Experimental Lakes Area (ELA)
We hung phosphates without a fair trial.
Eutrophic lakes

Oligotrophic lakes

Partial Pressure of CO₂ (PₐCO₂) in Lakes

- Lake Erie, 1 M (CCEW Data Report)
- Lake Michigan (Fee unpublished)
- Lake Minnetonka (Megard '72)
- Sewage lagoon (King '72)
- Shriners Pond (Kerr '72)

Eutrophic lakes

Oligotrophic lakes

Schindler et al. (1975) PNAS
Schindler 1974
Science
The Greening of Lakes:

Eutrophication: The result of increasing nutrients and/or less dilution by water

\[ I_p = \text{INPUT OF PHOSPHORUS, mg} \]
\[ V_0 = \text{VOLUME OF OUTFLOW, } M^3 \]

Schindler et al. 1978 J. Fish. Res. Board Canada
Mean phosphorus concentrations in Lake Norrviken after diversion of sewage effluents in 1969.
Trophic response to nutrient levels in Kootenay Lake (1950-1980)
Balaton Lake
Manipulations of L 227

II = Low N:P, 1975-1989
III + V = P only, 1990-2005
IV = Pike in lake, 1993-1996

Schindler et al. (2008)
PNAS 105: 11254-11258
Livestock manure production by sub-sub-drainage area, Western Canada, 2001

Statistics Canada (2006)
Nutrient content of fertilizers sold in Canada, 1950 to 2000

Source:
Total P release: 476 000 tonne/year

Chambers et al. 2001
Focus Rivers & Streams:
*La Biche River
*Owl River (OWL)
*Red Deer Brook (RDB)
*Big Bay (BBAY)
*Plamondon (PMD)
*Black Bird Creek (BBRD)
Phosphorus fluxes to LLB sediments

(A) core D1

(B) core D3
Sewage → Algal Fixation ← 

A core D1 \( \delta^{15}N \) 

B core D3 \( \delta^{15}N \) 

← Sewage →

(A) core D1  \( \delta^{15}N \)  
(B) core D3  \( \delta^{15}N \)
Increasing agriculture
Simply clearing land causes increased phosphorus export. Fertilizer, manure etc. will increase it still more.
The Effect of Partial Conversion of Forest to Pasture on Mean Export of Phosphorus (n=43 watersheds)

mg P / m² / yr

From Dillon and Kirchner (1975)
Lac la Biche Phosphorus Mass
2003 - 2005
Temperature, Phosphorus and Oxygen vs Depth

Blue – July 20, Red - July 29
Temperature, Phosphorus and Oxygen vs Depth
Blue – July 20, Red - July 29
Phytoplankton Mass and Composition
Water Balance for Lac La Biche Lake 2004

Inputs to Lake
- Precipitation: 26%
- Owl River: 62%
- Other Inflows: 3%
- Groundwater Estimated: 8%

Outputs and Storage
- Evaporation: 49%
- La Biche River: 40%
- Lake Storage: 11%
## Phosphorus Load, 2003, Seasonal

<table>
<thead>
<tr>
<th>Periods</th>
<th>All Inflows Kg x 1000</th>
<th>Outflow Kg x 1000</th>
<th>Lake Storage Kg x 1000</th>
<th>Sedimentation Kg x 1000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feb 1 to Apr 10</td>
<td>0.8</td>
<td>0</td>
<td>39.3</td>
<td>-38.5</td>
</tr>
<tr>
<td>Apr 10 to May 19</td>
<td>10.5</td>
<td>0.9</td>
<td>42.2</td>
<td>-32.6</td>
</tr>
<tr>
<td>May 19 to Jun 10</td>
<td>5</td>
<td>0.9</td>
<td>-66.3</td>
<td>70.4</td>
</tr>
<tr>
<td>Jun 10 to Jul 30</td>
<td>10.7</td>
<td>1</td>
<td>71.6</td>
<td>-61.9</td>
</tr>
<tr>
<td>Jul 30 to Aug 19</td>
<td>2.8</td>
<td>0.3</td>
<td>166.3</td>
<td>-163.8</td>
</tr>
<tr>
<td>Aug 19 to Sep 8</td>
<td>1.8</td>
<td>0.8</td>
<td>44.1</td>
<td>-43.1</td>
</tr>
<tr>
<td>Sep 8 to Oct 22</td>
<td>2.8</td>
<td>2.1</td>
<td>-279.6</td>
<td>280.3</td>
</tr>
</tbody>
</table>
### Phosphorus Sources

<table>
<thead>
<tr>
<th>Year, Period</th>
<th>Inflow Kg x 1000</th>
<th>Sediment return Kg x 1000</th>
<th>Total Kg x 1000</th>
<th>Sediment Return % of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>2003 Jun 10 - Sep 8</td>
<td>15</td>
<td>282</td>
<td>297</td>
<td>95</td>
</tr>
<tr>
<td>2004 Jun 9 - Aug 26</td>
<td>9</td>
<td>196</td>
<td>205</td>
<td>95</td>
</tr>
<tr>
<td>2005 Jun 7 - Aug 26</td>
<td>12*</td>
<td>143</td>
<td>155*</td>
<td>92</td>
</tr>
</tbody>
</table>

*Assuming inflow mass in 2005 = mean of 2003, 2004*
Lake Winnipeg Watershed

<table>
<thead>
<tr>
<th>Attributes</th>
<th>Winnipeg</th>
<th>Erie</th>
</tr>
</thead>
<tbody>
<tr>
<td>Watershed km$^2$</td>
<td>953 250</td>
<td>78 769</td>
</tr>
<tr>
<td>Lake km$^2$</td>
<td>24,387</td>
<td>25,821</td>
</tr>
<tr>
<td>WS / L</td>
<td>39.0</td>
<td>3.0</td>
</tr>
<tr>
<td>Length km</td>
<td>377</td>
<td>395</td>
</tr>
<tr>
<td>Residence T yrs</td>
<td>3.6</td>
<td>2.6</td>
</tr>
</tbody>
</table>
The Bradbury Grand Rapids, 1969
Blue-green N Fixers In Lake Winnipeg

AVHRR NDVI Image

Brown = Low Chlorophyll  
High Turbidity

Green = High Chlorophyll

6000 km² blue-green bloom
Proliferation of blue-green algae in the south basin of Lake Winnipeg
Microcystins
Lake Winnipeg Watershed

Concentration
ug/L

WHO
Drinking Water Guideline
1 ug/L

3.4
Lac Lu
Catastrophe Bay
Elk Island
Delta Marsh
Oak Hammock Marsh
Tranquil Channel
Public Concern About Nutrients is Increasing

Over-fertilizing of fields is common in livestock-abundant areas.

Over-fertilizing polluting province’s water bodies

By Helen Foulding

FARMERS in livestock-intensive areas of Manitoba are over-fertilizing their land, potentially contributing to water pollution as far away as Lake Winnipeg.

In an $81,000 study for the Manitoba Livestock Manure Management Initiative, DGH Engineering found the nutrients nitrogen and phosphorus building up in soils in the rural municipalities of Hanover and La Broquerie near Steinbach.

In two other municipalities where there is less livestock production — Roland, south of Carman, and St. Boniface in western Manitoba — there was less buildup.

Excess nutrients not taken up by crops wash off fields into streams and rivers, with Red River nutrients eventually working their way to Lake Winnipeg. The lake has been plagued with bad algal blooms in recent years that are toxic to fish and wildlife and interfere with the enjoyment of summer beaches.

DGH senior engineer Doug Small said farmers applying manure to their fields from livestock barns are also applying some chemical fertilizers.

In Hanover, fertilizer inputs average 68 kilograms per hectare of nitrogen and 14 kilograms per hectare of phosphorus, but the numbers in Hanover are 48 for nitrogen and 32 for phosphorus.

“We’re not saying it’s an immediate serious crisis,” Small said. “There’s an issue here that needs to be addressed for long-term sustainability.”

Only about five per cent of Manitoba farmland receives animal manure.

Small said the obvious solution is for farmers using manure to cut back on expensive chemical fertilizers — something that would save them money and conserve the natural gas used to make fertilizer.

In a previous study completed last year, Manitoba Conservation staff concluded that nitrogen and phosphorus loads in Lake Winnipeg increased 13 and 10 per cent respectively over the last three decades as a result of changes in the Red River basin.

“Those are very significant values in a short time,” Pip said.

A Lake Winnipeg small recently declared its亡ed in an early warning sign that the lake is in trouble, she said.

Lake Winnipeg has had very bad algae blooms for the last five years, including some this summer at Victoria Beach and on the western shore as far north as the St. Laurent entrance, Pip said.

She is calling for more regulation of the nutrient farmers apply to their land.

The latest Manitoba Conservation study, led by Alex Bourne, did not separate the effects of chemicals from sources of natural sources.

Manitoba’s livestock farmers are required to monitor the amount of nitrogen they apply in manure, but phosphorus is regulated only in Quebec.

Livestock farmers have long complained they are subject to much greater scrutiny that the majority of their neighbors who use chemical fertilizer — soon to be regulated in Ontario after the Walkerton contaminated water scandal.

Keystone Agricultural Producers vice-president David Rolfe said quality assurance programs that require farmers to better manage their fertilizer if they want to be certified might be a better approach than more regulation.

Manitoba’s water quality manager...
NDP imposes hog moratorium

Targets area where the bulk of barns exist

By Mary Agnes Welsh

Environment Minister Kerry Eby said Tuesday he has no intention of reversing the NDP decision to impose a moratorium on hog barns in the province.

The NDP announced last April that it would freeze all new applications for hog barns in the province. The moratorium was lifted in September, but the NDP decided to make it permanent last month.

Eby said the decision was made to allow the province to work through a lengthy, complex review of hog industry issues. The review has been underway since 2004.

The NDP said it would consider lifting the moratorium once the review is complete.

Eby said the province has received more than 2,000 applications for new hog barns in the past year.

On the matter of hogs, NDP both good and lucky

It is an unusual debate in politics to have a provincial government say it will impose a moratorium on a key industry, but that’s what the NDP did Tuesday.

The moratorium is expected to cost the province millions of dollars in lost economic activity, but it will also give the province time to review its hog industry policies.

The NDP said it will consider lifting the moratorium once it has completed its review of the hog industry.

No going hog-wild on hog barns with new ban

A year-long environmental review of hog barns in central Manitoba is expected to result in a ban on new hog barns in the area.

The review was launched in 2005 and is expected to take several years to complete.

Lake will benefit from fewer hog barns

A ban on new hog barns in central Manitoba is expected to benefit Lake Winnipeg, which is located in the area.

The NDP imposed a moratorium on new hog barns in the area in 2005.

Experts say the moratorium is expected to benefit Lake Winnipeg by reducing the amount of farm runoff into the lake.

The moratorium is expected to be lifted once the review is complete.

The NDP said it will consider lifting the moratorium once it has completed its review of the hog industry.

No new hog barns are allowed to be built within the area, which covers most of central Manitoba.
Manure P Balance ... A Challenge

- Relative to synthetic fertilizers, available N:P$_2$O$_5$ ratio of most manures is $\sim$1:1 or less
- Ratio of N:P$_2$O$_5$ in most crops greater than 2:1
- Application of manure to meet the crop’s N requirements results in P surplus
Prairie landscape in late spring: Red River Valley's closed basins show little erosion

Photo: Cargill
Prairie "pothole" landscape in spring also reveals low rates of erosion

Photo: M. Conly, National Water Research Institute
Figure 7: Total phosphorus loading to Lake Winnipeg from contributing sources, 1994-2001, in tonnes per year (t/yr). Source: Manitoba Water Stewardship, 2006.
Manitoba Clean Environment Commission
2003 recommendations:

Reduce N by 13%
Reduce P by 10%

Cost for Winnipeg
$ 1.8 Billion
To upgrade treatment plants
Go after phosphorus sources big time. 25% minimum reduction, 50% is better. Nitrogen reduction will not help the lake.

<table>
<thead>
<tr>
<th>Category</th>
<th>Nitrogen (%)</th>
<th>Phosphorus (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall annual nutrient load to Lake Winnipeg</td>
<td>96,000 tonnes/year</td>
<td>7,900 tonnes/year</td>
</tr>
<tr>
<td>Upstream jurisdictions</td>
<td>51</td>
<td>53</td>
</tr>
<tr>
<td>United States (Red River)</td>
<td>20</td>
<td>32</td>
</tr>
<tr>
<td>United States (Souris River)</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Saskatchewan and Alberta (Assiniboine and Saskatchewan)</td>
<td>9</td>
<td>5</td>
</tr>
<tr>
<td>Ontario (East side)</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Ontario (Winnipeg River)</td>
<td>17</td>
<td>10</td>
</tr>
<tr>
<td>Manitoba Sources</td>
<td>39</td>
<td>47</td>
</tr>
<tr>
<td>Manitoba Point Sources</td>
<td>5</td>
<td>9</td>
</tr>
<tr>
<td>City of Winnipeg</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>All others</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Manitoba Watershed Processes</td>
<td>24</td>
<td>32</td>
</tr>
<tr>
<td>Estimated natural background</td>
<td>19</td>
<td>17</td>
</tr>
<tr>
<td>Present day agriculture</td>
<td>5</td>
<td>15</td>
</tr>
<tr>
<td>Atmospheric Deposition</td>
<td>10</td>
<td>6</td>
</tr>
<tr>
<td>Nitrogen Fixation</td>
<td>10</td>
<td>--</td>
</tr>
</tbody>
</table>
Ag Census Divisions in Manitoba (2001)
Typical Solid **Beef** Manure and Nutrient Application Rates for Various N Rate Targets\(^1\)

<table>
<thead>
<tr>
<th></th>
<th>Barley</th>
<th>Grass</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Target Yield</strong></td>
<td>80 bu/ac</td>
<td>3 t/ac</td>
</tr>
<tr>
<td><strong>Target N Rate</strong> (net basis, lb N/ac)(^2)</td>
<td>80</td>
<td>150</td>
</tr>
<tr>
<td><strong>Manure Application Rate</strong> (tons/ac)</td>
<td>21</td>
<td>43</td>
</tr>
<tr>
<td><strong>P Application Rate</strong> (lb P(_2)O(_5)/ac)</td>
<td>134</td>
<td>279</td>
</tr>
<tr>
<td><strong>P Removal Rate</strong> (lb P(_2)O(_5)/ac)(^3)</td>
<td>35</td>
<td>30</td>
</tr>
<tr>
<td><strong>P Surplus (lb P(_2)O(_5)/ac)</strong></td>
<td>99</td>
<td>249</td>
</tr>
</tbody>
</table>

\(^1\) Manure analyses are from 45 beef manure samples (Tri-Provincial Manure Application and Use Guidelines), average avail N:P2O5=0.6

\(^2\) Assumes all manure is spring applied, with 35% volatilization loss of NH4-N during application onto grass, as estimated in Manure Application Rate Calculator 2005 (MAFRI)

\(^3\) Assumes that all the crop is removed and no additional manure is applied by the farmer or by grazing animals
Typical Liquid Hog Manure and Nutrient Application Rates for Various N Rate Targets

<table>
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<tr>
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<tbody>
<tr>
<td><strong>Target Yield</strong></td>
<td>80 bu/ac</td>
<td>3 t/ac</td>
</tr>
<tr>
<td><strong>Target N Rate (net basis, lb N/ac)</strong></td>
<td>78</td>
<td>150</td>
</tr>
<tr>
<td><strong>Manure Application Rate (gal/ac)</strong></td>
<td>3,305</td>
<td>9,415</td>
</tr>
<tr>
<td><strong>P Application Rate (lb P$_2$O$_5$/ac)</strong></td>
<td>70</td>
<td>199</td>
</tr>
<tr>
<td><strong>P Removal Rate (lb P$_2$O$_5$/ac)</strong></td>
<td>35</td>
<td>30</td>
</tr>
<tr>
<td><strong>P Surplus (lb P$_2$O$_5$/ac)</strong></td>
<td>35</td>
<td>170</td>
</tr>
</tbody>
</table>

1 Manure analyses are from 145 samples collected from Manitoba hog farms (Fitzgerald and Racz 2001), average available N:P$_2$O$_5$=0.97

2 Assumes all manure is spring applied, with 35% volatilization loss of NH$_4$-N during application onto grass, as estimated in Farm Practices Guidelines for Hog Producers in Manitoba, p. 27

3 Assumes that all the grass forage is removed as hay and no additional manure is applied by the farmer or by grazing animals.
P Increases in La Salle River (1974-1999)

Runoff and P transport: Most P loss in Prairies occurs during snowmelt
Soil test P and P concentrations in Manitoba waterways are strongly related.

Adapted from Salvano and Flaten. 2006. Phosphorus risk indicators: Correlation with water quality in Manitoba.

\[ y = 0.0169x - 0.1079 \]
\[ R^2 = 0.6326 \]
Erosion of the Phosphorus Paradigm? Nonsense!

Where are the examples of decreased nitrogen loading successfully reducing eutrophication of lakes?

Score: $P = \text{hundreds of lakes}$
$N = 0$
CLOACA MAGNA AVIUM: THE SPECIALIST ON GUANO


Kenney, B. C. Beware of spurious self-correlations. Water Resources Research ( ), 1041-1048. 82.