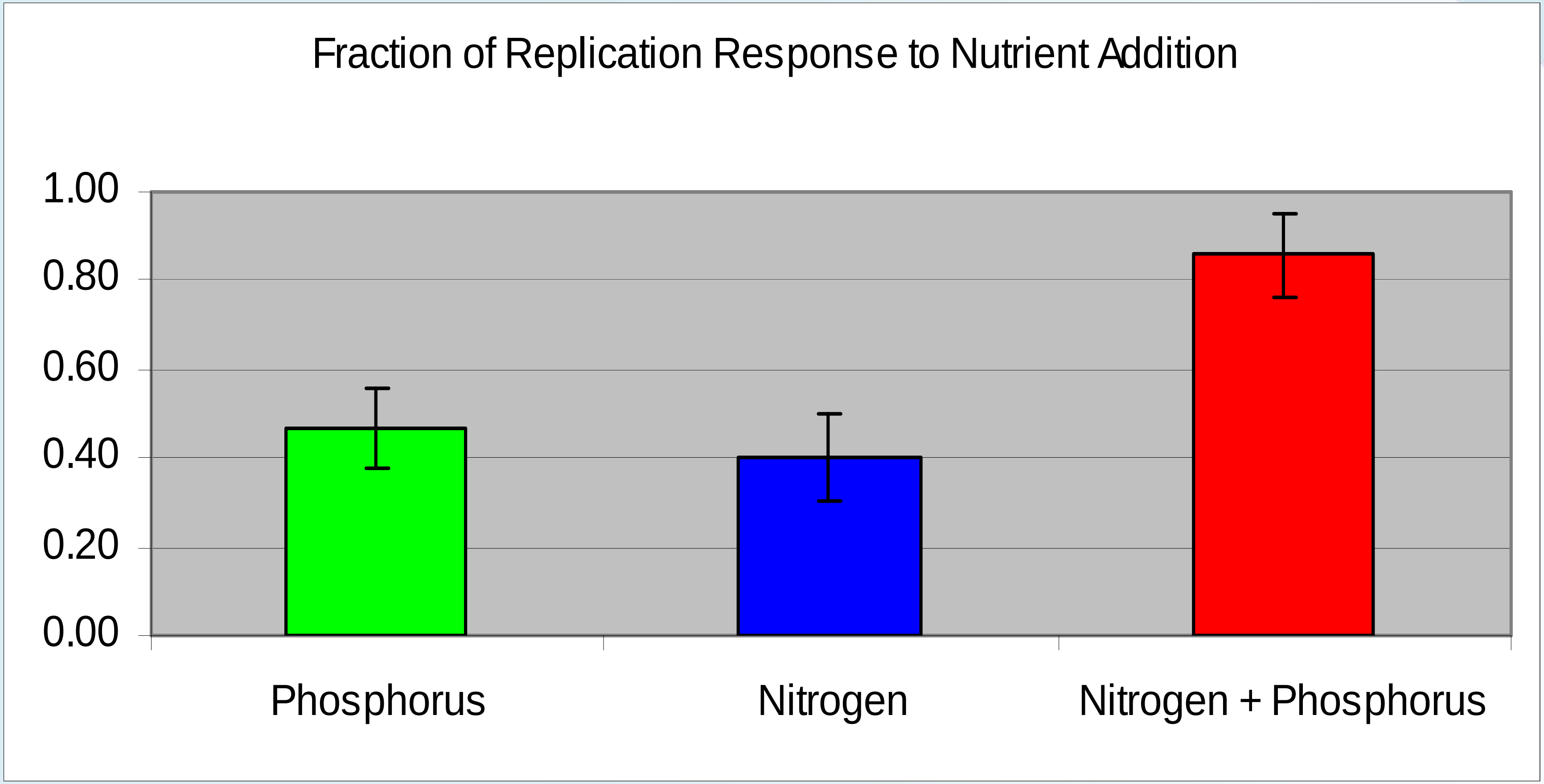
Elser *et al.* (1990) (continued)

- and further

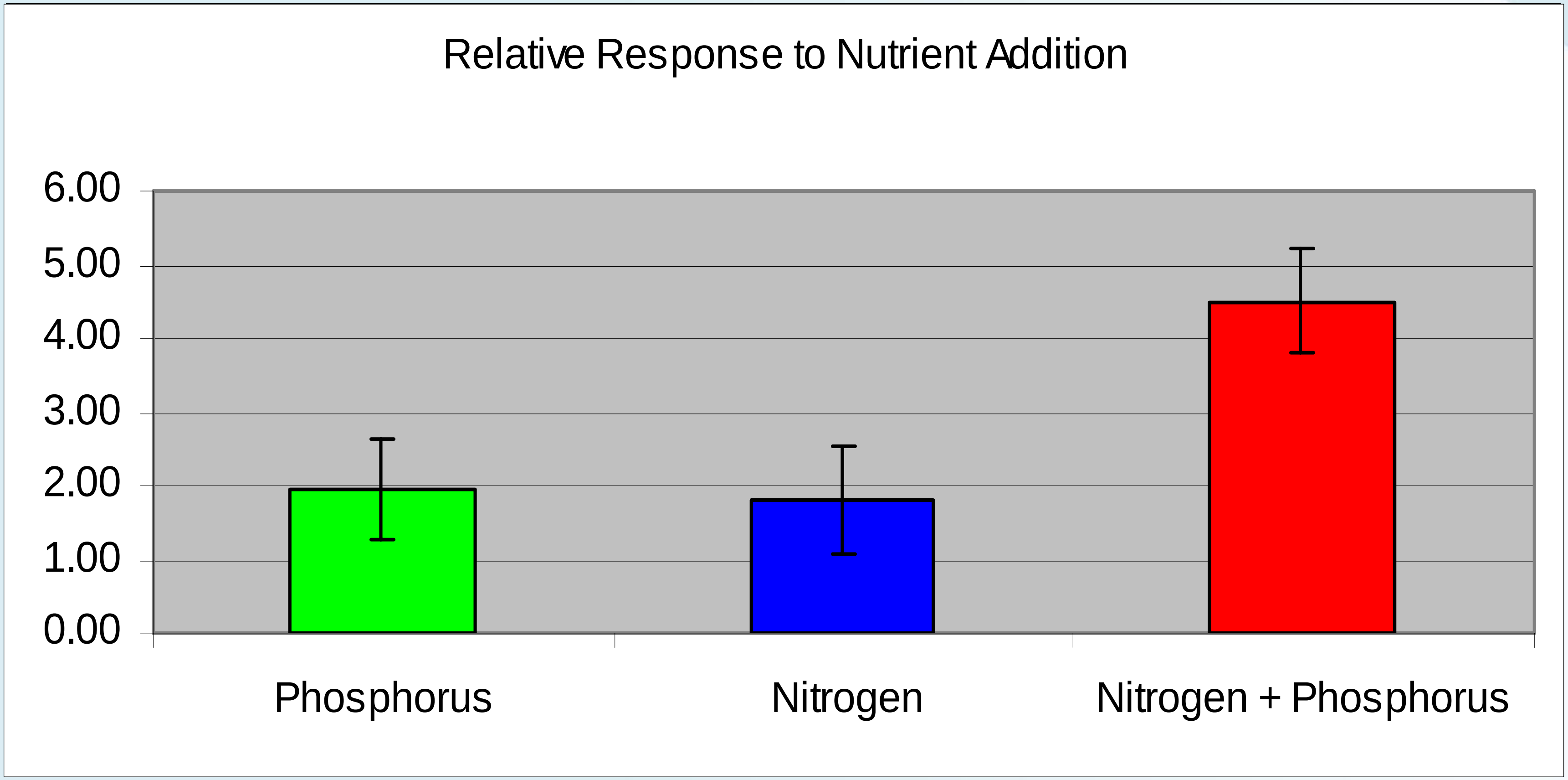
  "We suggest that greater attention should be given to both phosphorus and nitrogen in the future".

Manitoba

Elser *et al.* (1990)



Elser *et al.* (1990)



Summary, So Far...

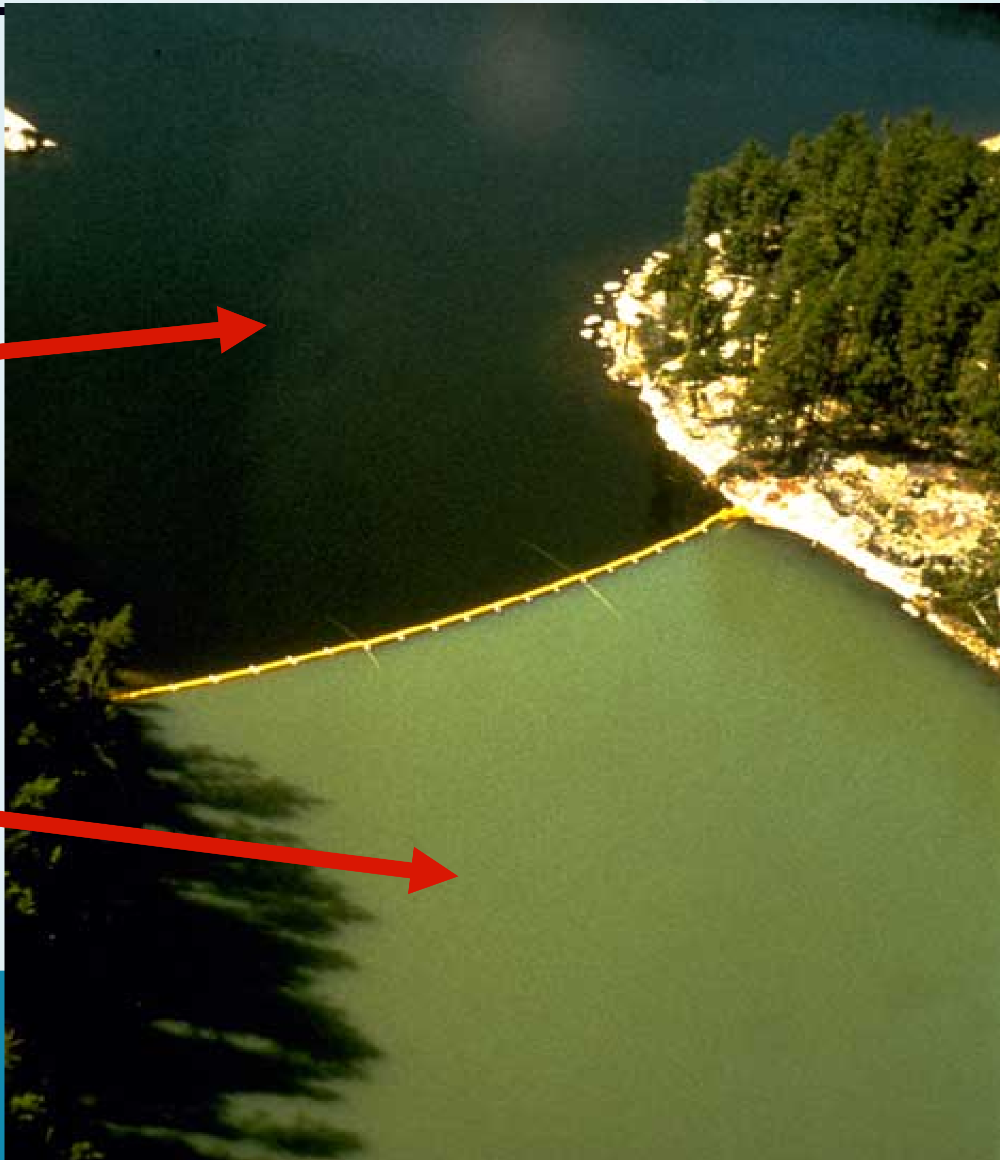
- Contemporary science strongly links both nitrogen and phosphorus to eutrophication
- There will be environmental benefits from reductions of both nitrogen and phosphorus

Schindler (1974)

Lake 226 (August 1973)

Nitrogen

Nitrogen + Phosphorus



Schindler (2006)

- **Re-visited the famous Lake 226 experiment and reported that:**

  "The half not receiving phosphorus remained in near-pristine conditions, while the part that received phosphorus as well as nitrogen and carbon developed algal blooms within weeks of beginning nutrient additions."

Manitoba

Schindler (2006) (continued)

- **Highlighted reasons for widespread use of the Lake 226 photograph:**

  "An aerial picture of the lake was particularly convincing evidence for the control of phosphorus to policy makers who did not fully understand the scientific arguments."

University of Manitoba (2007)

- **A University of Manitoba website contains a similar representation:**

  "ELA Lake 226 was the site of a visually spectacular experiment. The lake was divided into two approximately equal portions using a plastic divider curtain. Carbon and nitrogen were added to one half of the lake, while carbon, nitrogen and phosphorus were added to the other half. For eight consecutive years, the side receiving phosphorus developed eutrophic algal blooms, while the side receiving only carbon and nitrogen did not. However, after only two years, this experiment convinced even the skeptics that phosphorus is the key nutrient."

  (http://www.umanitoba.ca/institutes/fisheries/eutro.html)

Manitoba

Interlake Spectator (April 6, 2007)

- **In a story on algal blooms in Lake Winnipeg, a local scientist was quoted:**

  "They came to the conclusion that the primary culprit was phosphorous or phosphate. They proved it convincingly in an experiment in which they added equal amounts of carbon and nitrogen to both sides of a lake, then added phosphorous to one side only. That one side completely got enveloped in an algal bloom. This was significant because the major problem in Lake Erie was phosphates from human sewage and detergent."

Manitoba

Interlake Spectator (April 6, 2007) (continued)

- **and**

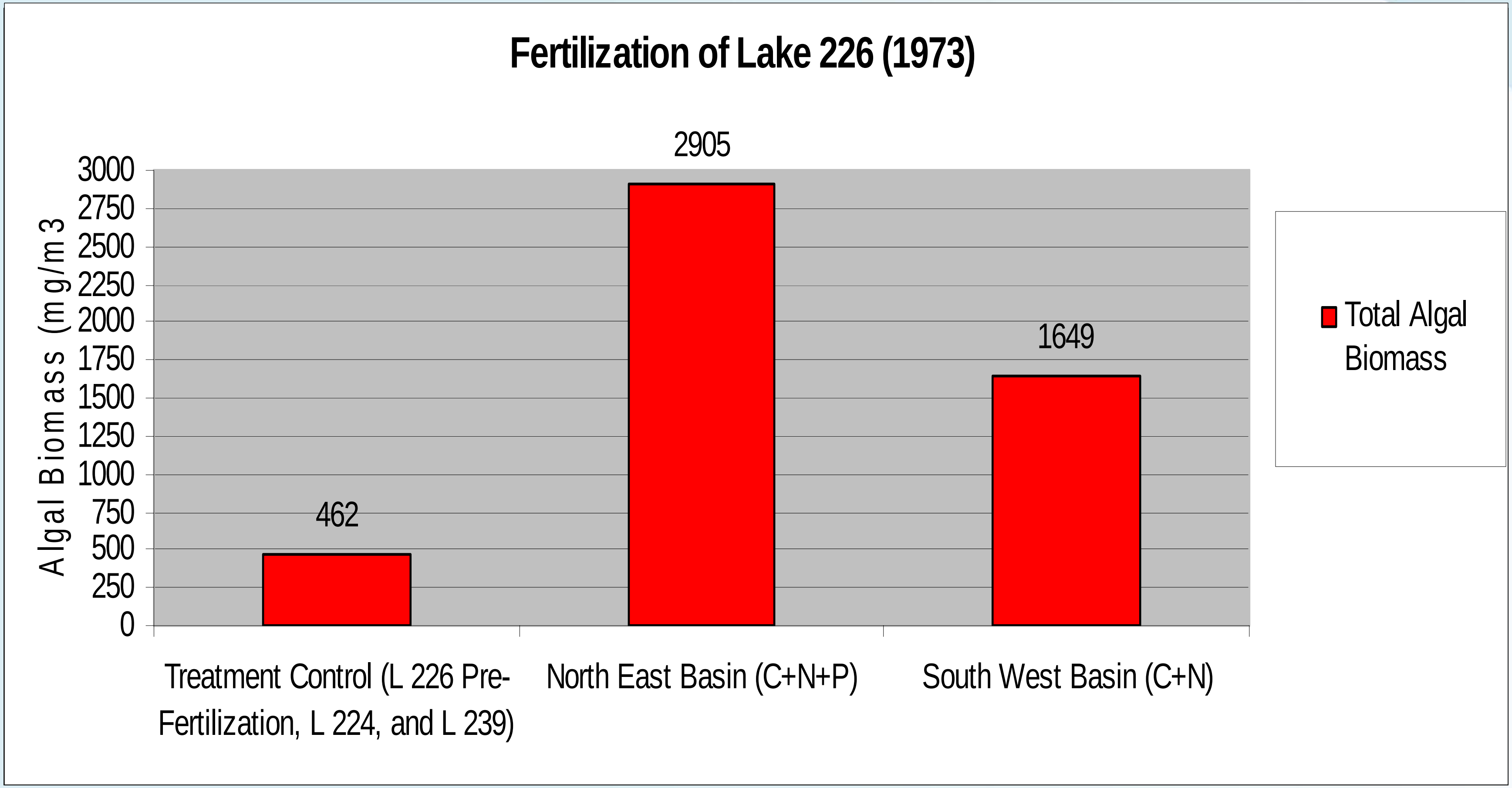
  "We have to get the message out that the nature of the problem is driven by phosphorous."

Findlay and Kasian (1987)

- **Documented the results from Lake 226 and reported that:**

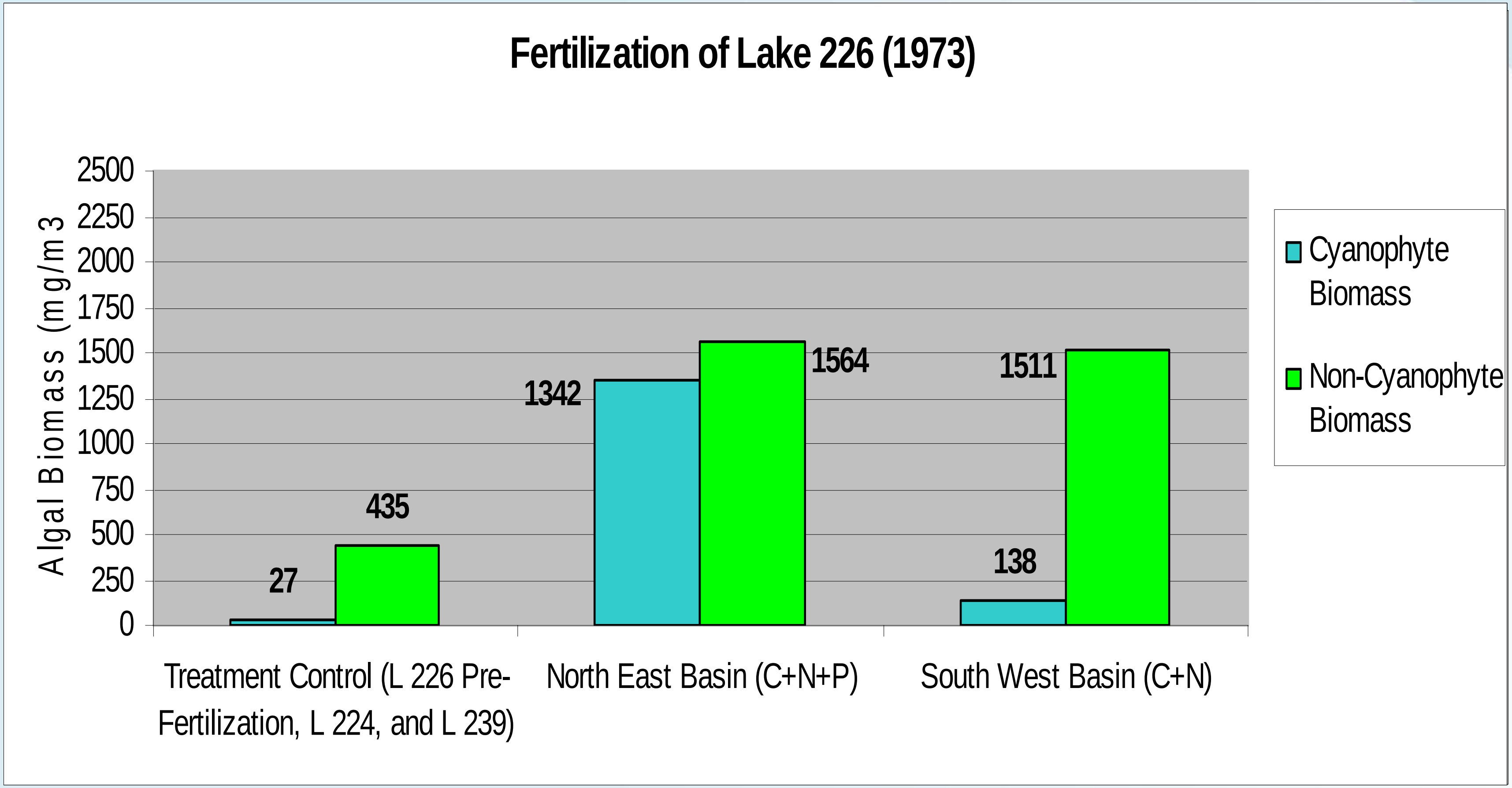
  “Over an 8-year period, the average biomass of phytoplankton in the basin receiving carbon, nitrogen, and phosphorus ... increased 4 to 8 times and the biomass in the basin receiving only carbon and nitrogen ... increased 2 to 4 times over non-fertilized years.”

Lake 226

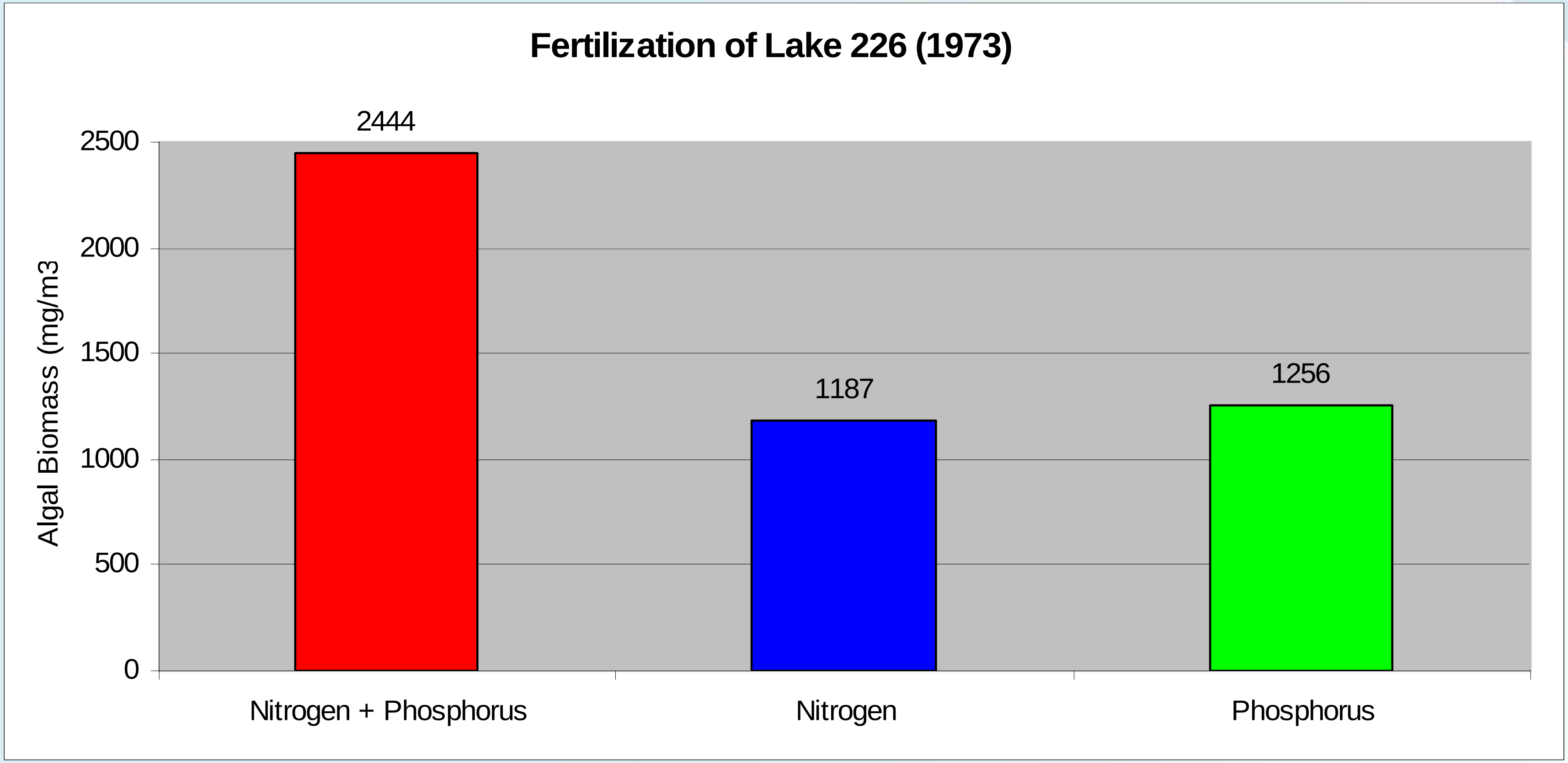


Fertilization of Lake 226 (1973)
Algal Biomass (mg/m3)
3000
2750
2500
2250
2000
1750
1500
1250
1000
750
500
250
0
462
2905
1649
Treatment Control (L 226 Pre-Fertilization, L 224, and L 239)
North East Basin (C+N+P)
South West Basin (C+N)
Total Algal Biomass

Lake 226 (continued)

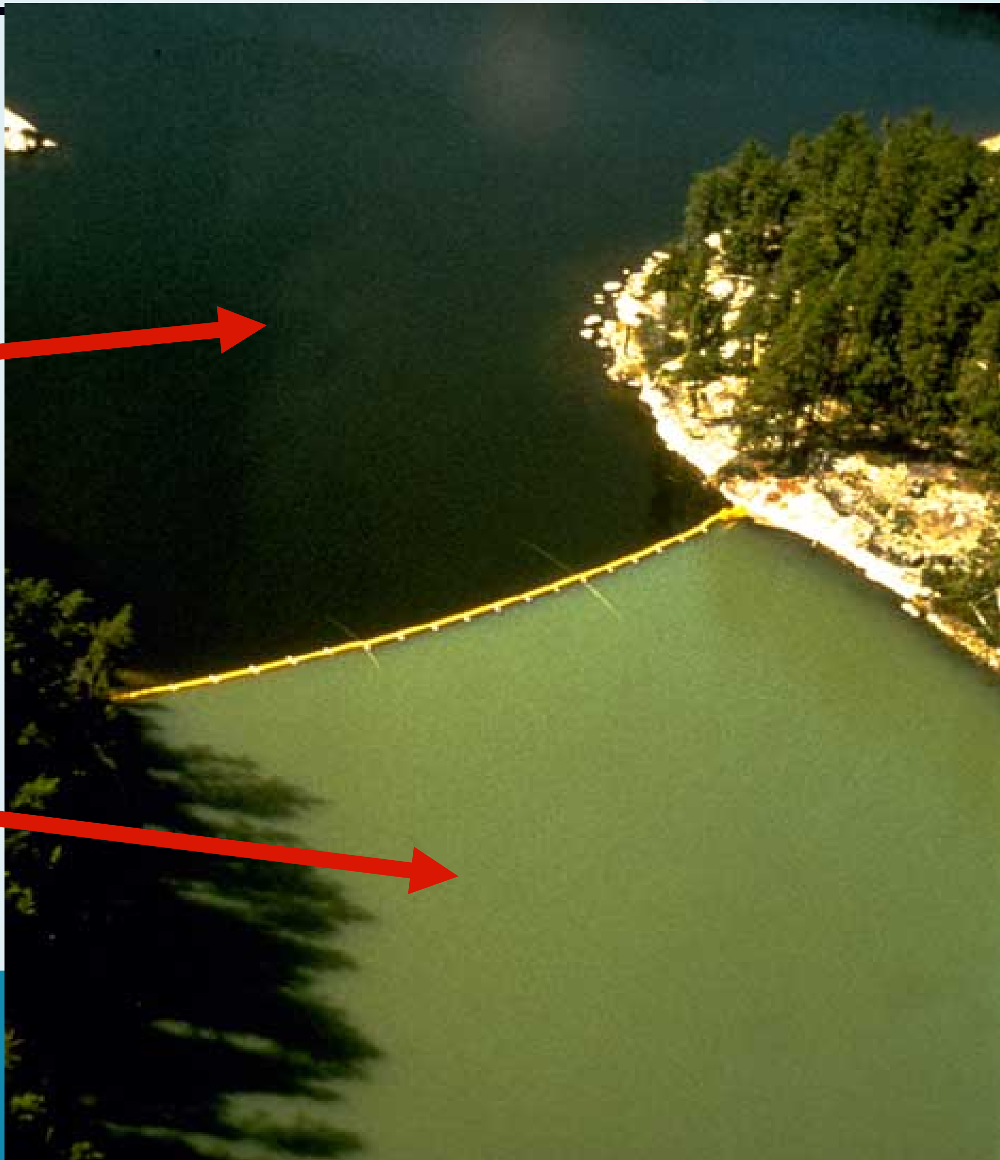


Lake 226 (continued)



Schindler (1974)

Lake 226 (August 1973)

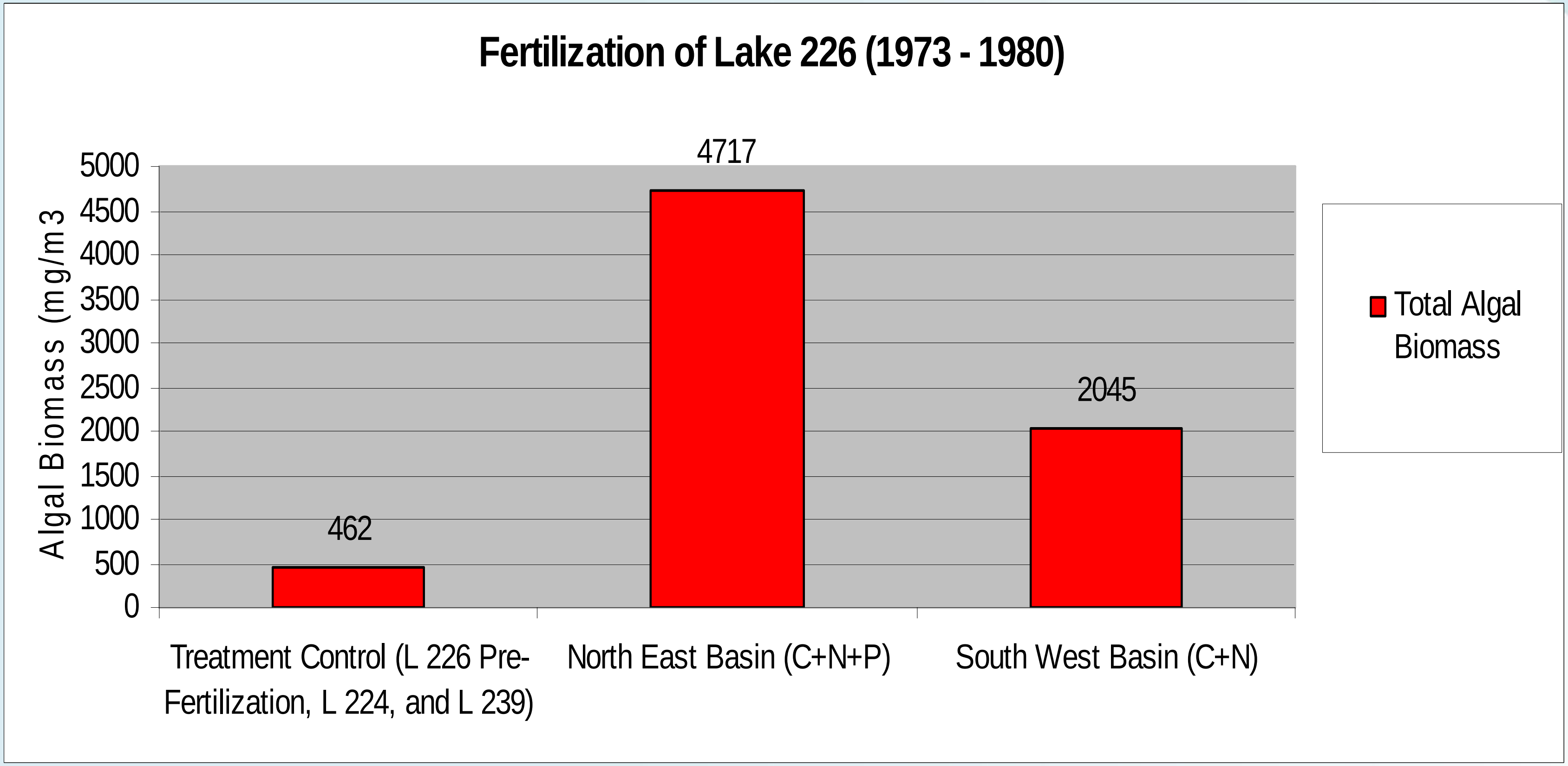


Nitrogen

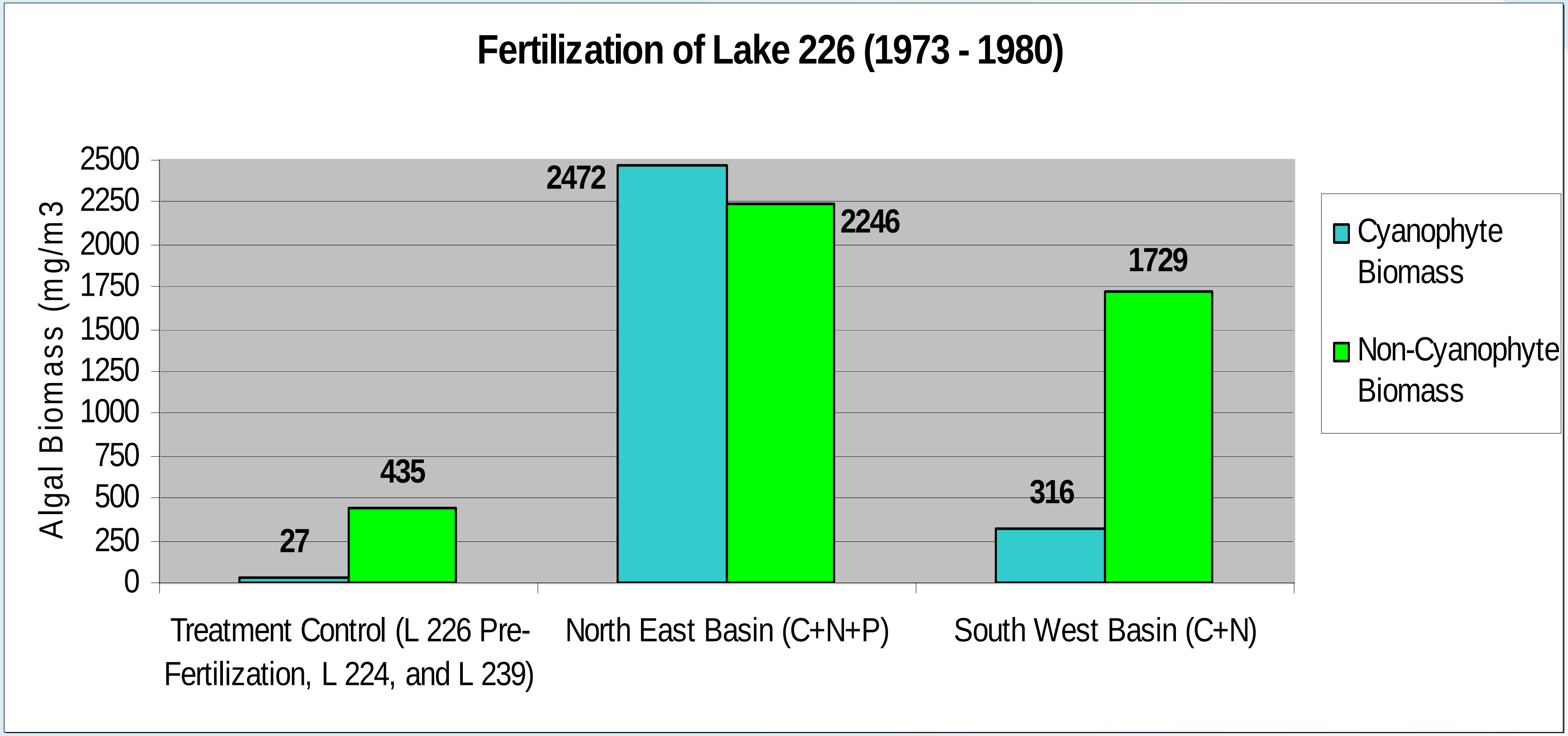
Nitrogen + Phosphorus

Manitoba

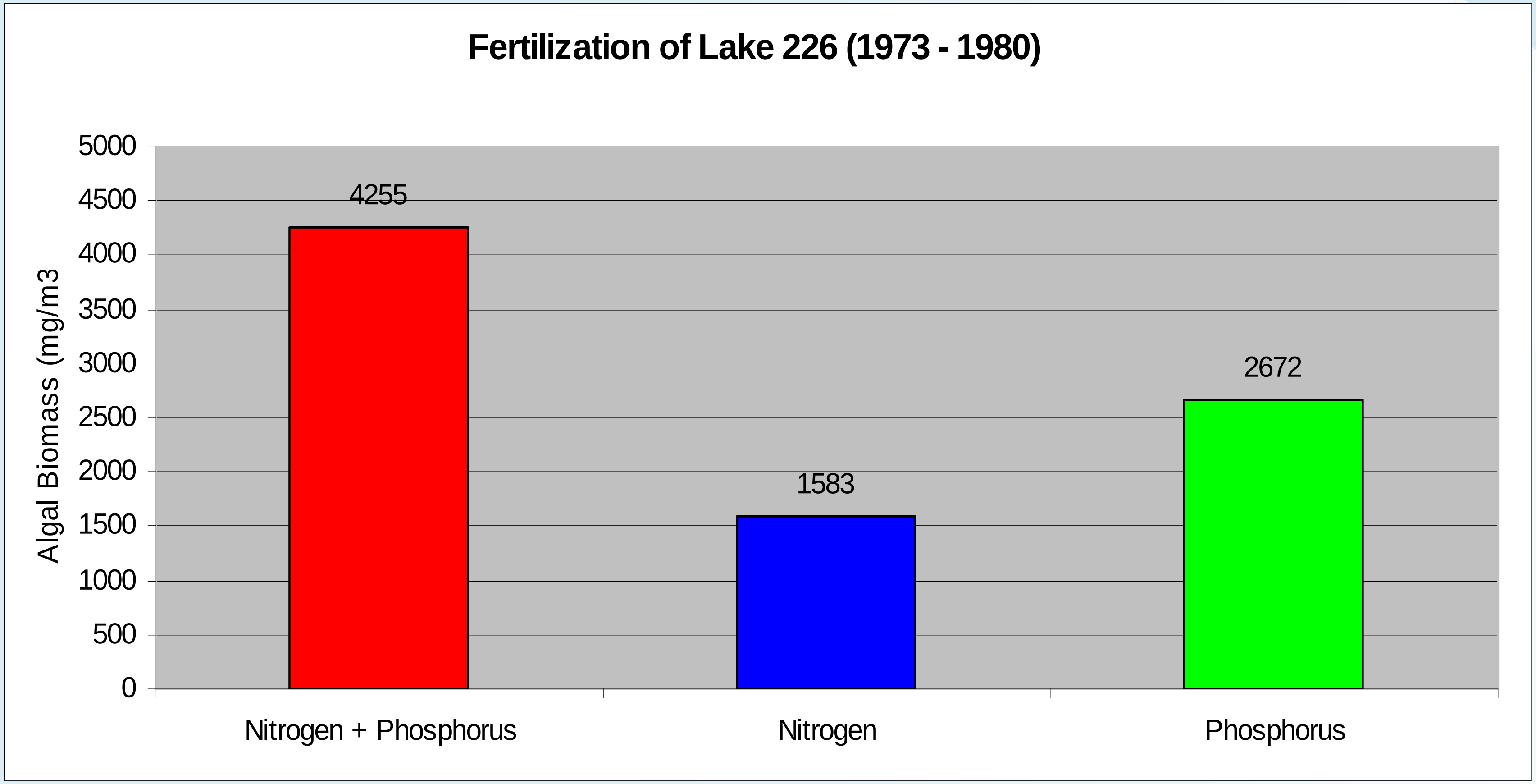
Lake 226 (continued)



Lake 226 (continued)



Lake 226 (continued)



Homer’s Odyssey: Ulysses and the Sirens

The Myth of Lake 226

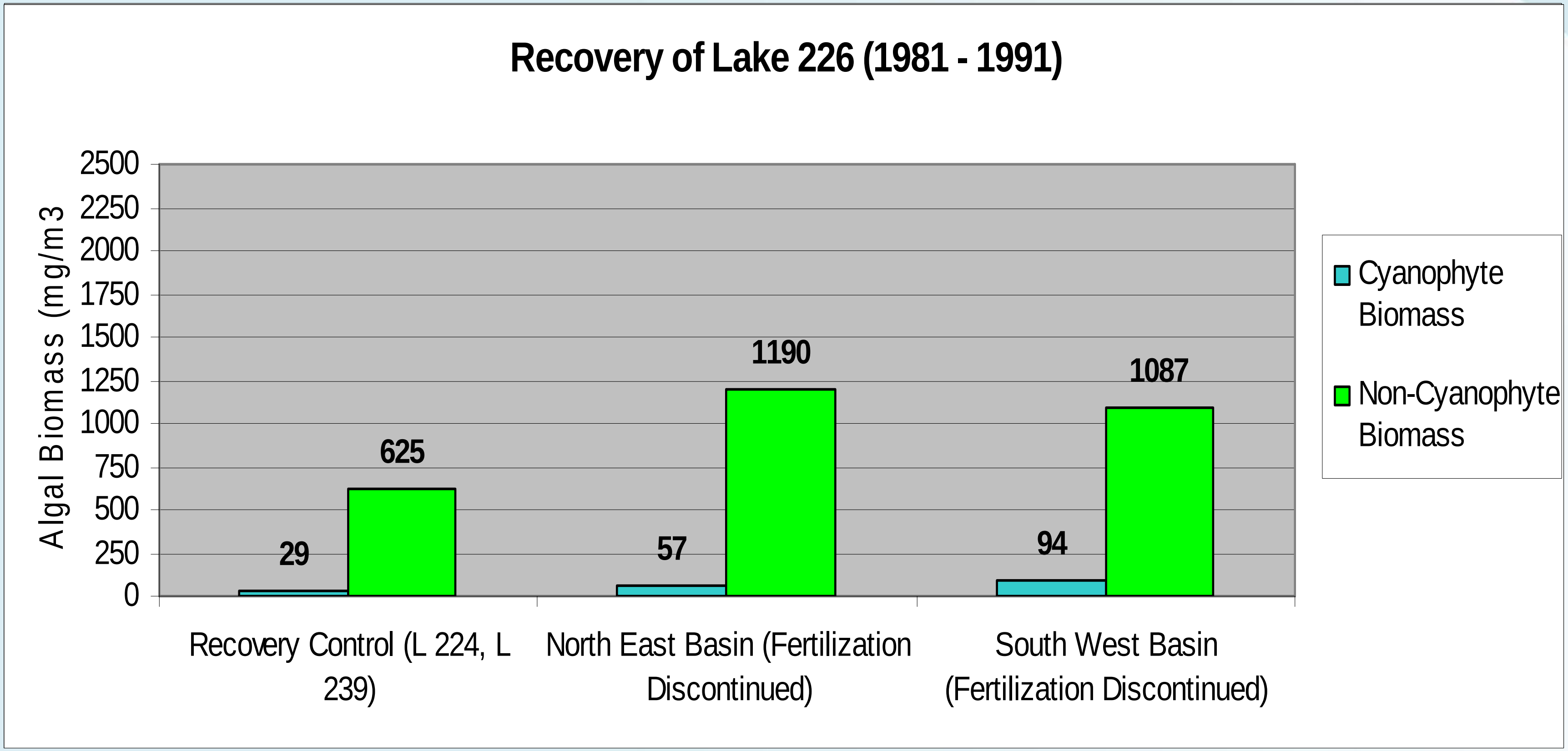
- **The data do not support the claim that:**

  "The half not receiving phosphorus remained in near-pristine conditions …"

The Myth of Lake 226 (continued)

- **Yet, the spectacular photograph was used to drive a phosphorus-only approach for three decades while the important role played by nitrogen demonstrated in the experiment, was overlooked**

Recovery in Lake 226



Wastewater Treatment to Reduce Nutrients

- Wastewater re-use, effluent irrigation, reduction of nutrients at source, etc.
- Phosphorus removal through chemical precipitation
  - aluminium sulphate (alum), ferric or ferrous salts (ferric chloride)
- Phosphorus and nitrogen removal through Biological Nutrient Reduction (BNR)

Chemical Precipitation of Phosphorus

- Less expensive than Biological Nutrient Reduction
- Creates a sludge in which phosphorus is tightly bound and not readily available for use by growing crops
- Unsustainable over the long-term due to significant environmental life-cycle costs
  - relies on mining of non-renewable metals (iron, aluminium)
  - if sludge is not acceptable to the agricultural community, it likely will be land-filled
  - phosphorus needs for growing crops will be met through mining of phosphorus

Manitoba

Phosphorus and Nitrogen Removal Through BNR

- More expensive than chemical precipitation since larger facilities are required and careful process control is needed
- Produces a sludge that can be used on agricultural lands
- When ammonia control is needed, full nitrogen removal requires an increase in tankage by about 20 %

Manitoba

Biological Nutrient Reduction in Western Canada

- Oldham and Rabinowitz (2002) reported 10 BNR systems in western Canada:
  - Kelowna, Penticton, Summerland, and Lake Country
  - Calgary, Edmonton, Red Deer, and Lethbridge
  - Prince Albert and Saskatoon

Manitoba

Criticism

1. Removing more nitrogen than phosphorus would harm Lake Winnipeg
2. Removing nitrogen will be ineffective since other sources of nitrogen will not be controlled
3. Removing phosphorus will be ineffective since other sources of phosphorus will not be controlled
4. Removing nitrogen is costly with unproven environmental benefits

Manitoba

Brief Response to Criticism

- We do not intend to remove more nitrogen than phosphorus
- Most of the arguments fail to recognize that BNR is already practiced in 10 cities in western Canada
- Arguments fail to recognize that ammonia control is needed in any case (nitrification), so cost comparison for full nitrogen removal (nitrification - denitrification) versus phosphorus removal by chemical precipitation is misleading

Manitoba

Comments on Criticism (continued)

- Most of the arguments fail to acknowledge the myth of Lake 226
- Some of the arguments appear to be science-based, but even on the briefest examination, turn out to be economic arguments - involve a social judgement that a lesser approach is "good enough" for Lake Winnipeg
- Arguments fail to recognize the life-cycle environmental costs associated with chemical precipitation of phosphorus

Manitoba

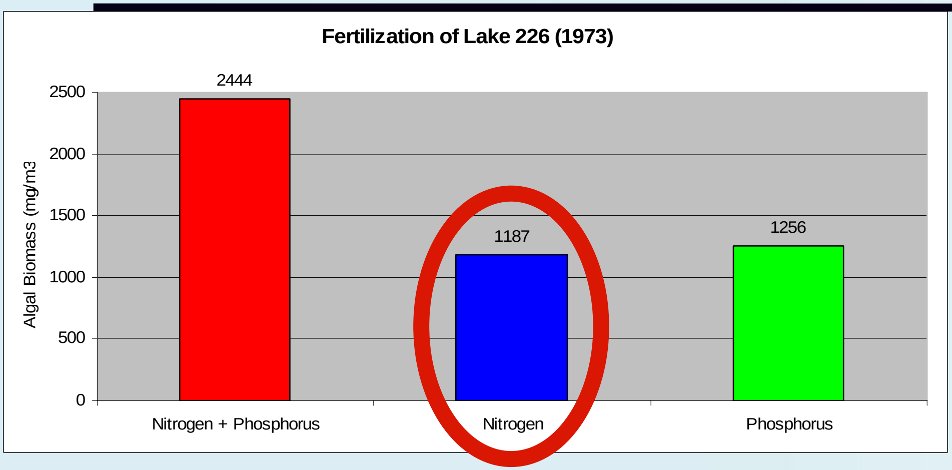
Comments on Criticism (continued)

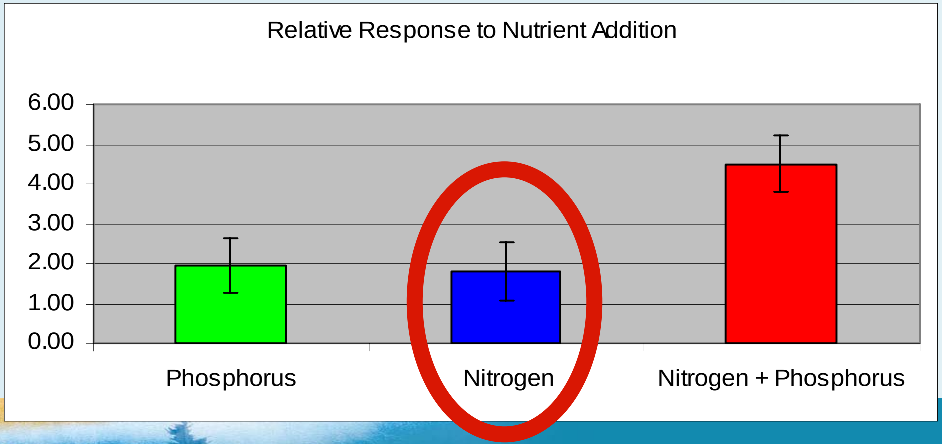
- Phosphorus-first strategy (then wait to see if Lake Winnipeg responds) will fail to restore the health of Lake Winnipeg for at least one more generation

Comments on Criticism (continued)

- Role played by introduction of nitrogen from the atmosphere is over-stated
  - assumes incorrectly that the present levels of nitrogen fixation will continue into the future
  - fails to recognize that not all cyanophytes can fix atmospheric nitrogen and for those that can, it is energetically expensive
  - argument is similar in logic to those already raised by other sectors wishing to avoid taking action

Comments on Criticism (continued)





Manitoba

Next Steps

- **Establish long-term ecologically-relevant water quality objectives for nutrients in Lake Winnipeg, its contributing watershed, and its downstream environment**

Next Steps (continued)

- Consult on establishing Water Quality Standards, Objectives, and Guidelines as a regulation under the Water Protection Act
- At the same time, propose and consult on new standards for nutrients for wastewater treatment facilities

Manitoba

Complexity

- **Schindler (2006):**

  "In summary, during the past 40 years, the understanding of eutrophication and its management have evolved from rather unfocused studies of algal nutrition to a very narrow focus on controlling one, sometimes two elements."

Complexity (continued)

- **and**

  "However, the focus has broadened in other ways, this time including the effects of increasing human activities on climate, land use, global nitrogen cycles, and fisheries.

- **and**

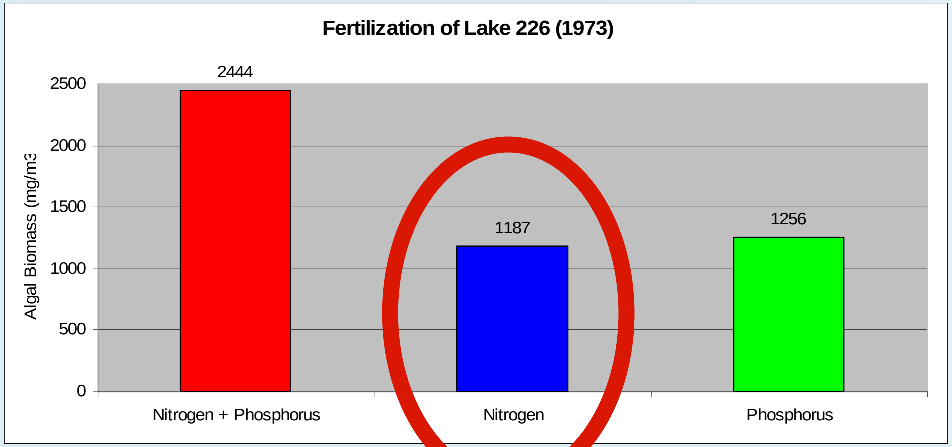
  "Reducing eutrophication in the century ahead will require complex policy decision that include controlling some combinations of the stresses described above in most waters."

- **and further**

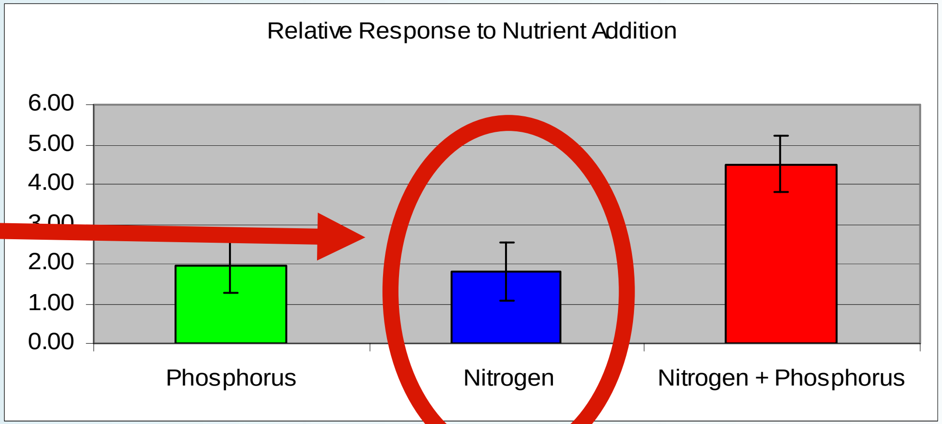
  "The control of eutrophication remains one of the greatest challenges to limnologists, estuarine scientists, and managers."

Manitoba

No Half-Measures



Nitrogen



Cooperative Approaches

- **Cooperative, innovative approaches are called for**
  - engineers
  - scientists
  - policy makers

Manitoba

Lessons from Easter Island

- Ronald Wright's "A Short History of Progress" (CBC's Massey Lecture Series)
  - Ancient civilization on Easter Island, cut down the last tree, knowing that it was the last tree
  - History records that the civilization collapsed - this was not a natural disaster but one they did to themselves

Manitoba

Easter Island (continued)

- We are now the second generation that have been responsible for the greatest change ever in our landscape, and the change continues
- Solutions are at hand and we need to avoid being enticed off-course
- We know better - Lake Winnipeg deserves better

Manitoba

Thank You