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Research in Support of the Manitoba Clean Environment Commission's Hog Production Industry Review

Task 1 – Analysis Framework for Total Nutrient Loading

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Table of Contents

1 INTRODUCTION 1

1.1 THE CEC REVIEW 1
1.2 TASK 1 PROJECT OBJECTIVE 1
1.3 RESEARCH METHODS 2
1.4 LAKE WINNIPEG WITHIN THE GLOBAL CONTEXT 2
1.4.1 Responding to the Nutrient Challenge 3
1.4.2 Total Nutrient Loading 5
1.4.3 Defining Nutrient Contributions from Agriculture 6

2 UNDERSTANDING DOWNSTREAM NUTRIENT LOADING 10

2.1 LAKE EUTROPHICATION 10
2.2 CUMULATIVE/TOTAL LOADS 12
2.3 NUTRIENT SOURCES 16
2.3.1 Internal Lake Processes 16
2.3.2 Atmospheric Deposition 17
2.3.3 Upstream Jurisdictions 17
2.3.4 Manitoba Point Sources 19
2.3.5 Manitoba Watershed Processes 21
2.3.5.1 Natural Background and Undefined Loading 22
2.3.5.2 Present Day Agriculture: Focusing on Phosphorus 26
2.4 HYDROLOGIC CONNECTIVITY OF HEADWATER STREAMS 29
2.5 MODELING NUTRIENT LOAD REDUCTIONS IN WATERSHEDS 31

3 UNDERSTANDING UPSTREAM WATERSHED MANAGEMENT 36

3.1 WATERSHED BOUNDARY DELINEATION AND HIERARCHIES 36
3.2 INTEGRATED WATER RESOURCES MANAGEMENT 37
3.3 PLANNING WITHIN AN IRWM FRAMEWORK 41
3.3.1 IWRM's Key Monitoring Element 43
3.3.2 The Need for Leadership and Coordination 45
3.3.3 Policy Instruments to be Utilized 45
3.3.3.1 Institutional Instruments 46
3.3.3.2 Regulatory Instruments 46
3.3.3.3 Expenditure Instruments 46
3.3.3.4 Economic Instruments 46

4 TOTAL NUTRIENT LOADING ON A WATERSHED BASIS 47

2.3.4 Understanding and Addressing Watershed Health 47
4.1.1.1 Research and Development 47
4.1.1.2 Current Watershed Nutrient Levels 47
4.1.1.3 Maximum Healthy Nutrient Limits 47
4.1.1.4 Incremental Changes in Nutrient Levels 48
4.2 IWRM AS A PLANNING FOUNDATION 48
4.2.1 Hydrologic Scale Considerations 49
4.2.2 Depicting a Draft TNL Framework 50

5 REFERENCES 53

1 Introduction

Lake Winnipeg has been described as "Canada's Sixth Great Lake," bringing a strong provincial and national focus on its critical hydrologic role within the Prairie Water Region, the economic importance of tourism and fisheries, and its major function as a reservoir for hydroelectric power generation (Canada-Manitoba Lake Winnipeg Implementation Committee 2005).

Further, the social and environmental importance which Manitobans attach to Lake Winnipeg's spirit, beauty, biodiversity, and history is clear. Manitobans care about Lake Winnipeg, and they expect its declining water quality problem to be addressed with effective action (Lake Winnipeg Stewardship Board-LWSB 2005, 2005b).

1.1 The CEC Review

On 8 November 2006, the Minister of Manitoba Conservation requested that the Manitoba Clean Environment Commission (CEC) to "conduct a review and produce a report on the environmental sustainability" of the hog industry in Manitoba (Manitoba Conservation 2006). Central to this review is the following item within its Terms of Reference:

1. The CEC, as a part of its investigation will review the current environmental protection measures now in place relating to hog production in Manitoba in order to determine their effectiveness for the purpose of managing hog production in an environmentally sustainable manner.

In Manitoba one of the largest environmental concerns is the sustainability of its water resources. Recently several organizations, such as the Lake Winnipeg and Lake Manitoba Stewardship boards have been formed to address critical water issues in Manitoba, in particular nutrient loading. Many human activities lead to the movement of nutrients, such as nitrogen and phosphorus entering Manitoba's waters. Research has been initiated to review the movement and sources of nutrients in Manitoba's watersheds, but is still in its initial stages.

To fully understand the impacts of particular sectors, such as agriculture or even more specific the hog industry, a total nutrient framework is required that addresses the cumulative impacts of all sectors, and natural nutrient sources on Manitoba's water resources. The development of framework would include a determination of baseline nutrient data and provide the necessary tools and processes to focus on specific sustainability concerns.

In January 2007, the CEC entered into discussions with the International Institute for Sustainable Development (IISD) to assist in fulfilling its Terms of Reference item #1. In March, IISD produced a concept paper for the CEC. This in turn resulted in the preparation of two research papers (Task 1 and Task 2).

1.2 Task 1 Project Objective

IISD's Task 1 for the CEC (Total Nutrient Loading Framework) is defined as:

Preparation of a detailed analysis framework describing the watershed pathways and processes associated with "total nutrient loading," including Manitoba hog industry contributions – with a focus on hydrologic, water quality, and soil management issues.

A hypothetical hog proponent (proponent X), representative of typical hog operations (based on recent development/proposals) in Manitoba will be used to identify cumulative impacts and issues in the Manitoba context.

1.3 Research Methods

In completing Task 1, IISD has conducted the following:

1. A review of relevant nutrient loading literature applicable to Manitoba, with some insights from leading international experiences;
2. A review of relevant hydrologic and watershed management literature, with a focus on nutrient pathways within successively larger watersheds;
3. Consideration of the linkages between anthropogenic contributions of nutrients and watershed processes, with a focus on agriculture within the Manitoba context; and
4. Development of a conceptual analytical framework to guide further analysis of the effectiveness of current environmental protection measures relating to managing hog production in Manitoba.

1.4 Lake Winnipeg within the Global Context

Eutrophication is one of the major forms of water pollution affecting lakes and reservoirs around the world today. The increased nutrient levels through point and non-point loadings from natural and anthropogenic sources leads to the growth of rooted aquatic plants, algal mats, de-oxygenation, and unpleasant aesthetics. The shores of formerly clean lakes develop algal slimes, excessive algal turbidity or dense growth of certain rooted aquatic plants and filamentous algae in shallow areas. As a result, lakes become unattractive for bathing, boating, and other water-oriented recreations. Fish production often increases but the species composition changes for the worst. Economically important species are often replaced by lower economic value species, while increased algae levels interfere with fishing nets and gear (LWSB 2006).

Since 1967, global scientific knowledge regarding the causes, effects, and management responses to address eutrophication has grown dramatically, but the challenge remains:

> This explosion of eutrophication-related research has made it unequivocally clear that a comprehensive strategy to prevent excessive amounts of nitrogen and phosphorus from entering our waterways is needed to protect our lakes, rivers, and coasts from water quality deterioration. However, despite these very significant advances, cultural eutrophication remains one of the foremost problems for protecting our valuable surface water resources.
>
> [Smith 2006:351]

Reducing or reversing the eutrophication process can be accomplished by limiting the cumulative effects of nutrient loading from municipal and industrial wastewaters, agricultural wastes and fertilizers, and residential sources (Nakamura and Ahn 2007, Paerl 2006, Schindler 2006, Pers 2005).

Using sound science as a foundation, many social, economic and environmental impacts can be addressed through a variety of policy instruments available to government, including: **institutional** instruments (internal education, strategies, policies, and procedures); **regulatory** (laws, regulations, and enforcement); **direct expenditure** (broad or targeted programs, education and awareness, and research and development); and **economic** instruments (taxes, fees, and incentives). Any policy instrument is comprised of two elements – design and implementation (IISD and TERI 2003).

Application of these policy instruments in the future will have to consider the predicted water quality impacts associated with global climate change projections. Current research predicts increased seasonal variability in water flows, with significant associated nutrient load increases in agricultural and other drainage systems, along with increased eutrophication problems (Schindler and Donahue 2006, Arheimer 2005b).

1.4.1 Responding to the Nutrient Challenge

Understanding the temporal and spatial variations associated with Lake Winnipeg is fundamental to the development of a "scientifically defensible nutrient management strategy," and there are major information gaps to fill before appropriate and effective nutrient loading criteria can be developed. Determining appropriate watershed and lake monitoring programs and protocols, defining "pristine" lake conditions, and separating natural from anthropogenic nutrient sources are all key issues which need to be considered (North/South Consultants 2006:152-154).

Focusing on nutrients specifically, it has been recommended that:

> …a thorough accounting of internal and external sources and sinks of nutrients should be derived and a nutrient balance constructed. This is typically the first step in a lake eutrophication study and the development of nutrient criteria. The particular value beyond the obvious (i.e. the quantification of sources of nutrients) is in the ability to compare all of the relative sources and sinks, including internal cycling. This is especially important from a management perspective as this information is critical for identifying potential mitigation and management options.
>
> [North/South Consultants 2006:157]

In the spring of 2006, the Province initiated a public review of a proposed regulation under the *Water Protection Act* (Water Quality Management Zones for Nutrients) and proposed revisions to the Livestock Manure and Mortalities Management Regulation under the *Manitoba Environment Act* (Manitoba Water Stewardship and Manitoba Conservation 2006).

Late in 2006, the Province of Manitoba significantly increased the use of its water quality management options related to Lake Winnipeg. On November 8, the Minister of Manitoba Conservation announced the following initiatives (Manitoba Government 2006):

- Regulations limiting the use and application of manure and synthetic fertilizer, in accordance with defined *Water Quality Management Zones*;
- New buffer zones to reduce phosphorus and nitrogen, including the use of cosmetic fertilizer in sensitive areas near water;
- Strengthened fines and inspection protocols to meet new nutrient reduction levels;
- Support for research and technology for agricultural producers;
- Referral of Manitoba's "Water Protection Plan" to the Clean Environment Commission for a full, independent, and public review in terms of its effectiveness; and
- Announcement of a "pause" on further development within the hog production sector, including requesting the Clean Environment Commission to conduct a review of the environmental sustainability of hog operations across Manitoba.

Also, Section 32 of the final report prepared by the Lake Winnipeg Stewardship Board (LWSB) includes a number of recommendations focused directly on the concept of "Matching Nutrient Inputs with Crop Nutrient Requirements and Exports, and Establishing Soil Phosphorus Limits." These recommendations were developed based on substantial scientific evidence provided by the Manitoba Phosphorus Expert Committee (MPEC 2006), which – in their mandated focus on livestock manure management – concluded that Manitoba should focus on minimizing phosphorus losses from agricultural land to surface water while seeking to balance phosphorus applications with loss rates over the long term (LWSB 2006). In turn, the LWSB recommended the following:

> 32.1 For planning individual livestock operations, the Province of Manitoba should ensure that operators have sufficient land available for new and expanding livestock operations to balance phosphorus application rates with removal rates over the long-term.
>
> 32.2 The Province of Manitoba should develop a regional terrestrial nutrient budget for Agro-Manitoba which would assist producers, municipalities, and regulators in siting intensive livestock operations and managing manure in an environmentally sustainably manner.
>
> 32.3 Where excess nutrients are being generated, the Province of Manitoba should work with private industry to develop practical options for treating and exporting manure to nutrient-deficient areas.
>
> 32.4 The Province of Manitoba should adopt the soil test phosphorus thresholds for agricultural land as recommended by the Manitoba Phosphorus Expert Committee. The Province should also act on the Committee's recommendation to support research which will help refine soil phosphorus thresholds for varying Manitoba soil types and landscapes.
>
> [Lake Winnipeg Stewardship Board 2006:66]

Recommendation 32.2 relates very closely to the concept of "total nutrient management" as considered in this report. *Total Nutrient Management* is to a great extent a watershed issue in the Manitoba context, and this is the challenge that has been given to the Lake Winnipeg Stewardship

Board to manage – through a process of Integrated Water Resources Management planning and implementation – delivered primarily by Manitoba's conservation districts.

In early 2007, the Province took further action, assigning additional responsibilities to the Lake Winnipeg Stewardship Board, as follows:

> The board will take on additional responsibilities to provide advice to government on the health of Lake Winnipeg and its basins. The main mandate of the Lake Winnipeg Stewardship Board will now be to co-ordinate development of a basin-wide watershed management plan in co-operation with regional watershed authorities led by local conservation districts.
>
> While the board will continue to identify and assist in implementing actions to reduce nitrogen and phosphorus to pre-1970s levels, its mandate will be expanded to provide advice to government on other measures needed to restore health to Lake Winnipeg, such as the identification of pollutants entering the lake. It will be additionally tasked with examining issues impacting the management and ecological sustainability of the lake's fisheries.
>
> The renewed terms of reference will also mandate the board to prepare periodic "state of the lake" reports, through contact with lake users, communities, scientists and others. These reports will be presented to government and will include information on the status of government action in implementing the board's recommendations and the status of progress toward reaching nutrient reduction targets.
>
> [Manitoba Government 2007]

1.4.2 Total Nutrient Loading

Before *Total Nutrient Management* can occur, and before a regional terrestrial nutrient budget can be generated for Agri-Manitoba, the International Institute for Sustainable Development (IISD) has proposed that a *Total Nutrient Loading Framework* should first be developed.

A Total Nutrient Loading (TNL) Framework would outline the requirements for effectively examining and monitoring the condition of relevant water bodies and guide modifications in the upstream anthropogenic activities of all composite watersheds – in order to reduce the negative impacts of eutrophication in Lake Winnipeg, ultimately also improving the quality of water throughout Agri-Manitoba. Each contributing drainage area has different nutrient loading effects, depending on the landscape and the activities within each respective watershed. Understanding all nutrient sources and the mitigating effects achieved and possible through sound management of these watersheds will provide an understanding of the relative contributions of each drainage system – to Lake Winnipeg, and to Manitoba's water quality in general.

A TNL Framework would also provide some useful measurement tools for watershed decision-makers to understand the implications of their actions on the larger region. Land use, planning, and other development activities occurring within various hydrologic units all affect downstream nutrient levels in rivers and lakes beyond the originating drainage area. A TNL Framework increases the knowledge within the region about sources and removals of nutrients as well as particular watersheds of concern. Recognizing the differences between various nutrient sources entering particular water bodies is also important. For example, two very significant (and the most studied) nutrients – nitrogen and phosphorus – have dissimilar pathways from the land into surface water bodies and need to be managed differently.

1.4.3 Defining Nutrient Contributions from Agriculture

As noted by Bourne (2002) and Manitoba Water Stewardship (2006), the relative sources of phosphorus entering Lake Winnipeg would appear to be fairly well understood, and they have been accepted by the Lake Winnipeg Stewardship Board (2006). They are noted in Table 1-1.

Additionally, the relative contributions of nitrogen entering Lake Winnipeg have also been documented (Manitoba Water Stewardship 2006) and accepted by the Lake Winnipeg Stewardship Board (2006). These are outlined in Table 1-2.

It is noted that certain and significant questions remain regarding the relative sources and contributions of phosphorus and nitrogen. Some challenges regarding the comparative methodology utilized by Bourne (2002) have also been raised by Flaten (2003b), specifically the lack of data surrounding loading from "within stream processes" and the dependence on known "direct effluent discharges" from wastewater treatment facilities to estimate in-stream loads. Flaten suggests this likely results in an inaccurate assessment of watershed-based loading (given that part of Bourne's approach involved estimating watershed-based loads by subtracting in-stream loads from *Total Measured Stream Nutrient Loads* (TMSNL), which were "calculated by multiplying the nutrient concentration by the discharge or flow rate at a specific location in the stream" (Bourne 2002:5).

Prior to Flaten's raising of this methodological concern, Bourne had previously noted that "release from streambed and streambank sediment," and "infiltration of ground water" were deemed to be beyond the scope of the preliminary nutrient research, and that these were consequently not considered as part of the TMSNL-based estimates (2002:6).

TMSNL estimates were also compared by Bourne (2002) with an estimate of watershed-based loading through the use of land use export coefficients. Flaten (2003b) also questions this triangulatory approach, implying that the use of four land use types (pasture, cropland, forest, and other) may not accurately represent Lake Winnipeg's contributing watersheds, given that three of the export coefficients used depend on solely on export values derived from non-Manitoba data.

Also, while Bourne's dual estimates for total phosphorus generated through watershed-based loading compared similarly for the Red River (1209 tonnes via land use coefficient method vs. 1261 tonnes via TMSNL estimate), they did not compare for the Assiniboine River (1039 tonnes-coefficient vs. 139 tonnes-TMSNL), suggesting serious estimate errors, at least for the Assiniboine River (Flaten 2003b:9 with data from Bourne 2002). In suggesting possible reasons for this discrepancy, Flaten further notes that:

> The use of nutrient export coefficients to determine P loading from land use assumes that all land within a particular land use category contributes equally to runoff. However, this concept is inconsistent with present-day hydrological theory on runoff processes. Runoff is highly variable both within and between catchments. Current hydrological modeling practice recognizes that soil type and moisture content, slope, management practices, and other factors besides land use are also important in determining amount of runoff and therefore TP export to the stream. Runoff is generated from various source areas within a catchment, and these areas respond with varying degrees to the intensity of the snowmelt or rainfall event.
>
> [Flaten 2003b:9]

This points to the need for a heightened emphasis on hydrological processes and watershed-based hydrologic management-focused approaches to addressing Manitoba's nutrient challenge.

Flaten offers another approach in attempting to understand watershed-based loads, by using Bourne's data (2002) to compare phosphorus loads immediately upstream and downstream of the heavily urbanized portion of the Red and Assiniboine Basins – the Capital Region in and around the City of Winnipeg:

> Bourne et al (2002) reported that the average annual TP load on the Red River downstream of Winnipeg at Selkirk is 4905 tonnes. Upstream of Winnipeg at St. Norbert it is 3103 tonnes. The Assiniboine River at Headingley conveys another 637 tonnes of TP , for a total of 3740 tonnes entering Winnipeg. Therefore, as the Red and Assiniboine course through Winnipeg and on to Selkirk, they gain 1165 tonnes of TP, or 24% of the total annual load delivered to Lake Winnipeg [assuming 4905 tonnes at Selkirk]. This highly developed and urbanized section of river appears to be, therefore, a significant contributor of P.
>
> [Flaten 2003b:9]

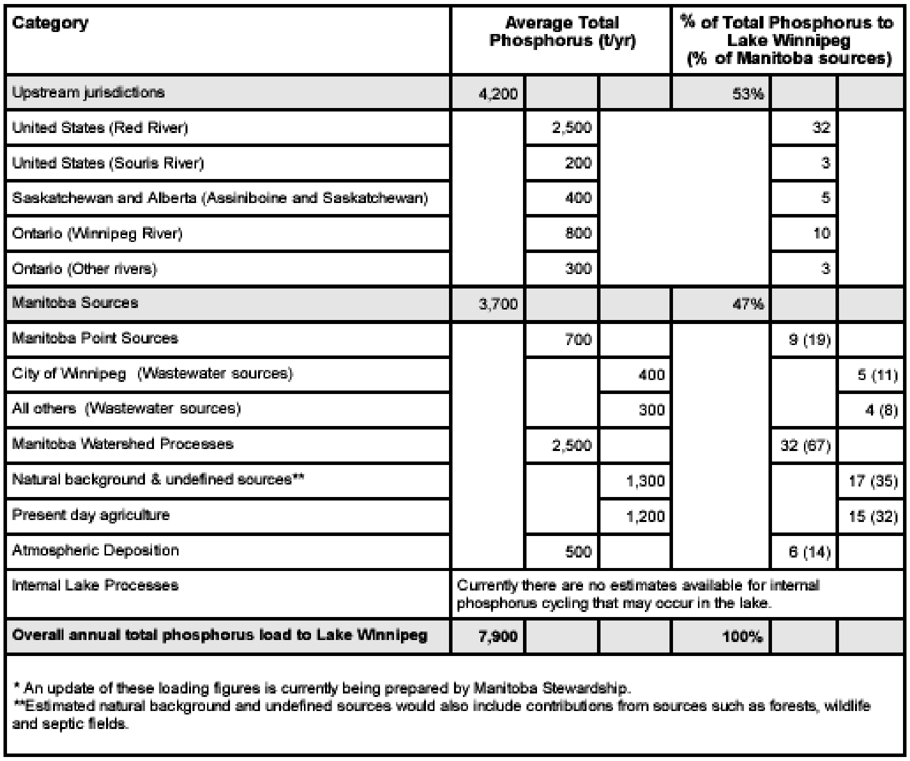
Flaten (2003b) also raises a genuine concern over the frequency of nutrient loading data collection in Manitoba, which is not continuous (while flow data is). Total nutrient loads are derived by calculating average flows and sampled nutrient concentrations; short-term fluctuations are missed. Flaten cites Rekolainen (1991) in suggesting that determining total phosphorus loads in this manner creates the possibility of underestimating total loading by 40%. The need for increased monitoring to clarify actual trends is obvious.

It is fundamental to note that the Bourne (2002) work was intended to be a "preliminary estimate" of total nutrient loads, as noted in the report title. However, the loading estimates, relative sources, and composite waterway concentrations have not been effectively challenged or revised with additional research beyond periodic updates by Manitoba Water Stewardship (2006), based on existing data collection protocols.

It is both conceivable and likely that arguments will persist among those individuals who and organizations which have particular interests in the direction of future institutional, regulatory, expenditure, and economic policy directions taken by the Province of Manitoba. Without more frequent and detailed monitoring of nutrient loading – to better understand how each contributing drainage system influences total nutrient loading downstream, and ultimately Lake Winnipeg – these rather poorly informed debates will continue.

It has been suggested by some researchers, that the resulting lack of clarity regarding relative nutrient contributions received from both Upstream and Manitoba sources (and the "level partitioning" which occurs within each source, particularly the Manitoba-based load estimates) represents a "failure of science." Whether a failure or simply the very beginning of real understanding, it needs to be addressed through more frequent and detailed monitoring, combined with a continued exploration of improving methods for understanding how Lake Winnipeg's composite watersheds each contribute to the health of this iconic water body – and to Manitoba's water quality in general.

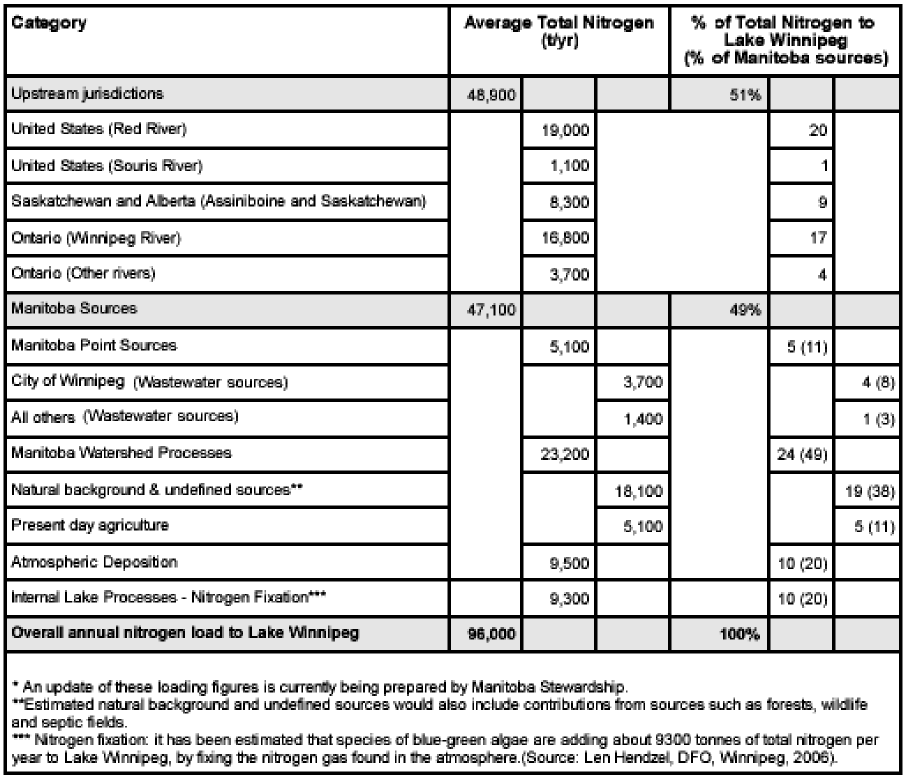
For the purposes of this report, the nutrient loading data accepted by the Lake Winnipeg Stewardship Board will be assumed to accurately represent the relative sources and composite watershed contributions as we currently understand them, represented by Table 1-1 and Table 1-2.



Category	Average Total Phosphorus (t/yr)			% of Total Phosphorus to Lake Winnipeg (% of Manitoba sources)		
Upstream jurisdictions	4,200			53%		
United States (Red River)		2,500			32	
United States (Souris River)		200			3	
Saskatchewan and Alberta (Assiniboine and Saskatchewan)		400			5	
Ontario (Winnipeg River)		800			10	
Ontario (Other rivers)		300			3	
Manitoba Sources	3,700			47%		
Manitoba Point Sources		700			9 (19)	
City of Winnipeg (Wastewater sources)			400			5 (11)
All others (Wastewater sources)			300			4 (8)
Manitoba Watershed Processes		2,500			32 (67)	
Natural background & undefined sources**			1,300			17 (35)
Present day agriculture			1,200			15 (32)
Atmospheric Deposition		500			6 (14)	
Internal Lake Processes	Currently there are no estimates available for internal phosphorus cycling that may occur in the lake.					
Overall annual total phosphorus load to Lake Winnipeg	**7,900**			**100%**		

* An update of these loading figures is currently being prepared by Manitoba Stewardship.
**Estimated natural background and undefined sources would also include contributions from sources such as forests, wildlife and septic fields.

Table 1-1: Summary of estimated annual phosphorus loading to Lake Winnipeg 1994-2001 (tonnes per year rounded to nearest 100 tonnes). Source: Bourne 2002 and Manitoba Water Stewardship 2006



Category	Average Total Nitrogen (t/yr)			% of Total Nitrogen to Lake Winnipeg (% of Manitoba sources)		
Upstream jurisdictions	48,900			51%		
United States (Red River)		19,000			20	
United States (Souris River)		1,100			1	
Saskatchewan and Alberta (Assiniboine and Saskatchewan)		8,300			9	
Ontario (Winnipeg River)		16,800			17	
Ontario (Other rivers)		3,700			4	
Manitoba Sources	47,100			49%		
Manitoba Point Sources		5,100			5 (11)	
City of Winnipeg (Wastewater sources)			3,700			4 (8)
All others (Wastewater sources)			1,400			1 (3)
Manitoba Watershed Processes		23,200			24 (49)	
Natural background & undefined sources**			18,100			19 (38)
Present day agriculture			5,100			5 (11)
Atmospheric Deposition		9,500			10 (20)	
Internal Lake Processes - Nitrogen Fixation***		9,300			10 (20)	
Overall annual nitrogen load to Lake Winnipeg	**96,000**			**100%**		

* An update of these loading figures is currently being prepared by Manitoba Stewardship.
**Estimated natural background and undefined sources would also include contributions from sources such as forests, wildlife and septic fields.
*** Nitrogen fixation: it has been estimated that species of blue-green algae are adding about 9300 tonnes of total nitrogen per year to Lake Winnipeg, by fixing the nitrogen gas found in the atmosphere.(Source: Len Hendzel, DFO, Winnipeg, 2006).

Table 1-2: Summary of estimated annual nitrogen loading to Lake Winnipeg 1994-2001 (tonnes per year rounded to nearest 100 tonnes). Source: Manitoba Water Stewardship 2006

Based on these tables and the data from which they were generated (Bourne 2002 and Manitoba Water Stewardship 2006), Manitoba Sources of phosphorus and nitrogen are categorized as *Manitoba Point Sources*, comprising industrial and domestic wastewater from the City of Winnipeg and various other sources, including licenced wastewater lagoons serving rural "towns and villages, Hutterite colonies, provincial parks, community centres, schools, and churches" (Bourne 2002:21).

Additionally, *Manitoba Watershed Processes* include nutrient loads contributed from various "natural background and undefined sources" (including forests, wildlife, and septic fields (LWSB 2006:25-26), along with "present day agriculture" sources. These two sources are interrelated, given the defining role of "land use" in determining total nutrient loads, given that:

> The load of nutrients from the land to surface water depends on soil type, vegetation cover, and precipitation. The type of land use practices or activities also heavily influences the movement of nutrient from land to surface waters. Rates of nutrient export can be lowered by the presence of riparian vegetation along stream channels and lake shores, while the development of drainage channels can have the opposite effect and result in increased nutrient export to surface waters. The amount of nutrient loading to land from atmospheric deposition and agricultural fertilizer and manure applications can also strongly influence the amount of nutrients that are available for export to surface waters.
>
> [Bourne 2002:30]

As outlined by Bourne (2002), the nutrient export coefficients of four land use categories (pasture, cropland, forest, and other) were utilized to estimate total nutrient loads for Lake Winnipeg arising from within Manitoba. These coefficients were based partially on data from Manitoba (South Tobacco Creek) and largely on data from South Dakota, North Dakota, Minnesota, and Wisconsin.

Each of these sources (natural background/undefined and agriculture) are very significant, and when combined as *Manitoba Watershed Processes*, together comprise 2,500 tonnes/year of phosphorus (approximately 32% of total phosphorus loads) and 23,200 tonnes/year of nitrogen (approximately 24% of total nitrogen loads) entering Lake Winnipeg (LWSB 2006:25-26).

As noted earlier, Section 32 of the LWSB final report provides important guidance regarding *Total Nutrient Loading* in Manitoba and nutrient contributions from agriculture, particularly phosphorus. The critical importance of "matching nutrient inputs, whether livestock manure or synthetic fertilizer, with crop requirements" is noted as a central focus for reducing total nutrient loads entering Lake Winnipeg (LWSB 2006:64).

To better understand how the hog industry may be influencing both local and downstream water quality – in the search for assurances that this sector is sustainable, or to implement policy tools to ensure that it is – we must understand how hog production (relative to other types of agricultural production) influences *Manitoba Watershed Processes.*

2 Understanding Downstream Nutrient Loading

Several natural and anthropogenic processes contribute to the total nutrient load in any given water body. Each contributing drainage system will have different sources of nutrients, depending on the type of landscape features, soil types, land use and human activities within its particular drainage area. Understanding the biophysical interrelationships between these different variables and the various differences between the composite watersheds of a larger system (in addition to any interrelationships between these composites) is fundamental to understanding total nutrient loading within a larger system, such as a river or lake basin.

In terms of Lake Winnipeg, it is also useful to consider the "source-sink" logic often utilized by environmental scientists in understanding the interrelationships between contributing pollution sources and their downstream impacts. Harper (2004) frames this discussion in terms of the broad "ecosystem services" provided by earth's finite resources, including water. In terms of the specific ecosystem services which humans value the most:

> You can conceptualize the earth as a system of *sources* (from which resources are drawn) and *sinks* (into which human wastes and effluents go)….In simpler words, sources function as "supply depots" and sinks function as "waste repositories" (Dunlap and Catton 2002). This is an abstract way of talking about the functions of the environment for people. A sink can refer to a trash dump, a river, or the atmosphere, which absorbs wastes of different kinds.
>
> [Harper 2004:85]

For the purpose of this report, the various "sources" of nitrogen and phosphorus loading will be explored, with the understanding that as a "sink," Lake Winnipeg is currently receiving contributions of these nutrients in the ratio of 12:1, based on annual loads of 96,000 t/yr of nitrogen and 7,900 t/yr of phosphorus (LWSB 2006:25-26).

Additional emphasis will be placed on phosphorus, due to its previous identification as the primary cause of Lake Winnipeg eutrophication, most clearly by the Lake Winnipeg Implementation Committee:

> Phosphorus is the nutrient that determines the amount of algal growth, because its supply in nature is limited…..Efforts to control the eutrophication should focus first on reducing phosphorus loading. When efforts are directed to reducing both nitrogen and phosphorus, the ratio of nitrogen to phosphorus entering the system should be maintained above 15:1.
>
> [LWIC 2005:17]

2.1 Lake Eutrophication

The gradual increase of nutrient levels and sediment in a lake is called lake eutrophication. Eutrophication occurs normally in nature as nutrients accumulate in a water body from its associated watershed. Coastal Environmental/PBS&J (1998) has outlined the progression of eutrophication in a typical lake through the following series of phases or trophic states:

> *Oligotrophy - nutrient-poor, biologically unproductive, low turbidity;*
>
> *Mesotrophy - intermediate nutrients and biological productivity, moderate turbidity;*

Eutrophy - nutrient-rich, high biological productivity, high turbidity; and

Hypereutrophy - the extreme end of the trophic continuum

Coastal Environmental/PBS&J (1998) further describe three key steps in the eutrophication process once the nutrients concentrations reach sufficient levels to promote increased algal blooms:

1) The increased algae concentrations block the light that supports plant growth, thereby reducing aquatic vegetation;
2) The increased amount of decaying algal cells settling on the lake bottom decreases the available oxygen in the water, result in larger fish kills; and
3) Once the dominant source of primary production in the lake is algae, the fish population can shift from mainly a carnivorous sport fish to a more of a herbivorous rough fish.

Lakes and streams are susceptible to increasing biochemical oxygen demand (BOD) loads caused by the decomposition of algal blooms as well as other organic matter. BOD is the amount of oxygen required to decompose the organic matter in the water using aerobic biochemical action and is commonly used to determine the impact of sewage effluents or spills from livestock production (Mallin 2006). Increasing nutrient inputs within an upstream watershed will stimulate algae growth, which can significantly increase the subsequent downstream BOD load in rivers and lakes, resulting in hypoxia (oxygen depletion) problems, such as fish kills and decreasing a lake's natural lifespan.

While natural eutrophication processes do impact a lake's lifespan, anthropogenic eutrophication can drastically shorten the time it takes for an affected lake to reach a hypereutrophic state (Smith 2006). Activities within the lake's contributing watershed such as forest clearing, road building, agricultural cultivation, residential and commercial development, stormwater runoff and wastewater discharges can all result in substantial increases in the discharge of nutrients to the water.

The impacts of eutrophication, such as algal growth and periodic fish kills, were identified as significant concerns as early as the 1950s (Schindler 2006). At this time, most research and mitigative attempts focused on treating the symptoms with copper sulfate and herbicides to control the algal blooms. During the 1960s, however researchers were able to link the increasing algal growth with the increased nutrients entering the lakes due to human activities (Schindler 2006; Smith 2006). Eutrophication research conducted during the 1970s demonstrated unequivocally that controlling phosphorus loading is the key factor in addressing lake eutrophication:

> As the result of accumulating evidence from limnologists, phosphorus control became the standard policy in most first-world countries. Many studies showed that controlling point sources of phosphorus effectively reduced eutrophication (e.g. Edmonson 1970; Ahlgren 1978; Holtan 1981). In 1974, a resolution was read at the 19th International Congress of the International Limnological Society (SIL): "Because of the critical role of phosphorus in the rapid eutrophication of inland waters, be it resolved that in addition to secondary treatment of sewage it is necessary to control additions of this element into any inland water." Phosphates in cleaning products, sewage, septic tanks, and agricultural wastes were specified in subsequent wording. The resolution was carried by the roughly 1,000 delegates at the Congress.
>
> [Schindler 2006:358]

Projected climate change impacts for the Canadian Prairies include warmer temperatures, less precipitation, and lower water levels (Hengeveld, 2006). The impacts of these changes could exacerbate the rate of eutrophication in Manitoba's lakes, particularly due to increased water residence times (resulting from reduced inflows from contributing streams and increased evaporation rates), which have been demonstrated to increase nutrient retention in lakes where point sources of nutrients are the primary loading contributor (Schindler 1978 in Schindler 2006). In lakes where non-point sources are the main component of nutrient loads, lake eutrophication impacts may in fact be reduced through climate change impacts such as reduced stream flows; however, associated decreases in silica loads may trigger earlier seasonal Cyanobacteria blooms (Schindler 1996 in Schindler 2006). In cases where both point and non-point sources are significant contributors to lake nutrient loading, the projects impacts of climate change are not yet clear (Schindler 2006).

Many lakes on the Canadian Prairies are shallow and have underlying soils which naturally contain high concentrations of phosphorus. During recurring periods of hypoxia during calm summer weather, high levels of phosphorus can be released from lake sediments. Subsequent windy weather causes this phosphorus to be mixed upward within the water column, raising overall phosphorus levels in the lake. In some lakes, this "internal loading" can serve as the primary source of phosphorus and eutrophication, exceeding anthropogenic and other sources (Schindler 2006:359). These sources are discussed further in Section 2.3.1, with particular reference to Lake Winnipeg.

2.2 Cumulative/Total Loads

All healthy ecosystems require nitrogen and phosphorus; they are essential components of life. These nutrients are found naturally in the environment and can also naturally exist in excess levels depending on the characteristics of particular ecosystems. Several human activities have the potential to increase the levels nutrients found within an ecosystem, and this may also occur through the movement of nutrients between ecosystems. For example, agriculture tends to import nutrients through the use of various types of fertilizer, and some of these nutrients may be introduced into the watersheds of an ecosystem through different land use practices and land management techniques. Different types of land use and management can greatly influence the rate at which nutrients may enter the watersheds of an ecosystem, as well as influence the rate at which nutrients become available for algal growth downstream (Bourne 2002).

The water quality of particular lakes is largely influenced by the quality of surface water runoff which is collected within its contributing watersheds. Accurately understanding the transport mechanisms and ultimate fate of nutrients and other materials carried by this runoff is central to understanding water quality within a downstream lake. Agriculture, urban development, mining, forestry, and other land use practices all influence the frequency, volume, and quality of this surface runoff, increasing the likelihood that anthropogenically-generated nutrients will enter a lake's contributing watershed. Both point and non-point sources of anthropogenic nutrient loading are generally associated with increased levels of nitrogen and phosphorus in watersheds, resulting in serious threats to downstream water quality (Soranno 1996).

Flaten notes that “many wastewater treatment plants in jurisdictions upstream of Manitoba have installed nutrient removal facilities” (2003b:15). With this increasing abatement of point-source sources of downstream eutrophication (i.e. in Lake Winnipeg), the prime focus in addressing eutrophication should logically be associated mainly with non-point nutrient sources.

The Lake Winnipeg Stewardship Board has accepted that one of Lake Winnipeg’s composite watersheds – the Red River Basin – appears to be the dominant source of nutrient loading for the lake, contributing 54% of total phosphorus and 30% of total nitrogen (2006:29). Unfortunately, as pointed by North/South Consultants (2006), the movement of nitrogen and phosphorus is extremely complex, with several entrance pathways within Lake Winnipeg’s composite watersheds, and indeed the contributing drainage systems within the Red River Basin itself, a predominantly agricultural landscape.

Bourne (2002) has developed a useful schematic depiction of Lake Winnipeg nutrient loading. These are presented as Figure 2-1 and 2-2 and serve as a foundation for the development of a *Total Nutrient Loading Framework*. However, a more thorough quantification of runoff, sediment yield, and nutrient loadings from each of Lake Winnipeg’s composite watersheds is required to accurately evaluate the effects of the myriad land use activities and management practices which are occurring within these contributing drainage systems.

The LWSB’s acceptance of the Bourne (2002) and subsequent Manitoba Water Stewardship (2006) nutrient loading data implies that, of all Lake Winnipeg’s composite watersheds, the Red River Basin (including its own composite subbasins, watersheds, and subwatersheds) should be the first priority system for addressing non point source loading to Lake Winnipeg. Exploring the interrelationships between land use and hydrology shall be the increasing focus of subsequent sections of this report, including in-depth consideration within Section 3.

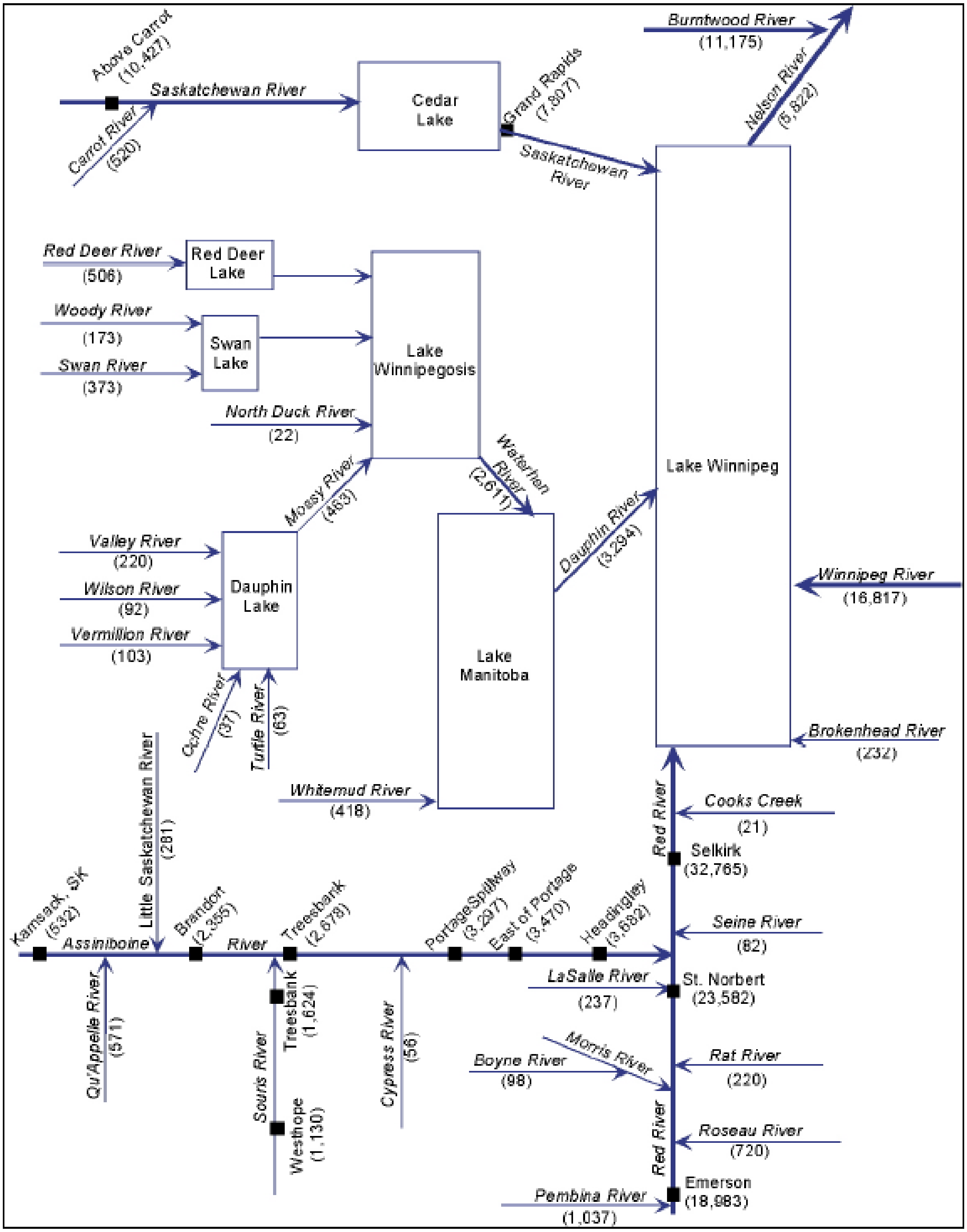


Figure 2-1: Schematic diagram of mean annual total nitrogen load *t/yr) in streams at long-term monitoring stations in Manitoba (1994-2001). Source: Bourne 2002:13

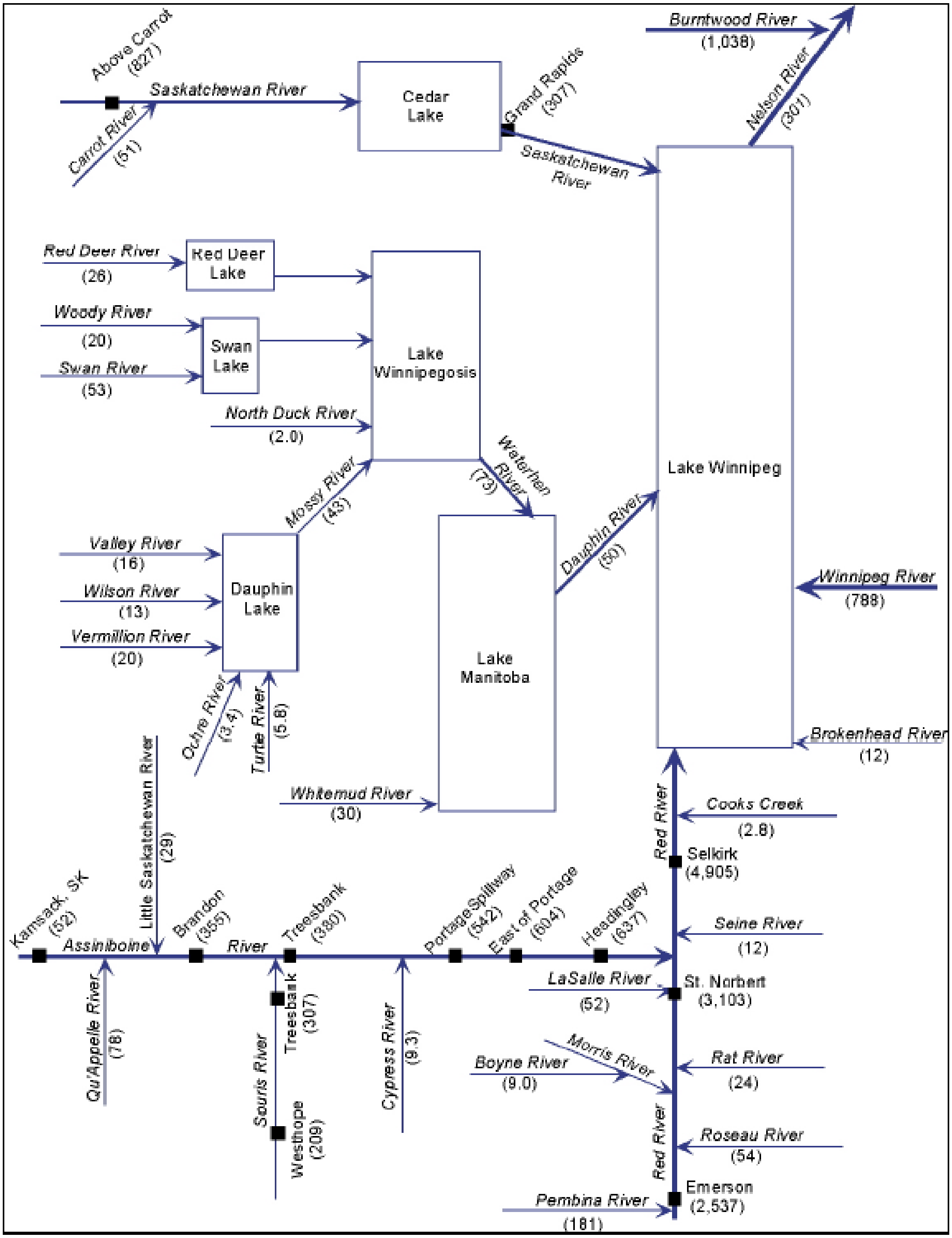


Figure 2-2: Schematic diagram of mean annual total phosphorus load (t/yr) in streams at long-term monitoring stations in Manitoba (1994-2001). Source: Bourne 2002:14

2.3 Nutrient Sources

Using the typology adopted by the Lake Winnipeg Stewardship Board (2006), nutrient loads entering Lake Winnipeg are contributed from the following sources:

- *Internal Lake Processes* (unknown for phosphorus, estimated at 9,300 t/yr nitrogen);
- *Atmospheric Deposition* (estimated at 500 t/yr phosphorus and 9,500 t/yr nitrogen);
- *Upstream Jurisdictions* (United States, Ontario, Saskatchewan, and Alberta), entering via the Red, Souris, Assiniboine, Saskatchewan, Winnipeg, and other river systems;
- *Manitoba Point Sources* (industrial and domestic wastewater from the City of Winnipeg and various other sources in rural Manitoba); and
- *Manitoba Watershed Processes* (including natural background loading, undefined sources, and present-day agriculture – all of which are interrelated to a significant degree)

2.3.1 Internal Lake Processes

Based on data from Fisheries and Oceans Canada, natural fixation of atmospheric nitrogen by blue-green algal communities has been estimated to contribute 9,300 t/yr of nitrogen to Lake Winnipeg, representing 10% of total nitrogen loading (LWSB 2006:27). Internal lake contributions of phosphorus are not well understood, and are not estimated.

North/South Consultants has noted that:

> Sediments typically serve as "sinks" for nutrients and other substances, including contaminants, and lake therefore retain nutrients. Phosphorus settles, most notably in particulate forms, to lake sediments and is precipitated as insoluble ion, calcium, or aluminum phosphates.
>
> However, under certain conditions, sediments may be net sources of nutrients. Internal loading refers to the release of nutrients (typically phosphorus) from the sediment to the overlying water column, thereby effectively behaving as an "internal" nutrient load.
>
> Physiochemical and biological conditions at the sediment-water interface that affect the occurrence of internal loading are: phosphorus saturation of sediments; low dissolved oxygen conditions; elevated temperatures; reducing conditions; turbulence; pH and temperature; biological activities of sediment biota; and iron availability.
>
> [North/South Consultants 2006:82-83]

Supported by an exhaustive review of the limnological literature, North/South Consultants note that internal lake nutrient loading appears to be a major source of nutrients which can continue to affect lake water quality for long periods of time, even after loads flowing into a water body have been substantially reduced. Also, "internal loading appears to vary over the year, typically being greatest in summer in shallow temperate lakes" (2006:85).

Based on analyses by Sondergaard (2003 and 2001 in North/South 2006), it has been suggested that internal loading within shallow lakes can in fact be the single greatest source of nutrients. Phosphorus may be released from shallow lakes through diffusion (via decomposition of organic material). Also, "shallow lakes an/or the nearshore areas of lake may also experience wind-driven sediment resuspension that can also introduce significant quantities of nutrients into the water column (James 2005 in North/South 2006:83).

2.3.2 Atmospheric Deposition

As noted by Bourne, "nitrogen and phosphorus can be deposited directly to land and water through rainfall and particulate deposition through the air. Nutrients can be deposited directly to surface waters as well as onto the land surface and then transported to surface waters" (2002:6-7). Citing Schindler (1976), Flaten also notes there are three pathways for phosphorus deposition: dry/particulate attached to dust and other matter, wet/dissolved in precipitation, and phosphine gas (primarily generated by wetlands) 2003b:12).

The relative contributions of these sources are not well understood, although some interesting research in Manitoba and beyond is cited by Flaten (2003b). Atmospheric contributions to Lake Winnipeg are estimated and accepted to be 500 t/yr of phosphorus and 9,500 t/yr of nitrogen, representing 6% and 10% of total nutrient loads respectively (LWSB 2006:25-26).

2.3.3 Upstream Jurisdictions

The contributing drainage area for Lake Winnipeg is approximately 953,000 km^2 while the lake itself is 23,750 km^2, resulting in a very high contributing drainage area – surface area ratio of 40:1 (LWSB 2006:4 and LWIC 2005:11). Given that Lake Winnipeg's drainage area is so large, accurately understanding and addressing the sources of upstream nutrient contributions is very problematic. This is primarily due to the fact that land in no less than three Canadian provinces and four US states collectively contributes nutrient loads to Lake Winnipeg, in addition to Manitoba's own nitrogen and phosphorus contributions.

Each of these jurisdictions contribute its own point source, atmospheric deposition, natural background, undefined, and present-day agriculture nutrient loads. At 4,200 t/yr of phosphorus and 48,900 t/yr of nitrogen, the Lake Winnipeg Stewardship Board has accepted that nutrient loads from upstream jurisdictions contribute 53% and 51% of total phosphorus and nitrogen loading to Lake Winnipeg (2006:25-26).

Overall, the Lake Winnipeg drainage area contains more than 65 million ha (650,000 km^2) of agricultural land, representing more than 68% of the entire landbase. In a given year, at least 50% of this agricultural land is cultivated (LWIC 2005:12), with the remaining amount reasonably expected to be in pasture, forage rotation, or zero-tillage. Based on Canadian and US statistical data, the Lake Winnipeg Stewardship Board estimates the presence of more than 12 million beef cattle and almost 15 million hogs (LWSB 2006:13).

Nutrient loading data provided by Manitoba Water Stewardship (2006), for the major river systems entering Lake Winnipeg has also been accepted by the Lake Winnipeg Stewardship Board (2006) and is presented in Chart 2-1 and 2-2 below. The Red, Assiniboine, and Saskatchewan River systems each comprise substantial contributing drainage areas beyond the borders of Manitoba. However, the Red River is clearly the dominant nutrient source for both phosphorus and nitrogen.

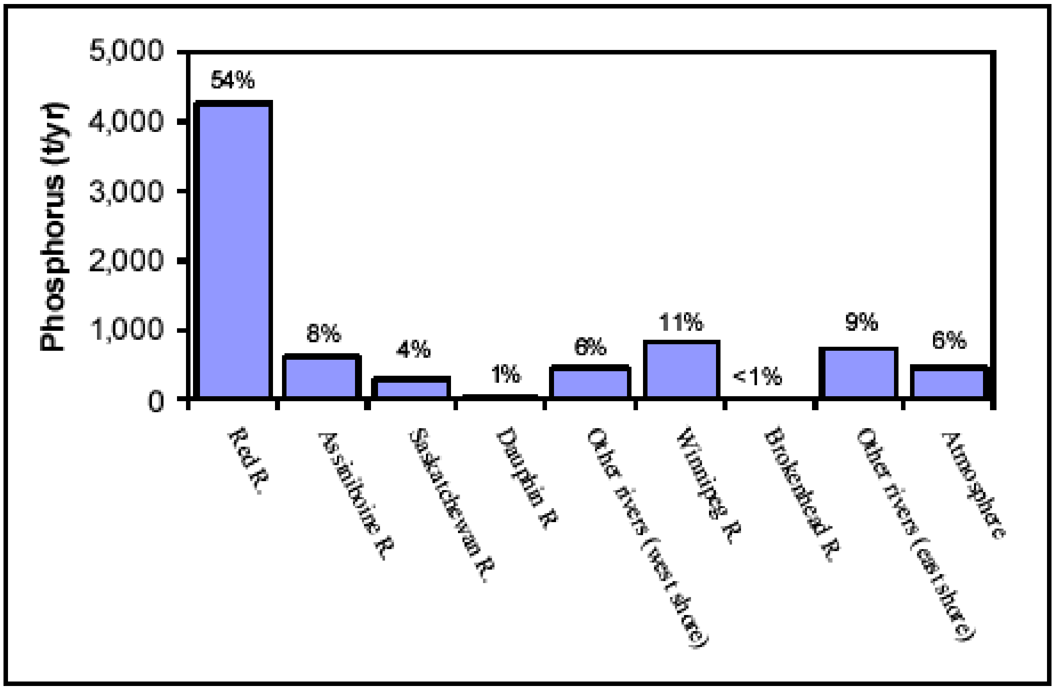


Chart 2-1: Total phosphorus loading to Lake Winnipeg from contributing sources, 1994-2001 (t/yr). Source: Manitoba Water Stewardship 2006 in LWSB 2006:29

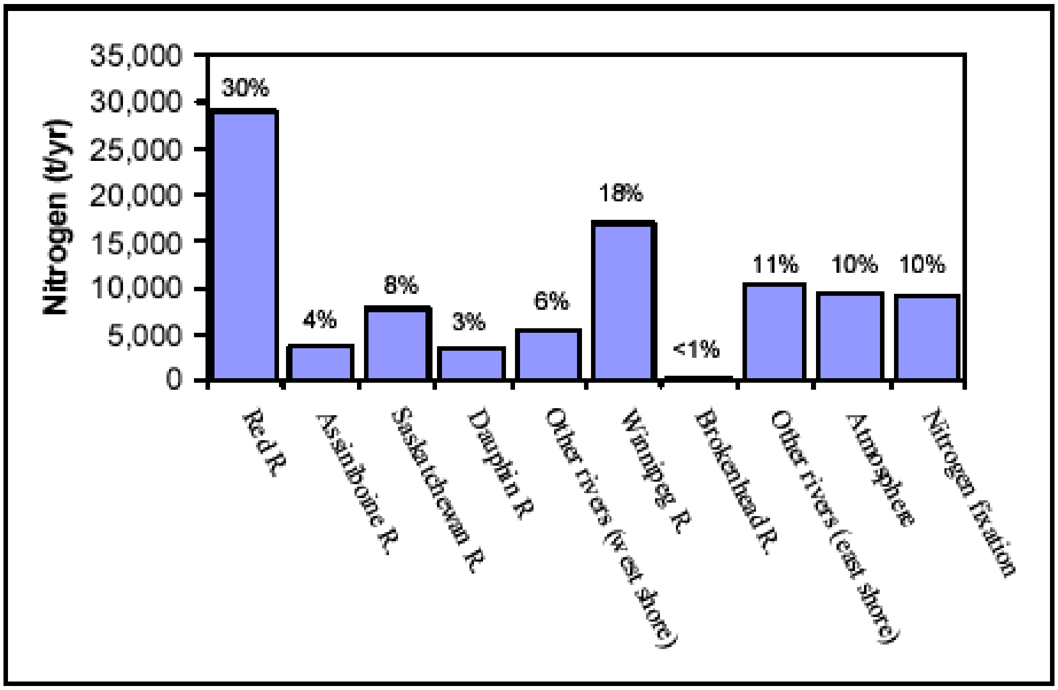


Chart 2-2: Total nitrogen loading to Lake Winnipeg from contributing sources, 1994-2001 (t/yr). Source: Manitoba Water Stewardship 2006 in LWSB 2006:29

As noted in Section 1.1.3, within a predominantly agricultural landscape there are necessarily strong interrelationships between natural background, undefined, and present-day agriculture nutrient loading sources. Together, these may be defined as *Upstream Jurisdiction Watershed Processes* and form a significant portion of total Upstream Jurisdiction contributions.

This reality is evident when considering the disproportionate nutrient contributions (54% of total phosphorus and 30% of total nitrogen) entering Lake Winnipeg via the Red River, which supplies only 11% of water flows (LWSB 2006:20,29). In addition, as noted by Williamson (2003) in Flaten (2003b), 59% of all Red River phosphorus loads are estimated to originate in the United States.

Substantial cooperation efforts exist and/or are underway within the three main drainage systems which contribute nutrients to Lake Winnipeg from beyond Manitoba. These likely represent the best means of addressing extra-provincial nutrient loads and are discussed further in Section 3.

However, activities in Manitoba – the source of almost half of total phosphorus loading entering Lake Winnipeg – are clearly a provincial priority which needs to be addressed now.

2.3.4 Manitoba Point Sources

At 700 t/yr of phosphorus and 5,100 t/yr of nitrogen, these sources are estimated to contribute 9% of total phosphorus and 5% of total nitrogen loads to Lake Winnipeg respectively (LWSB 2006:25-26). Point sources are most clearly defined as "direct effluent discharges…from industrial operations, domestic wastewater treatment facilities (includes wastewater treatment lagoons and wastewater treatment plants), and urban stormwater drains" (Bourne 2002:20-21).

Sizable wastewater treatment plants exist in Winnipeg, Brandon, and Portage la Prairie while many other rural "towns and villages, Hutterite colonies, provincial parks, community centres, schools, and churches" (Bourne 2002:21) manage wastewater treatment lagoons and are licenced to discharge their effluent into Manitoba surface waters. The Lake Winnipeg Stewardship Board's nutrient loading estimates were based on the research conducted by Bourne (2002) with additional information provided by Manitoba Water Stewardship (2006). These estimates are based on a combination of per capita nutrient loading estimates and actual measured discharges from larger municipal wastewater treatment facilities and industrial operations. Federally regulated facilities such as First Nations and national parks were not included due to a lack of available data.

Bourne notes that very few of the 400 licenced wastewater treatment facilities in Manitoba are required to monitor their effluent for nitrogen and phosphorus; neither do most of the 32 licenced industrial operations with wastewater discharges. Most industrial effluent is managed by municipal wastewater treatment facilities, while (beyond a small number of large industrial operations), industrial nutrient loading is likely underestimated (2002:21-24).

Stormwater and land drainage runoff contributions are another source of Lake Winnipeg nutrient loading from the City of Winnipeg. These contributions occur in the form of "combined sewer overflows, land drainage sewer discharges, and emergency sanitary overflows." There are 76 combined sewer and 90 land drainage sewer outfalls entering rivers within the City of Winnipeg (Bourne 2002:22).

Combined sewer overflows occur when combined domestic-land drainage sewer systems within 70% of Winnipeg discharge directly to the Red and Assiniboine Rivers during periods of heavy rain and snowmelt, known as "wet weather flows" (Flaten 2003b:14). Emergency sanitary overflows may also occur during wet weather flow periods when Winnipeg's wastewater treatment plants cannot effectively treat all receiving wastewater (Flaten 2003b), or during periods of critical maintenance or system malfunction.

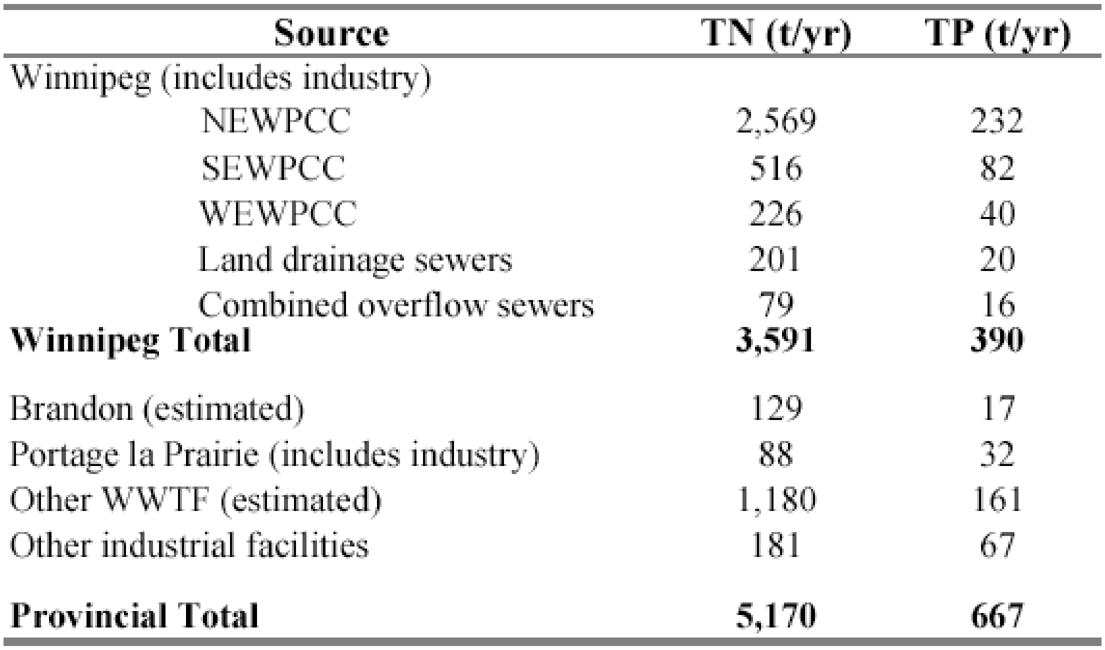
Land drainage sewers carry the precipitation runoff from developed urban areas, initially collected via the street-based network of collector sewers, directly to an adjacent water body. Data cited by Flaten (2003b) from the Wisconsin Department of Natural Resources (1991) suggests that combined industrial/commercial phosphorus loading from developed areas can easily double those generated by single-family and multi-family dwelling community areas. However, Flaten also cites other data collected in the City of Madison, noting that "the authors found lawns and streets to be the most significant sources of phosphorus in the test basins" (Waschbusch 1999), while Bannerman (1993) found that "lawns in residential and industrial areas contributed 14% and 44% respectively of the phosphorus load to stormwater runoff" (2003b:16).

Flaten raises the following important points regarding wastewater treatment:

> Another distinct characteristic of the effluent from water treatment facilities is that almost all of the total phosphorus is soluble phosphorus, and therefore its effect on the environment will be much acute than other sources where the dissolved phosphorus fraction of total phosphorus is not as high.
>
> Currently, wastewater treatment facilities within the Manitoba portion of the Red River watershed lack nutrient removal systems. However, many wastewater treatment plants in jurisdictions upstream of Manitoba have installed nutrient removal facilities.
>
> Wastewater treatment facilities also create a sludge by-product, usually referred to as "biosolids." This material, a residue from primary and secondary treatment processes, is dewatered to various extents and then land applied, much like manure. The amount of biosolids generated by a wastewater treatment facility depends on the level and type of treatment processes. The disposal of biosolids continues to be a major concern for wastewater treatment facilities across the continent.
>
> [Flaten 2003b:12]

While wastewater primary and secondary sewage treatment serves to remove most solids, sediment, and organic material (in addition to killing pathogens), it is important to note that wastewater treatment in Manitoba does not yet remove nutrients, which would be tertiary treatment (Cunningham 2007). Land application of biosolids does result in some total phosphorus reduction from the wastewater. While the dissolved phosphorus portion is less of a concern with biosolids (Flaten 2003b), this treatment process basically involves nutrient relocation. Biosolids are often applied to agricultural lands as a fertilizer supplement, and the potential for some nutrients to reenter a drainage system via erosion and runoff seems plausible. High toxicity and the presence of heavy metals necessitates the burial or incineration of most sewer sludges (Cunningham 2007).

Table 2-1 provides a useful overview of all Manitoba Point Source nutrient loads to Lake Winnipeg.



Source	TN (t/yr)	TP (t/yr)
Winnipeg (includes industry)		
NEWPCC	2,569	232
SEWPCC	516	82
WEWPCC	226	40
Land drainage sewers	201	20
Combined overflow sewers	79	16
Winnipeg Total	**3,591**	**390**
Brandon (estimated)	129	17
Portage la Prairie (includes industry)	88	32
Other WWTF (estimated)	1,180	161
Other industrial facilities	181	67
Provincial Total	**5,170**	**667**

Table 2-1: Average nutrient loads (t/yr) from effluent discharges to surface waters in Manitoba.
Source: Bourne 2002:24

2.3.5 Manitoba Watershed Processes

As discussed in Section 1.1.3, the various nutrient loads supplied by "natural background and undefined sources" (including forests, wildlife, and septic fields, along with "present day agriculture" sources are interrelated. Together, these *Manitoba Watershed Processes* comprise 2,500 tonnes/year of phosphorus (32% of total phosphorus loads and) and 23,200 tonnes/year of nitrogen (24% of total nitrogen loads) entering Lake Winnipeg (LWSB 2006:25-26).

Nutrient loads from Upstream Jurisdictions are a substantial source of Lake Winnipeg nutrient loading, and solutions in this area will likely require long-term bilateral discussions between Canada and the United States. in addition to interprovincial discussions between Manitoba, Saskatchewan, and Ontario. However to date, most local attention, action, and resources have been devoted to City of Winnipeg and other rural and industrial Manitoba Point Source nutrient contributions, reportedly because "these sources are the easiest to identify and manage" (LWSB 2006:27).

The Lake Winnipeg Stewardship Board notes that nutrient loads generated via *Manitoba Watershed Processes* (primarily via the Red River) are in fact much more significant than Manitoba Point Source contributions of phosphorus (more than threefold at 32% vs 9%) and nitrogen (almost fivefold at 24% vs 5%), also noting that:

> It is also clear that the contributions from the Red River watershed are high in comparison to the other major rivers in Lake Winnipeg's watershed, even though the Red River contributes considerably less flow (*11% of contributing flows*). Both the naturally fertile soils of this region and the intense residential and agricultural development contribute to this nutrient loading.

> The dominant form and process of phosphorus loading from the watershed appears to be as dissolved phosphorus during the spring runoff. The application of appropriate beneficial management practices on the landscape to reduce loading during the spring will be an important measure to improve water quality of streams feeding Lake Winnipeg.
>
> The relatively high contribution of nutrients originating from upstream jurisdictions (51 % of the nitrogen and 53% of the phosphorus) accentuates the need to work in cooperation with neighbouring provinces and states to reduce loading to Lake Winnipeg, and also to lead by example.
>
> [Lake Winnipeg Stewardship Board 2006:27]

Manitobans should be most concerned by the LWSB's acknowledgement that *Manitoba Watershed Processes* in fact represent 67% of all phosphorus loads generated within Manitoba and 49% of all nitrogen loads entering Lake Winnipeg from within the province. For phosphorus, watershed processes are reported to almost evenly comprised of "natural background/undefined" at 35% of Manitoba-based sources and 32% "present day agriculture." Manitoba-based loads for nitrogen are reported to be 38% "natural background/undefined" and 11% "present day agriculture" (LWSB 2006:25-26).

Manitoba's current and major challenge now is in fact to lead by example, in finding and implementing methods to reduce nutrient loading to Lake Winnipeg, contributed via *Manitoba Watershed Processes*. These include the following sources.

2.3.5.1 Natural Background and Undefined Loading

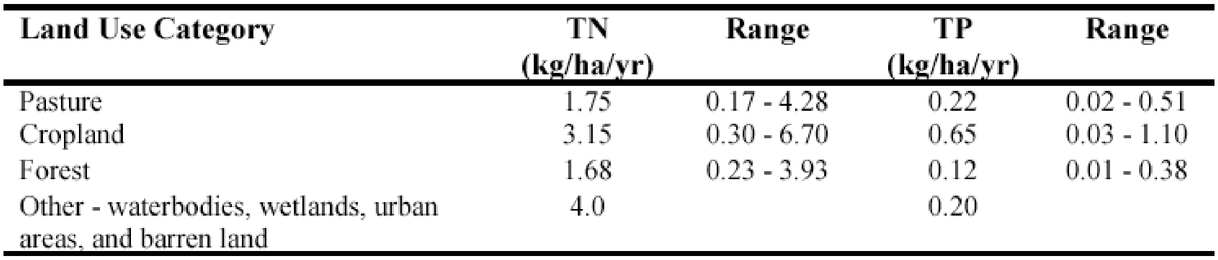
A wide variety of natural and human activities on the landscape can affect Lake Winnipeg water quality, in particular the nutrient loads which enter through its composite watersheds. Precipitation falling in the form or rain or through spring runoff flows downstream to the lake and is dramatically influenced by topography, soils, human-induced landscape change, and the contributing drainage systems through which water flows (whether natural streams or agricultural drains).

While these are natural processes, various land use activities and landscape changes can result in dramatic alternations to natural systems, causing impacts such as: increased streamflows and associated erosion and sediment transfer and deposition in and via waterways; increased soil erosion from the land into downstream waterways; increased nutrient loading associated with different agricultural vegetation types or a lack of beneficial riparian vegetation; contamination of groundwater and subsequent nutrient flow into receiving waterways; increased nutrient transport associated with agricultural and residential land drainage; and nutrient loads associated with rural residential septic field systems. These sources are described within the Manitoba context below.

Forests, Vegetation, Wildlife, and Soils
Erosion causes nutrients to be released from decaying forest litter and organisms, while other forms of decaying vegetation also export nutrients downstream via surface water runoff following precipitation events or meltwater. Various land use practices alter the amount of exposed soil in particular areas, as well the type and mass of vegetation available for decomposition (Bourne 2002).

Forested watersheds provide valuable ecosystem services, including the sequestration of nutrients (Sidle 2006) and the removal of forest cover has been demonstrated to increase annual runoff and sedimentation rates measured in downstream waterways (Foster 2005). Dissolved forms of most nutrients have been identified as the largest sources of forest-related nutrient export downstream (Yusop 2006). Some of Lake Winnipeg's composite watersheds are heavily forested, but not the Red River Basin, the single greatest contributing source of nutrient loads.

The Red River Basin is predominantly agricultural, containing many different land use types primarily related to the type of crop grown in a given year, or the type of pasture being managed. The nutrient export coefficients of various soil types can be used to estimate relative contributions of phosphorus and nitrogen from the land (including agricultural land), and their proportion of total nutrient loads within downstream water bodies. The coefficients in Table 2-2 were used towards estimating Lake Winnipeg's "natural background" nutrient loads.



Land Use Category	TN (kg/ha/yr)	Range	TP (kg/ha/yr)	Range
Pasture	1.75	0.17 - 4.28	0.22	0.02 - 0.51
Cropland	3.15	0.30 - 6.70	0.65	0.03 - 1.10
Forest	1.68	0.23 - 3.93	0.12	0.01 - 0.38
Other - waterbodies, wetlands, urban areas, and barren land	4.0		0.20	

Table 2-2: Mean and range of TN and TP export coefficients (kg/ha/yr) for specific land uses.
Sources: Chambers and Dale 1997; Green and Turner 2002 in Bourne 2002:29

While there has been some criticism of this approach (Flaten 2003b), (specifically the reference data for various export coefficients and the reliance on generalized coefficient application across diverse watersheds, particularly relating to their variability of precipitation receipt) Bourne notes that:

> Watershed nutrient loads are more difficult to quantify than direct effluent discharges because they are often more diffuse, highly variable, and intermittent. The load of nutrients exported from land to surface water depends on soil type, vegetation cover, and precipitation. The type of land use practices or activities also heavily influence the movement of nutrients from land to surface waters.
>
> Rates of nutrient export can be lowered by the presence of riparian vegetation along stream channels and lake shores, while the development of drainage channels can have he opposite effect and result in increased nutrient export to surface waters. The amount of nutrient loading to land from atmospheric deposition and agricultural fertilizer and manure applications can also strongly influence the amount of nutrients that are available for export to surface waters.
>
> [Bourne 2002:29-30]

Enhanced Drainage, Reduced Riparian Vegetation, and Precipitation Impacts
Bourne (2002) has noted that artificial drainage networks (typically to facilitate agricultural development) increase the natural rate at which nutrients are exported from the land to downstream waterways. Similarly, the loss of wetlands also amplifies these nutrient losses. Equally, losses of

riparian vegetation cause streambanks to become less stable, less able to retain nutrients, and more prone to erosion of nutrient-rich sediments.

These trends are echoed within the hydrologic connectivity literature (Section 2.4). Alexander notes that “land use changes or modifications to stream channels that increase the flow rates in headwater streams may heighten their influence on the chemical quality of downstream receiving waters” (2007:46). Wipfli (2007) also notes that different land uses and hydrologic management regimes such as: agricultural development and cultivation, forest harvesting, mining, road construction, urbanization, channelization flow regulation, irrigation, and reservoir creation all dramatically influence these natural processes, which influence downstream ecosystems.

It is interesting to note that the only existing Manitoba-based research directly contributing to understanding nutrient loads at the land-water interface within the province’s agricultural watersheds (South Tobacco Creek) has determined that “overall, nutrient loadings appear more responsive to the nature of the hydrological events rather than land use,” based on the observation that periods of higher loading do not correlate to the years when chemical fertilizer applications were the greatest (Glozier 2006:64). These findings are outlined in Table 2-3.

Year	Total Nitrogen	Total Dissolved N	Total Phosphorus	Total Dissolved P
	% of Applied Fertilizer			
1994	3.1	1.9	2.4	0.9
1995	7.6	4.6	6.4	2.1
1996	9.5	5.8	5.4	1.9
1997	10.6	5.8	5.4	1.9
1998	8.4	5.1	5.7	1.9
1999	3.3	2.0	2.6	0.7
2000	0.7	0.5	0.7	0.2
2001	8.8	4.9	7.2	2.3
Average	**6.5**	**3.8**	**4.9**	**1.5**

Table 2-3: Loadings of N and P at Miami, MB expressed as a percentage of fertilizer applied within the South Tobacco Creek minor watershed from 1994 to 2001. Source: Glozier 2006:64

However land-based contributions are important (if not from applied fertilizer). In seeking to understand this relationship, Glozier also notes that:

> …the hydrologic conditions during spring melt did have a large influence on total nutrient and sediment loading. On average, a relatively small proportion of the annual loading is transported during the summer (May to October) period…The majority of the dissolved nutrient transport occurs with snow melt events.
>
> Regarding the dissolved fractions, we observed low dissolved concentrations during base flow, higher dissolved P at the edge of field (under conventional tillage) than in the main stem, and the dissolved nutrient fraction peaking simultaneously with discharge. These observations, along with the rapid increase in dissolved concentration with longitudinal river distances, suggest that the source of dissolved nutrients may be largely land-based processes in contrast to the within-channel sediment source.
>
> [Glozier 2006:68-69]

Streambank and Streambed Erosion

As noted by Bourne (2002), nutrients can be associated with sediment carried in downstream through Manitoba waterways. Variables such as stream velocity and its associated energy contribute to "scouring" of nutrient particles from streambanks and/or streambeds. These in turn, can be redistributed downstream where phosphorus and nitrogen can enter the water column. Citing Haygarth and Jarvis (1999), Flaten notes that eroded sediment or suspended particles containing phosphorus "release precipitated or adsorbed phosphorus because the concentrations of phosphorus in most water bodies is much lower than that in soil solution" (2003:14). The hydrologic connectivity literature also supports this, noting that headwater stream management projects which involve channelization, enhanced drainage, diversion, crossings, tile drainage, and the general use of culverts all result in substantial changes to the drainage regime of a watershed. These changes generally result in negative water quality impacts, in addition to aquatic habitat loss (Freeman 2007).

South Tobacco Creek research in Manitoba has reported that:

> It became evident that a greater proportion of the nutrient and sediment load originated in the upper portion of the watershed and/or, that sediment and nutrients were lost from suspension in stream water between H-240 and Miami [mid-watershed and lower watershed monitoring stations]. Dissolved nutrients increased rapidly in the upper watershed and even began to decline in concentration before reaching Miami, while the particulates increased closer to the confluence of the north and south arms.
>
> Some sediment and particulate nutrients may be deposited on the streambed between H-240 and Miami if the energy of the stream decreased (e.g. a change in slope and velocity) and dissolved nutrients may have sorbed to sediments in the stream, transformed to other forms (including gaseous forms that could be lost to the atmosphere), or used as a food source by plants on organisms in the stream.
>
> Finally, in calculations of the proportion of total nutrient loadings for comparisons to larger downstream watersheds such as the Red River, the phosphorus load derived in STC was disproportionately high on a watershed basis while nitrogen load was proportional to the watershed area. Therefore, these small escarpment catchments play an important role in the overall loading to the larger river and lake ecosystems downstream and their dynamics should be examined and understood in more detail to understand the potential implications of land management practices to stream nutrient concentration and loading.
>
> [Glozier 2006:69]

Ground Water Infiltration and Rural Residential Septic Sources

Bourne explains that "infiltration of ground water via the streambed often provides a majority of the base flow in some streams during periods of low flow such as fall and winter." and that elevated levels of nitrogen can occur within groundwater, via "the downward leaching of nitrates and nitrites from animal manure and inorganic fertilizer applications, and leakage of municipal sewage lagoons and private septic systems" (2002:6).

Flaten (2003b) also notes that the transfer of particulate and/or dissolved phosphorus can occur via the flow of groundwater through contaminated soil. Organic phosphorus sources are particularly problematic. Flaten has also pointed to the potential nutrient loading contributions from groundwater and rural residential septic sources north of Winnipeg:

> There are many possible explanations for the TP loading within this section of the Red River Basin. In-stream processes, such as groundwater recharge and bank erosion, non-point

> sources from the densely developed area adjacent to this stretch of the river, especially leaky septic systems, and combined sewer overflows are all potential contributors. The identification of the sources of P in this section of river needs further investigation.
>
> [Flaten 2003b:10]

2.3.5.2 Present Day Agriculture: Focusing on Phosphorus

Bourne (2002) identified two main agricultural sources of nutrients: animal manure and inorganic fertilizer. These are discussed below.

Natural/Organic Agricultural Fertilizer/Manure
The LWSB makes a clear case for addressing phosphorus loading as an initial priority for reducing Lake Winnipeg nutrient loading, primarily due to the prevalence of livestock manure application in Agri-Manitoba, and the fact that:

> Currently, manure application rates in Manitoba are regulated based on crop nitrogen inputs alone. However, the ratio of phosphorus to nitrogen removed by crops is lower than the phosphorus to nitrogen ratio in manure. Therefore, when only the nitrogen content of the manure is considered when determining application rates, phosphorus is often applied at rates that exceed agronomic requirements. A build-up of phosphorus in the soil can lead to soil phosphorus saturation and the subsequent release of phosphorus when water travels through, or over, the soil.
>
> [LWSB 2006:64]

Phosphorus has been widely recognized as the logical first priority in addressing eutrophication in water bodies downstream from predominantly agricultural land use areas, primarily due to the propensity for its dissolved form to transport easily from the land into water bodies, and the fact that its particulate form readily attaches sediment (Hively 2006, Flaten 2003, and Soranno 1995). In addition to understanding the eutrophication contributions of phosphorus itself, these facts also denote the importance of understanding the interrelated processes of water flow and soil erosion, both of which can be accentuated by agricultural development and associated upland drainage.

The LWSB (2006:64) cites several sources including Manitoba Food and Rural Initiatives data (Farm Practices Guidelines) in outlining the relative Manitoba phosphorus contributions to agricultural land from livestock manure generated by beef cattle and hogs (based on 25,000 tonnes/year of total manure phosphorus in 2001). Manure phosphorus excretion values are based on data presented by Flaten (2003b:23) and current provincial cattle herd sizes provided by the Canadian Pork Council and Statistics Canada.

The LWSB provides a misleading reference that "In Manitoba, "7.9 million hogs were placed on the market in 2005," which actually refers to total hog production during that year, not the total number of hogs within the province at any particular time, which was actually 2,910,000 animals in 2005, 2,980,000 in 2006, and is currently 2,965,000 hogs (Statistics Canada 2007).

Based on the actual and standardized 2006 comparisons, these estimates suggest that:

- phosphorus generated from 2.965 million hogs in Manitoba represent an average daily contribution ranging from 14,825 kg/day and 115,635 kg/day of manure phosphorus to agricultural land;
- phosphorus generated from 1.7 million beef cattle in Manitoba represent an average daily contribution ranging between 88,400 kg/day and 210,800 kg/day of manure phosphorus to agricultural land;
- based on the 2001 calculations by Flaten (2003b: 21-23), it can be reasonably assumed that current manure phosphorus contributions to agricultural land in Manitoba are currently in the range of 20,346 tonnes/year for beef cattle and 7,909 tonnes/year for hogs, an overall increase of 3,255 tonnes/year of manure phosphorus beyond 2001 levels for these two sectors;
- Manure phosphorus from chickens and turkeys is not deemed to be as significant (3%); and
- while beef cattle manure was estimated to generate nearly 70% of total manure phosphorus generated by livestock with hogs supplying 27 % in 2001, recent growth in the hog sector appears to have been slightly outpaced by growth in the cattle sector (17% vs. 19%), suggesting the ratio of cattle:hog manure phosphorus contributions has not changed appreciably since 2001.

Flaten also notes that "the runoff from manured fields can contain significant amounts of dissolved phosphorus, particularly when manures have not been injected or incorporated into the soil following application." Groundwater may also be contaminated through leaching of phosphorus (in either its particulate or dissolved forms). "High concentrations of P in soil, especially in the form of organic P, create the potential for significant leaching of P into groundwater (2003:14).

Assuming the accuracy of the Lake Winnipeg phosphorus loading data contained within the Lake Winnipeg Stewardship Board final report (2006), the vast major of these manure phosphorus contributions are utilized locally near their sources, in the form of crop production and/or other forms of plant uptake (i.e. by riparian vegetation).

As described by Flaten (2003), various factors determine the amount of phosphorus exported from agricultural lands to downstream water bodies via surface runoff and/or groundwater flow:

- water infiltration rates determined by soil texture/structure;
- precipitation intensity/duration;
- snowfall volumes and speed of melt;
- crop management types and vegetative cover;
- slope, proximity to watercourses, and riparian health

Chemical/Inorganic Agricultural Fertilizer

The application of inorganic fertilizer to agricultural lands provides a source of nutrients that may later be exported to surface water through rainfall or snowmelt (Bourne 2002). In describing global nutrient loading trends, Alexander also notes that:

> Nitrogen in the environment has vastly increased in recent decades, largely associated with growing populations and associated land use from (1) creation of reactive nitrogen, via the Haber-Bosch process, for fertilizers and other industrial applications (2) cultivation of vast areas of crops that host nitrogen-fixing bacteria; and (3) fossil fuel burning and the

> associated emissions and nitrogen deposition (Smil, 2001). Worldwide, human activities have more than doubled the amount of reactive N entering the environment (Vitousek et al., 1997; Galloway et al., 2004).
>
> [Alexander 2007:43]

In terms of inorganic fertilizer usage in Manitoba, based on data from Korol and Rattray (2001, 1997), Flaten (2003b) notes that inorganic nitrogen use has grown by seven-fold since 1965. Phosphorus usage has more than doubled during the period (Chart 2-3).

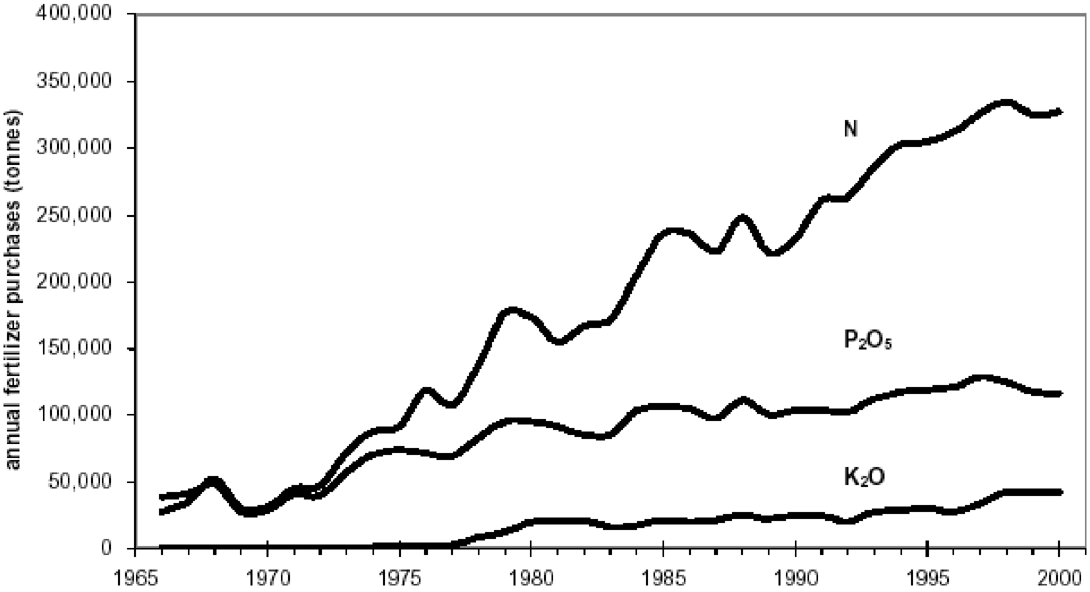


Chart 2-3: Annual fertilizer nutrient sales in Manitoba from 1965 to 2000 (adapted from Korol and Rattray 1997; Korol and Rattray 2001). Source: Flaten 2003b:18

The LWSB has also noted that approximately "85% of phosphorus applied to agricultural land comes from synthetic fertilizer," which represents another important aspect of phosphorus loading for Lake Winnipeg (2006:65). It has also been noted that harvested crops were fairly effective in utilizing fertilizer-based phosphorus sources until the mid-1990s. Since then, fertilizer application rates have exceeded crop removals (Johnston and Roberts 2001 in Flaten 2003b).

In recommending the development of a "terrestrial nutrient budget for Agri-Manitoba," the LWSB appears to have recognized (Recommendation 32.2) the importance of clarifying the relative phosphorus loading contributions from various sources within the agriculture sector, including beef cattle, hogs, and synthetic applications.

Addressing Manitoba Watershed Processes

As vital components of "present-day agriculture," each of these agricultural phosphorus sources comprises a significant portion of the overall *Manitoba Watershed Processes* total of 2,500 tonnes/year entering Lake Winnipeg. Equally, "natural background and undefined sources" are suggested to represent an almost identical portion. Together, as *Manitoba Watershed Processes*, these interrelated components represent 32% of total Lake Winnipeg phosphorus loads and 67% of all Manitoba-based sources (LWSB 2006:25).

The dearth of long-term, Manitoba-based data surrounding farm field contributions suggests that real clarification regarding these relative nutrient contributions will be difficult. As such, the nutrient challenge should be most appropriately focused on finding the best means by which to reduce nutrient loads from within Lake Winnipeg's contributing drainage systems – at the watershed (or possibly subwatershed) level – towards addressing nutrient loads generated through *Manitoba Watershed Processes* as a whole, recognizing the reality that its natural background/undefined and agriculture components are interrelated, and that loading reductions via each and/or either pathway would be beneficial overall.

2.4 Hydrologic Connectivity of Headwater Streams

The accumulation of individual hydrological units forms the headwater streams for the rivers and lakes of a regional water system. These headwater streams represent "individual elements of integrated hydrological system" (Nadeau 2007:118) in which both upstream and downstream portions of individual watersheds are linked. Multiple watersheds in turn contribute to common receiving waters further downstream (e.g. rivers and lakes) and are also connected in this way, contributing to overall ecosystem integrity of regional water systems.

Hydrologic connectivity has been defined as "the water-mediated transport of matter, energy and organisms within or between elements of the hydrologic cycle" (Freeman 2007). Freeman estimates that headwater streams encompass more than two-thirds of total stream length within most watersheds, directly connecting upland and riparian areas to the rest of the drainage system. In the United States (excluding Alaska), headwater streams cover 53% (2,900,000 km) of total waterway distance, and of this amount, more than 50% of this distance includes intermittent and ephemeral streams which rely solely on precipitation for their flow (Nadeau 2007: 118).

Headwater catchments control the recharge of aquifers, movement of water, and amount of time that water spends in the system, the "residence time" of water within a landscape (Alexander 2007:41). The associated hydrological processes in these streams also control the type, timing, and distances traveled of material transported to downstream waters (including nutrients). Headwater streams can be characterized by the volume and type of organic matter they transport downstream, mixing with other materials carried by other contributing waterways into receiving water bodies such as rivers or lakes (Wipfli 2007).

Recent modeling research has concluded that:

> …first order headwaters contribute approximately 70% of the mean-annual water volume and 65% of the nitrogen flux in second-order streams. The contributions to mean water volume and nitrogen flux decline only marginally to about 55% and 40% in fourth and higher-order rivers that include navigable waters in their tributaries. These results underscore the profound influence that headwater areas have on shaping downstream water quantity and water quality.
>
> [Alexander 2007:41]

Figure 2-3 depicts this relationship, and the very significant nitrogen contributions of headwater streams to total loads downstream, which Alexander attributes to "the high density of headwater streams and the high frequency of their connections to the channels of all higher order streams." (2007:54). Alexander explains this as a defining characteristic of all dendritic river networks.

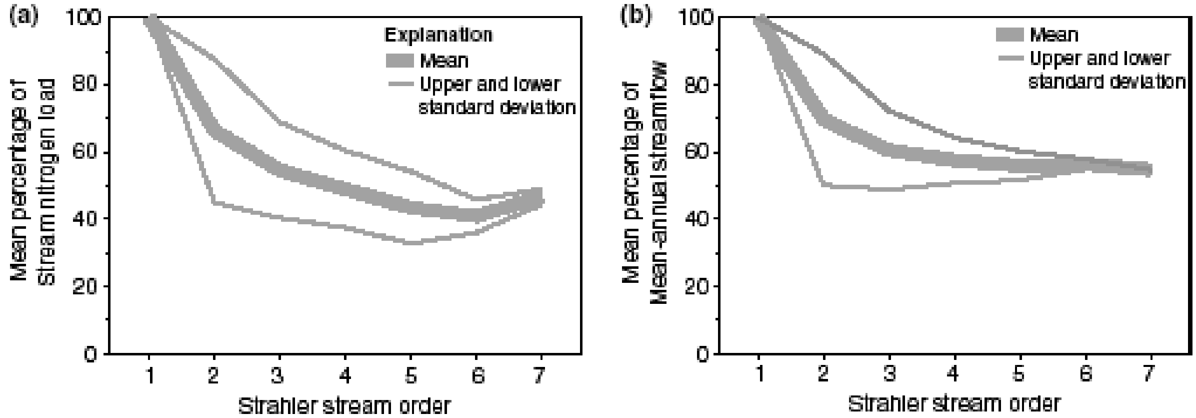


Figure 2-3: The percentage of the mean-annual load and streamflow in streams of the northeastern United States that originate in headwater catchments: a) nitrogen; b) streamflow. Source: Alexander 2007:54

The movement of material from small streams through a watershed to downstream water bodies is quantified in terms of relative rates, timing, and conversion processes (Wipfli 2007). Larger particles are converted into more easily transported smaller particles, while dissolved organic matter is converted into more useable larger particles for food chain consumers. Wipfli (2007) also notes that downstream water bodies are significantly influenced by headwater streams through hydrological and ecological processes. Anthropogenic alterations to natural systems cause changes downstream.

Alexander's research (2007) into the downstream fate and influence of nitrogen in watersheds has been based on the fact that its reactive and mobility properties make it an effective surrogate in understanding many pollutants. Alexander notes that:

> Once nitrogen is delivered to streams or rivers, the aquatic ecosystem itself plays a critical role in modifying the nitrogen (and other material) fluxes, via channel routing and instream processing. Stream channels have a natural dendritic design that plays an intrinsic role in transporting nitrogen and other pollutants from widely dispersed upstream sources and concentrating these materials in downstream waters.
>
> Hyporheic zones of streams [stream channel and streambank sediments] also play a key role in nitrogen transformations (uptake and cycling) and permanent removal (i.e. denitrification) as nitrogen is exposed to reactive benthic surfaces during transport.
>
> [Alexander 2007:44]

Increases in headwater stream peak flows are likely to reduce their natural uptake of nitrogen, thus increasing the distance (and concentration) of nitrogen transport downstream. Also, channelization of natural streams, resulting in the removal of natural pools and riffles, reduces the travel time of water moving downstream – simultaneously reducing natural nitrogen uptake by stream channel and streambank sediments (Alexander 2007). The development of artificial drainage systems can be expected to produce similar effects. The distribution of human and animal populations, land use, soil types, and vegetative cover all determine the concentrations, volume, and location of nitrogen loading to a stream and within a watershed (Boyer 2002).

It is important to note that riverine floodplains and riparian areas are critical locations for the denitrification process, particularly during floods, when increased water depths serve to improve nitrogen contacts with "microbially reactive floodplain sediments" (Alexander 2007:46). Similarly, wetlands have also been widely recognized for their ability to remove excess nutrients and improve downstream water quality (Newbold 2005).

Significant headwater stream modifications that reduce stream length tend to lower secondary productivity of rivers, which in turn affects aquatic life and wildlife that utilize the water resources (Freeman 2007). As noted by Meyer, "small streams differ widely in physical, chemical, and biotic attributes, thus providing habitats for a range of unique species" (2007:86). These attributes include such things as temperature ranges, available light, hydrologic regimes, water quality, substrate type, and food resources. The diversity of terrestrial and aquatic life across numerous headwater streams of a single watershed contributes to the biodiversity of the entire drainage system. (Meyer 2007).

Activities that modify or threaten these diverse headwater attributes in turn influence the downstream ecosystem. The ecological effects of altering headwater streams (and wetlands) in a watershed through enhanced drainage and increased peak flows are magnified by land uses that also increase runoff and nutrient loads to streams. The cumulative effects of these alterations typically result in increased downstream eutrophication and other negative ecological impacts.

Bourne (2002) and Glozier (2006) have also demonstrated the influential contributions of headwater streams in terms of their nutrient loads in Manitoba (Table 2-4).

River	Location	Area (km^2)	Total Nitrogen (kg/km^2)	Total Phosphorus (kg/km^2)
Red	Selkirk	127,000+153,000	258	39
Assiniboine	Headingley	153,000	89	15
Boyne	Carman	1325	74	7
Cypress	Bruxelles	815	69	11
Ochre	Ochre River	460	80	7
South Tobacco	Miami	76	290	70

Table 2-4: Average total N and P loadings in South Tobacco Creek between 1994 and 2001 relative to other Manitoba streams (adapted from Bourne et al. 2002). Source: Glozier 2006:60 with Assiniboine River Drainage data from ArcticNet (2007)

Citing Forrester (2004), Glozier notes that South Tobacco Creek is similar to other escarpmental streams, and its location along the Manitoba Escarpment contributes to its relatively high nutrient loads; "these small upland catchments likely play an important role in the overall loading to the larger river and lake ecosystems downstream, and their dynamics should be examined and understood in more detail" (2006:60).

2.5 Modeling Nutrient Load Reductions in Watersheds

Natural and anthropogenic watershed processes largely determine the potential for nutrient loading within downstream water bodies. By influencing these activities, it is possible to reduce and potentially reverse the impacts of elevated nutrients levels beyond healthy watershed nutrient limits.

Watershed modeling research has sought to better understand the cumulative contributions of relative nutrient sources and the efficacy of various institutional, expenditure, regulatory, and economic tools which policy-makers may utilize to influence the watershed activities. Some innovations in the area of watershed modeling and *Total Nutrient Management* experiences to date have been reported in the following areas and hydrologic levels.

Watershed Scale

The Rönneå Catchment is the pilot research watershed for the Swedish Water Management Research Program (VASTRA), located in the southern tip of the country and draining into Skölderviken Bay in the Jutland Strait. This 1,900 km^2 drainage system has been the focus of numerous long-term studies, including development of the HBV-NP model, a dynamic hydrologic model which has been refined to simulate Swedish landscapes and climatic conditions. Agricultural land use with the system represents 30% of total watershed area (Andersson 2005, Arheimer 2005).

In response to the EU Water Framework Directive, Sweden's efforts to reduce anthropogenic sources of eutrophication have resulted in national objectives focused on the reduction of nitrogen and phosphorus loads to each of its main river basins – by 30% and 20% respectively, by 2009. In support of these goals, substantial efforts have been devoted to integrated catchment modeling (Arheimer 2005).

The Rönneå Catchment was subdivided into 64 subwatershed units for HBV-NP calibration. Cumulative modeled subwatershed nutrient loads were compared with a total loading simulation for the entire Rönneå Catchment, yielding comparable results and likely applicability for the analysis of similar watersheds – at the watershed scale. Collection of more detailed data at the subwatershed level (e.g. soils, land use, point sources, and rural household loads) would be desirable for improving the understanding of nutrient behaviour within this particular system, although it may make the HBV-NP less applicable elsewhere, given the diversity of subwatershed systems (Andersson 2005).

Several nutrient reduction scenarios were tested by Arheimer (2005) using the HBV-NP model. These involved a variety of beneficial management practices (BMPs) and other interventions – focused on agricultural, rural households, wastewater treatment plants, and industrial loading sources. The most cost-effective scenario involved the construction of wetlands on 2% of all agricultural land, combined with improved rural household waste management (Arheimer 2005).

Subwatershed Scale

The Sugar Creek Watershed has been defined as one of the most impaired systems within the US State of Ohio. This 925 km^2 headwater system is the state's single largest contiguous watershed within the Ohio River system (Muskingum River). Given its apparent role in causing eutrophication and related water quality problems downstream, Sugar Creek (with 80% of its area in agricultural production) was targeted early for *Total Maximum Daily Load* planning and associated requirements for 60% reductions for both nitrogen and phosphorus contributed from all non-point loading sources (Prasad 2005).

At Sugar Creek, hydrologic data and nutrient loads have been analyzed using a digital elevation model (DEM) and a geographic information system (GIS) with the objective of understanding the relationship between landscape complexity and variation, along with anthropogenic land use and management. Several hydrologic parameters were defined for DEM application, with model results demonstrating a linkage between landscape features, agricultural production practices, and nutrient loads. The introduction of more detailed land use and management data at the field level would improve model utility (Prasad 2005).

Minor Watershed Scale

The Yamada River Watershed is a 19km^2 system northeast of Tokyo, Japan. Agriculture is the dominant land use, and non-point sources from fertilizer and animal wastes have been previously identified as key non-point nutrient loading sources. A water quality tank model has been utilized to assess the effectiveness of five nitrogen reduction scenarios. These included: soil washing, the use of slow-release fertilizer, reducing fertilizer application rates, use of cover crops, and the reduction of animal wastes (Kato 2005). Table 2-5 outlines the scenario results.

Scenario	Explanation	% Change in N	Year Achieved	Comment
Soil Washing (via precip)	Increase model precip to 200mm+	Initial decrease followed by future increase	2021	N load ultimately increases due to increased runoff
Slow-Release Fertilizer	No limit set for soil accumulation in model	Initial decrease followed by future increase	2030	Overuse of fertilizer will eventually worsen water quality
Fertilizer Applic. Reduction	Modeled application reduced to 0	-20%	2040	Likely unrealistic
Cover Crop Transition	Assume crop export from watershed	-10%	2040	Cover crops only absorb topsoil N
Animal Waste Reduction	All waste removed from watershed	-70%	2040	Most significant modeled scenario

Table 2-5: Nitrogen reduction scenario results generated through a water quality tank model for the Yamada River Watershed. Source: Adapted from Kato 2005:26

Individual Hydrologic Unit/Farm Scale

The Soil Moisture Distribution and Routing (SMDR) model was developed for watershed analyses of upland, well-vegetated agricultural areas (Gérard-Marchant 2006), further described as follows:

> The purpose of SMDR is to identify the location and evolution of variable source areas for overland flow generation and to estimate water fluxes to streams and groundwater. The SMDR is intended as a tool for planners or groups interested in watershed management. Therefore, it does not require extensive calibration and is designed to use data that are readily available in electronic form: i) a digital elevation map, ii) a soil type map and the associated table of soil hydrologic properties, iii) a land use and land cover map, and iv) weather data (temperature, precipitation and potential evapotranspiration).
>
> [Gérard-Marchant 2006:246]

The SMDR has been applied extensively within a privately-farmed 164 ha agricultural watershed in upstate New York – to determine the effectiveness of BMP implementation in reducing non point source nutrient loading of New York City's third largest water reservoir. It is one of the few hydrologic models that can accurately simulate "saturation-excess overland flow," …"which occurs when precipitation falls on saturated soil," which is generally more difficult to model than "infiltration-excess overland flow" (Gérard-Marchant 2006:245).

Hively has demonstrated that the SMDR model accurately simulates actual total dissolved phosphorus loads as observed at the watershed outlet. Building on this, the SMDR has predicted that total dissolved phosphorus loads from manure-treated soils were less than 10% of total watershed loads during two years of actual manure applications (1997-1998). However, these loads varied greatly in terms of daily loads, with certain days during April and May exceeding 90% of total watershed loads. These results are possibly explained by the fact that the farm operator was utilizing many BMPs, including no winter spreading of manure. However, the highest loads (>90%) were seen on April and May days when stored manure from the winter was spread, and local runoff was significant (Hively 2006).

It is appropriate to note that the first phase of a Watershed Evaluation of Beneficial Management Practices (WEBs) will be completed on 31 March 2008, at South Tobacco Creek in Manitoba.

Québec Whole Systems Research and Application

There has been substantial research progress and practical application in Québec – focused on both a "whole farm budget" for nutrients, as well as modeling the downstream mobility of phosphorus throughout sizable watersheds.

Pellerin (2006, 2006b) has conducted extensive work into the Mehlich-III soil phosphorus saturation index – on various soil types and various crops. This index appears to be a reliable indicator of phosphorus accumulation levels, "provided that soil texture is taken into account" (Pellerin 2006:721). Finer textured soils are prone to releasing more water-extractable phosphorus than soils which are more coarse. Lower phosphorus fertilization requirements for crops such as corn have been demonstrated within the finer soils (>300 g clay kg^{-1}), implying that corn can be fertilized at lower rates in these conditions, with no yield loss (Pellerin 2006b:908).

These and related findings support extensive cooperative efforts among Québec's provincial departments responsible for agriculture and environment – in addition to the province's association of pork producers. These organizations have been working together and sharing information in an attempt to reduce total nutrient loading, beginning at the farm level. The concepts and basic model information behind Québec's *Whole-Farm Nutrient Budget* effort was adopted from Holland, based on similar efforts in Europe which have been in place for more than 20 years (Trudelle 2007).

Central to the *Whole-Farm Nutrient Budget* which hog farmers are encouraged to adopt is the understanding that:

> Nutrients arrive on the farm (Inputs) in the form of purchased feed, fertilizer, and animals or as N fixed by legumes. It is desirable that these nutrients leave the farm as marketed products (Managed Outputs) such as animals or crops. Any imbalance between Input and Managed Outputs will either (1) be added to soil reserves (adding to future environmental risks), or (2) lost directly to the environment.
>
> Excess N will be lost to the air as ammonia gas or to surface and groundwater as nitrate or ammonia. Excess P is commonly stored in the soil, contributing to soil P levels in excess of agronomic requirements. A high soil P level increases the potential for P movement to surface waters, contributing to eutrophication issues.
>
> The purpose of the Whole-Farm Nutrient Budget is to estimate an individual farm's nutrient balance by identifying the sources of nutrient inputs/outputs, providing an "environmental yardstick" for measuring the nutrient performance of an agricultural operation.

> This balance measures ***nutrients that cross the border of the farm and is not concerned with nutrients recycled within the farm***. For example, homegrown crops fed to animals raised on your farm will not be considered because they do not cross the farm's boundary. Purchased feed products will be included because this nutrient Input crosses the boundary.
>
> [CDAQ 2006:58]

The Québec research and application has substantially raised awareness regarding the importance of feed rations as a key element of the *Whole-Farm Nutrient Budget*. Given that 50-85% of the phosphorus contained within plant-based ration ingredients are in the form of phytate, and are not available for use by the pig – this portion of feed-based phosphorus is excreted directly in the form of manure. The recent availability of the commercially-produced phytase enzyme can result in 25-35% reduction in manure phosphorus (CDAQ 2006:12). There is now a major focus on fed-based phosphorus reductions in Québec (Trudell 2007).

Current research in Québec is now focusing on understanding and addressing phosphorus mobility at the watershed scale. With a focus on improving downstream water quality within Lake Champlain, on the Québec-Vermont boundary, BMP application modeling of Québec's Pike River watershed has demonstrated that 50% of this 630 km^2 system would require intensive application of sustainable cropping practices, combined with the conversion to permanent cover of the most vulnerable 10% of erosive lands within the watershed (Michaud 2007).

3 Understanding Upstream Watershed Management

Addressing the scientific challenges associated with a complete understanding how phosphorus and nitrogen loads enter Lake Winnipeg – while implementing institutional management responses to address these excess nutrient loads – requires an analysis framework which can logically and systematically accommodate the difficult fact that water (and nutrients) flow into Lake Winnipeg from a variety of sources.

These sources are located both within and beyond Manitoba's boundaries and from a broad range of communities, individuals, industries, and natural background contributions.

The only appropriate framework within which these contributions may be usefully considered toward long-term management solutions is one which respects the fact water flows downstream – from the smallest hydrologic units – into successively larger catchments and river systems, until it reaches Lake Winnipeg.

3.1 Watershed Boundary Delineation and Hierarchies

Moving upstream using a nested hierarchy system, we note that each of these subregions and basins are subdivided into successively smaller subbasins, watersheds, subwatersheds, minor watersheds – down to the smallest measurable "hydrologic unit" of a few square kilometres or less.

In general terms "watershed" boundaries define the aerial extent of surface water drainage to a common point. The United States Geological Survey began developing a watershed classification system in the 1970s. This system has been refined over time, with recent contributions by the US Natural Resources Conservation Service (NRCS) resulting in a comprehensive watershed delineation system known as the Watershed Boundary Dataset, in which the largest six hydrologic unit levels exist.

The *Federal Standard for Delineation of Hydrologic Unit Boundaries* (NRCS 2004:12) notes "The selection and delineation of watersheds and subwatersheds requires good hydrologic judgment, and must be determined solely upon science-based hydrologic principles to assure a homogeneous national seamless digital data layer." In addition:

> Some earlier versions of watershed and subwatershed boundaries used administrative boundaries to define hydrologic units. Hydrologic unit boundaries must be determined solely upon hydrologic features. Do not use such administrative or political boundaries as county, state, national forest or other similar boundaries as criteria for defining a hydrologic unit boundary unless the administrative boundaries are coincident with topographic features that appropriately define the hydrologic unit. Although it may be impractical to make wholesale revisions to existing datasets that used administrative boundaries for delineating hydrologic units, these datasets would not be verified as meeting these standards until the hydrologic units are revised based on land surface, surface water flow and hydrologic features.
>
> [NRCS 2004:13]

The Minnesota Department of Natural Resources (Minnesota DNR) has added two smaller units, denoting watersheds down to 100 acres in size (Minor Watershed, Individual Hydrologic Unit), affording the possibility of detailed analysis down to the farm level (Minnesota DNR 2007). This level of watershed detail is critical when the central role played by individual decision-makers such as agricultural producers is to be considered as a key function within the Prairie Water Region. Table 1-1 has been adapted to the Prairies based on the NRCS and Minnesota protocols.

Table 3-1: Canadian Prairie Watershed Delineation
Source: Adapted from NRCS 2004 and Minnesota DNR 2007

Hydrologic Level	Classification	Approx. Area Limit	Example
1	Region	1,000,000 km^2	Lake Winnipeg/Prairies
2	Subregion	300,000 km^2	Red-Assiniboine System
3	Basin	150,000 km^2	Assiniboine River
4	Subbasin	30,000 km^2	Souris River
5	Watershed	3,000 km^2	Morris River
6	Subwatershed	1000 km^2	Tobacco Creek
7	Minor Watershed	100 km^2	South Tobacco Creek
8	Ind. Hydrologic Unit	10 km^2	On Farm Drainage

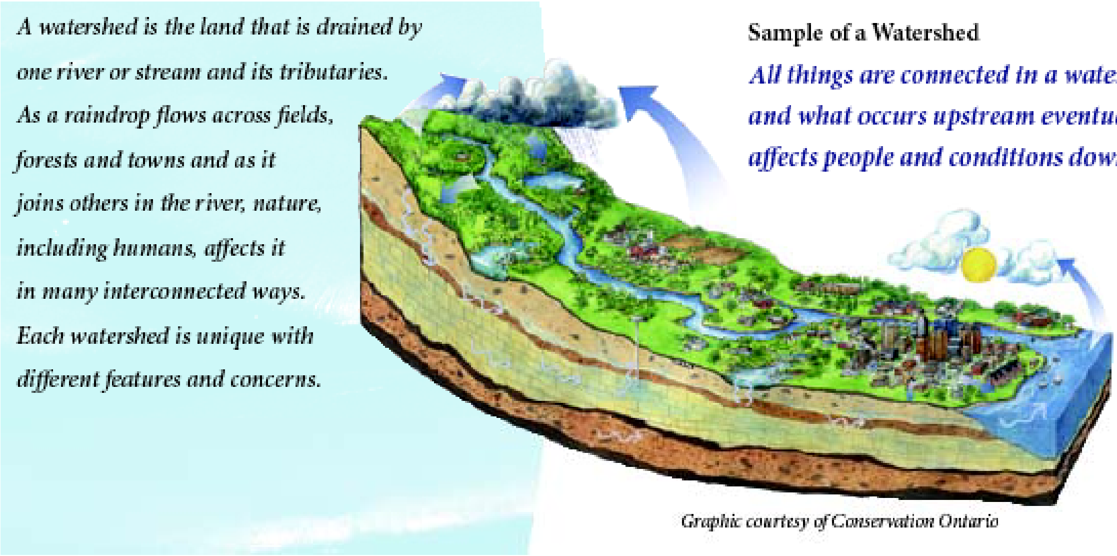
In flowing through these "watersheds," the quality of this water is influenced by almost any impact related to land use and landscape change, contamination, and other forms of water use. Integrated Water Resources Management (IWRM) is the common term used today to reflect this paradigm.

3.2 Integrated Water Resources Management

The North Saskatchewan Watershed Alliance (2006) has suggested that "an integrated watershed management approach brings all the people living in a watershed together to make decisions that respect the watershed as a whole," while:

> Landowners, stakeholders, and municipalities cooperate with the federal and provincial governments to manage water resources. This is because watersheds cross jurisdictional boundaries and fractured, politicized management can break up ecosystems.
>
> Local communities share in the responsibility, knowing their 'downstream' is somebody else's 'upstream'. What each user does in the watershed affects water quality for all users. This is especially important when we consider that the biggest problem in most watersheds is non-point source pollution – pollution that comes not from a single source like a factory or a treatment plant, but from thousands of small sources like homeowners fertilizing their lawns or motor oil washing off roads into storm drains.
>
> An integrated watershed management approach also makes watersheds the focus for management, rather than just the water. When we protect and enhance the watershed as an ecosystem, we recognize the relationship between human needs, ecological processes, and water quality. The state of our water is intimately connected to the health of the land, the presence of diverse plant and animal species, and the choices we make about land use.
>
> [North Saskatchewan Watershed Alliance 2006]

Ontario's watershed-based Conservation Authorities (Conservation Ontario) have developed one of the clearest watershed process descriptions available, as in Figure 3-1 below:


A watershed is the land that is drained by one river or stream and its tributaries. As a raindrop flows across fields, forests and towns and as it joins others in the river, nature, including humans, affects it in many interconnected ways. Each watershed is unique with different features and concerns.

Sample of a Watershed

All things are connected in a watershed and what occurs upstream eventually affects people and conditions downstream.

Graphic courtesy of Conservation Ontario

Figure 3-1: Description of a Watershed
Source: Conservation Ontario in Ausable Bayfield Maitland Valley Source Water Project 2007

Building on the hydrologic connectivity themes in Section 2.4, it is critical to understand the myriad interrelationships occurring within one watershed. It is equally important to grasp the concept that one watershed is "nested" within successively larger ones and that groups of smaller watersheds together comprise the drainage area of larger ones.

This concept is partially depicted within Figures 3-2 below, which simultaneously shows one watershed in southern Ontario (on the left) along with its composite "subwatersheds on the right.

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

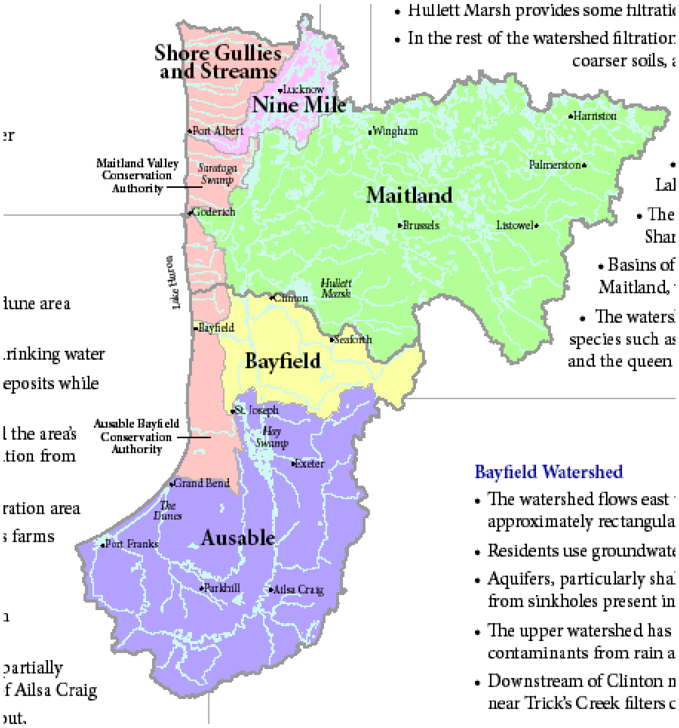


Figure 3-2: Watersheds and Subwatersheds
Source: Ausable Bayfield Maitland Valley Source Water Project 2007

Each of these subwatersheds are in turn comprised of smaller drainage areas or "minor watersheds." This is depicted somewhat in Figure 3-3.

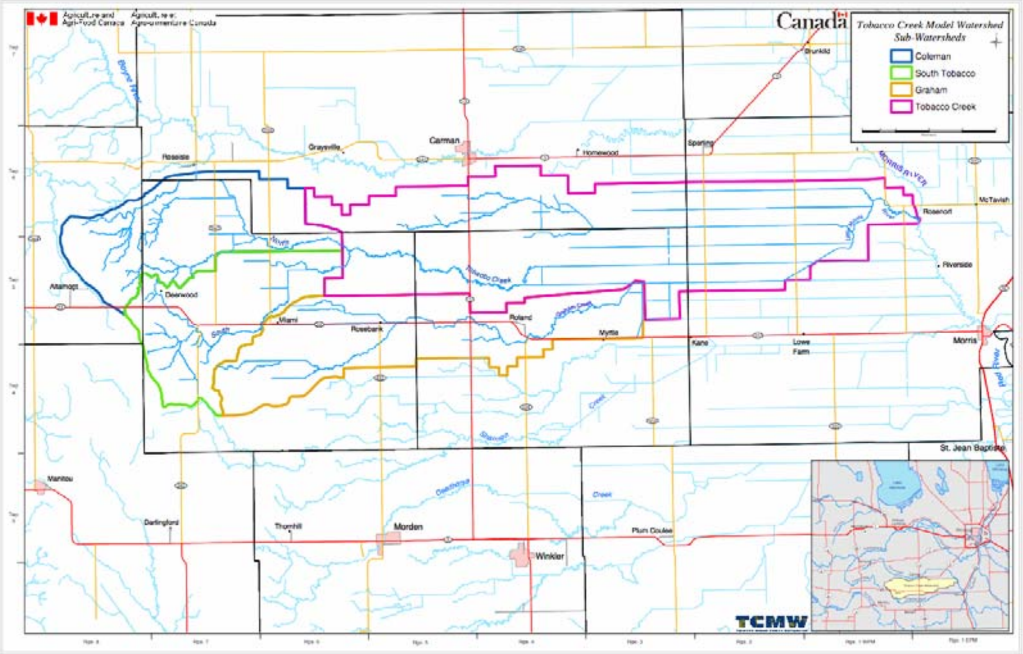


Figure 3-3: Subwatersheds and Minor Watersheds
Source: AAFC in Tobacco Creek Model Watershed 2004

Finally, these minor watersheds are in turn comprised of many "individual hydrologic units," which can range in size from several hectares to several hundred hectares (Figure 3-4). Helpful video descriptions of how the individual landscape decisions affect overall watershed are available from the Conservation Technology Information Center (2005).

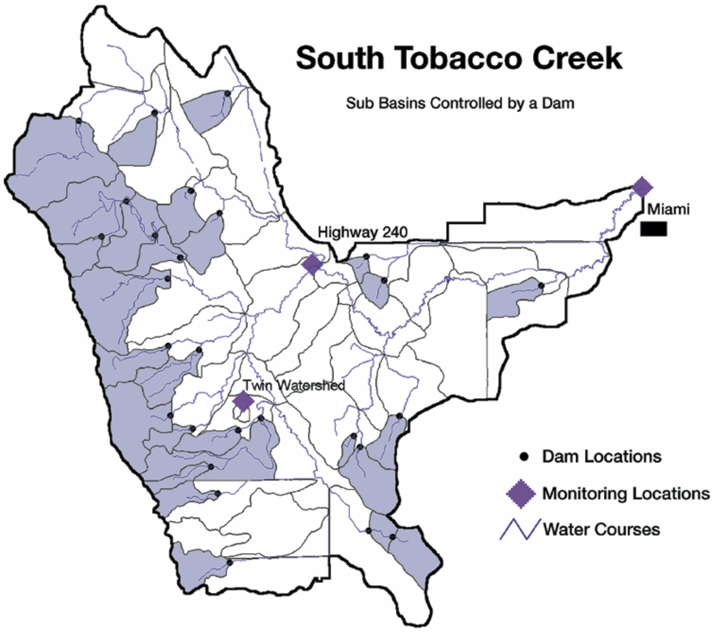


Figure 3-4: A Minor Watershed comprised of many Individual Hydrologic Units
Source: AAFC in Tobacco Creek Model Watershed 2004

It has often been at the watershed (3000 km^2) or subwatershed (1000 km^2) level where significant populations thresholds have stimulated groups of people to form communities among which meaningful and manageable relationships and interconnections exist. As such, it seems that a focus on watersheds (or subwatersheds) may make the most sense when attempting to address the myriad challenges which are the focus of Integrated Water Resources Management (IWRM). We recognize of course that implementation of IWRM and its supporting concepts also represent opportunities to achieve broader societal goals. These goals are of regional interest to communities beyond the watershed or subwatershed level.

The Millennium Assessment (MA) has provided a critical IWRM policy insight. A future scenario consistent with improved *Ecological Goods and Services* (EG&S) provision is one in which, "regional watershed-scale ecosystems are the focus of political and economic activity. Local institutions are strengthened and local ecosystem management strategies are common; societies develop a strongly proactive approach to the management of ecosystems (MA 2005:8&50). MA Wetlands and Water Synthesis discussion related to MA Responses 15.5.3 and 15.5.4 suggests that:

> The effective management of inland wetlands and water resources will require improved arrangements for river (or lake or aquifer) basin–scale management and integrated coastal zone management. The effective management of wetlands and water resources requires not only intersectoral coordination but also coordination across different jurisdictions. Actions taken upstream or upcurrent can have profound impacts on wetland resources downstream or down current. This in turn requires the use of integrated river basin (IRBM) or coastal zone management (ICZM). These integrated regional approaches to water resources management are recognized also as key strategy to contribute to the objectives of poverty alleviation.
>
> To date, however, few efforts at implementing IRBM have actually succeeded in achieving social, economic, and environmental objectives simultaneously. One of the key lessons emerging

> from ICZM experiences is that more integration per se does not guarantee better outcomes. Adopting an incremental approach—focusing on a few issues initially and then gradually addressing additional ones as capacity increases— is often more feasible and effective. In addition, these approaches can only succeed if appropriate institutional and governance arrangements are in place and, in particular, if the authority and resources of the management mechanism are consistent with their responsibilities.
>
> [MA: Water and Wetlands Synthesis 2005:58]

There is a growing body of literature exploring the political challenges which appear to be limiting the complete and successful application of integrated watershed management some early work by Nelson and Weschler (1998) noted the importance of strong community involvement, clear institutional arrangements, experience in cross-sectoral coordination, and the incorporation of fiscal incentives as important factors.

Community involvement and meaningful public participation are recurring themes in watershed management (Gooch 2005, Carr and Wilkinson 2005, and Morris 2005), while Low and Ranhir (2005) have noted the importance of ongoing organizational change, strategic adjustment, information processing, and biodiversity protection as additional criteria. Several of these elements – in addition to recognition of the value of science-based policy experimentation – were characterized earlier by Lee and Lawrence (1986) and (Lee 1989) as *Adaptive Management*.

Agriculture-related water quality and quantity problems are a significant and growing concern across the Canadian Prairies (Schindler and Donahue 2006) – as is the perennial problem of declining on-farm income (Statistics Canada 2006). Any national, regional, or provincial efforts to address these issues should logically be integrated across traditional boundaries of private land ownership (MacFarlane 1998), while considering and respecting the perceptions held by all affected private landowners (Urban 2005).

Methods for evaluating water quality and water quantity trends are quite well developed at the watershed level and are still evolving (Deumlich 2005; Ramakar 2005; and Jain 2005).

3.3 Planning Within an IRWM Framework

In 2005, IISD conducted an extensive IWRM policy review of the Prairie Water Region. *Prairie Water Strategies: Innovations and Challenges in Strategic and Coordinated Action at the Provincial Level* (Swanson et al 2005) utilized an analytical framework based on the IWRM Management Cycle developed by the Global Water Partnership (GWP), which articulated IWRM as:

> *"a process which promotes the co-ordinated development and management of water, land and related resources in order to maximize the resultant economic, social welfare in an equitable manner without compromising the sustainability of vital ecosystems"* [1]

To be successful, the notion of integrated water resources management has also been described as "adaptive, evolving dynamically with changing conditions."[2] Additionally, effective integrated water

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[1] Jønch-Clausen, Torkil (2004). "Integrated Water Resources Management (IWRM) and Water Efficiency Plans by 2005 - Why, what and how?" Global Water Partnership, Technical Committee.

resources management has been described as having three features which differentiate it from traditional resource-based management.[3] First, it is more "bottom up" than "top-down" and thus emphasizes the building of capacity among local resource users. Second, integrated water resources management encourages cross-sectoral, interdisciplinary management of water resources. Finally, it encompasses management of other activities (e.g. land use) which affect water resources (i.e., it is focused on comprehensive solutions).

The GWP described integrated management for water resource management as a cyclic process of consisting of seven steps as illustrated in Figure 3-5: (1) establish status and overall goals; (2) build commitment to reform processes; (3) analyze gaps; (4) prepare strategy and action plan; (5) build commitment to actions; (6) implement frameworks (using a variety of institutional, expenditure, regulatory, and economic instruments) ; and (7) monitor and evaluate progress.

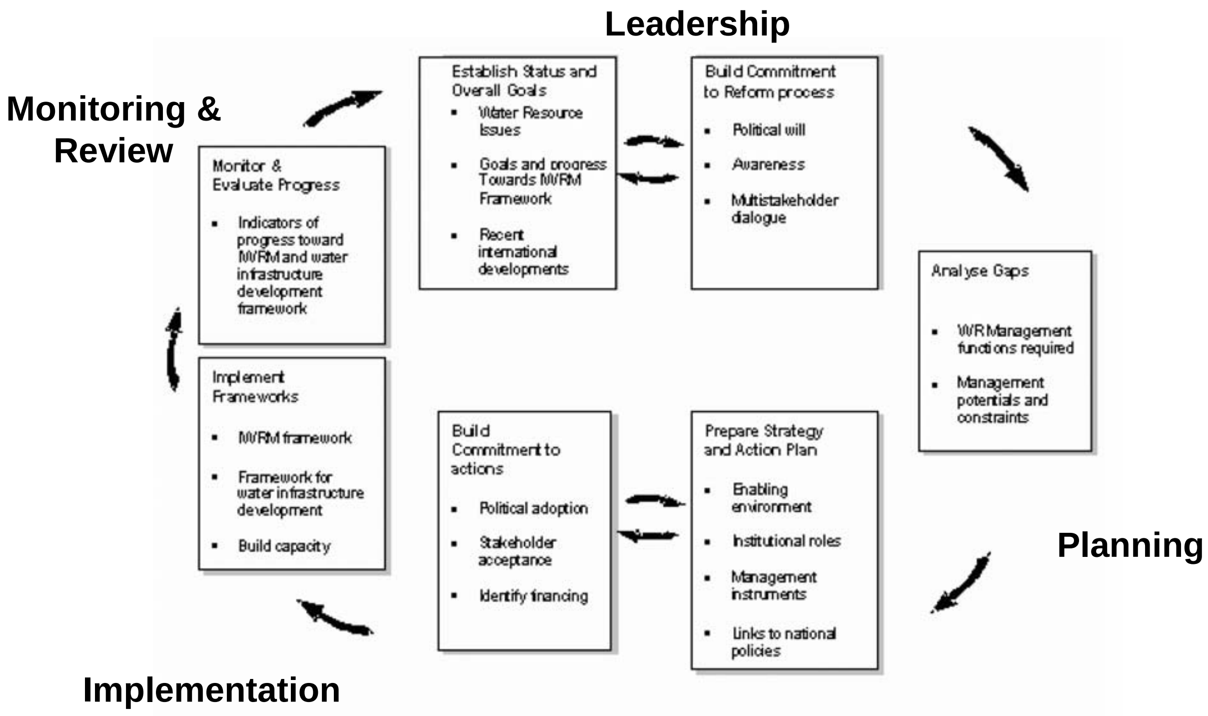

Figure 3-5. Global Water Partnership Integrated Water Resources Management Cycle
Source: (Jønch-Clausen 2004)

To study strategic and coordinated action for water resources at a provincial level, IISD simplified the above steps into four aspects as illustrated in Figure 3-6 (Swanson et al 2005). Included are:

Leadership (e.g., commitment through a strategy, focus through articulated goals and objectives);

Planning (e.g., departmental structure, inter-departmental planning, commitment to watershed planning and management) and ***Multi-level Coordination and Participation*** (e.g., coordination within a strategy process and among jurisdictions, and engagement of key stakeholders throughout the strategy process); and

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[2] Global Development Research Center. 2005. Principles of Integrated Water Resources Management. Available: http://www.gdrc.org/uem/water/iwrm/1pager-01.html (Accessed 18 July 2005).

[3] From personal communication with Environment Canada – Water Policy Branch (2004).

Implementation (e.g., responsibility, financing and leveraging a mix of policy instruments);

Monitoring, Evaluation and Improvement (e.g., indicator monitoring, formal and informal evaluation and improvement processes)***.***

In 2005, IISD used this analytical framework to prepare case studies on the water strategies of all three Prairie Provinces, and additionally, we applied this framework to interprovincial water management efforts – which led to a focus on the activities of Prairie Provinces Water Board. A detailed synthesis of these case studies was also conducted to identify common innovations and challenges in water strategies. Consideration of this synthesis then allowed for the identification of various shortcomings in the implementation of IRWM on the Canadian Prairies. [4]

3.3.1 IWRM's Key Monitoring Element

For the purposes of this project, the primary focus is on the fourth stage in the IWRM planning process (Figure 3-6): "Monitoring, Evaluation, and Improvement." Development of a *Total Nutrient Loading Framework* for Manitoba should logically focus on improving Lake Winnipeg water quality as an ultimate goal, as much of the water flowing in and through the province influences this iconic water body. However, in order to make progress on Lake Winnipeg, its composite watersheds must become a central focus for action. Lake Winnipeg water quality will improve if the nutrient loads associated with its various drainage components (at various scales) can be reduced.

As noted in Section 2, relative nutrient contributions from many sources must be considered, particularly the interrelated elements of *Manitoba Watershed Processes* which include "natural background/undefined" and "present-day agriculture." The importance of hydrologic connectivity – linking headwater streams to downstream water bodies – must also be incorporated, as does hydrologic scale. Also, the pivotal role of phosphorus and our current understanding of its export in particulate and dissolved from – from agricultural lands and through streambed and streambank erosion influence – must also be considered in some detail.

The ability to monitor water quality trends from individual hydrologic unit to the watershed, basin, or regional level is fundamental to understanding and/or utilizing the full potential of a *Total Nutrient Loading Framework*, if it were to be developed. In addition, this degree of monitoring would also serve to track the impacts of various IWRM initiatives, including those related to manure management.

Scientifically valid indicators of watershed health would need to be developed and monitored based on rigorous sampling protocols. Based on observed trends, progress toward nutrient loading reduction within each hydrologic unit could be observed, with determinations made as to whether this progress was due to various IWRM initiatives, or some other factors.

These evaluations would suggest how or if these IWRM actions could or should be improved over time, with a view toward continuous improvement. It is through this logic that an appropriate review of the relative nutrient contributions arising through hog production in Manitoba will be conducted in Task 2, assisting to understand the significance of these contributions, current review practices, and potential improvements.

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[4] Working versions of these case studies can be downloaded at http://www.iisd.org/natres/water/pwps_background.asp.

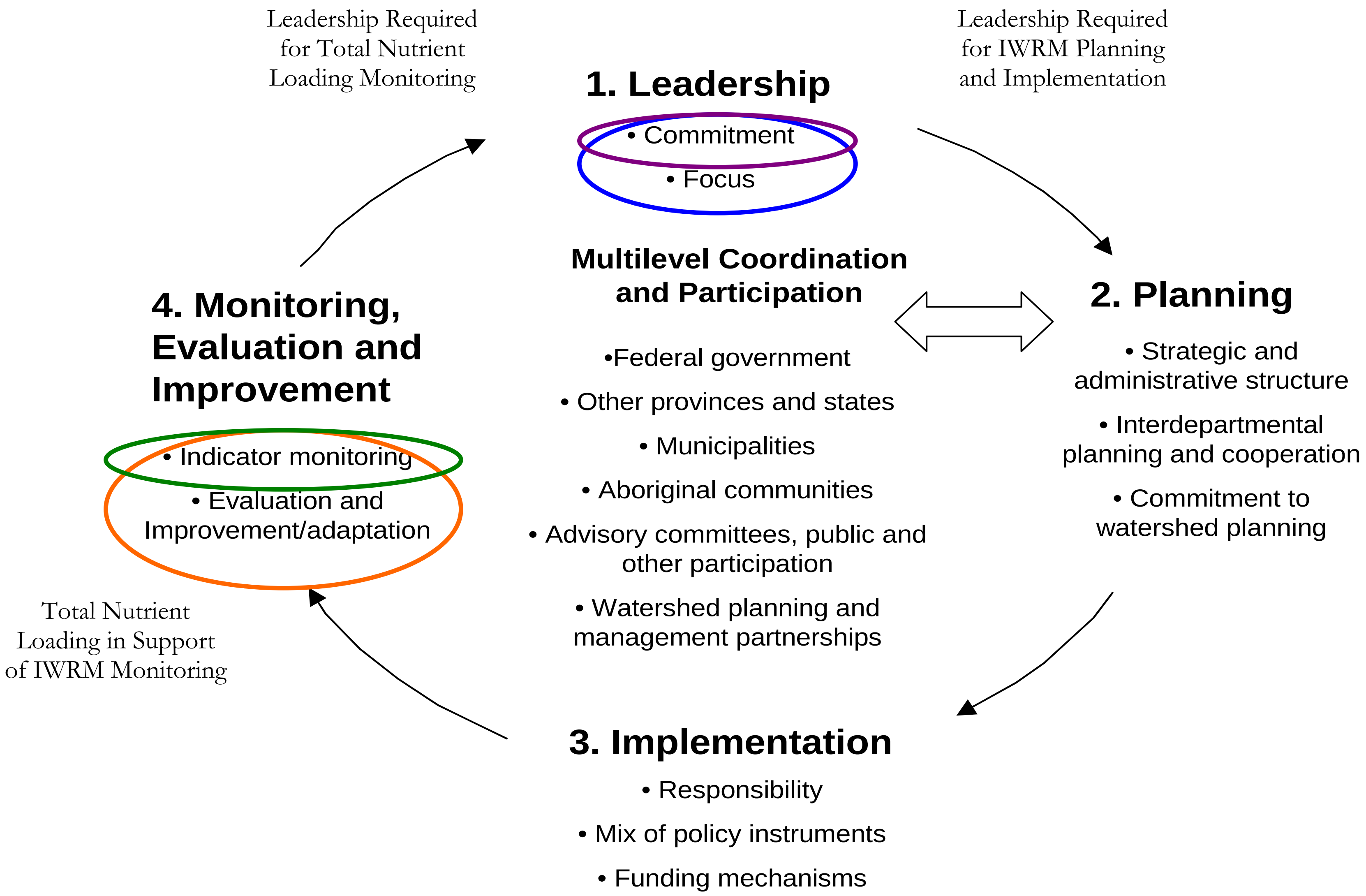


Figure 3-6: Total Nutrient Loading/Monitoring/Planning within the Context of IWRM
Source: Adapted from Swanson et al (2005)

3.3.2 The Need for Leadership and Coordination

Figure 3-6 also denotes the centrality of "Leadership" in the IWRM planning cycle. Without leadership, there can be no effective IWRM Planning and Implementation or Monitoring, Evaluation, and Improvement. As such, without leadership there can be no *Total Nutrient Loading Framework* and no improvements in Lake Winnipeg water quality.

With regard to these issues, the Province of Manitoba is the most appropriate authority to provide the leadership which is required to address the province's nutrient loading challenges. Given its authority over most aspects of natural resources management, Manitoba is responsible for most aspects of surface water management, agriculture, land use, environmental quality, and most municipal rural or urban issues related to municipalities.

Given these interrelated responsibilities, which are managed through the operations of numerous provincial government departments, effective provincial leadership would necessarily involve a high degree of interdepartmental planning, communications, and performance measurement. This is required to bring focus to the challenge of nutrient management, to harness the collective influence and full resources of government.

With the health of the province's signature water body serving as the focus for provincial action, it would logically be accepted that any provincial efforts related to IWRM or development of a *Total Nutrient Loading Framework* would, by their very interrelated and interdepartmental nature, involve the highest possible level of support, from the highest offices of government. This is required to demonstrate the full commitment of government to the nutrient management challenge.

To be truly province-wide in nature, such provincial leadership would not be entrusted to only one department – but to several – under the direction of a designated Executive (Cabinet) Committee or perhaps the Premier, as the President of Executive Council. Such an approach would necessarily involve a high level of strategic coordination.

Leadership does take this form in other provinces where water issues have become major provincial priorities, such as in Alberta and Saskatchewan. In these provinces, provincial strategies related to safe drinking water and the implementation of watershed-based solutions have received the highest levels of Executive Council support, significant funding, and designations as *Cross-Government Strategies* for which several departments are accountable. These *Cross-Government Strategies* are also governed by clear guidelines for interdepartmental planning and reporting.

3.3.3 Policy Instruments to be Utilized

IWRM approaches, actions, and solutions need to be explored from the perspectives of federal and provincial governments, rural municipalities, landowners, production decision-makers, and society. This is essentially the same group of stakeholders, which are ideally also responsible for IWRM planning, implementation, and performance measurement. Key decisions are made by all participants, and their various land use and water-related decisions occurring within a particular watershed can result in downstream impacts of many types.

The development of a *Total Nutrient Loading Framework* is a logical approach to understanding, acting, and measuring progress toward reduced nutrient loads from the contributing watersheds of a downstream water body, these same composite watersheds, or general environmental quality.

Using sound science as a foundation, many social, economic and environmental impacts can be evaluated and adapted to – through a variety of policy instruments available to government, including: **institutional** instruments (internal education, strategies, policies, and procedures); **regulatory** (laws, regulations, and enforcement); **direct expenditure** (broad or targeted programs, education and awareness, and research and development); and **economic** instruments (taxes, fees, and incentives).Any policy instrument is comprised of two elements – design and implementation (IISD and TERI 2003).

3.3.3.1 Institutional Instruments

These include government strategies, new or revised institutional structures, and changes to policy and procedures of governments.

3.3.3.2 Regulatory Instruments

Regulations are one of the tools used by governments of all levels to restrict activities that are concerns for an entire sector, as an example, there are restrictions on how wastewater is managed.

3.3.3.3 Expenditure Instruments

Direct program expenditures designed to achieve particular goals may include the funding of various beneficial management practices (BMPs) is to improve the condition of an area of concern. In the case of water quality, certain BMPs can reduce the flow of nutrients into a water body. BMP development and implementation should be based on encouraging individual decision makers to change their practices and remain with that particular practice after funding has expired.

3.3.3.4 Economic Instruments

These may involve incentives and/or changes to the tax system to encourage or reward individual decision-makers for changing the way they undertake certain activities.

4 Total Nutrient Loading on a Watershed Basis

Using the IWRM cycle and policy instruments discussed in Section 3, an effective *Total Nutrient Loading (TNL) Framework* can be developed. The following section outlines some of the critical components of the framework and the interactions between these components.

The development of a TNL Framework is driven by concerns regarding the health of a watershed, usually about a particular water resource. The design and implementation of such a framework is in itself the application of an *institutional* policy instrument. It would logically take the form of a "Total Nutrient Loading Strategy" centered on the institutionalization of watershed-based planning and management founded on the concepts of IWRM.

2.3.4 Understanding and Addressing Watershed Health

The ultimate focus of a the TNL Framework would be on understanding and addressing changes in the health of Manitoba's watersheds, at various scales (from individual hydrologic units to basins, and regional water systems). The health of a water resource is of critical importance to the overall sustainability of a region, as it influences all social, environmental and economic factors.

In reality, the development of a TNL Framework represents one component of a comprehensive IWRM strategy. Other key elements would include the management of excess water flows during periods of intense precipitation, planning for drought, managing other contaminants, and improving overall water use efficiency in agriculture, industrial, and domestic settings.

However, with a present need to focus on nutrient reduction, several key aspects are required.

4.1.1.1 Research and Development

Research is fundamental component of a TNL Framework. Several questions still remain about nutrient movement from individual hydrologic units, through a watershed, and finally into a regional level water body. The research component assists in determining the maximum allowable levels of nutrients in the water, as well as monitoring nutrient levels in streams, rivers and lakes. The research activities usually lead to the development and recommendation of beneficial management practices. The results of the research influence watershed management decisions.

4.1.1.2 Current Watershed Nutrient Levels

Knowledge regarding current nutrient levels provides information necessary for the determination of which policy instruments may be most appropriate to improve downstream water quality. The various instruments used will either be: regulatory, expenditure, or economic in nature. In order to ensure that current nutrient levels (and their sources) are well understood, a significant degree of watershed monitoring will be required – from the individual hydrologic unit to the basin or regional level. It is likely that some of this required monitoring could be undertaken through the use of "representative watersheds" which have similar watershed and landscape features to others.

4.1.1.3 Maximum Healthy Nutrient Limits

An approximation of the maximum healthy nutrient limits for a watershed should be known for each contributing drainage system, as well as for downstream water bodies. Unfortunately, the maximum healthy nutrient levels are not know in most cases, so precautionary limits should be used in the interim. While exact numbers may not be known, estimates can be used to promote nutrient reduction activities.

4.1.1.4 Incremental Changes in Nutrient Levels

The final element in the design of a TNL Framework would involve the ability to track incremental changes in nutrient loads within a watershed. These may result from either natural or anthropogenic sources, and they may be either positive or negative – in terms of their influence upon *Total Nutrient Loading* of the particular hydrologic unit being assessed.

Increased nutrient loads may occur in association with increased (or more intense) precipitation, which in turn causes increases in erosion and the movement of both dissolved and particulate nutrients downstream. These loads may also increase due to wastewater discharges from municipal sewage treatment facilities or agricultural runoff – among many other natural background or anthropogenic sources. As noted in Section 2, a substantial portion of these loads are in some way related to watershed processes, and a very significant portion of these arise from within Manitoba.

Nutrient loads within a watershed may also decrease due to natural factors, such as the type and mass of particular forms of riparian vegetation. The effective application of various policy instruments can also serve to reduce watershed nutrient loads. They may decrease in association with: various types of BMPs and effective watershed management coordinated by a conservation, farming, or other organization (expenditure instrument); specific regulations designed to reduce nutrient loading (regulatory instrument), or the use of particular incentives (economic instrument).

However, the primary focus of this project is centred on understanding how the individual decisions of private agricultural landowners (primarily hog producers actually affect *Total Nutrient Loading*, and how these impacts can be reduced – through the application of various policy instruments. It is these incremental changes (and decisions) which are of the greatest interest at this time. The proposed TNL Framework will demonstrated how the impact of one additional hog barn development may theoretically be assessed in terms of its incremental impact on watershed health.

4.2 IWRM as a Planning Foundation

An effective TNL Framework would indicate to decision makers and other stakeholders concerned with the health of a water body, exactly what current levels of nutrient loading exist within a particular watershed – and how these would be affected by the incremental increase of one new hog barn. If this could be achieved, the planning process would benefit from the increased knowledge related to the various nutrient sources and removals.

Meanwhile, all stakeholders concerned about the health of a particular watershed would have greater knowledge regarding the incremental impact of one new hog barn on *Total Nutrient Loads*, offering greater clarity regarding this impact and greater comfort for those who are responsible for making the decision. Ideally, this would result in sustainable water resource management through an informed implementation process.

4.2.1 Hydrologic Scale Considerations

Nutrient loading throughout any drainage system can occur naturally and anthropogenically within each composite hydrological unit. The summation of these inputs determines *Total Nutrient Loading* levels for each particular watershed (at any scale). From a monitoring perspective, more data is typically better than less, and as such, measurements from each hydrological unit within the watershed hierarchy would be considered ideal. Realistically, however, this is not always possible or necessarily the most efficient method of measurement. Developing a TNL Framework requires an appropriate scale to be effective for a particular watershed system.

Selecting the appropriate scale for measurement requires an understanding of the regions hydrological classifications and the activities within each watershed and its sub-units. Table 4-1 outlines the hydrologic levels introduced in Section 3, their classification name, and the approximate area of each classification. Landscapes, climatic conditions, and anthropogenic activities tend to differ between each watershed and result in different nutrient loading potentials.

Table 4-1: Hydrologic Scales within a TNL Framework

Hydrologic Level	Classification	Approx. Area Limit
1	Region	1,000,000 km^2
2	Subregion	300,000 km^2
3	Basin	150,000 km^2
4	Subbasin	30,000 km^2
5	Watershed	3000 km^2
6	Subwatershed	1000 km^2
7	Minor Watershed	100 km^2
8	Ind. Hydrologic Unit	10 km^2

More detailed monitoring provides more information about nutrient sources, but at a watershed level this detail may not provide sufficient information to develop effective strategies for reducing nutrient loads. Total nutrient monitoring needs to be based on the value of information received and the costs associated with the measurement.

There are still un-answered questions relating to the source of nutrients that need to be further researched. Intensive monitoring and research are gradually increasing the available knowledge surrounding nutrient loading. With this research, the effectiveness of nutrient source and removal models are becoming more accurate, possibly resulting in the need for less physical monitoring within each watershed.

4.2.2 Depicting a Draft TNL Framework

The challenge for Manitoba now, is the delivery of an effective institutional framework for IWRM planning, implementation, and performance measurement. Choosing the right scale at which nutrient loads can be monitored and analyzed for effective nutrient loading reduction may differ across the province, based on such factors as soil types, topography, land use, and development intensity. IWRM is also largely a question of governance – of how individuals and groups can come together – to address mutual concerns related to the health of their watershed community.

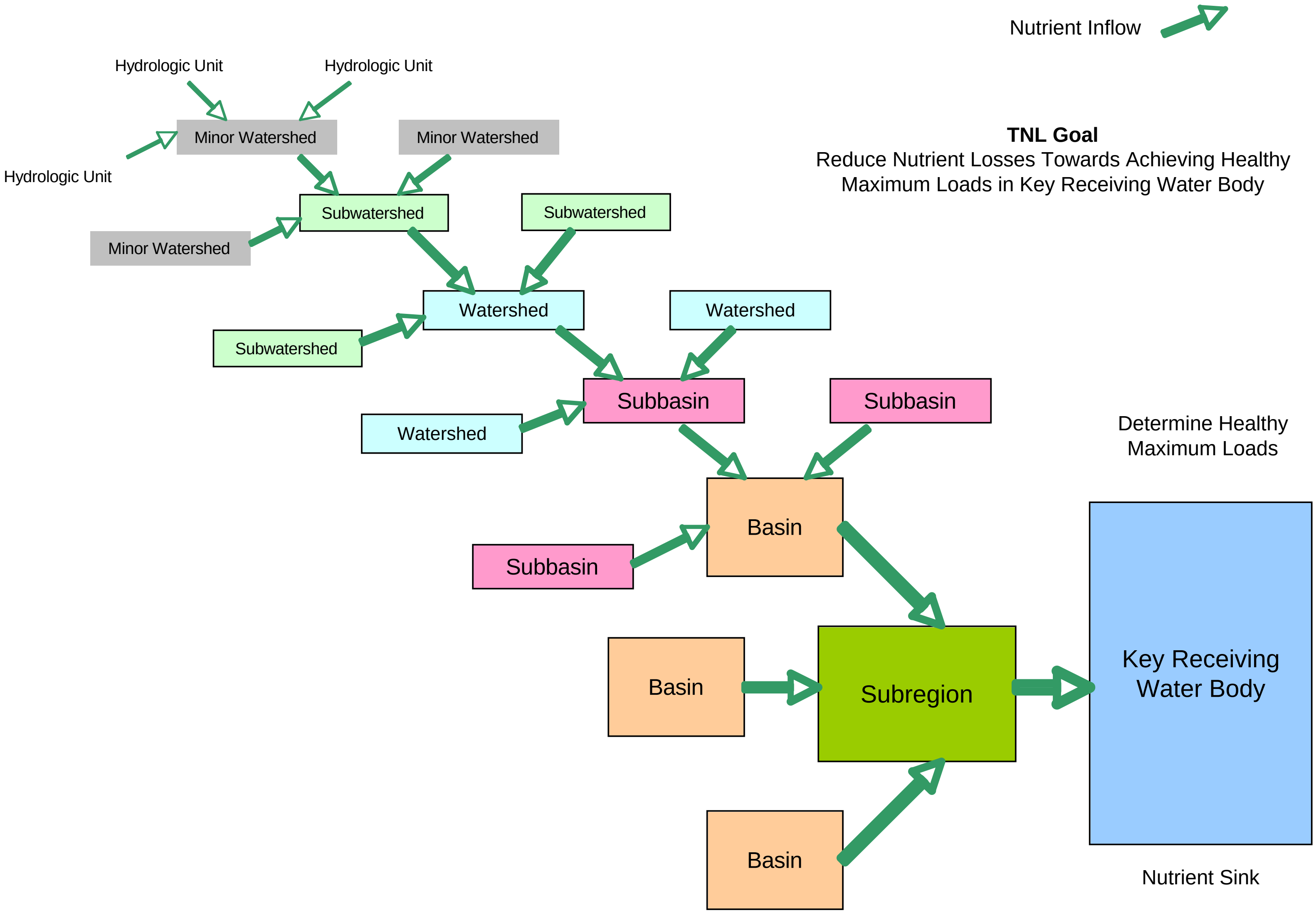
Determining exactly when participating individuals, organizations, and communities are ready to collaborate and implement watershed-based solutions is a nascent research topic. The common drainage areas shared by communities should be *meaningful* to the people who live in them and use their resources. They should also be *manageable* so that local governance entities such as local municipalities, watershed districts, and other community stakeholders may in fact have significant influence in improving their condition. For these reasons, it seems most logical that the focus for IWRM (and TNL Loading) should be on the watershed or subwatershed level.

Figure 4.1 outlines the flow of nutrients through a water resource. This *Total Nutrient Loading Framework* demonstrates the cumulative effects of numerous individual hydrologic units, minor watersheds, and subwatersheds – supplying multiple watersheds and sub-basins – which in turn comprise larger basins and sub-regions – which ultimately drain into a major water body. Further details are included in Figure 4-2, with a focus on the watershed and subwatershed levels.

This framework also indicates how the use of various policy instruments such as regulation, direct expenditures (e.g. BMPs), and economic incentives could reduce the outflow of nutrients into the watershed and ultimately the sub-region.

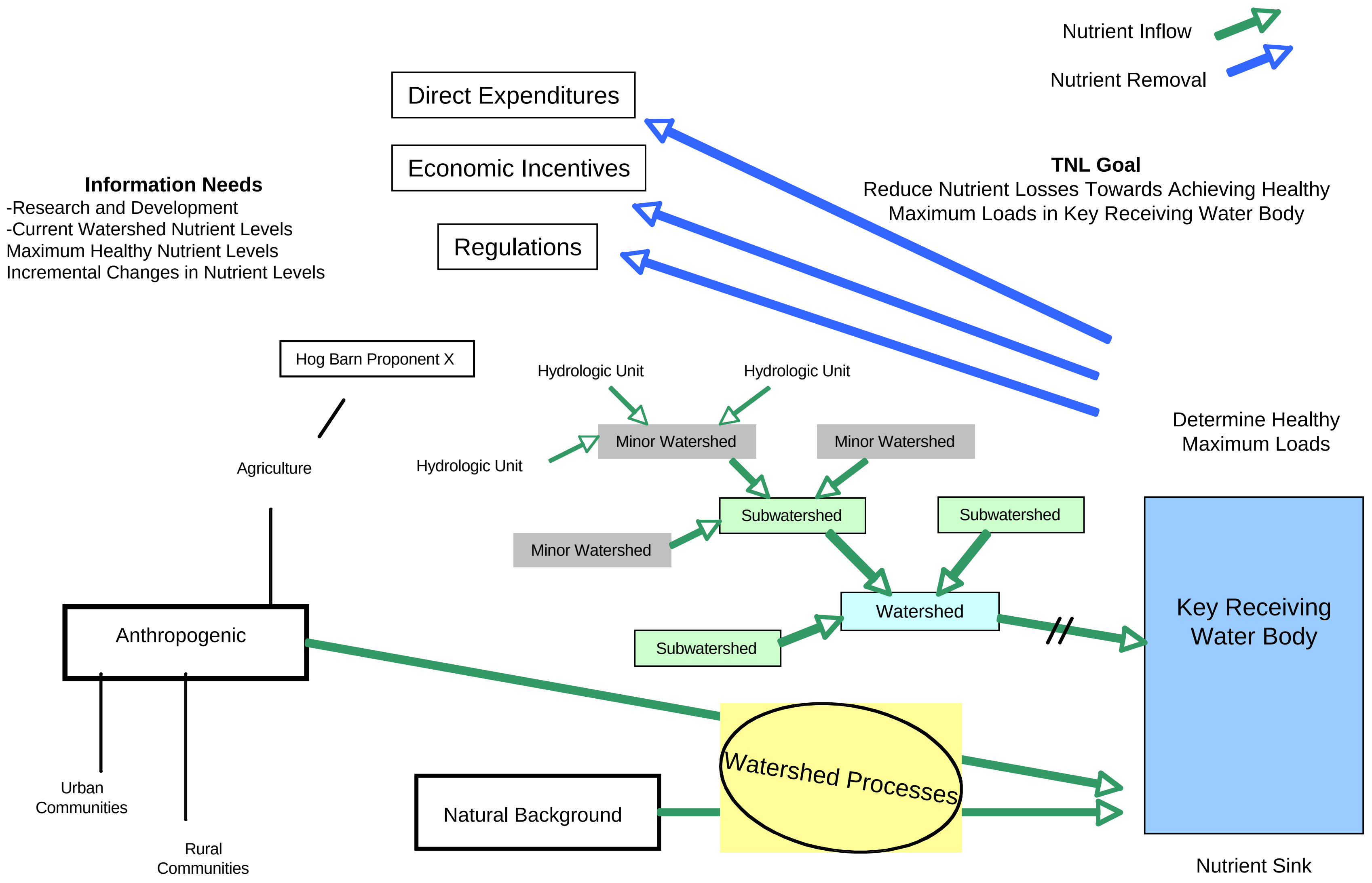
The ability to assess the *Total Nutrient Loading* impact of one new hog barn development within any hydrologic unit could and should be the objective of an effective TNL Framework. An analysis of this aspect of the TNL Framework – exploring the current and a possible future decision-making process related to such a development (Proponent X), shall be the focus of our work Task 2.

Figure 4-1: Total Nutrient Loading Framework (Generalized)



TNL Goal
Reduce Nutrient Losses Towards Achieving Healthy Maximum Loads in Key Receiving Water Body

Figure 4-2: Total Nutrient Loading Framework (Watershed/Subwatershed Focus)



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