City of Winnipeg
Water and Waste Department

PHASE 2 Technical Memorandum for Red and Assiniboine Ammonia Criteria Study

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Technical Memorandum # RC2.0

River Conditions

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PREAMBLE

This Technical Memorandum (T.M.) is intended for internal discussion. It is not intended as a report representing policy or direction of the City of Winnipeg.

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1. INTRODUCTION

1.1 OBJECTIVES

The overall objective of this workstream was to determine the river conditions, both hydrologic and water quality, in the study area (see Figure 1-1) for the existing and future potential discharges to the river. The goal of the work in the river conditions workstream was to answer three key questions as defined in the Phase 2 Workshop. These questions are:

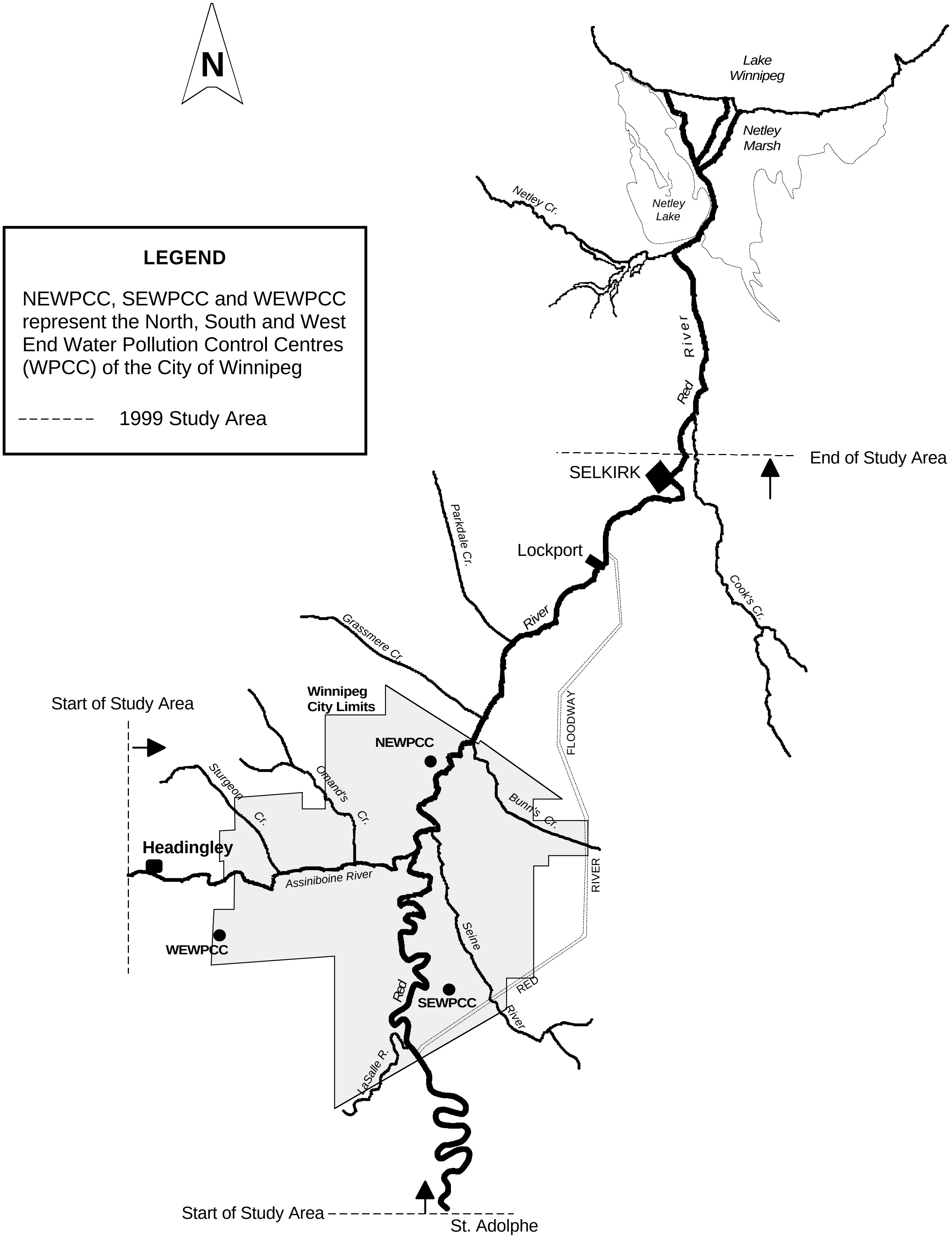
- 3) What are the ammonia dynamics in the rivers?
    - concentrations
    - how often (frequency)?
    - how long (duration)?
    - where (extent)?

- 6) How would potential ammonia control affect concentrations in the rivers?
    - frequency, duration, exposure and extent

- 7) What would the effect of control be on the river conditions and aquatic life?
    - related impacts, especially with respect to the algal community.

The sub-objectives of this workstream were specifically:

- to depict existing bathymetry and flow velocities of the rivers for the range of flows occurring historically;
- to describe the dynamic water-quality conditions (specifically for ammonia) over a continuous period of record;
- to determine the potential changes in river conditions resulting from a range of ammonia-control options; and
- to project river conditions (specifically for ammonia and algae) for critical periods for which protective criteria for ammonia may apply.



Ammonia Study Area

Figure 1-1

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1.2 OUTLINE

The organization of this document is as follows:

- Section 2 will review the hydrology of the Red and Assiniboine rivers within the study area. It will begin with a general overview of hydrology and then specifically look at monthly statistical analysis of the flows within the study area and compare them to the conditions in 1999 when the various field-monitoring programs were conducted. Using these flows and calibrated sophisticated hydraulic tools (MIKE11) flow versus velocity and flow versus depth curves will be developed. Also, velocity frequency distributions for the historic period which will be developed and compared to 1999 conditions.

- Section 3 will deal with the general water quality information which has been collected over the past 20 years. Specifically we will deal with ammonia, pH and temperature, as they are the key parameters in determining toxicity effects on aquatic life. We will also discuss phosphorus, nitrogen (TKN and nitrate) and algae, and describe the nutrient cycle within the study area. Other specific special programs will also be reviewed briefly and a discussion of the 1999 monitoring program will also be contained in this section.

- Section 4 will discuss the Water Pollution Control Centres (WWPCs) and their discharges, with a general description of the WPCCs, their history, and locations. The database of effluent quality will be reviewed, specifically with respect to ammonia, pH, temperature as well as phosphorus and nitrogen. A statistical analysis will be performed on historic loads and there will be information drawn from the nitrification study.

- Section 5 will compare nutrient loadings upstream of the City of Winnipeg and from the WPCCs.

- Section 6 will specifically deal with the relationship between ammonia and algae. Experiments conducted in conjunction with the University of Manitoba were done to determine if ammonia productivity is impacted by ammonia, phosphorus and nitrate concentrations.

- Section 7 will deal with near-field water quality modelling. This modelling is used to understand the mixing zone downstream of the treatment plants and, specifically, to assess the exposure of mussels within the plume during the 1999 conditions.

- Section 8 deals with the long-term water quality modelling. The approach used to develop a long-term prediction of ammonia concentrations at key stations throughout the study area is discussed. This section also presents the calibration of the models and the predictions over a 35-year period using historical loads from 1962 to 1997 and future projected loads in the year 2041. Some of the interim analysis on the assessment of various nitrification scenarios is also shown in this section. Also discussed is how this information can be used to develop true risk assessments for the aquatic life within the study area.

- Section 9 deals with a review of less comprehensive steady-state assessment methods.

- Section 10 deals with critical period modelling. In this section, the complex WASP model which describes the full nutrient cycle including algal growth and uptake will be discussed. The objective is to assess critical conditions for a low-flow season such as 1988. Various analyses are done to determine whether the impacts of ammonia on growth have a significant effect on algae within the study area. Also in this section the impact of varying phosphorus output from the plants would be presented. There is potential for an increase in phosphorus output from the WPCCs with the nitrification process and a decrease in phosphorus output with specialized treatment procedures such as biological nutrient removal. The effects of these potential scenarios would be assessed in this section.

- Section 11 will deal with the key observations to this Technical Memorandum.

2. HYDROLOGY

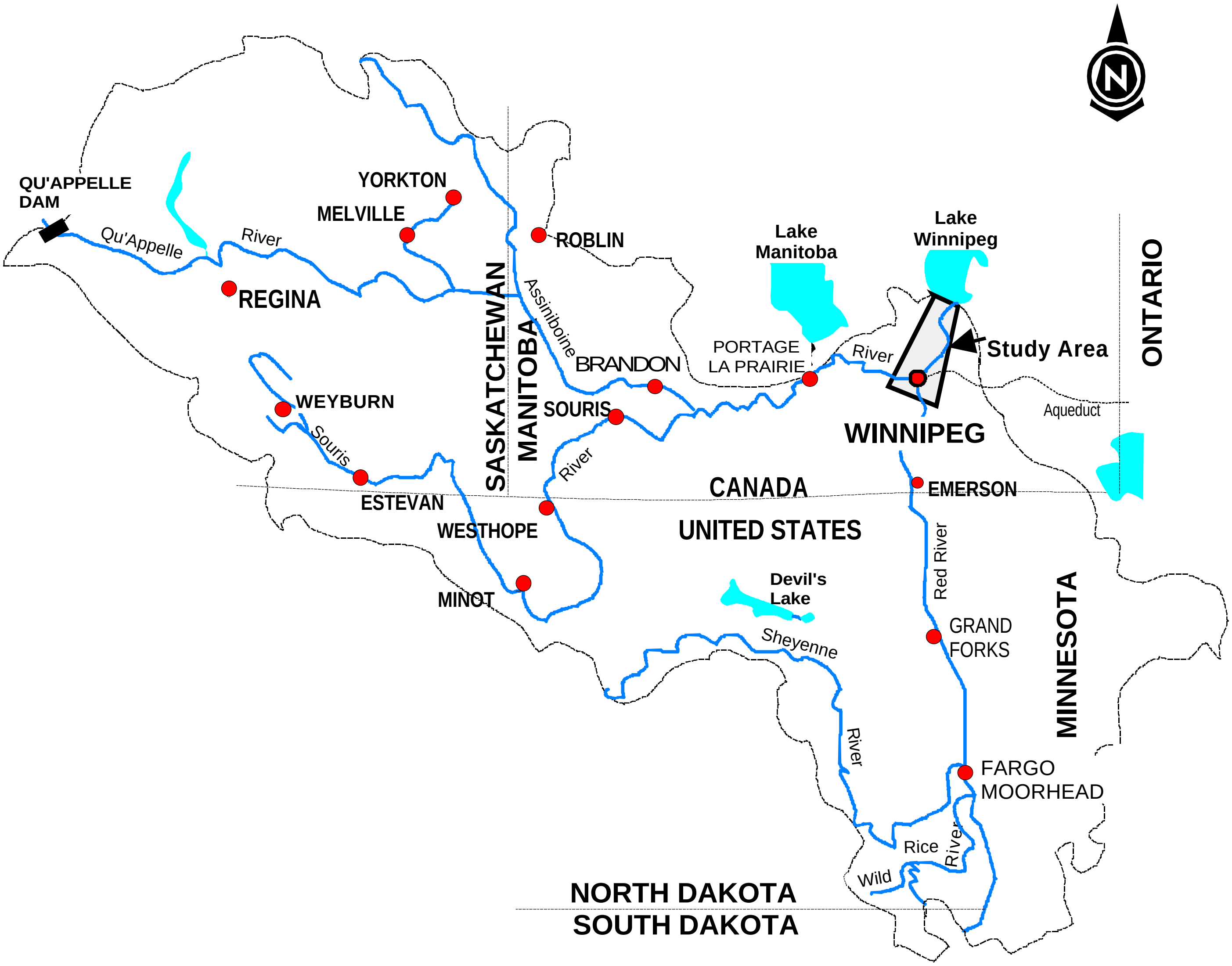
2.1 GENERAL AREA OVERVIEW

The study area comprises a small fraction of the overall river basins (Figure 2-1). The Red and Assiniboine rivers drain the prairie regions of southern Manitoba, southeastern Saskatchewan, North Dakota, northern South Dakota, and northwestern Minnesota. The basin is almost entirely underlain by limestone bedrock. The bedrock is covered with a thick deposit of clay. Soils in the region are black and fine textured. The Red River Valley plain is virtually level while the Assiniboine River passes through the Manitoba escarpment in the western portion of the province.

The main tributaries of the Red and Assiniboine rivers include the Ottertail, Cheyenne, Red Lake, Pembina, Roseau and Souris rivers, plus numerous small rivers and streams (see Figure 2-1). The total drainage area exceeds 270,000 km^2 (MacLaren 1986). Much of tributary has been extensively drained.

The flow in the rivers is dominated by spring runoff. The snowmelt, in combination with the spring rains, have been responsible for major floods. Flows usually decrease steadily in the summer. The minimum annual flow month often occurs in January or February. Annual average flows on the Red River upstream of Winnipeg (Ste. Agathe) are 162 m^3/s (1962-1997 data). Flows at Lockport, which include the contribution from the Assiniboine River, average annually 225 m^3/s . The average annual flows of the Assiniboine River at Headingley upstream of Winnipeg are 41 m^3/s.

River flows and levels are regulated throughout the drainage basin, with over 15 control structures (Wardrop/Tetr*ES* 1990). On the Assiniboine River system, important control structures include the Shellmouth Dam and the Portage Diversion. The river's reservoir is located on tributary of the Assiniboine, and five small structures control flows on the Qu'Appelle River in Saskatchewan, which is a tributary of the Assiniboine River. The Souris River is also regulated within Saskatchewan. The Winnipeg Floodway and the St. Andrews Lock are the major hydraulic structures on the Red River in Manitoba although many smaller ones have been built on tributaries such as the La Salle River. In the U.S.A. five major reservoirs are located on



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The Red and Assiniboine Rivers Watershed

Figure 2-1

tributaries of the Red River: the Red Rock Reservoir on the Red Rock River; Orwell on the Otter Tail River; Bald Hill on the Sheyenne River; and Homme Dam on the Park River and Lake Traverse.

Additional regulation of the Red and Assiniboine rivers and their drainage basins may occur in the future. Current proposals include a control structure on the Red, an intermittent diversion of the Pembina River into Pelican Lake and diversions of water from the Assiniboine River to southwestern Manitoba.

2.2 REGIONAL LAND USE

Land use in the drainage basins is principally agricultural, but numerous cities and towns are located on the riverbanks. The principal urban centres are: Fargo, Moorhead, Grand Forks, Winnipeg and Selkirk on the Red River and Minot, Brandon and Portage la Prairie on the Assiniboine River. Agriculture use affects water-quality runoff through the runoff the nutrients, pesticides and sediments. Towns and cities and residential areas discharge domestic and industrial sewage which has received varying levels of treatment. Sections of the riverbank still remain in their natural state and support a variety of birds and mammals, while many aquatic species are present within the rivers. Waterfowl conservation projects in the region are a major water user in the Red River basin.

2.3 FLOWS WITHIN THE STUDY AREA

Water Survey Canada maintains continuous flow gauges at three locations (St. Agathe, Headingley and Lockport) within the study area. St. Agathe located upstream of the City of Winnipeg on the Red River has a record of daily flows from 1962 to the present. The Headingley Station located just upstream of the City of Winnipeg on the Assiniboine River has a record of daily flows from 1912 to 1997. The Lockport Station, located downstream of Lockport, has a daily record from 1962 to the present. The period of record studied in this report is from 1962 to 1997 (the last complete year before the study was initiated). It is possible to construct weekly flow averages at St. Agathe using the record at Emerson (from 1912 to the present) and regression analysis. This has not been done in this study. Since the early 1970s, the

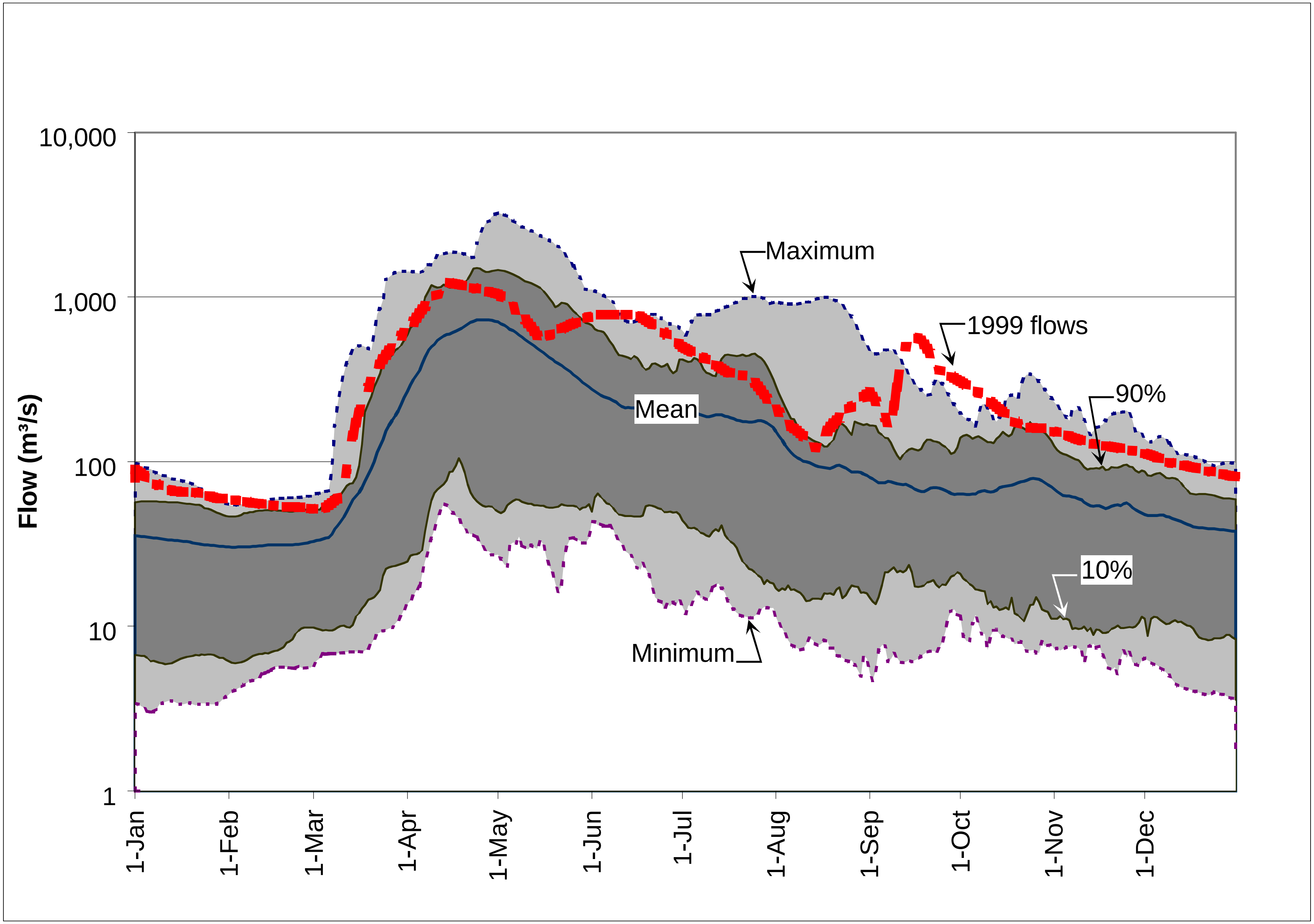
Assiniboine River has been regulated to maintain minimum flows. The record from 1962 to 1997 has been reconstructed by the Province of Manitoba using modelling techniques. This reconstructed record is used as a proxy for potential future flows. Additional withdrawals due to increased water consumption for irrigation along the Assiniboine River has not been considered at this stage.

The daily flows at St. Agathe were analyzed in order to determine the frequency of various flows at any time of the year. A frequency analysis was done on each date of the year for the 36-year record. The results are shown on Figure 2-2. The following analysis is illustrated on this figure:

- the maximum flow on any given date in the historic record;
- the 90th percentile flow on that given date;
- the mean flow on that given date;
- the 10th percentile flow on that given date; and
- the minimum flow on that given date.

Also shown are the flows occurring during 1999 when the field programs were conducted in the various workstreams of this study. It should be noted that the scale on this figure is a log scale, indicating the large variability in flow on a given date from year to year. This variability indicates that there is considerable change in river conditions from year to year and any field program in a single year will fail to capture the full range of conditions. Figure 2-2 illustrates that the 1999 river conditions were always higher than the mean flow for any date during the year. Often, the flow was above the 90% exceedance frequency for a given date. In early June and September of 1999, there were record high flows for a given date.

A similar analysis was done for the flows recorded at the Lockport Station (see Figure 2-3). The flows at Lockport represent typical flows in the river downstream of The Forks within the City of Winnipeg. As with St. Agathe, the range of flows from year to year on any given date is considerable. The maximum flows are a similar order of magnitude to St. Agathe, however the flows are higher due to contributions from tributaries, the most significant being the Assiniboine River. Figure 2-3 shows that the minimum flows (which are critical to maintaining aquatic life and reducing the influence of wastewater discharges) are considerably higher at Lockport indicating the moderating influence of the Assiniboine River flows. The relative magnitude of



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stagatflw
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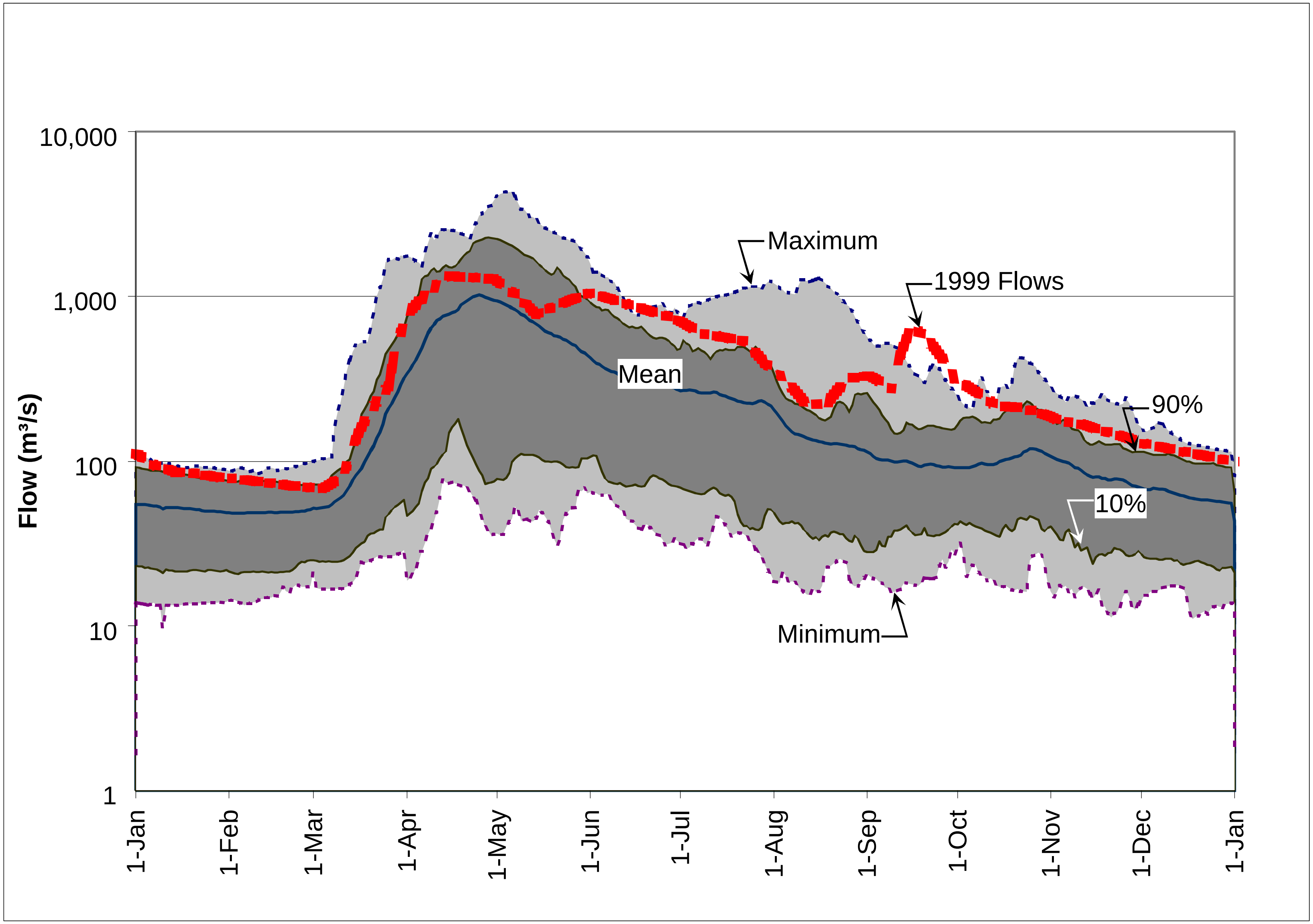
Frequency of Ste. Agathe Flows - 1962-1997

Figure 2-2



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lckptflw (DM lockportflows1999)
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Frequency of Lockport Flows - 1962-1997

Figure 2-3

flows in 1999 was very similar to that at St. Agathe, being above average at all times, with record flows in early June and September.

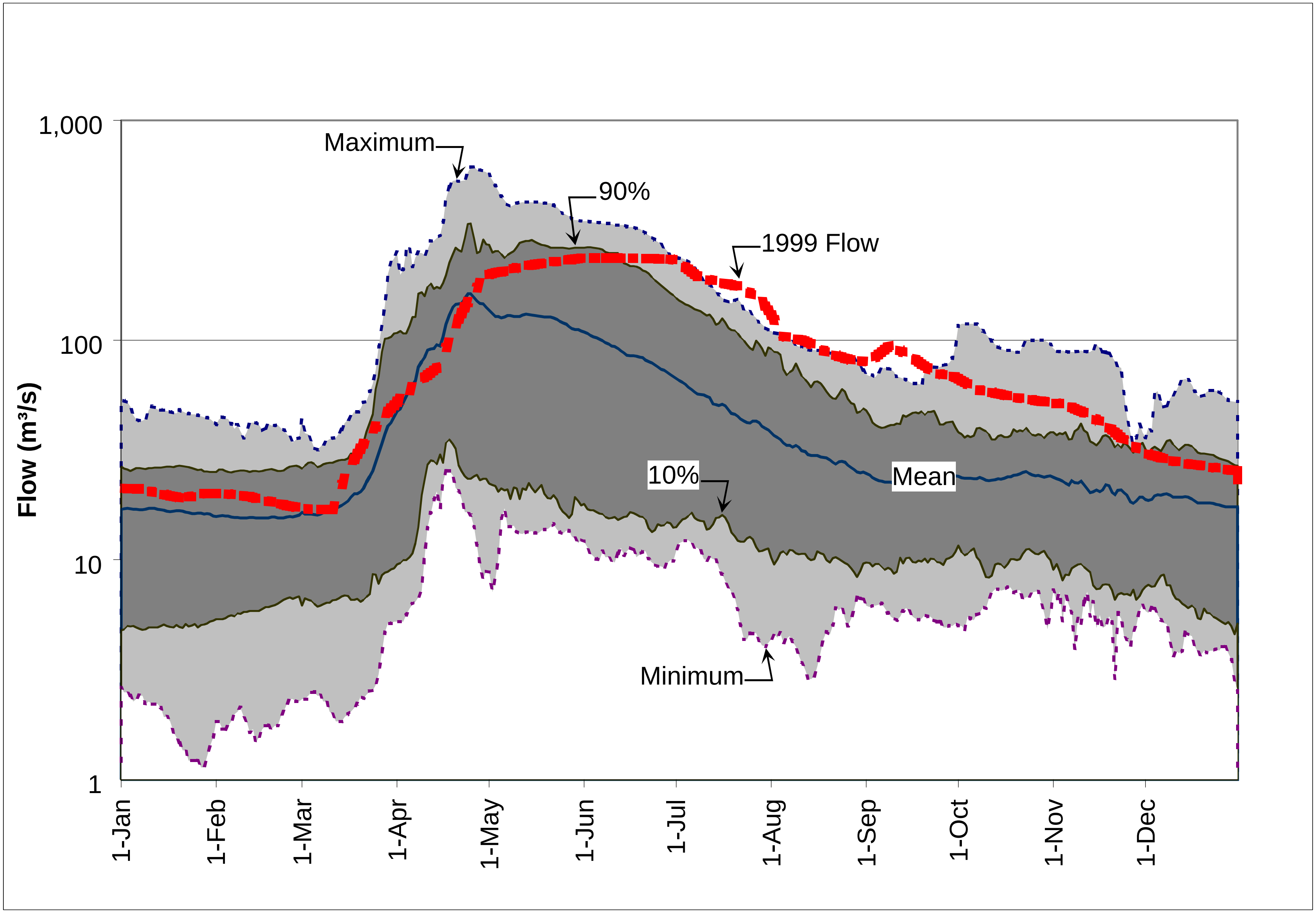
Two analyses were done for the flows at Headingley on the Assiniboine River. An analysis was done using the actual historical flows from 1962 to 1997 and a second analysis was done using the reconstructed flows which assume the Shellmouth Dam was in operation for the entire period. As with the Red River, the Assiniboine River is extremely variable on a given date from one year to the next. Under natural conditions, there can be extremely low flows in late winter from January through March. The moderating influence of the Shellmouth Dam is illustrated by Figures 2-4 and 2-5. Figure 2-5 shows that the minimum flow of 5.6 m^3/s (200 cfs) will be maintained for any time of the year. A comparison of 1999 conditions shows that wet conditions (similar to those observed for the Red River) prevailed on the Assiniboine River. The Assiniboine River flows in the winter months were close to normal conditions through to the beginning of May. Wet conditions, from May through June, caused an increase in the flows to very high levels by mid-June. These record flows in the Assiniboine River continued from early July through to mid-September.

The preceding analysis illustrates the extreme variability from year to year for flows of all reaches of the study area. The 1999 flows were at or near record levels through much of the summer and fall.

2.4 RIVER HYDRAULICS

As illustrated in the previous section, the flows in the river can change dramatically from season to season and have a large range for any given date from year to year. In order to understand how these flows can influence hydraulic parameters a hydraulic model was developed of the Red and Assiniboine rivers within the study area. By determining hydraulic parameters such as depth, water velocity, and wetted perimeter for a range of historic flows, a perspective on the hydraulic parameters collected during the 1999 field program was gained.

In addition, this hydraulic model provides input into the water-quality simulation models, for example, the velocity depth and volume, which are used in the critical period and long-term river modelling described in Section 10. The MIKE11 model, a sophisticated hydrodynamic model,



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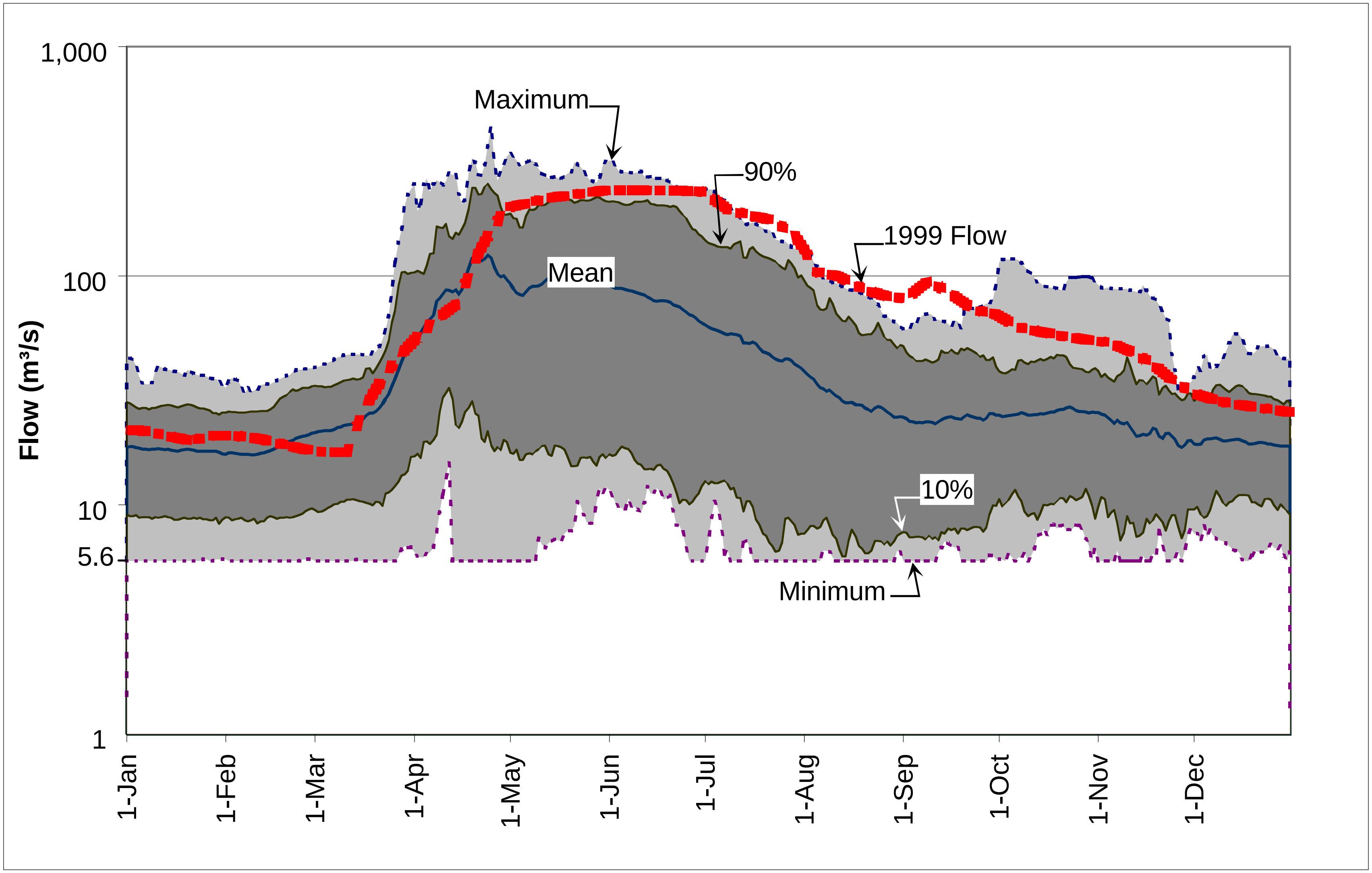
Frequency of Headingley Flows
(Historic Data) - 1962-1997
Figure 2-4



Note: With Shellmouth regulation minimum flows will not drop below 5.6 m³/s (200 cfs)

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Hdglyflw2 (DM headingley1999controls)
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Frequency of Headingley Flows
(Reconstruction Assuming Regulation) - 1962-1997
Figure 2-5

was used to perform the analysis. A description of the MIKE11 model was given in a previous Technical Memorandum on Model Selection (Tetr*ES* 1999).

The model was set up with 489 cross-sections, as shown on the model network schematic on Figure 2-6. To establish known boundary condition, the model was extended outside the study area, upstream to St. Agathe at the flow gauging station and downstream to Lake Winnipeg to utilize measured water levels. Some typical cross-sections for the Red River are shown on Figure 2-7, while some typical cross-sections for the Assiniboine River are shown on Figure 2-8. Hydrodynamic simulations were performed year-round to provide a better understanding of seasonal flow characteristics. The winter conditions from November to March occur during ice cover and the increased hydraulic resistance had to be accounted for. Spring conditions (April, May) occur during open-water season with the Lockport Dam open. Summer conditions for June to August and fall conditions from September and October occur during open-water conditions with the Lockport Dam in operation. The Lockport Dam was simulated as overflow gate position for different flows to maintain 734 ft a.s.l. water elevation at James Avenue in the centre of Winnipeg. This operation of the dam maintains water levels within Winnipeg in order to provide recreation opportunities for boaters during summer.

The model was calibrated based on 1988 river flows which were very low. This year was selected since the critical conditions with relatively high ammonia would occur during low flow. A summary of the calibration is shown on Table 2-1 for winter, spring and summer. Verification was done on 1992 data for winter, spring and summer conditions (see Table 2-2). The results show the model was reasonably well calibrated and verified for winter and summer conditions.

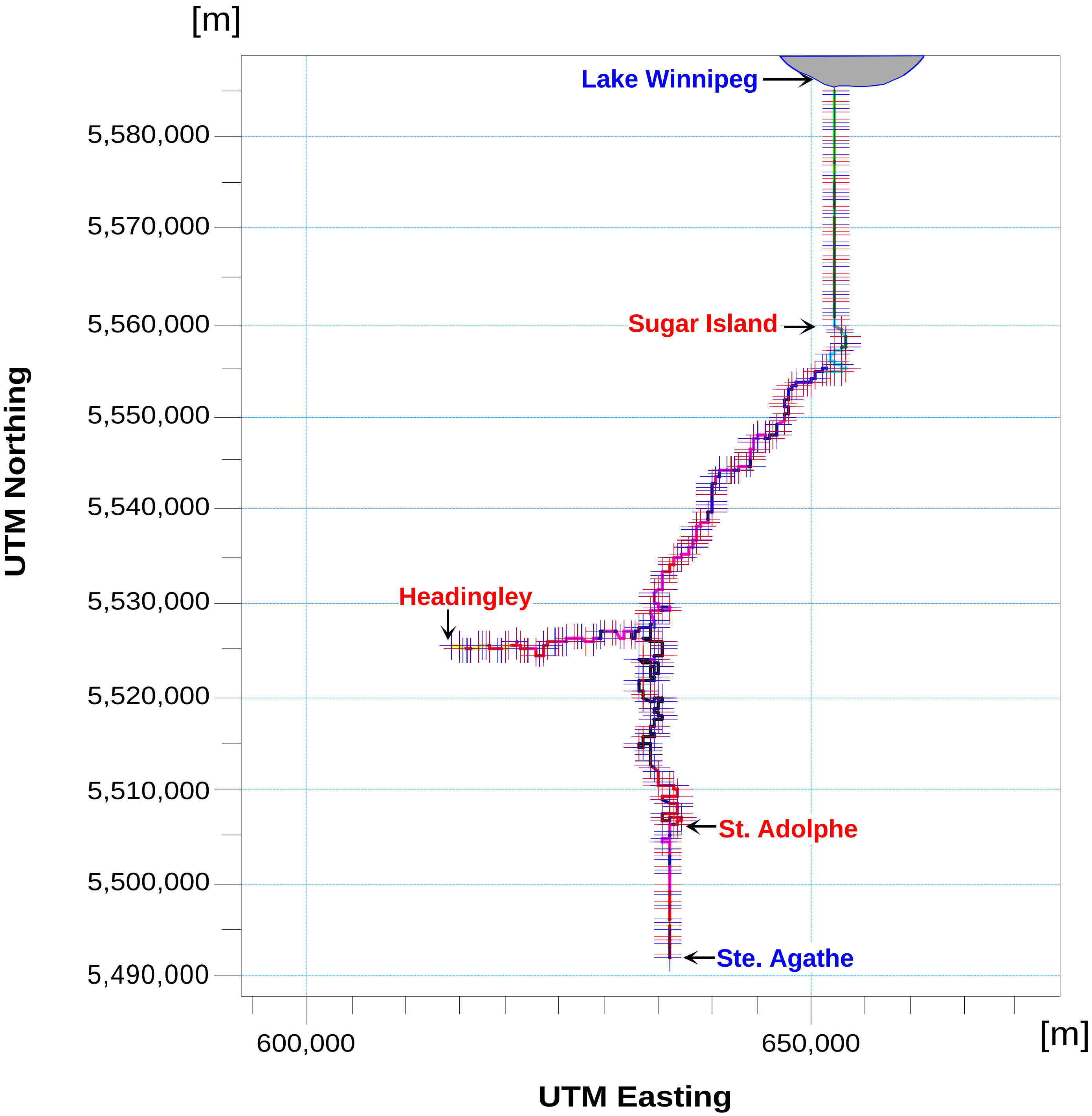
In order to develop the simple relationship between flow and velocity needed to perform long-term water-quality modelling for 35 years on a daily basis, the MIKE11 model was run through the full-range of historic data. Simple relationships were then developed during the winter to transform flow into velocity at each reach in the study area during the winter months. These equations called Leopold Mannix equations are described below.

$$V = aQ^b \qquad \text{eq(1)}$$

$$D = cQ^d \qquad \text{eq(2)}$$

Where

V = velocity in m/s



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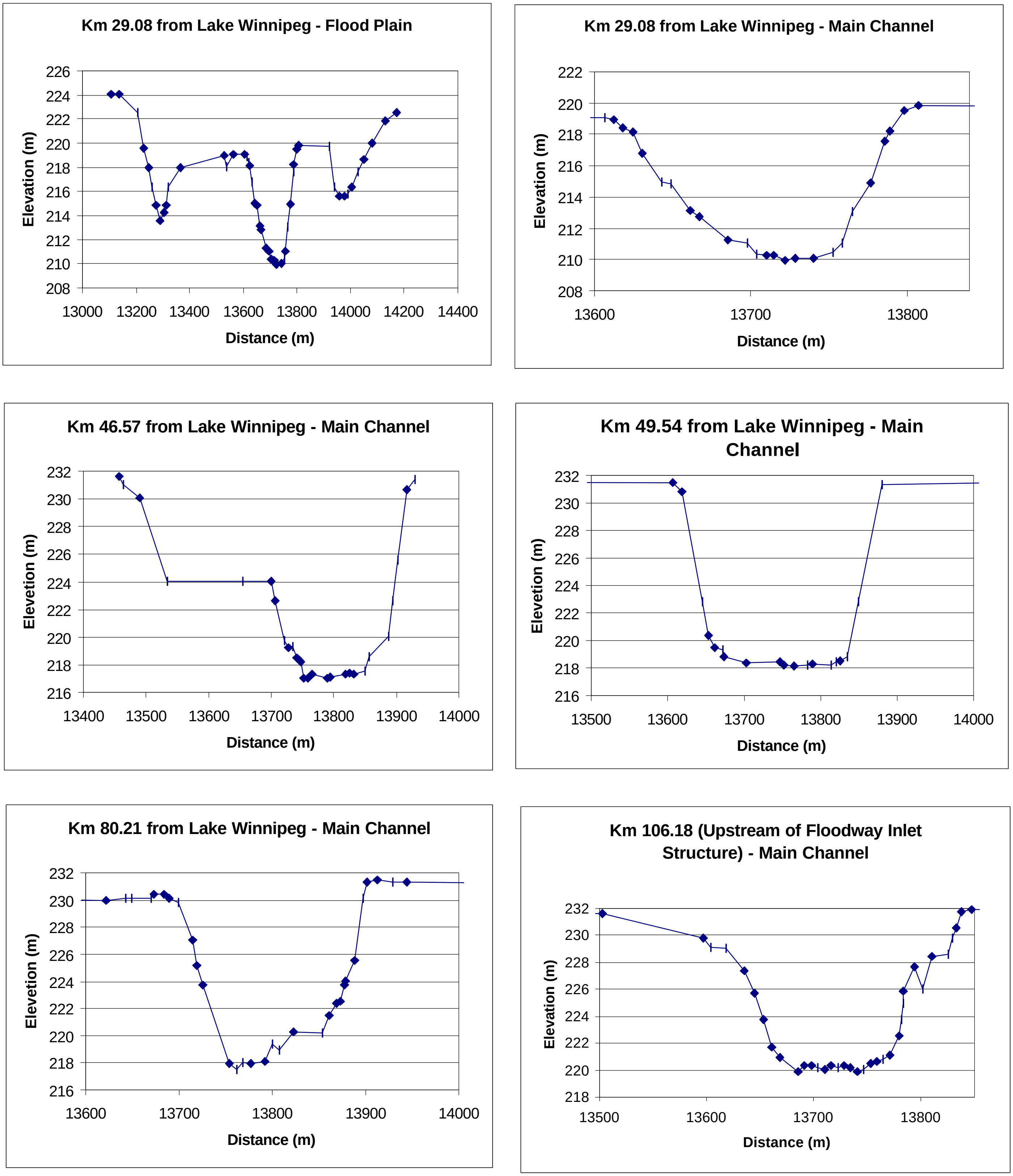
MIKE 11 Model Network
Figure 2-6



Km 29.08 from Lake Winnipeg - Flood Plain

Km 29.08 from Lake Winnipeg - Main Channel

Km 46.57 from Lake Winnipeg - Main Channel

Km 49.54 from Lake Winnipeg - Main Channel

Km 80.21 from Lake Winnipeg - Main Channel

Km 106.18 (Upstream of Floodway Inlet Structure) - Main Channel

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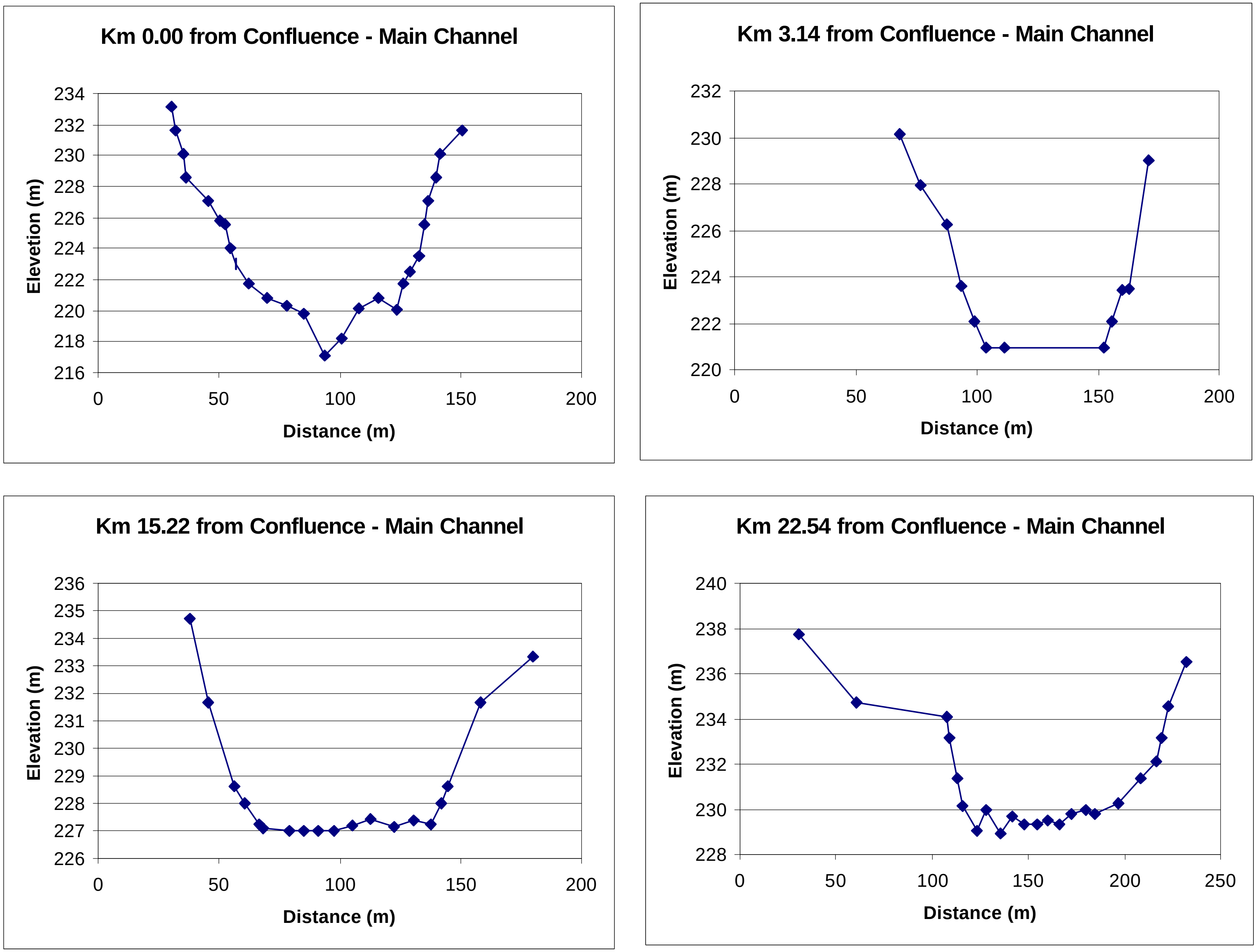
Typical Cross-Sections of the Red River
Figure 2-7



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Typical Cross-Sections
of the Assiniboine River
Figure 2-8

TABLE 2-1

CALIBRATION BASED ON 1988 DATA

DATA/PARAMETER	SEASON		
	WINTER (Jan 1-7)	SPRING (Apr 8-11)	SUMMER (Jun 1-6)
Flow at St. Agathe (m^3/s)	19	428	67
Flow at Headingley (m^3/s)	11	37	59
Elevation of Lake Winnipeg (m)	217.031	217.050	217.150
Water Elevation at James Ave. (m)	221.532	224.285	223.685
Computed water level at James Ave. (m)	221.327	224.144	223.710
Error at James Ave. (m)	-0.205	-0.141	0.025
Manning's *n*	0.050	0.030	0.030

TABLE 2-2

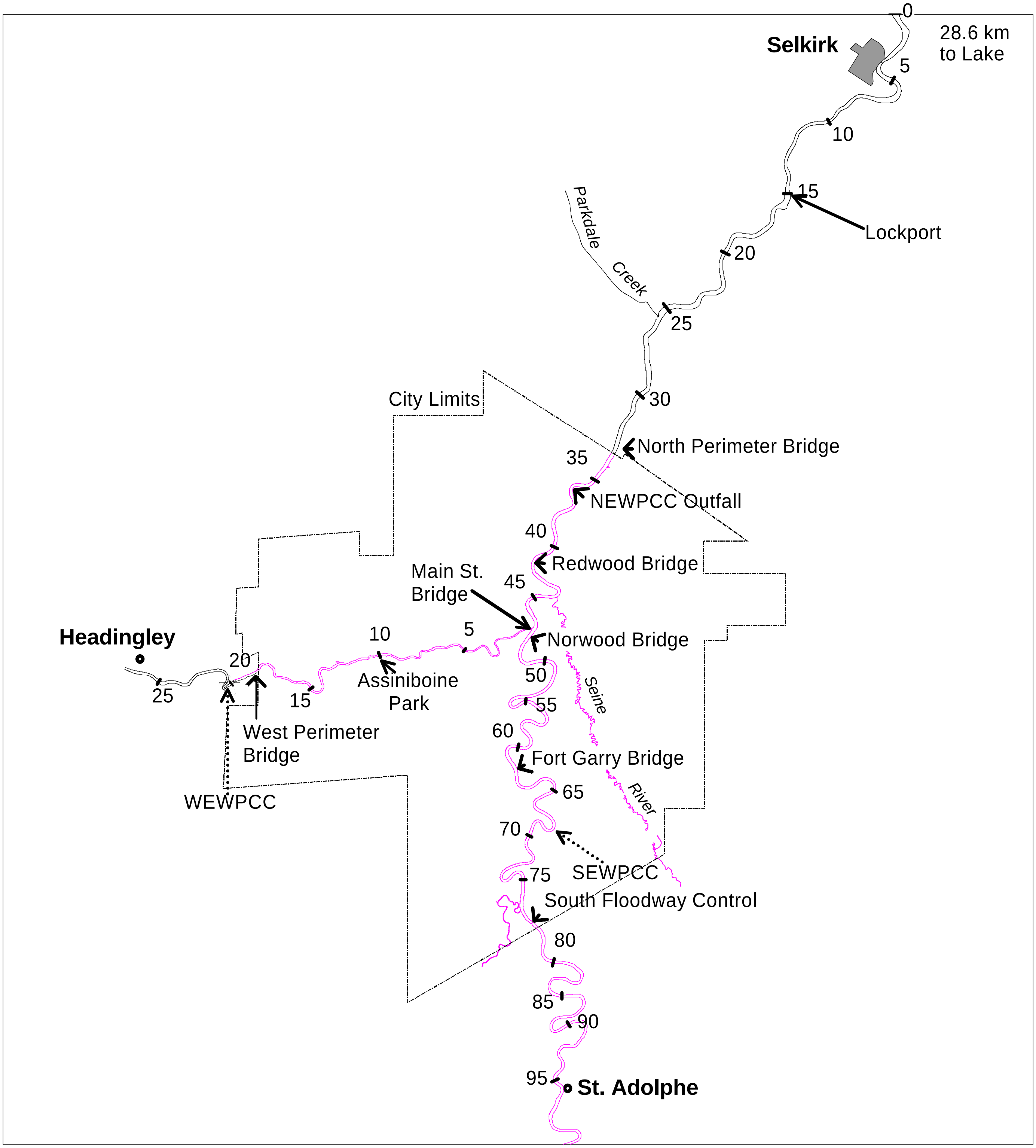
VERIFICATION BASED ON 1992 DATA

DATA/PARAMETER	SEASON		
	WINTER (Jan 1-7)	SPRING (Apr 1-7)	SUMMER (Jul 8-14)
Flow at St. Agathe (m^3/s)	15	760	135
Flow at Headingley (m^3/s)	20	119	16
Elevation of Lake Winnipeg (m)	217.026	217.079	217.72
Water Elevation at James Ave. (m)	221.499	226.117	223.665
Computed water level at James Ave. (m)	221.427	225.706	223.715
Error at James Ave. (m)	-0.072	-0.411	0.050

Q = flow in m^3/s
D = average depth in m

These equations allow for a quick calculation of water velocity required in the water-quality model. In the summer months, with the operation of the Lockport Dam, the flow velocity relationship is more complex at stations influenced by the backwater of the dam. Polynomial equations were fitted to the MIKE11 output data to develop a relationship between flow and velocity. Again, the equations were used to provide a quick calculation of velocities on any given day during the 35-year record being modelled in the water-quality model. It should be emphasized that these equations should not be considered to be used for any generalized flow-velocity relationships and should never be extrapolated beyond the flows illustrated in the graphs. A complete set of graphs for each segment and a table giving the coefficients for the equations is available in Appendix A. A polynomial equation was used rather than a piece-wise linear interpolation between each point, for ease of use in estimating velocities for the water-quality model. An analysis was done to estimate the frequency of average velocities at various cross-sections through the river system. This analysis is shown for each month at the various cross-sections as indicated on Figure 2-9. A review of this analysis indicates the following:

- in January and February (Figure 2-10) velocities are very low in the Red River, always less than 0.2 m/s and often much less than 0.1 m/s at many locations. In the Assiniboine River, the velocities are generally higher in the range of 0.2 to 0.4 in January and February.
- in March (Figure 2-11) the Red River velocities are generally low, less than 0.2 with the exception being years with an early spring melt, when the velocities in the upstream reaches of the river (upstream of The Forks) can be as high as 0.3 to 0.5 m/s. Downstream of The Forks, the flows are more consistent varying between 0.2 and 0.5 m/s, depending upon the location. In the area of Lister Rapids the velocities are in the range of 0.2 m/s while in other portions of the lower Red River, the velocities are less than 0.1 m/s.
- In March the Assiniboine River velocities are more consistent in the range of 0.2 to 0.4 m/s.
- In April the Red River flows can be extremely variable, depending upon the size of the spring flood. Velocities could be as low as 0.1 and as high as 0.8 m/s in the upstream reaches of the Red River. In the downstream reaches the velocities are generally in the range of 0.4 to 0.5 m/s (at Lister Rapids). On the Assiniboine River April velocities are generally higher than the Red River in the range of 0.2 to 0.8 m/s. The fastest section is the region in the area of Omands Creek where there is a small rapids.



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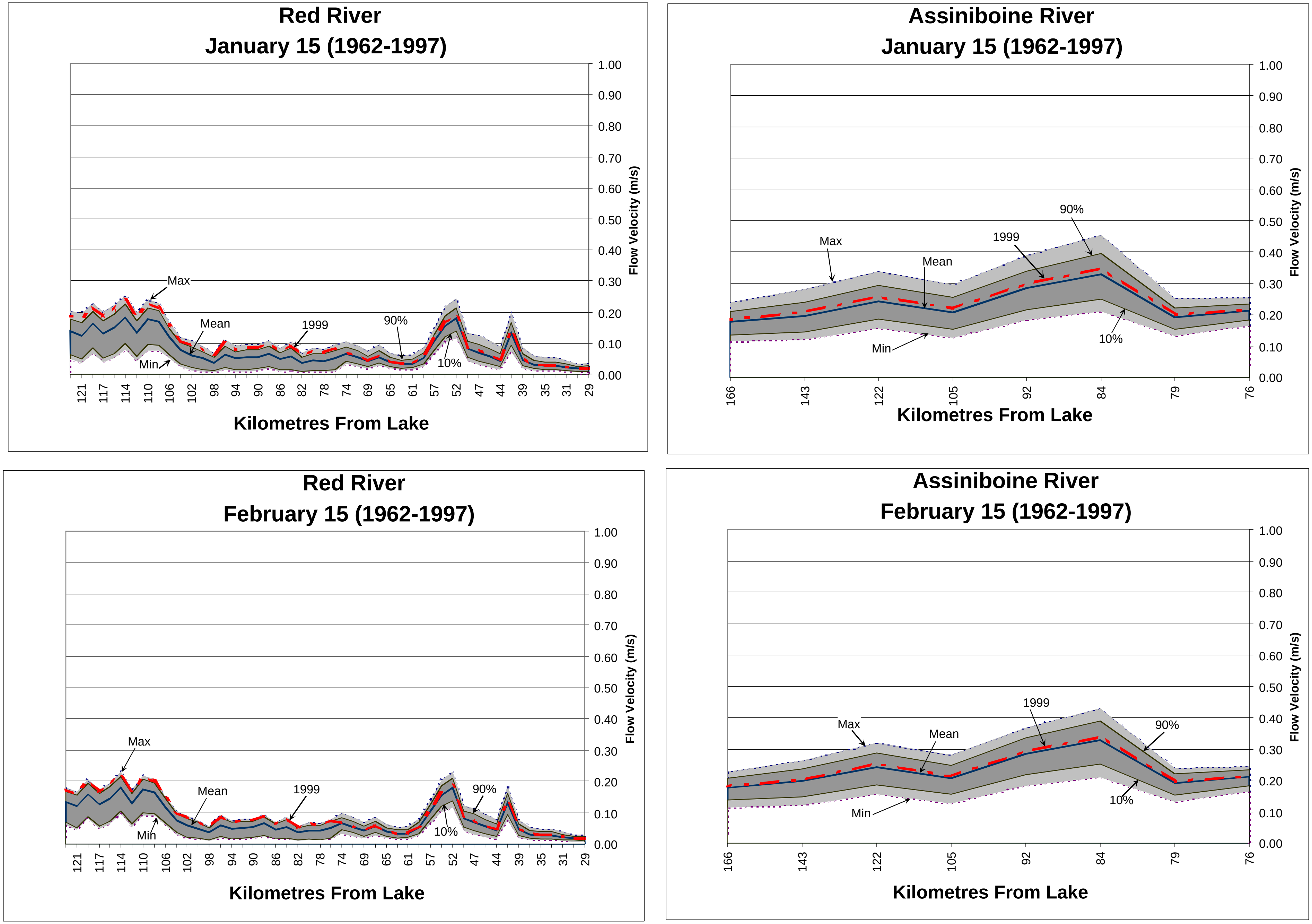
River Distances (km) in the Study Area and Locations of Key Features

Figure 2-9



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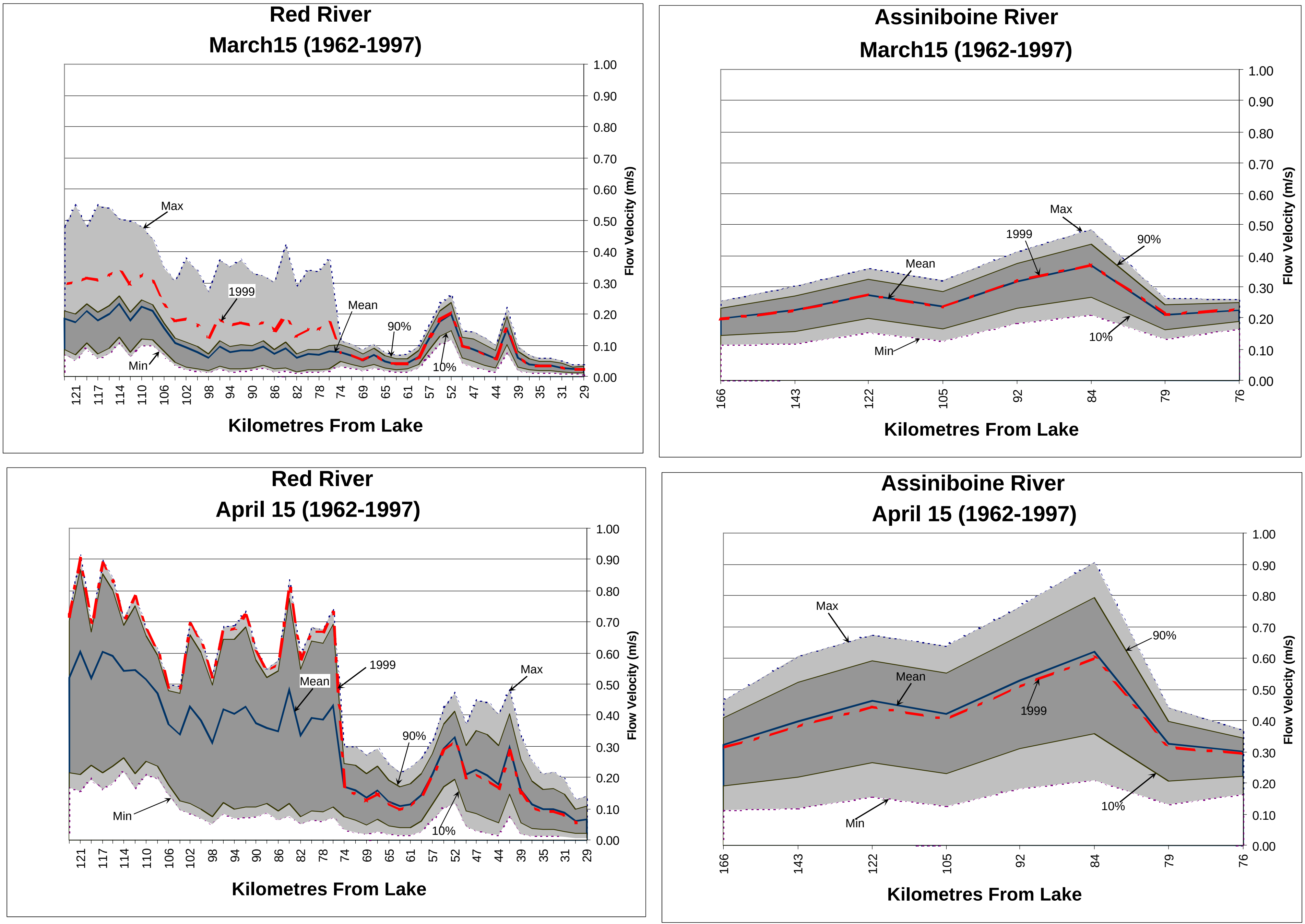
Range of Velocities for January and February

Figure 2-10



Red River
March15 (1962-1997)

Assiniboine River
March15 (1962-1997)

Red River
April 15 (1962-1997)

Assiniboine River
April 15 (1962-1997)

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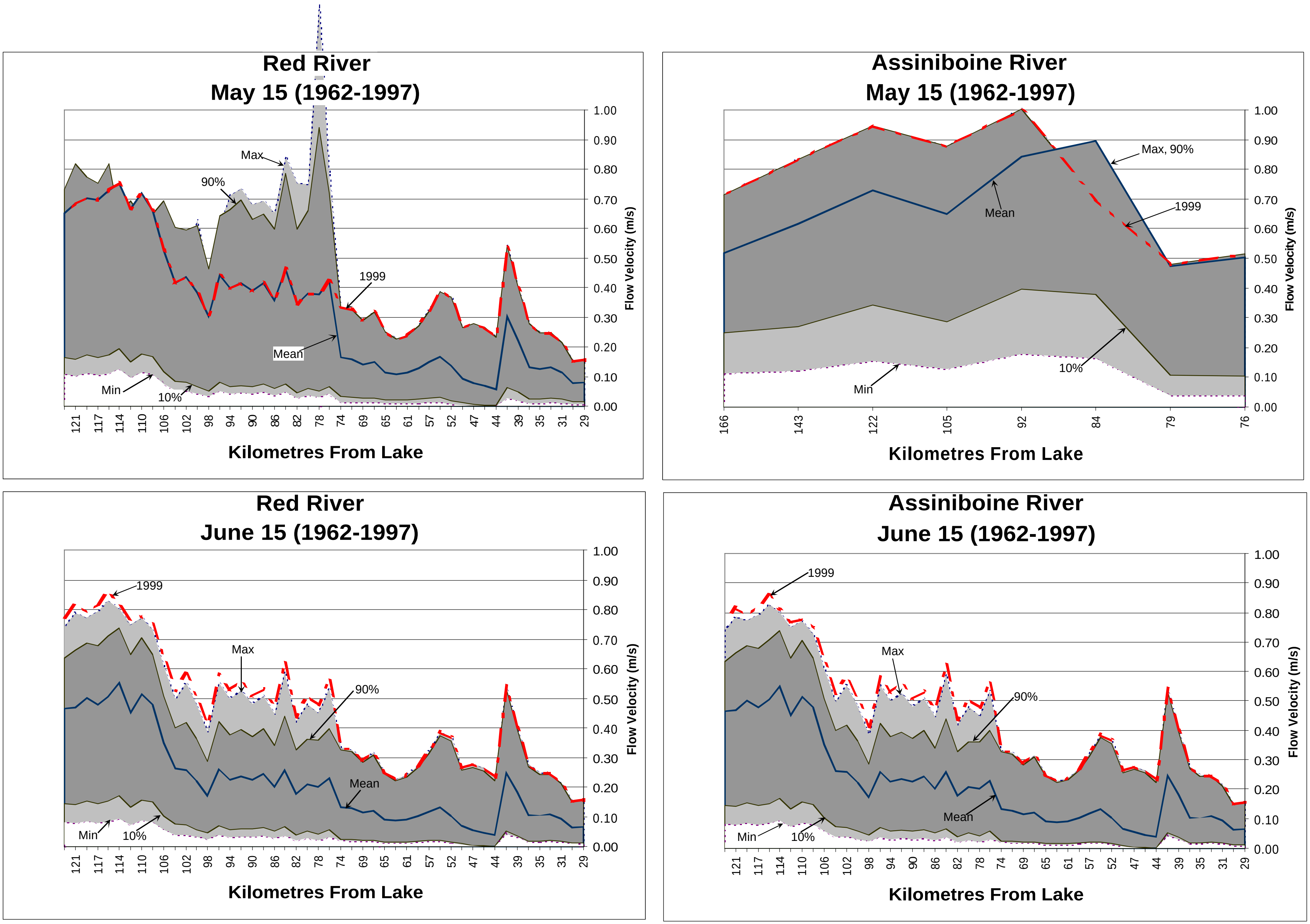
Range of Velocities for March and April

Figure 2-11

Figure 2-12 and 2-13 show spring and summer velocities in the reaches of the Red and Assiniboine Rivers. As can be seen, during this period in 1999 the velocities were at the very high end of the historic range for all locations in both rivers. In the lower Red and the Assiniboine rivers, the velocities were at record highs for August. In September 1999, the velocities were at record levels in the upper Red (in the range of 0.4 to 0.8 m/s). These velocities are more typical of spring fresh-up velocities rather than fall velocities. The velocities continued to decrease through October, November and December (see Figures 2-14 and 2-15), although they remained at near record highs in 1999 through November for the Assiniboine and Lower Red rivers. By December 1999, velocities in the river system had dropped below 0.3 m/s at all locations on the Red River as would be expected for typical December conditions. In December 1999, the Assiniboine River had started to drop back towards normal conditions with velocities less than 0.4 at all locations.

In order to determine how the width and depth of each river responds to variations in flow the MIKE11 model was run at the low (10 percentile average) and high (90 percentile) flows as well as for average conditions. The width and the depth for each reach was calculated for each of these flows. There was very little variation in width for changing flows on all reaches of the Red River throughout the study area (see Figure 2-16). At the upstream end of the study area, the Red River is approximately 120 metres wide increasing to 150 metres wide downstream of The Forks and as much as 250 metres wide in the Lister Rapids area.

During the summer months the depth in the Red River can vary with flow. The average depth at any location throughout the study area varies between 2 metres and 5 metres depending on location and flow in the river. Within the centre of the City of Winnipeg, the Lockport Dam maintains a depth of about 5 metres for all flows between the 10th and the 90th percentiles. Upstream of The Forks, the depth can vary from as little as 3 to 4 metres during low and average conditions and as much as 5 metres during high flow conditions. Downstream of the City of Winnipeg the depths are influenced by Lister Rapids (located between Lockport and Winnipeg) and the operation of the Lockport Dam. The average depth can decrease to approximately 2 metres during high flows in the summer. When the flows are very high, the gradient between Winnipeg and Lockport is steep, causing a shallow river in the area from Lister Rapids to the Lockport Dam. However, in low and average-flow conditions, the dam maintains high water levels in the range of 4 to 5 metres at the Lockport Dam. This is done in order to maintain high water levels within the City of Winnipeg. During lower flows, when the



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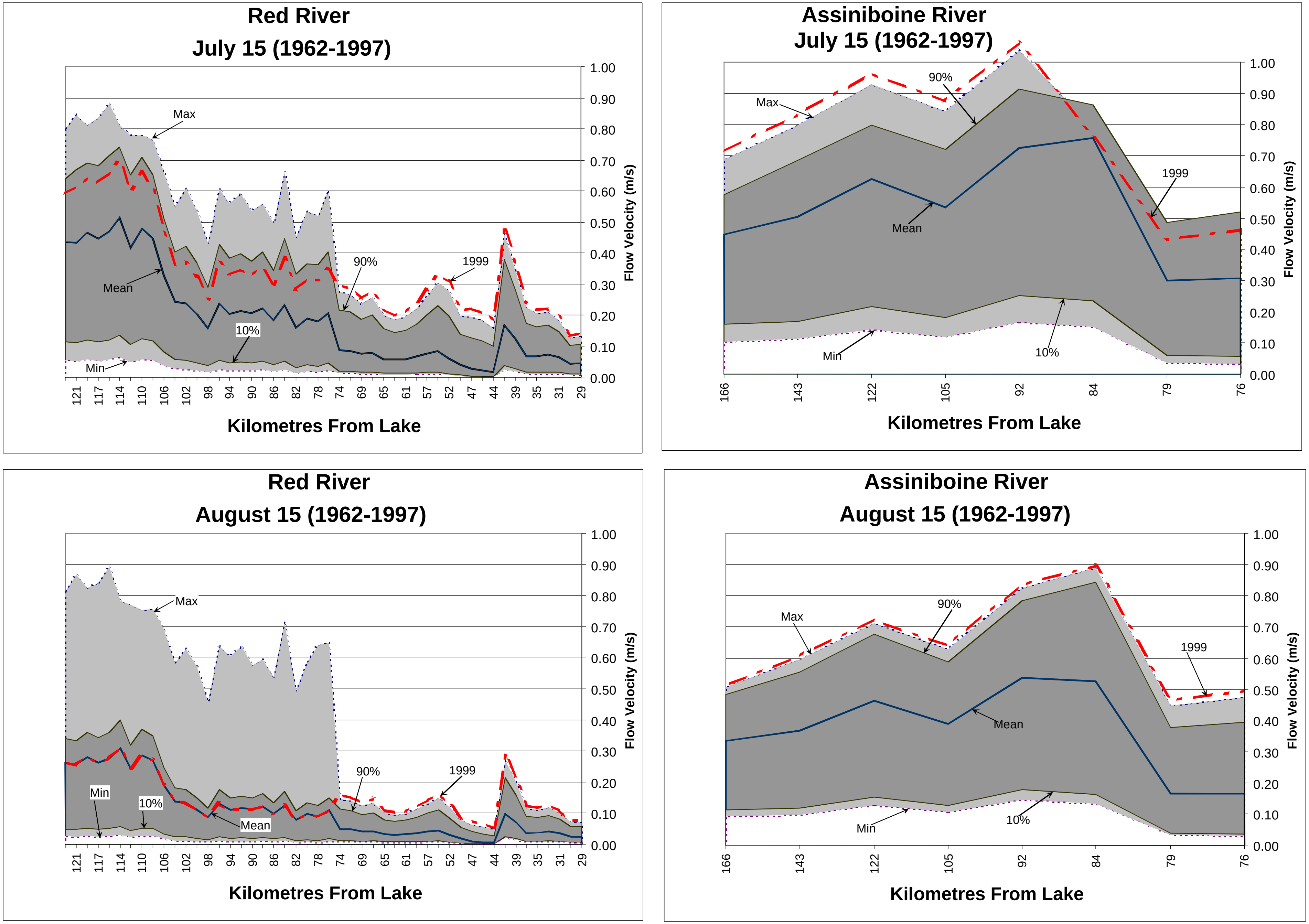
Range of Velocities for May and June
Figure 2-12



Red River
July 15 (1962-1997)

Assiniboine River
July 15 (1962-1997)

Red River
August 15 (1962-1997)

Assiniboine River
August 15 (1962-1997)

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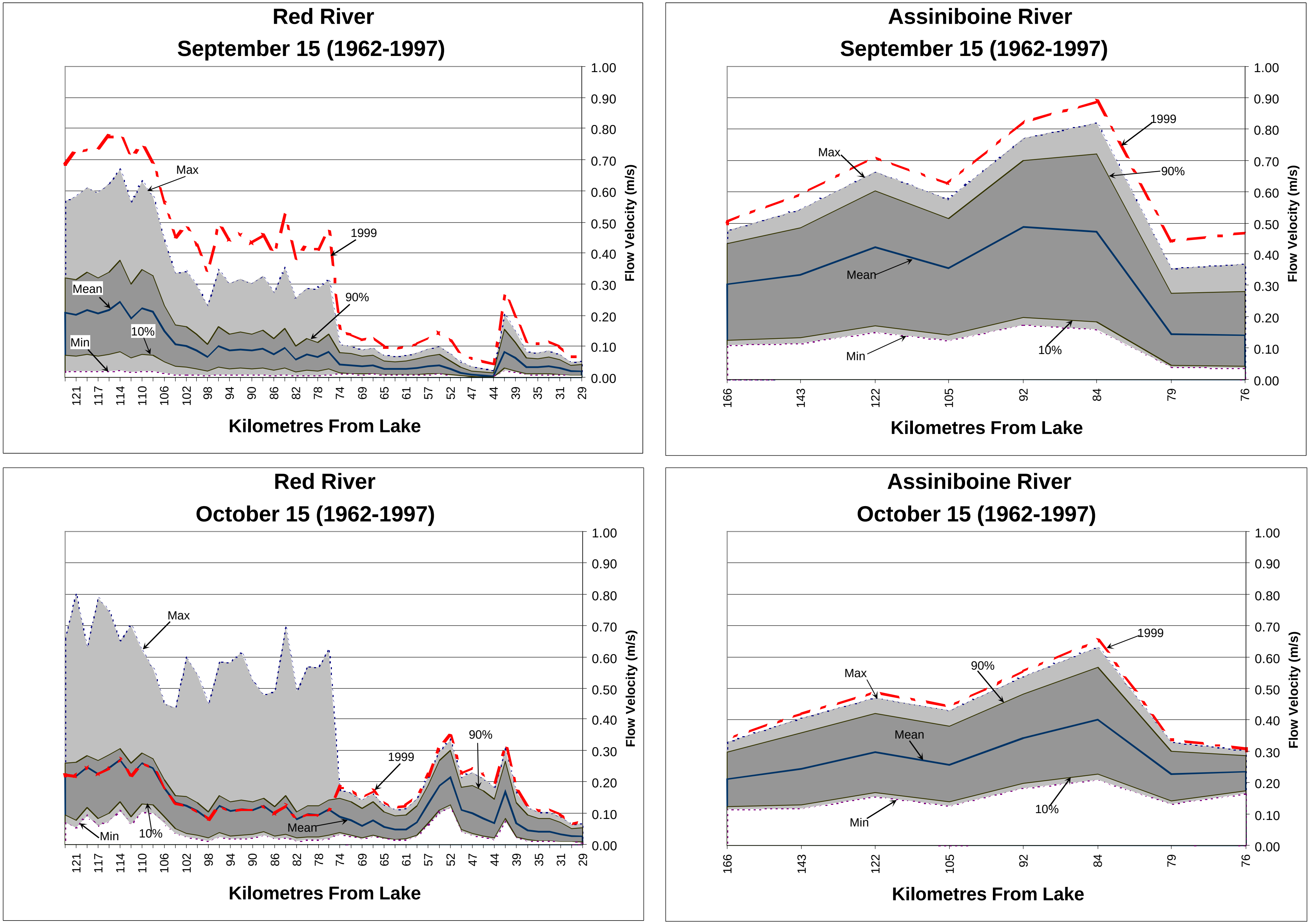
Range of Velocities for July and August

Figure 2-13



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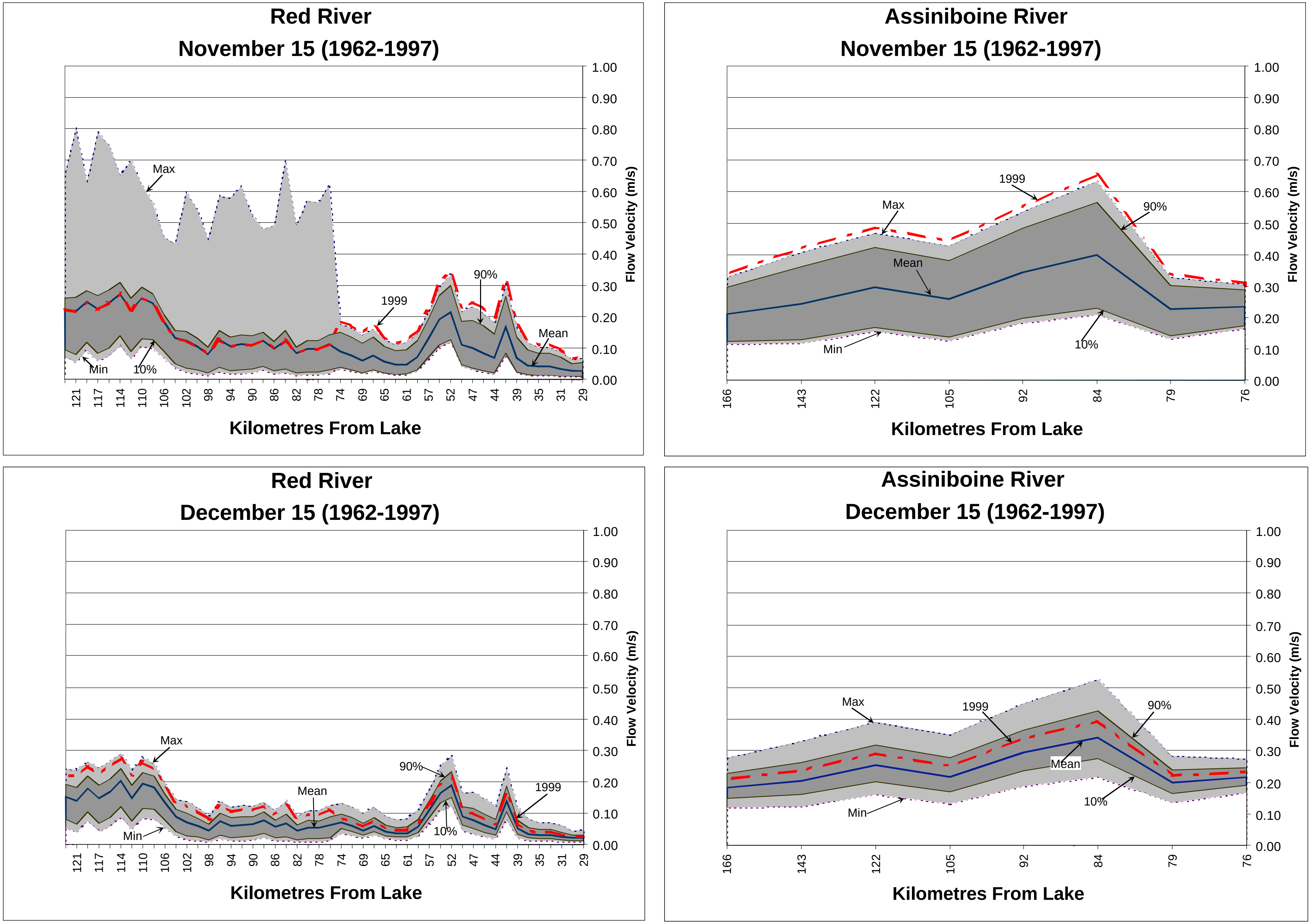
Range of Velocities for September and October

Figure 2-14



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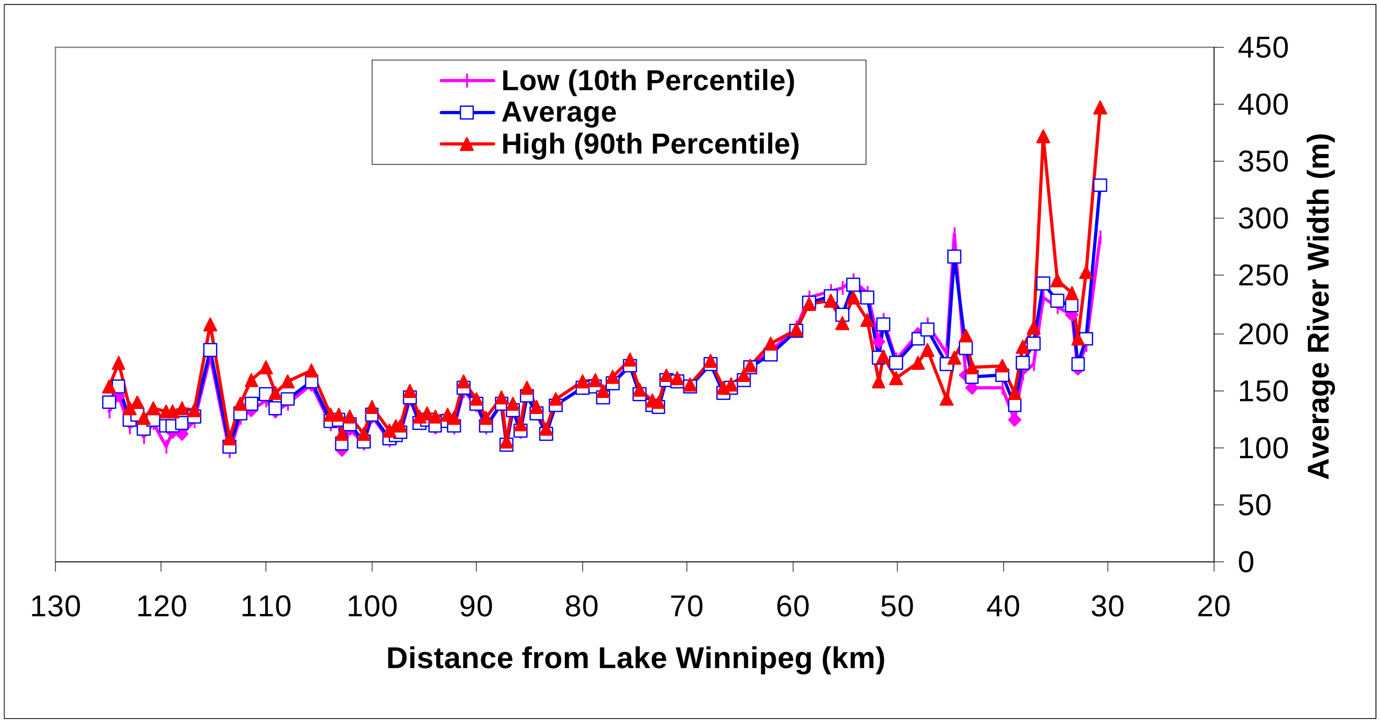
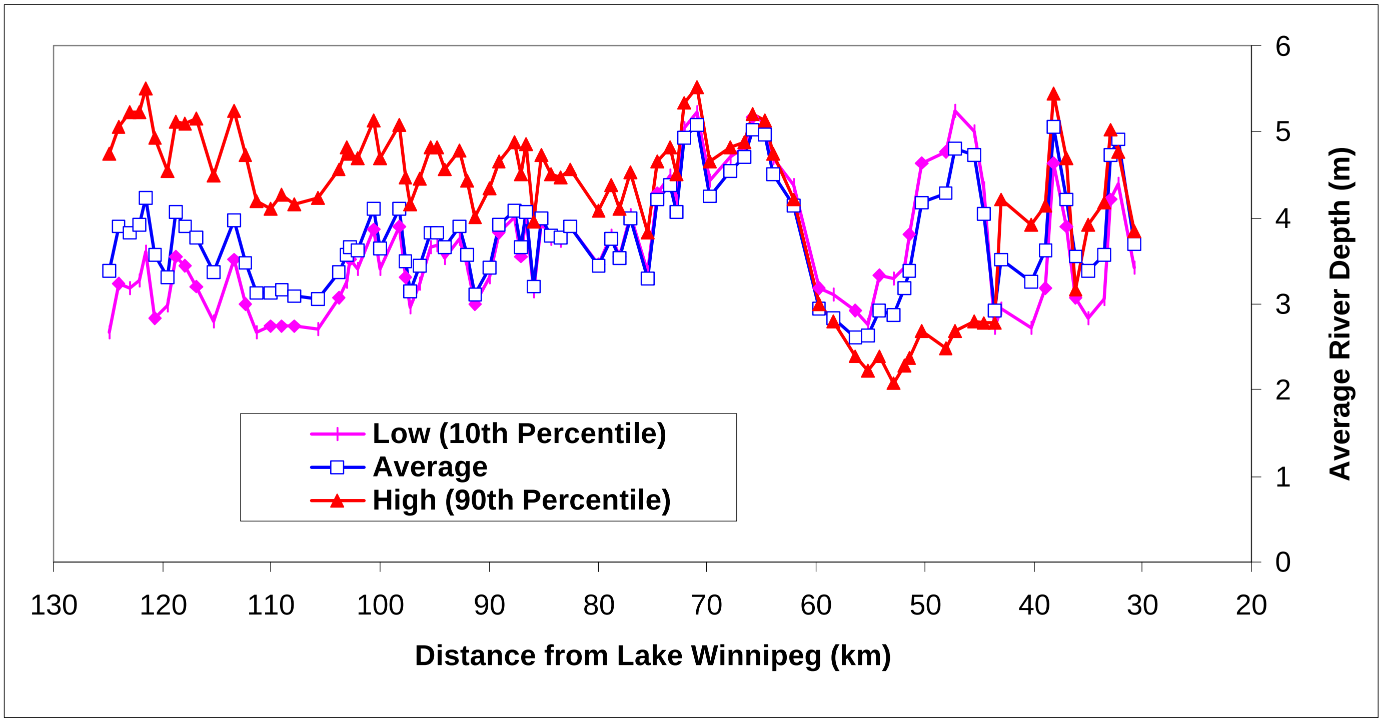
Range of Velocities for November and December

Figure 2-15





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Range of Red River Width and Depth in Summer

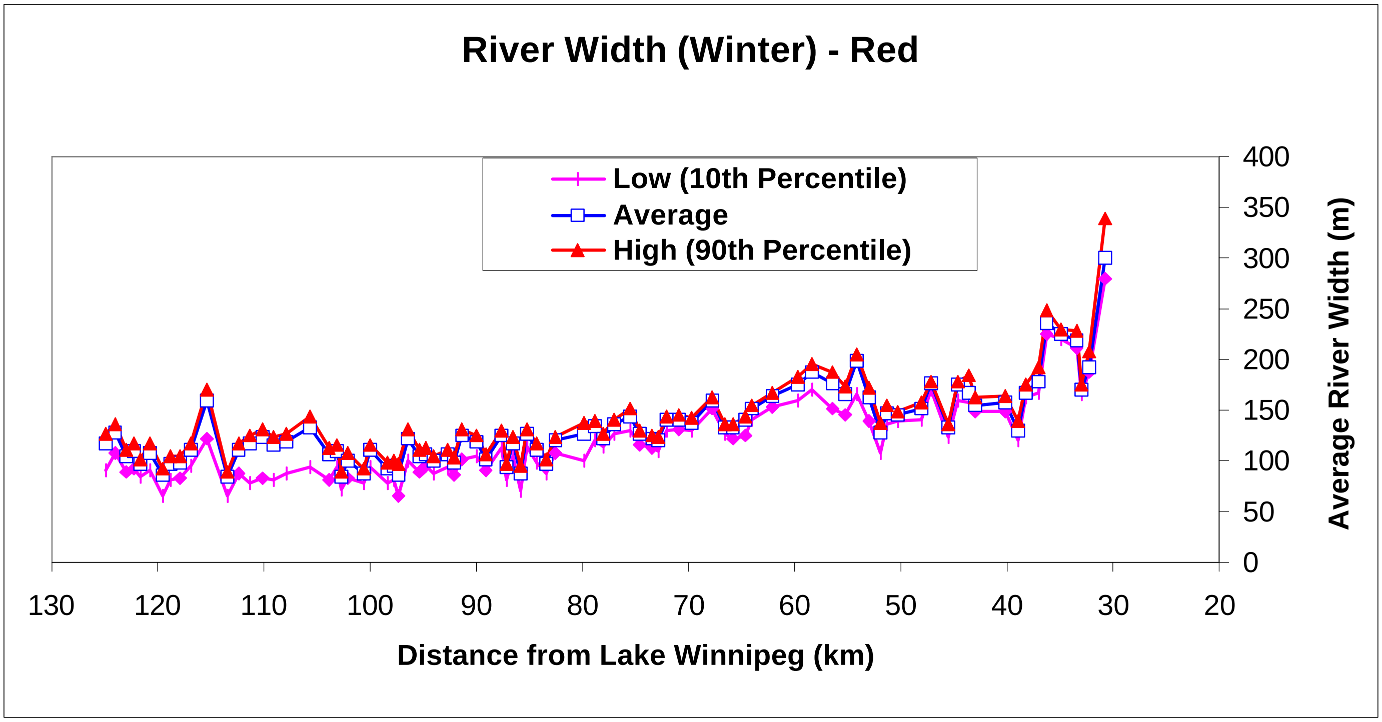
Figure 2-16

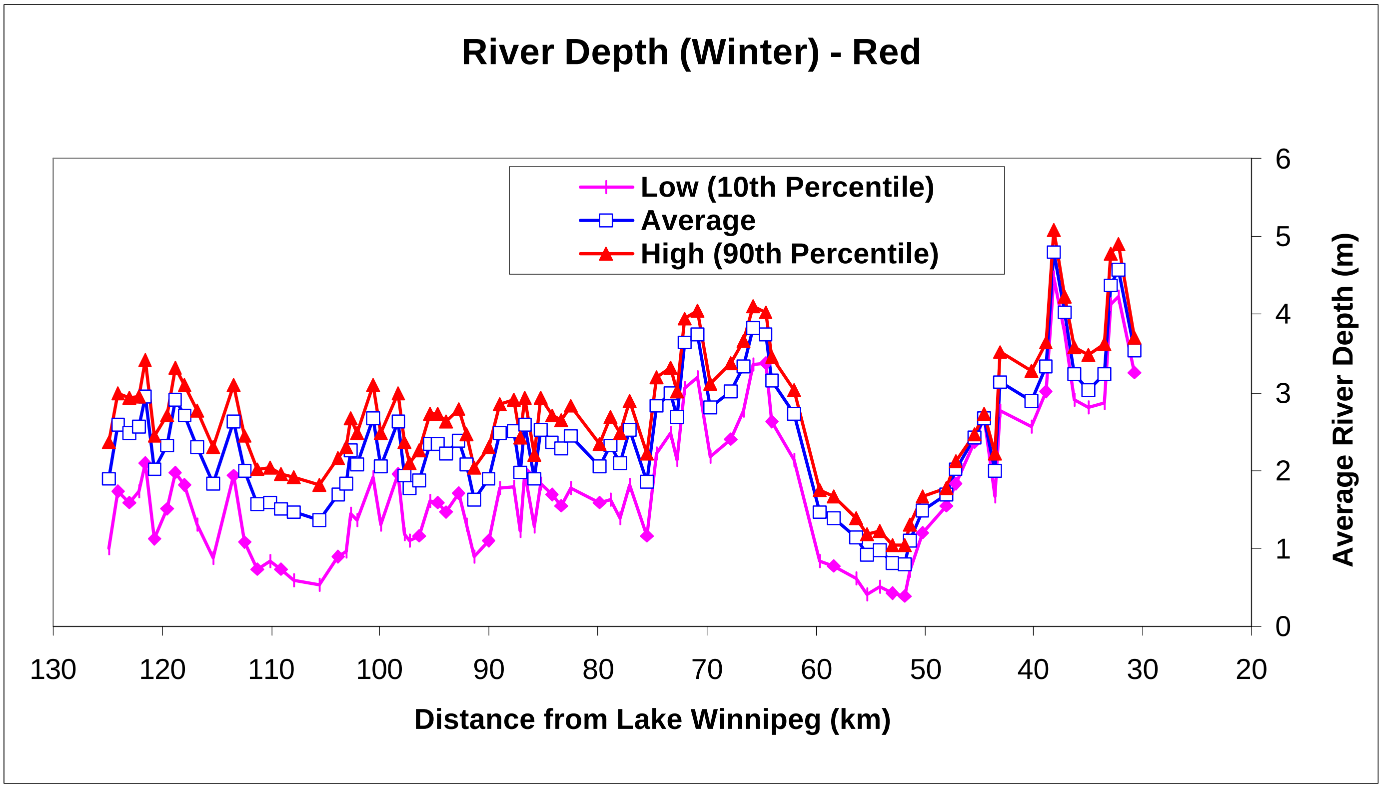
dam is in operation, the depth at Lister Rapids can increase to 3 metres (see Figure 2-16). In winter, the widths of the river are similar to those in summer, and the depth decreases significantly (see Figure 2-17). Thus, the Red River is very shallow in winter, especially in the Lister Rapids Region.

The width of the Assiniboine River decreases from approximately 150 metres in the Headingley reaches to as little as 50 metres in the heart of downtown Winnipeg. The width of the river remains fairly constant between the low and high flow conditions and in winter and summer (see Figure 2-18 and 2-19). The reaches near Headingley do have a tendency to become wider during high flows and can increase in some areas from 100 metres during low flows to 150 metres wide during high flows.

The depths within the Assiniboine River vary as a natural river over most of the reaches. Depths can vary from as low as 0.5 metre during low flows to as high as 1.5 metres during high flows for most of the reaches between Headingley and Omands Creek. Downstream of Omands Creek the depths increase as much as 3 metres due to the influence of the backwater from the Red River. Depths during low and average flows are almost identical in the lower reaches of the Assiniboine River and during high flows the increase in depth is less than 0.5 metre. During 1999 conditions the flow widths and depths were similar to those for high flows or the 90th percentile condition on both the Red and Assiniboine rivers.

In winter, the depth of the lower Assiniboine in the downtown area of Winnipeg decreases significantly due to the removal of the Lockport Dam (see Figure 2-19). It is generally in the range of 1 to 1.5 in winter, in the lower Assiniboine River.





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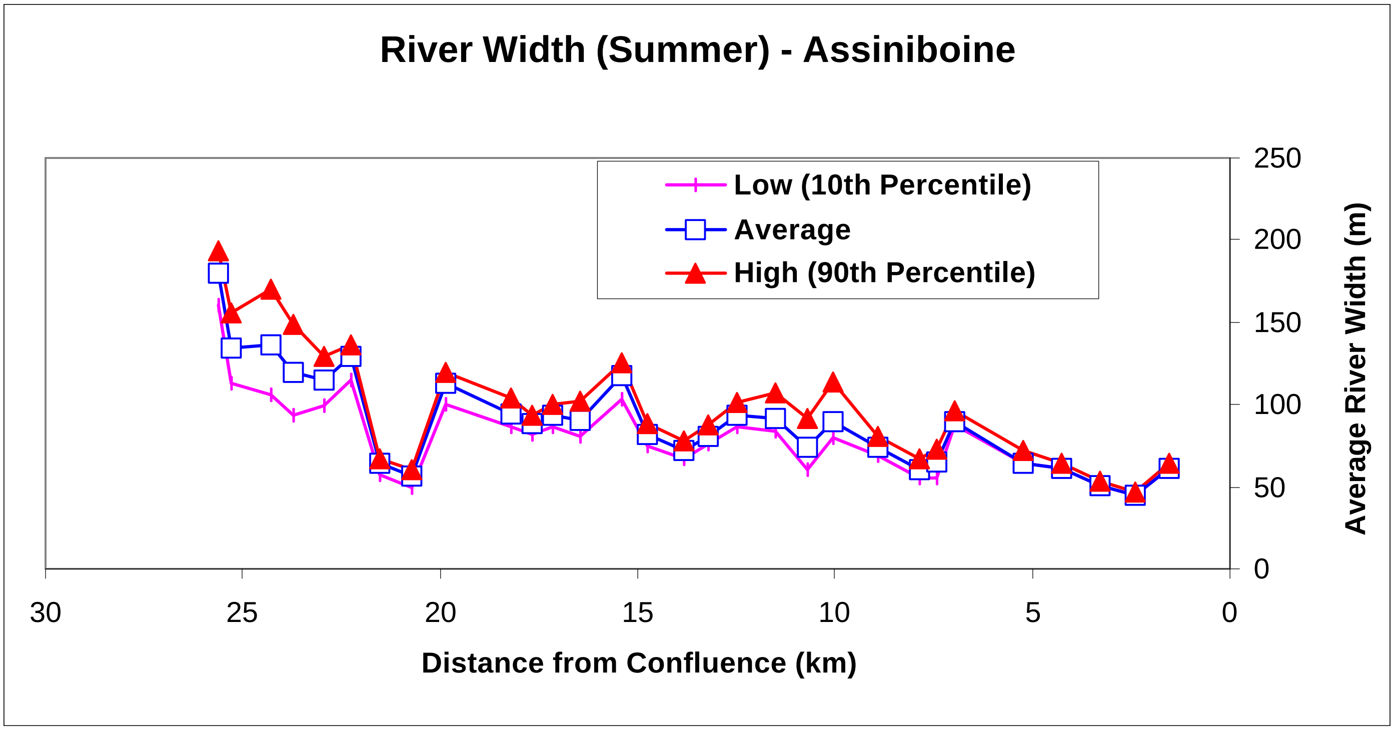
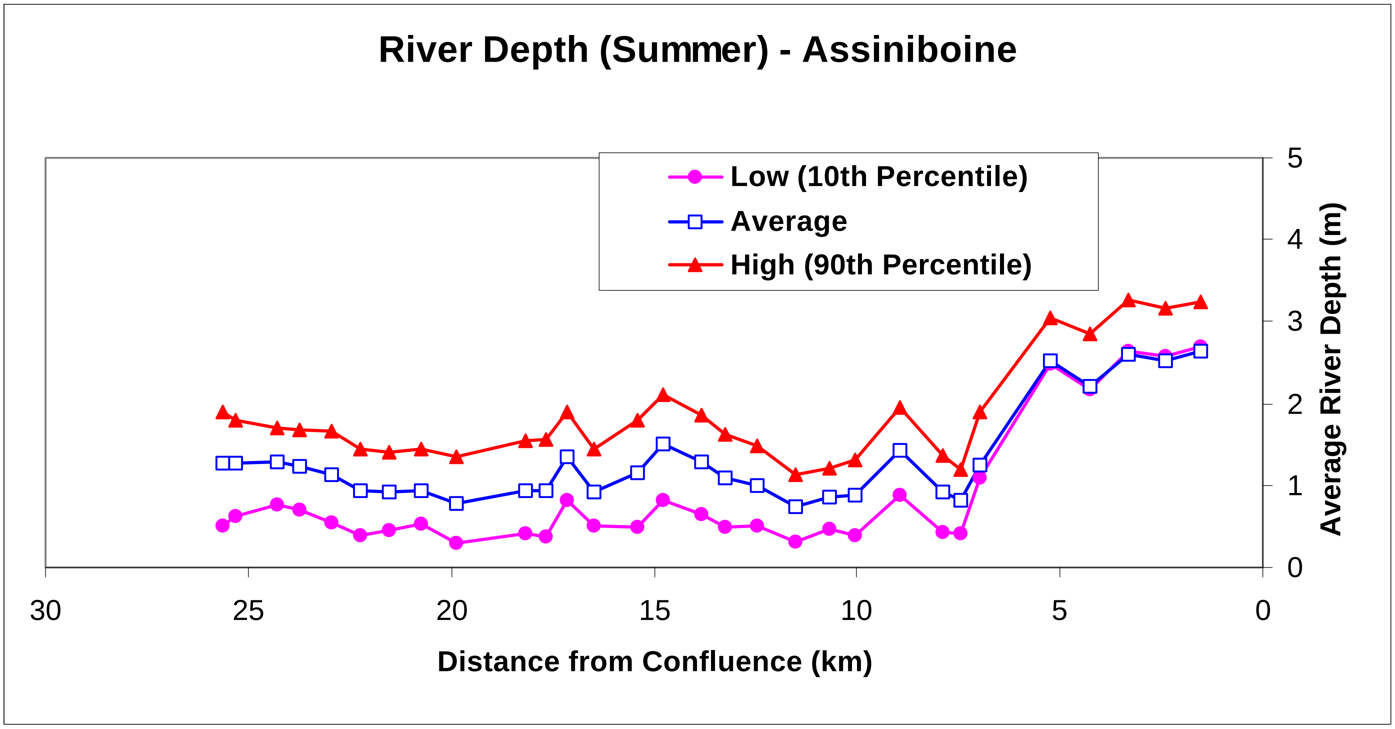
Range of Red River Width and Depth in Winter
Figure 2-17





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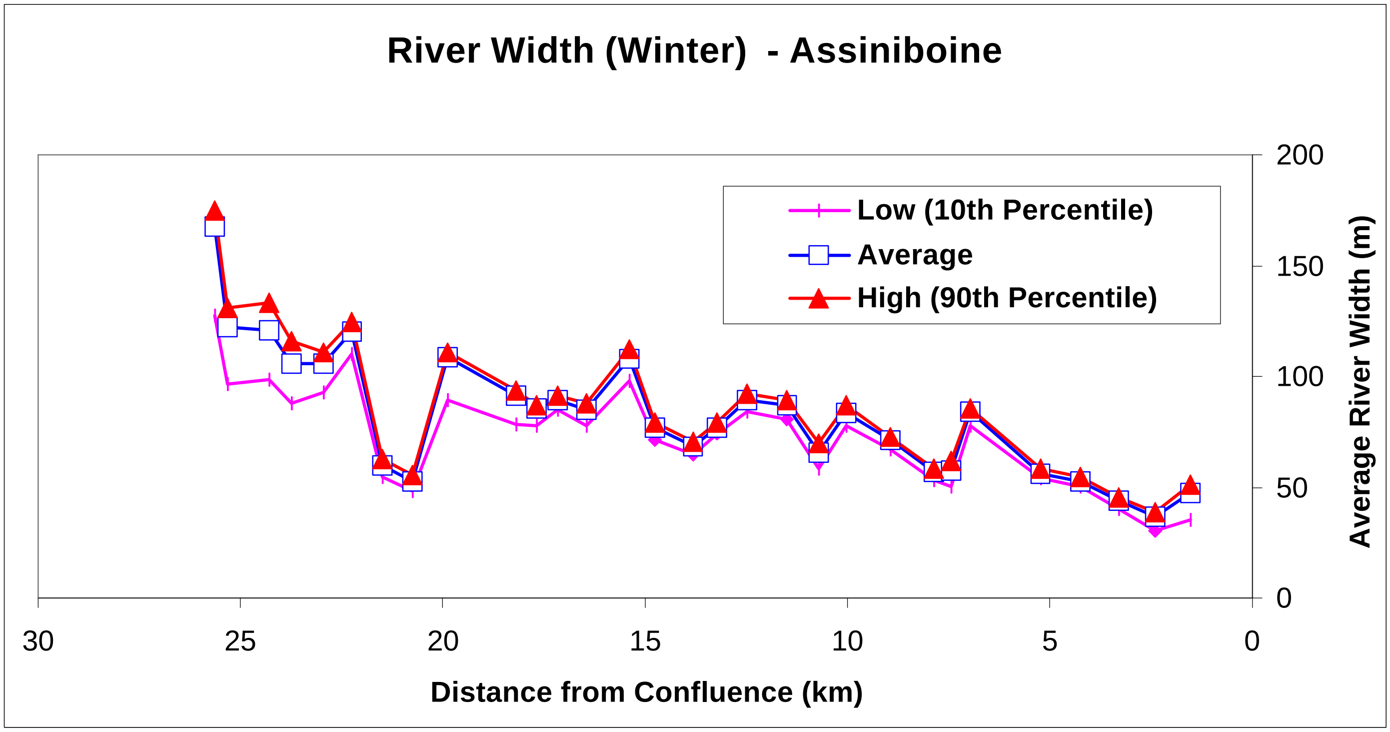
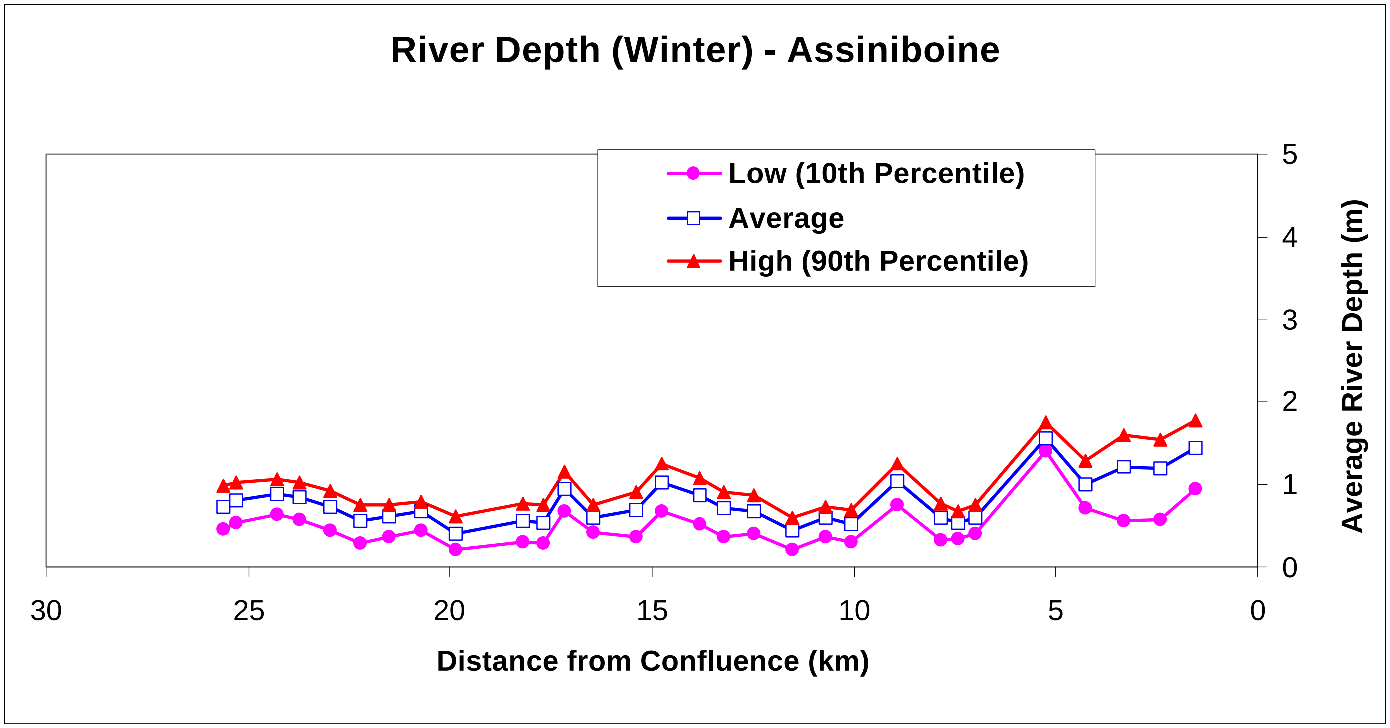
Range of Assiniboine River Width and Depth in Summer

Figure 2-18





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Range of Assiniboine River Width and Depth in Winter

Figure 2-19

3. WATER QUALITY

3.1 GENERAL

Water quality on the Red River is monitored as it enters Manitoba by the International Red River Pollution Board under the direction of the International Joint Commission. The pH of the Red River ranges between 7.4 and 8.7 with most fluctuations attributed to algae activity or the impacts of runoff. Total suspended solids are generally very high in the river typically ranging between 400 and 800 mg/L as compared to the average WPCC effluent concentration of 20 mg/L. Exceptionally warm water temperatures are also experienced during low-flow conditions (such as 1988) although dissolved oxygen levels continue to meet Manitoba Water Quality Objectives. The high sediment load is largely attributed to underlain clay within the streambeds. Sediment is also contributed from runoff from rural and urban land. Nutrients and pesticides are contributed from agricultural runoff as well as from urban runoff and wastewater discharges. Phosphorus and various forms of nitrogen are the most common plant nutrients within the Red and Assiniboine rivers. Algal concentrations can vary considerably depending upon available light conditions which is influenced by the suspended solids flow. In general, toxic material such as trace metals and organics are present at acceptably low levels (Williamson 1988b).

The Red and Assiniboine rivers are valued as aesthetic and sport-fishing rivers. The rivers support a wide variety of water-based recreational activities. Over the years there has been an increasing trend towards public awareness and regulated concern towards the protection of water quality in these streams.

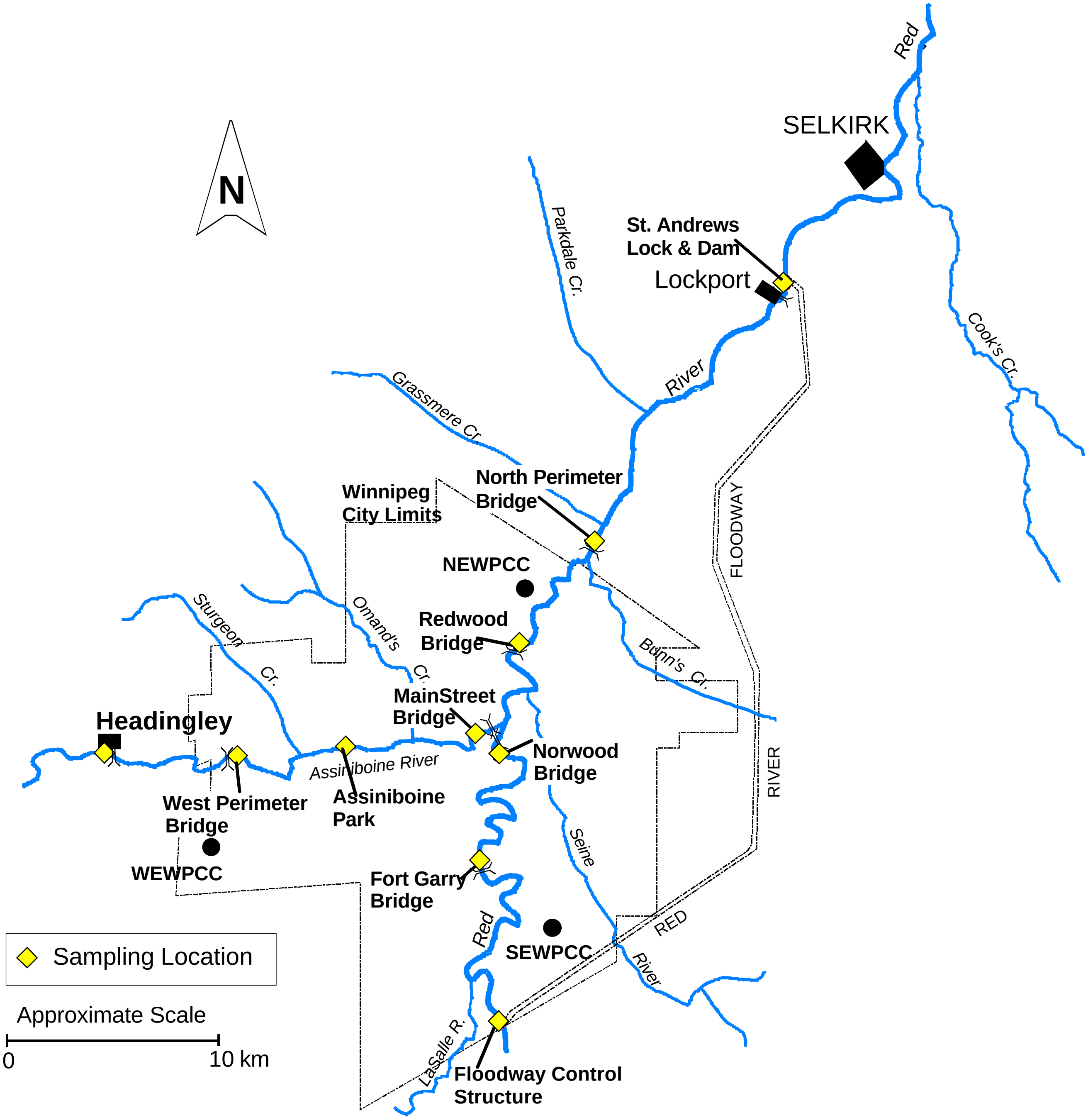
The focus of this Technical Memorandum is on selected parameters. The key parameters are total ammonia and un-ionized ammonia (of which the concentration is dependant upon ambient pH and temperature). Another important aspect found in this study was that the algal concentration has shown a positive correlation with pH in the river. Increasing pH will increase the fraction of un-ionized ammonia which can be toxic to fish at high concentrations. Some of the important factors in the growth of algae are available nutrients such as phosphorus and nitrogen (measured as TKN and nitrate) and Total Suspended Solids which can cause light limitation in the rivers. This water-quality information review will look at various sources of data such as:

- the City of Winnipeg routine data monitoring database which has been collected bi-weekly from 1977 to the present;
- 1988 monitoring program which was conducted during low-flow river conditions (close to Q7-10). The 1988 data will be the key dataset for calibrating the critical period water-quality model (WASP) which will assess ammonia and algal interactions;
- other programs conducted especially for this study were the 1998 Plume Mixing study to determine mixing characteristics of the North End plume and for CORMIX model calibration; and
- the 1999 monitoring program which was conducted to monitor nutrient and algal interaction through summer and fall. It should be noted that the river conditions at this time were very high and the assessment will have to take this into account.

3.2 CITY OF WINNIPEG LONG-TERM WATER-QUALITY DATABASE

Since 1977, the City has been routinely collecting water-quality samples throughout the study area. Over the years, the sample-station locations have varied as new sites were added in order to provide more information. The current sampling locations are located on Figure 3-1. The sampling was done bi-weekly, year-round (conditions permitting) and the data was analyzed and stored electronically on spreadsheets. For this study, the data was compiled into one single database which allows for efficient analysis. There are currently over 4,500 sets of data, with each set containing about 15 parameters. The parameters which relate to ammonia and algal growth were assessed in this study (microbiological indicators such as fecal coliforms were not assessed in this study). The monthly averages for each of the key parameters were calculated for the long-term record from 1977 to 1997 and the values of the minimum and maximum month are shown for the key parameters in Table 3-1. The monthly variation in key parameters at all stations is shown in Table 3-2 (see Appendix B for more detailed summary of each station).

Temperature, pH, and total ammonia are all factors which influence the concentration of un-ionized ammonia in the stream. Un-ionized ammonia is of significance as being the toxic form of ammonia (see the Technical Memorandum on Ammonia Toxicity). The concentration of ammonia and how it varies with temperature and pH is shown on Figure 3-2. The percentage of total ammonia which is in the un-ionized form (NH_3) increases with increasing pH and



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City of Winnipeg Bi-Weekly Routine Sampling Locations

Figure 3-1

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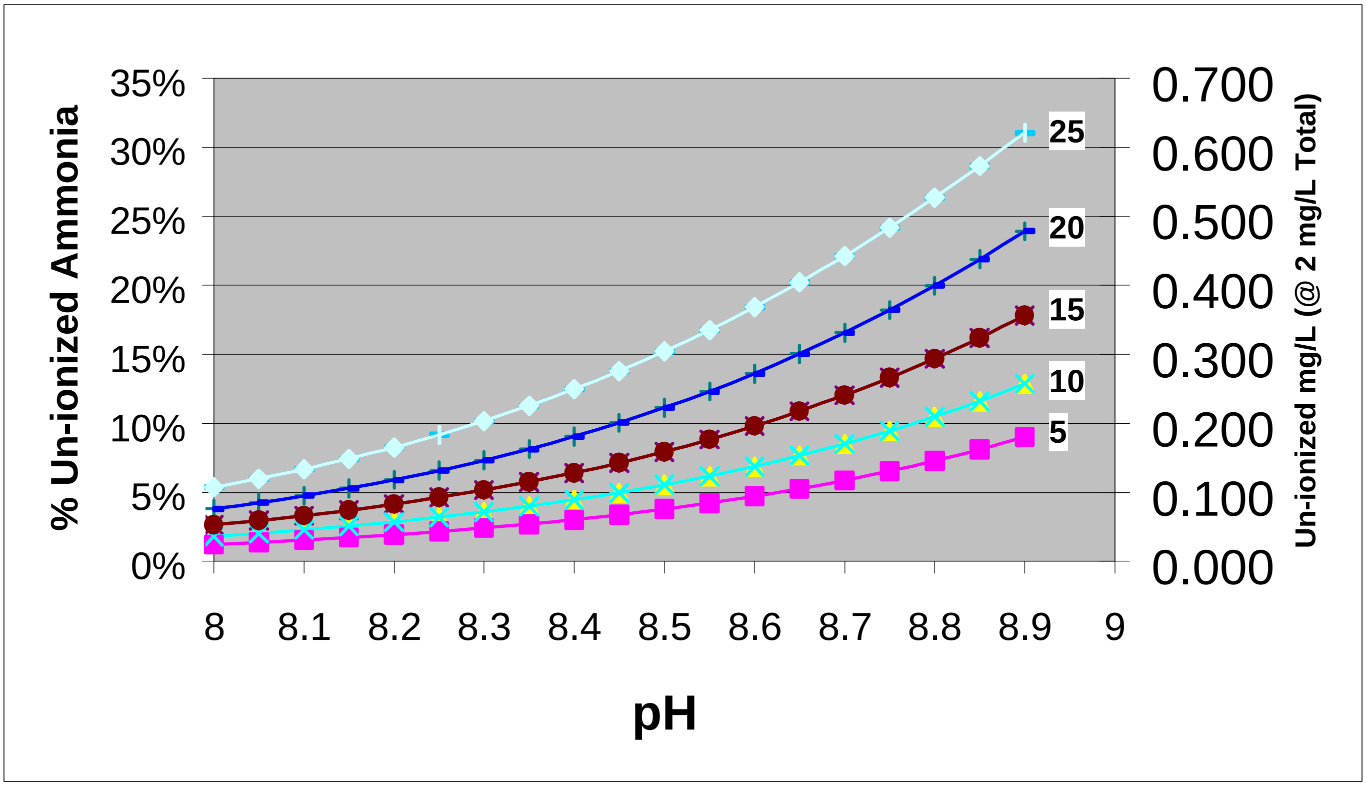
TABLE 3-1
TYPICAL RANGE OF MONITORED PARAMETERS

Parameter	Range of Long Term Monthly Averages 1977-1997	
	Min	Max
Temperature C	1.3	22.8
Dissolved Oxygen mg/l	7.5	12.0
Total Organic Carbon mg/l	14.4	17.9
pH	7.77	8.36
Suspended Solids mg/L	21	243
Turbidity N.T.U.	12	75
Total Phosphorus mg/L	0.24	0.44
Total Kjeldahl Nitrogen mg/L	1.65	2.21
Ammonia mg/L	0.16	0.80
Nitrate Nitrite mg/L	0.15	0.90
Chlorophyll_a	10	40

TABLE 3-2
MONTHLY VARIATION IN PARAMETERS AT ALL STATIONS
1977-1997

Month	Temperature C	pH	Ammonia mg/L	Total Kjeldahl Nitrogen mg/L	Nitrate Nitrite mg/L	Total Phosphorus mg/L	Dissolved Oxygen mg/l	Total Organic Carbon mg/l	Turbidity N.T.U.	Suspended Solids mg/L	Chlorophyll_a
January	1.7	7.86	0.80	2.12	0.45	0.35	9.3	15.7	12	22	15
February	1.8	7.77	0.68	2.08	0.64	0.29	8.6	17.7	23	21	11
March	2.0	7.80	0.51	2.00	0.88	0.29	9.5	15.1	17	40	10
April	7.2	8.07	0.39	2.21	0.90	0.44	9.9	17.3	75	243	24
May	15.3	8.19	0.19	2.05	0.30	0.30	9.2	14.8	65	128	27
June	20.1	8.16	0.20	1.65	0.31	0.28	7.9	15.0	67	116	21
July	22.8	8.19	0.16	1.91	0.32	0.31	7.5	14.4	49	144	22
August	21.3	8.30	0.24	1.83	0.18	0.30	7.6	15.2	43	82	26
September	15.6	8.35	0.28	1.82	0.16	0.28	8.7	16.4	46	61	40
October	8.4	8.32	0.32	1.98	0.26	0.30	10.6	16.2	33	67	35
November	3.4	8.36	0.39	1.68	0.15	0.24	12.0	17.6	27	48	25
December	1.3	8.10	0.47	1.79	0.26	0.33	11.1	17.9	23	42	20
Annual Average	**11.2**	**8.14**	**0.37**	**1.93**	**0.40**	**0.31**	**9.1**	**16.0**	**43**	**88**	**24**



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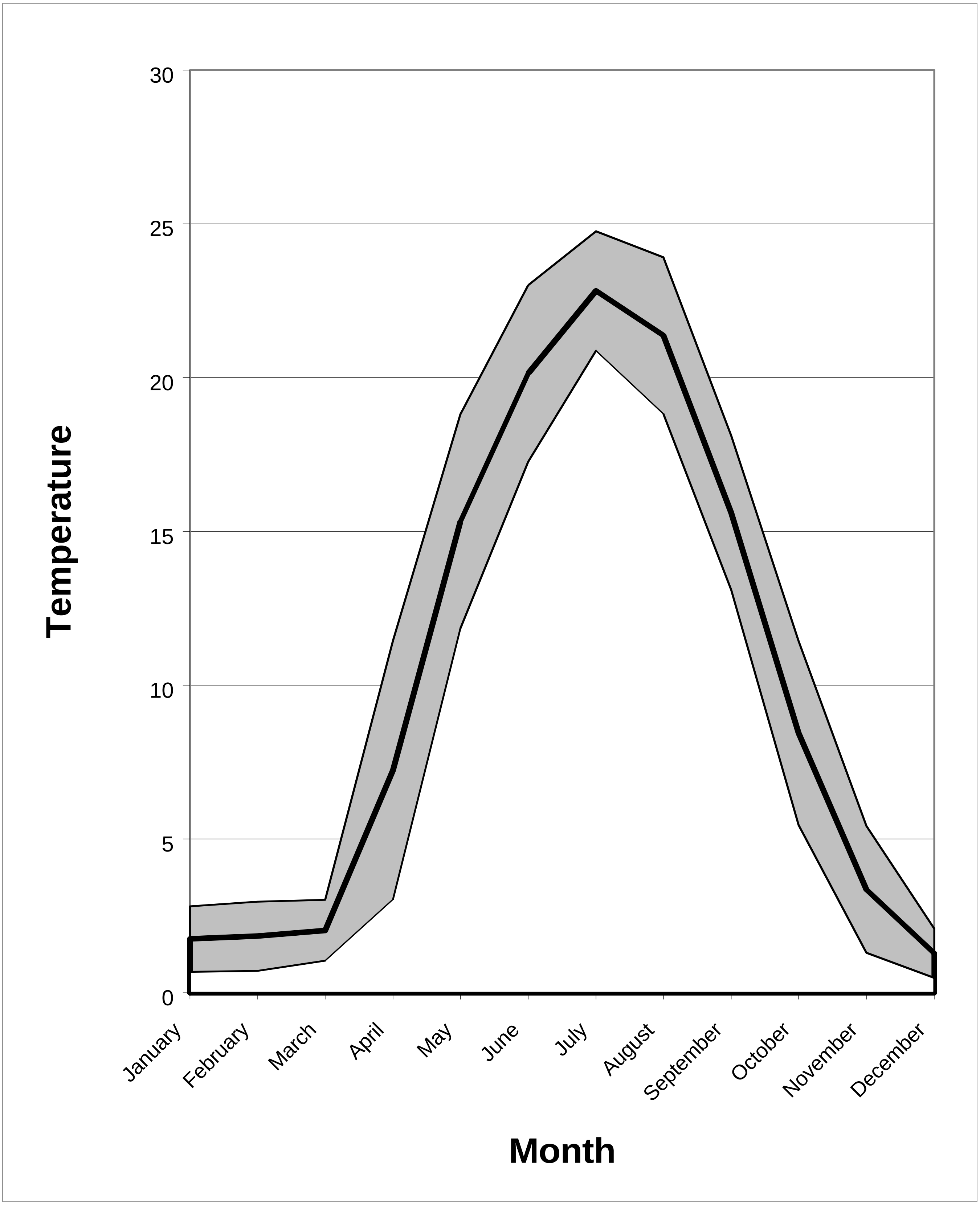
Variation of Un-ionized Ammonia with Temperature and pH
Figure 3-2

temperature. As Figure 3-2 shows, the percent un-ionized ammonia can vary from as little as 1% of the total ammonia when the pH is around 8.0 and the temperature is 5°C. At a temperature of 25°C and a pH of 8.9, over 30% of the ammonia is in the un-ionized state.

In reviewing the variation of parameters for each season, the following comments can be made:

- **Temperatures** vary significantly over the year in the Red and Assiniboine rivers from as low as 1°C to as high as 23°C in July. Although quite variable, the temperature is predictable from year to year, as seen on Figure 3-3. In any given month, the water temperature can be predicted within 4 or 5 degrees.
- **pH** within the Red and Assiniboine rivers vary from a low of 7.8 in February and March to as high as 8.3 to 8.4 from August through November. The standard deviation of the pH within any given month is approximately 0.2 pH units. pH also varies spatially across the region with higher pH values upstream of the City of Winnipeg and the values decreasing as the rivers flow through the heart of the City (i.e., at the Redwood Bridge and North Perimeter Bridge) and then rising slightly again towards Lockport. This indicates the influence of the City discharges such as CSOs and the NEWPCC is to lower pH (see Figures 3-4 and 3-5).
- **Average Ammonia Concentrations** in the region also vary significantly from month to month. The lowest concentrations are generally in the spring and summer months, with the highest concentrations occurring in late fall and winter. Concentrations of ammonia are significantly influenced by the WPCC discharges as well as background conditions. More detailed analysis of the variance of the distribution of ammonia concentrations will be discussed in a later section on long-term modelling (see Section 8.0).
- **Nitrogen Concentrations** are measured in the form of total Kjeldahl nitrogen (TKN) and nitrates. TKN and nitrate are generally higher in the winter and spring months and are reduced over the summer months. These nitrogen species are important as they form a pool of nutrients for algal growth.
- **Total Phosphorus Concentrations** are measured year-round and are generally fairly constant between .25 and .35 often with higher concentrations occurring during the freshet (0.44 mg/L). During low-flow conditions, discharges from the WPCCs can influence phosphorus concentrations immediately downstream of the plant. More discussion on nutrient loadings for both phosphorus and nitrogen will be presented later in Section 5.0.



Temperature Variation by Month
Red & Assiniboine River
(Mean +/- Standard Deviation)
Figure 3-3

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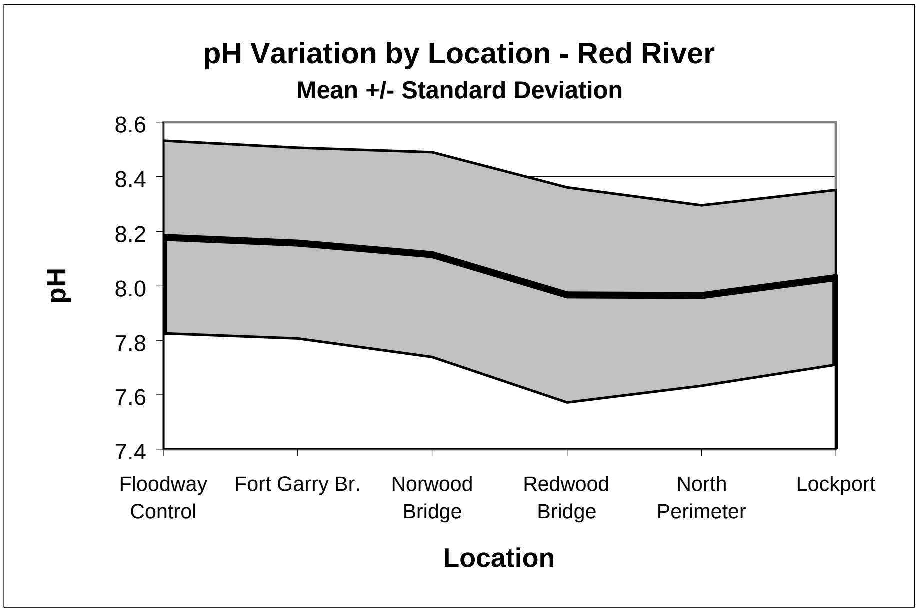

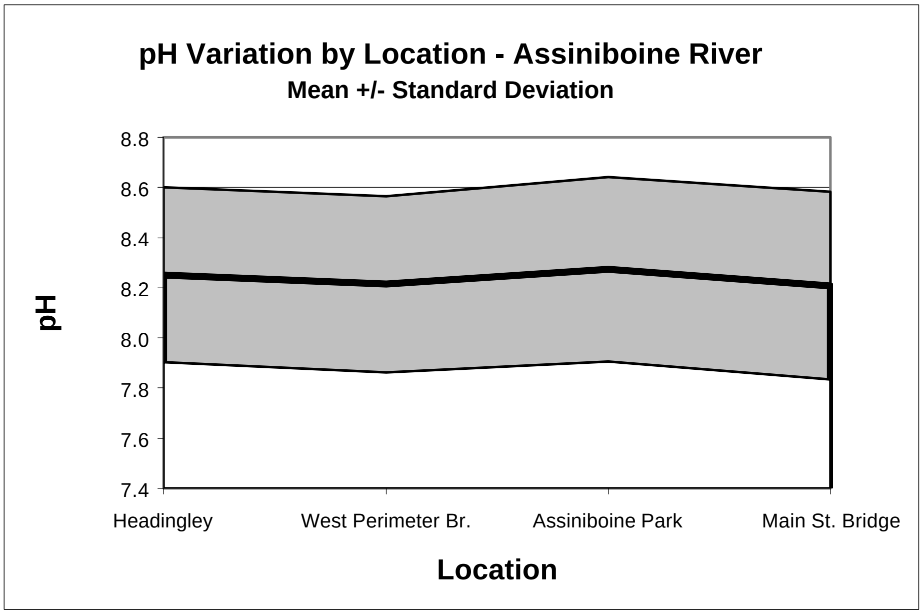

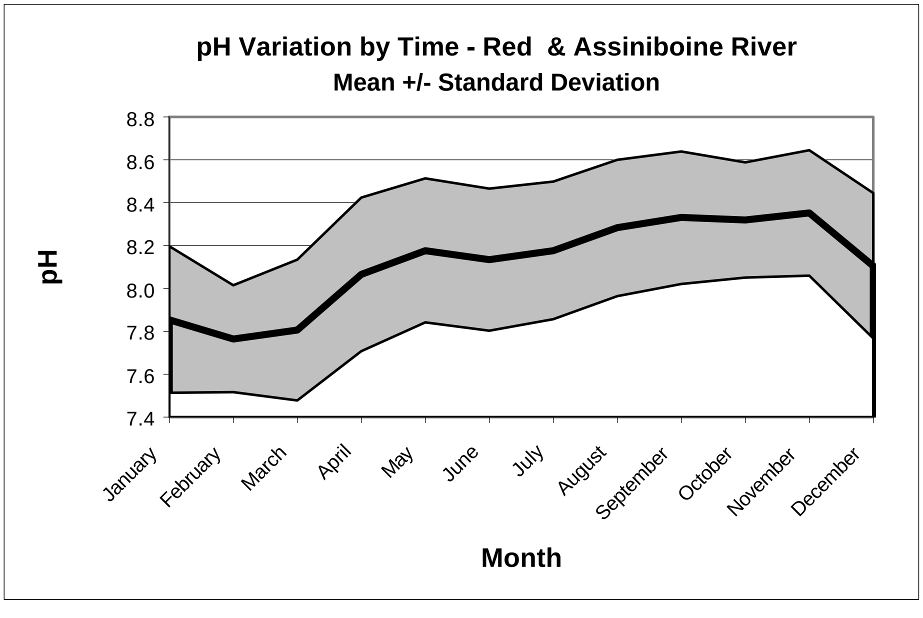

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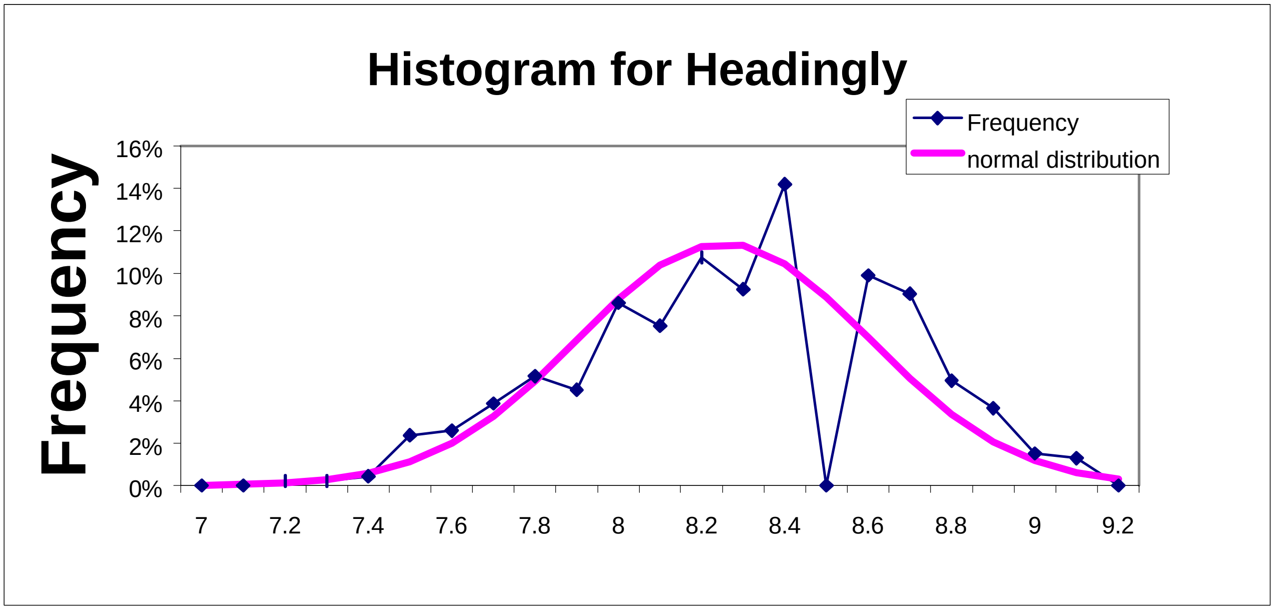
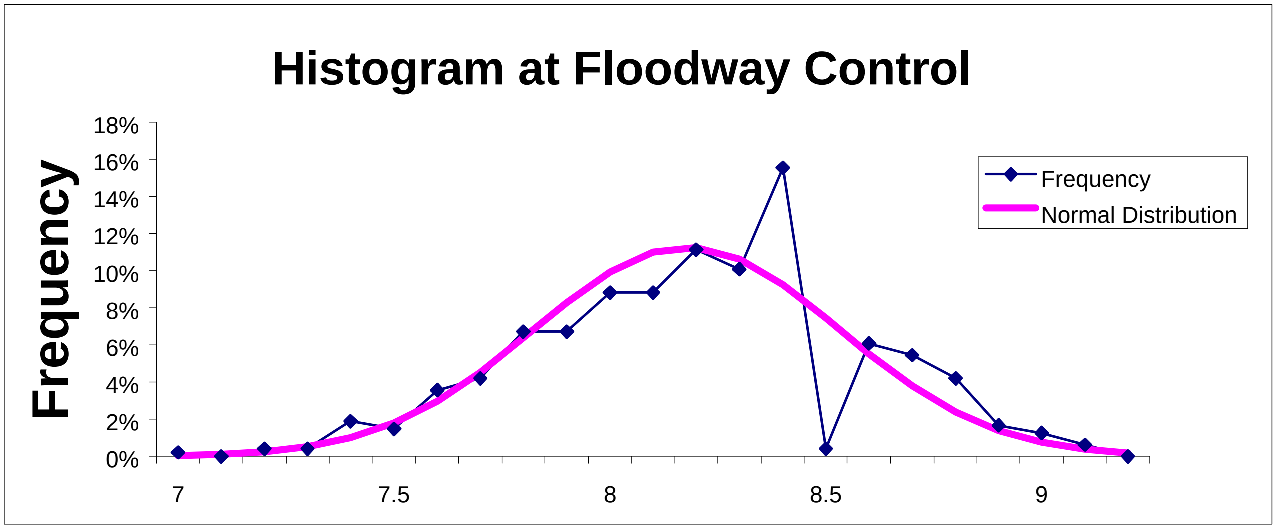
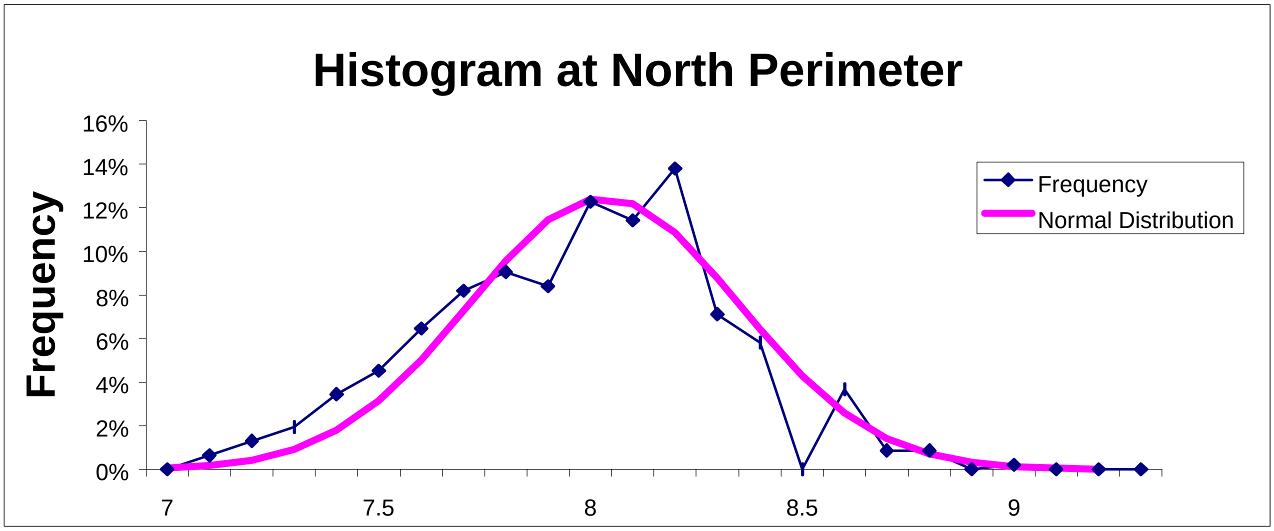
Seasonal and Spatial pH Variance
Figure 3-4







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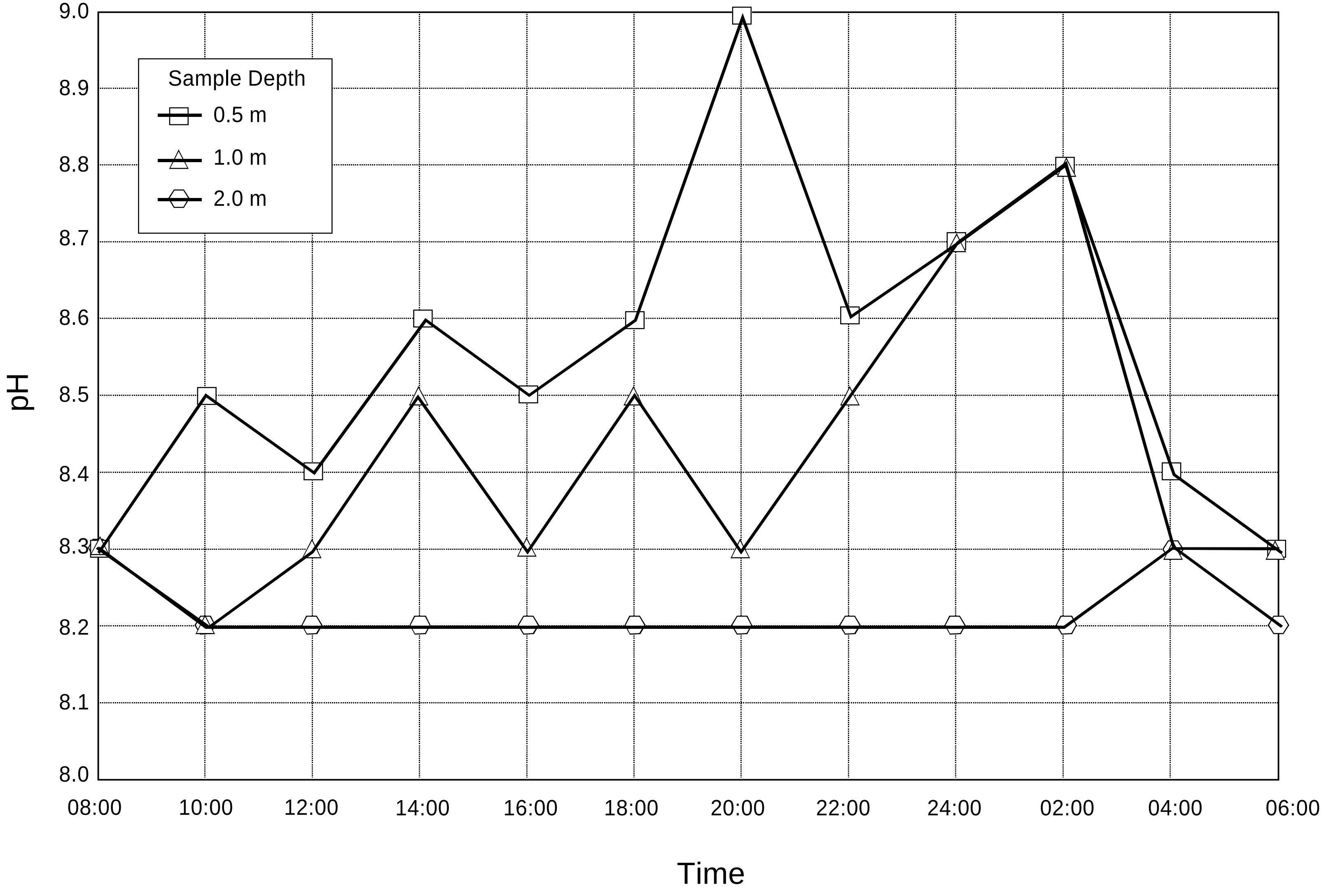
Histograms of pH at Headingley,
Floodway Control and North Perimeter Sites
Figure 3-5

- **Dissolved Oxygen** is generally good within the study area being near or above 8 mg/L year-round. Higher concentrations occur in the late fall and early winter when it is often above 10 mg/L.
- **Total organic carbon** varies between 15 and 18 mg/L. There is no strong seasonal trend for TOC.
- **Turbidity and Suspended Solids** – show a seasonal trend which indicates much higher concentrations occurring in April and then slowly declining through to the fall. The lowest concentrations of suspended solids occur in mid-winter.
- **Chlorophyll 'a'** also shows a seasonal trend in concentrations. Chlorophyll 'a' is a measure of the concentration of algae in the water column. Average concentrations are lowest in mid-winter (January, February, March), begin to rise in the summer, and are highest in the late summer and early fall (40 µg/L). The interaction between chlorophyll, nutrients, and suspended solids was studied in more detail in 1999 and is discussed later in Section 3.4.

3.3 1988 MONITORING PROGRAM

During 1988 the flows were extremely low in the Red and Assiniboine rivers. These flows approached the Q7-10 or conditions which could be critical to setting a criteria for ammonia. At that time the City of Winnipeg conducted a detailed river survey (Hempill and Ross 1989). Because this dataset is extremely valuable in understanding low-flow conditions in the river it was used to calibrate the critical conditions model discussed later in Section 11.0.

One finding in 1988 was that there was a variation in pH and temperature depending upon the depth of the sample (Tetr*ES* 1991). Diurnal and depth variation of pH is shown in Figure 3-6. There were small differences in temperature depending upon the depth, however pH varied more significantly. The pH rose to as high as 9.0 at a depth of 0.5 m while at 2.0 m depth the pH remains constant at 8.2. The algal activity within the photic zone was likely responsible for this increase in pH during the day. During the summer of 1988, the river flow was very low, thus increasing the potential for stratification.



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Diurnal Variation of
pH with Depth in 1988
Figure 3-6

The flow at Lockport during the sample period (August 1988) was in the range of 20 to 25 m^3/s. Hydraulic modelling of the lower Red River (see Section 2) suggests that the river velocity during the sample period was in the range of 0.02 to 0.03 m/s.

3.4 1998 PLUME MIXING MONITORING

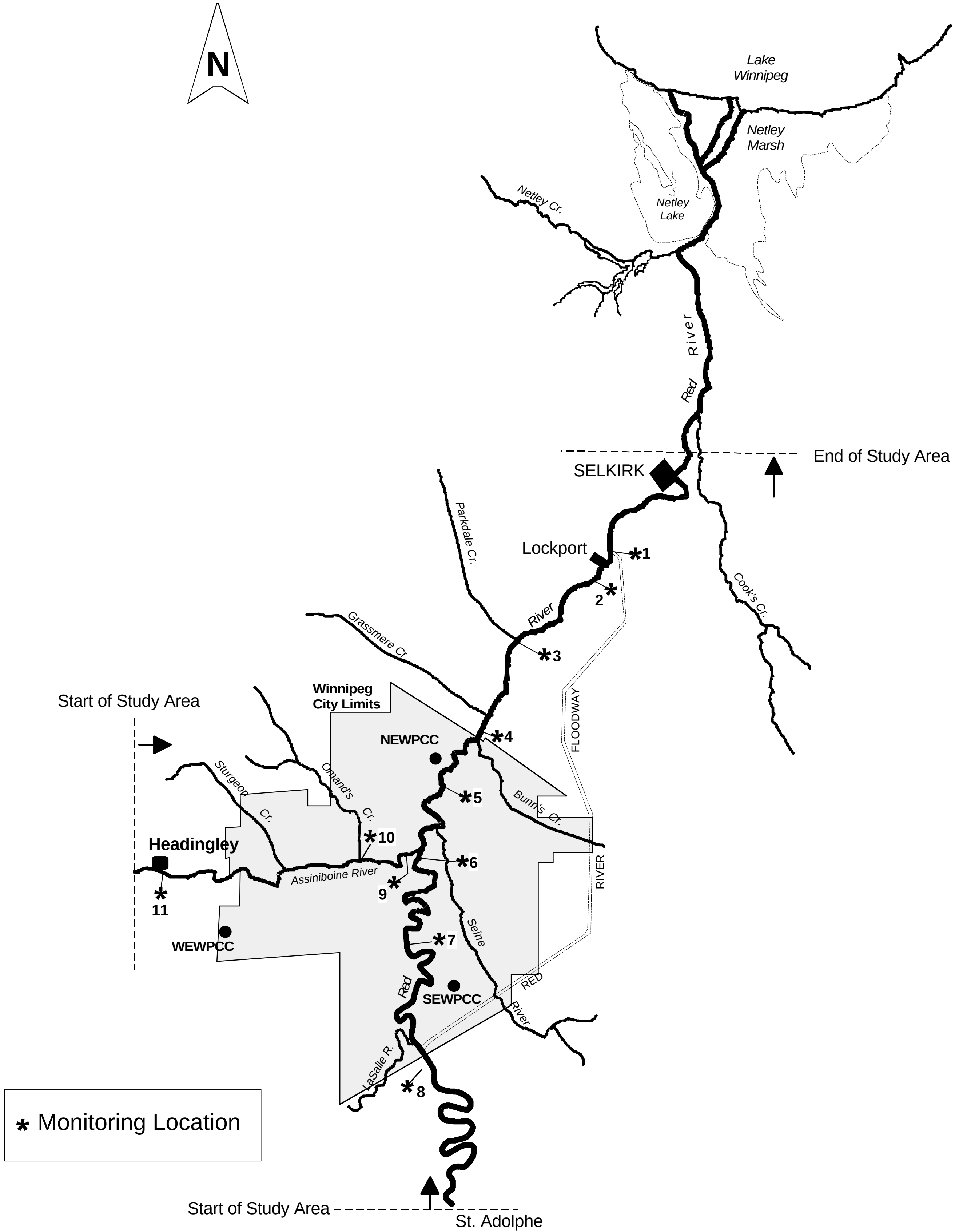
Details of the mixing of the effluent from NEWPCC, SEWPCC and WEWPCC plants with the receiving rivers were monitored in October 1998. This information was thoroughly documented in an earlier Technical Memorandum (Tetr*ES* November 1998). The information was used to verify the near-field water-quality mixing model (CORMIX). Discussion of the use of the CORMIX to understand mixing conditions during the field studies is given in Section 7.0.

3.5 1999 MONITORING PROGRAM

The goal of the 1999 Monitoring Program was to understand the variations in river conditions from early summer through late fall. Specifically, two goals were considered:

- to understand whether the algal community changed significantly as it passed through the City and was influenced by higher ammonia concentrations from the WPCCs; and
- to understand how algae affects key river-water chemistry such as pH which will have an influence on un-ionized ammonia concentrations as described earlier in Figure 3-2.

A sampling program was outlined in an earlier Technical Memorandum (TM on Phase 2 River Monitoring Program) and was conducted at 11 sites, as shown on Figure 3-7, and continued roughly every two or three weeks from early July to early November (see Schedule of River-Water Sampling Activities in Table 3-3). The program went generally as planned, however high river conditions did create some difficulties in obtaining samples downstream of Lockport (due to the locks being out of operation because of high river flows) and higher river velocity than usual making sampling some points on the Assiniboine River more difficult than anticipated. The results are given in Appendix C.



Locations for 1999
Monitoring Program
Figure 3-7

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TABLE 3-3

SCHEDULE OF RIVER WATER SAMPLING ACTIVITIES

SAMPLING EVENT	WEEK OF
Reconnaissance	22 June 99
1	5 July 99
2	19 July 99
3	9 August 99
4	30 August 99
5	13 September 99
6	4 October 99
7	18 October 99
8	1 November 99

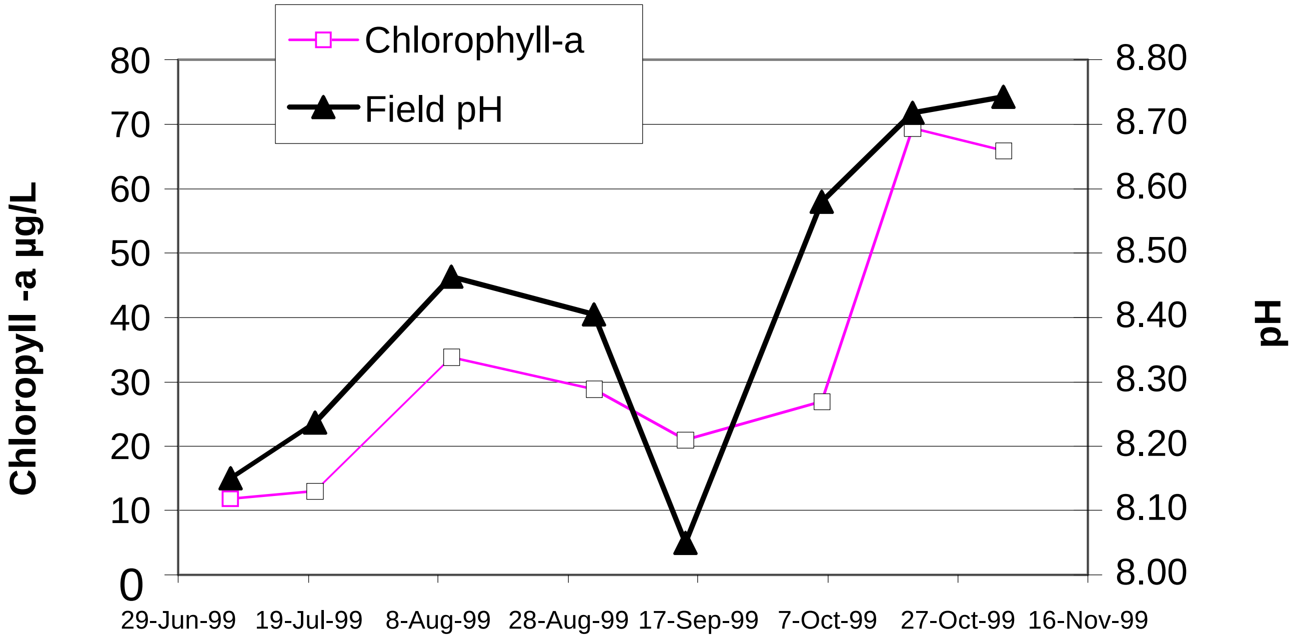
Very high river conditions throughout summer and fall caused ammonia concentrations to be low throughout the study area. These low ammonia concentrations made it impossible to determine whether high ammonia concentrations downstream of the WPCCs would create changes in the species composition of algae.

The results, however, did indicate that algae appears to influence water chemistry by having a direct impact on pH throughout the season. By viewing the variation in pH measured in the field and chlorophyll 'a' from July to November (see Figure 3-8), a general correlation of pH and chlorophyll can be determined. As chlorophyll concentrations in the river rose from about 10 µg/L to over 30 µg/L from early July through to early August, pH similarly rose from 8.15 to 8.45. From August through to September, pH dropped slightly, initially, then dramatically decreased to 8.0. This was during a corresponding drop in chlorophyll 'a' from 35 to 22 µg/L.

In early October through to late October and early November, chlorophyll 'a' concentrations dramatically rose from close to 20 µg/L to near 70 µg/L throughout the region. pH likewise rose dramatically from near 8 to above 8.7.

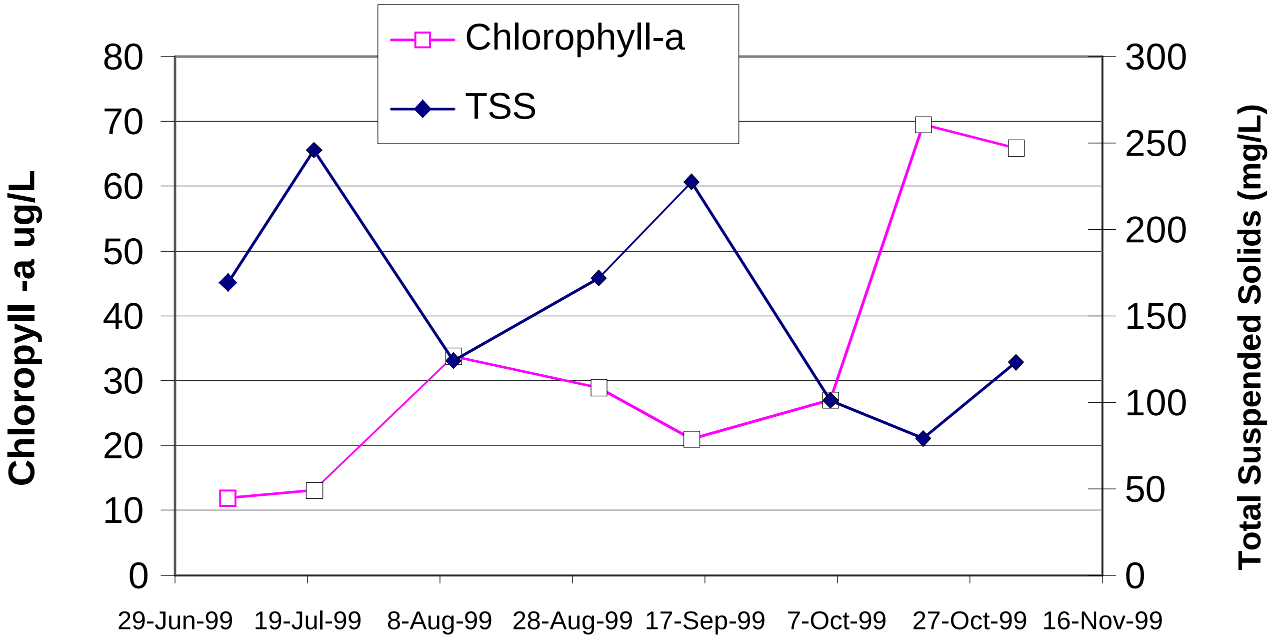
The concentration of chlorophyll 'a' appears to be inversely correlated to the concentration of total suspended solids (TSS). While TSS concentrations remained high in July, algal concentrations (as measured by chlorophyll 'a') remained relatively constant near 10 µg/L (see Figure 3-9). As TSS concentrations dropped from over 200 to close to 100 by early August, there was a corresponding increase in chlorophyll 'a' from 10 to 30 µg/L. As the flows in the river increased, TSS continued to increase through to mid-September. During this time, chlorophyll 'a' concentrations steadily declined back to 20 µg/L. However, as flow decreased from late September through to the end of November, TSS concentrations dropped to below 100 µg/L. As the TSS concentrations dropped there was an increase in the availability of light in the water column thus allowing for more algal growth. This growth is shown on Figure 3-9 in which chlorophyll 'a' concentrations increased to as high as 70 µg/L in October and November. This analysis indicates that during 1999 light rather than nutrients was the limiting factor in controlling algal growth.

One of the key analysis done in 1999 was to quantify the mass of algae by species. Figure 3-10 shows a plot of both algae as measured by mass in mg/L and by chlorophyll 'a' in µg/L. Figure



pH and Chlorophyll-a Trends in 1999

Figure 3-8



Total Suspended Solids and Chlorophyll-a Trends in 1999

Figure 3-9

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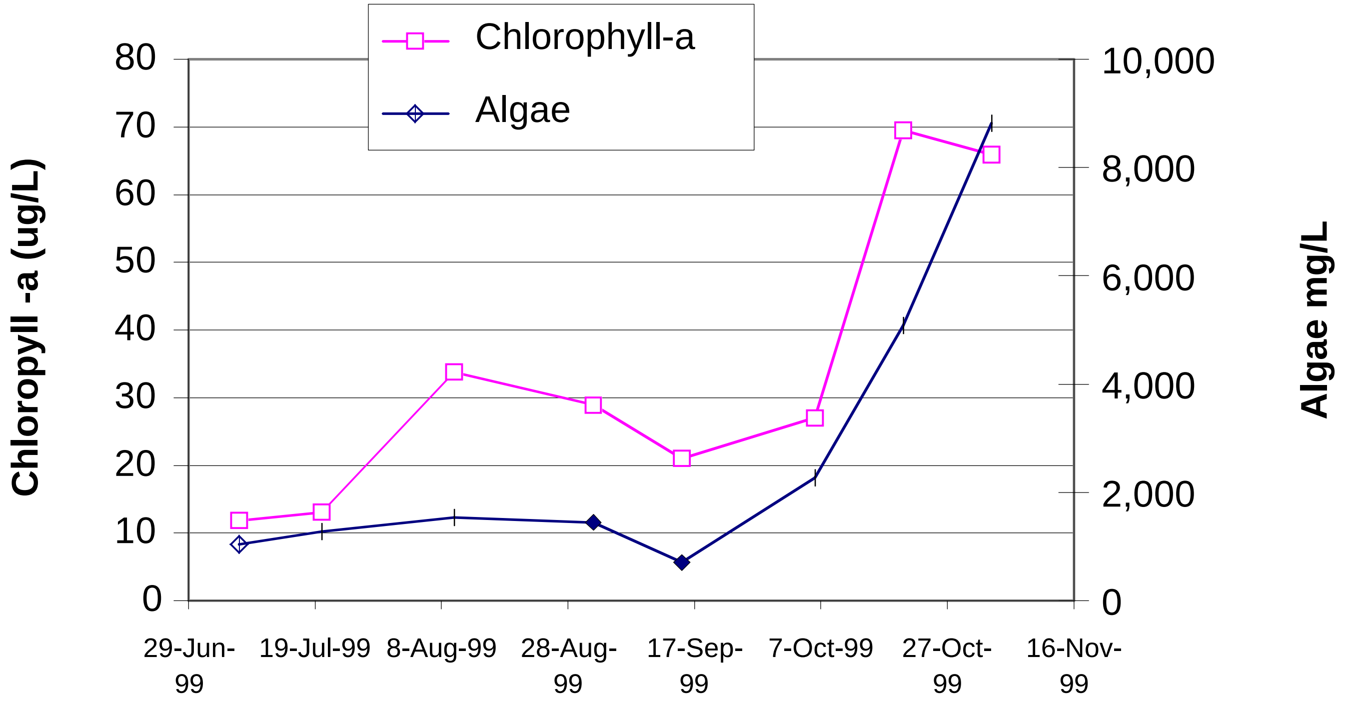
3-10 shows generally good correlation between the two measurement techniques. This indicates confidence in the methods used to determine the relative mass of each species of algae. Figure 3-11 indicates the changes in algae by selected species groups. Throughout most of the year the mass of algae remained relatively constant. In early October, there was a slight increase in the amount of cyanobacteria, which rose to over 1,000 mg/L. However, the large increase in total algae which occurred in late October and early November was due to diatoms which made up approximately 80% of the total mass of algae in the river at that time (see Figure 3-11). Recommended locations for routine monitoring of algae speciation are shown in Figure 3-12. Monitoring should occur biweekly from April through November.

An assessment of 1999 monitoring data was done by determining if there was any significant correlations between key parameters. The key findings are presented below.

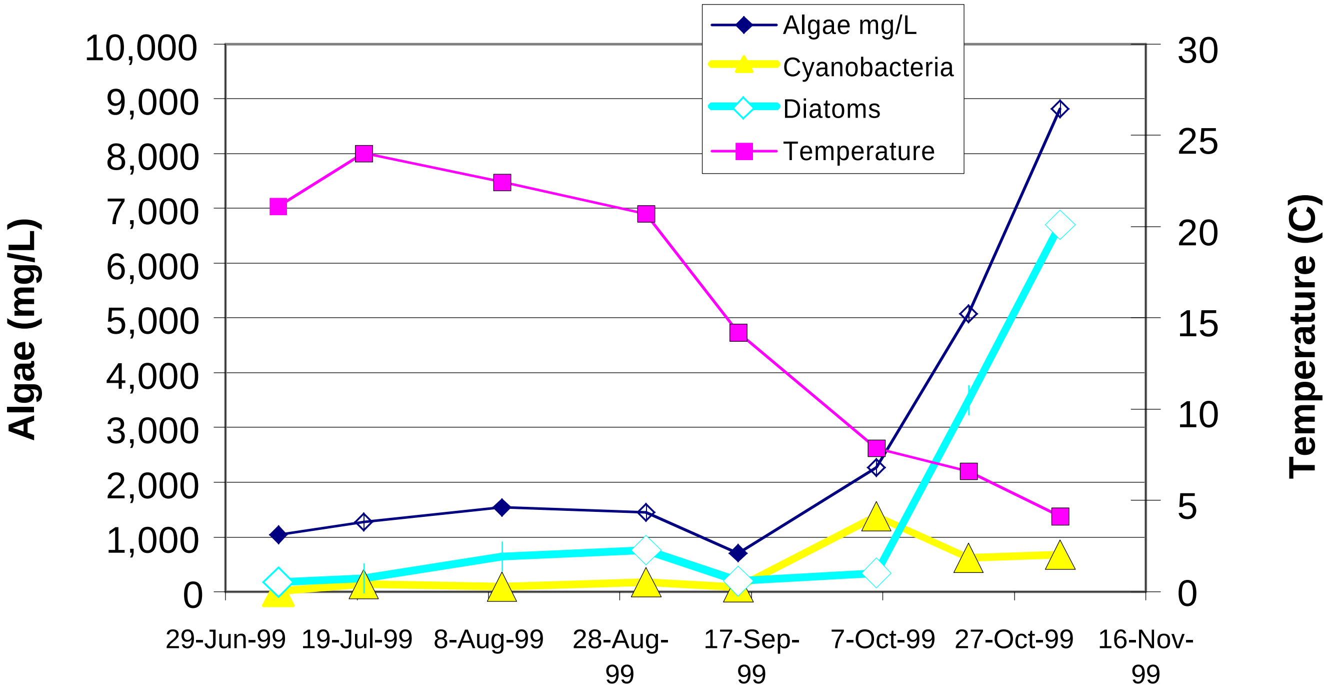
Algae Influence on pH

Field pH values sampled over the 1999 monitoring season were plotted against algae as measured by chlorophyll ‘a’ concentrations and a regression analysis was performed (see Figure 3-13). The results indicated a strong correlation ($r^2 = 0.76$) between log of chlorophyll ‘a’ concentrations and pH. This relationship is generally expected as algae will consume carbon dioxide during photosynthesis thus increasing the pH. This strength of this correlation was remarkable and indicates that increased algal growth can raise the pH from 8 to 8.9 over the period of one summer. As indicated earlier, pH is very important in its direct influence on the concentrations of un-ionized ammonia. The correlation between alkalinity and field pH was also investigated and as was expected, there is a positive correlation between the two. The strength of the correlation ($r^2 = 0.44$) however was not as strong as that indicated between chlorophyll ‘a’ and pH (see Figure 3-14).

In order to determine the causes of increased algal growth throughout the year various correlations between nitrogen species, phosphorus species, and light and chlorophyll ‘a’ concentrations were investigated.



Chlorophyll-a and Algae Concentration Trends in 1999
Figure 3-10



Temperature and Algae Concentration Trends in 1999
Figure 3-11

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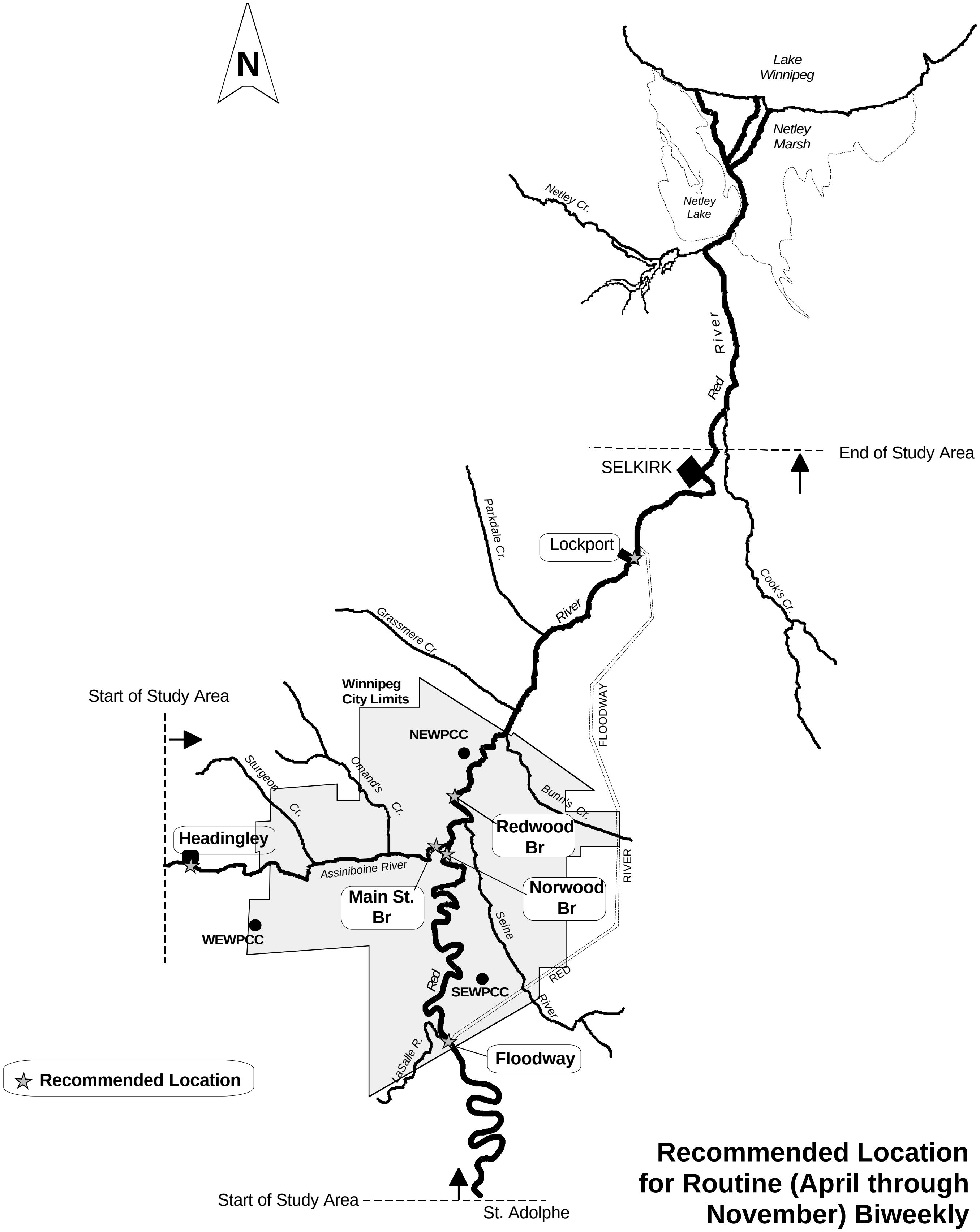

Recommended Location for Routine (April through November) Biweekly Algae Speciation

Figure 3-12

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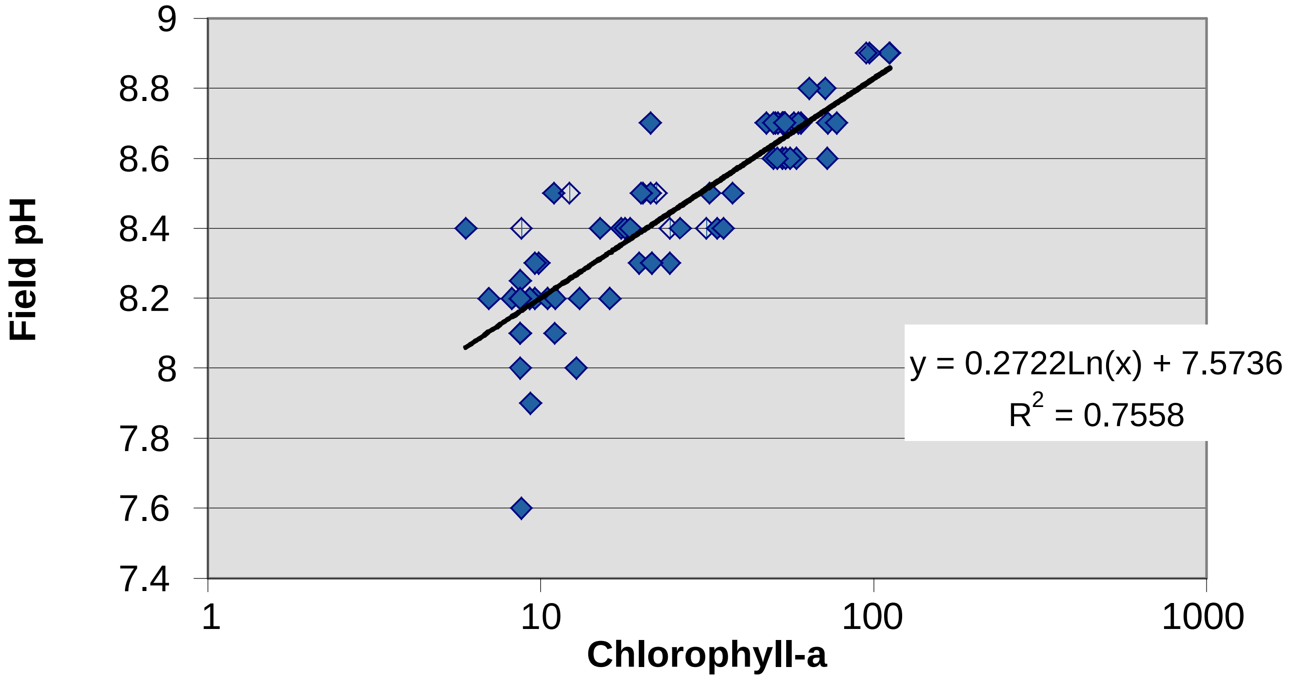
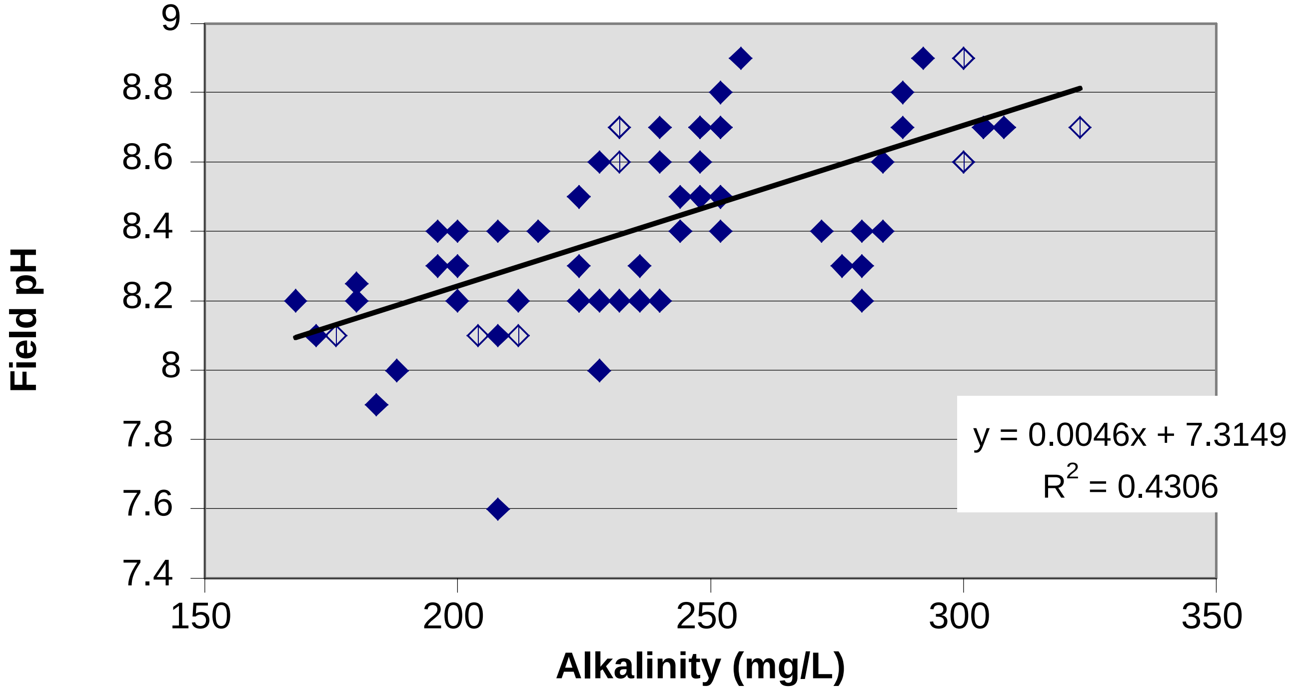


1999 Monitoring
Chlorophyll-a vs. pH
Figure 3-13



1999 Monitoring
Alkalinity vs. pH
Figure 3-14

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Nitrogen, Ammonia and Nitrate versus Chlorophyll ‘a’

The relationship between total nitrogen and chlorophyll ‘a’ was investigated (see Figure 3-15) and it showed a positive, although weak, correlation (r^2 = 0.1). The concentration of total nitrogen was likely not a key factor in algae concentrations throughout 1999. A similar assessment was done of ammonia as N versus chlorophyll ‘a’ (see Figure 3-16). Again the correlation although positive was very weak (r^2 = 0.02). The concentrations of nitrate and chlorophyll ‘a’ showed a negative correlation (see Figure 3-17). The correlation is quite strong (r^2 = 0.53) indicating that as algae concentrations increase, nitrate is consumed. Nitrate was definitely not limiting in 1999.

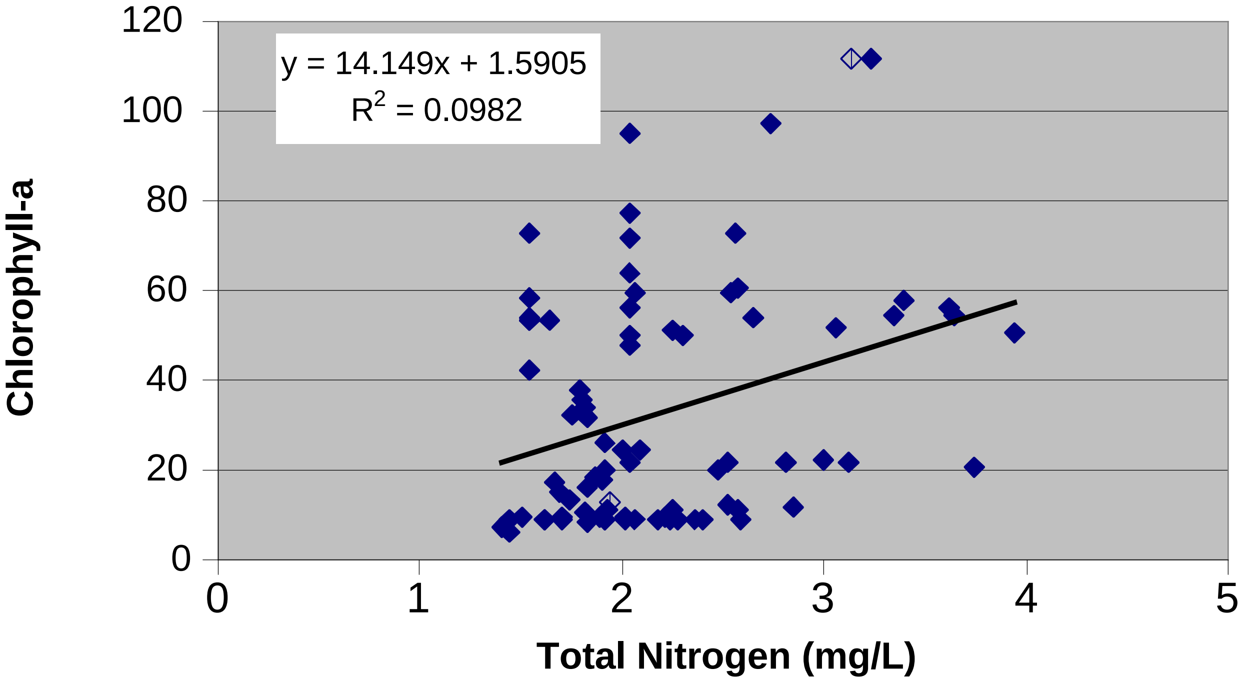
A similar correlation was done between the total of ammonia and nitrate. Similar results indicated a negative correlation between this total and chlorophyll ‘a’ indicating that the total of ammonia and nitrate as a nutrient was not limiting to algal growth (see Figure 3-18).

Phosphorus versus Chlorophyll ‘a’

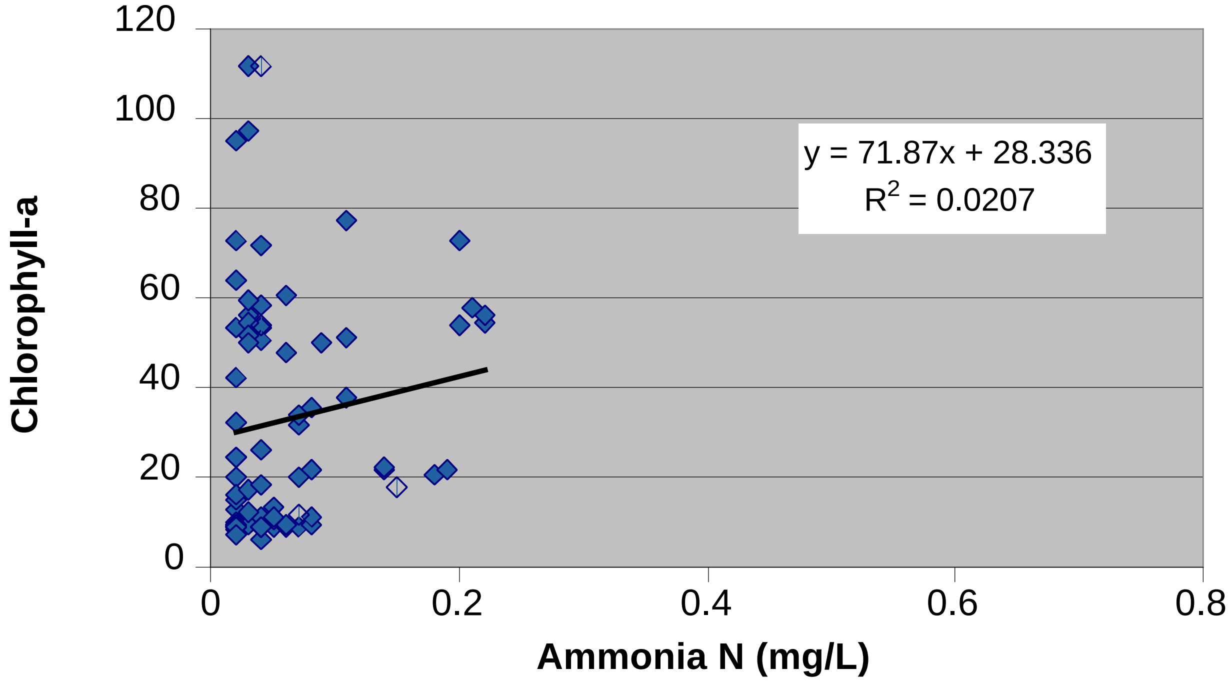
Total phosphorus versus chlorophyll ‘a’ showed almost no trend and the correlation was extremely weak (r^2 = 0.007), see Figure 3-19. The correlation between orthophosphate as P and chlorophyll ‘a’ showed a negative trend (see Figure 3-20). This indicates that orthophosphate was not limiting however was being consumed by chlorophyll ‘a’ therefore reducing in concentration as algae increased.

Influence of Light on Algal Growth

During the course of the 1999 river conditions field-monitoring program, light conditions were recorded at each sampling location. A light meter was used to simultaneously take light readings at the surface and at depths starting at the surface and moving down in increments of 0.1 metres. The percentage of light penetrating to each depth was calculated and a mathematical model of light attenuation was developed to represent the changing light conditions with depth. An example of how each model was calibrated for the conditions taken at each site on each date is shown on Figure 3-21. The light extinction coefficient for each sample was calibrated using data collected and is shown in Appendix C. Also calculated was the depth to which only 1% of the light penetrated. The amount of light on average to which the algae is



1999 Monitoring
Total Nitrogen vs. Chlorophyll-a
Figure 3-15



1999 Monitoring
Ammonia vs. Chlorophyll-a
Figure 3-16

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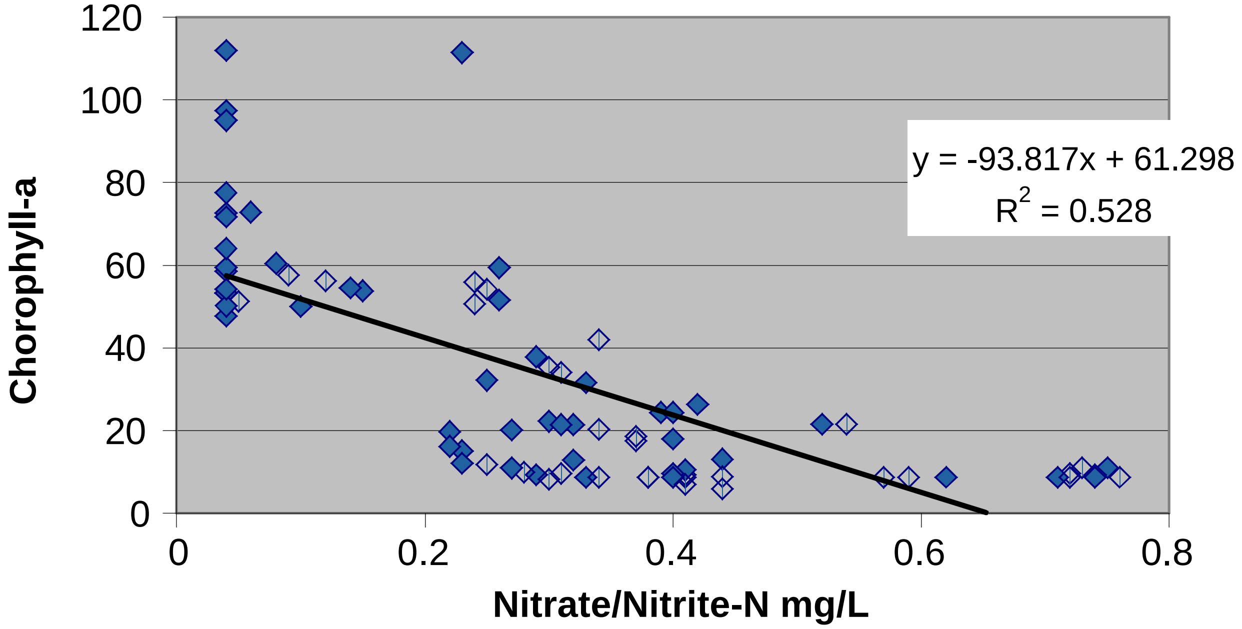
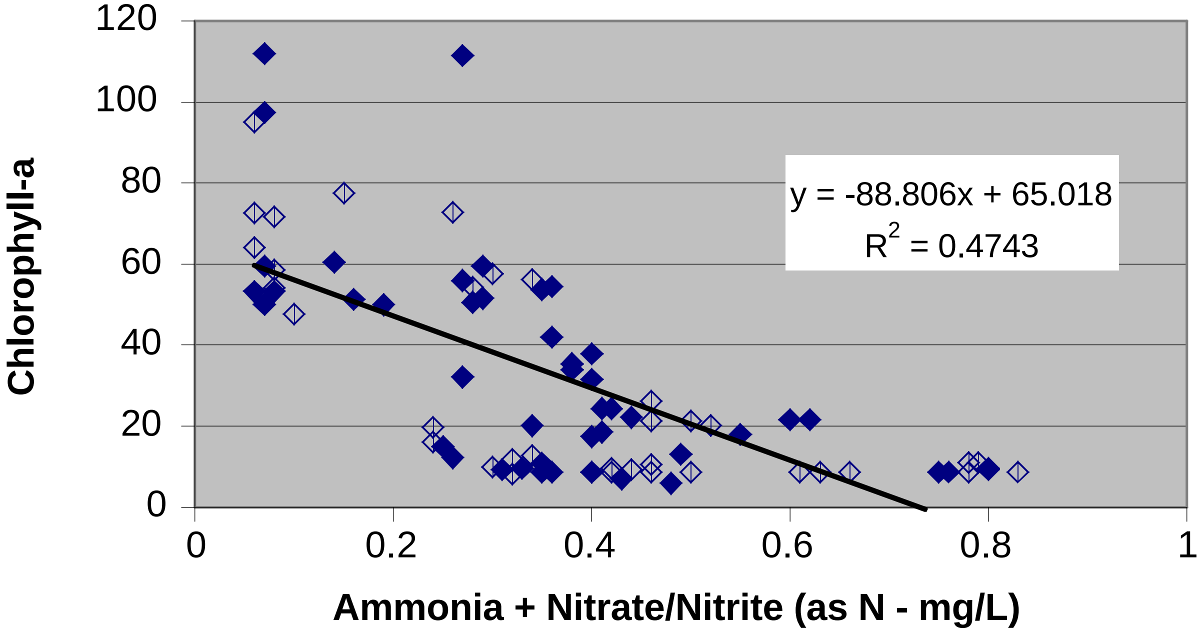


1999 Monitoring
Nitrate/Nitrite vs. Chlorophyll-a
Figure 3-17



1999 Monitoring
Ammonia plus Nitrate/Nitrite vs. Chlorophyll-a
Figure 3-18

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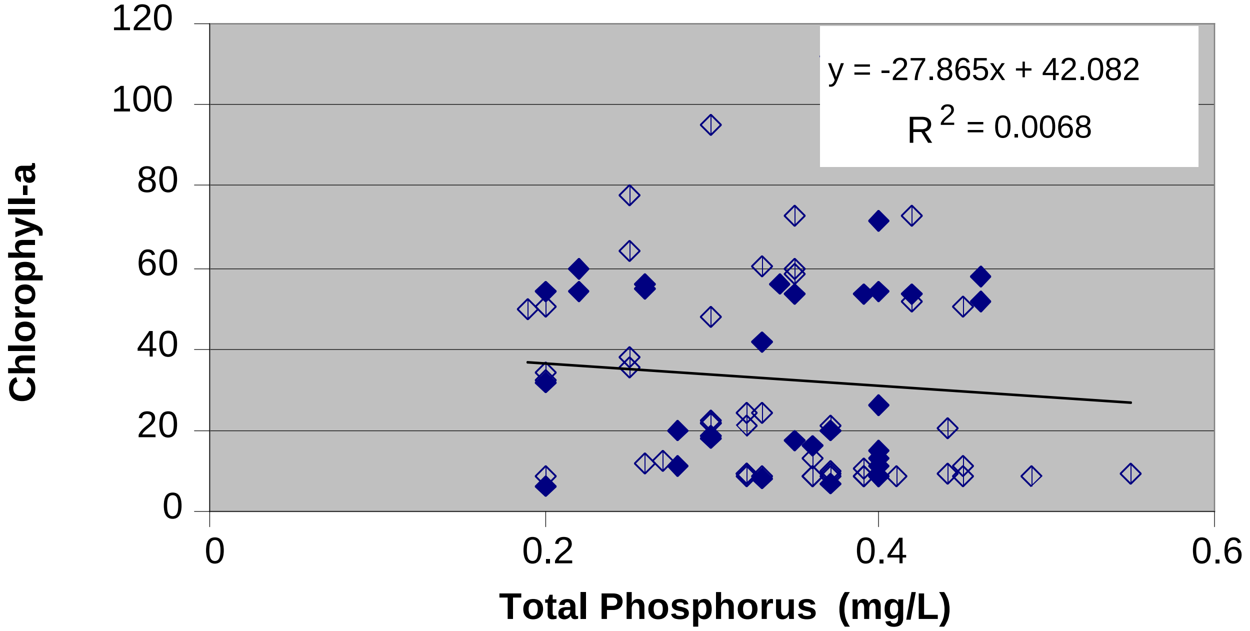
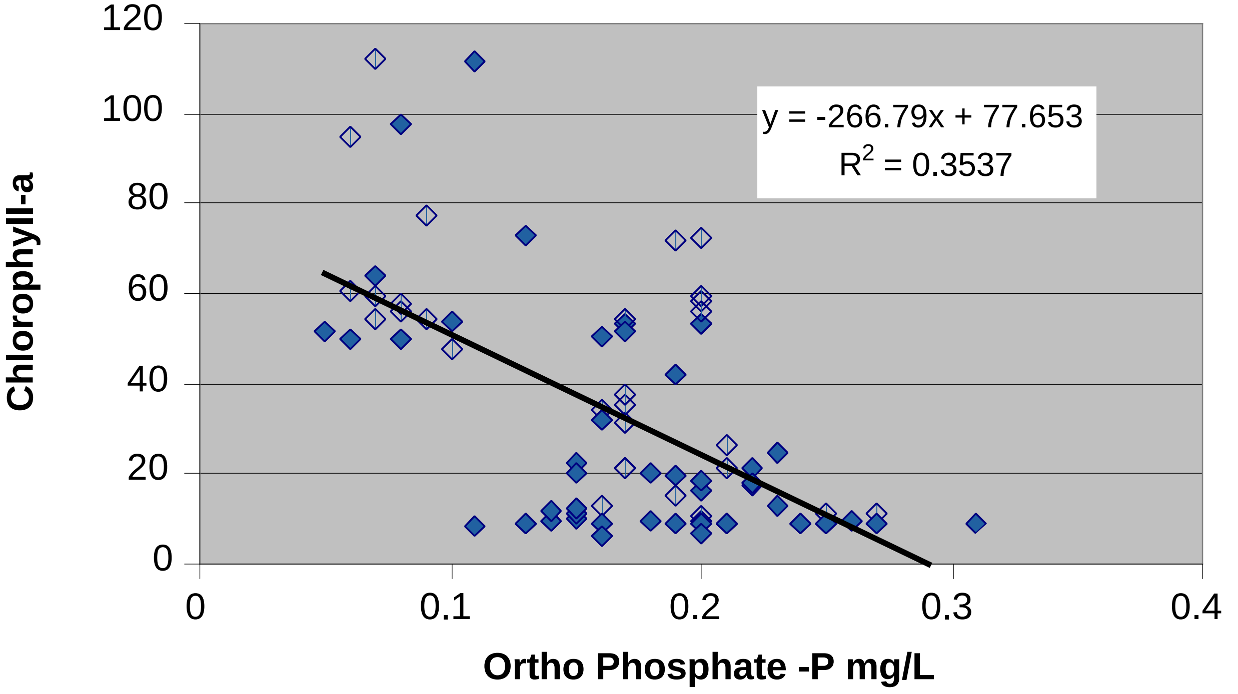


1999 Monitoring
Total Phosphorus vs. Chlorophyll-a
Figure 3-19



1999 Monitoring
Ortho-phosphate vs. Chlorophyll-a
Figure 3-20

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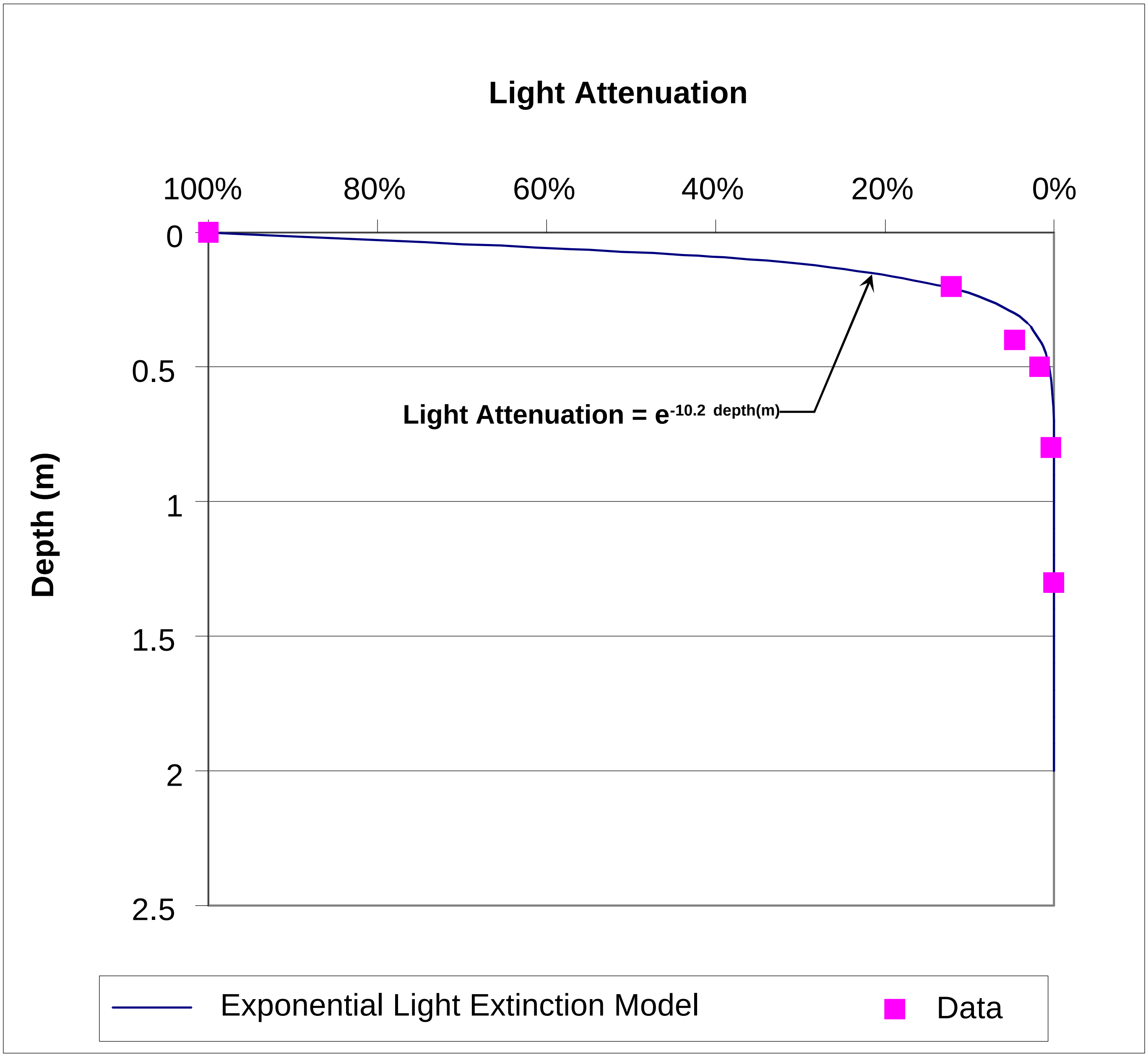

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Calibration of Light Attenuation Model
(August 10, 1999 at Parkdale Site [#3])
Figure 3-21

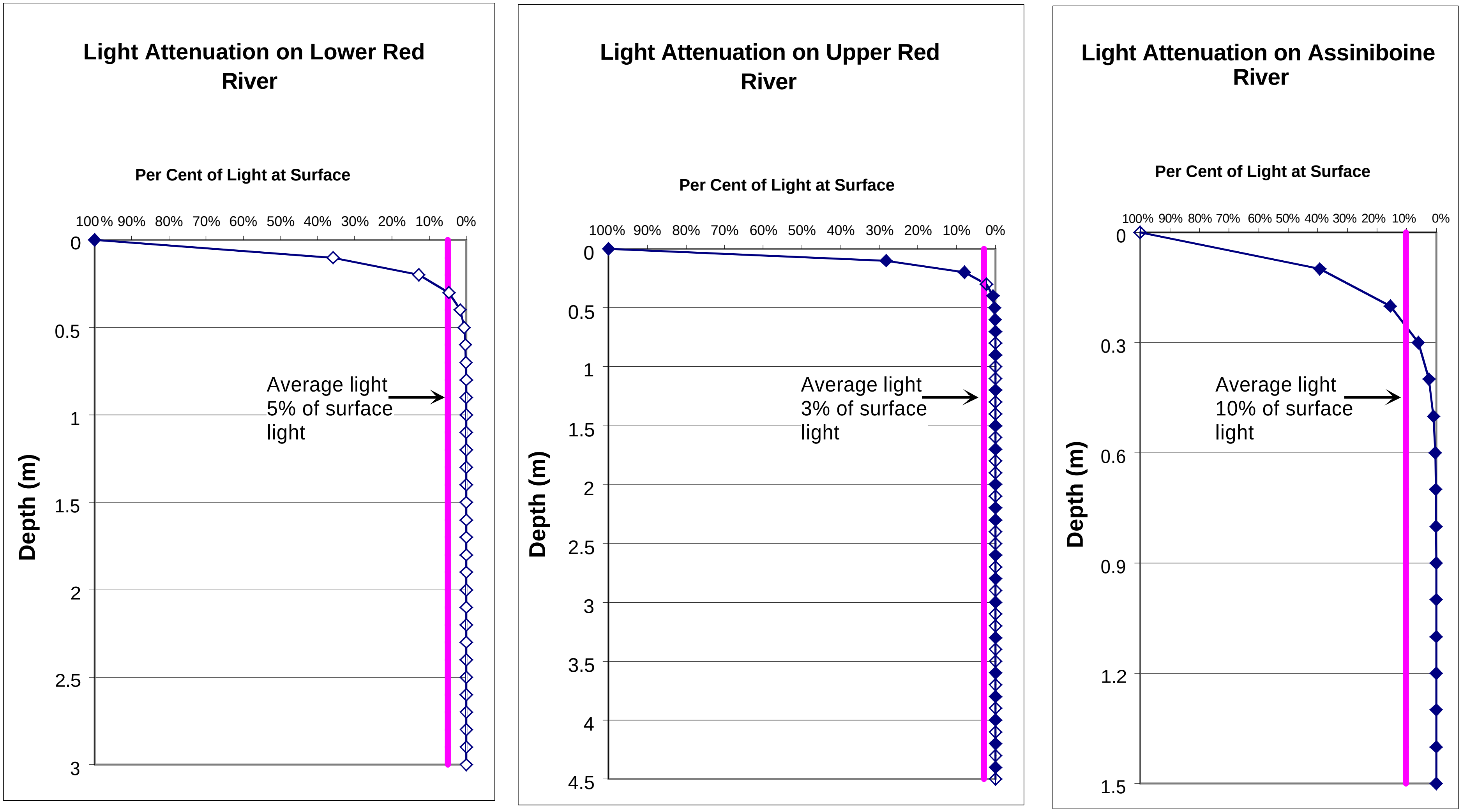
exposed to depends upon the light attenuation and the depth of the river. For example, a shallower river would have a greater percentage of its water column exposed to light than a deeper river with the same light attenuation coefficient.

The typical depth in three difference sections of the rivers in the study area was estimated using results of the hydraulic analysis described in Section 2.0. During 1999, the typical depth in the lower Red River (north of The Forks) was 3 metres, the upper Red River was 4.5 metres, and the Assiniboine River was 1.5 metres. Typical depths were used rather than a depth at a specific sample site since the average conditions the algae are exposed to varies as a water column moves downstream.

The average extinction coefficient in each of these reaches was calculated over the 1999 monitoring period and the light extinction equation was used to plot the graphs shown in Figure 3-22. It should be noted that each of the vertical scales on the graph are different. These graphs do illustrate how the average exposure to light within the water column varies in each of the reaches of the river. In the lower Red River the average light exposure to water column is about 5% of the surface light conditions, in the upper Red River the average light exposure was only 3%, while in the Assiniboine River the average light exposure was 10%. Table 3-4 summarizes the typical light conditions on the Red and Assiniboine rivers in 1999.

In order to determine whether average light conditions are correlated to chlorophyll ‘a’ concentrations in the river, the average light condition was calculated for each sample station and monitoring date. An assessment of average light conditions versus chlorophyll ‘a’ is shown in Figure 3-23. The correlation shows a fairly strong ($r^2 = 0.54$) positive correlation between average light in the water column as a percent of surface concentration of light and chlorophyll ‘a’ concentrations. This indicates that light was likely the limiting factor in algal growth in 1999.

In order to compare conditions in 1999 (high flows) to average conditions and low-flow conditions a correlation between a commonly-measured factor and the light extinction coefficient is required. A regression analysis for suspended solids versus the light-extinction coefficient is shown on Figure 3-24. The correlation ($r^2 = 0.66$) between these two parameters was fairly strong. This indicates that the light extinction coefficient can be predicted for other conditions in which suspended solids concentrations are known. Suspended solids are part of



Light Attenuation on Lower Red River

Light Attenuation on Upper Red River

Light Attenuation on Assiniboine River

Note: Depth scales are different

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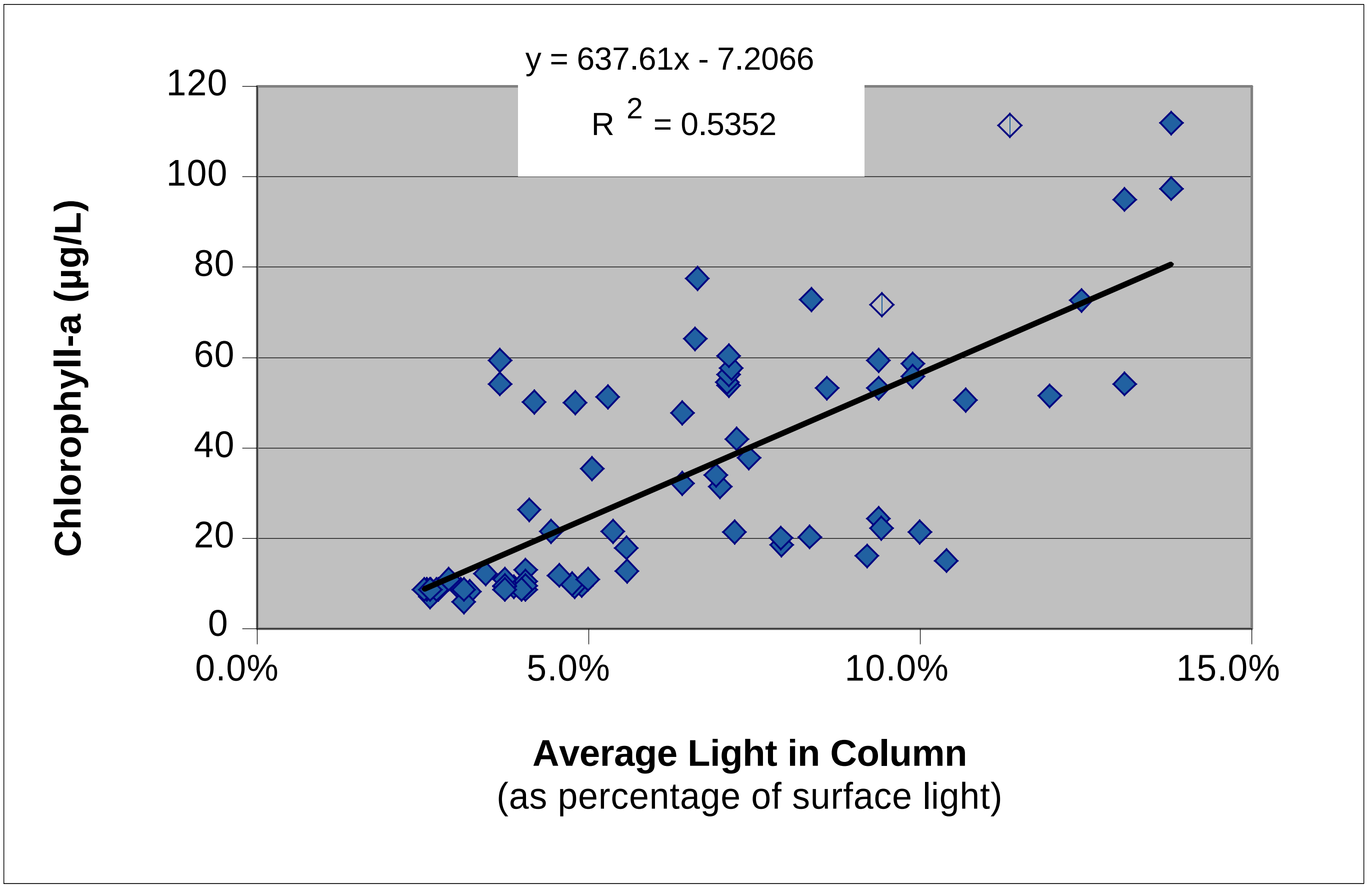
Light Attenuation at Various Depths

Figure 3-22

TABLE 3-4

TYPICAL LIGHT CONDITIONS IN THE RED AND ASSINIBOINE RIVERS IN 1999

ROUTINE	TYPICAL DEPTH (1999)	AVERAGE LIGHT EXTINCTION COEFFICIENT	AVERAGE LIGHT EXPOSURE IN WATER COLUMN
Lower Red	3 m	10.28	5.9%
Upper Red	4.5 m	12.6	2.9%
Assiniboine River	1.5 m	9.3	10.6%



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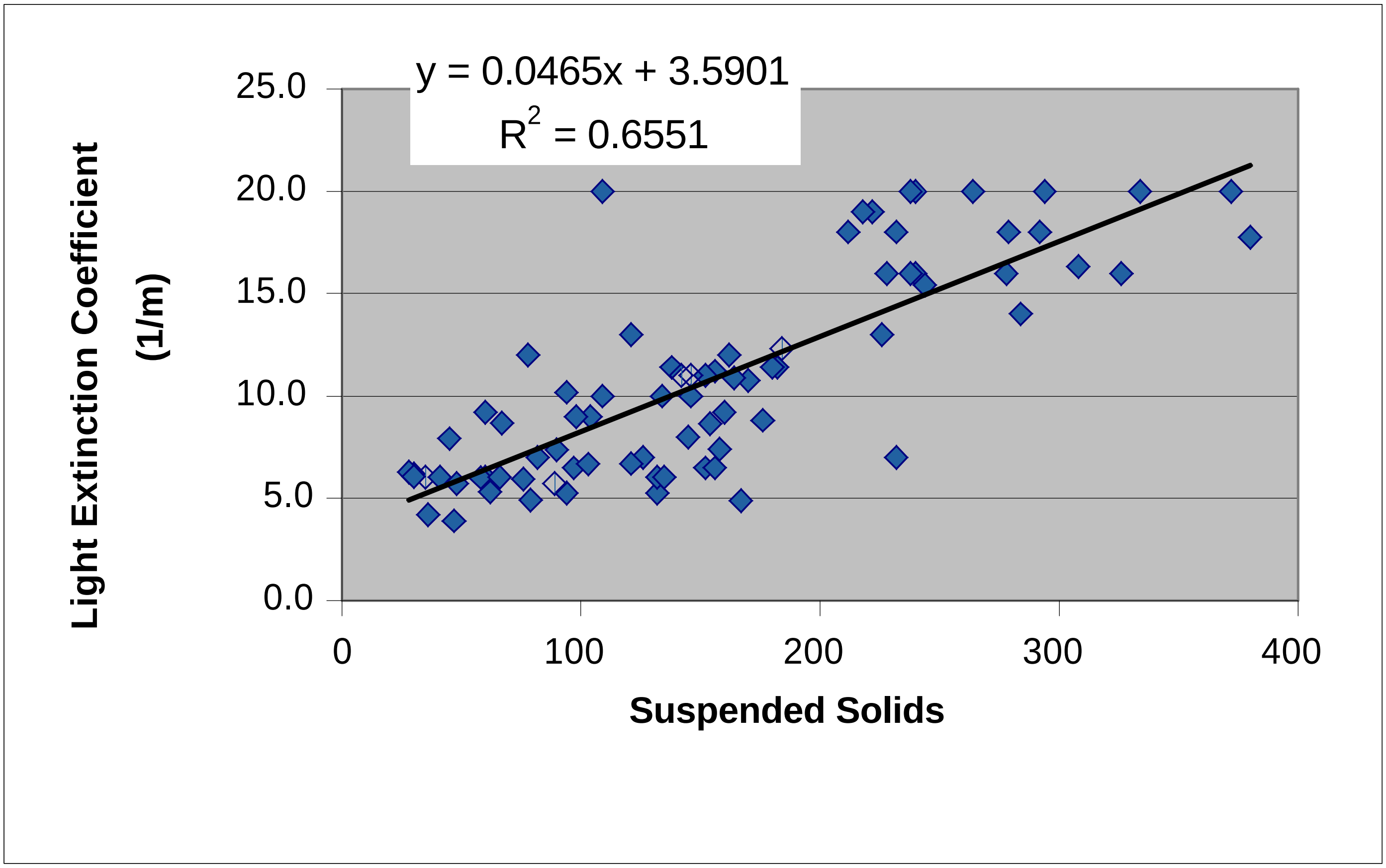
1999 Monitoring
Average Light Conditions vs. Chlorophyll-a
Figure 3-23

the bi-weekly monitoring program collected over the past 20 years therefore information is available for a range of conditions.

The 1999 river conditions were compared to average river conditions and river conditions during a low-flow period from 1988 to 1991. The suspended solids for each period were determined by reviewing monitoring records for the lower Red River (at Lockport), upper Red River (at the Floodway control), and the Assiniboine River (at Headingley). Using the average suspended solids, a light extinction coefficient was estimated using the regression equation developed in Figure 3-24. The river depth during the monitored period was estimated using the MIKE11 model results depicted in Figures 2-16 and 2-18 and described in Section 2.0. Using these assumptions, the average light exposure in the water column as a percentage of surface light conditions was estimated as shown on Table 3-5. The key points which can be made from this table are:

- the average light exposure in the water column in the lower Red River is not sensitive to changing river conditions, remaining at an average of about 5% to 7% of the surface light concentration;
- on the upper Red River, the light exposure in the water column would triple from the 1999 high-flow conditions (2.9% of surface light) to low-flow conditions experienced in the late 1980s and early 1990s (7.5% of surface light);
- on the Assiniboine River, the changes in light conditions in the water column are very sensitive to changes in river conditions. In 1999 the average light exposure would be calculated at only 10.6% of the surface light concentration. In an average year, light concentration would be as high as 20% of the surface light concentration, and in a low-flow year when the suspended solids are low and the river depth is at 0.5 metres, the average light exposure in the water column would be as high as 46% of the surface light concentration.

This indicates that if light is the limiting factor as shown in 1999 monitoring analysis discussed previously, then algal concentrations on the Assiniboine River could be expected to be much higher in low-flow conditions. Algal dynamics however are complex and another factor may become limiting. If light conditions in the river are such that light is not limiting, then either ammonia and nitrate or phosphorus may become a limiting factor.



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1999 Monitoring
Suspended Solids vs. Light Extinction Coefficient
Figure 3-24

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TABLE 3-5
VARIATIONS IN WATER COLUMN EXPOSURE TO LIGHT DUE TO CHANGING RIVER CONDITIONS

A) LOWER RED

Period	River Flow	Suspended Solids (mg/L)	Estimated Light Extinction Coefficient	Depth (m)	Average Light Exposure in Water Column
1999 (July to October)	High	130	9.6	3	5.9%
Average (July-October)	Average	69	6.8	4	6.3%
1988-1991 (July to October)	Low	61	6.4	4	6.7%

B) UPPER RED

Period	River Flow	Suspended Solids (mg/L)	Estimated Light Extinction Coefficient	Depth (m)	Average Light Exposure in Water Column
1999 (July to October)	High	207	13.2	4.5	2.9%
Average (July-October)	Average	115	8.9	3.5	5.5%
1988-1991 (July to October)	Low	64	6.6	3.5	7.5%

C) ASSINIBOINE

Period	River Flow	Suspended Solids (mg/L)	Estimated Light Extinction Coefficient	Depth (m)	Average Light Exposure in Water Column
1999 (July to October)	High	156	10.8	1.5	10.6%
Average (July-October)	Average	107	8.6	1	20.1%
1988-1991 (July to October)	Low	77	7.2	0.5	45.9%

4. WATER POLLUTION CONTROL CENTRES

The major continuous wastewater discharges to the rivers within the study area are the treated effluents from the three Water Pollution Control Centres (WPCCs). The City owns and operates three major pollution control centres at locations shown on Figure 4-1. Each of the centres is discussed in more detail below.

4.1 NORTH END WPCC (NEWPCC)

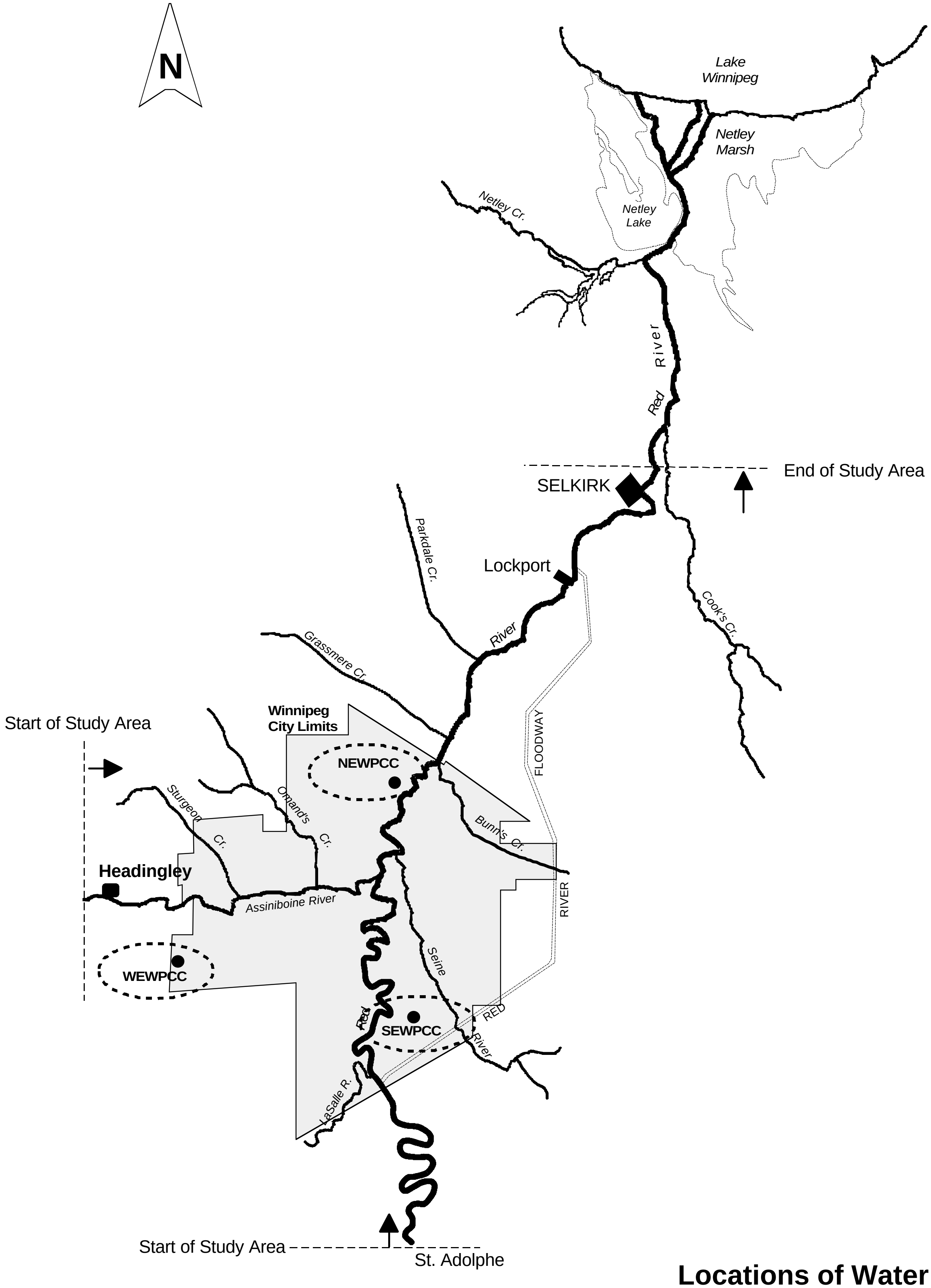
The NEWPCC is the largest of the three plants and has an existing service area of 16,200 hectares. The NEWPCC accepts about 70% of the wastewater generated by the City. It was built in several stages from its opening in 1937. The initial plant consisted of primary treatment which involved settling of the sewage. This plant was upgraded in the 1960s to include an activated sludge secondary treatment process. The plant was upgraded again in the 1980s and now consists of oxygen-based activated sludge secondary treatment processes, including sludge digestion and dewatering facilities. In the 1980s, virtually every component of the process was upgraded at a total cost of over $100 million.

4.2 SOUTH END WPCC (SEWPCC)

The SEWPCC is the second largest of the three regional treatment plants and has an existing service area of 7,700 hectares. This plant treats about 20% of the City-wide wastewater flow at present. The SEWPCC was commissioned in 1974. It provides primary treatment and oxygen-based activated sludge secondary treatment processes. Almost all components of the plant were upgraded in the early 1990s.

4.3 WEST END WPCC (WEWPCC)

The WEWPCC is the smallest of the three plants and has an existing service area of about 3,900 hectares. This plant treats about 10% of the City wastewater flow. This treatment plant



Locations of Water Pollution Control Centres
Figure 4-1

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began as lagoons which were commissioned in 1964. An extended aeration plant was added in 1976. Wastewater flows up to 27 mL/d were treated by the extended aeration plant with the excess directed to the lagoons. In 1998, the plant was upgraded to a high-purity oxygen activated sludge treatment plant. The lagoons have been converted to polishing ponds and the effluent is directed through the lagoons prior to discharge to the Assiniboine River.

4.4 WPCC EFFLUENT QUALITY

Quality characteristics of the raw and final effluent from the WPCCs are monitored regularly to aid in monitoring plant performance and discharge loading to the rivers. Some of the analytical parameters include the following:

- pH;
- suspended solids;
- grease;
- biochemical oxygen demand (BOD), 5-day total and inhibited at 20°C;
- total organic carbon;
- ammonia;
- total Kjeldahl nitrogen (TKN);
- nitrite and nitrate nitrogen;
- total phosphorus;
- total alkalinity;
- heavy metals (cadmium, lead, nickel, copper, chromium, zinc, iron); and
- microbiological indicators (fecal coliforms, total coliforms, E. Coli).

This data has been collated into a database for easy access during the study.

A summary of some of the key parameters used in the ammonia algal assessments is shown for 1984 to 1997 in Table 4-1. These parameter values are similar to current effluent quality for each WPCC. The exception is the WEWPCC in which an extended aeration plant has been replaced by a conventional high-purity oxygen plant. Therefore, some of the parameters, such as ammonia and nitrate, will not be representative of the current conditions. For current and

TABLE 4-1
HISTORIC WPCC INFLUENT AND EFFLUENT QUALITY
1984-1997

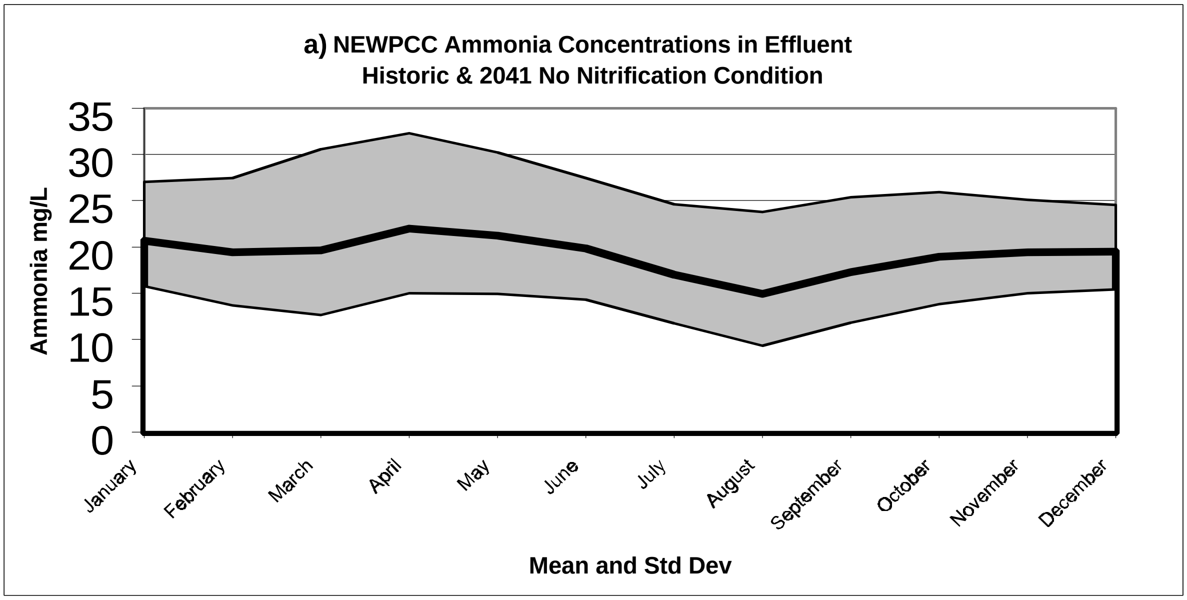
		NEWPCC		SEWPCC		WEWPCC	
		Raw	Final	Raw	Final	Raw	Final
Average Annual Flows (Ml/d)		244.4		55.5		33.3	
Ammonia - N	kg/d	6,302	4,646	1,301	964	762	208
	mg/L	25.8	19.0	23.4	17.4	22.9	6.2
Nitrate -N	kg/d	59	313	31	135	26	247
	mg/L	0.24	1.28	0.56	2.4	0.80	7.43
Total Kjeldhal Nitrogen -N	kg/d	9,308	6,766	2,168	1,271	1,071	449
	mg/L	38.1	27.7	39.1	22.9	32.2	13.5
Total Nitrogen -N	kg/d	9,367	7,079	2,199	1,406	1,097	696
	mg/L	38.3	29.0	39.6	25.3	33.0	20.9
Total Phosphorus -N	kg/d	1,423	631	409	225	214	139
	mg/L	5.8	2.6	7.4	4.1	6.4	4.2
BOD (Raw Total Final Inhibited)	kg/d	65,699	3,793	18,436	883	6,982	620
	mg/L	268.8	15.5	332.2	15.9	209.7	18.6
pH		7.4		7.2	7.1	7.3	

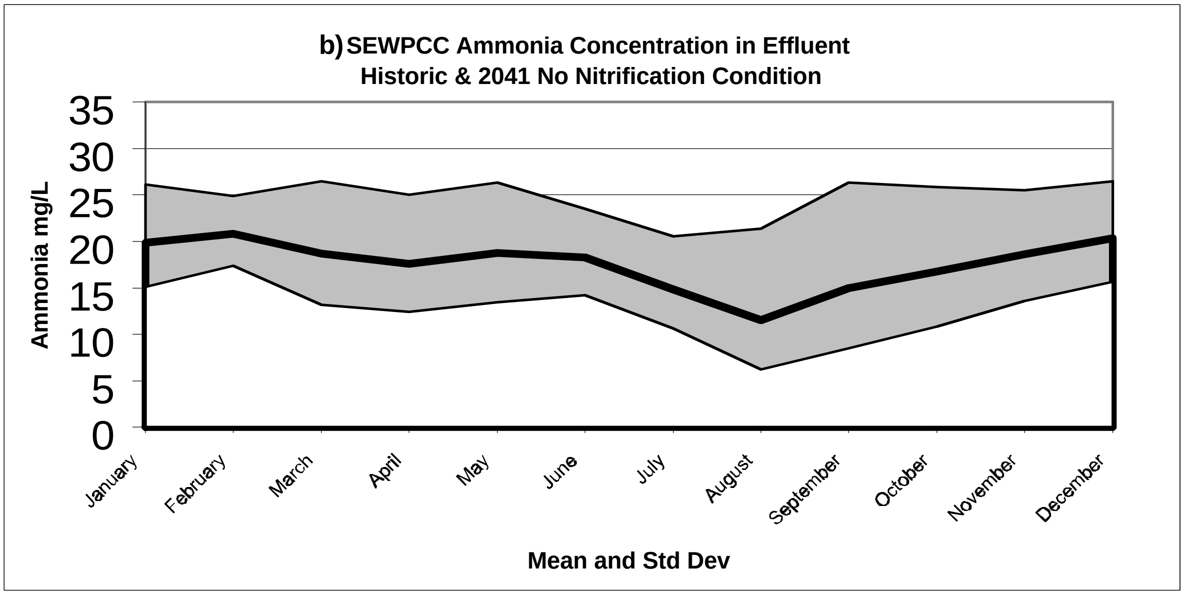
future conditions, the effluent quality of the SEWPCC will be more representative of the WEWPCC.

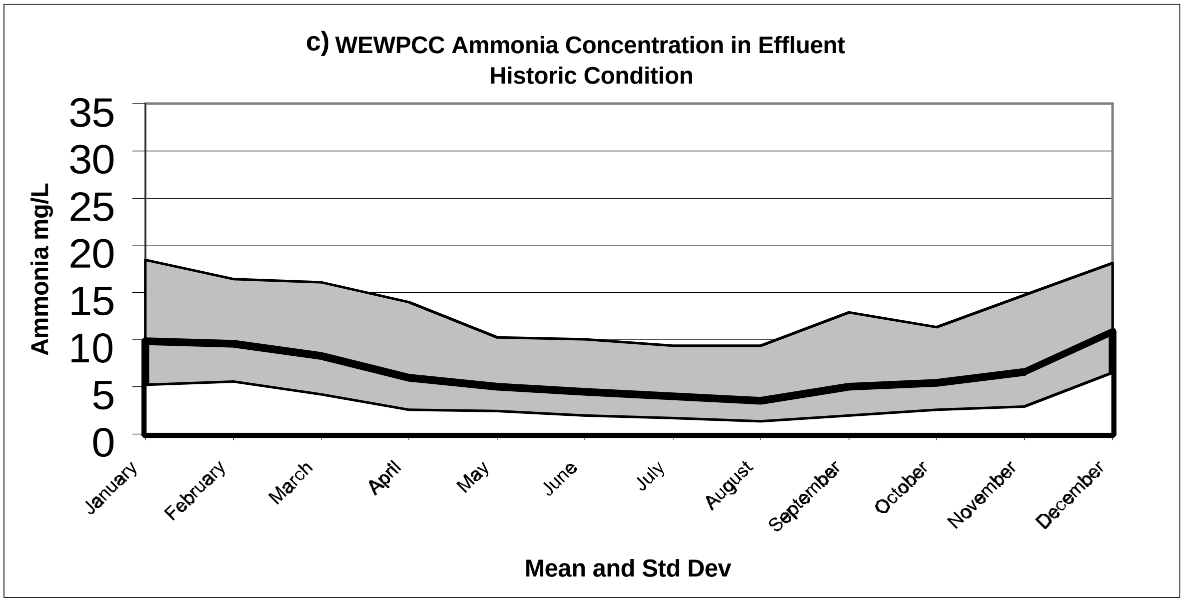
In order to determine future loads and wastewater flows, Josephson (1999) developed waste load projections to the year 2041. A summary of those projected mass loadings and the calculated concentrations for ammonia, nitrate-nitrite, TKN and phosphorus is shown in Table 4-2. Since these flow projections were based on water projections which include the ongoing trend to water conservation (Tetr*ES* 1998) the mass loading will increase faster than the wastewater flow to the plant. Therefore concentrations of these parameters will actually increase in the raw wastewater arriving at the treatment plant. These projections show that the increase in load going to each of the plants will be distributed equally in the future. The WEWPCC load will actually remain about the same as current levels and the NEWPCC load will increase only slightly. The largest increase both proportionately and absolutely will be at the SEWPCC. This will have implications on river conditions as discussed in the later chapter on long-term modelling (see Section 8.0).

Since ammonia is the key parameter of this study, its variation in the effluent was assessed in more detail. Each plant has its own unique pattern of effluent quality over the year. From year to year, the concentrations of ammonia in the effluent also appear to vary significantly. A statistical analysis was done on the effluent from each plant, for each month of the year, using data from the period of record of 1984 to 1997. The results of this analysis are shown on Figure 4-2. This analysis was used to define the outputs of the three plants for the historic conditions for which there was no planned nitrification of the wastewater. The modelling of these effects is discussed later in Section 8.0. The conditions at the WEWPCC show much lower ammonia concentrations than the other two plants. This is because the historic plant used an extended aeration process which promoted nitrification. In the future, the conditions at the WEWPCC should be similar to those of the SEWPCC. Also, it is expected that future flow to the WPCCs will increase as shown in Table 4-2 and the effluent load will increase proportionately. The stochastic load for any given month can be generated from this analysis. This stochastic procedure is discussed in more detail in Section 8.0.

Nutrient concentrations and loadings from each of the three WPCCs were summarized using historic records. The influent or raw wastewater concentrations and effluent concentrations are summarized for phosphorus (Figure 4-3) and nitrogen (Figure 4-4).


a) NEWPCC Ammonia Concentrations in Effluent
Historic & 2041 No Nitrification Condition


b) SEWPCC Ammonia Concentration in Effluent
Historic & 2041 No Nitrification Condition


c) WEWPCC Ammonia Concentration in Effluent
Historic Condition

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Historic Monthly Ammonia Variation at WPCCs

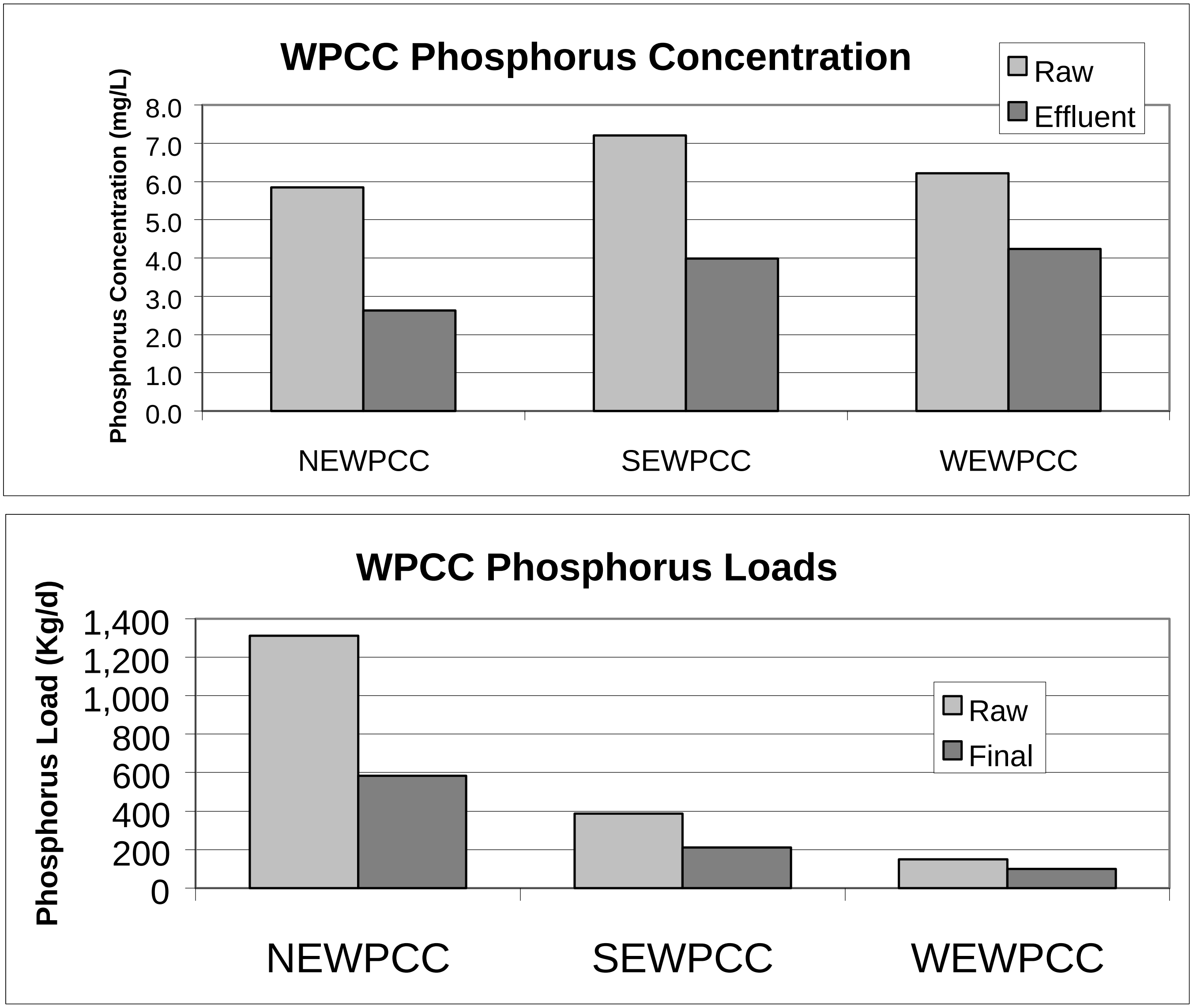
Figure 4-2

TABLE 4-2
CURRENT AT PROJECTED FLOWS AND LOADINGS TO THE WPCCS

		NEWPCC		SEWPCC		WEWPCC	
		Current (1997)	Projected (2041)	Current (1997)	Projected (2041)	Current (1997)	Projected (2041)
Average Annual Flows (Ml/d)		261.6	267.1	63.3	87.0	35.3	34.7
Ammonia - N	kg/d	7,510	7,899	1,487	2,172	831	884
	mg/L	28.7	29.6	23.5	25.0	23.5	25.5
Nitrate -N	kg/d	20.5	21.6	2.8	4.2	7.7	8.2
	mg/L	0.08	0.08	0.04	0.05	0.22	0.24
Total Kjeldhal Nitrogen -N	kg/d	10,891	11,455	2,386	3,486	1,196	1,271
	mg/L	41.6	42.9	37.7	40.1	33.9	36.6
Total Phosphorus -P	kg/d	1538	1618	406	593	204	217
	mg/L	5.9	6.1	6.4	6.8	5.8	6.3

Source: Josephson 1999

Memo to Brian Station August 27,1999
Revised Wastewater Flow & Mass Loading Projections for the NEWPCC, SEWPCC & WEWPCC



Source: City of Winnipeg data; 1984 - 1997

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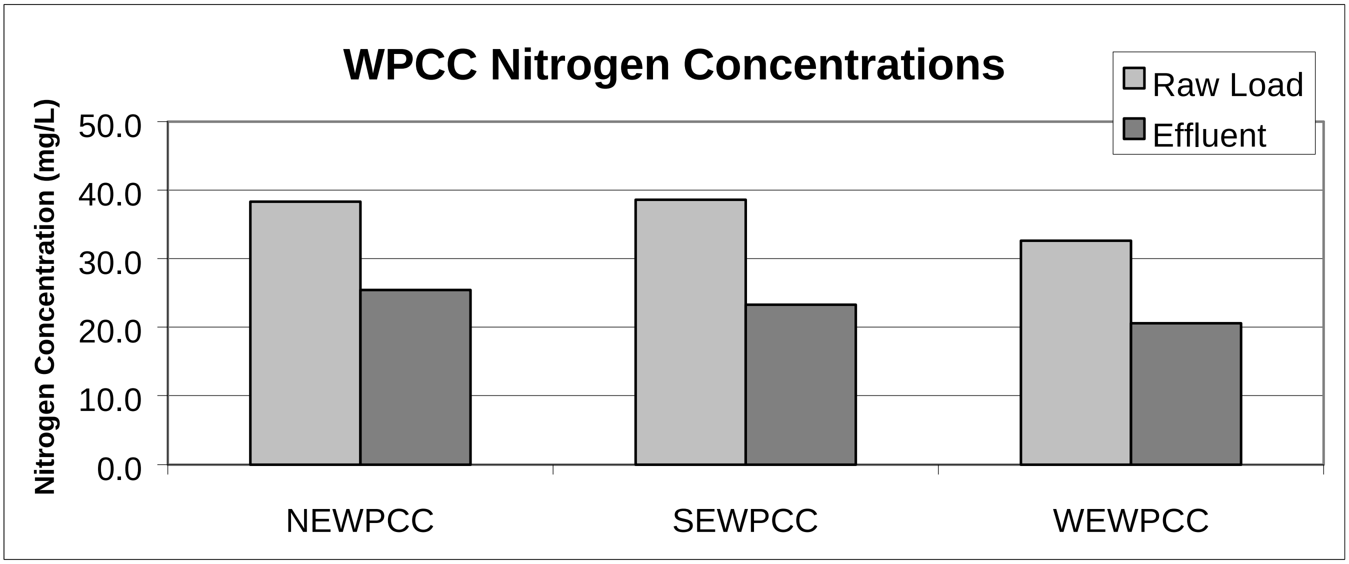
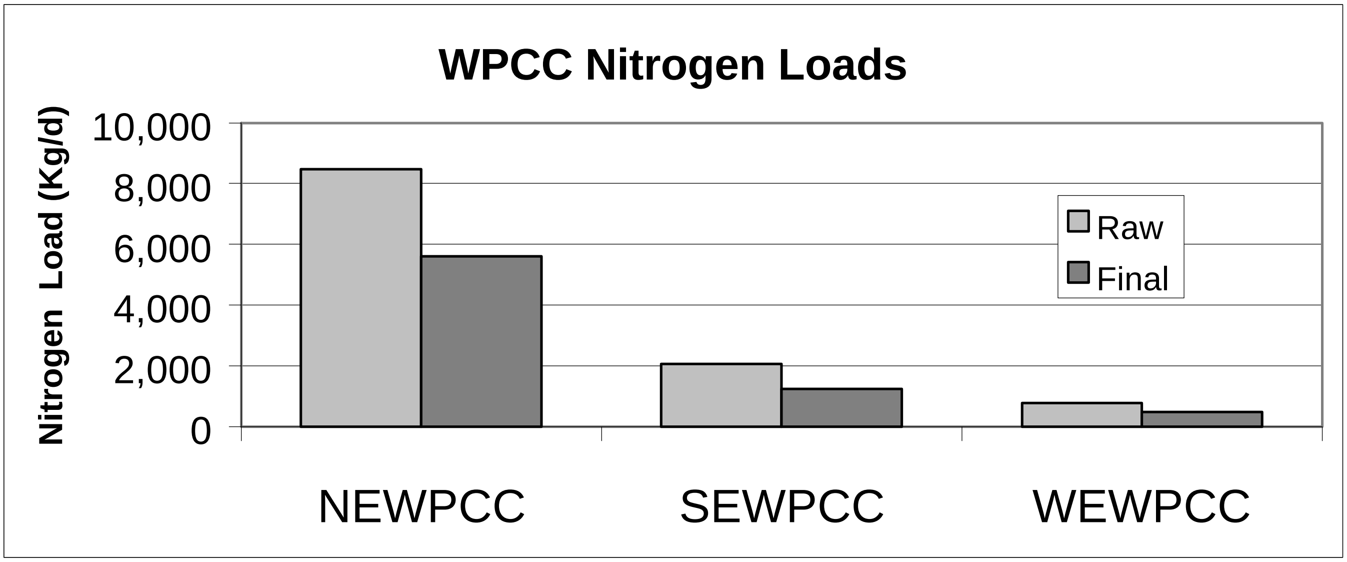
WPCC Phosphorus Loads
Figure 4-3





Source: City of Winnipeg data; 1984 - 1997

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WPCC Nitrogen Loads
Figure 4-4

It should be noted that the NEWPCC removed greater than 50% of the phosphorus during treatment (although the WPCC was not specifically designed for this). The SEWPCC and WEWPCC showed similar, although not as large, reduction in phosphorus during treatment.

The WPCCs reduced total nitrogen load although not as significantly as for phosphorus.

4.5 EFFLUENT QUALITY UNDER VARIOUS SCENARIOS

In order to obtain a perspective of ammonia concentrations in the river, various scenarios were developed to understand historic conditions, current conditions, and potential future conditions. A summary of these scenarios is shown on Table 4-3, and a brief description of each of the scenarios is discussed below.

Historic

The historic scenario considered the years from 1962 to 1997. These years are selected since this is the period of record in which there was a complete daily record of river flow at the stations directly upstream of the City of Winnipeg (St. Agathe and Headingley). This 36-years of record has a large variation in river flow, therefore it can be considered as a reasonable period to assess the historic conditions. During the historic conditions nitrification was not considered in the design at any of the plants. As discussed earlier, the lagoons had been in operation since the 1960s and the South End plant was commissioned in 1974. During this period, the North End plant’s service population did not grow significantly however both the South End and West End showed a significant growth as the populations in the southern and western suburbs grew. An estimate of the incoming ammonia load for each of the years from 1962 to 1997 is shown on Table 4-4. These loads were developed using the kg/capita/day estimates for each of the WPCCs developed by Josephson (1999). In order to estimate the effluent load for each of the days, calculations were made on the historic influent and effluent from 1994 to 1997. The ratio of influent and effluent monthly concentrations is shown in Table 4-5. Each of the WPCCs has some ability to reduce the ammonia concentration although it varies from month to month. The West End showed the most significant decreases during this period since the combination of an extended aeration plant and lagoons provided significant nitrification. The standard deviation of the daily records was calculated for each month of the year. Using this information as well as

TABLE 4-3
SUMMARY OF EFFLUENT QUALITY UNDER VARIOUS SCENARIOS

	Scenarios	Nitrification Options			Year
		NEWPCC	***SEWPCC***	***WEWPCC***	
1	Historic	None	None	None	1962-1997
2	Current	None	None	None	1997-2000
3	No Nitrification	None	None	None	2041
4	Optimize Existing	Centrate Removal	None	Lagoons	2041
5	Optimize Existing Plus Moderate	Centrate Removal	Moderate	Lagoons	2041
6	Moderate & Lagoons	Moderate	Moderate	Lagoons	2041
7	High & Lagoons	High	High	Lagoons	2041
8	High & WE BP	High	High	Best Practicable	2041
9	Best Practicable	Best Practicable	Best Practicable	Best Practicable	2041

TABLE 4-4
ESTIMATED POPULATION AND INFLUENT AMMONIA LOAD TO EACH WPCC

		Estimated Population			Influent Ammonia Load kg/d		
Year	Winnipeg Population	NEWPCC Population	SEWPCC Population	WEWPCC Population	NEWPCC	SEWPCC	WEWPCC
1962	478,415	377,205	66,639	34,571	7,544	600	346
1963	484,885	377,232	69,971	37,683	7,545	630	377
1964	491,295	376,752	73,469	41,074	7,535	661	411
1965	497,735	375,822	77,143	44,771	7,516	694	448
1966	504,176	374,376	81,000	48,800	7,488	729	488
1967	510,385	372,143	85,050	53,192	7,443	765	532
1968	516,594	369,312	89,303	57,979	7,386	804	580
1969	522,803	365,838	93,768	63,197	7,317	844	632
1970	529,012	361,212	97,800	70,000	7,224	880	700
1971	535,220	362,875	100,245	72,100	7,258	902	721
1972	540,351	363,337	102,751	74,263	7,267	925	743
1973	545,482	363,671	105,320	76,491	7,273	948	765
1974	550,613	363,874	107,953	78,786	7,277	972	788
1975	555,744	363,943	110,652	81,149	7,279	996	811
1976	560,874	362,774	113,200	84,900	7,255	1,019	849
1977	561,589	361,276	115,294	85,019	7,226	1,038	850
1978	562,303	359,738	117,427	85,138	7,195	1,057	851
1979	563,018	358,161	119,600	85,257	7,163	1,076	853
1980	563,732	356,543	121,812	85,376	7,131	1,096	854
1981	564,447	354,885	124,066	85,496	7,098	1,117	855
1982	565,215	353,238	126,361	85,616	7,065	1,137	856
1983	575,820	361,386	128,699	85,736	7,228	1,158	857
1984	581,550	364,615	131,079	85,856	7,292	1,180	859
1985	582,735	363,255	133,504	85,976	7,265	1,202	860
1986	594,551	372,481	135,974	86,096	7,450	1,224	861
1987	600,497	375,791	138,490	86,217	7,516	1,246	862
1988	606,502	379,113	141,052	86,337	7,582	1,269	863
1989	612,567	382,447	143,661	86,458	7,649	1,293	865
1990	618,693	385,795	146,319	86,579	7,716	1,317	866
1991	622,200	386,474	149,026	86,700	7,729	1,341	867
1992	617,790	379,185	151,783	86,822	7,584	1,366	868
1993	621,119	379,585	154,591	86,943	7,592	1,391	869
1994	623,600	379,084	157,451	87,065	7,582	1,417	871
1995	626,310	378,759	160,364	87,187	7,575	1,443	872
1996	629,017	382,395	162,712	87,298	7,648	1,464	873
1997	631,882	378,739	165,722	87,420	7,575	1,491	874

Notes

The Ammonia Input For each Plant (Josephson 1999):

NEWPCC -0.02 kg/capita/day
SEWPCC -0.009 kg/capita/day
WEWPCC -0.01 kg/capita/day

TABLE 4-5
HISTORIC RATIO OF INFLUENT AND EFFLUENT MONTHLY MEANS AND VARIATION OF AMMONIA CONCENTRATIONS (1984 TO 1997)

(Historic)

		Ratio of Effluent to Influent			Standard Deviation of Log		
Number	**Month**	**NEWPCC Ammonia**	**SEWPCC Ammonia**	**WEWPCC Ammonia**	**NEWPCC Std**	**SEWPCC Std**	**WEWPCC Std**
1	January	0.7	0.8	0.4	0.12	0.12	0.27
2	February	0.7	0.8	0.4	0.15	0.08	0.23
3	March	0.7	0.7	0.3	0.19	0.15	0.29
4	April	0.7	0.7	0.2	0.17	0.15	0.37
5	May	0.7	0.8	0.2	0.15	0.15	0.31
6	June	0.7	0.7	0.2	0.14	0.11	0.35
7	July	0.6	0.6	0.2	0.16	0.14	0.37
8	August	0.5	0.5	0.1	0.20	0.27	0.43
9	September	0.6	0.6	0.2	0.17	0.25	0.41
10	October	0.6	0.7	0.2	0.14	0.19	0.32
11	November	0.7	0.7	0.3	0.11	0.14	0.35
12	December	0.7	0.8	0.4	0.10	0.11	0.22

TABLE 4-6

MONTHLY MEAN AND VARIATION OF AMMONIA CONCENTRATIONS FOR NO NITRIFICATION, CENTRATE REMOVAL OR LAGOON POLISHING

(Current & Future 2041 No Nitrification Option)

		Geometric Mean Effluent Conc.			Standard Deviation of Log		
Number	**Month**	**NEWPCC Ammonia mg/L**	**SEWPCC Ammonia mg/L**	**WEWPCC Ammonia mg/L**	**NEWPCC Std**	**SEWPCC Std**	**WEWPCC Std**
1	January	29.7	22.8	22.8	0.14	0.13	0.13
2	February	29.3	23.7	23.7	0.20	0.19	0.19
3	March	22.0	15.3	15.3	0.12	0.11	0.11
4	April	13.7	11.6	11.6	0.16	0.15	0.15
5	May	21.8	15.1	15.1	0.12	0.11	0.11
6	June	22.7	18.6	18.6	0.37	0.35	0.35
7	July	17.2	8.5	8.5	0.51	0.39	0.39
8	August	22.7	18.9	18.9	0.37	0.35	0.35
9	September	25.2	19.6	19.6	0.19	0.18	0.18
10	October	22.7	16.1	16.1	0.28	0.25	0.25
11	November	25.1	19.6	19.6	0.19	0.18	0.18
12	December	29.3	23.6	23.6	0.20	0.19	0.19

the information developed on Table 4-4, a 36-year record of daily ammonia output from each of the plants could be developed using Monte Carlo modelling techniques. This daily effluent from the plants was used in conjunction with the river model described in Section 8 to determine the historic impacts of the effluent on the river during this period.

Current

To get an understanding of the current risk to aquatic life from ammonia a scenario was developed which used the current predictions for ammonia concentrations from each of the three WPCCs (see Table 4-6) and the current average annual flows as shown on Table 4-2. The 36-years of river flows which have occurred between 1962 and 1997 were simulated in a water quality model (Section 8) to indicate the potential conditions in 2001. These flows were adjusted to account for regulation of the rivers. In this manner, an estimate of what the potential ammonia concentration in the river under the current effluent discharge conditions could be determined. The NEWPCC was considered to have no centrate removal or nitrification. Similarly, the SEWPCC was also considered to have no nitrification. Although the lagoons now act as a polishing pond, this simulation was done by assuming that the WEWPCC would bypass the lagoons. Using this analysis of this current base case, the benefits of using lagoons can be determined.

No-Nitrification

No-nitrification used the same geometric mean and standard deviation (of the logs) for the ammonia concentrations as shown on Table 4-6. The annual average flow however was adjusted to count for the projected flows in 2041. As with the current conditions, the lagoons were not considered to be operating for the WEWPCC and the same distribution of ammonia concentrations was used as for the SEWPCC.

Optimize Existing

In this case, the centrate was considered to be removed from the NEWPCC and the lagoons were used as a polishing pond for the WEWPCC. The SEWPCC remained in the no-nitrification condition. The geometric mean and standard deviation (of the logs) are shown for each month in Table 4-7.

TABLE 4-7

MONTHLY MEAN AND VARIATION OF AMMONIA CONCENTRATIONS FOR CENTRATE REMOVAL AND LAGOON POLISHING BUT NO NITRIFICATION

(Optimize Existing)

		Geometric Mean Effluent Conc.			Standard Deviation of Log		
Number	**Month**	**NEWPCC Ammonia mg/L**	**SEWPCC Ammonia mg/L**	**WEWPCC Ammonia mg/L**	**NEWPCC Std**	**SEWPCC Std**	**WEWPCC Std**
1	January	20.6	22.8	27.4	0.12	0.13	0.45
2	February	18.6	23.7	28.2	0.18	0.19	0.28
3	March	14.8	15.3	26.8	0.11	0.11	0.18
4	April	9.2	11.6	9.8	0.13	0.15	0.52
5	May	14.7	15.1	2.2	0.11	0.11	1.02
6	June	14.0	18.6	3.8	0.32	0.35	0.97
7	July	11.4	8.5	3.7	0.44	0.39	1.08
8	August	14.0	18.9	2.6	0.32	0.35	1.24
9	September	15.4	19.6	4.3	0.16	0.18	0.98
10	October	15.7	16.1	7.1	0.25	0.25	0.66
11	November	15.4	19.6	12.9	0.16	0.18	0.74
12	December	18.6	23.6	21.3	0.18	0.19	0.23

TABLE 4-8

MONTHLY MEAN AND VARIATION OF AMMONIA CONCENTRATIONS FOR CENTRATE REMOVAL AND LAGOON POLISHING AND MODERATE TREATMENT AT SEWPCC

(Optimize Existing Plus Moderate)

		Geometric Mean Effluent Conc.			Standard Deviation of Log		
Number	**Month**	**NEWPCC Ammonia mg/L**	**SEWPCC Ammonia mg/L**	**WEWPCC Ammonia mg/L**	**NEWPCC Std**	**SEWPCC Std**	**WEWPCC Std**
1	January	20.6	8.3	27.4	0.12	0.08	0.45
2	February	18.6	7.6	28.2	0.18	0.12	0.28
3	March	14.8	5.3	26.8	0.11	0.07	0.18
4	April	9.2	5.6	9.8	0.13	0.10	0.52
5	May	14.7	6.5	2.2	0.11	0.08	1.02
6	June	14.0	7.4	3.8	0.32	0.24	0.97
7	July	11.4	4.6	3.7	0.44	0.27	1.08
8	August	14.0	9.5	2.6	0.32	0.27	1.24
9	September	15.4	7.6	4.3	0.16	0.12	0.98
10	October	15.7	7.2	7.1	0.25	0.18	0.66
11	November	15.4	7.0	12.9	0.16	0.12	0.74
12	December	18.6	8.7	21.3	0.18	0.13	0.23

Optimize Existing Plus Moderate

This condition also used 2041 average annual flows from the plants with centrate removal at the NEWPCC and lagoon polishing at the WEWPCC however, in addition, a moderate level of treatment was assumed for the SEWPCC. The monthly mean and variation of ammonia concentrations for this scenario are shown on Table 4-8.

Moderate and Lagoons

In this condition (also in 2041) the NEWPCC were also considered to have a moderate treatment level along with the SEWPCC. Again, the lagoons were used as a polishing pond for the WEWPCC. The monthly mean and variation of ammonia concentrations for this scenario are shown in Table 4-9.

High and Lagoons

In this scenario (also for 2041) the NEWPCC and SEWPCC were considered to have a high level of treatment. The WEWPCC used the lagoons as a polishing pond, as in the previous scenario. The monthly mean and variation of ammonia concentrations for this scenario are shown in Table 4-10.

High and WE BP

In this scenario (2041) the NEWPCC and SEWPCC were considered to have the high level of treatment as in the previous scenario, however the WEWPCC was considered to have best practical treatment (BPT). The monthly mean and variation of ammonia concentrations for this scenario are shown in Table 4-11.

Best Practical Treatment

In this scenario the best practical treatment option was considered for all three WPCCs, using 2041 average annual flows. The monthly mean and variation of ammonia concentrations for the best practical treatment options is shown in Table 4-12.

TABLE 4-9

MONTHLY MEAN AND VARIATION OF AMMONIA CONCENTRATIONS FOR CENTRATE REMOVAL AND LAGOON POLISHING AND MODERATE TREATMENT AT SEWPCC AND NEWPCC

(Moderate & Lagoons)

		Geometric Mean Effluent Conc.			Standard Deviation of Log		
Number	**Month**	**NEWPCC Ammonia mg/L**	**SEWPCC Ammonia mg/L**	**WEWPCC Ammonia mg/L**	**NEWPCC Std**	**SEWPCC Std**	**WEWPCC Std**
1	January	14.1	8.3	27.4	0.11	0.08	0.45
2	February	12.4	7.6	28.2	0.15	0.12	0.28
3	March	10.4	5.3	26.8	0.09	0.07	0.18
4	April	8.8	5.6	9.8	0.13	0.10	0.52
5	May	10.8	6.5	2.2	0.10	0.08	1.02
6	June	9.2	7.4	3.8	0.27	0.24	0.97
7	July	8.0	4.6	3.7	0.37	0.27	1.08
8	August	9.1	9.5	2.6	0.26	0.27	1.24
9	September	10.1	7.6	4.3	0.14	0.12	0.98
10	October	10.4	7.2	7.1	0.21	0.18	0.66
11	November	10.1	7.0	12.9	0.14	0.12	0.74
12	December	12.3	8.7	21.3	0.15	0.13	0.23

TABLE 4-10

MONTHLY MEAN AND VARIATION OF AMMONIA CONCENTRATIONS FOR CENTRATE REMOVAL AND LAGOON POLISHING AND HIGH TREATMENT AT SEWPCC AND NEWPCC

(High & Lagoons)

		Geometric Mean Effluent Conc.			Standard Deviation of Log		
Number	**Month**	**NEWPCC Ammonia mg/L**	**SEWPCC Ammonia mg/L**	**WEWPCC Ammonia mg/L**	**NEWPCC Std**	**SEWPCC Std**	**WEWPCC Std**
1	January	9.9	5.1	27.4	0.09	0.07	0.45
2	February	8.6	4.7	28.2	0.13	0.09	0.28
3	March	7.5	3.5	26.8	0.08	0.05	0.18
4	April	8.0	4.2	9.8	0.12	0.09	0.52
5	May	10.3	4.5	2.2	0.09	0.06	1.02
6	June	6.5	5.1	3.8	0.22	0.19	0.97
7	July	5.9	3.2	3.7	0.32	0.21	1.08
8	August	6.3	6.9	2.6	0.22	0.23	1.24
9	September	7.0	4.9	4.3	0.12	0.10	0.98
10	October	7.4	5.0	7.1	0.18	0.14	0.66
11	November	7.0	4.4	12.9	0.12	0.09	0.74
12	December	8.5	4.9	21.3	0.13	0.10	0.23

TABLE 4-11

MONTHLY MEAN AND VARIATION OF AMMONIA CONCENTRATIONS FOR POTENTIAL BEST PRACTICABLE TREATMENT OPTIONS

(High & WE BP)

		Geometric Mean Effluent Conc.			Standard Deviation of Log		
Number	**Month**	**NEWPCC Ammonia mg/L**	**SEWPCC Ammonia mg/L**	**WEWPCC Ammonia mg/L**	**NEWPCC Std**	**SEWPCC Std**	**WEWPCC Std**
1	January	9.9	5.1	0.8	0.09	0.07	0.52
2	February	8.6	4.7	0.9	0.13	0.09	0.44
3	March	7.5	3.5	0.7	0.08	0.05	0.06
4	April	8.0	4.2	2.6	0.12	0.09	0.72
5	May	10.3	4.5	5.4	0.09	0.06	0.34
6	June	6.5	5.1	3.9	0.22	0.19	0.77
7	July	5.9	3.2	0.9	0.32	0.21	0.35
8	August	6.3	6.9	1.2	0.22	0.23	0.76
9	September	7.0	4.9	0.6	0.12	0.10	1.01
10	October	7.4	5.0	0.5	0.18	0.14	0.46
11	November	7.0	4.4	0.7	0.12	0.09	0.46
12	December	8.5	4.9	0.7	0.13	0.10	0.22

TABLE 4-12

MONTHLY MEAN AND VARIATION OF AMMONIA CONCENTRATIONS FOR POTENTIAL BEST PRACTICABLE TREATMENT OPTIONS

(Best Practicable)

		Mean Effluent Conc.			Standard Deviation of Log		
Number	**Month**	**NEWPCC Ammonia mg/L**	**SEWPCC Ammonia mg/L**	**WEWPCC Ammonia mg/L**	**NEWPCC Std**	**SEWPCC Std**	**WEWPCC Std**
1	January	0.778	0.778	0.778	0.52	0.52	0.52
2	February	0.888	0.888	0.888	0.44	0.44	0.44
3	March	0.653	0.653	0.653	0.06	0.06	0.06
4	April	2.601	2.601	2.601	0.72	0.72	0.72
5	May	5.425	5.425	5.425	0.34	0.34	0.34
6	June	3.911	3.911	3.911	0.77	0.77	0.77
7	July	0.931	0.931	0.931	0.35	0.35	0.35
8	August	1.224	1.224	1.224	0.76	0.76	0.76
9	September	0.642	0.642	0.642	1.01	1.01	1.01
10	October	0.474	0.474	0.474	0.46	0.46	0.46
11	November	0.703	0.703	0.703	0.46	0.46	0.46
12	December	0.738	0.738	0.738	0.22	0.22	0.22

Source :RCPL 2000 (K. Fries Email to D. Morgan)

5. COMPARISON OF NUTRIENT LOADINGS UPSTREAM OF WINNIPEG AND FROM WPCCs

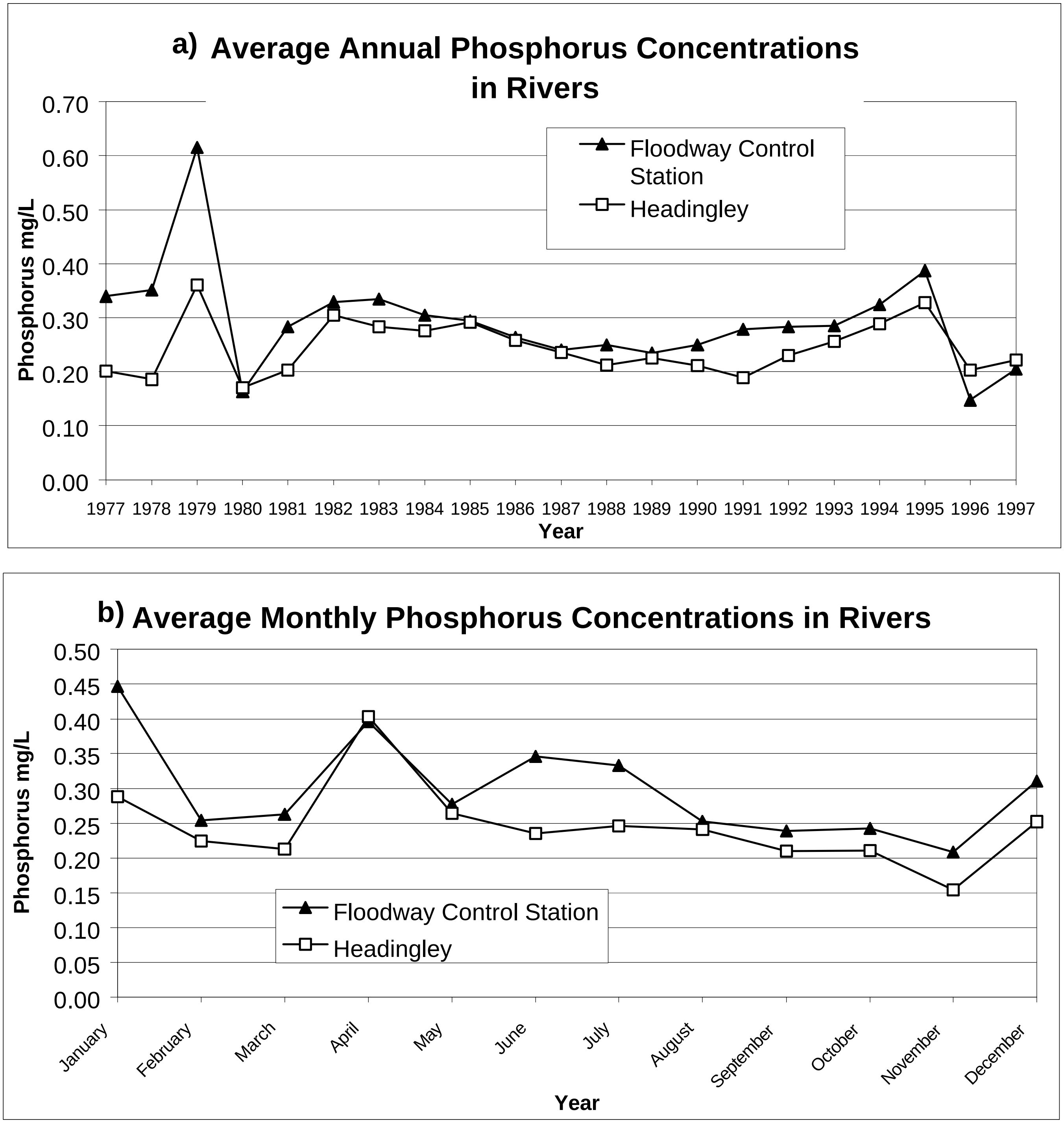
This section will assess trends in phosphorus loadings coming from upstream of the City of Winnipeg and from the Water Pollution Control Centres (WPCCs).

5.1 PHOSPHORUS LOADINGS

The average annual phosphorus concentrations in the rivers at stations upstream of the City of Winnipeg (the Floodway Control Station and Headingley) were assessed to determine if there are any long-term trends in phosphorus concentrations. The average phosphorus trends for each year from 1977 to 1997 are shown on Figure 5-1a. This trend shows phosphorus concentrations are generally between 0.2 mg/L and 0.4 mg/L on an average annual basis. The Red River appeared to have some abnormally high concentrations in 1979. The trends in the 1980s were generally fairly stable or decreasing and in the 1990s, the trends seemed to be increasing slightly although 1996 and 1997 had lower concentrations of total phosphorus. The monthly average concentrations were also assessed using the same period of record from 1977 to 1997 (see Figure 5-1b) The concentrations are not extremely variable from month to month, however the highest concentrations generally occur on the Red River in January and April, and on the Assiniboine River in April.

In order to determine the mass loadings the average annual phosphorus concentration was multiplied by the average annual flow (see Figure 5-2). As can be seen from Figure 5-2, flows are quite variable from year to year on the Red River and show no obvious trend, although from 1993 to 1997 the average annual flows appeared to be increasing significantly. Obviously the flood of 1996 and 1997 had a great impact on the average annual flow.

The upstream annual loadings from 1977 to 1997 are plotted on Figure 5-3a. This indicates there is a significant variable trend in annual loadings over the past two decades. Loadings were moderately high for most of the 1980s, although they dropped significantly from 1988 through 1991, due to low flows in the rivers. From 1993 to 1997, the loads have been fairly high. The year 1995 had the phosphorus load from a combination of high flows and high


a) Average Annual Phosphorus Concentrations in Rivers

b) Average Monthly Phosphorus Concentrations in Rivers

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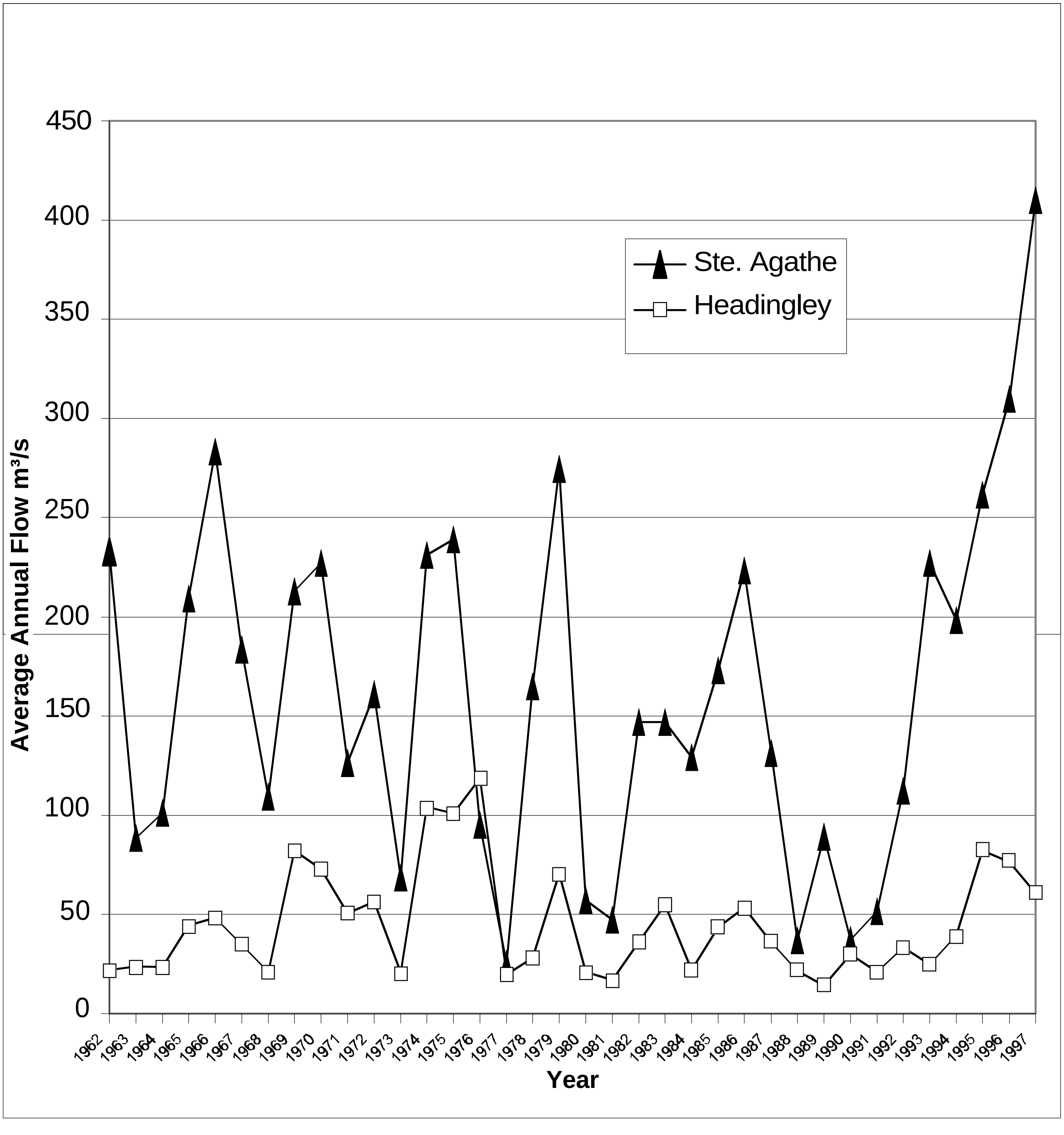
Phosphorus Concentrations in Rivers

Figure 5-1



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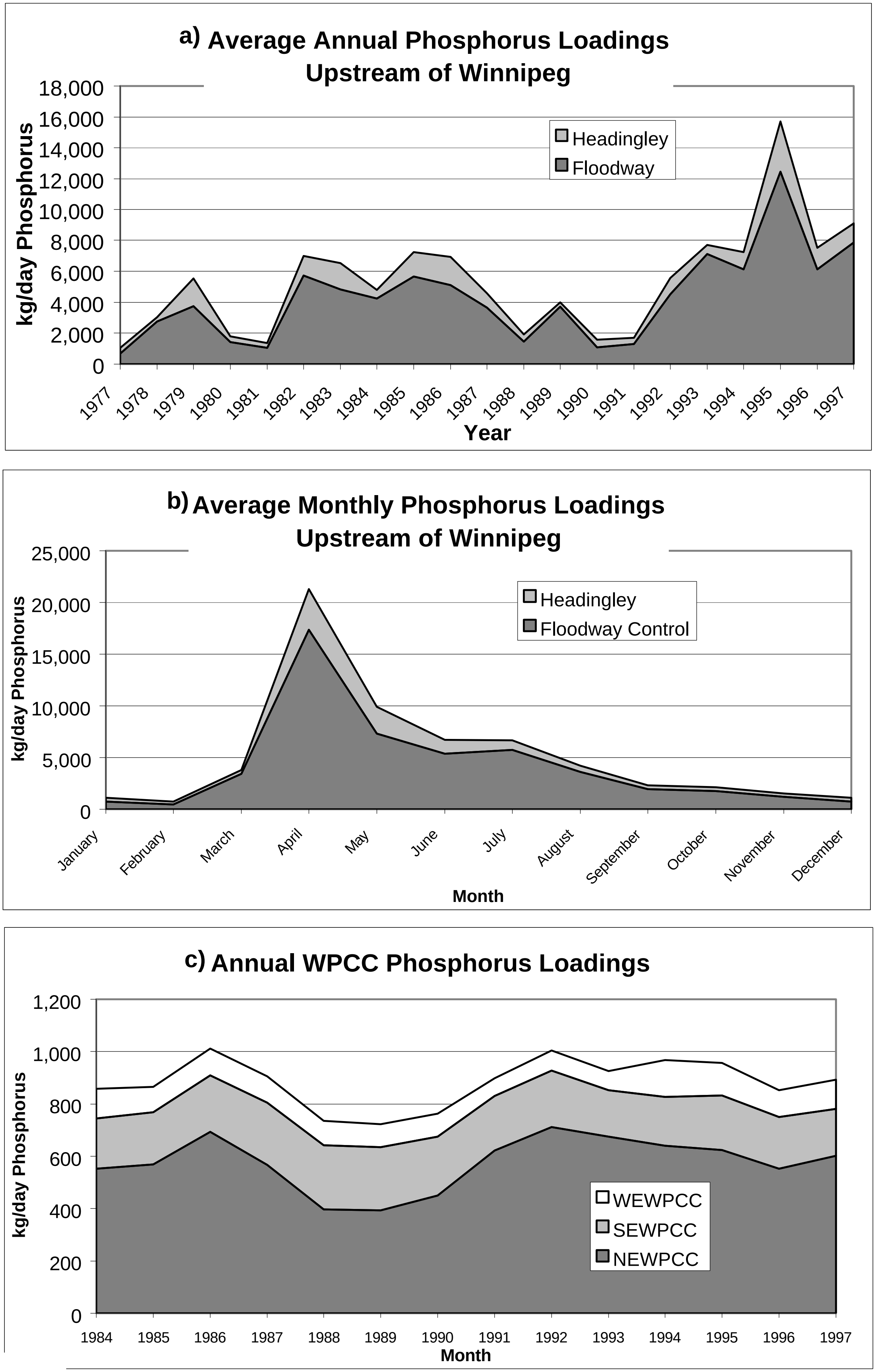
Average Annual River Flow

Figure 5-2



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Phosphorus Loads in Rivers and WPCCs

Figure 5-3

concentrations resulting in an annual load which was almost 8 times higher than those in the early 1990s. There is significant variation in phosphorus load from month to month due to the extreme variation in flows. Most of the load comes during the spring freshet in March, April, and May.

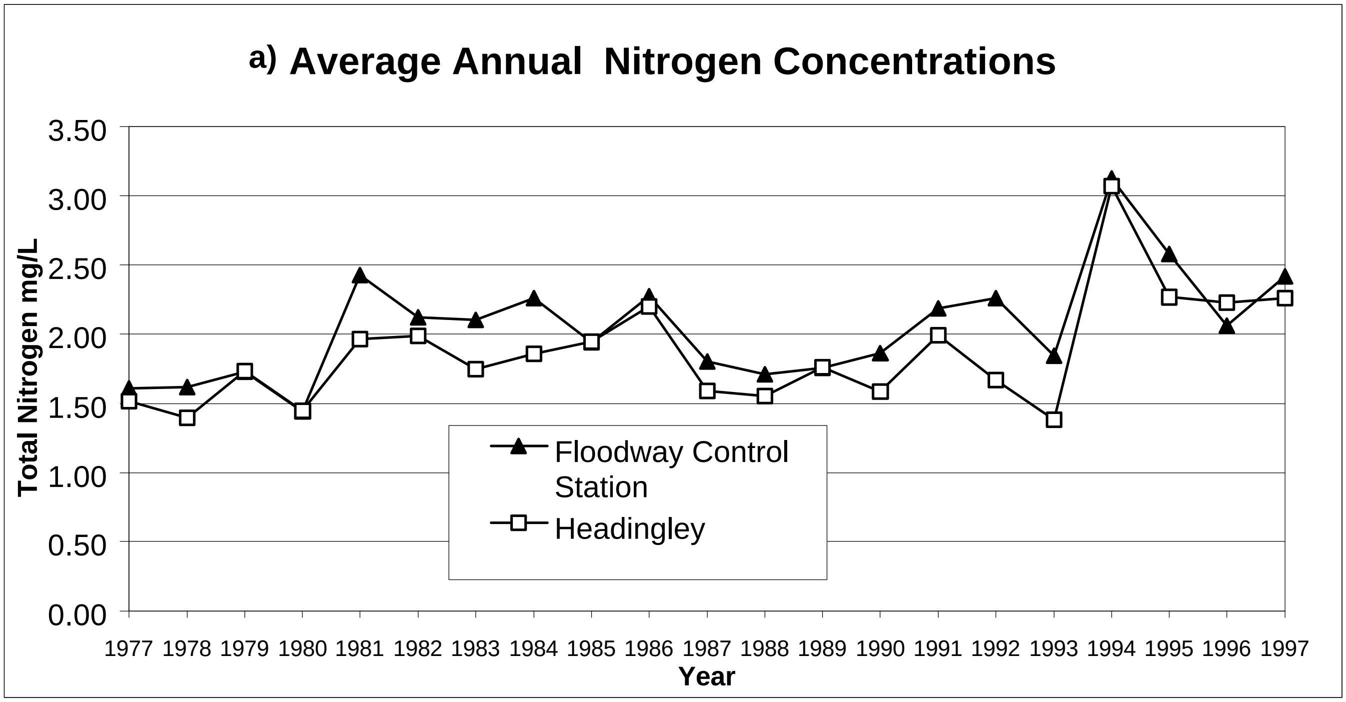
For comparison purposes, the loads from the three Winnipeg treatment plants were also assessed (see Figure 5-3c). The loads from the treatment plants are an order of magnitude less than those found in the river from sources upstream of the City of Winnipeg. However, during low-flow conditions in the early 1980s, the WPCC loads could be as close as 50% of the loads from upstream sources. This would indicate that during low-flow conditions the plants could impact nutrient conditions in the lower Red River. During high-flow conditions, the loads from upstream sources are 10 to 16 times higher than those from the plants. This would indicate that during high loading conditions to Lake Winnipeg, the loads coming from Winnipeg's treatment plants are only about 7 to 10% of the total load going to the lake from the Red River.

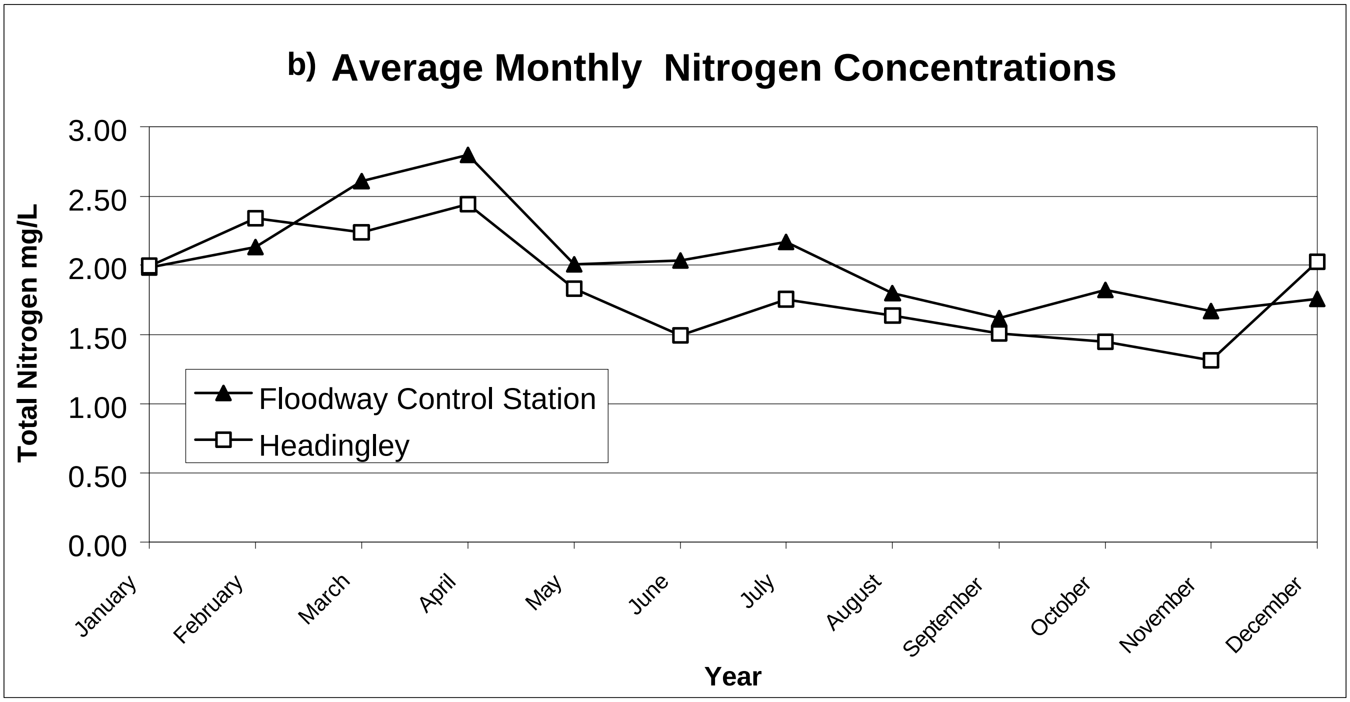
5.2 NITROGEN LOADINGS

An analysis of average annual total nitrogen concentrations in the river upstream of the City of Winnipeg is shown from 1977 to 1997 on Figure 5-4a. Although variable from year to year, total nitrogen concentrations have shown a general increase from 1977 through 1997. In the early 1970s, concentrations at the upstream stations (Floodway Control Station and Headingley) were around 1.5 mg/L. Currently, concentrations appear to be closer to 2.2 mg/L.

An analysis of monthly trends indicates that, similar to phosphorus, nitrogen concentrations appear to be highest in March and April then reduce through the summer and fall (see Figure 5-4b).

Ammonia loads were also calculated using the average annual concentration and the average annual flow in the river for each year from 1977 to 1997. Total loads in the river were lower in the late 1970s early 1980s, increased to moderate levels throughout most of the 1980s, but then dropped to very low levels from 1988 through 1991 inclusive. Since 1993 loadings of total nitrogen increased about 4 to 5 fold (see Figure 5-5a). Average monthly nitrogen loads upstream of Winnipeg are shown on Figure 5-5b. This indicates that the largest load comes





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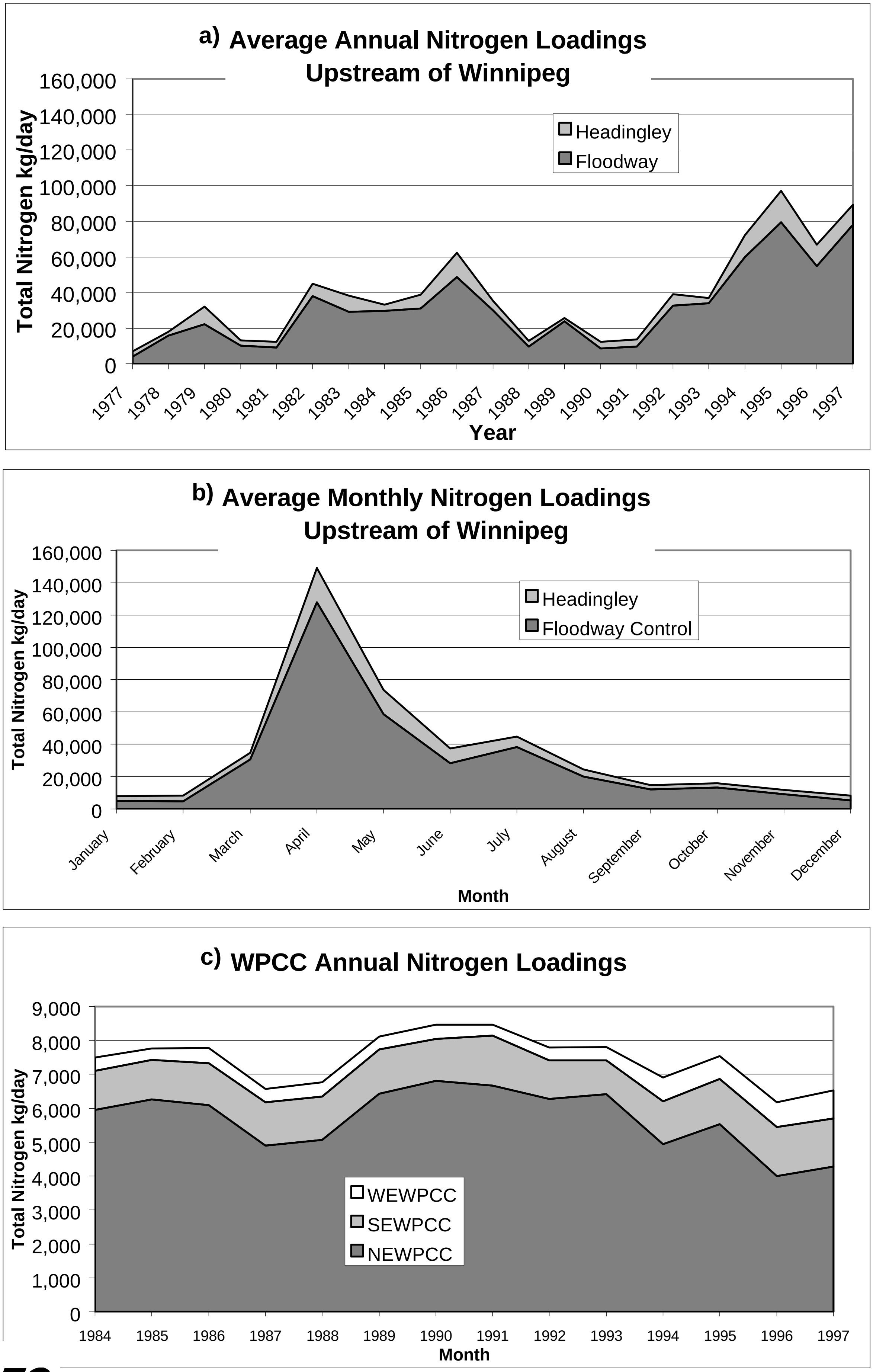
Nitrogen Concentrations in Rivers
Figure 5-4



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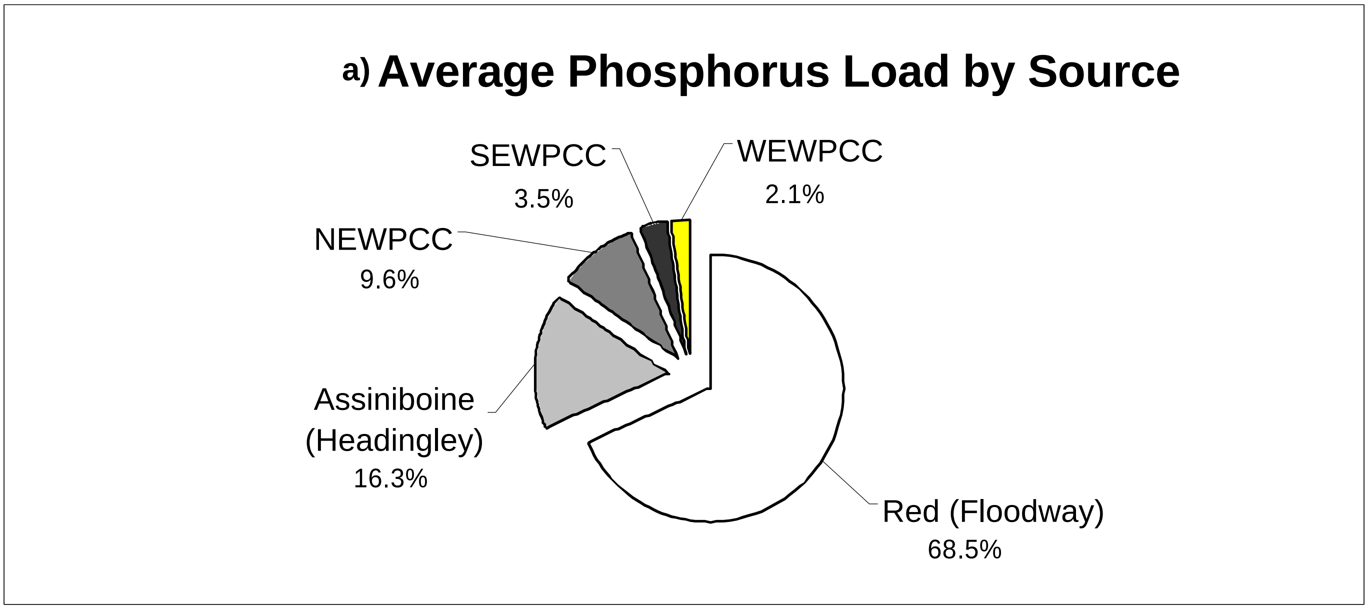
Nitrogen Loads in Rivers and WPCCs

Figure 5-5

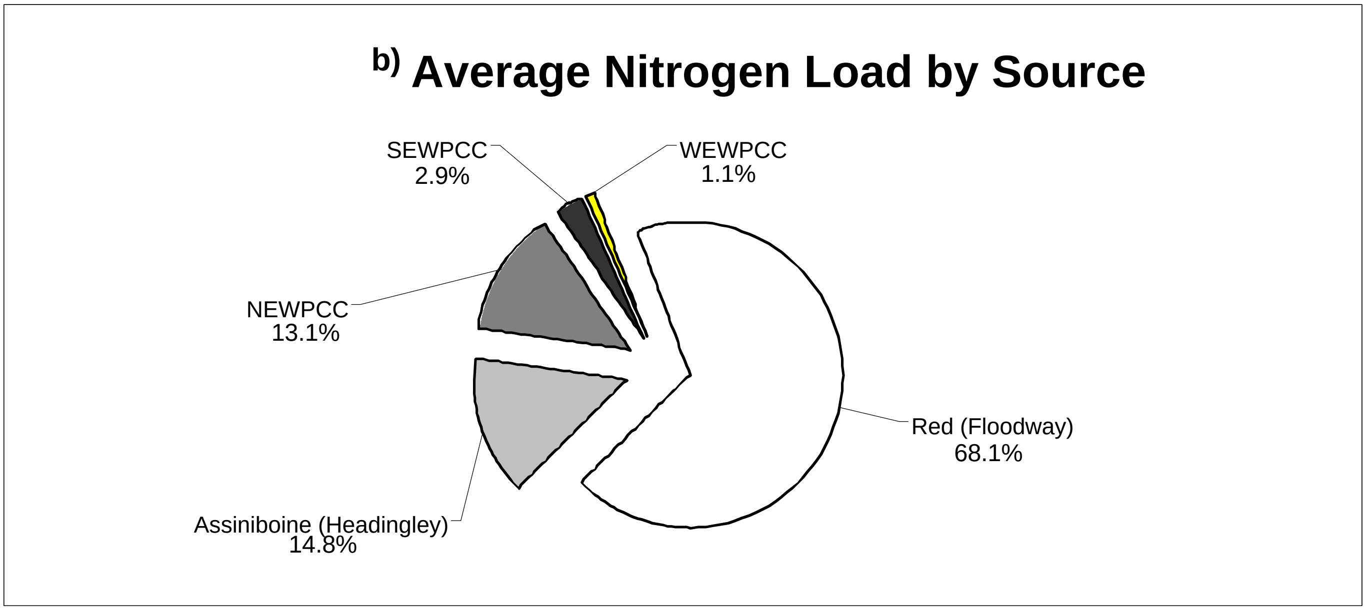
during the spring freshet in April and May (similar to that observed for phosphorus). In a similar assessment to phosphorus the WPCC annual loads for nitrogen were calculated from 1984 through 1997. Nitrogen loads from the treatment plants were relatively constant, or actually decreasing slightly in the last few years. Nitrogen loads from the WPPCs are about an order of magnitude less than the total loads from upstream sources. During low-flow conditions, nitrogen loads may be close to 50% of the total load from upstream sources of the City, however, during high flow conditions, the nitrogen load from the WPCCs is only about 10% of the load in the rivers. This indicates that during high-loading conditions to Lake Winnipeg (i.e., the last four or five years) loads from the City of Winnipeg's WPCCs would only be about 10% of the total load.

5.3 SUMMARY OF NUTRIENT LOADINGS IN THE RIVER

A summary of the average annual load for phosphorus and nitrogen is shown in Figure 5-6. On an average basis, the annual load from the WPCCs is about 20% of the total load in the river. However, in a low-flow year, the nutrient loads could increase to as much as 30 or 40% of the load in the river and, in a high-flow year, it would only amount to about 10% of the load in the river.



a) Average Phosphorus Load by Source



b) Average Nitrogen Load by Source

Source: City of Winnipeg Data and Provincial Flow Records; 1977 - 1997

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Nutrient Load by Source

Figure 5-6

6. AMMONIA IMPACTS ON ALGAE

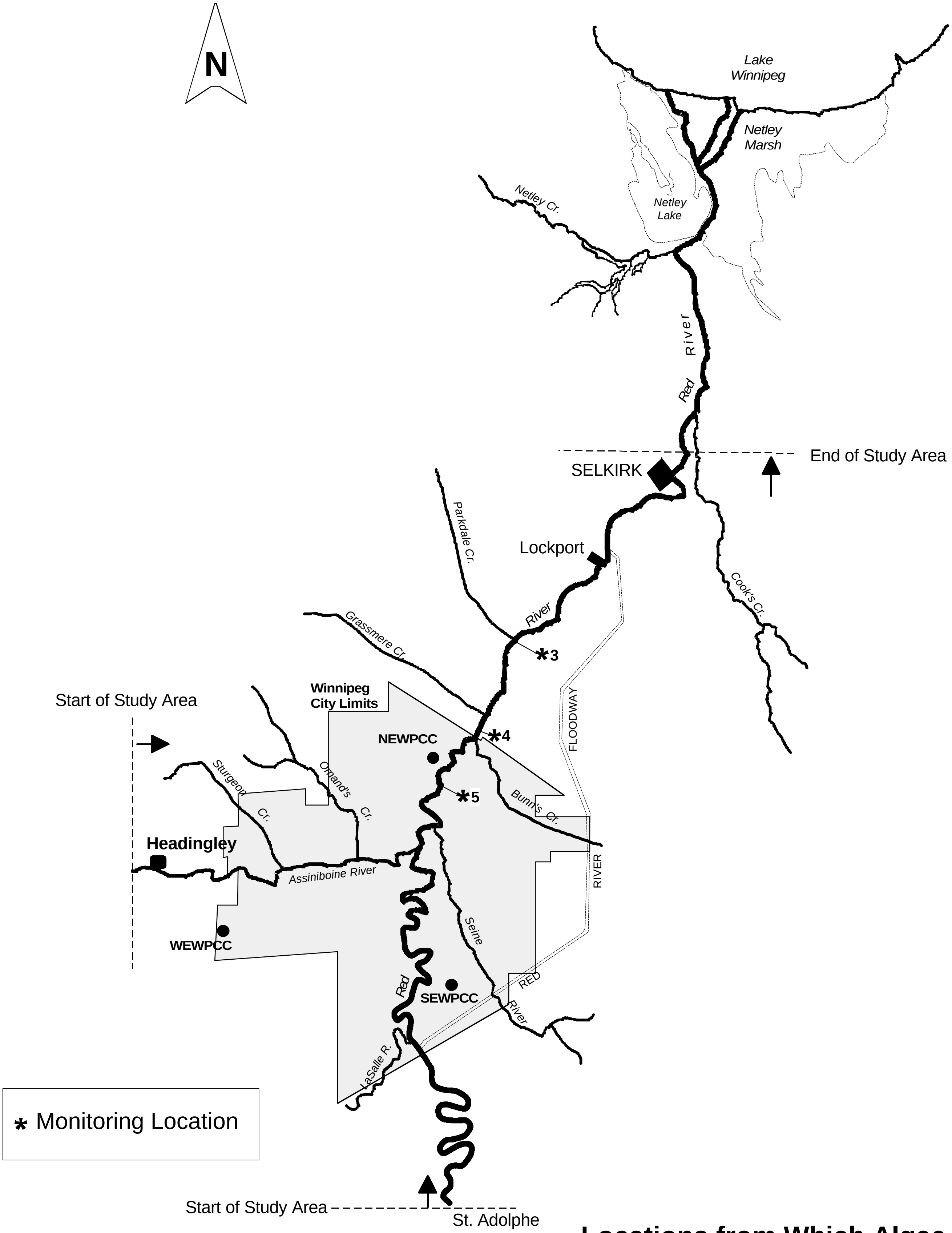
During 1999, in parallel with the field sampling program described earlier, experiments were undertaken on suspended algae collected from the Red River in order to determine if elevated levels of ammonia impacted algal productivity. In order to simulate impacts as they may occur in the river when algae enters an effluent plume during low-flow conditions, phosphorus was also increased in order to maintain N-P ratios during a second set of “spiking” experiments. A third type of experiment considered the impact of elevated nitrate levels on algal productivity. This experiment was done in order to shed some light on what the change in algal productivity may be, due to nitrification at the plant. Similar to the assessment of ammonia impacts, a parallel test was done which maintained N-P ratios by increasing orthophosphate concentration simultaneously with nitrate.

6.1 METHODOLOGY

During the field monitoring program, samples were taken early in the morning (between 7:00 a.m. and 9:00 p.m.) at three locations shown on Figure 6-1. One station was located upstream of the NEWPCC and two stations were located downstream of the NEWPCC. Stations and their relative locations can be described as:

- Station 5 was Fraser’s Grove Park (which is located upstream of the NEWPCC);
- Station 4 was located near the North Perimeter Bridge within the plume and during 1999 was about 1 to 3 hrs travel time downstream of the NEWPCC; and
- Station 3 was located at Parkdale and during 1999 was between 3 and 8 hrs travel time downstream of the NEWPCC.

The purpose of selecting these multiple stations was to determine whether the effects of ammonia on algae would change as algae acclimated to the impact of the plume. Station 5 was considered to have no acclimation time, while Stations 4 and 3 would be used to determine whether increased time of acclimation would change the response of algae to ammonia. Due to the very high flows occurring in 1999 (described early in Section 2) the travel times were about 2 to 3 times less than the time that would be expected during average conditions and 10 times



Locations from Which Algae Samples Were Collected

Figure 6-1

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less than the expected travel time under low-flow conditions. In addition, the concentrations to which the algae were exposed in the Red River itself were significantly less than those under average or low flow conditions, due to increased dilution from the higher flows. Therefore the time of exposure to ammonia to allow for acclimation to ammonia would be very limited.

Upon arrival on Day 1, ambient ammonia and Chlorophyll ‘a’ concentrations were determined. The samples were then split into 8 sub-samples and spiked with ammonium chloride to provide a concentration range from ambient levels to approximately 5 mg/L (as nitrogen). Actual achieved concentrations of ammonia were determined analytically along with the pH, alkalinity, and dissolved inorganic content of the water samples. The eight ammonia-treated samples were then used for the determination of the parameters of the curvilinear relationships between carbon dioxide assimilation and photosynthetically available radiation (PAR) (see Figure 6-2). Each set of determinations was conducted in a temperature-controlled water-filled incubator illuminated by a high-pressure sodium light source. End results for each of the ammonia-treated samples were:

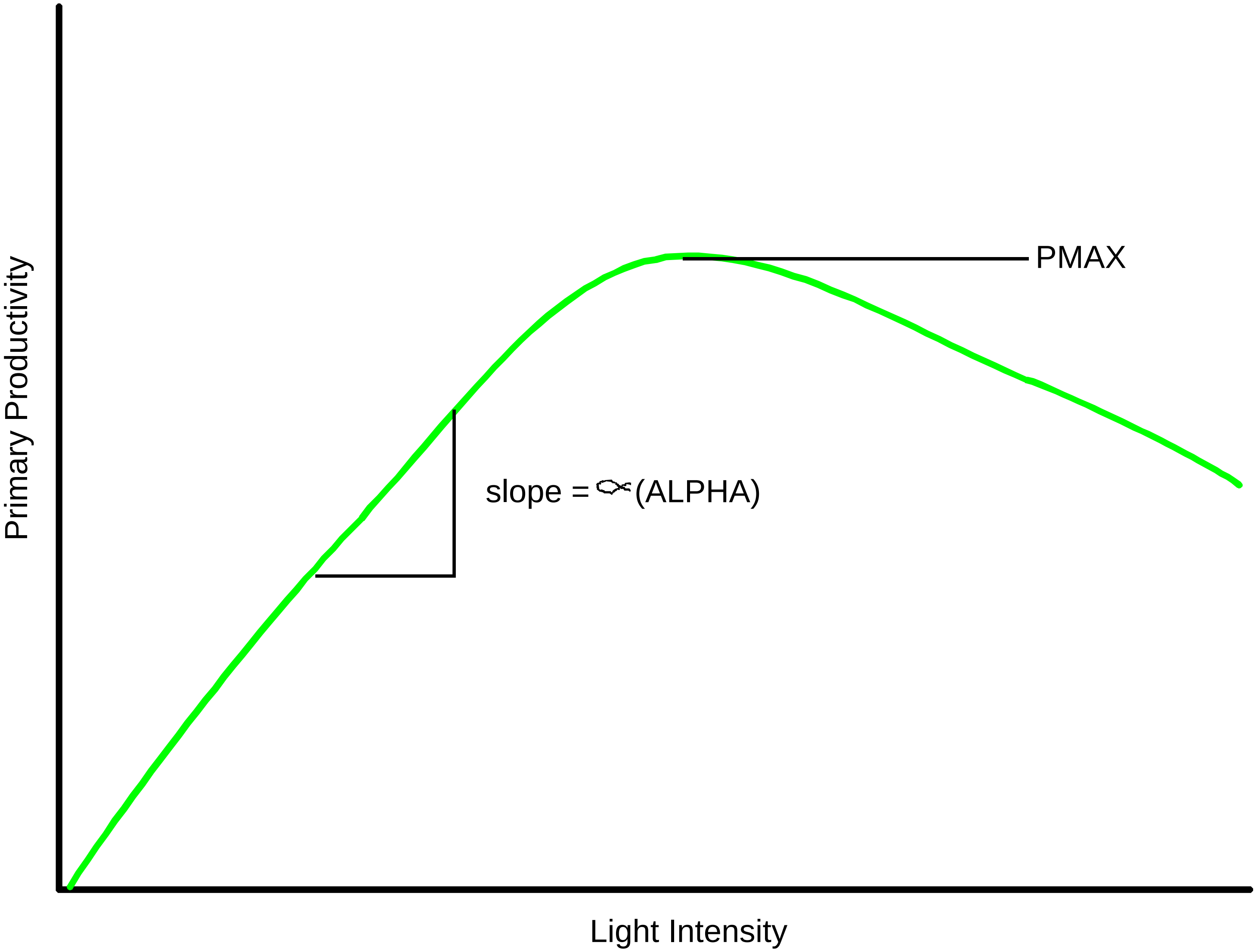
- PMAX - the maximum rate of carbon assimilation; and
- ALPHA - photosynthetic efficiency (i.e., the slope of the light limited photosynthesis).

Actual values of these parameters along with the standard errors and 95% confidence limits were determined by non-linear regression. Chlorophyll ‘a’ normalized equivalent values were determined. These data permitted the determination of the impact of increased levels of total ammonia and un-ionized ammonia (based on pH and temperature derived corrections) on:

- PMAX;
- specific PMAX (divided by Chlorophyll ‘a’ concentration);
- ALPHA; and
- specific ALPHA (Chlorophyll normalized);

at each of the three sampling sites.

On Day 2 of each sampling period, new water samples were again transported to the laboratory where ambient ammonia, soluble reactive phosphorus levels, and Chlorophyll ‘a’ were determined. The intention of the second day’s experiments was to examine the impact of the



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Maximum Productivity Experiments
Figure 6-2

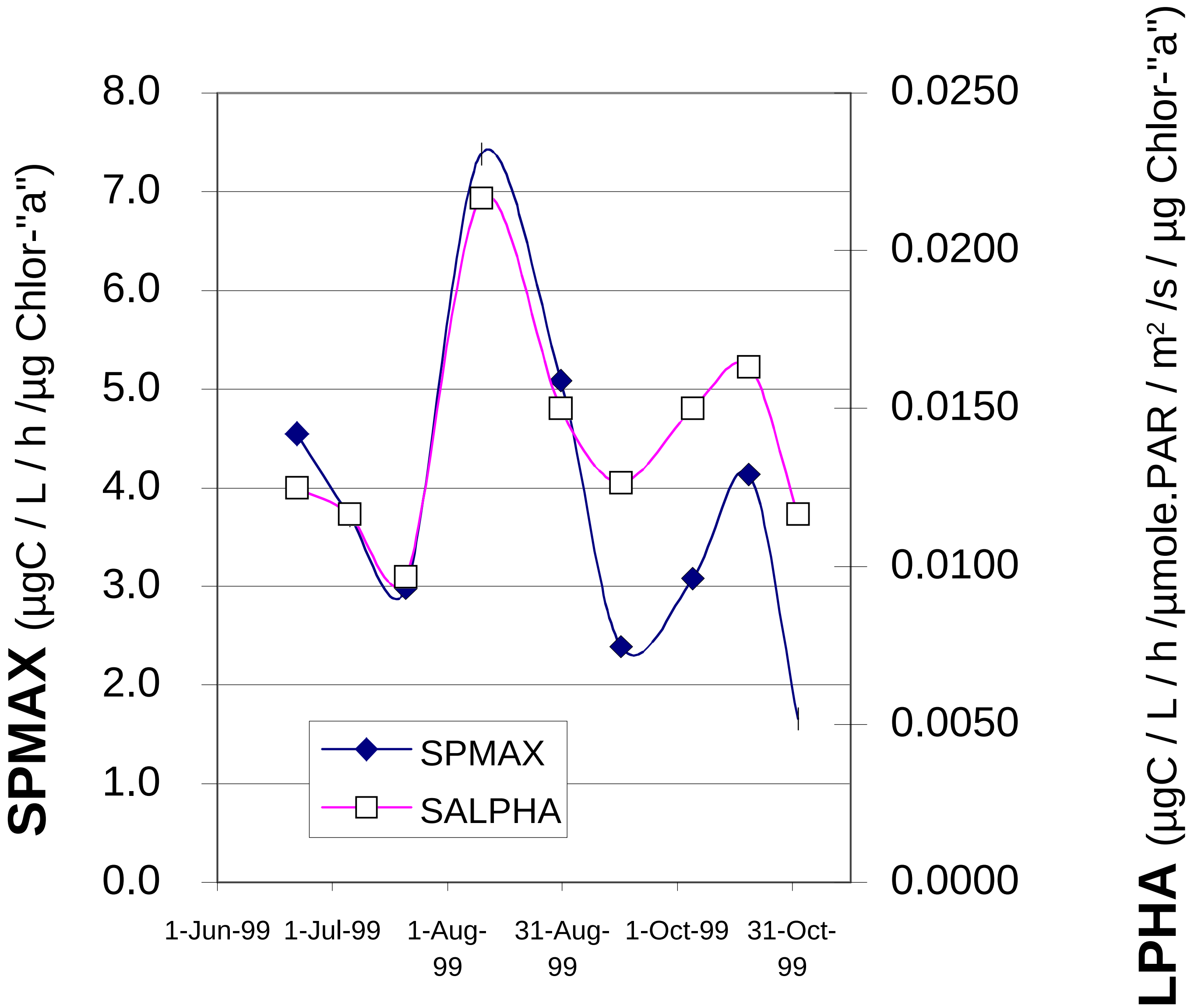
same range of ammonia on the above photosynthesis parameters, but under conditions in which the N/P ratio (i.e., total ammonia N/soluble reactive phosphorus P) was maintained at approximately 10. This required that the samples be spiked to obtain target ammonia levels and also target soluble reactive phosphorus (SRP) concentrations. At lower concentrations of ammonia, N/P ratios of 10 were not attainable due to low ammonia levels, but there were attainable at higher ammonia concentrations. Determination of photosynthetic parameters was done as described above.

On October 5, 1999, the ammonia and phosphorus spiking analysis on Day 2 was substituted by a **nitrate** spiking experiment. Nitrate concentrations were increased in a similar fashion as described for ammonia above. In addition, a third set was done increasing both nitrate and phosphorus as described above. Again, determination of photosynthetic parameters was done and the analysis are presented below.

6.2 RESULTS

6.2.1 Variations in Algal Activity Over the Sampling Period

Sampling and testing of algae occurred every two or three weeks, from late June to early November. The results of calculations for the average specific maximum productivity and specific photosynthetic efficiency are shown on Figure 6-3. As can be seen, the photosynthetic parameters varied considerably from week to week. From late July to early August, specific maximum productivity and specific photosynthetic efficiency doubled. August had the highest rates of photosynthetic activity, however by late September, the specific maximum productivity dropped to its lowest point. In October, the specific maximum productivity and photosynthetic efficiency increased again only to drop in the last sample collected on November 3, 1999. This variability of photosynthetic parameters should be taken into account to help put into perspective the variability in parameters brought about by high ammonia concentrations.



Changes in Specific Maximum Productivity and Specific Photosynthetic Efficiency from June to November (Unspiked Samples)

Figure 6-3

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6.2.2 Impact of Ammonia on Photosynthesis

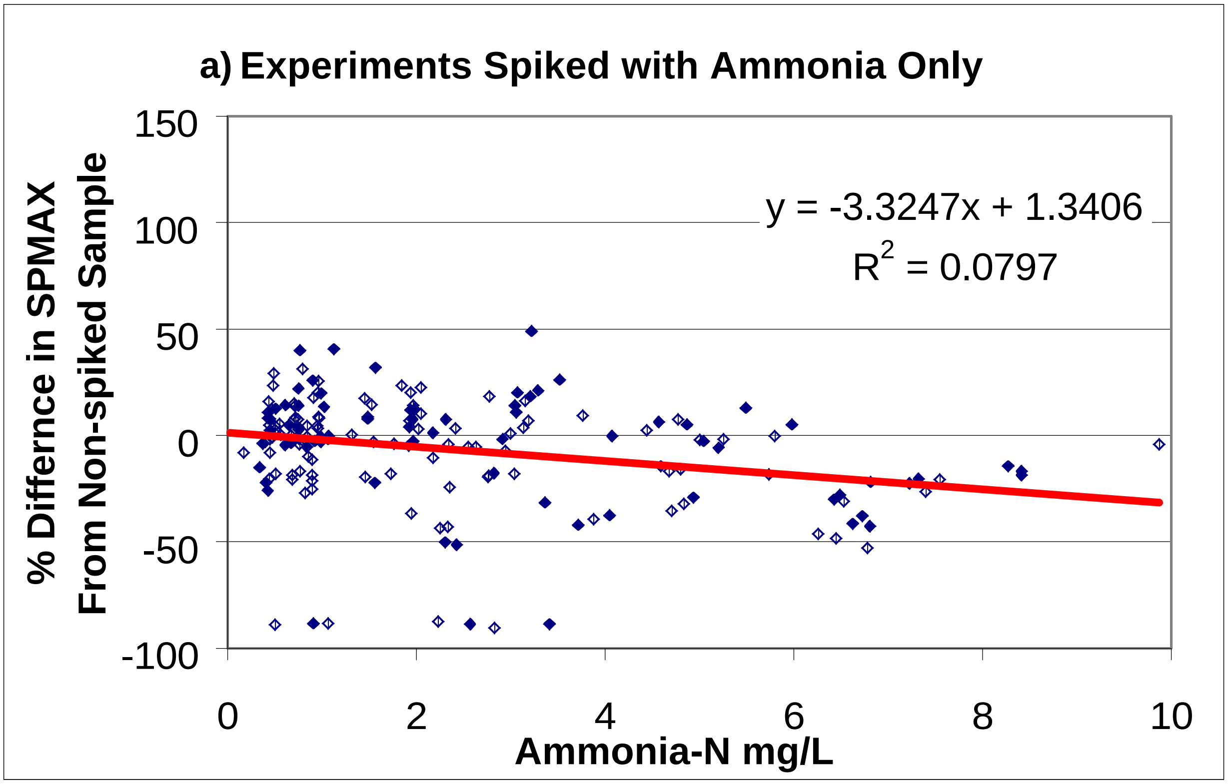
The results from roughly 200 tests done over the year in which ammonia was spiked to various concentrations were assessed to determine the percent change in specific maximum productivity as compared to specific maximum productivity of a non-spiked sample. The results are shown on Figure 6-4a. This analysis shows that at very low levels (less than 1 mg/L), there is an increase in productivity followed by a steady decline as ammonia concentrations rise about 1 towards 10 mg/L. At about 3 mg/L, the maximum productivity is about 10% lower than that which occurs with no treatment of the sample with additional ammonia. This analysis shows a consistent although not strong trend towards decreasing maximum productivity with increasing ammonia concentrations. The gradient of the trend is statistically significant (see Appendix D-14).

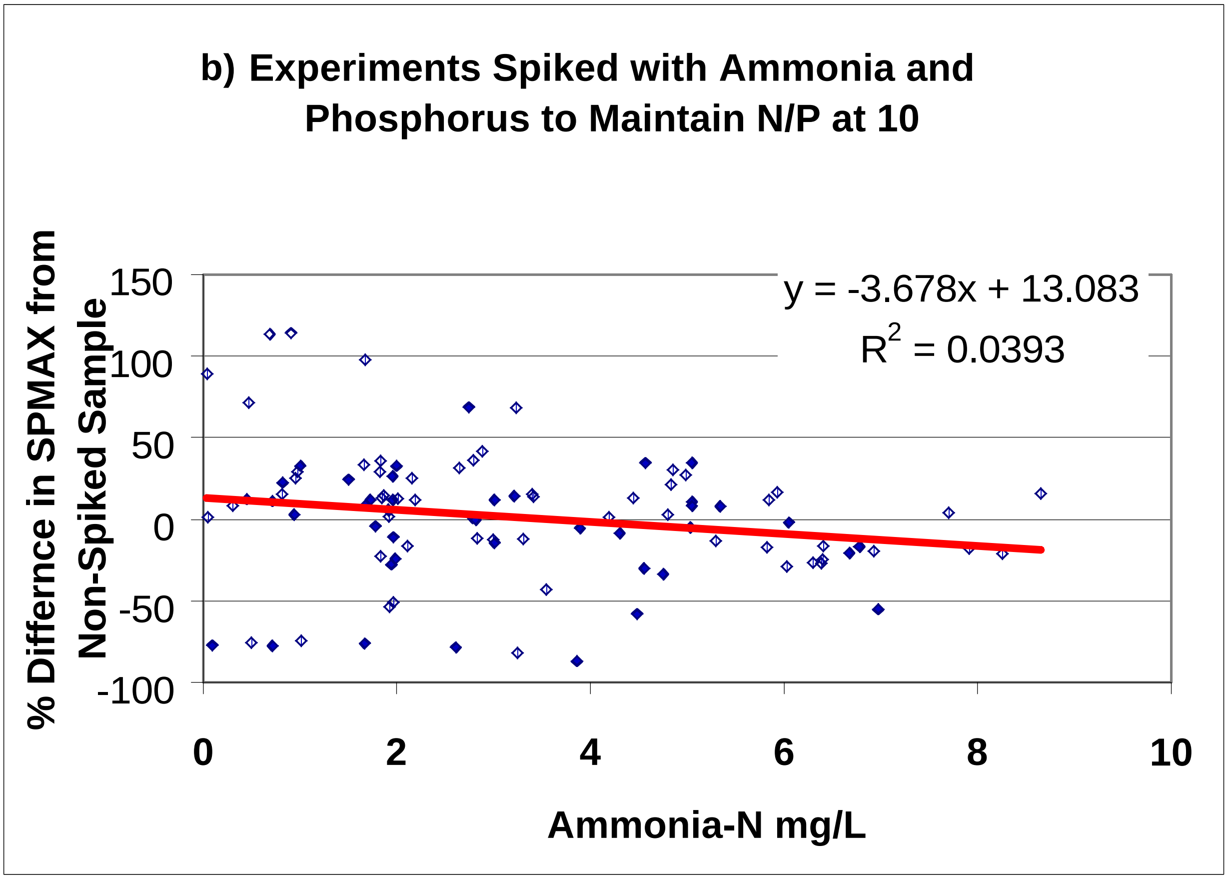
In the experiments in which ammonia and phosphorus were increased together in order to maintain an N-P ratio of about 10, the results are similar. There appears to be a somewhat higher increase in photosynthetic activity for small increases in ammonia and phosphorus, however when ammonia was increased beyond 2 or 3 mg/L, this specific maximum productivity decreased below that of an untreated sample. Again, although the trend is consistent, it is not strong (see Figure 6-4b), however, the gradient is statistically significant (see Appendix D-14).

A similar analysis on samples spiked with ammonia only and those spiked with ammonia and phosphorus was done to determine changes in photosynthetic efficiency (ALPHA). The results shown on Figure 6-5 indicate trends which are similar to those discussed for changes in specific maximum productivity (see Appendix D-15). Decreases in primary productivity and photosynthetic efficiency are about 4-7% per mg/L ammonia.

6.2.3 Impact of Nitrate on Photosynthetic Parameters

One of the key questions (No. 7) was to determine what would be the effect of ammonia control on the river conditions and aquatic life. Ammonia control would convert ammonia to nitrate producing concentrations of nitrate that are similar to the concentrations of ammonia in the river which have occurred in the past. Therefore, an experiment was done to determine the impact of nitrate on algal photosynthetic parameters. For one of the sampling periods (October 5, 1999),


a) Experiments Spiked with Ammonia Only


b) Experiments Spiked with Ammonia and Phosphorus to Maintain N/P at 10

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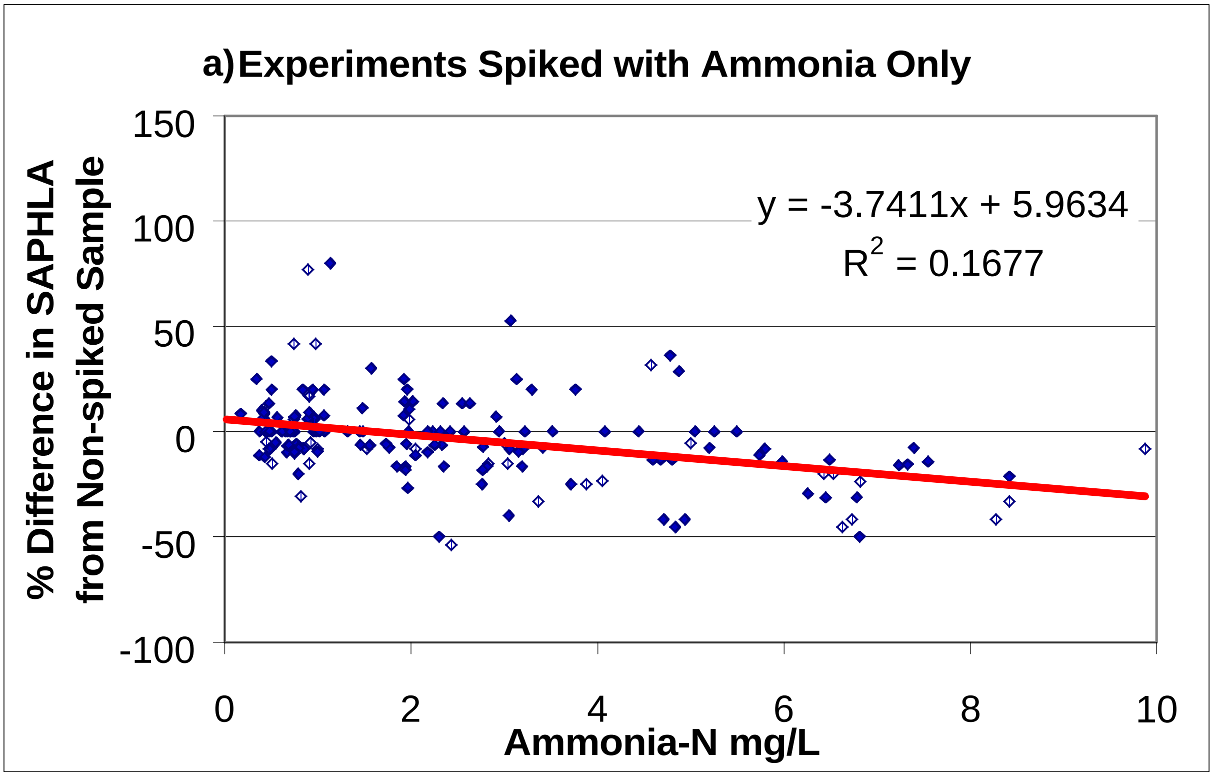
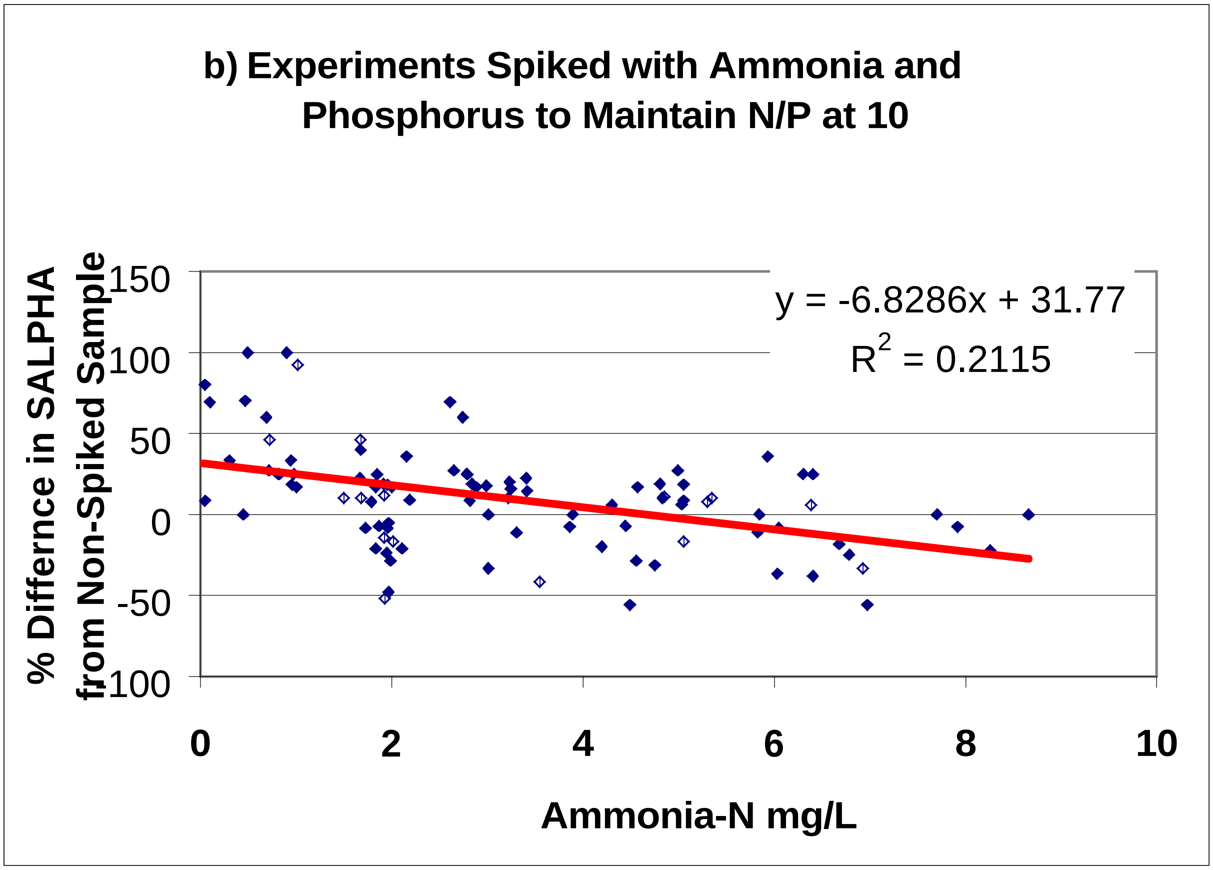
Ammonia Impacts on
Algal Maximum Productivity
Figure 6-4





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Ammonia Impacts on Algal Photosynthetic Efficiency

Figure 6-5

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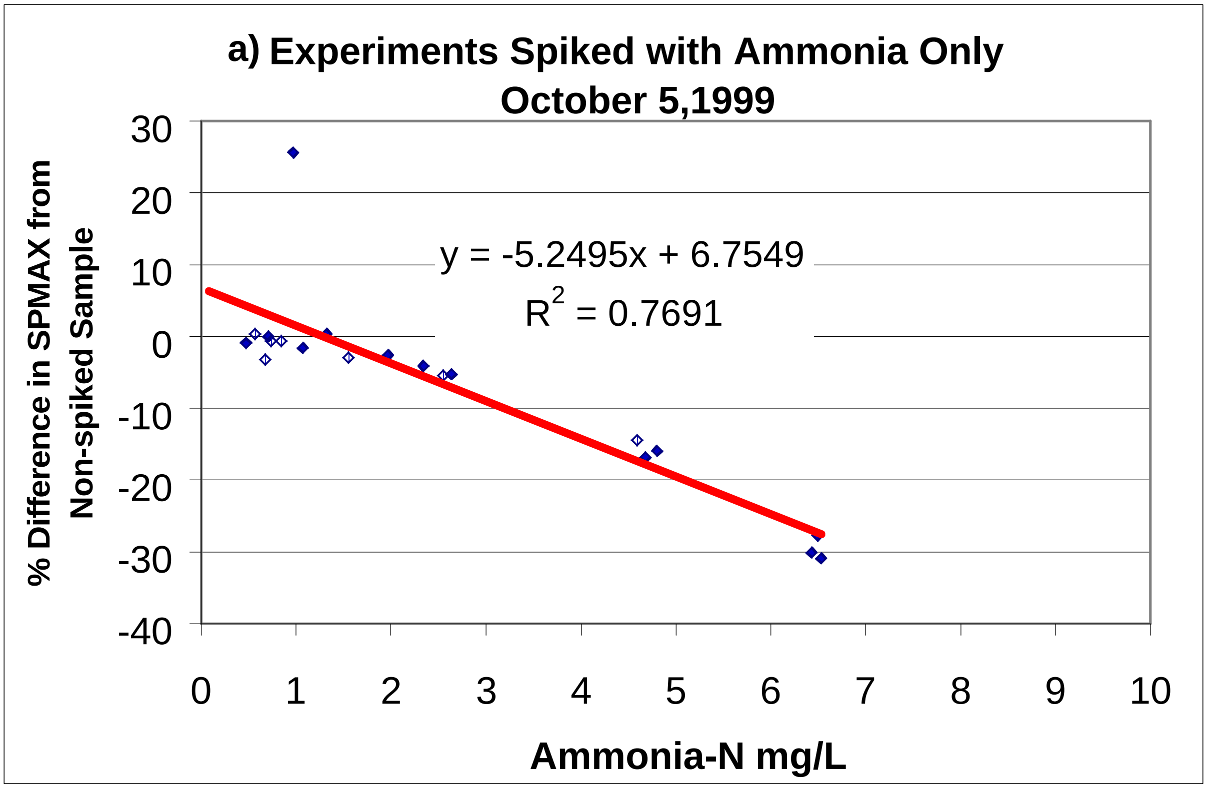
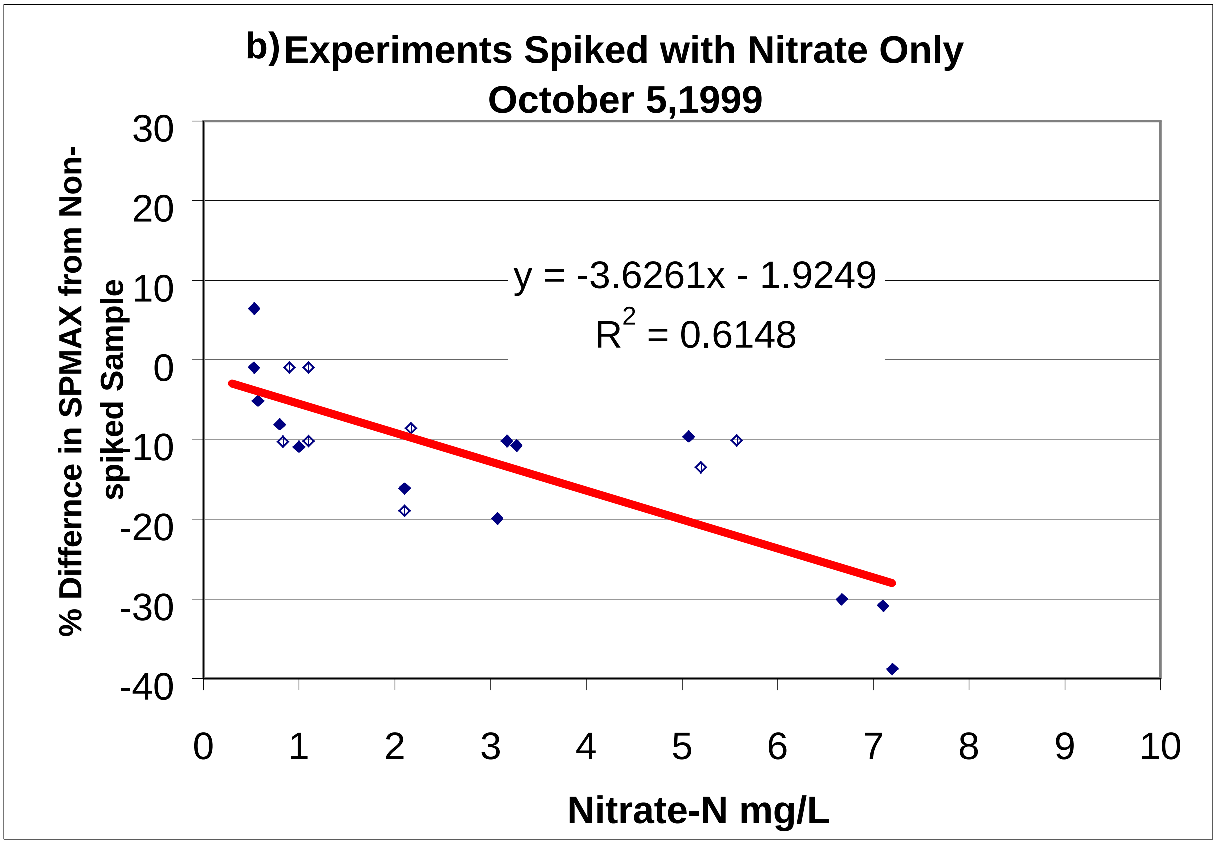


a) Experiments Spiked with Ammonia Only
October 5,1999



b) Experiments Spiked with Nitrate Only
October 5,1999

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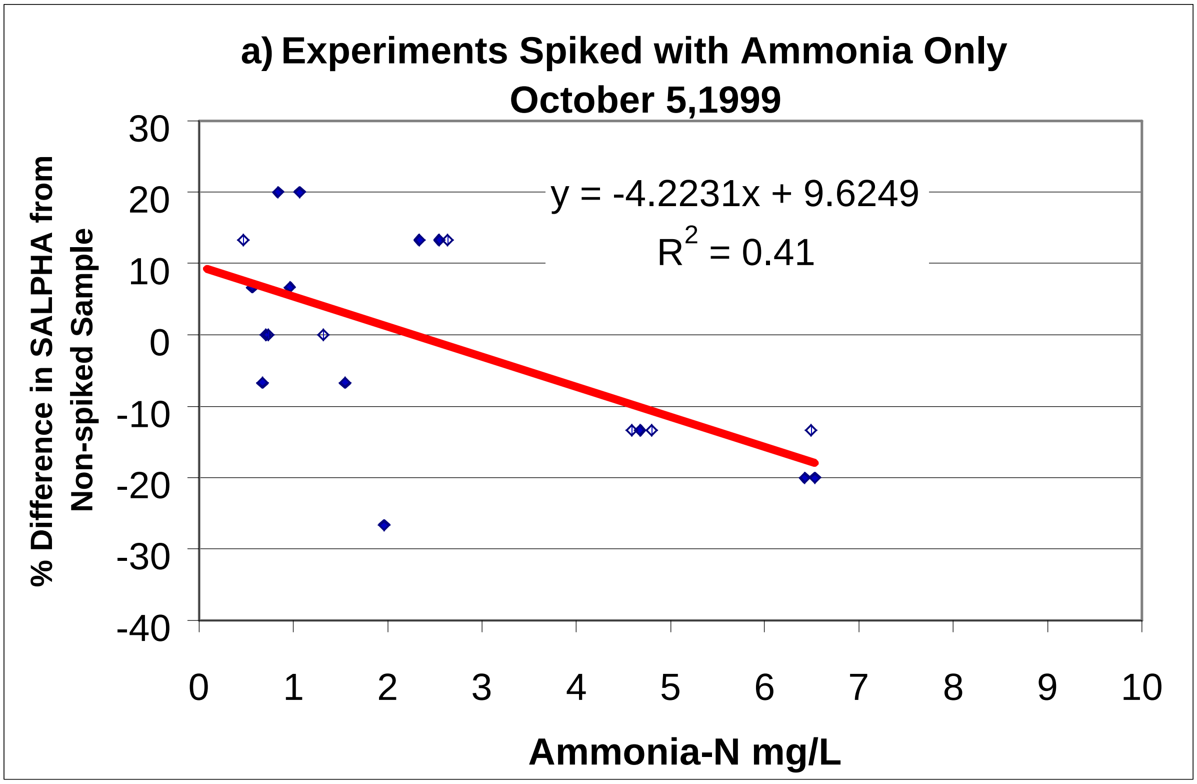
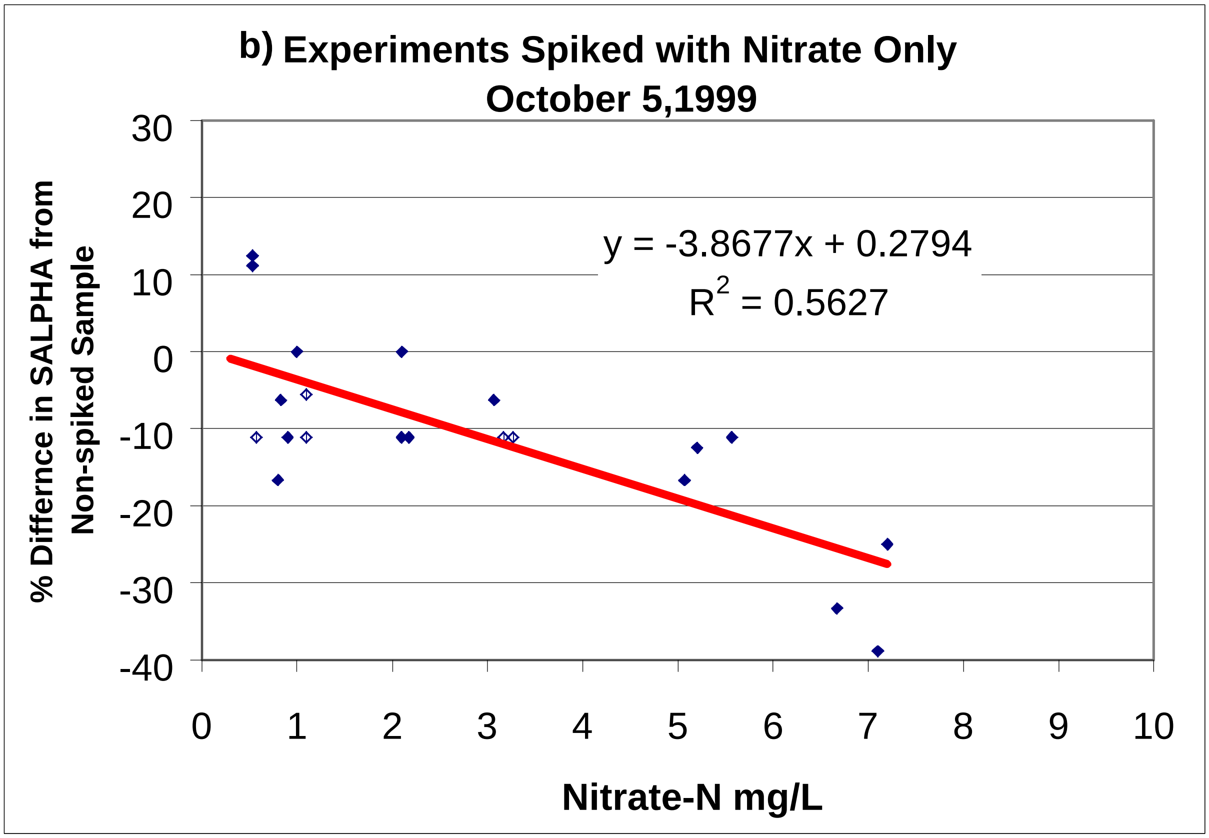
Ammonia and Nitrate Impacts on Algal Maximum Productivity
Figure 6-6


a) Experiments Spiked with Ammonia Only
October 5,1999


b) Experiments Spiked with Nitrate Only
October 5,1999

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Ammonia and Nitrate Impacts on Algal Photosynthetic Efficiency

Figure 6-7

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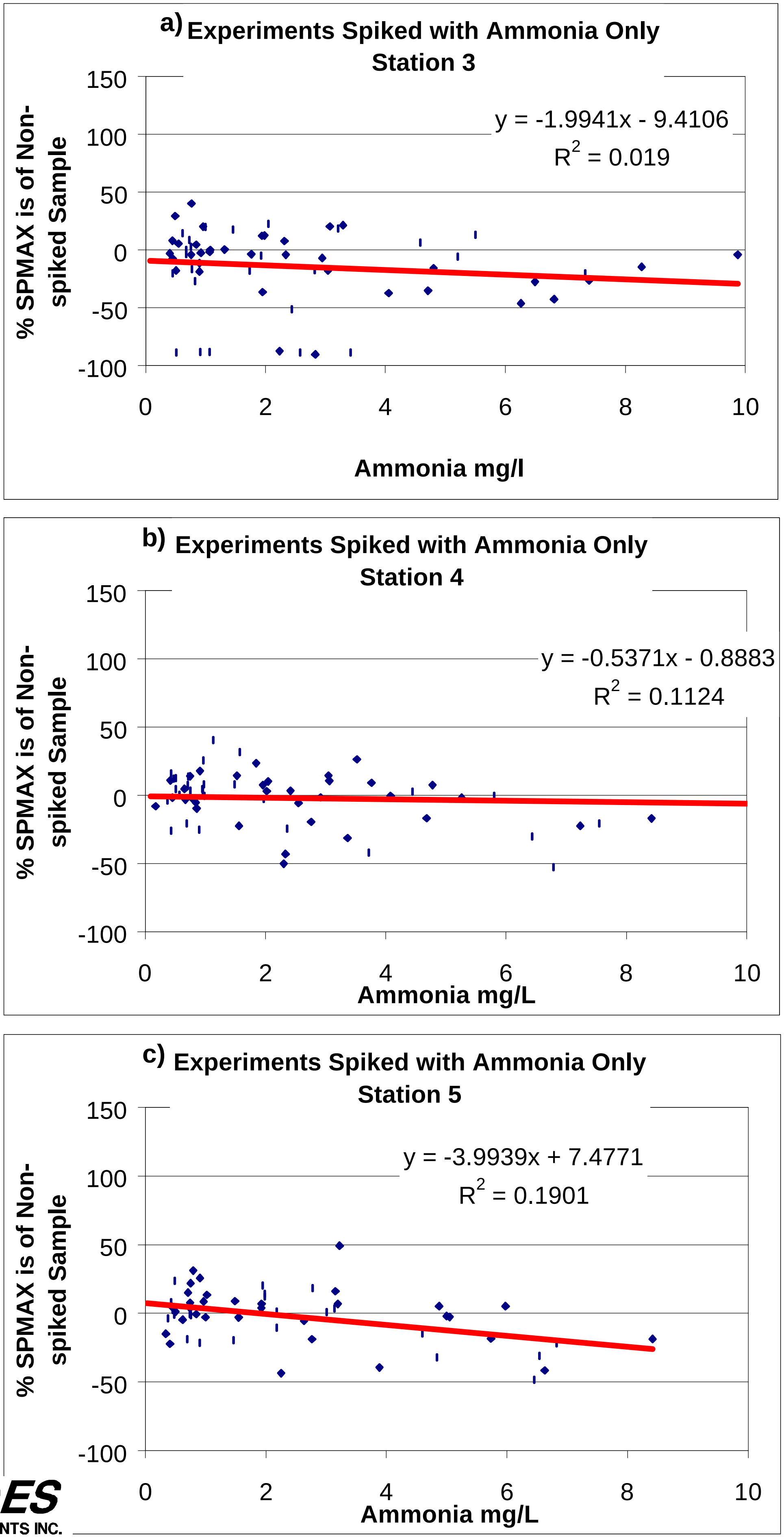
the effects of treating the samples with elevated concentrations of nitrate was done in parallel with the treatment of ammonia. The results shown on Figures 6-6 and 6-7 are statistically significant (Appendices D-16 and D-17). As can be seen from these results (see Figure 6-6) these experiments were very consistent. Both ammonia and nitrate showed similar effects on specific maximum productivity. For this date, the trend towards decreasing maximum productivity with increasing ammonia or nitrate was both consistent and strong (R^2 = 0.774 ammonia versus maximum productivity and R^2 = 0.61 for nitrate versus maximum productivity).

When the impacts of ammonia and nitrate for photosynthetic efficiency were compared, the results were also consistent (see Figure 6-7). The decreases in primary productivity and photosynthetics are similar to the earlier graphs, about 4-5% per mg/L of efficiency ammonia.

6.2.4 Variations in Algal Sensitivity With Location in the River

One hypothesis which was to be tested in the 1999 monitoring program was to determine whether algae may acclimate to ammonia in the river. If this occurred, it would be expected that algae collected downstream of the NEWPCC would show less sensitivity to elevated ammonia concentrations than algae collected upstream of the NEWPCC. As discussed earlier, with high river flows the concentration difference between upstream and downstream of the NEWPCC was not as great as expected and the travel time to the downstream sample station was much less than expected. Therefore the duration and magnitude of higher ammonia exposure experienced by the algae is not significant. The impact of ammonia on algae was assessed at the three different stations, Station 3 - 3 to 8 hours downstream of the NEWPCC, Station 4 - 1 hr downstream of the NEWPCC and Station 5 upstream of the NEWPCC (see Figure 6-8). The degree of algal sensitivity to ammonia appears to decrease in the stations downstream of the NEWPCC. The trends however are not strong, and therefore cannot be considered to be conclusive.



Ammonia and Nitrate Impacts on Algal Maximum Productivity at Stations 3, 4, & 5

Figure 6-8

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6.3 KEY OBSERVATIONS

The key observations from this algal assessment are:

- Photosynthetic activity in algae appears to decrease with increase in ammonia concentrations above 1 mg/L.
- Decreases in algal activity due to elevated nitrate concentrations are similar effect to those shown by ammonia.
- There should not be a significant change in algal productivity for the same river condition if a nitrification process converts the ammonia to nitrate prior to discharge.

7. NEAR-FIELD WATER-QUALITY MODELLING (CORMIX)

7.1 BACKGROUND

The characteristics of the mixing zone within the river is often a factor in the development of criteria to give guidance for the need or development of a mitigation system. This mixing zone is of importance because in this region the concentration is often much higher than it would be after complete mixing within the river. Criteria often allow concentrations to be higher than the long-term chronic guidance concentration and still not be considered an exceedance. This “waiver” could be considered if the concentration is not acutely toxic and sensitive species do not reside in the high concentrations long enough to have an acute effect. If the fish species are considered to avoid the plume, then the high concentrations in the mixing zone should not develop a barrier to movement of fish.

Over the course of the study, the field mixing zone analysis was used in conjunction with the *in situ* toxicity assessments done in 1999 (see Toxicity Technical Memorandum). This analysis was used to estimate the ammonia concentration at the locations where *in situ* mussel cages were placed. This will be useful in developing a dose-response analysis for mussels to ammonia.

Mixing zone analysis was also used in the fish behaviour study to determine the location of the plume during February 2000, and can be used to help interpret fish behaviour in the area of the plume.

7.2 CORMIX MODEL

The CORMIX model was developed at Cornell University and has been adopted and distributed by the U.S. EPA to perform mixing zone analysis. It is a set of analytical models (equations) of which the best equation can be selected to estimate mixing behaviour under various river and effluent conditions. The key parameters required in order to use this model are:

- river flow,

- river depth;
- river temperature;
- effluent flow;
- diameter of the outfall; and
- temperature of the effluent.

Tetr*ES* Consultants has developed a post-processor in order to use the output from the CORMIX model and provide information to a Geographic Information System (GIS). This information can then be mapped on the river and used to provide illustrations of the plume mixing.

7.3 VERIFICATION

The analytical equations used in the CORMIX model are based on physical science and physically based input parameters, therefore the model can produce representative predictions of the plumes. There are no coefficients to be adjusted for calibration in the CORMIX model.

In order to gain confidence in the output of the model a monitoring term program was conducted in the fall of 1998 to identify the mixing zones downstream of the three treatment plants (NEWPCC, SEWPCC, WEWPCC). The results of this monitoring were provided in an earlier TM (Tetr*ES* 1998). The verification generally confirmed mixing downstream of the North End Plant and the West End Plant. At the South End Plant, it was difficult to find a chemical tracer of the plume. This was due to the high river flows which diluted the ammonia concentration to very low levels. A description of the mixing zones and typical plumes downstream of the treatment plants follows in the next sub-section.

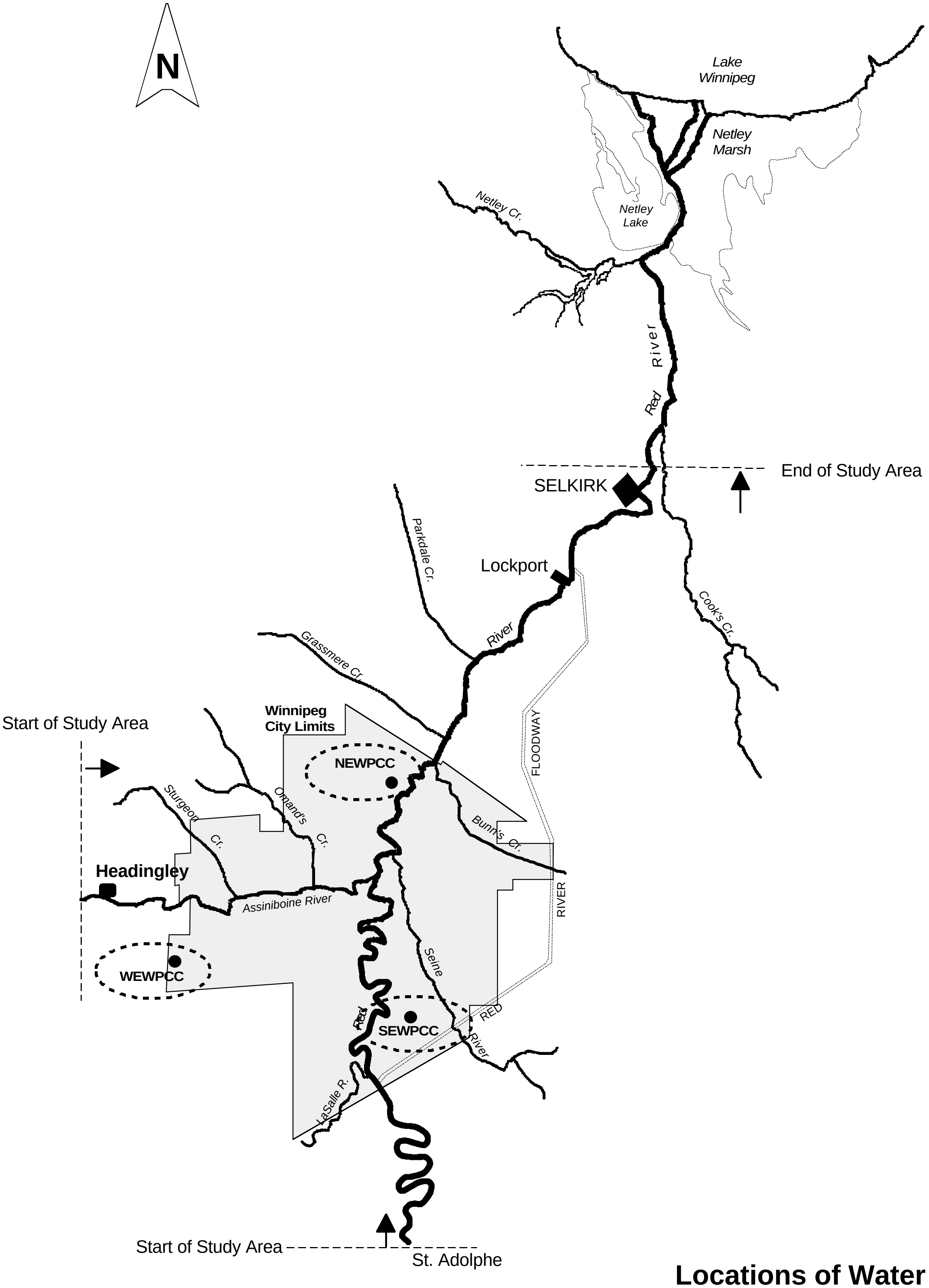
7.4 MIXING ZONE ASSESSMENTS

7.4.1 North End Water Pollution Control Centre (NEWPCC) Assessment

The NEWPCC is the largest of the three plants. It is located on the north leg of the Red River (see Figure 7-1). Typical effluent flow and the outfall diameter shown in Table 7-1 along with typical river conditions during low and average flow. The mixing in this part of the Red River is very dependent on the flow within the Red River. At high flows, there is a tendency for the plume to hug the bank and stay unmixed for a considerable distance, 3 to 5 km downstream of the North End Plant. However, during low flow conditions (which are often critical with respect to criteria setting), the high momentum of the North End discharge and the approximately 90° bend of the river will cause complete mixing immediately downstream of the outfall. The analysis of CORMIX indicated that the plume interacted with the far bank very quickly, thus validating the prediction equations available within CORMIX. For average river flow in August, a CORMIX model prediction is illustrated in Figure 7-2. This analysis indicated that the mixing of the NEWPCC effluent is complete downstream of the Chief Peguis Bridge during typical conditions in which an objective may be applied.

7.4.2 South End Water Pollution Control Centre (SEWPCC) Assessment

The SEWPCC is the second largest of the treatment plants and is located on the south leg of the Red River (see Figure 7-1). Typical key parameters are shown in Table 7-1. This outfall extends almost half way across the river before discharging. Therefore, the plume originates at the bottom of the river, near the mid-stream. An illustration of a typical plume discharge is shown in Figure 7-3. The plume typically will mix completely within one kilometre of the discharge. Under 7Q10 conditions, the plume will be completely mixed within the first 100 m. CORMIX analysis shows interaction with the far bank during very low flow, thus validating the available mixing equations, however indicating relatively quick mixing.



Locations of Water Pollution Control Centres

Figure 7-1

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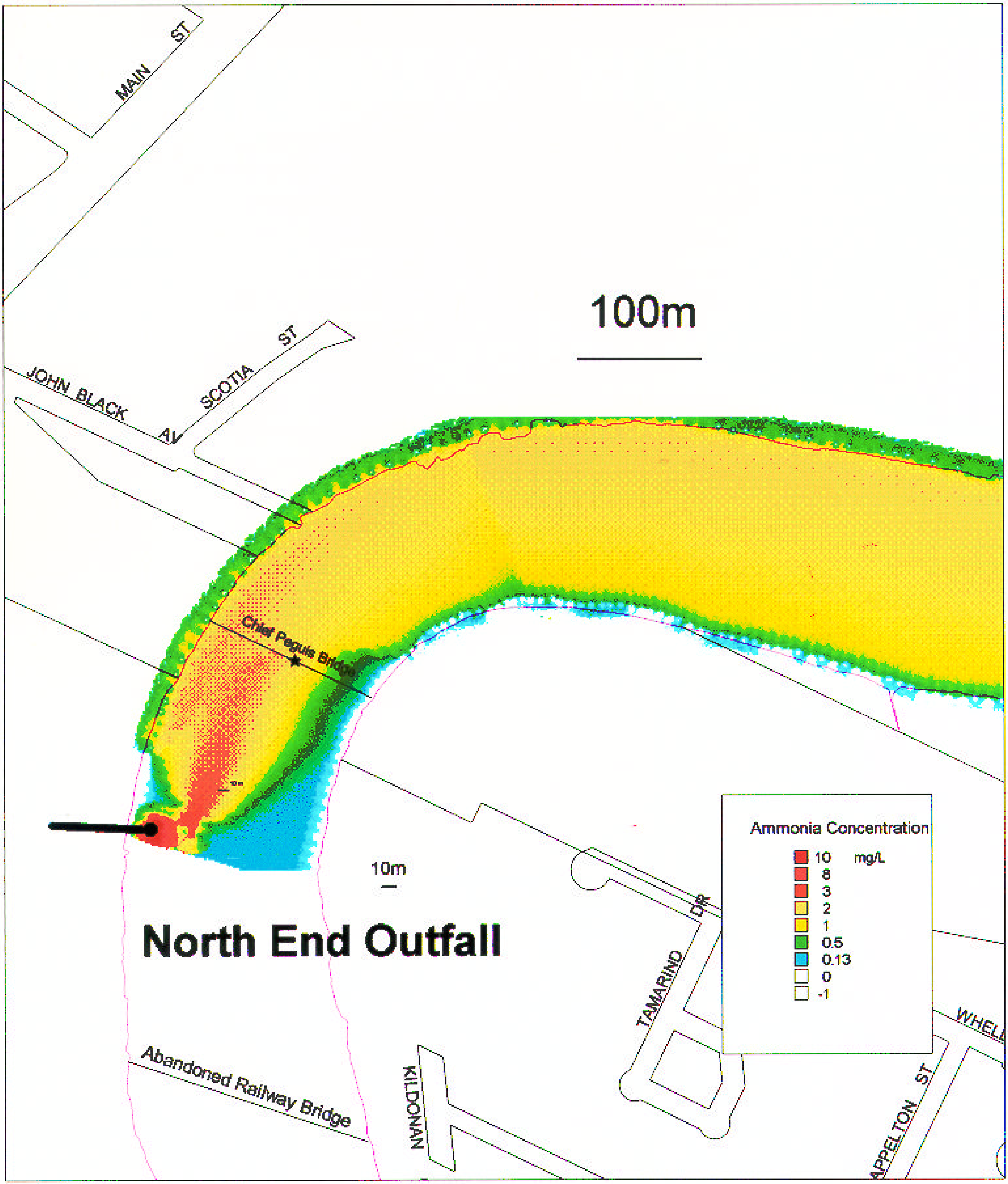
TABLE 7-1
KEY PARAMETERS USED IN CORMIX MODELLING

	Discharge		
Parameter's	**NEWPCC**	**SEWPCC**	**WEWPCC**
Effluent Flow (ML/d)	268	80	34
Effluent Flow (m^3/s)	3.10	0.93	0.39
River Flow (Low m^3/s)	18	10	5.6
River Velocity (Low m/s)	0.05	0.05	0.2
River Flow (Normal m^3/s)	100	90	30
River Velocity (Normal m/s)	0.1	0.1	0.3
Effluent Temperature (°C)	15	15	15
River Temperature (°C)	22	22	22
Diameter of Outfall (m)	1.83	1.06	na
Location	LEFT	RIGHT	RIGHT -Bank Discharge
Distance From Bank (m)	15.8	60	0
River Width (m)	150	125	90
River Depth (m)	5.5	3.2	0.5
Outfall Depth (m)	4.5	3.2	na



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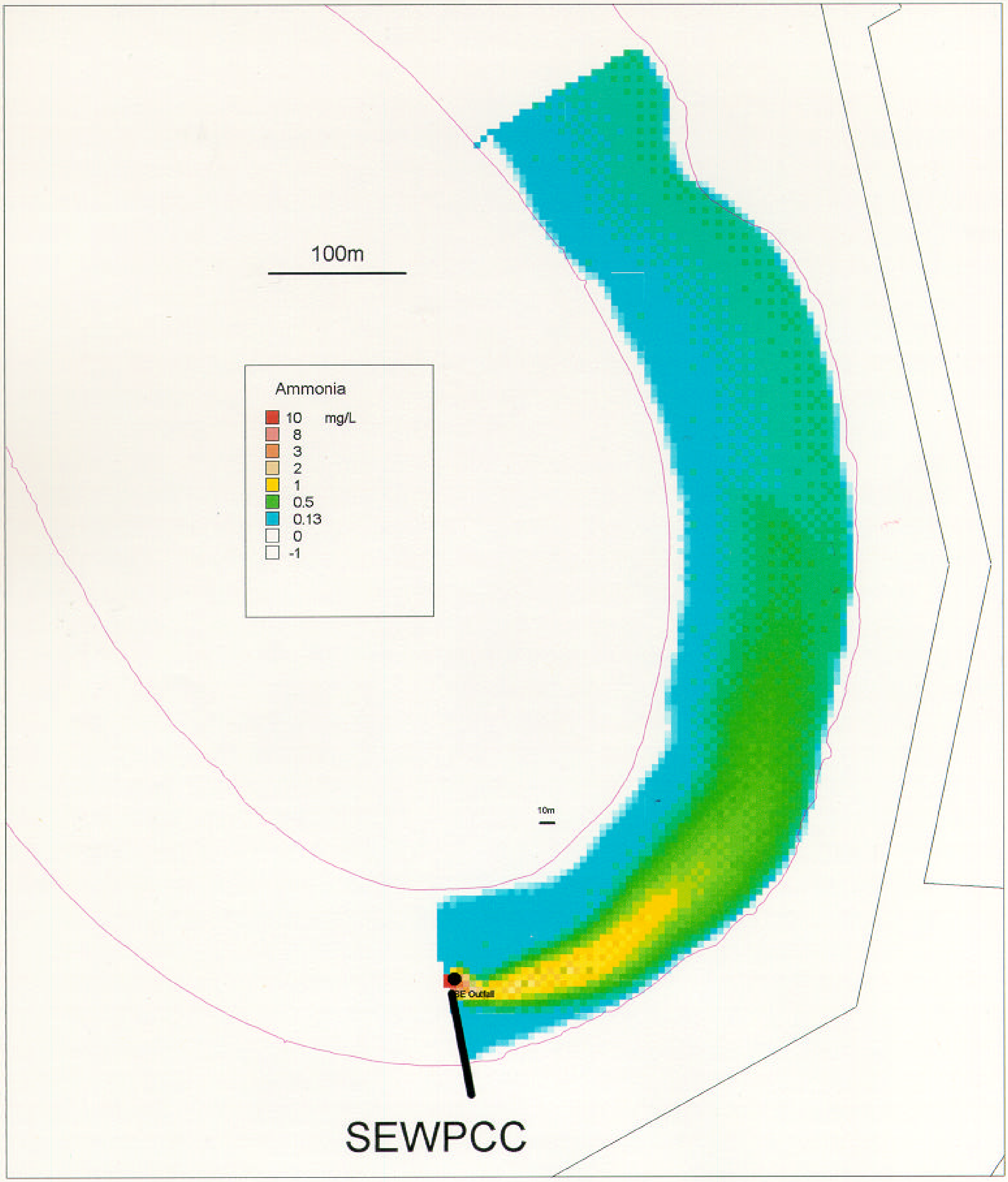
NEWPCC Plume for Typical Discharge and River Flow

Figure 7-2



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SEWPCC Plume for typical Discharge in August

Figure 7-3

7.4.3 West End Water Pollution Control Centre (WEWPCC) Assessment

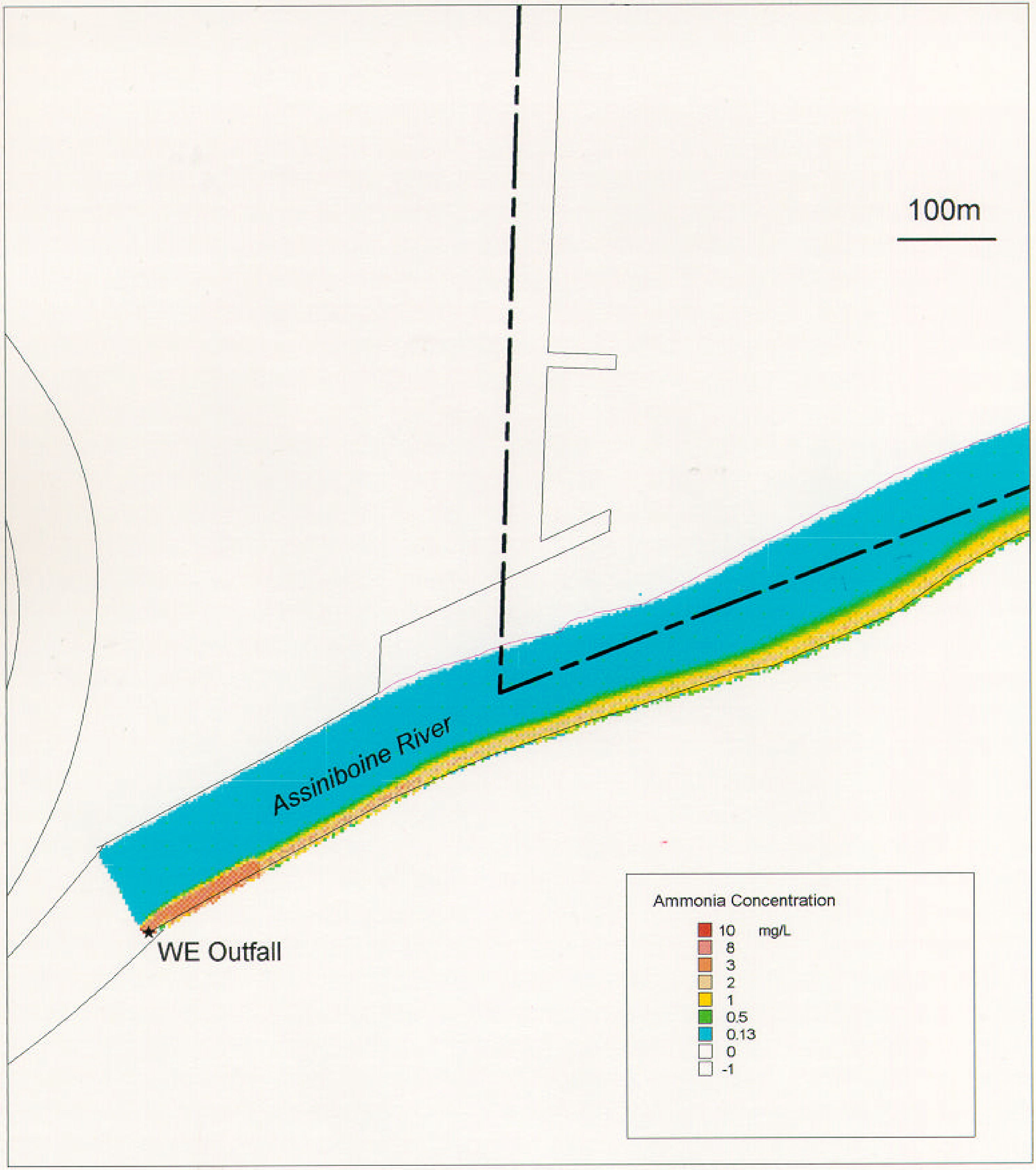
The WEWPCC is the smallest of the three plants and discharges into the Assiniboine River upstream of the City of Winnipeg (see Figure 7-1). The discharge flows out of an effluent pipe into a ditch by the side of the river. The river is fairly shallow at the point of discharge, therefore there is complete vertical mixing (see Table 7-1 for key parameters). Effluent modelling and monitoring has indicated that the WEWPCC effluent is attached to the bank for a considerable distance downstream and does not mix until after the Assiniboine Park Bridge. This condition would prevail under all conditions even the lowest flow conditions. An example of WEWPCC plume mixing during average August river conditions is shown in Figure 7-4. Plume dynamics during low river flow conditions (5.6 m^3/s) are shown in Figure 7-5.

7.5 POTENTIAL FUTURE ASSESSMENTS

Under low flow conditions, the influence of the NEWPCC plume extends across the river and the concentrations of ammonia remain high for a considerable distance down to Lockport. Therefore, the key assessments in terms of impacts on the river, can be done with a 1-dimensional (1-D) model, as shown in Section 8. The SEWPCC plume will mix rapidly during low flow condition. Therefore, again, the critical long-term assessment can be done with a 1-D model.

WEWPCC effluent does not mix fully until downstream of Assiniboine Park. Therefore, a considerable section of the river does not have full mixing. This area of full mixing may not be significant if the concentrations are not high enough to be acutely toxic. The width of the mixing zone is generally less than 25% of the river and therefore should not pose a barrier to fish movement. Fish behaviour, being assessed in a parallel workstream, may add to the understanding of fish behaviour in and around the plume.

If it is deemed necessary to have complete mixing immediately downstream of any of the outfalls, this can be done with a multi-port diffuser. The detailed assessment of multi-port diffusers is beyond the scope analysis at this point but could be done at a later date using the CORMIX model.



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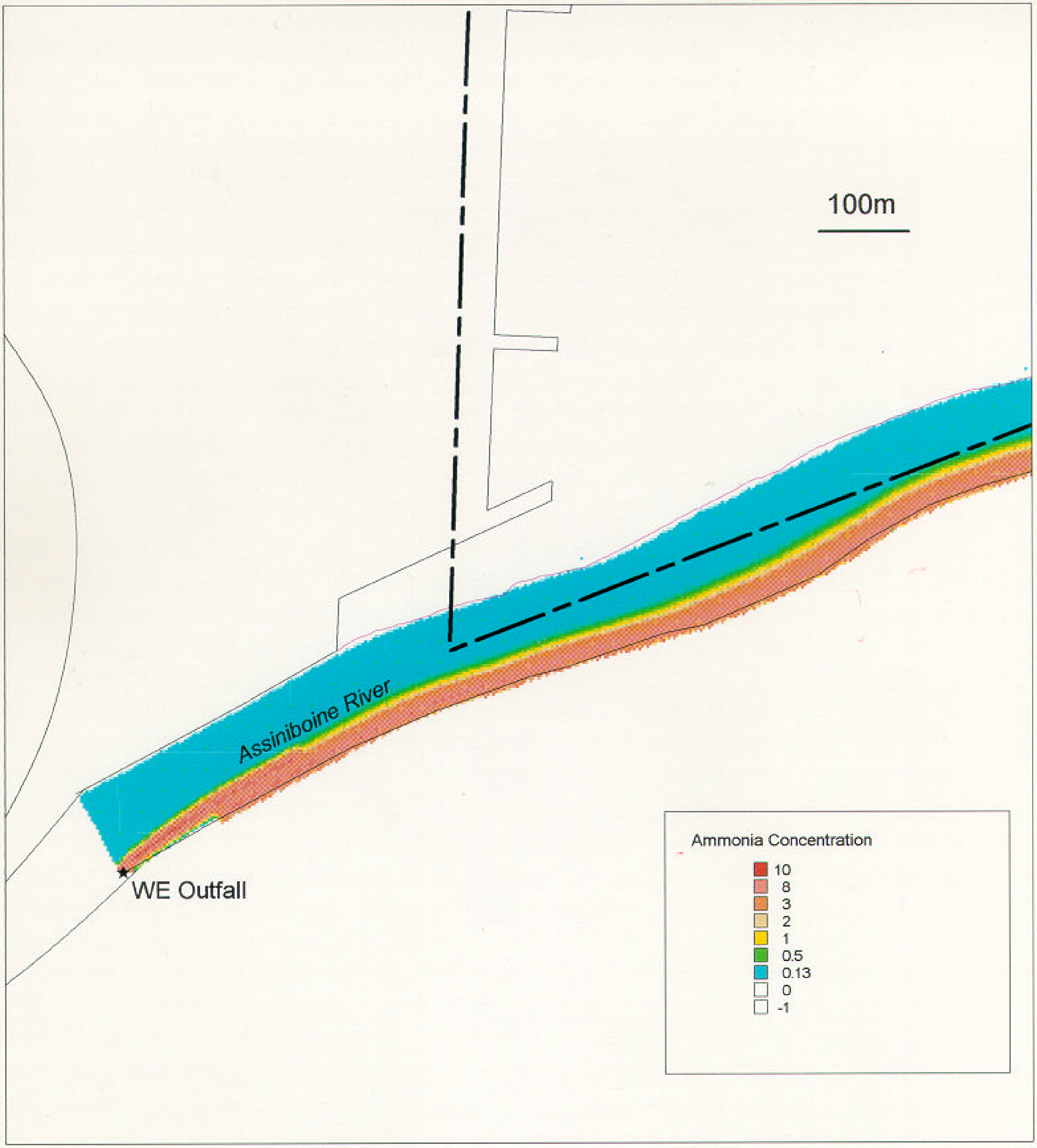
Ammonia Plume Mixing Model Output from WEWPCC- Average August Flow

Figure 7-4



Ammonia Plume Mixing Model Output For WEWPCC results for Low Flow Conditions

Figure 7-5

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8. LONG-TERM DYNAMIC MODELLING

8.1 GENERAL APPROACH

A water-quality criteria is developed in order to give guidance to the development of licences for wastewater discharge limits. This licence can direct the treatment plant designers in the development of a system which will reduce the risks to the local assemblage to an acceptable level as determined by the criteria. In order to estimate this risk, we need to know the impact an effluent discharge will have in terms of influencing the frequency and duration of periods during which the water-quality criteria is exceeded. When a limited water-quality database is available, steady-state modelling techniques are used in conjunction with an average design flow. (This design-flow method is discussed in more detail in Section 9.) Steady-state modelling considers only a single condition; effluent flow and waste load as well as water chemistry are assumed to be constant.

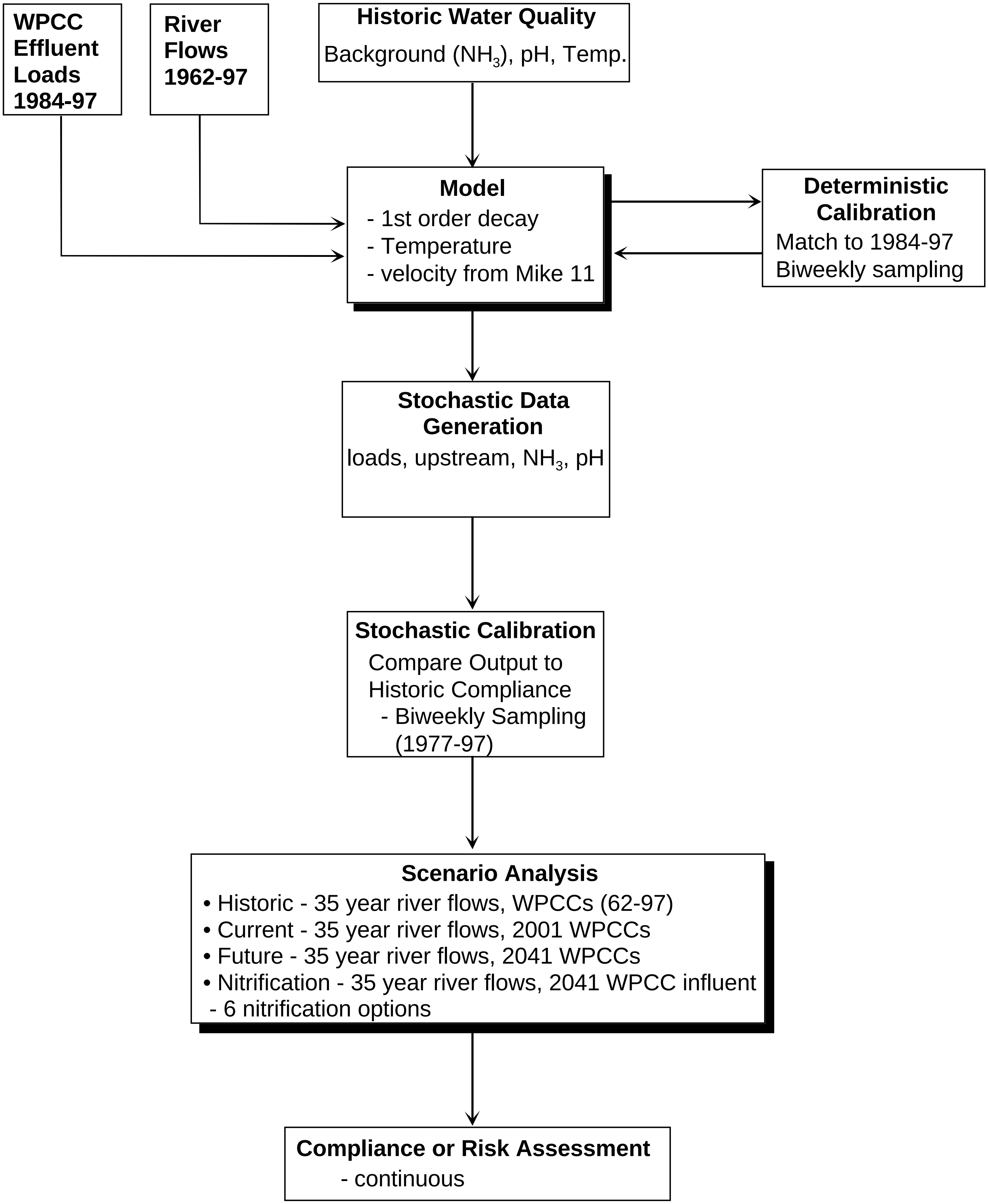
The EPA states in their *Technical Support Document for Water Quality Based Toxic Controls* (EPA 1991) that “the impact of the receiving water flow variability on the duration for which and frequency with which criteria are exceeded, it is **implicitly** included in the design condition if these conditions reflect the desired toxicological effects regime. Dynamic modelling techniques **explicitly** predict the effects of receiving water, effluent flow and concentration variability.”

The US EPA recommends one of three dynamic modelling techniques for waste load allocations (WLA). These are:

- continuous simulation;
- Monte Carlo simulation; and
- log normal probability modelling.

The methodology selected in this study was the continuous simulation model. An outline of the continuous long-term modelling approach discussed in this section is given in Figure 8-1.

The advantage of the dynamic methods is that they can calculate a long-term time series of receiving water concentrations (RWCs) rather than a single worst case concentration based on



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Long-Term Modelling Approach
Figure 8-1

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design flow conditions. Therefore these methods can be used to calculate a probability distribution for RWCs. The EPA states that “prediction of complete probability distributions allows the risk inherent in alternative treatment strategies to be directly quantified.” The advantage of dynamic modelling methods versus the steady-state methods is that maximum daily and monthly average permit limits can be obtained directly from the effluent long term average (LTA) concentration and coefficient of variation (CV) that characterizes distribution. Generally, steady-state modelling has been used to calculate only a chronic waste-load allocation. Steady-state modelling generates a single allowable effluent value and no information about effluent variability.

The analysis of the output of the continuous simulation model will be discussed in an integration technical memorandum dealing with a risk assessment. This Technical Memorandum will focus on the methodologies used to develop a long-term time series of predicted un-ionized ammonia concentrations from the past, under current conditions, and under various treatment conditions in the future (2041). The EPA states that “continuous simulation models have the following advantages compared to steady-state formulations:

- the frequency and duration of the toxicant concentration in a receiving water can be predicted;
- the cost correlation and interaction of time varying pH, flow, temperature, pollutant discharge and other parameters are incorporated;
- the effect that the serial correlation of daily flows and other parameters has on the persistence of criteria excursions is incorporated;
- long-term streamflow records from ungauged rivers using precipitation and evapotranspiration can be synthesized;
- the long-term simulations can prevent the initial conditions used in the model from affecting the calibration of fate in transport processes.”

The first 3 bullets stated by the EPA are the most important in the study of the Red and Assiniboine Rivers. The only drawback stated by the EPA is that “unlike steady-state models, continuous simulation will require significantly more data to apply, calibrate, and/or verify a specific problem and require that input data for the application of the model be time series data.” Fortunately these problems are not an issue in the Red and Assiniboine rivers due to the long-term database of river flows and water quality collected by the City of Winnipeg and the Province of Manitoba over the past 40 years.

Water quality data in the rivers dates back to 1977, data from the effluent from the treatment plants dates back to 1984, and gauged records at all locations on the three rivers dates back to 1962. At Headingley, there is continuous stream flow data back to 1912, however, the data upstream of Winnipeg at St. Agathe has only been recorded since 1962. There is potential to estimate the record on the Red River at St. Agathe to 1912, by using the longer period of record recorded at Emerson at the Canadian/USA border. This has not been done at this time and would require a regression analysis. The suitability of using this type of data to project low flows has not been investigated.

Another advantage of this long-term simulation method is that it can be used to perform a direct risk assessment on some of the key species for which considerable toxicity data has been collected (see Toxicity TM Workstream). This risk assessment will be developed in another Technical Memorandum on integration of the various workstreams.

8.2 STOCHASTIC DATA GENERATION

In order to predict the river conditions in the future, an understanding of the past conditions is needed. The river flows for future conditions were determined by assessing the long-term record of flows at Headingley, St. Agathe and Lockport. The flows are representative of what could happen in the future, however, they must be modified to account for current conditions of river regulation. The Shellmouth Dam is regulated partially to minimize the impact of low flows on the Assiniboine River. The Water Resources Branch of Manitoba Conservation has developed a program to predict a time series of flows from 1962 to 1997, under regulation rules for the Shellmouth Dam, based on natural flows of the river.

The City of Winnipeg has collected water-quality records on a bi-weekly frequency since 1977. The change in variation in river flow from year to year was shown earlier in Section 2.2. In order to predict water quality on any given day in the future, two methods could be used. The water-quality data could be considered to match the same date as the river flow data. This would allow for about 20 years of parallel datasets. However, there is no water-quality data between

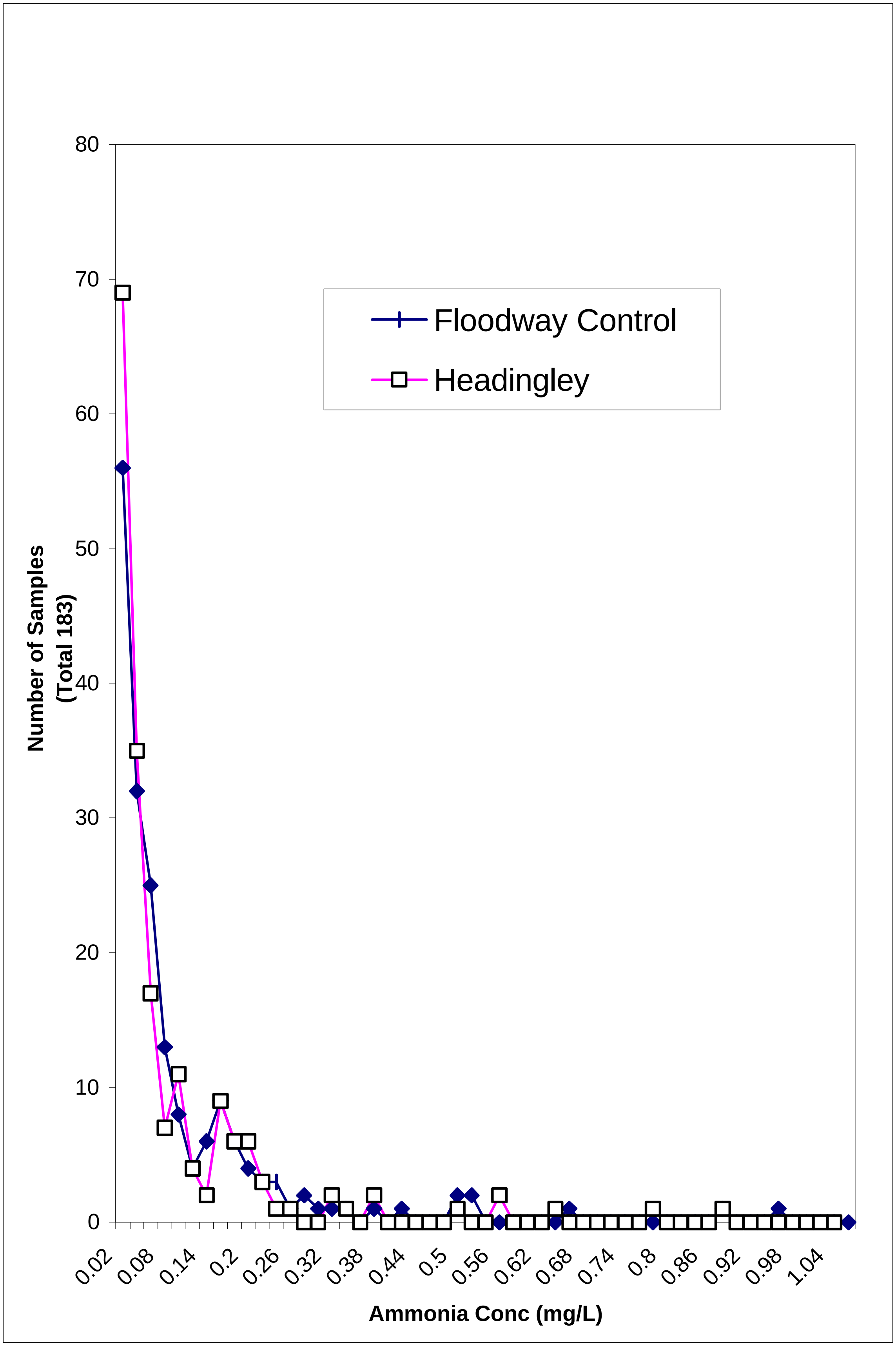
1962 and 1977 therefore water-quality data such as background ammonia, pH and temperature for each of the stations must be developed. The temperature of the river water does not vary significantly throughout the region and a statistical function which predicts the river temperature based on a date of the year can be developed from past records. An analysis of pH records indicates that it varies by location in the river system. Therefore, a statistical method (Monte Carlo) was required to predict the pH on any given day for each monitoring station. Analysis of the river data shows the pH varies normally (see Figure 3-5) at each of the stations. pH also varied monthly at each of the stations. Therefore, a monthly normal distribution method was used to generate likely pHs for any given month of the year at each sample station.

Ammonia concentrations are required on the upstream reaches of the Red and the Assiniboine rivers in order to create initial conditions for the water-quality model. Analysis of water-quality data at the Floodway Control Structure and Headingley are shown to vary from month to month. The statistical distribution of upstream ammonia is not normal or log-normal as illustrated in Figure 8-2. Various background ammonia concentrations at each of these stations upstream of the City of Winnipeg are shown in Tables 8-1 and 8-2. The Monte Carlo method was used to randomly “draw” background ammonia conditions for each day of the month based on the values in this table. Each of the previously-mentioned water quality concentrations were considered to have an equal probability of being drawn on any given day.

Using the methods described above, a river flow, water temperature, pH, and background ammonia could be selected for any day in the future. A 36-year record (1962-1997) was developed of river conditions. This record of basic river conditions could be used to assess the impacts of various Water Pollution Control Centre (WPCC) effluent loads on water quality which were developed as discussed in the next section.

8.3 WPCC EFFLUENT LOADS

In order to develop the historic effluent discharges which can be used in the calibration of the model (see sub-sections 8.5 and 8.6), the historic WPCC effluent data from 1984 to 1997 was used. Monthly mean ammonia concentrations for both the raw wastewater and the effluent were developed for each of the WPCCs. The ratio of effluent to influent ammonia concentrations for each month was calculated as shown on Table 4-5. In order to estimate



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Histograms of Ammonia Data Upstream of City of Winnipeg

Figure 8-2

TABLE 8-1
RANKED AMMONIA CONCENTRATIONS FOR EACH MONTH AT HEADINGLEY

Rank	January	February	March	April	May	June	July	August	September	October	November	December
1	0.07	0.05	0.02	0	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.08
2	0.08	0.06	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.1
3	0.09	0.07	0.05	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.12
4	0.1	0.1	0.05	0.05	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.12
5	0.12	0.1	0.1	0.06	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.16
6	0.15	0.12	0.18	0.09	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.18
7	0.16	0.14	0.22	0.09	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.2
8	0.16	0.15	0.37	0.15	0.02	0.02	0.02	0.02	0.02	0.02	0.04	0.64
9	0.16	0.15	0.55	0.18	0.02	0.02	0.02	0.02	0.02	0.03	0.04	
10	0.17	0.19			0.03	0.02	0.02	0.02	0.02	0.03	0.05	
11	0.17	0.19			0.03	0.02	0.03	0.02	0.02	0.03	0.05	
12	0.18	0.2			0.04	0.03	0.04	0.03	0.03	0.03	0.05	
13	0.2	0.22			0.04	0.03	0.04	0.04	0.03	0.03	0.06	
14	0.24	0.31			0.04	0.04	0.04	0.05	0.03	0.03	0.15	
15	0.25	0.5			0.05	0.05	0.04	0.05	0.03	0.04		
16	0.34	0.55			0.05	0.06	0.08	0.08	0.03	0.04		
17	0.37				0.06	0.31	0.1	0.09	0.04	0.07		
18	0.78				0.13		0.19		0.04	0.09		
19	0.88				0.21							

TABLE 8-2
RANKED AMMONIA CONCENTRATIONS FOR EACH MONTH AT FLOODWAY CONTROL

Rank	January	February	March	April	May	June	July	August	September	October	November	December
1	0.07	0.06	0.02	0.05	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
2	0.08	0.09	0.02	0.06	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
3	0.08	0.09	0.06	0.07	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
4	0.1	0.13	0.08	0.09	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.05
5	0.11	0.15	0.08	0.14	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.09
6	0.14	0.18	0.11	0.15	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.17
7	0.14	0.28	0.14	0.17	0.03	0.03	0.02	0.02	0.02	0.02	0.03	0.23
8	0.15	0.37	0.15	0.18	0.03	0.03	0.04	0.02	0.02	0.02	0.03	0.25
9	0.15	0.5	0.15	0.21	0.03	0.03	0.04	0.02	0.03	0.02	0.05	
10	0.16	0.51	0.19	0.24	0.04	0.04	0.04	0.03	0.03	0.02	0.06	
11	0.16	0.51	0.21	0.66	0.05	0.04	0.05	0.04	0.03	0.03	0.06	
12	0.17	0.96	0.27		0.05	0.04	0.05	0.04	0.03	0.03	0.07	
13	0.22		0.41		0.06	0.06	0.08	0.06	0.03	0.03	0.07	
14	0.31				0.07	0.06	0.09	0.06	0.04	0.03	0.07	
15	0.33				0.1	0.08	0.11	0.06	0.04	0.05	0.11	
16	0.49				0.16	0.09	0.14	0.06	0.04	0.05		
17	0.88				0.18	0.23	0.19	0.06	0.04	0.05		
18					0.2		0.19		0.07	0.06		
19					0.3					0.06		

influent loads to the WPCCs a methodology used by Josephson (1999) to estimate ammonia load in kilograms per capita per day was used. Population served by each of the three treatment plants were estimated for each of the years from 1962 to 1997. The historic inflow in kilograms per day to each of the plants can then be estimated. Using the coefficients developed in Table 4-5, an estimate of the effluent concentration and mass loadings from each of the plants could be determined from 1962 to 1997. This methodology can be used to estimate historic water quality back to 1962. Since the WEWPCC and lagoons and the SEWPCC were not in operation through that whole period, this method may slightly over- or under-estimate the ammonia concentrations in the sections of the river immediately downstream of those plants. The NEWPCC data should provide a fairly realistic prediction of effluent quality during that period. Since in the 1960s and 1970s the SEWPCC and WEWPCC were significantly smaller than the NEWPCC it is unlikely the over- or under-estimation of ammonia concentrations will make a significant difference in calculations of aquatic risk or compliance in the risk assessment (see Integration TM).

In order to predict current and future effluent water quality, information was obtained from the parallel study (RCPL 2000) being done on various nitrification options for the WPCCs. A tabulation of the monthly mean and standard deviation of the effluent quality for each scenario is given in Section 4.5.

8.4 MODEL DEVELOPMENT

In order to predict the concentration of total ammonia in the river under various future scenarios for a continuous daily record of over 35 years, an effective yet simple water-quality model was required. Since the parameter of interest over the long term is ammonia, a first-order decay model was developed to model the changes of ammonia as it travels through the river system over various times of the year. The model developed is a 1-Dimensional (1-D) model, which assumes that there is complete lateral mixing of the effluent within a short range downstream of the outfall. This assumption is fairly consistent with the conditions downstream of the NEWPCC and WEWPCC during lower flow conditions due to the high volume of effluent relative to river flow during these critical periods.

This 1-D model is less representative of the conditions in the Assiniboine River especially between the WEWPCC and Assiniboine Park. Halfway between Assiniboine Park and the Main Street there is likely greater mixing and the model would be representative of the conditions in the lower Assiniboine River. If other analysis indicates that fish are attracted to the mixing zone rather than avoiding it, and the concentrations within the mixing zone may be toxic to fish, it is possible to increase dilution with a multi-port diffuser. This can be assessed at a later stage during licencing and design of the outfall. The costs of multi-port diffuser are relatively low when compared to the costs of nitrification.

The first order decay model developed uses Chicks law, that is

$$C = C_O e^{-kt} \qquad \text{eq(8-1)}$$

$$K = K_{20}\theta^{(20-T)} \qquad \text{eq(8-2)}$$

Where:

$C =$ concentration in the river (mg/L)

$C_O =$ initial concentration of the river immediately downstream of the outfall determined by calculation the dilution of the effluent by river water (mg/L)

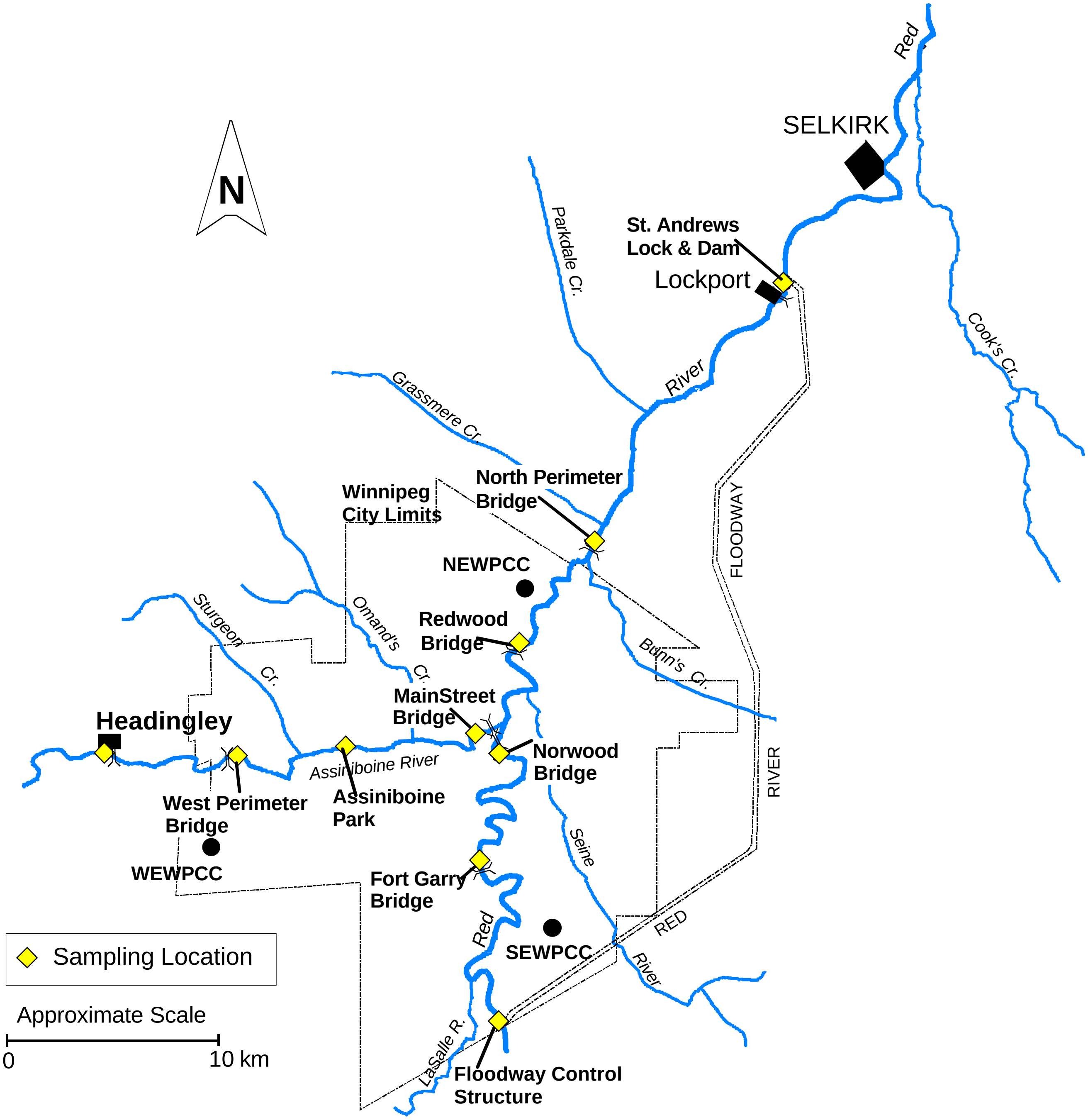
$K =$ decay coefficient which varies dependent upon the temperature of the water

$t =$ the travel time between the outfall and the point for which the concentration needs to be determined (in days)

$K_{20} =$ decay coefficient at 20°C

The travel times from each outfall to the sample station for which we want to estimate the concentration was determined using the velocities calculated by the MIKE11 model. This model was described in more detail in Section 2.3.

The model was developed using object-orientated programming language available in Paradox (ObjectPal). This allowed the use of very large databases containing 36 years of daily records for flows in the rivers and travel times for each day from point to point in the river, as well as daily waste-loads estimated for each WPCCs using the methods described earlier. The model can provide an output of concentrations at each of the sample stations shown in Figure 8-3.



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City of Winnipeg Bi-Weekly Routine Sampling Locations

Figure 8-3

These sample stations coincide with the sample stations for which there is a long period of record of water-quality data.

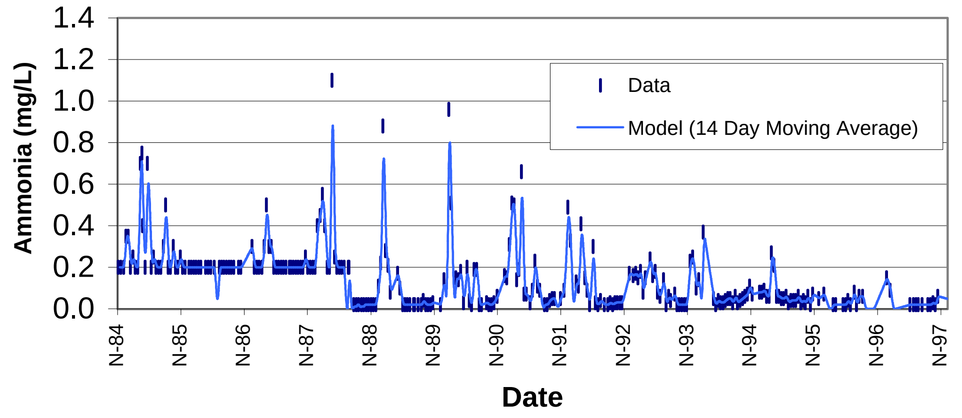
8.5 DETERMINISTIC MODEL CALIBRATION

In order to determine if the model described above could accurately represent ammonia concentrations within the river the actual measured loads from the treatment plant were used in a model in conjunction with actual river flows and water temperatures from 1984 to 1997. The model then predicted water quality in the river for each day from 1984 to 1997. The 14-day moving average of these model results was calculated in order to match against the bi-weekly monitoring done between 1984 and 1997 at nine stations. The background concentrations at Headingley and the Floodway were calculated by interpolating between the actual record taken approximately every 14 days. A representation of these calibration results are shown on Figures 8-4 through 8-6. The upper Red River model results are shown on Figure 8-4. Representations at the Floodway Control sample station illustrate how a 14-day average developed from the interpolation of the data matches against the actual data points. The Fort Garry Bridge and Norwood Bridge illustrate how accordingly the model predictions calibrate to the data. Ammonia concentrations at the Norwood Bridge have only been monitored since 1990, therefore there is no data to match against during the 1980s. However, by referring to Figure 8-4, it is evident that the model gives a good representation of water-quality variation in the river when the effluent quality is known.

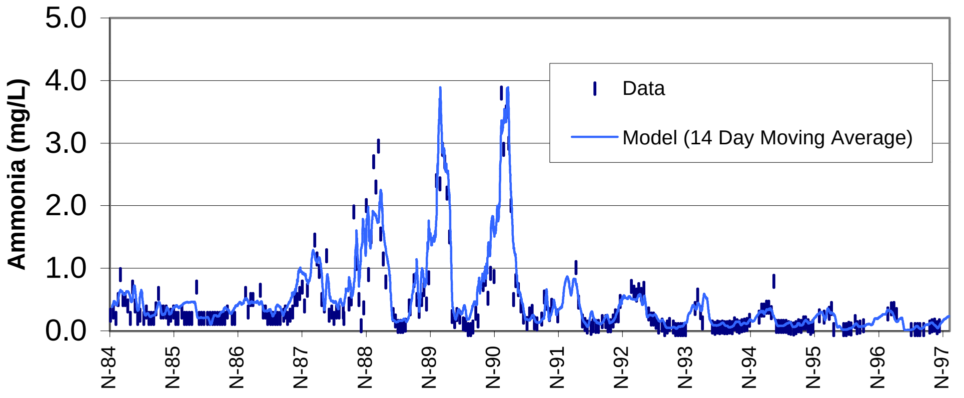
Similarly, a comparison of model results to monitored data was done for the Assiniboine River (see Figure 8-5). Although there is limited data at the Assiniboine Park Bridge, and there are known limitations in the representation of a 1-D model, the concentrations represented by this model appear to be fairly accurate. Over a long period of record from 1984 to 1997, at the Main Street Bridge, the concentrations predicted by the model closely represent the data.

For the lower Red River (downstream of The Forks) a similar analysis and comparison was done (see Figure 8-6). There is less data at the Redwood Bridge (1990-1997) and, since 1991, the model predicts the ammonia concentrations fairly accurately during this period. The representations in late 1990 and early 1991 do not appear to accurately represent the data which could be a limitation in either the model or the early data collected at the Redwood

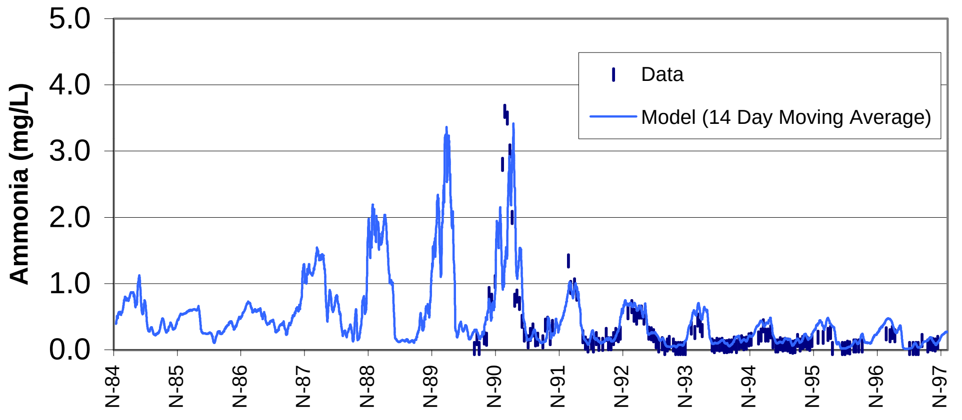
a) Floodway Control



b) Fort Garry Bridge

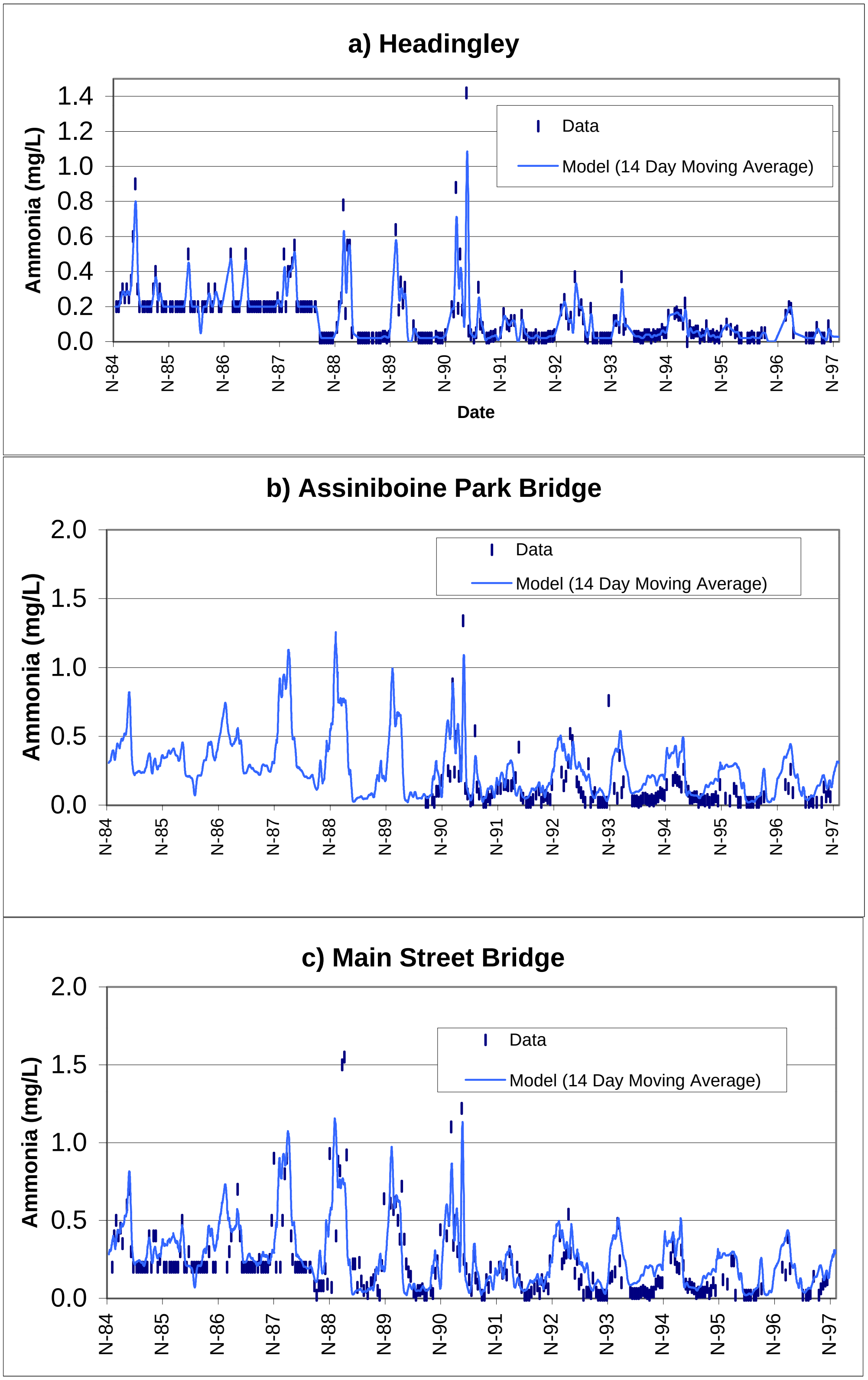


c) Norwood Bridge

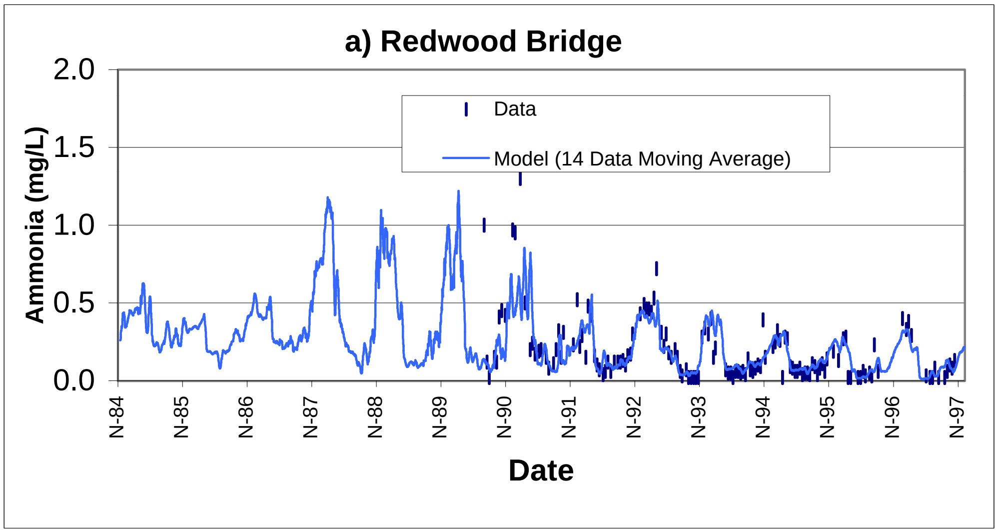


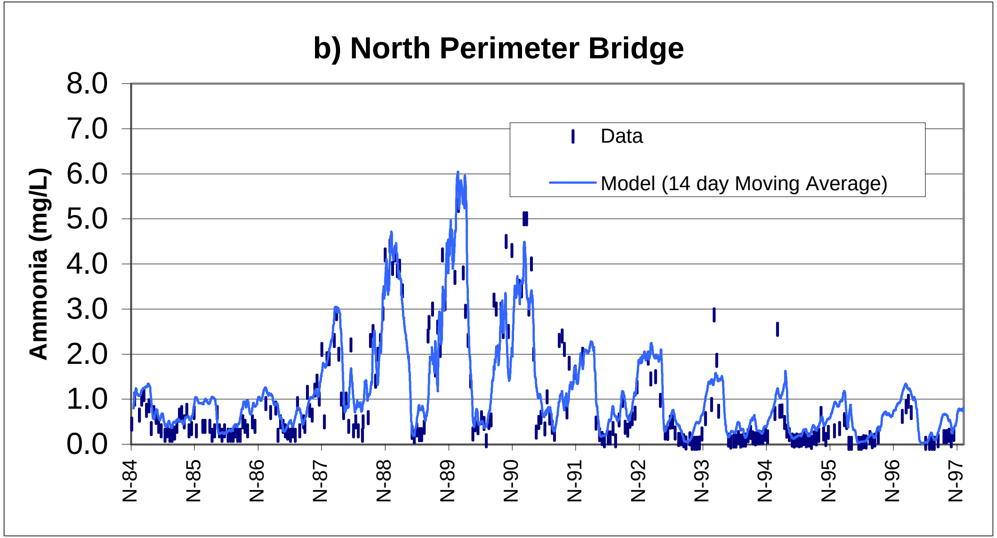
Deterministic Calibration of Upper Red River for Ammonia

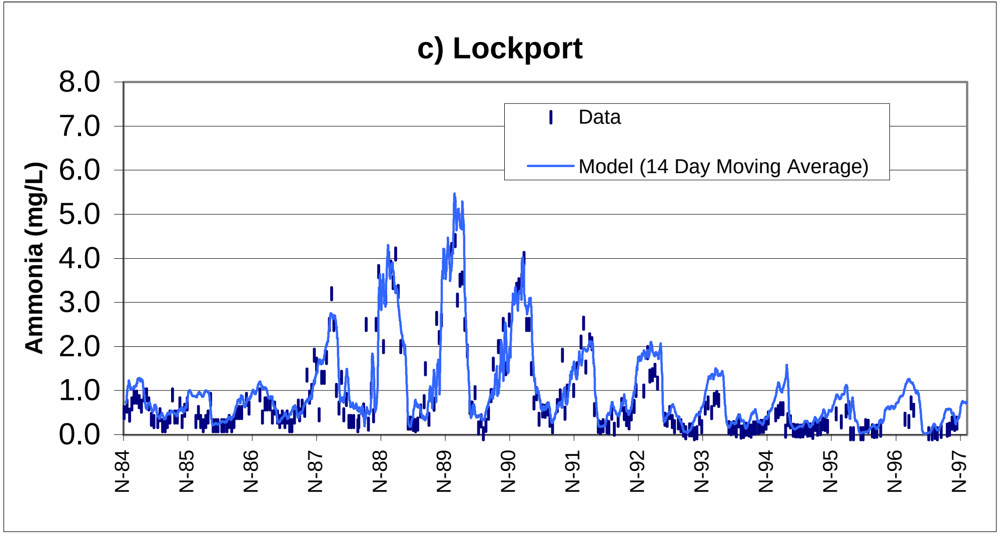
Figure 8-4



Deterministic Calibration of Assinniboine River for Ammonia
Figure 8-5







Deterministic Calibration of Lower Red River for Ammonia
Figure 8-6

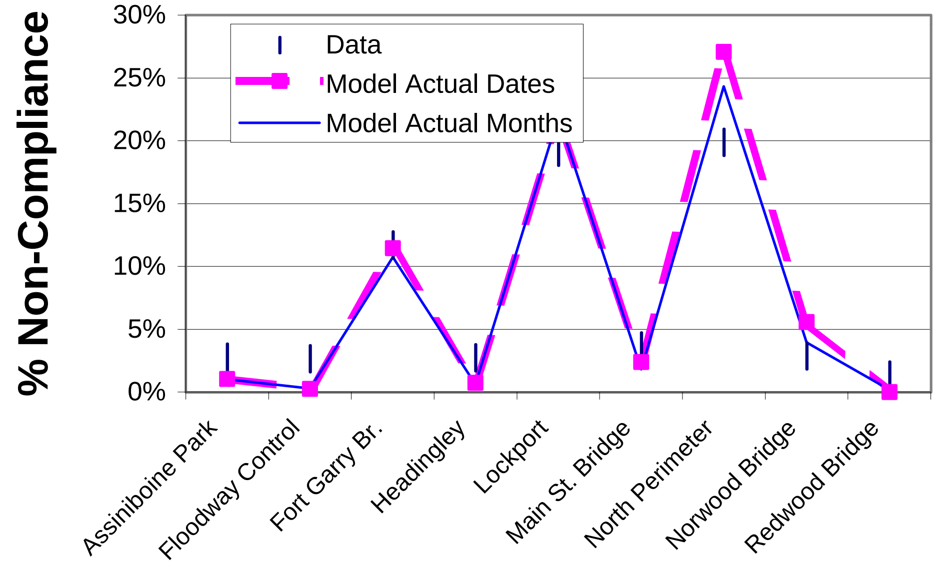
Bridge. At the key stations downstream of the North Perimeter Bridge and Lockport for which the concentrations are high, the model represents the actual monitored data very accurately over a 13-year period.

In summary, the excellent match between predicted and measured water-quality data at seven stations within the study area indicate that water quality throughout the region can be predicted with known effluent discharge concentrations. Therefore the first order decay model coefficients, dilution calculations and travel times developed with MIKE11 can be used to predict future river conditions.

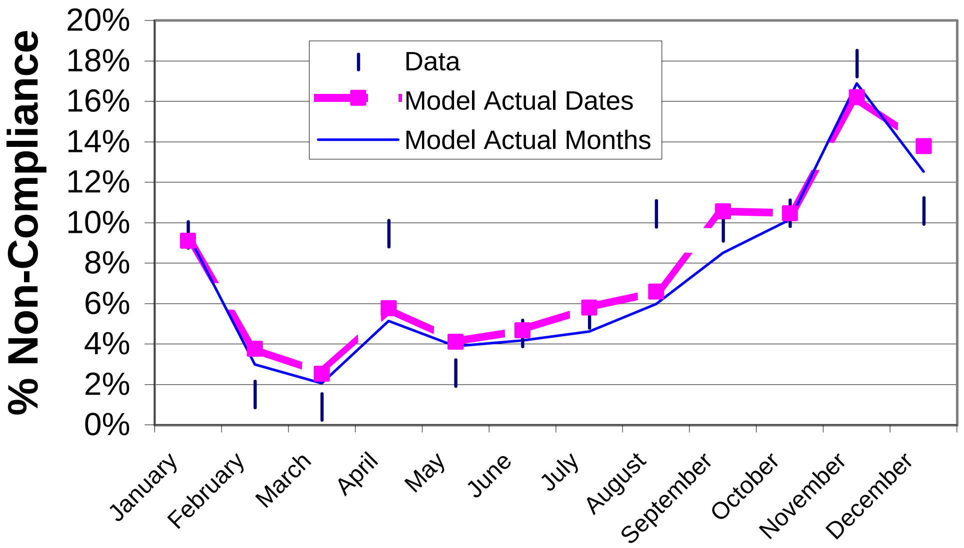
8.6 STOCHASTIC MODEL CALIBRATION

In order to predict un-ionized ammonia concentrations throughout the region over a 35-year period rather than the 13-year period described above, we need to have a good statistical representation of upstream ammonia concentrations, pH, temperatures, as well as effluent variation from each WPCC. In order to test whether stochastic Monte Carlo model simulations accurately represent conditions in the river a stochastic model calibration was performed. Using the Monte Carlo method to generate the key parameters of upstream ammonia concentration, pH, temperature and effluent loads, water-quality concentrations at 7 sampling stations were predicted using the model. Using the 1988 Manitoba Surface Water Quality Objectives (MSWQOs) percent compliance of river ammonia concentrations from the model output from 1977 to 1997 was calculated. For this period of record, there are bi-weekly monitoring data at these 7 locations. The 1988 MSWQO for un-ionized ammonia was used since this objective considers temperature, pH, as well as total ammonia in order to estimate un-ionized ammonia. The historic compliance at each station was calculated and compared to the model estimates of compliance.

The stochastic calibration is shown in Figures 8-7 and 8-8. At each of the stations, the actual data was used (total ammonia, pH and temperatures) to calculate the percent of time the MSWQOs of 1988 were exceeded. Two methods were used to assess the model output data. First, the model predictions for the actual dates on which bi-weekly sampling occurred were used with the generated pH and temperature and total ammonia concentration to calculate whether the objectives were exceeded. Secondly, the entire month (28 to 31 days) of daily



Stochastic Calibration-
Comparison of MSWQO at Each Station
Figure 8-7



Stochastic Calibration
Monthly Compliance at all Stations
Figure 8-8

records were used for total ammonia, pH and temperature generated by the model in order to calculate compliance. Figure 8-7 shows that, for each of the nine stations monitored and modelled, the compliance estimates are fairly similar. The model predicts non-compliance higher than actual non-compliance at the North Perimeter Bridge. This could be due to the 1-D modelling assumption which would assume complete mixing at the North Perimeter Bridge. In reality the sampling station, in the middle of the river, may at some times miss sampling the plume, therefore indicating compliance more often than actually occurs.

Another analysis was done by matching the non-compliance record for each month at all stations (using the actual bi-weekly database) versus the monthly non-compliance record from data predicted by the model for the actual dates on which bi-weekly sampling occurred. These results are shown on Figure 8-8. The model predictions throughout the year are an accurate representation of un-ionized ammonia as represented by non-compliance to the 1988 MSWQO. Some of the months, such as April and August, may have slightly under-predicted un-ionized ammonia concentrations while other months such as December, February and March may have slightly over-predicted un-ionized ammonia concentrations.

In summary, the Monte Carlo method used to predict pH, temperature, background ammonia, as well as effluent quality, will give representative un-ionized ammonia concentrations and can be used to determine compliance or non-compliance for any selected criteria magnitude.

8.7 DEVELOPMENT OF SCENARIOS FOR ASSESSMENT

A range of historical, current and potential future waste-load allocation scenarios were developed in order to provide a time series of un-ionized ammonia concentrations for either an assessment of compliance or develop a probability of impacts for specific species using site-specific toxicity data. For all the scenarios, a daily pH and temperature for the area was generated for the entire record, using the Monte Carlo simulation methods. Similarly, the background ammonia concentrations were generated using the Monte Carlo analysis discussed earlier in this section. The scenarios which were developed and run with the model include the following:

- an historic water-quality record from 1962 to 1997 (**Historic**);
  - actual river flows on all three rivers were used; and
  - an estimation of the actual historic loads for each of the areas were used to obtain daily effluent discharge predictions.

- current river conditions (**Current**);
  - the 36 years of historic daily flows (1962-1997) were used for the Red River and the 36 years of river flows as simulated considering the upstream regulation was used on the Assiniboine River;
  - the 1997 average annual plant flows were used in combination with the no-treatment monthly effluent quality mean and standard deviation as developed by RCPL (see Section 4).

For the following future scenarios the same 2041 plant discharges (Josephson 1999) and regulation river flow for 36 years of record were used:

- future no-nitrification conditions in 2041 (No-nitrification);
  - the no-nitrification at SEWPCC;
  - the no-centrate removal option at NEWPCC provided by RCPL (see Section 4); and
  - the WEWPCC effluent with no-nitrification ammonia concentration and no lagoon polishing from the WEWPCC was used.

- future optimized treatment plant scenario (Optimize Existing);
  - NEWPCC uses centrate removal option;
  - SEWPCC uses no-nitrification option;
  - WEWPCC uses lagoons as polishing pond option.

- future optimized treatment plants plus water treatment at SEWPCC (Optimize Existing plus Moderate);
  - NEWPCC uses centrate removal option;
  - SEWPCC uses moderate treatment option;
  - WEWPCC uses lagoons option.

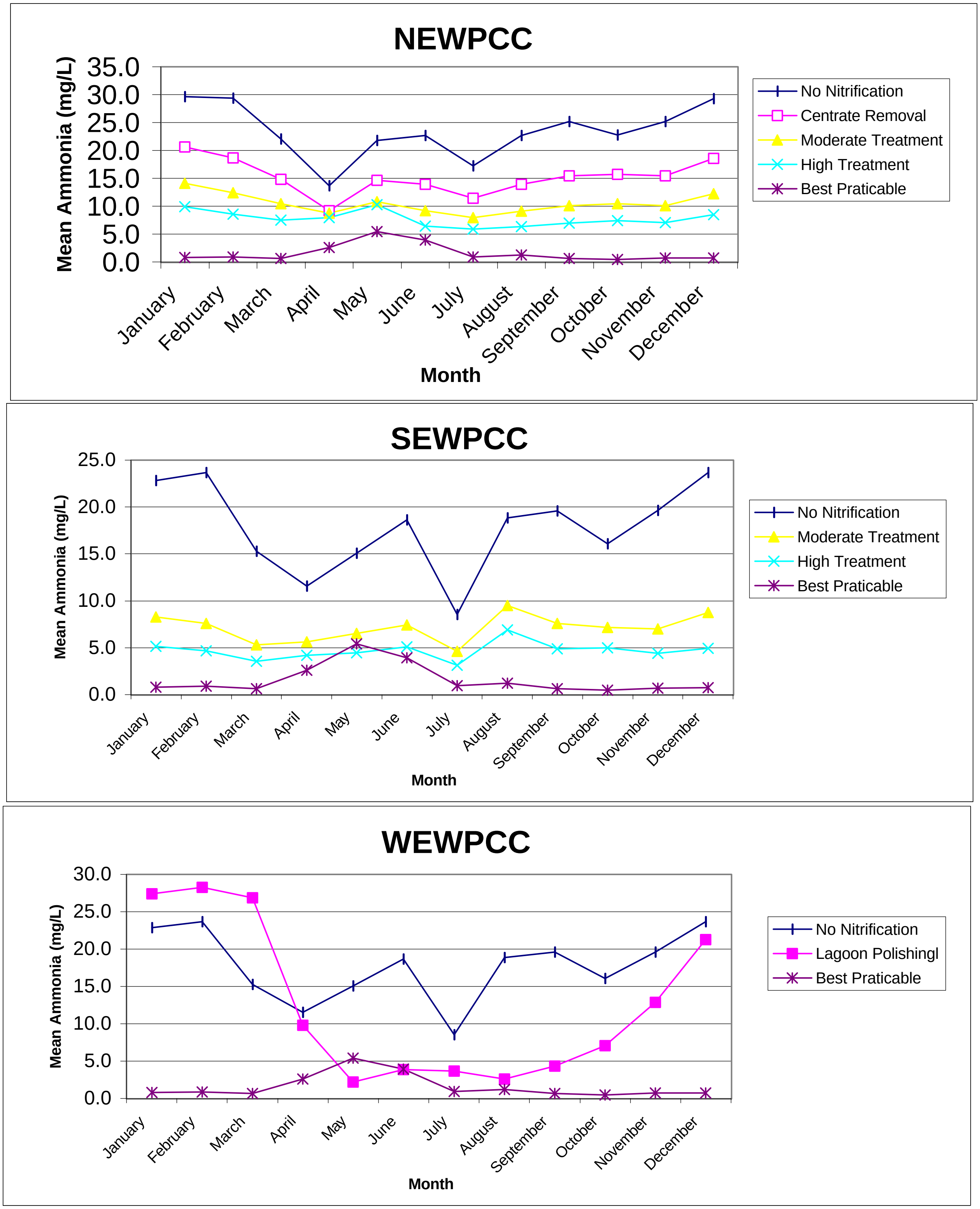
- future moderate treatment plus lagoons (Moderate & Lagoons);
    - NEWPCC uses moderate treatment option;
    - SEWPCC uses moderate treatment option;
    - WEWPCC uses lagoons option.

- high treatment plus lagoons (High & Lagoons);
    - NEWPCC uses high treatment option;
    - SEWPCC uses high treatment option;
    - WEWPCC uses lagoons option.

- high plus best practical treatment (High at WE BP);
    - NEWPCC uses high treatment option;
    - SEWPCC uses high treatment option;
    - WEWPCC uses best practical treatment option.

- best practical treatment scenario (Best Practicable);
    - NEWPCC uses best practical treatment option;
    - SEWPCC uses best practical treatment option;
    - WEWPCC uses best practical treatment option.

The mean effluent qualities for each WPCC option used in the above scenarios are illustrated in Figure 8-9. For details on the monthly mean and standard deviation of each option see Section 4.



Range of Effluent Concentration from
Various Treatment Options at WPCC
Figure 8-9

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9. STEADY-STATE MODELLING ASSESSMENTS

9.1 BACKGROUND

In order to apply an ammonia criteria to develop a permit for a wastewater discharger, it is necessary to use an appropriate waste-load allocation model. As discussed in the previous section and stated by US EPA (1991), "*dynamic models are preferred for the application of aquatic-life criteria in order to make the best use of specified concentrations, durations and frequencies. If dynamic models cannot be used, then an alternative is steady-state modelling. The steady-state modelling is based on various simplified assumptions, it is less complex, and might be less realistic, than dynamic modelling*."

Often steady-state modelling is used in the application of criteria since there are limited data available for the stream or the option of dynamic modelling would be too costly to consider. In the application of a site-specific criteria for the Red and Assiniboine rivers these conditions do not apply. However, in order to compare the more commonly used steady-state design flow methodology to the risk-assessment methodology based on dynamic modelling and site-specific toxicity data applied in this study, we will illustrate the design flow or steady-state technique for the Red and Assiniboine rivers.

For steady-state modelling methodologies, the EPA recommends two methods for determining design flows, the hydrologically-based method, and the biologically-based method. The hydrologically-based method has been historically used in many parts of the U.S. and in the Province of Manitoba. It is based on selecting and identifying an extreme value such as the 7Q10 flow. This flow is defined as the 7-day average flow which will occur on average once every 10 years. The method of calculating such a flow is to calculate a 7-day moving average for the period of record and select the lowest flow in each year. Then a statistical frequency analysis (often the Log-Pearson Type 3) is used to find the flow with approximately a 10% probability of occurring in each year (the 10-year return frequency). The EPA felt there was some disadvantages in this method in that it was essentially independent of biological considerations. The design flows calculated using this method might allow more or fewer excursions than once every 3 years on average, which is the EPA criteria.

Since the environmental conditions for which aquatic criteria can be applied may change significantly from month to month (as pH and temperature do in the ammonia criteria), it was often deemed necessary to calculate a monthly design flow. The hydrologically-based method was then modified to estimate 7Q10s for each month of the year. There is some concern that this methodology may not provide the required return frequency. More recently, some of the criteria such as ammonia have indicated that longer averaging periods such as 30 days are more appropriate. Therefore modifications to the 7Q10 have included developing an annual 30Q10, as well as a monthly 30Q10.

The biologically-based design flow method (developed by the US EPA) directly uses the averaging periods and frequency specified in the aquatic life water-quality criteria for individual pollutants and whole effluents for determining design flows. The EPA describes the method as "*an empirical iterative convergent procedure that includes the calculation of harmonic means of the flow to determine the total number of excursions*." The method allows the use of exact duration and frequency as specified in the criteria. For example, there may be a one day duration and three years recovery for an acute criteria and 30-days duration and three years recovery for a chronic criteria.

The EPA ammonia criteria for example, allows a water-quality excursion to occur on average, once every three years. If the 30-day average period is used as recommended in their criteria, then a water-quality excursion is counted for each distinct non-overlapping 30-day period where an average in-stream concentration exceeds the criteria concentration limit. If the excursion occurs for more than 30 days, then it can be calculated as more than one excursion. For example, if each day of a block of 45 consecutive days was above the criteria magnitude then using a 30-day averaging period the number of excursions in this block would be 45/30 = 1.5. Therefore this methodology can count multiple excursions in one year. The biologically-based method, however, does not have a methodology to account for calculating monthly design flows. This could have some limitations when developing permits for streams in which monthly temperature and pH vary significantly (such as the Red and Assiniboine rivers).

9.2 CALCULATION OF DESIGN CONDITIONS

To calculate a range of potential design flows to be used for comparative purposes in developing illustrative waste-load allocations for the treatment plants, the US EPA program DFLOW was obtained. Based on historic stream flow records, this program could be used to calculate both hydrologically-based and biologically-based design flows. A summary of these design flows based on the period of record of 1962 to 1997 for 1Q10s, 7Q10s, 7Q30s and 30B3s (30 day duration biologically-based once in three years on average excursions) is shown on Table 9-1. Also calculated were the monthly 1Q10, 7Q10, and 7Q30 for each of the three rivers. Also required for the receiving stream design conditions in order to apply an ammonia criteria are pH and temperature values. For the annual design flow conditions the average annual pH and temperature were used for each stream. For the monthly design flows, the monthly average for pH and temperature for each of the receiving streams was used and is also tabulated in Table 9-2.

These design conditions can be used in a steady-state model to develop a waste-load allocation for each of the WPCCs once a suitable site-specific criteria is selected. This analysis will be done in the Integration TM and the results will be compared to the risk analysis method proposed which uses the dynamic modelling output.

TABLE 9-1
ANNUAL LOWFLOW (1962-1997)

	Extreme Value[1] m³/s)			Biologically-Based[2](m³/s)		
	1Q10	**7Q10**	**30Q10**	**1B3**	**4B3**	**30B3**
St. Agathe	6.37	6.88	7.85	3.55	3.75	6.52
Lockport	17.01	18.67	20.45	14.99	15.87	18.75
Headingley (adj)	4.65	4.98	6.20	5.60	5.63	6.38
Headingley	3.39	3.82	4.69	3.76	4.01	4.65

[1] *Based on Log Pearson Type III Distribution*

[2] *Length of clustering period = 120 days; Maximum number of excursions counted per cluster = 5*

TABLE 9-2
MONTHLY LOWFLOW[1] (1962-1997)

	1Q10											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
St. Agathe	4.38	4.80	8.07	23.99	39.82	31.54	13.30	9.64	10.91	8.57	6.18	5.09
Lockport	16.32	16.75	20.68	34.03	64.40	55.45	31.79	22.23	21.77	23.12	17.53	18.94
Headingley (adjusted)	6.47	7.36	7.64	6.29	6.72	8.84	5.66	5.66	5.66	5.66	5.66	7.04
	7Q10											
St. Agathe	4.51	5.01	8.31	26.17	43.80	34.69	15.93	11.86	13.22	9.98	7.27	5.47
Lockport	16.81	17.18	21.51	41.01	67.81	57.97	33.76	27.56	23.48	24.59	22.12	21.49
Headingley (adjusted)	6.68	7.88	7.98	9.38	11.25	9.55	5.88	5.83	5.85	7.08	6.54	8.96
	30Q10[2]											
St. Agathe	5.11	6.26	13.56	78.38	48.64	47.32	22.27	13.65	17.93	12.29	8.37	7.29
Lockport	18.15	19.04	32.35	135.75	86.76	76.81	46.93	35.39	41.49	34.24	27.40	22.72
Headingley (adjusted)	8.02	8.40	11.01	26.24	17.53	12.85	9.93	7.93	8.53	9.73	10.41	10.62

1 Non-Parametric

2 February values based on 28-day average

10. CRITICAL PERIOD ALGAE MODELLING

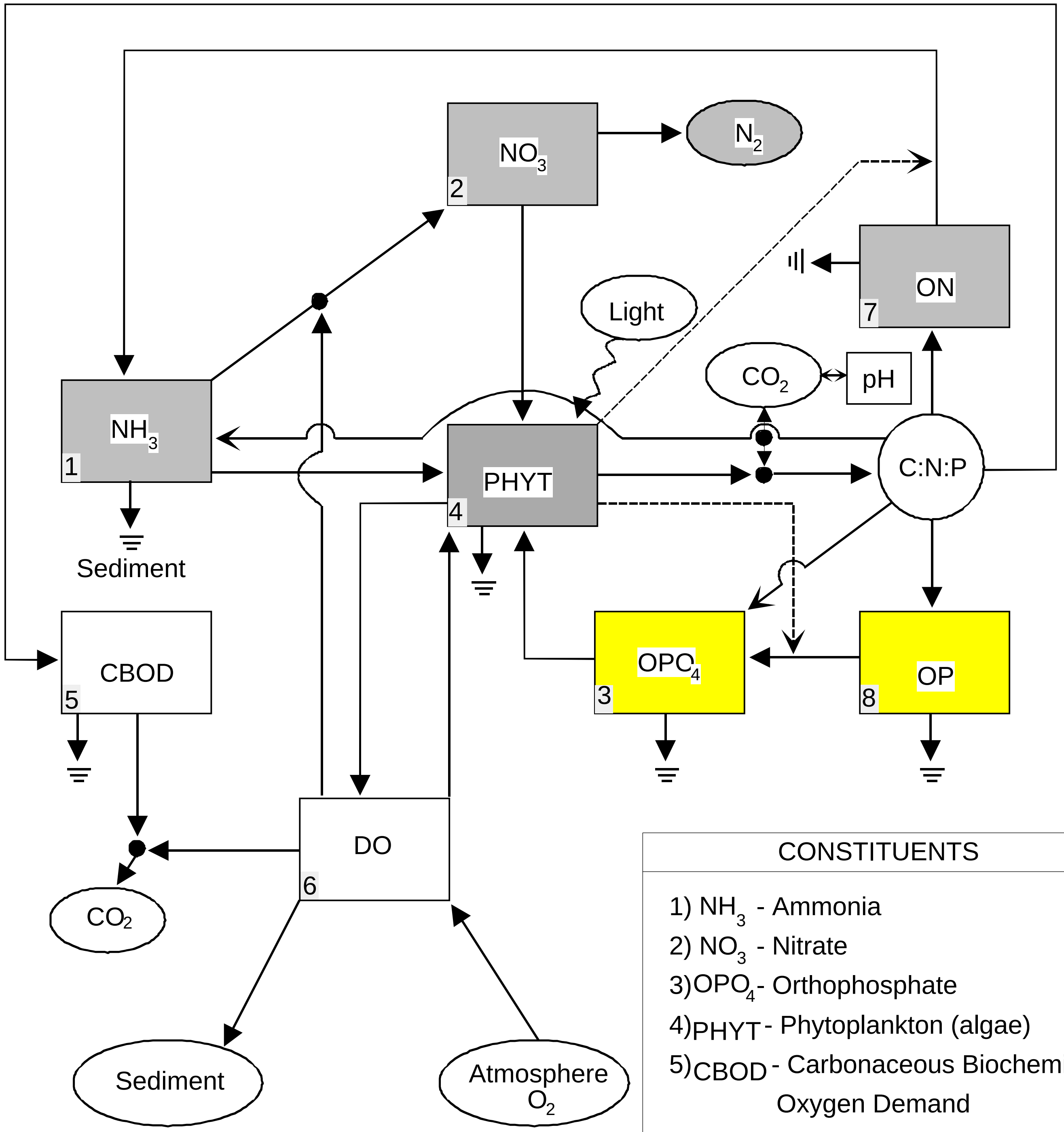
10.1 OBJECTIVES

The objective of this section is to determine the impact of various potential wastewater treatment actions on algal concentrations throughout the study area. A critical low-flow period was selected in order to analyze various scenarios. The period selected was 1988 from June through November. During this time the river flows were very low and water temperatures were relatively high. In this critical period the influence of the wastewater discharges on the water quality in terms of nutrient loadings and ammonia were very significant. In addition, the City of Winnipeg carried out special monitoring plans during the summer of 1988 to collect a wide range of parameters influencing nutrients and dissolved oxygen. Therefore the model could be calibrated for this period. A comparison of the calibrated-model output versus monitoring data for 1988 is given in Appendix E. Also given in Appendix E are the rates and coefficients used in the model. An illustration of the model structure is shown in Figure 10-1.

The four scenarios which were assessed and compared were:

1. a baseline 2041 scenario which assumed no-nitrification or phosphorus removal;
2. a 2041 phosphorus-removal scenario which assumed phosphorus in each of the plants was maintained at 1 mg/L;
3. the condition which may occur if full nitrification is done in which the phosphorus concentrations at each of the plants would increase by 1 to1.5 mg/L over current conditions; and
4. the reduction in upstream phosphorus to maintain the concentration at 0.1 mg/L.

A summary of the phosphorus concentration for each scenario is shown in Table 10-1. These scenarios will be compared to determine if there is any significant changes in algal concentration as expressed by chlorophyll ‘a’. This may be important to the application of an ammonia criteria and an ammonia risk assessment since monitoring in 1999 indicated that there is a strong correlation between algal concentration and pH on the Red and Assiniboine rivers (see Section 3).



CONSTITUENTS

1) NH_3 - Ammonia
2) NO_3 - Nitrate
3) OPO_4 - Orthophosphate
4) PHYT - Phytoplankton (algae)
5) CBOD - Carbonaceous Biochemical Oxygen Demand
6) DO - Dissolved Oxygen
7) ON - Organic Nitrogen
8) OP - Organic Phosphorus

Source: Ambrose et al., 1993
US EPA; WASP5 Manual

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Major System Interactions of the WIN/WASP Eutrophication Model

Figure 10-1

TABLE 10-1
UPSTREAM AND COW PHOSPHORUS LOADS FOR EACH SCENARIO

	Total Phosphorus (mg/L)				
	NEWPCC	SEWPCC	WEWPCC	Floodway Control	Headingley
Scenario 1- Base Case	2.6	4.0	4.2	0.1 to 0.25 (Variable Historic)	0.2 to 0.4 (Variable Historic)
Scenario 2 - COW Phosphorus Control	1.0	1.0	1.0	0.1 to 0.25 (Variable Historic)	0.2 to 0.4 (Variable Historic)
Scenario 3 - COW Nitrification (P Increase)	4.6	6.0	6.2	0.1 to 0.25 (Variable Historic)	0.2 to 0.4 (Variable Historic)
Scenario 4- COW and Upstream P Control	1.0	1.0	1.0	0.1	0.1

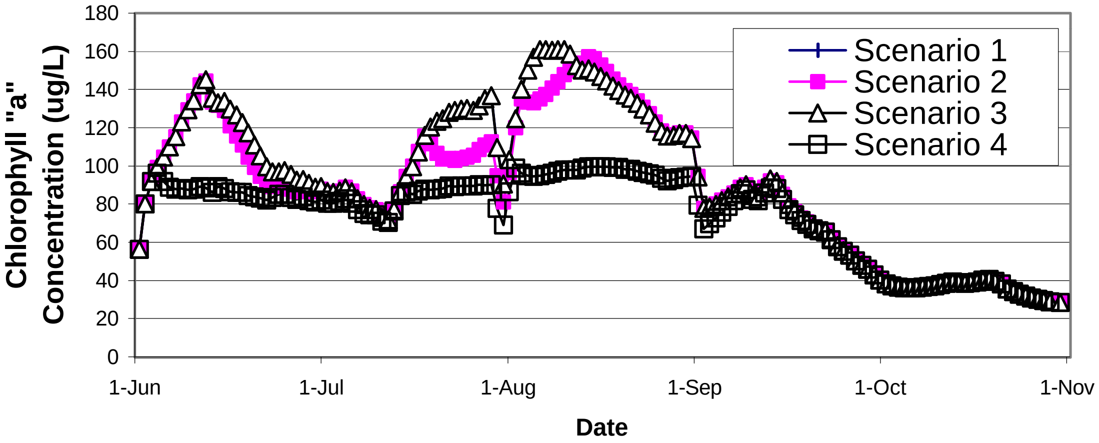
The work-plan indicated that there may be a condition in which nitrification of ammonia to nitrate may change the productivity and growth of algae. In Section 6, it was noted that ammonia productivity did decrease with higher concentrations of ammonia above 1 mg/L, however, experiments in 1999 indicated that higher concentrations of nitrate had the same impact on algal productivity. Therefore it can be concluded that nitrification would not change the rate of growth or productivity of algae.

10.2 RESULTS OF NUTRIENT CONTROL OPTIONS AT THE WPCCS AND FROM SOURCES UPSTREAM OF WINNIPEG

Four different scenarios, in which there is variation in phosphorus discharges from the effluent of the City of Winnipeg WPCCs or a change in the concentrations of phosphorus from the historical conditions, were assessed. Results of the modelling in terms of concentration of chlorophyll ‘a’ from June 1 to November 1 are shown in Figures 10-2 through 10-8. Each figure represents chlorophyll concentrations at various sample stations located throughout the study area.

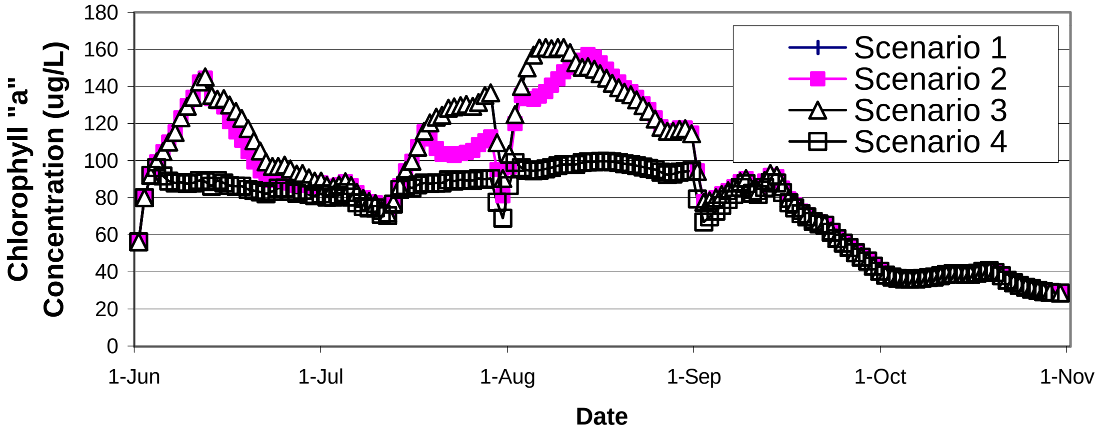
The upper Red River is represented by two stations, the Fort Garry Bridge and the Norwood Bridge (Figure 10-2 and 10-3 respectively). In both cases, phosphorus control at the City of Winnipeg WPCCs (Scenario 2) has little effect on chlorophyll ‘a’ concentrations occurring in the early summer; this increase is due to increased spring runoff upstream. The algal concentrations could be modified slightly during the summer by City of Winnipeg phosphorus control, however, they remain around 160 µg/L. An increase in phosphorus loading, which could be caused by the nitrification process (Scenario 3), appears to have no impact on algal concentrations. This is likely due to phosphorus concentrations being high enough that they are not the limiting nutrient at this time. Controls on both City of Winnipeg and upstream phosphorus loads (Scenario 4) could limit the algal concentrations to 100 µg/L.

On the Assiniboine River, the scenarios in which the City of Winnipeg phosphorus discharges either decrease (Scenario 2) or increase (Scenario 3) have no impact on chlorophyll concentrations at either the Assiniboine Park Bridge (Figure 10-4) or the Main Street Bridge (Figure 10-5). Concentrations on the Assiniboine River often reach 200 µg/L. This is likely due to the upstream phosphorus concentrations dominating phosphorus in the Assiniboine River.



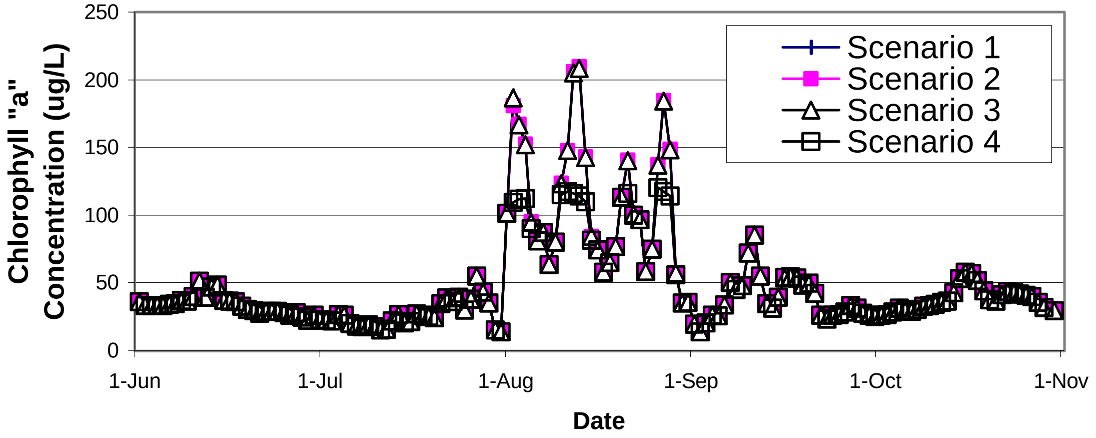
Chlorophyll "a" Concentrations at Fort Garry Bridge (June-Oct 1988)

Figure 10-2



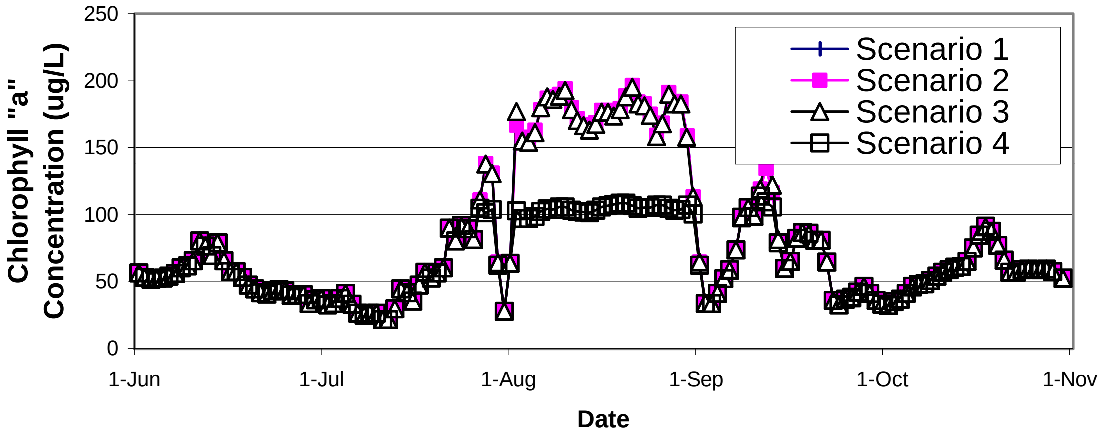
Chlorophyll "a" Concentrations at Norwood Bridge (June-Oct 1988)

Figure 10-3



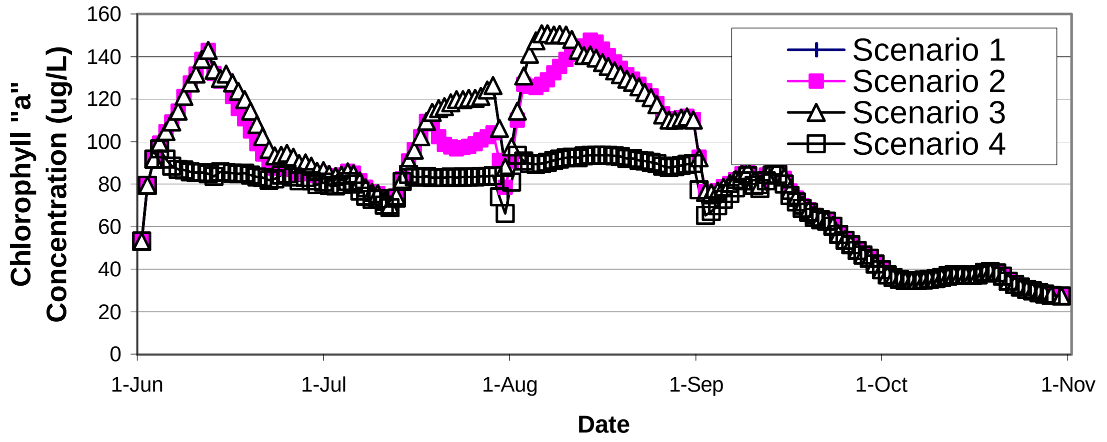
Chlorophyll "a" Concentrations at Assiniboine Park Bridge (June-Oct 1988)

Figure 10-4



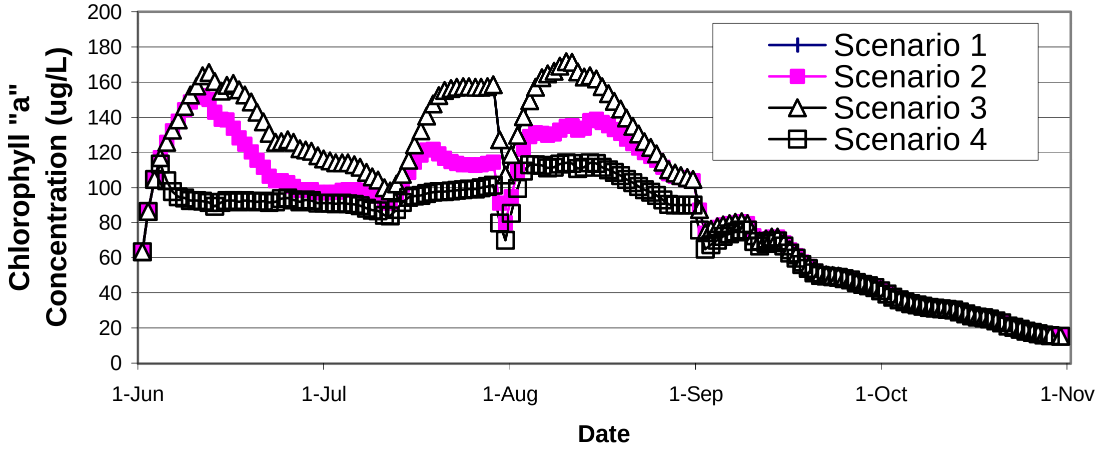
Chlorophyll "a" Concentrations at Main Street Bridge (June-Oct 1988)

Figure 10-5



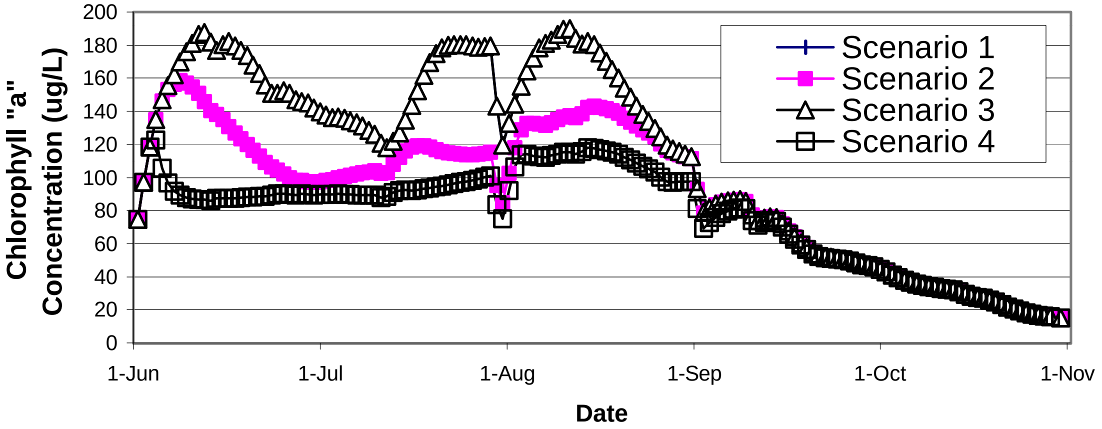
Chlorophyll "a" Concentrations at Redwood Bridge (June-Oct 1988)

Figure 10-6



Chlorophyll "a" Concentrations at North Perimeter Bridge (June-Oct 1988)

Figure 10-7



Chlorophyll "a" Concentrations at Lockport (June-Oct 1988)

Figure 10-8

The scenario in which upstream controls were assumed to maintain background phosphorus levels at 0.1 mg/L limits the chlorophyll ‘a’ concentration to about 100 to 110 µg/L.

The four scenarios are illustrated for the lower Red River on Figures 10-6 to 10-8. At the Redwood Bridge, the analysis shows that the City of Winnipeg controls may have some impact on chlorophyll ‘a’ concentrations. The concentration may drop from 150 to 130 µg/L in some instances, however, increases in upstream phosphorus can produce chlorophyll ‘a’ concentrations if over 140 µg/L. An increase in phosphorus load from the City due to nitrification at the plants would show no increase in chlorophyll ‘a’ concentrations. This is likely due to phosphorus not being a limiting nutrient during the summer months. Upstream control of phosphorus to maintain the concentrations at 0.1 mg/L would maintain concentrations of chlorophyll ‘a’ at the Redwood Bridge below 100 µg/L.

At the North Perimeter Bridge (see Figure 10-7), controls of the City of Winnipeg phosphorus discharges appear to have a more significant impact on chlorophyll ‘a’ during the summer months. Peak chlorophyll ‘a’ concentrations showed a reduction of from between 160 and 170 µg/L to between 120 and 140 µg/L. Additional controls upstream would maintain the chlorophyll ‘a’ concentrations at less than 120 µg/L for all months of the year.

At Lockport (Figure 10-8), the influence of the City of Winnipeg discharges appears to be more significant. For the base case peak concentrations are around 190 µg/L of chlorophyll ‘a’. With phosphorus control at each of the WPCCs, these can be maintained at 140 µg/L or less during the summer months. There is still a peak occurring in June, however, it has been reduced. The addition of controls at upstream points could maintain the chlorophyll ‘a’ concentrations at less than 120 µg/L.

10.3 IMPACT ON UN-IONIZED AMMONIA

A summary of the monthly predicted chlorophyll ‘a’ concentrations for the various scenarios is shown on Table 10-2. In Section 3, a relationship between pH and chlorophyll ‘a’ concentrations was developed (see Figure 3-13). This figure can be used to estimate the pH for each month in each scenario based on chlorophyll ‘a’ concentrations. The estimated pH is

TABLE 10-2
MONTHLY PREDICTED CHLOROPHYL-"A" FOR VARIOUS SCENARIOS

	Lower Red			Upper Red		Assiniboine	
	Lockport	N. Perimeter	Redwood	Norwood	Fort Gary	Main St.	Assiniboine Pk
	Scenario 1-Base Case						
June	157.20	134.78	107.65	110.00	126.32	53.23	33.54
July	149.88	128.67	97.83	102.91	118.44	54.58	26.19
August	155.76	141.45	130.71	138.92	138.86	171.04	109.31
September	67.45	63.56	70.98	73.62	74.39	68.14	38.27
October	28.58	27.07	34.68	36.13	35.72	57.57	37.44
	Scenario 2 -COW Phosphorus Control						
June	123.52	119.25	104.34	105.56	118.75	53.23	33.54
July	108.13	104.93	90.05	94.07	108.24	54.58	26.19
August	129.48	123.40	127.03	134.66	134.55	170.70	109.07
September	67.30	63.42	70.81	73.44	74.23	67.47	38.27
October	28.57	27.06	34.68	36.13	35.72	57.57	37.44
	Scenario 3 -COW Nitrification (P Increase)						
June	157.09	134.69	107.58	109.94	126.25	53.22	33.54
July	149.71	128.51	97.65	102.73	118.26	54.50	26.18
August	155.67	141.33	130.35	138.53	138.55	169.91	108.98
September	67.40	63.51	70.90	73.53	74.31	68.07	38.25
October	28.56	27.05	34.66	36.11	35.70	57.53	37.43
	Scenario 4 -COW & Upstream Phosphorus Control						
June	91.32	92.85	83.93	85.24	94.46	53.23	33.54
July	91.99	92.31	79.41	82.74	94.78	52.24	26.19
August	109.16	104.03	90.84	96.33	100.51	102.67	90.38
September	64.22	60.50	67.82	70.42	71.20	65.92	38.27
October	28.54	27.03	34.68	36.12	35.71	57.57	37.44

shown in Table 10-3. The change in pH from the base case was calculated and is shown in Table 10-4. A typical temperature for each month was estimated using the temperature monitored for each month (see Table 3-2). By using the calculated information on pHs and the typical temperature, a change in the percent of un-ionized ammonia from the base case can be calculated for each month of each scenario. The percent change in un-ionized ammonia due to changes in pH for the various scenarios is shown on Table 10-5. Obviously there is a large reduction in un-ionized ammonia in Scenario 3 due to the reduction in total ammonia.

For the scenario with City of Winnipeg phosphorus control (Scenario 2) there is no change in un-ionized ammonia concentrations in the Assiniboine River and a decrease of 1 to 4% for the reaches between the SEWPCC and the NEWPCC. Downstream of the NEWPCC, the reduction in un-ionized ammonia is more significant. Reductions range from between 5 and 14%, depending on which month of the summer. During the fall, the model predicted algae limitations due to temperature and light conditions, therefore there was no difference in chlorophyll ‘a’, pH and the corresponding un-ionized ammonia concentration between scenarios.

For Scenario 3, in which nitrification could lead to increased phosphorus, there was no change in un-ionized ammonia since phosphorus does not appear to be the limiting nutrient in algal growth. When the City of Winnipeg and upstream phosphorus concentrations are limited (Scenario 4) the changes in un-ionized ammonia are quite significant. On the Assiniboine River, the reduction in un-ionized ammonia could vary between no change to 20% in the month of August. Twenty percent could be quite significant, as the month of August could be the limiting month if the design flow method is used. For the Red River, the reductions are significant for four months of the year between 2 and 23%. The greatest change could occur in the Lockport area in June or July where the combination of reductions in upstream phosphorus loads and loads from the City of Winnipeg WPCCs could make the chlorophyll ‘a’, pH, and subsequent un-ionized ammonia change significantly.

TABLE 10-3
MONTHLY PREDICTED PH FOR VARIOUS SCENARIOS

	Lower Red			Upper Red		Assiniboine	
	Lockport	N. Perimeter	Redwood	Norwood	Fort Gary	Main St.	Assiniboine Pk
	Scenario 1-Base Case						
June	8.98	8.93	8.87	8.88	8.92	8.68	8.55
July	8.96	8.92	8.84	8.86	8.90	8.68	8.48
August	8.97	8.95	8.92	8.94	8.94	9.00	8.87
September	8.74	8.72	8.76	8.77	8.77	8.74	8.58
October	8.50	8.49	8.56	8.57	8.56	8.70	8.58
	Scenario 2 -COW Phosphorus Control						
June	8.91	8.90	8.86	8.87	8.90	8.68	8.55
July	8.87	8.86	8.82	8.83	8.87	8.68	8.48
August	8.92	8.91	8.92	8.93	8.93	9.00	8.87
September	8.74	8.72	8.75	8.76	8.77	8.74	8.58
October	8.50	8.49	8.56	8.57	8.56	8.70	8.58
	Scenario 3 -COW Nitrification (P Increase)						
June	8.98	8.93	8.87	8.88	8.91	8.68	8.55
July	8.96	8.92	8.84	8.86	8.90	8.68	8.48
August	8.97	8.95	8.92	8.94	8.94	9.00	8.87
September	8.74	8.72	8.75	8.77	8.77	8.74	8.58
October	8.50	8.49	8.56	8.57	8.56	8.70	8.58
	Scenario 4 -COW & Upstream Phosphorus Control						
June	8.83	8.83	8.80	8.81	8.83	8.68	8.55
July	8.83	8.83	8.79	8.80	8.84	8.67	8.48
August	8.87	8.86	8.82	8.84	8.85	8.86	8.82
September	8.73	8.71	8.74	8.75	8.76	8.73	8.58
October	8.50	8.49	8.56	8.57	8.56	8.70	8.58

TABLE 10-4
MONTHLY PREDICTED PH DIFFERENCE FOR VARIOUS SCENARIOS

	Lower Red			Upper Red		Assiniboine	
	Lockport	N. Perimeter	Redwood	Norwood	Fort Gary	Main St.	Assiniboine Pk
	Scenario 2 -COW Phosphorus Control						
June	-0.07	-0.03	-0.01	-0.01	-0.02		
July	-0.09	-0.06	-0.02	-0.02	-0.02		
August	-0.05	-0.04	-0.01	-0.01	-0.01		
September							
October							
	Scenario 3 Nitrification leading to Increase Phosphorous						
June							
July							
August							
September							
October							
	Scenario 4 -COW & Upstream Phosphorus Control						
June	-0.15	-0.10	-0.07	-0.07	-0.08		
July	-0.14	-0.09	-0.06	-0.06	-0.06	-0.01	
August	-0.10	-0.09	-0.10	-0.10	-0.09	-0.14	-0.05
September	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	
October							

TABLE 10-5

MONTHLY PREDICTED CHANGE IN UNIONIZED AMMONIA DUE TO ALGAE AND PH VARIATIONS

		Lower Red			Upper Red		Assiniboine	
	Typical Temperature	Lockport	N. Perimeter	Redwood	Norwood	Fort Gary	Main St.	Assiniboine Pk
		Scenario 2 -COW Phosphorus Control						
June	20.1	-0.11	-0.06	-0.02	-0.02	-0.03		
July	22.8	-0.14	-0.09	-0.04	-0.04	-0.04		
August	21.3	-0.08	-0.06	-0.01	-0.01	-0.01		
September	15.6							
October	8.4							
		Scenario 3 Nitrification leading to Increased Phosphorous						
June	20.1							
July	22.8							
August	21.3							
September	15.6							
October	8.4							
		Scenario 4 -COW & Upstream Phosphorus Control						
June	20.1	-0.23	-0.17	-0.12	-0.12	-0.13		
July	22.8	-0.20	-0.14	-0.10	-0.10	-0.10	-0.02	
August	21.3	-0.15	-0.14	-0.16	-0.16	-0.14	-0.21	-0.09
September	15.6	-0.03	-0.03	-0.02	-0.02	-0.02	-0.02	
October	8.4							

Note: Assumes Total Ammonia Remains Constant

11. KEY OBSERVATIONS

11.1 HYDROLOGY

- The flows in the modelled area are highly variable from year to year and can vary for a given location by an order of magnitude for the same time of year.

- During the period of field studies in 1999, the flow in the Red and Assiniboine rivers was either in the highest 10% of historic flows for that time of year or at record high levels for that time of year. Using the MIKE11 hydraulic model, and the frequency analysis of flows on the Red and Assiniboine rivers, a relationship between flow and velocity and flow and depth was developed for each reach of the river. A probability distribution of range of velocities and depth of each reach for each of the rivers, at any time of year, was developed for the study area.

11.2 WATER QUALITY

- The City of Winnipeg has collected over 20-years of water quality data at 11 stations throughout the study area.

- Key parameters which could be used in the development of ammonia criteria such as pH and temperature vary significantly from month to month. This indicates the need for a monthly or seasonal assessment of total ammonia. pH also varies spatially across the region with pHs being higher upstream in the City of Winnipeg, decreasing as the rivers flow through the heart of the City (i.e., at the Redwood Bridge and North Perimeter Bridge), then rising slightly again towards Lockport. This indicates that there will be a variation of un-ionized ammonia due to changes in pH throughout the study area.

- A review of the 1988 data and studies indicated potential for stratification of pH with depth. The 1999 studies (during higher flow in the river) did not indicate any evidence of stratification of pH and indicated full mixing within the river.

- The 1999 monitoring program and analysis indicated that light was a limiting factor in the growth of algae.

- Analysis of data collected in 1999 indicated a strong correlation between suspended solids and an estimated light extinction coefficient.

- A review of historic river conditions indicated that the change in average light within the water column could increase greatly during average and low flows in the river at certain locations. The increase in average light in water column in the lower Red is estimated to be only about 10% for low flow conditions when compared to the high flow conditions monitored in 1999.

- On the upper Red, the light conditions may increase by 2.5 times during low-flow conditions when compared to the conditions monitored in 1999.

- On the Assiniboine River, the average light exposure in the water column may increase by over 4 times during low-flow conditions when compared to the conditions monitored in 1999. This analysis indicated that during low-flow conditions, the average light in water column may increase enough that light ceases to become the limiting factor and one of the nutrients, either nitrogen or phosphorus becomes limiting.

11.3 WATER POLLUTION CONTROL CENTRES

- The City has monitored data from 1984 to 1997, which can be used to develop a monthly mean and variation of the ammonia effluent quality from each of the three WPCCs.

- The flow from the NEWPCC and WEWPCC is projected to remain roughly equivalent to today's conditions in the year 2041. The SEWPCC will increase significantly by over 30% between 1997 and 2041.

- Although the treatment plant is not specifically designed for nutrient removal it should be noted that the NEWPCC removes greater than 50% of the phosphorus during treatment and the SEWPCC and WEWPCC show similar phosphorus treatment performance, although not as large a reduction in phosphorus. The WPCCs also reduced nitrogen load, although not as significantly as for phosphorus.

- A parallel study on the treatment plant systems is able to develop future conditions for various nitrogen-removing processes. A range of nine scenarios, including the historic conditions and the current conditions, as well as six future conditions in 2041 have been developed. These scenarios give estimations of the mean and monthly variation of ammonia discharges at each of the three WPCCs.

11.4 NUTRIENT LOADINGS

- Mass nutrient loadings coming from upstream of the City of Winnipeg are largely dependent upon the flow in the river. Most of the load comes during the spring freshet in March, April and May. Since 1993, the average annual load of nutrients has increased dramatically due to the high flow conditions in the river.

- The nutrient loads from Winnipeg's WPCCs have remained relatively stable over the past 15 years.

- On an average basis, the annual load from the WPCCs is about 20% of the total load to the river. However, in a low-flow year, the nutrient load could increase to as much as 30% or 40% of the load in the river, and in a high-flow year the load would only amount to 10% or less of the total load in the river.

11.5 AMMONIA IMPACTS ON THE ALGAE

- For increases in ammonia there is an increase in photosynthetic activity, however, when ammonia is increased beyond 2 or 3 mg/L productivity decreases. A regression analysis indicated that the trend is statistically significant and consistent although not strong.

Similarly, when algae is spiked with nitrate there is a decrease in productivity beyond 1 mg/L. The trend appears to be both strong and consistent.

11.6 NEAR-FIELD WATER QUALITY MODELLING

- In the low-flow conditions it is expected that the NEWPCC will mix thoroughly immediately downstream of the outfall. The SEWPCC discharge occurs in the middle of the river and mixing will occur relatively quickly under low-flow conditions.
- On the Assiniboine River the mixing is much less pronounced, with the plume hugging the bank for a considerable distance downstream to Assiniboine Park and beyond. However, it is expected that full mixing will occur by the time the plume reaches the Main Street Bridge near The Forks.

11.7 LONG-TERM DYNAMIC MODELLING

- Dynamic modelling is preferred by the EPA when using the water quality criteria to develop a waste-load allocation for discharges on a river.
- The considerable amount of water-quality and river-flow data along with advances in computational hardware and software have allowed a long-term continuous simulation model to be developed.
- The model is calibrated deterministically to verify that the dilution transport and transformation of ammonia could be predicted.
- The model is also calibrated stochastically to verify that future water quality and effluent data could be generated stochastically, which would represent the expected statistical distribution of ammonia at all stations in the study area for the future.

- A range of potential future scenarios were generated which can be used in conjunction with a selected criteria to assess compliance or with specific toxicity effects data to develop a probabilistic risk assessment.

11.8 STEADY-STATE WATER-QUALITY ASSESSMENTS

- The historic record was analyzed to develop steady-state design flows which can be used in developing waste-load allocations for comparison to those developed by the dynamic model and risk assessment.

11.9 CRITICAL PERIOD ALGAE MODELLING

- Phosphorus control has potential to limit algae concentrations in the river which in turn can reduce pHs. A reduced pH would mean a decrease in the concentration of un-ionized ammonia for a fixed concentration of total ammonia, thus reducing aquatic toxicity.
- Phosphorus controls at the City of Winnipeg WPCCs would have no impact on pHs, and un-ionized ammonia concentrations on the Assiniboine River. On the Red River, upstream of the NEWPCC, the reduction in un-ionized ammonia would be limited to less than 4%. Downstream of the NEWPCC, the impacts on un-ionized ammonia concentrations from phosphorus control in the City of Winnipeg would be more significant, ranging from 6 to 14% reduction, depending on the month and location.
- If nitrification leads to an increase in phosphorus, it would likely have no impact on algal concentrations, pH or un-ionized ammonia concentrations. This is due to the analysis that phosphorus is currently not the limiting nutrient on algal growth.
- If in addition to City of Winnipeg phosphorus controls, upstream phosphorus was maintained at 0.1 mg/L, the impact on chlorophyll ‘a’ concentrations, pH and un-ionized ammonia concentrations would be significant. On the Assiniboine River, for the month of August, the reduction in un-ionized ammonia at the Main Street Bridge could be as high as 20%. For most of the summer on the Red River within the City of Winnipeg, the un-ionized ammonia could be reduced by between 10 and 17%. The most significant change in un-ionized

ammonia could occur at Lockport, where un-ionized ammonia could be reduced by 15 to 23% during the summer months.

12. REFERENCES

12.1 LITERATURE CITED

Danish Hydraulics Institute. 1997. MIKE11. a microcomputer Based Modelling System for Rivers and Channels User and Reference Manuals.

Jirka, G., R. Domekar, and S. Hinton. 1996. User's Manual for CORMIX: A Hydrodynamic Mixing Zone Model and Decision Support System for Pollutant Discharges into Surface Waters. For U.S. EPA. September 1996.

MacLaren Engineers. 1986. Conceptual Design Study – Expansion Requirements of South and West End Water Pollution Control Centres. Report to City of Winnipeg, Waterworks, Waste and Disposal Department. November 1986.

Reid Crowthers. 2000a. The City of Winnipeg Nitrification Study Workshop No. 4 Documentation. City of Winnipeg Water and Waste Department. June 2000.

Ross, R.D., and L. Hemphill. 1991. 1988 Red River Survey. City of Winnipeg Waste Disposal Department, Laboratory Services Division. February 1991.

Tetr*ES* Consultants Inc. 1998a. Water Demand Evaluation and Projections Report. City of Winnipeg Water and Waste Department. February 1998.

Tetr*ES* Consultants Inc. 1998. Phase I Ammonia Criteria Technical Memorandum #RC.1.2. Field Report for Preliminary Ammonia Plume Characteristics Studies on the Red and Assiniboine Rivers during October 1998. City of Winnipeg Water and Waste Department. November 1999.

Tetr*ES* Consultants Inc. 1999. Phase I Ammonia Criteria Technical Memorandum #RC.1.1. Model Selection for Water Quality Modelling of the Red and Assiniboine Rivers. City of Winnipeg Water and Waste Department. March 1999.

Tetr*ES* Consultants Inc. 1999. Phase I Ammonia Criteria Technical Memorandum #RC.1.3. Phase 2 River Monitoring Program. City of Winnipeg Water and Waste Department. June 1999.

U.S. EPA. 1985. Rates, Constants, and Kinetics Formulations in Surface Water Quality Modelling (Second Edition). Athens, GA. EPA/600/3-85/040. June 1985.

U.S. EPA. 1988. Technical Guideline on Supplementary Stream Design Conditions for Steady State Modelling. EPA/440/4-88-091. Cincinnati. December 1988.

U.S. EPA. 1991. Technical Support document for Water Quality-based Toxics Controls. EPA/505/2-90-001. March 1991.

U.S. EPA. 1993. The Water Quality Analysis Simulation Program, WASP5. Athens, GA. September 1993.

Wardrop Engineering Inc./Tetr*ES* Consultants Inc. 1991. The Red and Assiniboine Surface Water Quality Objectives. Report to City of Winnipeg Waterworks, Waste and Disposal Department. September 1991.

Williamson, D. 1988a. Manitoba Surface Water Quality Objectives. Manitoba Environment and Workplace Safety and Health. July 1988.

Williamson, D. 1988b. Rational Document Supporting Revision to Manitoba Surface Water Quality Objectives. Manitoba Environment and Workplace Safety and Health. July 1988.

12.2 PERSONAL COMMUNICATIONS

City of Winnipeg. Biweekly Water Quality Database. 1977-1997.

Danesh, Shahnaz. 2000a. e-mail from D. Shahnaz of Reid Crowther to D. Morgan of Tetr*ES* Consultants Inc. re: statistics for NEWPCC and SEWPCC. September 16, 2000.

Danesh, Shahnaz. 2000a. e-mail from D. Shahnaz of Reid Crowther to D. Morgan of Tetr*ES* Consultants Inc. re: statistical analysis on effluent ammonia concentration data from NEWPCC and WEWPCC. October 10, 2000.

Fries, Kim. 2000. e-mail from K. Fries of Reid Crowther to D. Morgan of Tetr*ES* Consultants Inc. re: effluent ammonia distribution. January 25, 2000.

Josephson, T. 1999a. Memorandum to Chris Tait re: Population Projections for the NEWPCC, SEWPCC and WEWPCC Service Area. July 20, 1999.

Josephson, T. 1999b. Memorandum to E. Sharp, B. Station and A. Weremy of City of Winnipeg Water and Waste Department re: Wastewater Flow and Mass Loading Projections for the NEWPCC, SEWPCC and WEWPCC. August 5, 1999.

APPENDIX A

COEFFICIENTS AND GRAPHS FOR FLOW VS. VELOCITY AND DEPTH EQUATIONS

Table A-1

Coefficients for Velocity Estimates from Flow (Summer -"Dam-in" Conditions)

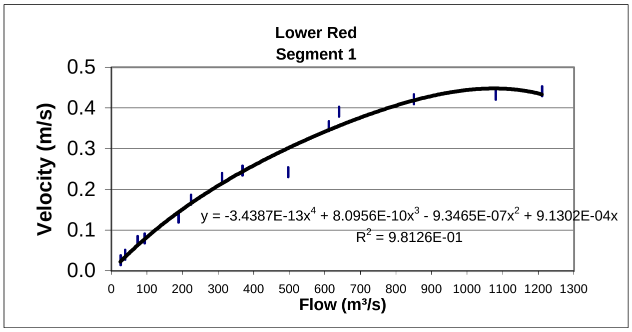
			Polynomial Coefficients						
Order	River	Segment	Coefficient 2	Coefficient 3	Coefficient 4	Coefficient 5	Km From Lake	KM to Start	KM to End
1	LowerRed	1	9.1302E-04	-9.3465E-07	8.0956E-10	-3.4387E-13	28.59	0	1
2	LowerRed	2	8.9127E-04	-9.5433E-07	6.7968E-10	-2.5652E-13	29.59	1	2.5
3	LowerRed	3	1.3180E-03	-1.8339E-06	2.3030E-09	-1.0817E-12	31.09	2.5	4
4	LowerRed	4	1.5217E-03	-2.0854E-06	2.3642E-09	-1.0272E-12	32.59	4	6
5	LowerRed	5	1.3587E-03	-9.8300E-07	5.8970E-10	-2.5070E-13	34.59	6	8
6	LowerRed	6	1.3209E-03	1.7662E-07	-1.0245E-09	4.1667E-13	36.59	8	10
7	LowerRed	7	2.6436E-03	-4.4067E-06	4.6144E-09	-1.7601E-12	38.59	10	13
8	LowerRed	8	3.6510E-03	-6.6587E-06	8.0350E-09	-3.5320E-12	41.59	13	15.5
9	LowerRed	9	-3.4352E-06	6.8891E-06	-8.3214E-09	2.8429E-12	44.09	15.5	17
10	LowerRed	10	3.5988E-05	7.7893E-06	-1.0106E-08	3.6980E-12	45.59	17	18.5
11	LowerRed	11	1.4758E-04	7.5941E-06	-1.0392E-08	3.9703E-12	47.09	18.5	20.5
12	LowerRed	12	5.2854E-04	4.9085E-06	-7.3470E-09	2.9604E-12	49.09	20.5	23
13	LowerRed	13	9.3881E-04	5.6093E-06	-9.2530E-09	3.8906E-12	51.59	23	25.5
14	LowerRed	14	1.5322E-03	2.3678E-06	-5.0290E-09	2.2383E-12	54.09	25.5	28
15	LowerRed	15	1.4670E-03	7.5974E-07	-2.5444E-09	1.2297E-12	56.59	28	30.5
16	LowerRed	16	1.2792E-03	3.5253E-07	-1.5770E-09	7.7748E-13	59.09	30.5	32.5
17	LowerRed	17	1.1373E-03	2.0085E-07	-1.1737E-09	5.8302E-13	61.09	32.5	34.5
18	LowerRed	18	1.1141E-03	5.7586E-09	-8.6728E-10	4.5584E-13	63.09	34.5	36.5
19	LowerRed	19	1.1165E-03	7.8196E-07	-2.2705E-09	1.1005E-12	65.09	36.5	38.5
20	LowerRed	20	1.5382E-03	1.4788E-07	-1.6733E-09	8.7948E-13	67.09	38.5	40.5
21	LowerRed	21	1.4909E-03	-4.7444E-07	-4.2733E-10	2.9919E-13	69.09	40.5	42.5
22	LowerRed	22	1.6653E-03	-3.8319E-07	-8.8722E-10	5.3465E-13	71.09	42.5	45
23	LowerRed	23	1.7679E-03	-7.5598E-07	-5.5851E-10	4.4420E-13	73.59	45	47.5
24	UpperRed	24	1.2600E-03	-9.2232E-07	2.6189E-10	5.6329E-14	76.09	47.5	49
25	UpperRed	25	8.9483E-04	7.7805E-07	-3.0533E-09	2.0412E-12	77.59	49	51
26	UpperRed	26	1.1178E-03	-6.5421E-07	-1.3864E-10	2.6385E-13	79.59	51	53
27	UpperRed	27	7.8703E-04	5.5298E-07	-1.9588E-09	1.1189E-12	81.59	53	55
28	UpperRed	28	1.4567E-03	-1.3148E-06	6.9933E-10	-1.1916E-13	83.59	55	57
29	UpperRed	29	1.1413E-03	-1.0200E-06	4.3119E-10	-9.0575E-15	85.59	57	59
30	UpperRed	30	1.4419E-03	-1.5805E-06	9.1173E-10	-1.7191E-13	87.59	59	61
31	UpperRed	31	1.3204E-03	-1.4098E-06	8.2784E-10	-1.5759E-13	89.59	61	63
32	UpperRed	32	1.3632E-03	-1.4209E-06	9.4656E-10	-2.4484E-13	91.59	63	65
33	UpperRed	33	1.2995E-03	-1.3094E-06	7.8704E-10	-1.6609E-13	93.59	65	67
34	UpperRed	34	1.5802E-03	-2.0575E-06	1.7835E-09	-6.6808E-13	95.59	67	69
35	UpperRed	35	1.0298E-03	-1.2921E-06	1.2140E-09	-4.9183E-13	97.59	69	71
36	UpperRed	36	1.3193E-03	-1.5470E-06	1.1608E-09	-3.5687E-13	99.59	71	73
37	UpperRed	37	1.6208E-03	-2.4064E-06	2.4866E-09	-1.0741E-12	101.59	73	75
38	UpperRed	38	1.6996E-03	-2.6956E-06	2.4252E-09	-8.4296E-13	103.59	75	77
39	UpperRed	39	2.3979E-03	-4.3447E-06	4.1240E-09	-1.4839E-12	105.59	77	79
40	UpperRed	40	3.5050E-03	-7.3998E-06	7.6379E-09	-2.9922E-12	107.59	79	81
41	UpperRed	41	3.6460E-03	-7.1190E-06	6.7517E-09	-2.5329E-12	109.59	81	83
42	UpperRed	42	3.0744E-03	-5.5508E-06	5.2212E-09	-1.9766E-12	111.59	83	85
43	UpperRed	43	4.0155E-03	-8.3232E-06	8.2592E-09	-3.1781E-12	113.59	85	86.25
44	UpperRed	44	3.5656E-03	-7.0065E-06	7.0521E-09	-2.7203E-12	114.84	86.25	88
45	UpperRed	45	3.3684E-03	-6.5416E-06	6.5733E-09	-2.5652E-12	116.59	88	90
46	UpperRed	46	3.5880E-03	-7.1734E-06	6.9734E-09	-2.5642E-12	118.59	90	92
47	UpperRed	47	3.2841E-03	-6.3581E-06	6.3750E-09	-2.4355E-12	120.59	92	94
48	UpperRed	48	3.4373E-03	-7.3959E-06	7.8965E-09	-3.1263E-12	122.59	94	97
49	Assiniboine	1	4.8887E-03	5.7190E-05	-7.5987E-07	2.0584E-09	76.09	0	2.5
50	Assiniboine	2	5.3511E-03	3.7579E-05	-6.0522E-07	1.6986E-09	78.59	2.5	5
51	Assiniboine	3	2.4837E-02	-2.4089E-04	9.6792E-07	-1.4689E-09	83.59	5	8.5
52	Assiniboine	4	2.7757E-02	-3.6301E-04	2.1477E-06	-4.4777E-09	92.09	8.5	13
53	Assiniboine	5	1.9860E-02	-2.4985E-04	1.4649E-06	-3.0036E-09	105.09	13	16.5
54	Assiniboine	6	2.4034E-02	-3.1565E-04	1.8709E-06	-3.8594E-09	121.59	16.5	21
55	Assiniboine	7	1.8655E-02	-2.3330E-04	1.3665E-06	-2.8034E-09	142.59	21	23.75
56	Assiniboine	8	1.7586E-02	-2.3783E-04	1.4416E-06	-3.0039E-09	166.34	23.75	26

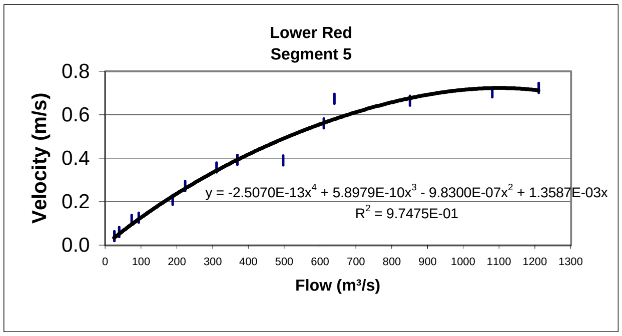
Table A-2

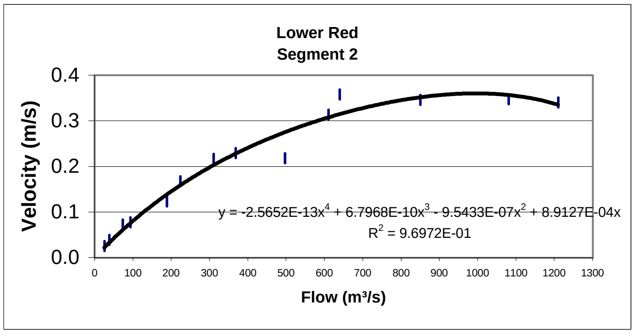
Leopold Maddox Coeficient for Depth and Velocity Estimation from Flow (Winter "Dam-out" Conditions)

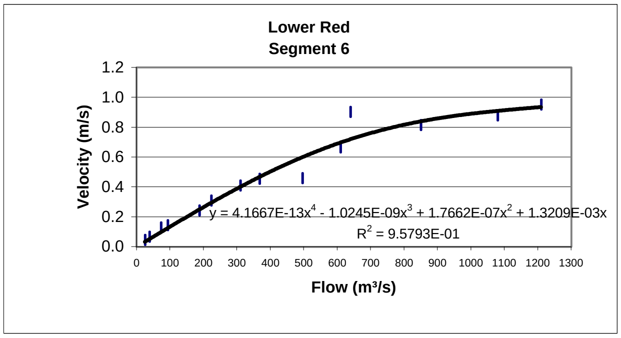
Order	Segment	River	EndKm	StartKm	EndKm From Lake	StartKm From Lake	Velocity-const	Velocity-Exp	Depth-const	Depth-Exp	Key Locations
1	1	LowerRed	0	1	28.59	29.59	0.0017	0.8259	3.3892	0.0462	
2	2	LowerRed	1	2.5	29.59	31.09	0.0019	0.7863	2.4781	0.0612	
3	3	LowerRed	2.5	4	31.09	32.59	0.0018	0.8753	3.783	0.0547	
4	4	LowerRed	4	6	32.59	34.59	0.0025	0.835	2.1808	0.1147	
5	5	LowerRed	6	8	34.59	36.59	0.0026	0.8244	2.4564	0.074	
6	6	LowerRed	8	10	36.59	38.59	0.0027	0.8473	3.2466	0.082	
7	7	LowerRed	10	13	38.59	41.59	0.0049	0.7886	1.7285	0.1522	
8	8	LowerRed	13	15.5	41.59	44.09	0.0298	0.5201	1.5939	0.1511	
9	9	LowerRed	15.5	17	44.09	45.59	0.0034	0.894	1.9052	0.0775	
10	10	LowerRed	17	18.5	45.59	47.09	0.0053	0.8275	1.2199	0.1476	
11	11	LowerRed	18.5	20.5	47.09	49.09	0.0085	0.7402	0.8173	0.2101	
12	12	LowerRed	20.5	23	49.09	51.59	0.0144	0.6075	0.3499	0.3568	
13	13	LowerRed	23	25.5	51.59	54.09	0.0597	0.3855	0.1435	0.5014	
14	14	LowerRed	25.5	28	54.09	56.59	0.0506	0.3975	0.1741	0.4782	
15	15	LowerRed	28	30.5	56.59	59.09	0.0289	0.449	0.2803	0.4238	
16	16	LowerRed	30.5	32.5	59.09	61.09	0.0083	0.6459	0.8873	0.2688	
17	17	LowerRed	32.5	34.5	61.09	63.09	0.0037	0.7729	1.4892	0.1993	North Perimeter Bridge (33.31 Km)
18	18	LowerRed	34.5	36.5	63.09	65.09	0.0036	0.7677	1.7881	0.1802	
19	19	LowerRed	36.5	38.5	65.09	67.09	0.0047	0.7392	2.0546	0.1713	NEWPCC (36.75 Km)
20	20	LowerRed	38.5	40.5	67.09	69.09	0.0083	0.6673	1.0006	0.2678	
21	21	LowerRed	40.5	42.5	69.09	71.09	0.0049	0.7515	1.8674	0.1902	Redwood Bridge (41.66 Km)
22	22	LowerRed	42.5	45	71.09	73.59	0.0077	0.6855	1.4228	0.2198	
23	23	LowerRed	45	47.5	73.59	76.09	0.0114	0.6121	0.7168	0.3152	
24	24	UpperRed	47.5	49	76.09	77.59	0.004	0.7321	1.202	0.2544	Norwood Bridge (47.59 Km)
25	25	UpperRed	49	51	77.59	79.59	0.0031	0.7554	0.9382	0.2817	
26	26	UpperRed	51	53	79.59	81.59	0.0032	0.7521	0.8394	0.3041	
27	27	UpperRed	53	55	81.59	83.59	0.0025	0.7661	1.0574	0.2783	
28	28	UpperRed	55	57	83.59	85.59	0.0043	0.7383	0.8408	0.3098	
29	29	UpperRed	57	59	85.59	87.59	0.0042	0.6908	0.9492	0.2974	
30	30	UpperRed	59	61	87.59	89.59	0.0089	0.5781	0.8394	0.3157	
31	31	UpperRed	61	63	89.59	91.59	0.0054	0.6636	0.4588	0.4108	Fort Garry Bridge (62.00 Km)
32	32	UpperRed	63	65	91.59	93.59	0.0042	0.7232	0.8043	0.3284	
33	33	UpperRed	65	67	93.59	95.59	0.004	0.7221	0.8213	0.3281	
34	34	UpperRed	67	69	95.59	97.59	0.0064	0.6549	0.5266	0.3909	SEWPCC (68.47 Km)
35	35	UpperRed	69	71	97.59	99.59	0.0029	0.7311	0.7623	0.3418	
36	36	UpperRed	71	73	99.59	101.59	0.0044	0.6989	0.7972	0.3393	
37	37	UpperRed	73	75	101.59	103.59	0.0059	0.67	0.5332	0.4048	
38	38	UpperRed	75	77	103.59	105.59	0.013	0.5097	0.1992	0.5818	
39	39	UpperRed	77	79	105.59	107.59	0.031	0.3888	0.2209	0.5587	Floodway control (77.76 Km)
40	40	UpperRed	79	81	107.59	109.59	0.0486	0.3552	0.297	0.501	
41	41	UpperRed	81	83	109.59	111.59	0.0483	0.3704	0.3125	0.4926	
42	42	UpperRed	83	85	111.59	113.59	0.0237	0.4909	0.7712	0.3486	
43	43	UpperRed	85	86.25	113.59	114.84	0.0505	0.3712	0.3433	0.4801	
44	44	UpperRed	86.25	88	114.84	116.59	0.0283	0.475	0.5417	0.4209	
45	45	UpperRed	88	90	116.59	118.59	0.0198	0.5347	1.0138	0.2991	
46	46	UpperRed	90	92	118.59	120.59	0.0408	0.3974	0.6913	0.3605	
47	47	UpperRed	92	94	120.59	122.59	0.0177	0.5529	1.044	0.3065	
48	48	UpperRed	94	97	122.59	125.59	0.0278	0.4588	0.6626	0.3798	
49	1	Assiniboine	0	2.5	76.09	77.59	0.1112	0.2252	0.3195	0.5846	Main Street Bridge (0.31 Km)
50	2	Assiniboine	2.5	5	78.59	82.59	0.0736	0.3358	0.3607	0.5387	
51	3	Assiniboine	5	8.5	83.59	91.09	0.1031	0.4065	0.2071	0.53	
52	4	Assiniboine	8.5	13	92.09	104.09	0.091	0.398	0.1975	0.4783	
53	5	Assiniboine	13	16.5	105.09	120.59	0.0571	0.4519	0.2697	0.4499	
54	6	Assiniboine	16.5	21	121.59	141.59	0.0759	0.4088	0.1712	0.5199	West Perimeter Bridge (18.39 Km); WEWPCC (19.87 Km)
55	7	Assiniboine	21	23.75	142.59	165.34	0.0539	0.4526	0.2334	0.4547	
56	8	Assiniboine	23.75	26	166.34	191.34	0.0584	0.3876	0.2754	0.4584	Headingley Bridge (25.61 Km)

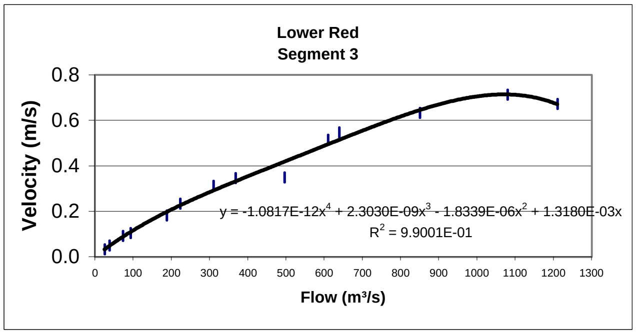
Figure A-1:Flow vs. Velocity Relationships for Lower Red

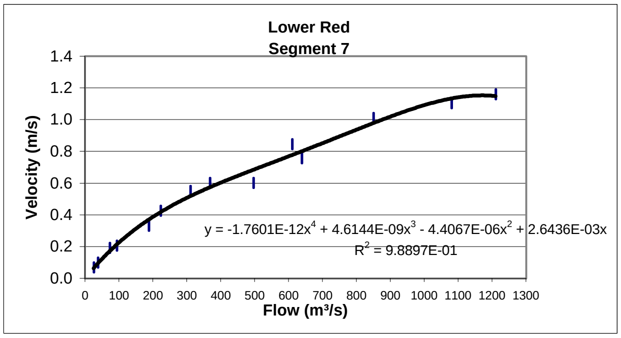


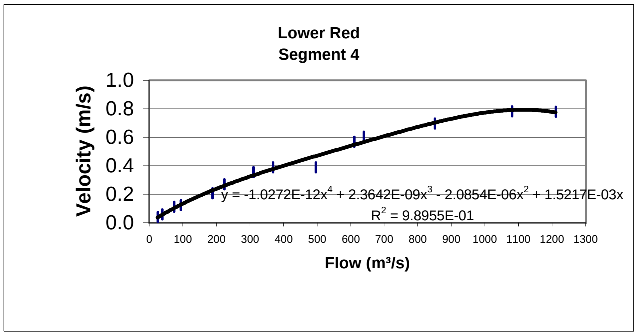












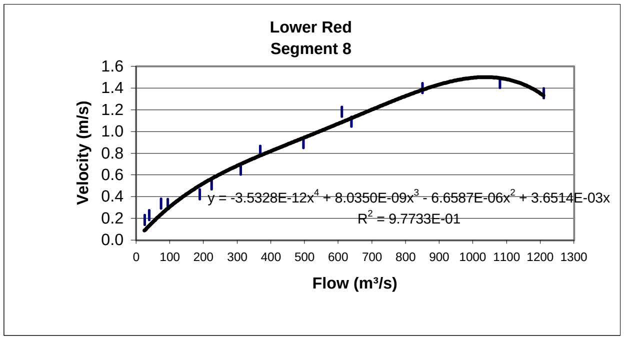
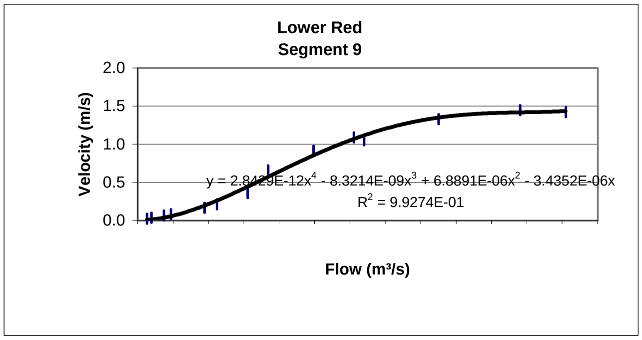
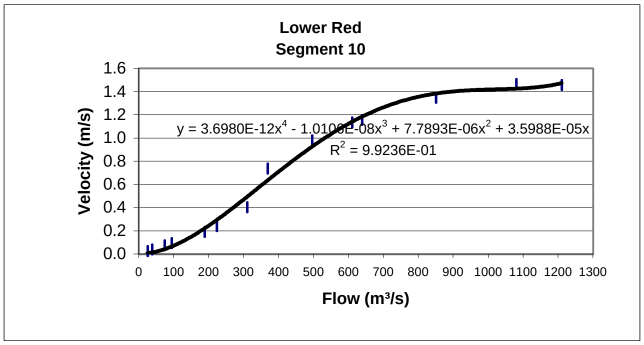
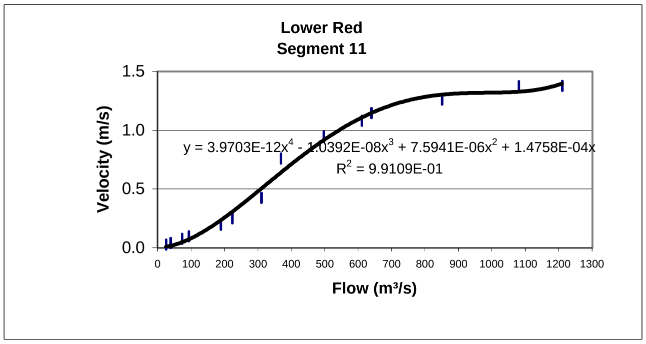
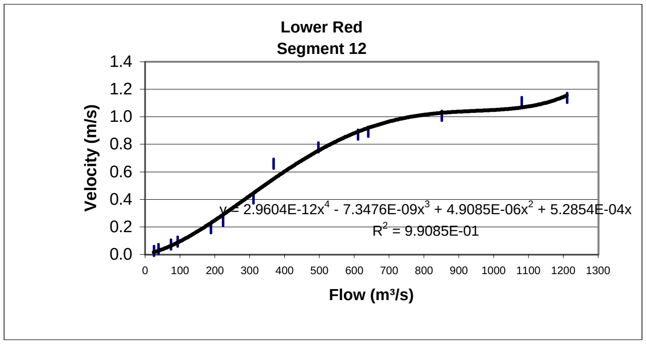


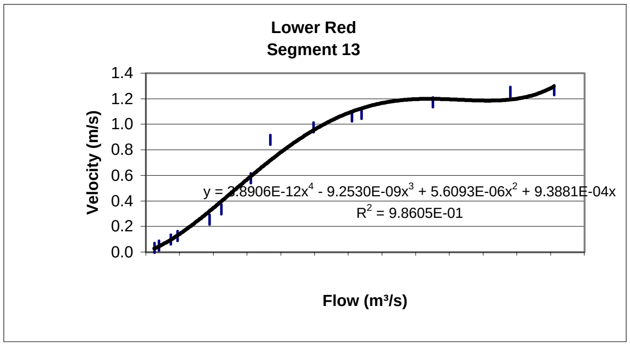
Figure A-1:Flow vs. Velocity Relationships for Lower Red

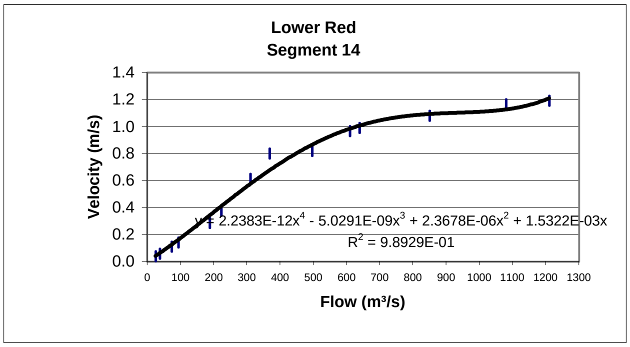


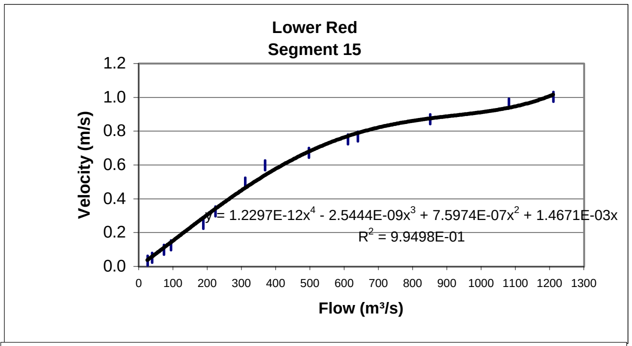












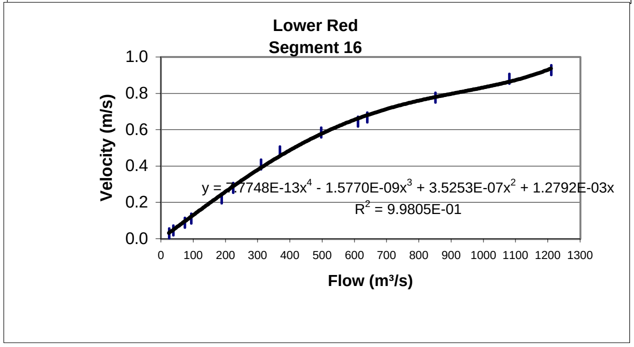
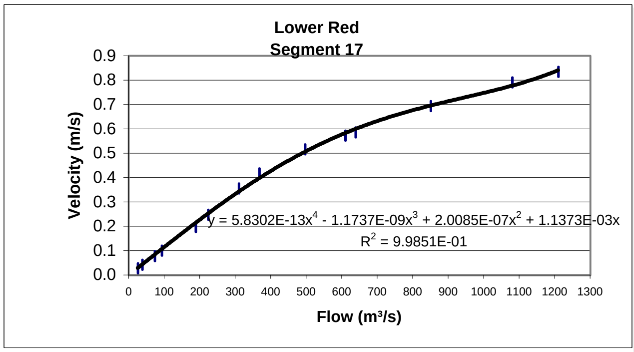
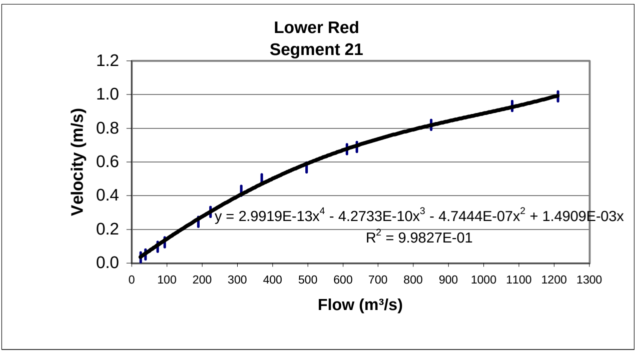
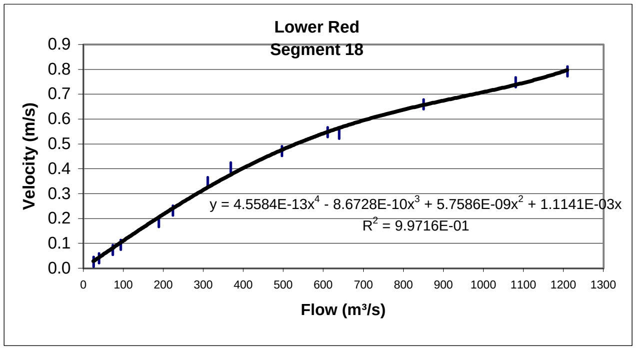
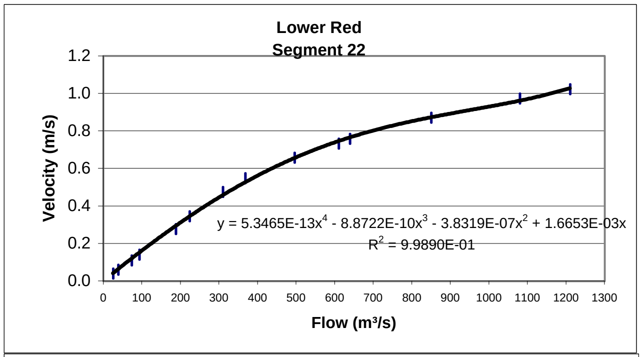


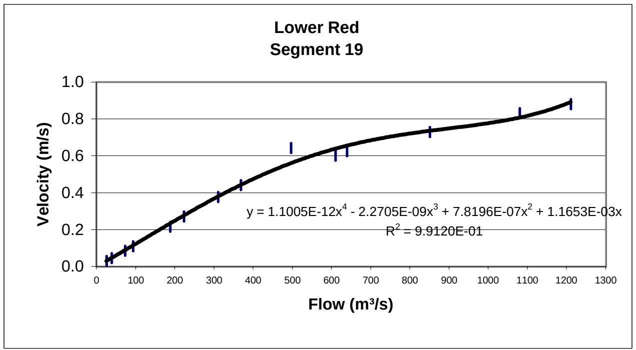
Figure A-1:Flow vs. Velocity Relationships for Lower Red

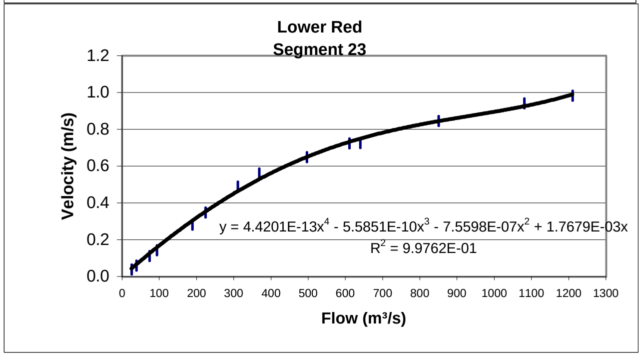












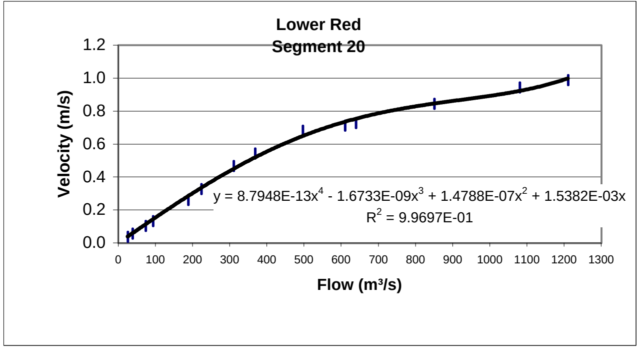


Figure A-2: Flow vs. Velocity Relationships for Upper Red

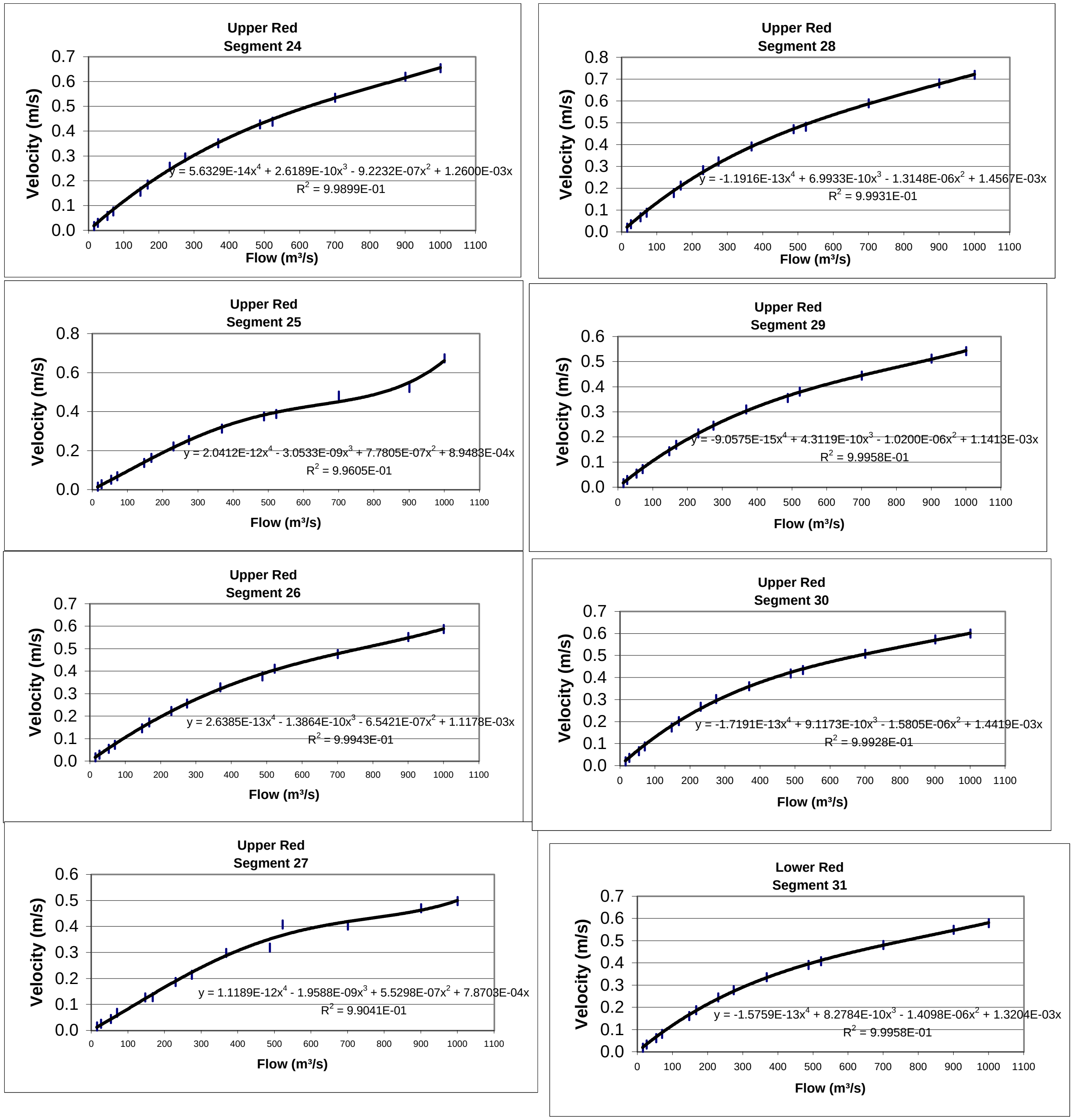


Figure A-2: Flow vs. Velocity Relationships for Upper Red

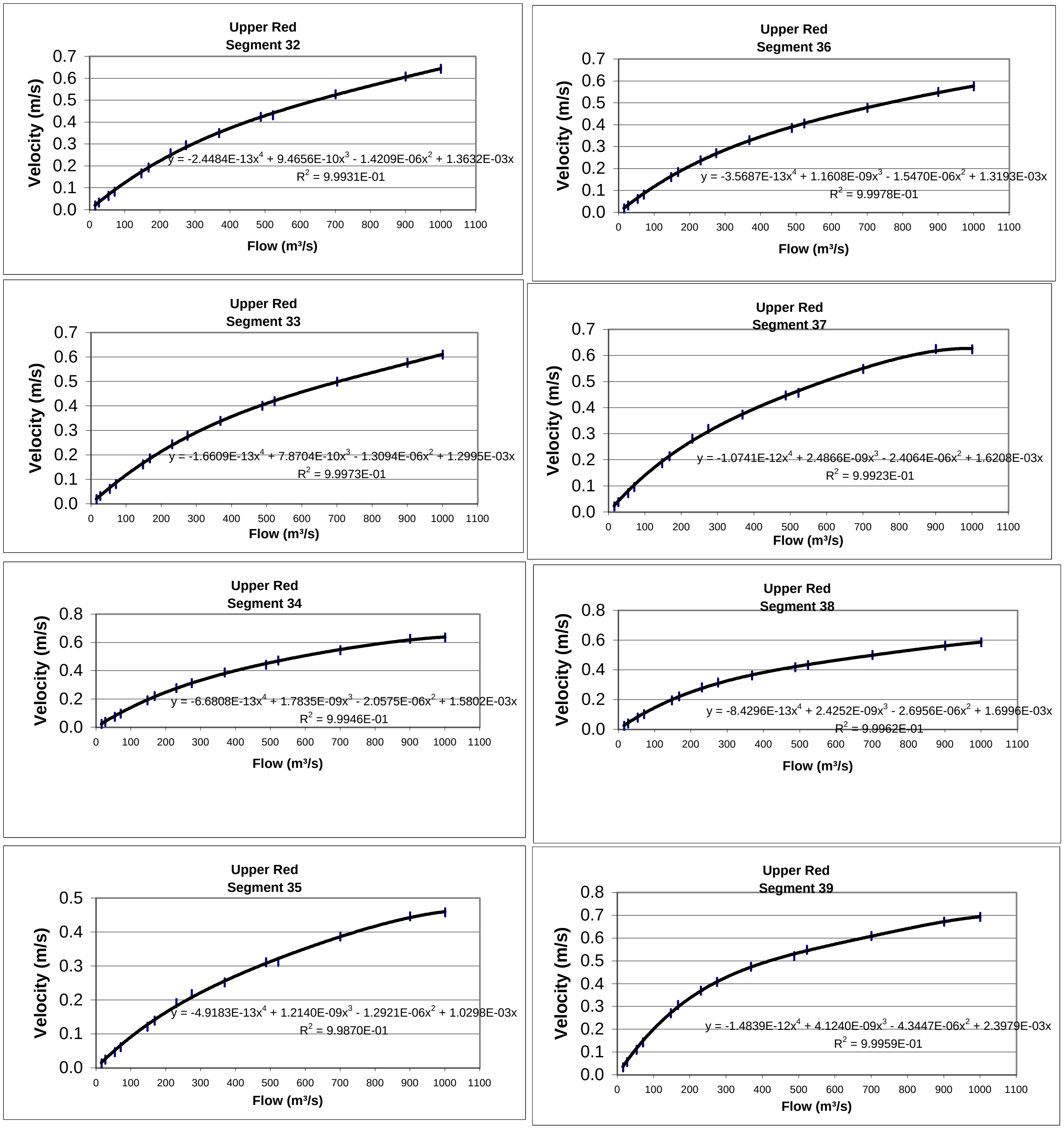


Figure A-2: Flow vs. Velocity Relationships for Upper Red

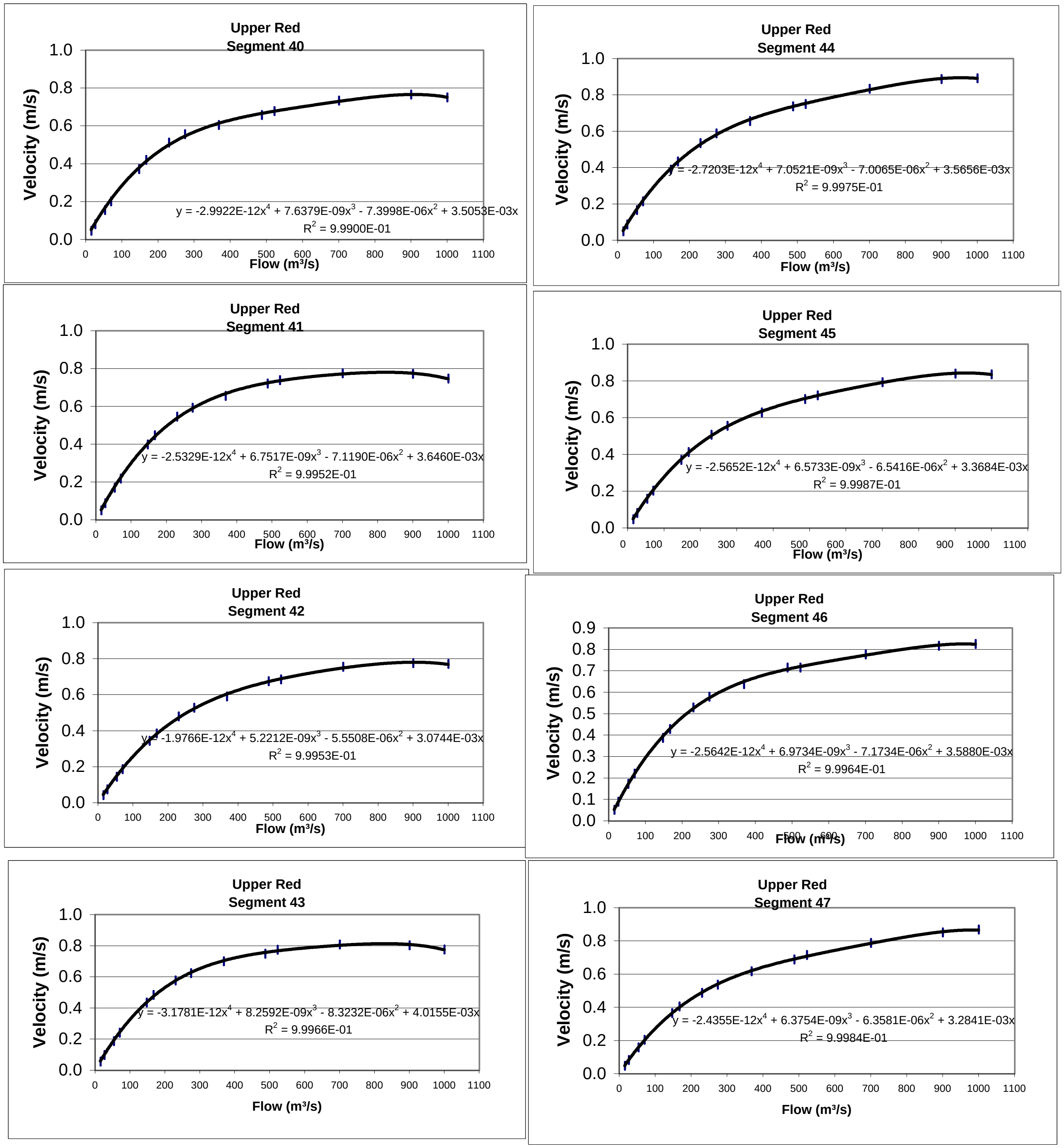
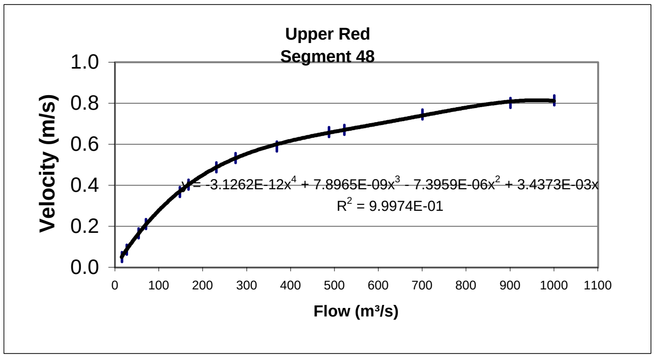


Figure A-2: Flow vs. Velocity Relationships for Upper Red



$y = -3.1262E{-12}x^4 + 7.8965E{-09}x^3 - 7.3959E{-06}x^2 + 3.4373E{-03}x$

$R^2 = 9.9974E{-01}$

APPENDIX B

SUMMARY OF MONTHLY WATER QUALITY PARAMETERS FROM LONG-TERM ROUTINE MONITORING (1977 TO 1997)

TABLE B-1
MONTHLY VARIATION IN SUSPENDED SOLIDS MG/L
1977-1997

Month	Assiniboine River		Red River			Monthly Average
	Headingley	Main St. Bridge	Floodway Control	North Perimeter	Lockport	
January	28	41	11	16	12	**22**
February	28	39	10	18	11	**21**
March	37	52	30	39	41	**40**
April	243	227	211	256	276	**243**
May	146	139	145	105	106	**128**
June	113	99	170	98	98	**116**
July	145	109	200	130	138	**144**
August	118	69	102	63	59	**82**
September	89	57	72	46	39	**61**
October	85	62	86	49	51	**67**
November	53	81	37	29	40	**48**
December	74	88	15	15	16	**42**
Annual Average	**99**	**89**	**97**	**76**	**77**	**88**

TABLE B-2
MONTHLY VARIATION IN TURBIDITY N.T.U.
1977-1997

Month	Assiniboine River		Red River			Monthly Average
	Headingley	Main St. Bridge	Floodway Control	North Perimeter	Lockport	
January	15	19	9	9	7	**12**
February	27	26	7	9	7	**15**
March	17	22	16	19	19	**19**
April	102	91	111	121	128	**110**
May	53	53	64	46	42	**52**
June	45	39	83	47	44	**52**
July	59	44	92	56	58	**62**
August	49	36	54	39	33	**42**
September	40	30	44	28	24	**33**
October	35	30	45	30	27	**33**
November	21	36	22	18	23	**24**
December	49	42	13	9	9	**24**
Annual Average	**43**	**39**	**49**	**38**	**36**	**41**

TABLE B-3
MONTHLY VARIATION IN TOTAL PHOSPHORUS MG/L
1977-1997

Month	Assiniboine River				Red River						Monthly Average
	Headingley	West Perimeter Br.	Assiniboine Park	Main St. Bridge	Floodway Control	Fort Garry Br.	Norwood Bridge	Redwood Bridge	North Perimeter	Lockport	
January	0.29	0.18	0.39	0.35	0.45	0.41	0.31	0.24	0.47	0.45	**0.35**
February	0.22	0.20	0.22	0.30	0.25	0.30	0.29	0.27	0.41	0.38	**0.29**
March	0.21	0.26	0.20	0.33	0.26	0.33	0.29	0.32	0.35	0.36	**0.29**
April	0.40	0.54	0.43	0.41	0.40	0.42	0.40	0.45	0.45	0.51	**0.44**
May	0.26	0.42	0.31	0.29	0.28	0.27	0.31	0.31	0.28	0.27	**0.30**
June	0.24	0.30	0.23	0.27	0.35	0.30	0.31	0.26	0.31	0.28	**0.28**
July	0.25	0.35	0.30	0.26	0.33	0.32	0.33	0.32	0.32	0.31	**0.31**
August	0.24	0.35	0.29	0.29	0.25	0.28	0.34	0.30	0.35	0.33	**0.30**
September	0.21	0.42	0.23	0.28	0.24	0.28	0.27	0.26	0.32	0.29	**0.28**
October	0.22	0.36	0.29	0.29	0.25	0.31	0.32	0.27	0.35	0.32	**0.30**
November	0.15	0.27	0.19	0.30	0.20	0.26	0.22	0.23	0.29	0.30	**0.24**
December	0.24	0.81	0.18	0.29	0.30	0.34	0.16	0.18	0.36	0.42	**0.33**
Annual Average	**0.25**	**0.35**	**0.28**	**0.30**	**0.30**	**0.31**	**0.31**	**0.29**	**0.35**	**0.35**	**0.31**

TABLE B-4
MONTHLY VARIATION IN TOTAL KJELDAHL NITROGEN
1977-1997

Month	Assiniboine River				Red River						Monthly Average
	Headingley	West Perimeter Br.	Assiniboine Park	Main St. Bridge	Floodway Control	Fort Garry Br.	Norwood Bridge	Redwood Bridge	North Perimeter	Lockport	
January	1.49	1.39	1.83	1.92	1.63	2.54	2.35	1.77	3.38	2.92	**2.12**
February	1.62	1.54	1.71	1.74	1.59	2.22	2.29	2.00	3.16	2.95	**2.08**
March	1.53	1.80	1.76	1.91	1.68	2.05	2.17	2.06	2.48	2.52	**2.00**
April	1.89	2.85	2.36	2.01	1.85	1.88	2.44	2.45	2.12	2.26	**2.21**
May	1.75	2.62	2.16	1.96	1.77	1.79	2.38	1.85	2.11	2.06	**2.05**
June	1.43	1.63	1.61	1.54	1.60	1.58	1.77	1.59	1.85	1.86	**1.65**
July	1.63	2.15	2.07	1.78	1.72	1.82	1.97	1.81	2.16	1.95	**1.91**
August	1.53	1.84	1.95	1.67	1.53	1.70	2.08	1.69	2.30	2.05	**1.83**
September	1.46	2.03	1.73	1.65	1.45	1.71	1.90	1.67	2.40	2.20	**1.82**
October	1.43	2.20	1.96	1.56	1.58	1.86	2.11	2.00	2.65	2.42	**1.98**
November	1.19	1.47	1.38	1.56	1.45	1.68	1.55	1.61	2.49	2.45	**1.68**
December	1.62	1.40	1.20	1.96	1.53	2.00	1.23	1.50	2.77	2.66	**1.79**
Annual Average	**1.55**	**1.94**	**1.86**	**1.77**	**1.62**	**1.88**	**2.08**	**1.84**	**2.45**	**2.34**	**1.93**

TABLE B-5
MONTHLY VARIATION IN AMMONIA MG/L
1977-1997

Month	Assiniboine River				Red River						Monthly Average
	Headingley	West Perimeter Br.	Assiniboine Park	Main St. Bridge	Floodway Control	Fort Garry Br.	Norwood Bridge	Redwood Bridge	North Perimeter	Lockport	
January	0.32	0.22	0.22	0.46	0.34	1.23	1.15	0.51	1.93	1.64	**0.80**
February	0.32	0.15	0.20	0.43	0.36	0.82	0.71	0.50	1.71	1.56	**0.68**
March	0.25	0.39	0.22	0.49	0.27	0.56	0.46	0.36	1.06	1.06	**0.51**
April	0.34	0.49	0.27	0.37	0.38	0.42	0.22	0.22	0.56	0.60	**0.39**
May	0.14	0.25	0.04	0.16	0.15	0.15	0.09	0.08	0.46	0.35	**0.19**
June	0.16	0.10	0.07	0.17	0.22	0.20	0.09	0.18	0.38	0.40	**0.20**
July	0.12	0.07	0.06	0.14	0.15	0.16	0.06	0.12	0.42	0.33	**0.16**
August	0.14	0.06	0.04	0.14	0.14	0.24	0.10	0.08	0.91	0.58	**0.24**
September	0.12	0.27	0.04	0.15	0.13	0.34	0.13	0.10	0.89	0.61	**0.28**
October	0.11	0.23	0.05	0.18	0.13	0.30	0.16	0.12	1.08	0.81	**0.32**
November	0.11	0.20	0.15	0.29	0.13	0.39	0.25	0.22	1.15	1.02	**0.39**
December	0.23	0.24	0.07	0.27	0.17	0.60	0.27	0.25	1.43	1.14	**0.47**
Annual Average	**0.19**	**0.21**	**0.11**	**0.26**	**0.21**	**0.42**	**0.28**	**0.22**	**0.95**	**0.82**	**0.37**

TABLE B-6
MONTHLY VARIATION IN NITRATE NITRITE MG/L
1977-1997

Month	Assiniboine River				Red River						Monthly Average
	Headingley	West Perimeter Br.	Assiniboine Park	Main St. Bridge	Floodway Control	Fort Garry Br.	Norwood Bridge	Redwood Bridge	North Perimeter	Lockport	
January	0.50	0.50	0.52	0.55	0.36	0.37	0.42	0.47	0.38	0.42	**0.45**
February	0.72	0.68	0.71	0.73	0.54	0.55	0.67	0.66	0.58	0.58	**0.64**
March	0.71	0.76	0.73	0.82	0.93	1.15	0.94	0.95	0.90	0.89	**0.88**
April	0.55	0.86	0.77	0.58	0.94	1.08	1.25	1.05	0.97	0.99	**0.90**
May	0.11	0.20	0.14	0.17	0.30	0.37	0.54	0.49	0.32	0.38	**0.30**
June	0.07	0.12	0.19	0.13	0.44	0.44	0.49	0.55	0.33	0.39	**0.31**
July	0.08	0.19	0.14	0.15	0.41	0.43	0.49	0.46	0.39	0.44	**0.32**
August	0.06	0.06	0.06	0.13	0.23	0.25	0.23	0.17	0.24	0.38	**0.18**
September	0.05	0.11	0.04	0.12	0.18	0.19	0.18	0.17	0.18	0.35	**0.16**
October	0.10	0.09	0.10	0.15	0.31	0.38	0.40	0.36	0.32	0.40	**0.26**
November	0.07	0.13	0.12	0.12	0.17	0.17	0.17	0.17	0.17	0.20	**0.15**
December	0.30	0.38	0.30	0.31	0.17	0.19	0.23	0.24	0.22	0.25	**0.26**
Annual Average	**0.26**	**0.32**	**0.29**	**0.32**	**0.42**	**0.47**	**0.50**	**0.49**	**0.42**	**0.48**	**0.40**

Table B-7
Monthly Variation in Chlorophyll_a
1977-1997

Month	Assiniboine River				Red River						Monthly Average
	Headingley	West Perimeter Br.	Assiniboine Park	Main St. Bridge	Floodway Control	Fort Garry Br.	Norwood Bridge	Redwood Bridge	North Perimeter	Lockport	
January	17	17	17	12	9	18	15	15	17	15	**15**
February	15	17	14	4	3	15	13	13	7	18	**11**
March	12	5	10	3	6	13	13	12	6	16	**10**
April	43	40	43	43	18	21	19	16	19	17	**24**
May	30	32	31	34	27	25	24	22	27	26	**27**
June	26	25	23	28	14	17	18	20	21	23	**21**
July	44	44	53	41	11	10	15	16	15	17	**22**
August	42	43	39	49	17	14	15	22	24	29	**26**
September	56	59	58	60	27	27	34	35	37	42	**40**
October	47	51	49	51	26	25	28	33	33	36	**35**
November	20	26	23	20	27	24	26	29	26	23	**25**
December	7	11	14	8	22	18	28	20	24	23	**20**
Annual Average	**32**	**33**	**34**	**32**	**18**	**19**	**20**	**21**	**22**	**24**	**24**

Table B-8
Monthly Variation in pH
1977-1997

Month	Assiniboine River				Red River						Monthly Average
	Headingley	West Perimeter Br.	Assiniboine Park	Main St. Bridge	Floodway Control	Fort Garry Br.	Norwood Bridge	Redwood Bridge	North Perimeter	Lockport	
January	7.93	7.90	7.94	7.89	7.94	7.88	7.85	7.69	7.75	7.84	**7.86**
February	7.84	7.82	7.80	7.83	7.84	7.78	7.78	7.63	7.64	7.72	**7.77**
March	7.90	7.89	7.77	7.90	7.87	7.82	7.81	7.62	7.70	7.77	**7.80**
April	8.19	8.16	8.16	8.12	8.10	8.07	8.04	7.96	7.97	7.98	**8.07**
May	8.30	8.27	8.36	8.27	8.22	8.23	8.16	8.00	8.03	8.08	**8.19**
June	8.30	8.28	8.40	8.22	8.10	8.13	8.04	7.98	8.00	8.10	**8.16**
July	8.38	8.34	8.38	8.28	8.16	8.19	8.11	7.99	8.02	8.10	**8.19**
August	8.45	8.40	8.54	8.39	8.32	8.30	8.28	8.16	8.04	8.14	**8.30**
September	8.50	8.45	8.60	8.43	8.38	8.37	8.33	8.17	8.09	8.17	**8.35**
October	8.45	8.42	8.43	8.45	8.39	8.33	8.36	8.14	8.09	8.18	**8.32**
November	8.47	8.40	8.36	8.45	8.47	8.42	8.37	8.26	8.17	8.20	**8.36**
December	8.15	8.13	8.05	8.05	8.27	8.26	8.17	7.94	7.92	8.05	**8.10**
Annual Average	**8.25**	**8.21**	**8.27**	**8.21**	**8.18**	**8.16**	**8.12**	**7.97**	**7.97**	**8.03**	**8.14**

APPENDIX C

SUMMARY OF 1999
RIVER MONITORING RESULTS

TABLE C-1
SUMMARY OF 1999 MONITORING PROGRAM

					From Laboratory Analysis											From Field			
Routine Number	Date	Sample pt.	ID	Location ID Value	pH	Alkalinity (mg/L)	Nitrate (mg/L)	Total Phosphorus (mg/L)	TKN (mg/L)	Total Nitrogen (mg/L as N)	Ammonia (mg/Las N)	Ammonia + Nitrate in (mg/L as N)	Ortho PO4 - P (mg/L)	Chlorophyll "a" (ug/L)	Total Suspended Solids (mg/L)	Light Extinction Coefficient	Average Light as % of Surface Condition	Depth to 99% light extinction (m)	field pH
1	6-Jul-99	Upstream Lockport	RR2	2	8.3	228	0.32	0.36	1.62	1.94	0.02	0.34	0.16	13	154	8.6	5.6%	0.53	8
1	6-Jul-99	Parkdale	RR3	3	8.3	224	0.31	0.32	1.4	1.71	0.02	0.33	0.14	10	170	10.8	4.9%	0.43	8.2
1	6-Jul-99	North Perimeter Bridge	RR4	4	8.3	224	0.29	0.32	1.6	1.89	0.02	0.31	0.14	9	156	11.2	4.8%	0.41	8.2
1	6-Jul-99	Fraser Grove Park	RR5	5	8.3	224	0.28	0.37	1.55	1.83	0.02	0.3	0.15	10	182	11.4	4.7%	0.40	8.3
1	6-Jul-99	Norwood Bridge	RR6	6	8.2	200	0.3	0.33	1.53	1.83	0.02	0.32	0.11	8	180	11.4	3.2%	0.40	8.2
1	7-Jul-99	Fort Garry Bridge	RR7	7	8.2	208	0.33	0.33	1.29	1.62	0.02	0.35	0.13	9	184	12.3	3.1%	0.37	7.6
1	7-Jul-99	South Floodway Gates	RR8	8	8.2	204	0.34	0.32	1.37	1.71	0.02	0.36	0.13	9	222	19.0	2.6%	0.24	8.1
1	6-Jul-99	Donald to Main St.	RR9	9	8.4	272	0.23	0.4	1.46	1.69	0.02	0.25	0.19	15	160	9.2	10.4%	0.50	8.4
1	7-Jul-99	Omand's Creek	RR10	10	8.4	276	0.22	0.37	1.7	1.92	0.02	0.24	0.19	20	146				8.3
1	7-Jul-99	Headingly Bridge	RR11	11	8.4	280	0.22	0.36	1.61	1.83	0.02	0.24	0.2	16	138	11.4	9.2%	0.40	8.2
2	22-Jul-99	Lockport Flodway Exit	RR1	1	8.3	236	0.44	0.4	1.3	1.74	0.05	0.49	0.23	13	278	16.0	4.0%	0.29	8.2
2	20-Jul-99	Upstream Lockport	RR2	2	8.3	240	0.41	0.37	1.8	2.21	0.03	0.44	0.2	9	232	18.0	3.9%	0.26	8.2
2	20-Jul-99	Parkdale	RR3	3	8.3	240	0.41	0.39	1.5	1.91	0.05	0.46	0.19	9	228	16.0	4.0%	0.29	8.2
2	20-Jul-99	North Perimeter Bridge	RR4	4	8.2	232	0.41	0.39	1.4	1.81	0.05	0.46	0.2	11	240	16.0	4.0%	0.29	8.2
2	20-Jul-99	Fraser Grove Park	RR5	5	8.3	236	0.4	0.32	1.1	1.5	0.02	0.42	0.18	10	238	16.0	4.0%	0.29	8.3
2	21-Jul-99	Norwood Bridge	RR6	6	8.2	212	0.4	0.45	2	2.4	0.02	0.42	0.25	9	380	17.7	2.6%	0.26	8.2
2	21-Jul-99	Fort Garry Bridge	RR7	7	8.2	212	0.38	0.4	1.8	2.18	0.02	0.4	0.21	9	326	16.0	2.7%	0.29	8.1
2	21-Jul-99	South Floodway Gates	RR8	8	8.3	208	0.38	0.37	1.9	2.28	0.02	0.4	0.2	9	292	18.0	2.6%	0.26	8.1
2	21-Jul-99	Donald to Main St.	RR9	9	8.5	280	0.37	0.35	1.3	1.67	0.03	0.4	0.22	18	170				8.4
2	22-Jul-99	Omand's Creek	RR10	10	8.4	284	0.39	0.32	1.7	2.09	0.02	0.41	0.23	24	168				8.4
2	22-Jul-99	Headingly Bridge	RR11	11	8.4	280	0.4	0.33	1.6	2	0.02	0.42	0.23	24	152	11.0	9.4%	0.42	8.3
3	10-Aug-99	Lockport Flodway Exit	RR1	1	8.5	244	0.33	0.2	1.5	1.83	0.07	0.4	0.17	32	30	6.2	7.0%	0.74	8.4
3	10-Aug-99	Upstream Lockport	RR2	2	8.5	244	0.31	0.2	1.5	1.81	0.07	0.38	0.16	34	28	6.3	6.9%	0.73	8.4
3	10-Aug-99	Parkdale	RR3	3	8.4	252	0.3	0.25	1.5	1.8	0.08	0.38	0.17	35	94	10.2	5.0%	0.45	8.4
3	10-Aug-99	North Perimeter Bridge	RR4	4	8.5	252	0.29	0.25	1.5	1.79	0.11	0.4	0.17	38	48	5.7	7.4%	0.81	8.5
3	10-Aug-99	Fraser Grove Park	RR5	5	8.6	252	0.25	0.2	1.5	1.75	0.02	0.27	0.16	32	82	7.0	6.4%	0.66	8.5
3	10-Aug-99	Norwood Bridge	RR6	6	8.4	216	0.44	0.2	1	1.44	0.06	0.5	0.16	9	45	7.9	4.0%	0.58	8.4
3	10-Aug-99	Fort Garry Bridge	RR7	7	8.4	216	0.44	0.2	1	1.44	0.04	0.48	0.16	6	78	12.0	3.1%	0.38	8.4
3	11-Aug-99	South Floodway Gates	RR8	8	8.5	228	0.41	0.37	1	1.41	0.02	0.43	0.2	7	279	18.0	2.6%	0.26	8.2
3	10-Aug-99	Donald to Main St.	RR9	9	8.7	304	0.04	0.39	1.5	1.54	0.02	0.06	0.17	53	224				8.7
3	11-Aug-99	Omand's Creek	RR10	10	8.7	300	0.04	0.42	1.6	1.64	0.02	0.06	0.2	53	226	13.0	8.6%	0.35	8.6
3	11-Aug-99	Headingly Bridge	RR11	11	8.7	300	0.04	0.42	1.5	1.54	0.02	0.06	0.2	73	232	7.0	12.4%	0.66	8.6
4	1-Sep-99	Lockport Flodway Exit	RR1	1	8.4	200	0.54	0.3	1.5	2.04	0.08	0.62	0.22	22	121	13.0	4.4%	0.35	8.3
4	1-Sep-99	Upstream Lockport	RR2	2	8.4	196	0.52	0.3	2	2.52	0.08	0.6	0.21	22	60	9.2	5.4%	0.50	8.3
4	1-Sep-99	Parkdale	RR3	3	8.5	208	0.42	0.4	1.5	1.92	0.04	0.46	0.21	26	244	15.4	4.1%	0.30	8.4
4	1-Sep-99	North Perimeter Bridge	RR4	4	8.4	200	0.4	0.3	1.5	1.9	0.15	0.55	0.22	18	67	8.7	5.6%	0.53	8.4
4	1-Sep-99	Fraser Grove Park	RR5	5	8.4	196	0.37	0.3	1.5	1.87	0.04	0.41	0.2	19	132	5.2	7.9%	0.88	8.4
4	1-Sep-99	Norwood Bridge	RR6	6	8.3	180	0.59	0.4	2	2.59	0.04	0.63	0.21	9	308	16.3	2.7%	0.28	8.25
4	1-Sep-99	Fort Garry Bridge	RR7	7	8.3	168	0.57	0.4	1.5	2.07	0.04	0.61	0.21	9	218	19.0	2.6%	0.24	8.2
4	2-Sep-99	South Floodway Gates	RR8	8	8.3	172	0.75	0.4	1.5	2.25	0.04	0.79	0.27	11	284	14.0	2.9%	0.33	8.1
4	1-Sep-99	Donald to Main St.	RR9	9	8.8	288	0.04	0.4	2	2.04	0.04	0.08	0.19	72	164	10.9	9.4%	0.42	8.8
4	2-Sep-99	Omand's Creek	RR10	10	8.8	284	0.04	0.35	1.5	1.54	0.04	0.08	0.2	59	146	10.0	9.9%	0.46	8.6
4	2-Sep-99	Headingly Bridge	RR11	11	8.8	288	0.04	0.35	1.5	1.54	0.04	0.08	0.2	53	146	11.0	9.4%	0.42	8.7

					From Laboratory Analysis											From Field			
Routine Number	Date	Sample pt.	ID	Location ID Value	pH	Alkalinity (mg/L)	Nitrate (mg/L)	Total Phosphorus (mg/L)	TKN (mg/L)	Total Nitrogen (mg/L as N)	Ammonia (mg/Las N)	Ammonia + Nitrate in (mg/L as N)	Ortho PO4 - P (mg/L)	Chlorophyll "a" (ug/L)	Total Suspended Solids (mg/L)	Light Extinction Coefficient	Average Light as % of Surface Condition	Depth to 99% light extinction (m)	field pH
5	15-Sep-99	Lockport Flodway Exit	RR1	1	8.2	188	0.76	0.49	1.6	2.36	0.07	0.83	0.24	9	372	20.0	3.7%	0.23	8
5	15-Sep-99	Upstream Lockport	RR2	2	8.2	184	0.74	0.55	1.5	2.24	0.06	0.8	0.26	9	334	20.0	3.7%	0.23	7.9
5	15-Sep-99	Parkdale	RR3	3	8.3	180	0.73	0.45	1.2	1.93	0.05	0.78	0.25	11	294	20.0	3.7%	0.23	8.2
5	15-Sep-99	North Perimeter Bridge	RR4	4	8.3	180	0.72	0.44	1.3	2.02	0.08	0.8	0.26	10	240	20.0	3.7%	0.23	
5	15-Sep-99	Fraser Grove Park	RR5	5	8.3	184	0.71	0.41	1.3	2.01	0.04	0.75	0.25	9	238	20.0	3.7%	0.23	
5	15-Sep-99	Norwood Bridge	RR6	6	8.1	172	0.74	0.39	1.5	2.24	0.04	0.78	0.24	9	264	20.0	2.5%	0.23	
5	15-Sep-99	Fort Garry Bridge	RR7	7	8.2	172	0.72	0.36	1.2	1.92	0.04	0.76	0.27	9	212	18.0	2.6%	0.26	
5	16-Sep-99	South Floodway Gates	RR8	8	8.1	176	0.62	0.36	1	1.62	0.04	0.66	0.31	9	162	12.0	3.1%	0.38	8.1
5	15-Sep-99	Donald to Main St.	RR9	9	8.7	188	0.34	0.33	1.2	1.54	0.02	0.36	0.19	42	109	20.0	7.2%	0.23	
5	16-Sep-99	Omand's Creek	RR10	10	8.7	292	0.26	0.35	1.8	2.06	0.03	0.29	0.2	59	142	11.0	9.4%	0.42	
5	16-Sep-99	Headingly Bridge	RR11	11	8.7	269	0.24	0.34	1.8	2.04	0.03	0.27	0.2	56	134	10.0	9.9%	0.46	
6	6-Oct-99	Lockport Flodway Exit	RR1	1	8.4	248	0.32	0.37	2.8	3.12	0.14	0.46	0.17	21	47	3.9	10.0%	1.18	8.7
6	6-Oct-99	Upstream Lockport	RR2	2	8.4	244	0.3	0.3	2.7	3	0.14	0.44	0.15	22	36	4.2	9.4%	1.10	8.5
6	6-Oct-99	Parkdale	RR3	3	8.4	248	0.34	0.44	3.4	3.74	0.18	0.52	0.18	20	79	4.9	8.3%	0.94	8.5
6	6-Oct-99	North Perimeter Bridge	RR4	4	8.5	248	0.31	0.32	2.5	2.81	0.19	0.5	0.17	21	76	5.9	7.2%	0.77	8.5
6	6-Oct-99	Fraser Grove Park	RR5	5	8.4	252	0.27	0.28	2.2	2.47	0.07	0.34	0.15	20	94	5.3	7.9%	0.88	8.5
6	6-Oct-99	Norwood Bridge	RR6	6	8.4	224	0.27	0.28	2.3	2.57	0.08	0.35	0.15	11	89	5.7	5.0%	0.80	8.5
6	6-Oct-99	Fort Garry Bridge	RR7	7	8.4	228	0.25	0.26	2.6	2.85	0.07	0.32	0.14	12	97	6.5	4.5%	0.71	
6	7-Oct-99	South Floodway Gates	RR8	8		224	0.23	0.27	2.3	2.53	0.03	0.26	0.15	12	109	10.0	3.4%	0.46	8.5
6	6-Oct-99	Donald to Main St.	RR9	9	8.6	308	0.24	0.45	3.7	3.94	0.04	0.28	0.16	51	176	8.8	10.7%	0.52	8.7
6	7-Oct-99	Omand's Creek	RR10	10		308	0.25	0.4	3.1	3.35	0.03	0.28	0.17	54	152	6.5	13.1%	0.71	8.7
6	7-Oct-99	Headingly Bridge	RR11	11		304	0.26	0.42	2.8	3.06	0.03	0.29	0.17	52	158	7.4	12.0%	0.62	8.7
7	20-Oct-99	Lockport Flodway Exit	RR1	1	8.5	252	0.15	0.22	2.5	2.65	0.2	0.35	0.1	54	35	6.0	7.1%	0.76	8.7
7	20-Oct-99	Upstream Lockport	RR2	2	8.5	248	0.14	0.26	3.5	3.64	0.22	0.36	0.09	55	30	6.1	7.1%	0.76	8.6
7	20-Oct-99	Parkdale	RR3	3	8.5	240	0.12	0.26	3.5	3.62	0.22	0.34	0.08	56	60	6.0	7.1%	0.76	8.6
7	20-Oct-99	North Perimeter Bridge	RR4	4	8.5	240	0.09	0.46	3.3	3.39	0.21	0.3	0.08	58	58	6.0	7.1%	0.77	8.7
7	20-Oct-99	Fraser Grove Park	RR5	5	8.5	248	0.08	0.33	2.5	2.58	0.06	0.14	0.06	60	66	6.0	7.1%	0.76	8.7
7	20-Oct-99	Norwood Bridge	RR6	6	8.5	232	0.1	0.19	2.2	2.3	0.09	0.19	0.06	50	41	6.0	4.8%	0.76	8.6
7	20-Oct-99	Fort Garry Bridge	RR7	7	8.6	228	0.05	0.46	2.2	2.25	0.11	0.16	0.05	51	62	5.3	5.3%	0.87	8.6
7	21-Oct-99	South Floodway Gates	RR8	8	8.6	323	0.04	0.22	2.5	2.54	0.03	0.07	0.07	59	104	9.0	3.7%	0.51	8.7
7	20-Oct-99	Donald to Main St.	RR9	9	8.8	292	0.04	0.37	3.1	3.14	0.03	0.07	0.07	112	132	6.0	13.8%	0.76	8.9
7	21-Oct-99	Omand's Creek	RR10	10	8.8	300	0.23	0.43	3	3.23	0.04	0.27	0.11	111	145	8.0	11.3%	0.58	8.9
7	21-Oct-99	Headingly Bridge	RR11	11	8.8	300	0.04	0.4	2.7	2.74	0.03	0.07	0.08	97	135	6.0	13.8%	0.76	8.9
8	3-Nov-99	Upstream Lockport	RR2	2	8.6	252	0.06	0.35	2.5	2.56	0.2	0.26	0.13	73	167	4.9	8.4%	0.94	8.7
8	3-Nov-99	Parkdale	RR3	3	8.6	248	0.04	0.3	2	2.04	0.06	0.1	0.1	48	126	7.0	6.4%	0.66	8.7
8	3-Nov-99	North Perimeter Bridge	RR4	4	8.7	248	0.04	0.25	2	2.04	0.11	0.15	0.09	78	103	6.7	6.6%	0.69	8.7
8	3-Nov-99	Fraser Grove Park	RR5	5	8.8	252	0.04	0.25	2	2.04	0.02	0.06	0.07	64	121	6.7	6.6%	0.69	8.8
8	3-Nov-99	Norwood Bridge	RR6	6	8.7	232	0.04	0.2	2	2.04	0.03	0.07	0.08	50	90	7.4	4.2%	0.63	8.7
8	3-Nov-99	Fort Garry Bridge	RR7	7	8.7	232	0.04	0.2	1.5	1.54	0.04	0.08	0.07	54	98	9.0	3.7%	0.51	8.7
8	3-Nov-99	Donald to Main St.	RR9	9	8.8	256	0.04	0.3	2	2.04	0.02	0.06	0.06	95	156	6.5	13.1%	0.71	8.9

APPENDIX D

ALGAL PRODUCTIVITY EXPERIMENT DATA

TABLE D-1
INITIAL WATER QUALITY CONDITIONS

DATE	STATION	TREATMENT	T ^{O}C	DIC mg/L	ALK mg/L	CHLA µg/l	NH_4/NH_3 mg/L	NH_3 mg/L	PH
22-Jun-99	3	A	19.1	53.8	224.2	14.7	0.360	0.015	8.1
22-Jun-99	3	B	18.5	44.5	185.6	14.7	0.360	0.015	8.0
22-Jun-99	3	C	20.5	52.0	216.5	14.7	0.360	0.015	8.1
22-Jun-99	3	D	19.9	52.0	216.5	14.7	0.360	0.015	8.2
22-Jun-99	3	E	20.4	52.9	220.4	14.7	0.360	0.015	8.3
22-Jun-99	3	F	19.9	53.8	224.2	14.7	0.360	0.015	8.2
22-Jun-99	3	G	18.7	54.7	228.1	14.7	0.360	0.015	8.1
22-Jun-99	3	H	18.7	51.0	212.6	14.7	0.360	0.015	8.0
22-Jun-99	4	A	19.1	51.0	212.6	15.3	0.090	0.003	8.0
22-Jun-99	4	B	18.5	52.0	216.5	15.3	0.090	0.003	8.0
22-Jun-99	4	C	20.5	52.9	220.4	15.3	0.090	0.003	8.2
22-Jun-99	4	D	19.9	47.3	197.2	15.3	0.090	0.003	8.2
22-Jun-99	4	E	20.4	52.9	220.4	15.3	0.090	0.003	8.2
22-Jun-99	4	F	19.9	52.0	216.5	15.3	0.090	0.003	8.2
22-Jun-99	4	G	18.7	52.0	216.5	15.3	0.090	0.003	8.1
22-Jun-99	4	H	18.7	52.0	216.5	15.3	0.090	0.003	8.1
6-Jul-99	3	A	20.1	54.7	228.1	16.3	0.123	0.005	8.0
6-Jul-99	3	B	20.3	52.9	220.4	16.3	0.123	0.005	8.1
6-Jul-99	3	C	20.9	55.7	232.0	16.3	0.123	0.005	8.2
6-Jul-99	3	D	20.6	51.0	212.6	16.3	0.123	0.005	8.1
6-Jul-99	3	E	20.9	54.7	228.1	16.3	0.123	0.005	8.2
6-Jul-99	3	F	20.6	54.7	228.1	16.3	0.123	0.005	8.0
6-Jul-99	3	G	20.8	55.7	232.0	16.3	0.123	0.005	8.2
6-Jul-99	3	H	20.4	53.8	224.2	16.3	0.123	0.005	8.0
6-Jul-99	4	A	20.1	46.4	193.3	16.5	0.117	0.005	8.0
6-Jul-99	4	B	20.3	52.0	216.5	16.5	0.117	0.005	8.0
6-Jul-99	4	C	20.9	49.2	204.9	16.5	0.117	0.005	8.0
6-Jul-99	4	D	20.6	53.8	224.2	16.5	0.117	0.005	8.2
6-Jul-99	4	E	20.9	55.7	232.0	16.5	0.117	0.005	8.1
6-Jul-99	4	F	20.6	49.2	204.9	16.5	0.117	0.005	8.2
6-Jul-99	4	G	20.8	52.9	220.4	16.5	0.117	0.005	8.1
6-Jul-99	4	H	20.4	53.8	224.2	16.5	0.117	0.005	8.1
6-Jul-99	5	A	20.1	53.8	224.2	13.6	0.035	0.001	8.0
6-Jul-99	5	B	20.3	54.7	228.1	13.6	0.035	0.001	8.1
6-Jul-99	5	C	20.9	56.6	235.8	13.6	0.035	0.001	8.1
6-Jul-99	5	D	20.6	56.6	235.8	13.6	0.035	0.001	8.1
6-Jul-99	5	E	20.9	55.7	232.0	13.6	0.035	0.001	8.3
6-Jul-99	5	F	20.6	56.6	235.8	13.6	0.035	0.001	8.2
6-Jul-99	5	G	20.8	53.8	224.2	13.6	0.035	0.001	8.2
6-Jul-99	5	H	20.4	55.7	232.0	13.6	0.035	0.001	8.2
6-Jul-99	3	A	20.3	53.8	224.2	13.6	0.098	0.005	8.0
6-Jul-99	3	B	20.8	53.8	224.2	13.6	0.098	0.005	8.0
6-Jul-99	3	C	21.3	53.8	224.2	13.6	0.098	0.005	8.0
6-Jul-99	3	D	21.3	53.8	224.2	13.6	0.098	0.005	8.0
6-Jul-99	3	E	21.3	53.8	224.2	13.6	0.098	0.005	8.0
7-Jul-99	3	F	21.5	53.8	224.2	13.6	0.098	0.005	8.0
7-Jul-99	3	G	21.9	53.8	224.2	13.6	0.098	0.005	8.0
7-Jul-99	3	H	21.6	53.8	224.2	13.6	0.098	0.005	8.0
7-Jul-99	4	A	20.3	50.1	208.8	15.8	0.044	0.002	8.1
7-Jul-99	4	B	20.8	50.1	208.8	15.8	0.044	0.002	8.1
7-Jul-99	4	C	21.3	50.1	208.8	15.8	0.044	0.002	8.1

TABLE D-1
INITIAL WATER QUALITY CONDITIONS

DATE	STATION	TREATMENT	T ^{O}C	DIC mg/L	ALK mg/L	CHLA µg/l	NH$_4$/NH$_3$ mg/L	NH$_3$ mg/L	PH
7-Jul-99	4	D	21.3	50.1	208.8	15.8	0.044	0.002	8.1
7-Jul-99	4	E	21.3	50.1	208.8	15.8	0.044	0.002	8.1
7-Jul-99	4	F	21.5	50.1	208.8	15.8	0.044	0.002	8.1
7-Jul-99	4	G	21.9	50.1	208.8	15.8	0.044	0.002	8.1
7-Jul-99	4	H	21.6	50.1	208.8	15.8	0.044	0.002	8.1
7-Jul-99	5	A	20.3	53.8	224.2	22.1	0.047	0.002	8.0
7-Jul-99	5	B	20.8	53.8	224.2	22.1	0.047	0.002	8.0
7-Jul-99	5	C	21.3	53.8	224.2	22.1	0.047	0.002	8.0
7-Jul-99	5	D	21.3	53.8	224.2	22.1	0.047	0.002	8.0
7-Jul-99	5	E	21.3	53.8	224.2	22.1	0.047	0.002	8.0
7-Jul-99	5	F	21.5	53.8	224.2	22.1	0.047	0.002	8.0
7-Jul-99	5	G	21.9	53.8	224.2	22.1	0.047	0.002	8.0
7-Jul-99	5	H	21.6	53.8	224.2	22.1	0.047	0.002	8.0
7-Jul-99	3	A	21.5	50.6	210.7	13.0	0.158	0.008	8.2
7-Jul-99	3	B	21.6	50.6	210.7	13.0	0.158	0.008	8.2
7-Jul-99	3	C	22.2	50.6	210.7	13.0	0.158	0.008	8.2
7-Jul-99	3	D	22.3	50.6	210.7	13.0	0.158	0.008	8.2
7-Jul-99	3	E	22.7	50.6	210.7	13.0	0.158	0.008	8.2
7-Jul-99	3	F	22.6	50.6	210.7	13.0	0.158	0.008	8.2
7-Jul-99	3	G	22.6	50.6	210.7	13.0	0.158	0.008	8.2
7-Jul-99	3	H	22.6	50.6	210.7	13.0	0.158	0.008	8.2
21-Jul-99	4	A	21.5	51.3	213.9	12.8	0.152	0.008	8.1
21-Jul-99	4	B	21.6	51.3	213.9	12.8	0.152	0.008	8.1
21-Jul-99	4	C	22.2	51.3	213.9	12.8	0.152	0.008	8.1
21-Jul-99	4	D	22.3	51.3	213.9	12.8	0.152	0.008	8.1
21-Jul-99	4	E	22.7	51.3	213.9	12.8	0.152	0.008	8.1
21-Jul-99	4	F	22.6	51.3	213.9	12.8	0.152	0.008	8.1
21-Jul-99	4	G	22.6	51.3	213.9	12.8	0.152	0.008	8.1
21-Jul-99	4	H	22.6	51.3	213.9	12.8	0.152	0.008	8.1
21-Jul-99	5	A	21.5	53.8	224.2	12.4	0.109	0.006	8.1
21-Jul-99	5	B	21.6	53.8	224.2	12.4	0.109	0.006	8.1
21-Jul-99	5	C	22.2	53.8	224.2	12.4	0.109	0.006	8.1
21-Jul-99	5	D	22.3	53.8	224.2	12.4	0.109	0.006	8.1
21-Jul-99	5	E	22.7	53.8	224.2	12.4	0.109	0.006	8.1
21-Jul-99	5	F	22.6	53.8	224.2	12.4	0.109	0.006	8.1
21-Jul-99	5	G	22.6	53.8	224.2	12.4	0.109	0.006	8.1
21-Jul-99	5	H	22.6	53.8	224.2	12.4	0.109	0.006	8.1
21-Jul-99	3	A	22.4	52.9	220.4	15.5	0.126		8.2
21-Jul-99	3	B	22.4	52.9	220.4	15.5	0.126		8.2
21-Jul-99	3	C	22.4	52.9	220.4	15.5	0.126		8.2
21-Jul-99	3	D	22.4	52.9	220.4	15.5	0.126		8.2
21-Jul-99	3	E	22.4	52.9	220.4	15.5	0.126		8.2
21-Jul-99	3	F	22.4	52.9	220.4	15.5	0.126		8.2
21-Jul-99	3	G	22.4	52.9	220.4	15.5	0.126		8.2
21-Jul-99	3	H	22.4	52.9	220.4	15.5	0.126		8.2
21-Jul-99	4	A	22.4	54.7	228.1	15.7	0.083		8.3
21-Jul-99	4	B	22.4	54.7	228.1	15.7	0.083		8.3
21-Jul-99	4	C	22.4	54.7	228.1	15.7	0.083		8.3
21-Jul-99	4	D	22.4	54.7	228.1	15.7	0.083		8.3
21-Jul-99	4	E	22.4	54.7	228.1	15.7	0.083		8.3
21-Jul-99	4	F	22.4	54.7	228.1	15.7	0.083		8.3

TABLE D-1
INITIAL WATER QUALITY CONDITIONS

DATE	STATION	TREATMENT	T ^{O}C	DIC mg/L	ALK mg/L	CHLA µg/l	NH_4/NH_3 mg/L	NH_3 mg/L	PH
21-Jul-99	4	G	22.4	54.7	228.1	15.7	0.083		8.3
21-Jul-99	4	H	22.4	54.7	228.1	15.7	0.083		8.3
22-Jul-99	5	A	22.4	52.9	220.4	14.8	0.035		8.3
22-Jul-99	5	B	22.4	52.9	220.4	14.8	0.035		8.3
22-Jul-99	5	C	22.4	52.9	220.4	14.8	0.035		8.3
22-Jul-99	5	D	22.4	52.9	220.4	14.8	0.035		8.3
22-Jul-99	5	E	22.4	52.9	220.4	14.8	0.035		8.3
22-Jul-99	5	F	22.4	52.9	220.4	14.8	0.035		8.3
22-Jul-99	5	G	22.4	52.9	220.4	14.8	0.035		8.3
22-Jul-99	5	H	22.4	52.9	220.4	14.8	0.035		8.3
10-Aug-99	3	A	22.0	57.5	239.7	27.9	0.236		8.3
10-Aug-99	3	B	22.0	57.5	239.7	27.9	0.236		8.3
10-Aug-99	3	C	22.0	57.5	239.7	27.9	0.236		8.3
10-Aug-99	3	D	22.0	57.5	239.7	27.9	0.236		8.3
10-Aug-99	3	E	22.0	57.5	239.7	27.9	0.236		8.3
10-Aug-99	3	F	22.0	57.5	239.7	27.9	0.236		8.3
10-Aug-99	3	G	22.0	57.5	239.7	27.9	0.236		8.3
10-Aug-99	3	H	22.0	57.5	239.7	27.9	0.236		8.3
10-Aug-99	4	A	22.0	58.5	243.6	26.3	0.160		6.3
10-Aug-99	4	B	22.0	58.5	243.6	26.3	0.160		6.3
10-Aug-99	4	C	22.0	58.5	243.6	26.3	0.160		6.3
10-Aug-99	4	D	22.0	58.5	243.6	26.3	0.160		6.3
10-Aug-99	4	E	22.0	58.5	243.6	26.3	0.160		6.3
10-Aug-99	4	F	22.0	58.5	243.6	26.3	0.160		6.3
10-Aug-99	4	G	22.0	58.5	243.6	26.3	0.160		6.3
10-Aug-99	4	H	22.0	58.5	243.6	26.3	0.160		6.3
10-Aug-99	5	A	22.0	59.4	247.4	31.8	0.034		6.4
10-Aug-99	5	B	22.0	59.4	247.4	31.8	0.034		6.4
10-Aug-99	5	C	22.0	59.4	247.4	31.8	0.034		6.4
10-Aug-99	5	D	22.0	59.4	247.4	31.8	0.034		6.4
10-Aug-99	5	E	22.0	59.4	247.4	31.8	0.034		6.4
10-Aug-99	5	F	22.0	59.4	247.4	31.8	0.034		6.4
10-Aug-99	5	G	22.0	59.4	247.4	31.8	0.034		6.4
10-Aug-99	5	H	22.0	59.4	247.4	31.8	0.034		6.4
11-Aug-99	3	A	22.0	55.7	232.0	38.1	0.289		8.3
11-Aug-99	3	B	22.0	55.7	232.0	38.1	0.289		8.3
11-Aug-99	3	C	22.0	55.7	232.0	38.1	0.289		8.3
11-Aug-99	3	D	22.0	55.7	232.0	38.1	0.289		8.3
11-Aug-99	3	E	22.0	55.7	232.0	38.1	0.289		8.3
11-Aug-99	3	F	22.0	55.7	232.0	38.1	0.289		8.3
11-Aug-99	3	G	22.0	55.7	232.0	38.1	0.289		8.3
11-Aug-99	3	H	22.0	55.7	232.0	38.1	0.289		8.3
11-Aug-99	4	A	22.0	57.5	239.7	53.7	0.164		8.3
11-Aug-99	4	B	22.0	57.5	239.7	53.7	0.164		8.3
11-Aug-99	4	C	22.0	57.5	239.7	53.7	0.164		8.3
11-Aug-99	4	D	22.0	57.5	239.7	53.7	0.164		8.3
11-Aug-99	4	E	22.0	57.5	239.7	53.7	0.164		8.3
11-Aug-99	4	F	22.0	57.5	239.7	53.7	0.164		8.3
11-Aug-99	4	G	22.0	57.5	239.7	53.7	0.164		8.3
11-Aug-99	4	H	22.0	57.5	239.7	53.7	0.164		8.3
11-Aug-99	5	A	22.0	55.7	232.0	39.2	0.033		8.4

TABLE D-1
INITIAL WATER QUALITY CONDITIONS

DATE	STATION	TREATMENT	T ^{O}C	DIC mg/L	ALK mg/L	CHLA µg/l	NH_4/NH_3 mg/L	NH_3 mg/L	PH
11-Aug-99	5	B	22.0	55.7	232.0	39.2	0.033		8.4
11-Aug-99	5	C	22.0	55.7	232.0	39.2	0.033		8.4
11-Aug-99	5	D	22.0	55.7	232.0	39.2	0.033		8.4
11-Aug-99	5	E	22.0	55.7	232.0	39.2	0.033		8.4
11-Aug-99	5	F	22.0	55.7	232.0	39.2	0.033		8.4
11-Aug-99	5	G	22.0	55.7	232.0	39.2	0.033		8.4
11-Aug-99	5	H	22.0	55.7	232.0	39.2	0.033		8.4
31-Aug-99	3	A	21.1	47.9	199.7	28.5	0.162		8.1
31-Aug-99	3	B	21.1	47.9	199.7	28.5	0.162		8.1
31-Aug-99	3	C	21.1	47.9	199.7	28.5	0.162		8.1
31-Aug-99	3	D	21.1	47.9	199.7	28.5	0.162		8.1
31-Aug-99	3	E	21.1	47.9	199.7	28.5	0.162		8.1
31-Aug-99	3	F	21.1	47.9	199.7	28.5	0.162		8.1
31-Aug-99	3	G	21.1	47.9	199.7	28.5	0.162		8.1
31-Aug-99	3	H	21.1	47.9	199.7	28.5	0.162		8.1
31-Aug-99	4	A	21.1	45.0	187.5	26.2	0.093		8.0
31-Aug-99	4	B	21.1	45.0	187.5	26.2	0.093		8.0
31-Aug-99	4	C	21.1	45.0	187.5	26.2	0.093		8.0
31-Aug-99	4	D	21.1	45.0	187.5	26.2	0.093		8.0
31-Aug-99	4	E	21.1	45.0	187.5	26.2	0.093		8.0
31-Aug-99	4	F	21.1	45.0	187.5	26.2	0.093		8.0
31-Aug-99	4	G	21.1	45.0	187.5	26.2	0.093		8.0
31-Aug-99	4	H	21.1	45.0	187.5	26.2	0.093		8.0
31-Aug-99	5	A	21.1	47.0	195.6	22.7	0.032		8.0
31-Aug-99	5	B	21.1	47.0	195.6	22.7	0.032		8.0
31-Aug-99	5	C	21.1	47.0	195.6	22.7	0.032		8.0
31-Aug-99	5	D	21.1	47.0	195.6	22.7	0.032		8.0
31-Aug-99	5	E	21.1	47.0	195.6	22.7	0.032		8.0
31-Aug-99	5	F	21.1	47.0	195.6	22.7	0.032		8.0
31-Aug-99	5	G	21.1	47.0	195.6	22.7	0.032		8.0
31-Aug-99	5	H	21.1	47.0	195.6	22.7	0.032		8.0
1-Sep-99	3	A	20.9	47.0	195.6	32.3	0.206		8.0
1-Sep-99	3	B	20.9	47.0	195.6	32.3	0.206		8.0
1-Sep-99	3	C	20.9	47.0	195.6	32.3	0.206		8.0
1-Sep-99	3	D	20.9	47.0	195.6	32.3	0.206		8.0
1-Sep-99	3	E	20.9	47.0	195.6	32.3	0.206		8.0
1-Sep-99	3	F	20.9	47.0	195.6	32.3	0.206		8.0
1-Sep-99	3	G	20.9	47.0	195.6	32.3	0.206		8.0
1-Sep-99	3	H	20.9	47.0	195.6	32.3	0.206		8.0
1-Sep-99	4	A	20.9	47.9	199.7	26.6	0.091		8.0
1-Sep-99	4	B	20.9	47.9	199.7	26.6	0.091		8.0
1-Sep-99	4	C	20.9	47.9	199.7	26.6	0.091		8.0
1-Sep-99	4	D	20.9	47.9	199.7	26.6	0.091		8.0
1-Sep-99	4	E	20.9	47.9	199.7	26.6	0.091		8.0
1-Sep-99	4	F	20.9	47.9	199.7	26.6	0.091		8.0
1-Sep-99	4	G	20.9	47.9	199.7	26.6	0.091		8.0
1-Sep-99	4	H	20.9	47.9	199.7	26.6	0.091		8.0
1-Sep-99	5	A	20.9	47.0	195.6	24.8	0.045		8.0
1-Sep-99	5	B	20.9	47.0	195.6	24.8	0.045		8.0
1-Sep-99	5	C	20.9	47.0	195.6	24.8	0.045		8.0
1-Sep-99	5	D	20.9	47.0	195.6	24.8	0.045		8.0

TABLE D-1
INITIAL WATER QUALITY CONDITIONS

DATE	STATION	TREATMENT	T ^{O}C	DIC mg/L	ALK mg/L	CHLA µg/l	NH_4/NH_3 mg/L	NH_3 mg/L	PH
1-Sep-99	5	E	20.9	47.0	195.6	24.8	0.045		8.0
1-Sep-99	5	F	20.9	47.0	195.6	24.8	0.045		8.0
1-Sep-99	5	G	20.9	47.0	195.6	24.8	0.045		8.0
1-Sep-99	5	H	20.9	47.0	195.6	24.8	0.045		8.0
15-Sep-99	3	A	12.8	41.8	167.1	14.6	0.169		7.9
15-Sep-99	3	B	14.7	41.8	167.1	14.6	0.169		7.9
15-Sep-99	3	C	13.0	41.8	167.1	14.6	0.169		7.9
15-Sep-99	3	D	14.7	41.8	167.1	14.6	0.169		7.9
15-Sep-99	3	E	14.5	41.8	167.1	14.6	0.169		7.9
15-Sep-99	3	F	15.0	41.8	167.1	14.6	0.169		7.9
15-Sep-99	3	G	14.2	41.8	167.1	14.6	0.169		7.9
15-Sep-99	3	H	14.9	41.8	167.1	14.6	0.169		7.9
15-Sep-99	4	A	12.8	41.8	167.1	13.9	0.098		7.9
15-Sep-99	4	B	14.7	41.8	167.1	13.9	0.098		7.9
15-Sep-99	4	C	13.0	41.8	167.1	13.9	0.098		7.9
15-Sep-99	4	D	14.7	41.8	167.1	13.9	0.098		7.9
15-Sep-99	4	E	14.5	41.8	167.1	13.9	0.098		7.9
15-Sep-99	4	F	15.0	41.8	167.1	13.9	0.098		7.9
15-Sep-99	4	G	14.2	41.8	167.1	13.9	0.098		7.9
15-Sep-99	4	H	14.9	41.8	167.1	13.9	0.098		7.9
15-Sep-99	5	A	12.8	41.8	167.1	11.6	0.037		7.9
15-Sep-99	5	B	14.7	41.8	167.1	11.6	0.037		7.9
15-Sep-99	5	C	13.0	41.8	167.1	11.6	0.037		7.9
15-Sep-99	5	D	14.7	41.8	167.1	11.6	0.037		7.9
15-Sep-99	5	E	14.5	41.8	167.1	11.6	0.037		7.9
15-Sep-99	5	F	15.0	41.8	167.1	11.6	0.037		7.9
15-Sep-99	5	G	14.2	41.8	167.1	11.6	0.037		7.9
15-Sep-99	5	H	14.9	41.8	167.1	11.6	0.037		7.9
16-Sep-99	3	E		43.8	175.3	18.1	0.132		8.0
16-Sep-99	3	F		43.8	175.3	18.1	0.132		8.0
16-Sep-99	3	G		43.8	175.3	18.1	0.132		8.0
16-Sep-99	3	H		43.8	175.3	18.1	0.132		8.0
16-Sep-99	4	E		42.8	171.2	15.1	0.179		8.0
16-Sep-99	4	F		42.8	171.2	15.1	0.179		8.0
16-Sep-99	4	G		42.8	171.2	15.1	0.179		8.0
16-Sep-99	4	H		42.8	171.2	15.1	0.179		8.0
16-Sep-99	4	E		43.8	175.3	14.5	0.170		8.0
16-Sep-99	4	F		43.8	175.3	14.5	0.170		8.0
16-Sep-99	4	G		43.8	175.3	14.5	0.170		8.0
16-Sep-99	4	H		43.8	175.3	14.5	0.170		8.0
5-Oct-99	3	A	9.6	62.2	248.6	28.3	0.706		7.8
5-Oct-99	3	B	10.0	62.2	248.6	28.3	0.706		7.8
5-Oct-99	3	C	9.7	62.2	248.6	28.3	0.706		7.8
5-Oct-99	3	D	9.9	62.2	248.6	28.3	0.706		7.8
5-Oct-99	3	E	10.1	62.2	248.6	28.3	0.706		7.8
5-Oct-99	3	F	9.8	62.2	248.6	28.3	0.706		7.8
5-Oct-99	3	G	9.8	62.2	248.6	28.3	0.706		7.8
5-Oct-99	3	H	9.6	62.2	248.6	28.3	0.706		7.8
5-Oct-99	4	A	9.6	59.1	236.4	30.5	0.084		7.8
5-Oct-99	4	B	10.0	59.1	236.4	30.5	0.084		7.8
5-Oct-99	4	C	9.7	59.1	236.4	30.5	0.084		7.8

TABLE D-1
INITIAL WATER QUALITY CONDITIONS

DATE	STATION	TREATMENT	T ^{O}C	DIC mg/L	ALK mg/L	CHLA µg/l	NH$_4$/NH$_3$ mg/L	NH$_3$ mg/L	PH
5-Oct-99	4	D	9.9	59.1	236.4	30.5	0.084		7.8
5-Oct-99	4	E	10.1	59.1	236.4	30.5	0.084		7.8
5-Oct-99	4	F	9.8	59.1	236.4	30.5	0.084		7.8
5-Oct-99	4	G	9.8	59.1	236.4	30.5	0.084		7.8
5-Oct-99	4	H	9.6	59.1	236.4	30.5	0.084		7.8
5-Oct-99	5	A	9.6	60.1	240.5	31.1	0.080		7.8
5-Oct-99	5	B	10.0	60.1	240.5	31.1	0.080		7.8
5-Oct-99	5	C	9.7	60.1	240.5	31.1	0.080		7.8
5-Oct-99	5	D	9.9	60.1	240.5	31.1	0.080		7.8
5-Oct-99	5	E	10.1	60.1	240.5	31.1	0.080		7.8
5-Oct-99	5	F	9.8	60.1	240.5	31.1	0.080		7.8
5-Oct-99	5	G	9.8	60.1	240.5	31.1	0.080		7.8
5-Oct-99	5	H	9.6	60.1	240.5	31.1	0.080		7.8
6-Oct-99	3	A	8.9	60.4	241.5	30.7			7.9
6-Oct-99	3	B	9.9	60.4	241.5	30.7			7.9
6-Oct-99	3	C	8.7	60.4	241.5	30.7			7.9
6-Oct-99	3	D	9.8	60.4	241.5	30.7			7.9
6-Oct-99	3	E	9.3	60.4	241.5	30.7			7.9
6-Oct-99	3	F	9.1	60.4	241.5	30.7			7.9
6-Oct-99	3	G	8.8	60.4	241.5	30.7			7.9
6-Oct-99	3	H	8.8	60.4	241.5	30.7			7.9
6-Oct-99	4	A	8.9	61.7	246.6	32.7			7.9
6-Oct-99	4	B	9.9	61.7	246.6	32.7			7.9
6-Oct-99	4	C	8.7	61.7	246.6	32.7			7.9
6-Oct-99	4	D	9.8	61.7	246.6	32.7			7.9
6-Oct-99	4	E	9.3	61.7	246.6	32.7			7.9
6-Oct-99	4	F	9.1	61.7	246.6	32.7			7.9
6-Oct-99	4	G	8.8	61.7	246.6	32.7			7.9
6-Oct-99	4	H	8.8	61.7	246.6	32.7			7.9
6-Oct-99	5	A	8.9	60.4	241.5	33.7			8.0
6-Oct-99	5	B	9.9	60.4	241.5	33.7			8.0
6-Oct-99	5	C	8.7	60.4	241.5	33.7			8.0
6-Oct-99	5	D	9.8	60.4	241.5	33.7			8.0
6-Oct-99	5	E	9.3	60.4	241.5	33.7			8.0
6-Oct-99	5	F	9.1	60.4	241.5	33.7			8.0
6-Oct-99	5	G	8.8	60.4	241.5	33.7			8.0
6-Oct-99	5	H	8.8	60.4	241.5	33.7			8.0
20-Oct-99	3	A	8.4	6.4	241.7	73.4	0.455	0.007	8.0
20-Oct-99	3	B	6.6	6.4	241.7	73.4	0.455	0.007	8.0
20-Oct-99	3	C	7.0	6.4	241.7	73.4	0.455	0.007	8.0
20-Oct-99	3	D	7.0	6.4	241.7	73.4	0.455	0.007	8.0
20-Oct-99	3	E	6.9	6.4	241.7	73.4	0.455	0.007	8.0
20-Oct-99	3	F	6.9	6.4	241.7	73.4	0.455	0.007	8.0
20-Oct-99	3	G	7.6	6.4	241.7	73.4	0.455	0.007	8.0
20-Oct-99	3	H	7.4	6.4	241.7	73.4	0.455	0.007	8.0
20-Oct-99	4	A	8.4	61.5	245.8	82.1	0.260	0.003	8.0
20-Oct-99	4	B	6.6	61.5	245.8	82.1	0.260	0.003	8.0
20-Oct-99	4	C	7.0	61.5	245.8	82.1	0.260	0.003	8.0
20-Oct-99	4	D	7.0	61.5	245.8	82.1	0.260	0.003	8.0
20-Oct-99	4	E	6.9	61.5	245.8	82.1	0.260	0.003	8.0
20-Oct-99	4	F	6.9	61.5	245.8	82.1	0.260	0.003	8.0

TABLE D-1
INITIAL WATER QUALITY CONDITIONS

DATE	STATION	TREATMENT	T ^{O}C	DIC mg/L	ALK mg/L	CHLA µg/l	NH_4/NH_3 mg/L	NH_3 mg/L	PH
20-Oct-99	4	G	7.6	61.5	245.8	82.1	0.260	0.003	8.0
20-Oct-99	4	H	7.4	61.5	245.8	82.1	0.260	0.003	8.0
20-Oct-99	5	A	8.4	61.5	245.8	85.2	0.090	0.002	8.0
20-Oct-99	5	B	6.6	61.5	245.8	85.2	0.090	0.002	8.0
20-Oct-99	5	C	7.0	61.5	245.8	85.2	0.090	0.002	8.0
20-Oct-99	5	D	7.0	61.5	245.8	85.2	0.090	0.002	8.0
20-Oct-99	5	E	6.9	61.5	245.8	85.2	0.090	0.002	8.0
20-Oct-99	5	F	6.9	61.5	245.8	85.2	0.090	0.002	8.0
20-Oct-99	5	G	7.6	61.5	245.8	85.2	0.090	0.002	8.0
20-Oct-99	5	H	7.4	61.5	245.8	85.2	0.090	0.002	8.0
21-Oct-99	3	E	8.0	61.9	247.4	82.5			8.0
21-Oct-99	3	F	7.7	61.9	247.4	82.5			8.0
21-Oct-99	3	G	7.7	61.9	247.4	82.5			8.0
21-Oct-99	3	H	7.3	61.9	247.4	82.5			8.0
21-Oct-99	4	E	8.0	61.5	245.8	84.8			8.0
21-Oct-99	4	F	7.7	61.5	245.8	84.8			8.0
21-Oct-99	4	G	7.7	61.5	245.8	84.8			8.0
21-Oct-99	4	H	7.3	61.5	245.8	84.8			8.0
21-Oct-99	5	E	8.0	60.8	243.3	81.8			8.0
21-Oct-99	5	F	7.7	60.8	243.3	81.8			8.0
21-Oct-99	5	G	7.7	60.8	243.3	81.8			8.0
21-Oct-99	5	H	7.3	60.8	243.3	81.8			8.0
2-Nov-99	3	A	4.4	60.5	241.8	106.6	0.313	0.002	7.8
2-Nov-99	3	B	5.0	60.5	241.8	106.6	0.313	0.002	7.8
2-Nov-99	3	C	5.6	60.5	241.8	106.6	0.313	0.002	7.8
2-Nov-99	3	D	6.7	60.5	241.8	106.6	0.313	0.002	7.8
2-Nov-99	3	E	6.2	60.5	241.8	106.6	0.313	0.002	7.8
2-Nov-99	3	F	6.4	60.5	241.8	106.6	0.313	0.002	7.8
2-Nov-99	3	G	6.9	60.5	241.8	106.6	0.313	0.002	7.8
2-Nov-99	3	H	7.0	60.5	241.8	106.6	0.313	0.002	7.8
2-Nov-99	4	A	4.4	61.1	244.6	106.3	0.158	0.002	7.9
2-Nov-99	4	B	5.0	61.1	244.6	106.3	0.158	0.002	7.9
2-Nov-99	4	C	5.6	61.1	244.6	106.3	0.158	0.002	7.9
2-Nov-99	4	D	6.5	61.1	244.6	106.3	0.158	0.002	7.9
2-Nov-99	4	E	6.2	61.1	244.6	106.3	0.158	0.002	7.9
2-Nov-99	4	F	6.4	61.1	244.6	106.3	0.158	0.002	7.9
2-Nov-99	4	G	6.9	61.1	244.6	106.3	0.158	0.002	7.9
2-Nov-99	4	H	7.0	61.1	244.6	106.3	0.158	0.002	7.9
2-Nov-99	5	A	4.4	60.1	240.5	105.5	0.024	0.000	7.9
2-Nov-99	5	B	5.0	60.1	240.5	105.5	0.024	0.000	7.9
2-Nov-99	5	C	5.6	60.1	240.5	105.5	0.024	0.000	7.9
2-Nov-99	5	D	6.5	60.1	240.5	105.5	0.024	0.000	7.9
2-Nov-99	5	E	6.2	60.1	240.5	105.5	0.024	0.000	7.9
2-Nov-99	5	F	6.4	60.1	240.5	105.5	0.024	0.000	7.9
2-Nov-99	5	G	6.9	60.1	240.5	105.5	0.024	0.000	7.9
2-Nov-99	5	H	7.0	60.1	240.5	105.5	0.024	0.000	7.9
3-Nov-99	3	C	5.2	62.0	247.8	95.7			7.8
3-Nov-99	3	D	5.3	62.0	247.8	95.7			7.8
3-Nov-99	3	E	6.0	62.0	247.8	95.7			7.8
3-Nov-99	3	F	6.0	62.0	247.8	95.7			7.8
3-Nov-99	3	G	6.5	62.0	247.8	95.7			7.8

TABLE D-1
INITIAL WATER QUALITY CONDITIONS

DATE	STATION	TREATMENT	T ^{O}C	DIC mg/L	ALK mg/L	CHLA µg/l	NH_4/NH_3 mg/L	NH_3 mg/L	PH
3-Nov-99	3	H	6.1	62.0	247.8	95.7			7.8
3-Nov-99	4	C	5.2	62.5	249.9	99.1			7.8
3-Nov-99	4	D	5.3	62.5	249.9	99.1			7.8
3-Nov-99	4	E	6.0	62.5	249.9	99.1			7.8
3-Nov-99	4	F	6.0	62.5	249.9	99.1			7.8
3-Nov-99	4	G	6.5	62.5	249.9	99.1			7.8
3-Nov-99	4	H	6.1	62.5	249.9	99.1			7.8
3-Nov-99	5	C	5.2	59.1	236.4	102.9			7.8
3-Nov-99	5	D	5.3	59.1	236.4	102.9			7.8
3-Nov-99	5	E	6.0	59.1	236.4	102.9			7.8
3-Nov-99	5	F	6.0	59.1	236.4	102.9			7.8
3-Nov-99	5	G	6.5	59.1	236.4	102.9			7.8
3-Nov-99	5	H	6.1	59.1	236.4	102.9			7.8

TABLE D-2
UPTAKE OF NITROGEN AND PHOSPHORUS

Start Date	Finish Date	STATION	TREATMENT	INITIAL NH_3/NH_4 µg/L	NH_3-N µg/L	FINAL µg/L	UPTAKE µg/L/24 hr	CHLA µg/L	UPTAKE mg-N/24 hr/ µg-CHLA
N-uptake									
21-Jul-99	22-Jul-99	3	A	158	8	126	32	13.0	2.5
21-Jul-99	22-Jul-99	3	A	455	7	471	-16	73.4	-0.2
21-Jul-99	22-Jul-99	3	B	401	21	315	86	13.0	6.6
21-Jul-99	22-Jul-99	3	B	442	6	435	7	73.4	0.1
21-Jul-99	22-Jul-99	3	C	612	34	427	185	13.0	14.2
21-Jul-99	22-Jul-99	3	C	768	12	748	20	73.4	0.3
21-Jul-99	22-Jul-99	3	D	670	37	446	224	13.0	17.2
21-Jul-99	22-Jul-99	3	D	899	13	921	-22	73.4	-0.3
21-Jul-99	22-Jul-99	3	E	1452	83	1297	155	13.0	11.9
21-Jul-99	22-Jul-99	3	E	1731	25	1931	-200	73.4	-2.7
21-Jul-99	22-Jul-99	3	E	1919	30	1902	17	82.5	0.2
21-Jul-99	22-Jul-99	3	F	2316	131	2209	107	13.0	8.2
21-Jul-99	22-Jul-99	3	F	1948	28	2786	-838	73.4	-11.4
21-Jul-99	22-Jul-99	3	F	2994	46	2819	175	82.5	2.1
21-Jul-99	22-Jul-99	3	G	3294	187	2720	574	13.0	44.1
21-Jul-99	22-Jul-99	3	G	3946		4654	-708	73.4	-9.6
21-Jul-99	22-Jul-99	3	G	4300	66	5384	-1084	82.5	-13.1
21-Jul-99	22-Jul-99	3	H	5493	311	5222	271	13.0	20.8
21-Jul-99	22-Jul-99	3	H	6259	96		6259	73.4	85.2
21-Jul-99	22-Jul-99	3	H	6384	96	7051	-667	82.5	-8.1
21-Jul-99	22-Jul-99	4	A	152	8	74	78	12.8	6.1
21-Jul-99	22-Jul-99	4	A	260	3	239	21	82.1	0.3
21-Jul-99	22-Jul-99	4	B	370	20	309	61	12.8	4.8
21-Jul-99	22-Jul-99	4	B	425	5	437	-12	82.1	-0.1
20-Oct-99	21-Oct-99	4	C	653	36	506	147	12.8	11.5
20-Oct-99	21-Oct-99	4	C	689	9	751	-62	82.1	-0.8
20-Oct-99	21-Oct-99	4	D	704	39	619	85	12.8	6.6
20-Oct-99	21-Oct-99	4	D	893	10	938	-45	82.1	-0.5
20-Oct-99	21-Oct-99	4	E	1482	85	1440	42	12.8	3.3
20-Oct-99	21-Oct-99	4	E	1560	18	1898	-338	82.1	-4.1
20-Oct-99	21-Oct-99	4	F	2047	116	2379	-332	12.8	-26.0
20-Oct-99	21-Oct-99	4	F	2332	27	2753	-421	82.1	-5.1
20-Oct-99	21-Oct-99	4	G	3520	199	3542	-22	12.8	-1.7
20-Oct-99	21-Oct-99	4	G	3404		4300	-896	82.1	-10.9
20-Oct-99	21-Oct-99	4	H	4441	251	3723	718	12.8	56.1
20-Oct-99	21-Oct-99	4	H	6780	82	6864	-84	82.1	-1.0
20-Oct-99	21-Oct-99	5	A	105	6	32	73	15.5	4.7
20-Oct-99	21-Oct-99	5	A	90	2	19	71	85.2	0.8
20-Oct-99	21-Oct-99	5	B	373	20	361	12	15.5	0.8
20-Oct-99	21-Oct-99	5	B	407	6	440	-33	85.2	-0.4
20-Oct-99	21-Oct-99	5	C	615	34	503	112	15.5	7.2
20-Oct-99	21-Oct-99	5	C	689	11	668	21	85.2	0.2
20-Oct-99	21-Oct-99	5	D	794	44	698	96	15.5	6.2
20-Oct-99	21-Oct-99	5	D	893	13	876	17	85.2	0.2

TABLE D-2
UPTAKE OF NITROGEN AND PHOSPHORUS

Start Date	Finish Date	STATION	TREATMENT	INITIAL NH_3/NH_4 µg/L	NH_3-N µg/L	FINAL µg/L	UPTAKE µg/L/24 hr	CHLA µg/L	UPTAKE mg-N/24 hr/ µg-CHLA
20-Oct-99	21-Oct-99	5	E	1485	85	1509	-24	15.5	-1.5
20-Oct-99	21-Oct-99	5	E	1460	21	1806	-346	85.2	-4.1
20-Oct-99	21-Oct-99	5	F	2179	123	2408	-229	15.5	-14.8
20-Oct-99	21-Oct-99	5	F	2252	33	2836	-584	85.2	-6.9
21-Oct-99	22-Oct-99	5	G	3221	182	2899	322	15.5	20.7
21-Oct-99	22-Oct-99	5	G	3946		4425	-479	85.2	-5.6
21-Oct-99	22-Oct-99	5	H	5046	286	5537	-491	15.5	-31.6
21-Oct-99	22-Oct-99	5	H	6447	99	6801	-354	85.2	-4.2
N-uptake									
21-Oct-99	22-Oct-99	4	E	1911	30	1911	0	84.8	0.0
21-Oct-99	22-Oct-99	4	F	2832	44	2761	71	84.8	0.8
21-Oct-99	22-Oct-99	4	G	5030	78	5155	-125	84.8	-1.5
21-Oct-99	22-Oct-99	4	H	6301	94	6947	-646	84.8	-7.6
21-Oct-99	22-Oct-99	5	E	1848	29	1931	-83	81.8	-1.0
21-Oct-99	22-Oct-99	5	F	2786	43	2769	17	81.8	0.2
21-Oct-99	22-Oct-99	5	G	4800	74	4717	83	81.8	1.0
21-Oct-99	22-Oct-99	5	H	6405	96	6989	-584	81.8	-7.1
2-Nov-99	3-Nov-99	3	A	313	2	23	290	106.6	2.7
2-Nov-99	3-Nov-99	3	B	448	4	166	282	106.6	2.6
2-Nov-99	3-Nov-99	3	C	722	6	731	-9	106.6	-0.1
2-Nov-99	3-Nov-99	3	D	955	9	944	11	106.6	0.1
2-Nov-99	3-Nov-99	3	E	1942	17	1652	290	106.6	2.7
2-Nov-99	3-Nov-99	3	F	2817	24	2423	394	106.6	3.7
2-Nov-99	3-Nov-99	3	G	4707	43	5009	-302	106.6	-2.8
2-Nov-99	3-Nov-99	3	H	6812	63	6551	261	106.6	2.4
2-Nov-99	3-Nov-99	4	A	158	2	34	124	106.3	1.2
2-Nov-99	3-Nov-99	4	B	423	4	414	9	106.3	0.1
2-Nov-99	3-Nov-99	4	C	712	7	662	50	106.3	0.5
2-Nov-99	3-Nov-99	4	D	910	10	906	4	106.3	0.0
2-Nov-99	3-Nov-99	4	E	1846	20	1923	-77	106.3	-0.7
2-Nov-99	3-Nov-99	4	F	2759	31	2503	256	106.3	2.4
2-Nov-99	3-Nov-99	4	G	4936	57	5071	-135	106.3	-1.3
2-Nov-99	3-Nov-99	4	H	6728	78	6760	-32	106.3	-0.3
2-Nov-99	3-Nov-99	5	A	24	0	34	-10	105.5	-0.1
2-Nov-99	3-Nov-99	5	B	423	4	420	3	105.5	0.0
2-Nov-99	3-Nov-99	5	C	705	7	769	-64	105.5	-0.6
2-Nov-99	3-Nov-99	5	D	903	10	881	22	105.5	0.2
2-Nov-99	3-Nov-99	5	E	1942	21	1940	2	105.5	0.0
2-Nov-99	3-Nov-99	5	F	2767	31	2673	94	105.5	0.9
2-Nov-99	3-Nov-99	5	G	4832	56	4800	32	105.5	0.3
2-Nov-99	3-Nov-99	5	H	6624	77	6801	-177	105.5	-1.7
3-Nov-99	4-Nov-99	3	C	823		699	124	95.7	1.3
3-Nov-99	4-Nov-99	3	D	1004		853	151	95.7	1.6
3-Nov-99	4-Nov-99	3	E	1831		1790	41	95.7	0.4
3-Nov-99	4-Nov-99	3	F	2882		2748	134	95.7	1.4

TABLE D-2
UPTAKE OF NITROGEN AND PHOSPHORUS

Start Date	Finish Date	STATION	TREATMENT	INITIAL NH_3/NH_4 µg/L	NH_3-N µg/L	FINAL µg/L	UPTAKE µg/L/24 hr	CHLA µg/L	UPTAKE mg-N/24 hr/ µg-CHLA
3-Nov-99	4-Nov-99	3	G	5050		3821	1229	95.7	12.8
3-Nov-99	4-Nov-99	3	H	6926		6655	271	95.7	2.8
3-Nov-99	4-Nov-99	4	C	814		763	51	99.1	0.5
3-Nov-99	4-Nov-99	4	D	974		874	100	99.1	1.0
3-Nov-99	4-Nov-99	4	E	1998		1765	233	99.1	2.4
3-Nov-99	4-Nov-99	4	F	2790		2753	37	99.1	0.4
3-Nov-99	4-Nov-99	4	G	9571		4675	4896	99.1	49.4
3-Nov-99	4-Nov-99	4	H	6780		6113	667	99.1	6.7
3-Nov-99	4-Nov-99	5	C	713		703	10	102.9	0.1
3-Nov-99	4-Nov-99	5	D	954		893	61	102.9	0.6
3-Nov-99	4-Nov-99	5	E	1827		1723	104	102.9	1.0
3-Nov-99	4-Nov-99	5	F	2648		2582	66	102.9	0.6
3-Nov-99	4-Nov-99	5	G	4988		4363	625	102.9	6.1
3-Nov-99	4-Nov-99	5	H	6676		6155	521	102.9	5.1
P-uptake									
21-Oct-99	22-Oct-99	3	E	215		211	4	82.5	0.0
21-Oct-99	22-Oct-99	3	F	335		317	18	82.5	0.2
21-Oct-99	22-Oct-99	3	G	566		533	33	82.5	0.4
21-Oct-99	22-Oct-99	3	H	765		770	-5	82.5	-0.1
21-Oct-99	22-Oct-99	4	E	205		201	4	84.8	0.0
21-Oct-99	22-Oct-99	4	F	317		311	6	84.8	0.1
21-Oct-99	22-Oct-99	4	G	537		478	59	84.8	0.7
21-Oct-99	22-Oct-99	4	H	786		776	10	84.8	0.1
21-Oct-99	22-Oct-99	5	E	201		209	-8	81.8	-0.1
21-Oct-99	22-Oct-99	5	F	335		331	4	81.8	0.0
21-Oct-99	22-Oct-99	5	G	556		560	-4	81.8	0.0
21-Oct-99	22-Oct-99	5	H	772		755	17	81.8	0.2
3-Nov-99	4-Nov-99	3	C	85		54	32	95.7	0.3
3-Nov-99	4-Nov-99	3	D	93		65	28	95.7	0.3
3-Nov-99	4-Nov-99	3	E	197		184	13	95.7	0.1
3-Nov-99	4-Nov-99	3	F	289		273	17	95.7	0.2
3-Nov-99	4-Nov-99	3	G	506		478	28	95.7	0.3
3-Nov-99	4-Nov-99	3	H	701		682	19	95.7	0.2
3-Nov-99	4-Nov-99	4	C	80		61	19	99.1	0.2
3-Nov-99	4-Nov-99	4	D	97		82	15	99.1	0.2
3-Nov-99	4-Nov-99	4	E	197		182	15	99.1	0.2
3-Nov-99	4-Nov-99	4	F	312		291	20	99.1	0.2
3-Nov-99	4-Nov-99	4	G	516		508	7	99.1	0.1
3-Nov-99	4-Nov-99	4	H	697		679	19	99.1	0.2
3-Nov-99	4-Nov-99	5	C	73		56	17	102.9	0.2
3-Nov-99	4-Nov-99	5	D	93		65	28	102.9	0.3
3-Nov-99	4-Nov-99	5	E	191		174	17	102.9	0.2
3-Nov-99	4-Nov-99	5	F	297		271	26	102.9	0.3
3-Nov-99	4-Nov-99	5	G	503		488	15	102.9	0.1
3-Nov-99	4-Nov-99	5	H	692		671	20	102.9	0.2

TABLE D-3
UPTAKE OF PHOSPHORUS

Start Date	Finish Date	STATION	TREATMENT	CHLOROPHYLL-A µg/L	SRP START µg/L	SRP FINISH µg/L	UPTAKE µg/L/24 hr	UPTAKE mg-N/24 hr/ µg-CHLA
1-Sep-99	2-Sep-99	3	A	32.3	200	197	-3.0	-0.093
1-Sep-99	2-Sep-99	3	B	32.3	189	197	8.0	0.248
1-Sep-99	2-Sep-99	3	C	32.3	200	201	1.0	0.031
1-Sep-99	2-Sep-99	3	D	32.3	189	195	6.0	0.186
1-Sep-99	2-Sep-99	3	E	32.3	196	203	7.0	0.217
1-Sep-99	2-Sep-99	3	F	32.3	308	303	-5.0	-0.155
1-Sep-99	2-Sep-99	3	G	32.3	540	539	-1.0	-0.031
1-Sep-99	2-Sep-99	3	H	32.3	750	770	20.0	0.619
1-Sep-99	2-Sep-99	4	A	26.6	183	201	18.0	0.677
1-Sep-99	2-Sep-99	4	B	26.6	183	185	2.0	0.075
1-Sep-99	2-Sep-99	4	C	26.6	175	189	14.0	0.527
1-Sep-99	2-Sep-99	4	D	26.6	185	199	14.0	0.527
1-Sep-99	2-Sep-99	4	E	26.6	200	205	5.0	0.188
1-Sep-99	2-Sep-99	4	F	26.6	316	317	1.0	0.038
1-Sep-99	2-Sep-99	4	G	26.6	556	553	-3.0	-0.113
1-Sep-99	2-Sep-99	4	H	26.6	744	776	32.0	1.204
1-Sep-99	2-Sep-99	5	A	24.8	171	168	-3.0	-0.121
1-Sep-99	2-Sep-99	5	B	24.8	171	168	-3.0	-0.121
1-Sep-99	2-Sep-99	5	C	24.8	159	181	22.0	0.889
1-Sep-99	2-Sep-99	5	D	24.8	179	181	2.0	0.081
1-Sep-99	2-Sep-99	5	E	24.8	208	201	-7.0	-0.283
1-Sep-99	2-Sep-99	5	F	24.8	318	348	30.0	1.217
1-Sep-99	2-Sep-99	5	G	24.8	530	553	23.0	0.929
1-Sep-99	2-Sep-99	5	H	24.8	768	780	12.0	0.485
15-Sep-99	16-Sep-99	3	A	14.6	165	186		
15-Sep-99	16-Sep-99	3	B	14.6	178	198		
15-Sep-99	16-Sep-99	3	C	14.6	175	194		
15-Sep-99	16-Sep-99	3	D	14.6	190	110		
15-Sep-99	16-Sep-99	3	E	18.1	1693	203		
15-Sep-99	16-Sep-99	3	F	18.1	3079	333		
15-Sep-99	16-Sep-99	3	G	18.1	5138	541		
15-Sep-99	16-Sep-99	3	H	18.1	7114	778		
15-Sep-99	16-Sep-99	4	A	14.0	196	180		
15-Sep-99	16-Sep-99	4	B	14.0	200	200		
15-Sep-99	16-Sep-99	4	C	14.0	194	202		
15-Sep-99	16-Sep-99	4	D	14.0	190	184		
15-Sep-99	16-Sep-99	4	E	15.1	2101	276		
15-Sep-99	16-Sep-99	4	F	15.1	3202	340		
15-Sep-99	16-Sep-99	4	G	15.1	5321	558		
15-Sep-99	16-Sep-99	4	H	15.1	7909	792		
15-Sep-99	16-Sep-99	5	A	11.6	182	182		
15-Sep-99	16-Sep-99	5	B	11.6	180	192		
15-Sep-99	16-Sep-99	5	C	11.6	171	184		
15-Sep-99	16-Sep-99	5	D	11.6	167	173		
15-Sep-99	16-Sep-99	5	E	14.5	2060	203		
15-Sep-99	16-Sep-99	5	F	14.5	3059	337		
15-Sep-99	16-Sep-99	5	G	14.5	5178	558		
15-Sep-99	16-Sep-99	5	H	14.5	7766	782		

TABLE D-4
UPTAKE OF AMMONIA

Start Date	Finish Date	STATION	TREATMENT	CHLOROPHYLL-A µg/L	SRP START µg/L	SRP FINISH µg/L	UPTAKE µg/L	UPTAKE mg-N/24 hr/ µg-CHLA
31-Aug-99	1-Sep-99	3	A	28.46	162	284	122	4.29
31-Aug-99	1-Sep-99	3	B	28.46	450	373	-77	-2.71
31-Aug-99	1-Sep-99	3	C	28.46	759	824	65	2.28
31-Aug-99	1-Sep-99	3	D	28.46	894	878	-16	-0.56
31-Aug-99	1-Sep-99	3	E	28.46	1922	1598	-324	-11.38
31-Aug-99	1-Sep-99	3	F	28.46	2943	2928	-15	-0.53
31-Aug-99	1-Sep-99	3	G	28.46	5202	3410	-1792	-62.97
31-Aug-99	1-Sep-99	3	H	28.46	7395	6798	-597	-20.98
31-Aug-99	1-Sep-99	4	A	26.21	93	46	-47	-1.79
31-Aug-99	1-Sep-99	4	B	26.21	450	471	21	0.80
31-Aug-99	1-Sep-99	4	C	26.21	750	643	-57	-2.18
31-Aug-99	1-Sep-99	4	D	26.21	954	1088	134	5.11
31-Aug-99	1-Sep-99	4	E	26.21	2022	2006	-16	-0.61
31-Aug-99	1-Sep-99	4	F	26.21	2914	2944	30	1.15
31-Aug-99	1-Sep-99	4	G	26.21	5256	4598	-658	-25.11
31-Aug-99	1-Sep-99	4	H	26.21	7545	6423	-1122	-42.81
31-Aug-99	1-Sep-99	5	A	22.74	32	64	32	1.41
31-Aug-99	1-Sep-99	5	B	22.74	442	487	-45	-1.98
31-Aug-99	1-Sep-99	5	C	22.74	744	604	-140	-6.16
31-Aug-99	1-Sep-99	5	D	22.74	964	836	-128	-5.63
31-Aug-99	1-Sep-99	5	E	22.74	1976	2102	126	5.54
31-Aug-99	1-Sep-99	5	F	22.74	3001	3040	39	11.72
31-Aug-99	1-Sep-99	5	G	22.74	5002	7386	2384	104.84
31-Aug-99	1-Sep-99	5	H	22.74	5756	6621	885	38.92
1-Sep-99	2-Sep-99	3	A	32.31	225	206	-19	-0.59
1-Sep-99	2-Sep-99	3	B	32.31	411	421	10	0.31
1-Sep-99	2-Sep-99	3	C	32.31	693	723	30	0.93
1-Sep-99	2-Sep-99	3	D	32.31	849	775	-74	-2.29
1-Sep-99	2-Sep-99	3	E	32.31	1785	1883	98	3.03
1-Sep-99	2-Sep-99	3	F	32.31	3891			
1-Sep-99	2-Sep-99	3	G	32.31	5298	5215	-83	-2.56
1-Sep-99	2-Sep-99	3	H	32.31	7915	6207	-1708	-52.86
1-Sep-99	2-Sep-99	4	A	26.58	120	91	-29	-1.09
1-Sep-99	2-Sep-99	4	B	26.58	433	454	21	0.79
1-Sep-99	2-Sep-99	4	C	26.58	632	747	115	4.33
1-Sep-99	2-Sep-99	4	D	26.58	953	965	12	0.45
1-Sep-99	2-Sep-99	4	E	26.58	2156	2150	-6	-0.23
1-Sep-99	2-Sep-99	4	F	26.58	3415			
1-Sep-99	2-Sep-99	4	G	26.58	5932	5388	-544	-20.47
1-Sep-99	2-Sep-99	4	H	26.58	7698	7771	73	2.75
1-Sep-99	2-Sep-99	5	A	24.76	32	45	13	0.53
1-Sep-99	2-Sep-99	5	B	24.76	410	498	88	3.55
1-Sep-99	2-Sep-99	5	C	24.76	646	818	172	6.95
1-Sep-99	2-Sep-99	5	D	24.76	793	983	190	7.67
1-Sep-99	2-Sep-99	5	E	24.76	1969	2109	140	5.65
1-Sep-99	2-Sep-99	5	F	24.76	3307			
1-Sep-99	2-Sep-99	5	G	24.76	5825	5281	-544	-21.97

TABLE D-4
UPTAKE OF AMMONIA

Start Date	Finish Date	STATION	TREATMENT	CHLOROPHYLL-A µg/L	SRP START µg/L	SRP FINISH µg/L	UPTAKE µg/L	UPTAKE mg-N/24 hr/ µg-CHLA
1-Sep-99	2-Sep-99	5	H	24.76	8257	7666	-591	-23.87
15-Sep-99	16-Sep-99	3	A	14.58	69	169	100	6.86
15-Sep-99	16-Sep-99	3	B	14.58	491	430	-61	-4.18
15-Sep-99	16-Sep-99	3	C	14.58	765	631	-134	-9.19
15-Sep-99	16-Sep-99	3	D	14.58	995	993	-2	-0.14
15-Sep-99	16-Sep-99	3	E	14.58	2046	1881	-165	-11.32
15-Sep-99	16-Sep-99	3	E	18.09	1956	1206		
15-Sep-99	16-Sep-99	3	F	14.58	3205	2903	302	-20.71
15-Sep-99	16-Sep-99	3	F	18.09	2011	2953		
15-Sep-99	16-Sep-99	3	G	14.58	5874	4217	-1657	-113.65
15-Sep-99	16-Sep-99	3	G	18.09	5050	6218		
15-Sep-99	16-Sep-99	3	H	14.58	8271	7885	-386	-26.48
15-Sep-99	16-Sep-99	3	H	18.09	6051	7614		
15-Sep-99	16-Sep-99	4	A	13.94	187	98	-89	-6.39
15-Sep-99	16-Sep-99	4	B	13.94	471	427	-44	-3.16
15-Sep-99	16-Sep-99	4	C	13.94	750	718	-32	-2.30
15-Sep-99	16-Sep-99	4	D	13.94	973	960	-13	-0.93
15-Sep-99	16-Sep-99	4	E	13.94	1525	2052	527	37.81
15-Sep-99	16-Sep-99	4	E	15.13	1956	2048		
15-Sep-99	16-Sep-99	4	F	13.94	3059	2965	-94	-6.74
15-Sep-99	16-Sep-99	4	F	15.13	2190	2890		
15-Sep-99	16-Sep-99	4	G	13.94	5749	6093	344	24.68
15-Sep-99	16-Sep-99	4	G	15.13	5843	6239		
15-Sep-99	16-Sep-99	4	H	13.94	8417	7114	-1303	-43.47
15-Sep-99	16-Sep-99	4	H	15.13	5050	8907		
15-Sep-99	16-Sep-99	5	A	11.57	42	37	-5	-0.43
15-Sep-99	16-Sep-99	5	B	11.57	481	449	-32	-2.77
15-Sep-99	16-Sep-99	5	C	11.57	750	735	-15	-1.30
15-Sep-99	16-Sep-99	5	D	11.57	1000	943	-77	-6.66
15-Sep-99	16-Sep-99	5	E	11.57	1971	2019	48	4.15
15-Sep-99	16-Sep-99	5	E	14.54	1869	1902		
15-Sep-99	16-Sep-99	5	F	11.57	2771	2919	148	12.79
15-Sep-99	16-Sep-99	5	F	14.54	1919	2886		
15-Sep-99	16-Sep-99	5	G	11.57	5978	6009	31	2.68
15-Sep-99	16-Sep-99	5	G	14.54	4446	6239		
15-Sep-99	16-Sep-99	5	H	11.57	8417	7927	-490	-42.35
15-Sep-99	16-Sep-99	5	H	14.54	8656	8531		

Table D-5
ALGAE PRODUCTIVITY TESTS RAW DATA

DATE	STATION	NH_3/NH_4^+-N g/L μg/L	NH_3-N mg/L μg/L	PO_4 μg/L	N/P	P-MAX	ALPHA	SPMAX	SALPHA
22-Jun-99	3	360	15			68.580	0.193	4.690	0.013
22-Jun-99	3	510	19			56.430	0.163	3.850	0.011
22-Jun-99	3	841	39			71.790	0.179	4.900	0.012
22-Jun-99	3	1075	63			68.490	0.188	4.680	0.013
22-Jun-99	3	1762	133			66.060	0.170	4.510	0.012
22-Jun-99	3	3036	190			56.370	0.162	3.850	0.011
22-Jun-99	3	818	35			50.090	0.133	3.420	0.009
22-Jun-99	3	2430	85			33.420	0.091	2.280	0.006
22-Jun-99	4	90	3			67.420	0.188	4.400	0.012
22-Jun-99	4	173	6			62.140	0.195	4.050	0.013
22-Jun-99	4	504	29			70.400	0.185	4.600	0.012
22-Jun-99	4	855	50			60.830	0.173	3.970	0.011
22-Jun-99	4	844	51			63.950	0.167	4.170	0.011
22-Jun-99	4	2351	147			51.090	0.148	3.330	0.010
22-Jun-99	4	3363	145			46.280	0.122	3.020	0.008
22-Jun-99	4	2304	100			33.810	0.092	2.190	0.006
6-Jul-99	3	123	5			60.850	0.206	33.740	0.013
6-Jul-99	3	503	24			60.300	0.202	3.710	0.012
6-Jul-99	3	909	57			64.230	0.184	3.950	0.011
6-Jul-99	3	1064	53			64.000	0.222	3.940	0.014
6-Jul-99	3	2232	140			68.430	0.215	4.210	0.013
6-Jul-99	3	2568	102			62.600	0.219	3.850	0.013
6-Jul-99	3	3413	213			62.180	0.188	3.820	0.012
6-Jul-99	3	2828	111			52.890	0.171	3.250	0.011
6-Jul-99	4	117	5			51.260	0.164	3.120	0.010
6-Jul-99	4	505	20			57.750	0.198	3.510	0.012
6-Jul-99	4	946	38			53.630	0.200	3.260	0.012
6-Jul-99	4	1131	70			71.970	0.290	4.380	0.018
6-Jul-99	4	1569	79			67.660	0.218	4.110	0.013
6-Jul-99	4	3761	232			56.120	0.194	3.410	0.012
6-Jul-99	4	2416	121			52.990	0.169	3.220	0.010
6-Jul-99	4	4079	199			51.160	0.167	3.110	0.010
6-Jul-99	5	358	1			58.060	0.168	4.280	0.012
6-Jul-99	5	340	17			49.360	0.198	3.640	0.015
6-Jul-99	5	502	25			58.730	0.212	4.330	0.016
6-Jul-99	5	744	37			64.710	0.233	4.440	0.017
6-Jul-99	5	1925	149			64.750	0.205	4.440	0.015
6-Jul-99	5	3132	193			60.110	0.203	4.430	0.015
6-Jul-99	5	2177	136			51.950	0.170	3.830	0.012
6-Jul-99	5	3191	194			62.100	0.131	4.570	0.010
7-Jul-99	3	98	5	205	0.480	103.370	0.298	7.630	0.022
7-Jul-99	3	497	25	205	2.420	111.590	0.356	8.230	0.026
7-Jul-99	3	720	37	205	3.510	103.030	0.262	7.600	0.019
7-Jul-99	3	1018	53	205	4.970	116.550	0.344	8.600	0.025
7-Jul-99	3	1670	86	205	8.150	109.390	0.261	8.070	0.019
7-Jul-99	3	2610	137	309	8.450	98.870	0.303	7.290	0.022
7-Jul-99	3	3246	175	389	8.340	83.190	0.200	6.140	0.015
7-Jul-99	3	3858	203	469	8.230	60.180	0.166	4.440	0.012
7-Jul-99	4	44	2	198	0.220	93.430	0.287	5.900	0.018
7-Jul-99	4	469	23	198	2.370	84.770	0.266	5.350	0.017
7-Jul-99	4	687	36	198	3.470	105.410	0.248	6.660	0.016
7-Jul-99	4	907	47	198	4.580	105.680	0.318	6.680	0.020
7-Jul-99	4	1674	87	198	8.450	97.710	0.225	6.170	0.014
7-Jul-99	4	2744	144	303	9.060	83.240	0.225	5.260	0.016
7-Jul-99	4	3233	174	385	8.400	83.130	0.198	5.250	0.012
7-Jul-99	4	4191	221	520	8.060	49.940	0.122	3.160	0.008
7-Jul-99	5	47	2	119	0.390	95.770	0.284	4.340	0.013
7-Jul-99	5	304	15	119	2.550	102.240	0.345	4.640	0.016
7-Jul-99	5	450	23	119	3.780	106.040	0.262	4.810	0.012
7-Jul-99	5	944	49	119	7.930	97.020	0.357	4.400	0.016
7-Jul-99	5	1729	89	119	14.530	105.650	0.251	4.790	0.011
7-Jul-99	5	2814	147	286	9.840	94.110	0.286	4.270	0.013
7-Jul-99	5	3013	162	424	7.110	80.670	0.187	3.660	0.008
7-Jul-99	5	3547	187	471	7.530	53.670	0.150	2.440	0.007
21-Jul-99	3	158	8			45.610	0.138	3.150	0.010
21-Jul-99	3	401	21			38.840	0.140	3.060	0.011
21-Jul-99	3	612	34			46.860	0.130	3.600	0.010
21-Jul-99	3	670	37			52.460	0.108	3.040	0.009
21-Jul-99	3	1452	83			48.180	0.128	3.700	0.010
21-Jul-99	3	2316	131			42.090	0.132	3.390	0.010
21-Jul-99	3	3294	187			49.800	0.160	3.820	0.012
21-Jul-99	3	5493	311			46.390	0.124	3.560	0.010
21-Jul-99	4	152	8			35.060	0.120	2.740	0.009
21-Jul-99	4	370	20			33.670	0.106	2.630	0.008

Table D-5
ALGAE PRODUCTIVITY TESTS RAW DATA

DATE	STATION	NH_3/NH_4^+-N g/L μg/L	NH_3-N mg/L μg/L	PO_4 μg/L	N/P	P-MAX	ALPHA	SPMAX	SALPHA
21-Jul-99	4	653	36			36.720	0.121	2.870	0.009
21-Jul-99	4	704	39			37.700	0.119	2.950	0.009
21-Jul-99	4	1482	85			37.910	0.123	2.960	0.010
21-Jul-99	4	2047	116			38.650	0.104	3.020	0.008
21-Jul-99	4	3520	199			44.210	0.121	3.460	0.009
21-Jul-99	4	4441	251			35.990	0.111	2.810	0.009
21-Jul-99	5	109	6			37.780	0.126	3.050	0.010
21-Jul-99	5	373	20			36.410	0.122	2.940	0.010
21-Jul-99	5	615	34			35.980	0.121	2.910	0.010
21-Jul-99	5	794	44			49.430	0.106	4.000	0.008
21-Jul-99	5	1485	85			41.120	0.124	3.320	0.010
21-Jul-99	5	2179	123			38.190	0.106	3.090	0.009
21-Jul-99	5	3221	182			56.390	0.125	4.550	0.010
21-Jul-99	5	5046	286			36.760	0.122	2.970	0.010
22-Jul-99	3	126		199					
22-Jul-99	3	1679	118	239	7.030	52.990	0.164	3.420	0.011
22-Jul-99	3	3012	210	337	8.940	54.540	0.162	3.520	0.010
22-Jul-99	3	5346	365	493	10.840	52.820	0.166	3.400	0.011
22-Jul-99	4	83		195					
22-Jul-99	4	1663	144	247	6.730	52.940	0.164	3.660	0.011
22-Jul-99	4	3403	294	331	10.280	56.550	0.174	3.610	0.011
22-Jul-99	4	4850	409	493	9.840	55.950	0.166	3.570	0.010
22-Jul-99	5	35		185					
22-Jul-99	5	1501	130	247	6.080	55.890	0.162	3.790	0.011
22-Jul-99	5	3217	277	331	9.720	51.350	0.159	3.480	0.011
22-Jul-99	5	4833	408	467	10.350	54.520	0.160	3.700	0.011
10-Aug-99	3	236	19.000			176.550	0.529	6.320	0.019
10-Aug-99	3	547	45.000			186.020	0.502	6.660	0.018
10-Aug-99	3	749	62.000			181.040	0.483	6.490	0.017
10-Aug-99	3	921	77.000			172.070	0.494	6.160	0.018
10-Aug-99	3	1980	165.000			198.080	0.601	7.100	0.021
10-Aug-99	3	3069	259.000			212.070	0.820	7.600	0.029
10-Aug-99	3	4573	383.000			187.480	0.693	6.720	0.025
10-Aug-99	3	7327	623.000			140.260	0.455	5.030	0.016
10-Aug-99	4	160	13.000			234.380	0.658	8.910	0.025
10-Aug-99	4	431	35.000			223.600	0.622	10.330	0.022
10-Aug-99	4	795	66.000			228.480	0.607	8.690	0.023
10-Aug-99	4	982	82.000			232.990	0.645	8.860	0.025
10-Aug-99	4	1958	163.000			251.700	0.789	9.570	0.030
10-Aug-99	4	3045	257.000			267.690	0.386	10.180	0.015
10-Aug-99	4	4777	400.000			251.970	0.894	9.580	0.034
10-Aug-99	4	7231	615.000			181.780	0.598	6.910	0.021
10-Aug-99	5	34	3.000			219.390	0.667	6.910	0.021
10-Aug-99	5	447	37.000			224.430	0.642	7.070	0.020
10-Aug-99	5	748	62.000			216.270	0.612	6.810	0.019
10-Aug-99	5	995	83.000			213.090	0.610	6.710	0.019
10-Aug-99	5	1929	160.000			234.460	0.770	7.390	0.024
10-Aug-99	5	3153	266.000			255.060	0.593	8.031	0.019
10-Aug-99	5	4872	408.000			230.880	0.856	7.270	0.027
10-Aug-99	5	6816	579.000			171.610	0.522	5.404	0.016
11-Aug-99	3	289		161	1.800				
11-Aug-99	3	1832	150	219	8.370	186.650	0.573	4.900	0.015
11-Aug-99	3	2107	175	335	6.290	200.850	0.552	5.280	0.015
11-Aug-99	3	4749	398	580	8.190	160.060	0.507	4.210	0.013
11-Aug-99	3	6032	505	833	7.240	170.710	0.443	4.490	0.012
11-Aug-99	4	164		172	0.940				
11-Aug-99	4	1927	158	190	10.140	222.470	0.653	4.140	0.012
11-Aug-99	4	1963	163	306	6.420	235.280	0.681	4.380	0.013
11-Aug-99	4	4487	376	546	8.220	200.280	0.613	3.730	0.011
11-Aug-99	4	6973	584	795	8.770	214.700	0.573	4.000	0.011
11-Aug-99	5	33		149	0.220				
11-Aug-99	5	1943	159	199	9.760	196.040	0.632	5.000	0.016
11-Aug-99	5	1987	165	317	6.270	205.080	0.574	5.230	0.015
11-Aug-99	5	4558	382	555	8.210	189.180	0.594	4.820	0.015
11-Aug-99	5	6399	536	791	8.090	203.840	0.525	5.200	0.013
31-Aug-99	3	162	7.000			136.110	0.367	4.790	0.013
31-Aug-99	3	450	19.000			125.330	0.370	4.410	0.013
31-Aug-99	3	759	31.000			130.600	0.402	4.590	0.014
31-Aug-99	3	894	36.000			120.680	0.662	4.240	0.023
31-Aug-99	3	1922	79.000			129.500	0.387	4.550	0.014
31-Aug-99	3	2943	121.000			126.400	0.366	4.450	0.013
31-Aug-99	3	5202	215.000			128.370	0.355	4.510	0.012
31-Aug-99	3	7395	296.000			100.270	0.348	3.520	0.012
31-Aug-99	4	93	4.000			129.680	0.358	4.950	0.014
31-Aug-99	4	450	19.000			127.450	0.371	4.860	0.014

Table D-5
ALGAE PRODUCTIVITY TESTS RAW DATA

DATE	STATION	NH_3/NH_4^+-N g/L µg/L	NH_3-N mg/L µg/L	PO_4 µg/L	N/P	P-MAX	ALPHA	SPMAX	SALPHA
31-Aug-99	4	750	31.000			134.150	0.382	5.120	0.015
31-Aug-99	4	954	38.000			134.280	0.392	5.120	0.015
31-Aug-99	4	2022	83.000			133.580	0.421	5.100	0.016
31-Aug-99	4	2914	119.000			127.660	0.388	4.870	0.015
31-Aug-99	4	5256	217.000			127.360	0.359	4.860	0.014
31-Aug-99	4	7545	302.000			102.480	0.328	3.920	0.012
31-Aug-99	5	32	1.000			125.390	0.402	5.510	0.018
31-Aug-99	5	442	18.000			131.350	0.410	5.780	0.018
31-Aug-99	5	744	31.000			134.760	0.425	5.930	0.019
31-Aug-99	5	964	39.000			136.290	0.428	5.990	0.019
31-Aug-99	5	1976	81.000			140.790	0.435	6.190	0.019
31-Aug-99	5	3001	123.000			126.420	0.390	5.560	0.017
31-Aug-99	5	5002	206.000			122.770	0.393	5.400	0.017
31-Aug-99	5	5736	229.000			102.260	0.353	4.500	0.016
1-Sep-99	3	225		200					
1-Sep-99	3	411		189					
1-Sep-99	3	693		200					
1-Sep-99	3	844		189					
1-Sep-99	3	1785	72	196		148.100	0.459	4.580	0.014
1-Sep-99	3	3891	159	308		146.430	0.434	4.530	0.013
1-Sep-99	3	5298	214	540		134.250	0.449	4.160	0.014
1-Sep-99	3	7915	315	750		127.200	0.378	3.940	0.012
1-Sep-99	4	120		183					
1-Sep-99	4	433		183					
1-Sep-99	4	632		175					
1-Sep-99	4	953		185					
1-Sep-99	4	2156	87	200		164.710	0.511	6.200	0.019
1-Sep-99	4	3415	140	316		149.820	0.420	5.640	0.016
1-Sep-99	4	5932	240	556		153.150	0.500	5.760	0.019
1-Sep-99	4	7698	306	744		136.520	0.390	5.140	0.014
1-Sep-99	5	32		171					
1-Sep-99	5	410		171					
1-Sep-99	5	646		159					
1-Sep-99	5	793		179					
1-Sep-99	5	1969	79	208		121.530	0.420	4.910	0.017
1-Sep-99	5	3307	136	318		120.190	0.390	4.850	0.016
1-Sep-99	5	5825	236	530		113.270	0.400	4.570	0.016
1-Sep-99	5	8257	328	768		107.340	0.340	4.340	0.014
15-Sep-99	3	69	2.000			30.920	0.169	2.120	0.012
15-Sep-99	3	491	13.000			39.940	0.154	2.740	0.011
15-Sep-99	3	765	18.000			35.950	0.164	2.970	0.011
15-Sep-99	3	995	26.000			37.100	0.164	2.540	0.011
15-Sep-99	3	2046	52.000			37.870	0.156	2.600	0.011
15-Sep-99	3	3205	85.000			36.590	0.157	2.510	0.011
15-Sep-99	3	9874	148.000			29.960	0.154	2.030	0.011
15-Sep-99	3	8271	218.000			26.380	0.101	1.810	0.007
15-Sep-99	4	187	5.000			33.130	0.171	2.360	0.012
15-Sep-99	4	471	12.000			36.400	0.147	2.650	0.011
15-Sep-99	4	750	17.000			37.960	0.170	2.690	0.012
15-Sep-99	4	973	25.000			35.550	0.231	2.550	0.017
15-Sep-99	4	1525	39.000			37.610	0.159	2.700	0.011
15-Sep-99	4	3059	81.000			36.450	0.152	2.610	0.011
15-Sep-99	4	5799	145.000			32.750	0.150	2.350	0.011
15-Sep-99	4	8417	222.000			27.770	0.104	1.960	0.008
15-Sep-99	5	42	1.000			30.980	0.160	2.680	0.014
15-Sep-99	5	481	13.000			38.290	0.159	3.310	0.014
15-Sep-99	5	750	17.000			37.870	0.171	3.270	0.015
15-Sep-99	5	1020	27.000			35.150	0.166	3.040	0.014
15-Sep-99	5	1971	51.000			35.450	0.162	3.060	0.014
15-Sep-99	5	2771	73.000			36.680	0.153	3.170	0.013
15-Sep-99	5	5978	150.000			32.660	0.141	2.820	0.012
15-Sep-99	5	8417	222.000			25.310	0.124	2.180	0.011
16-Sep-99	3	132		204	0.650				
16-Sep-99	3	1956	40.000	169	11.570	48.520	0.199	2.680	0.011
16-Sep-99	3	2011	40.000	308	6.530	43.190	0.178	2.390	0.010
16-Sep-99	3	5050	116.000	514	9.830	42.590	0.180	2.350	0.010
16-Sep-99	3	6051	128.000	711	8.510	46.710	0.197	2.080	0.011
16-Sep-99	4	179		188	0.950				
16-Sep-99	4	1956	40.000	210	9.310	44.760	0.192	2.960	0.013
16-Sep-99	4	2190	44.000	320	6.840	44.800	0.182	2.960	0.012
16-Sep-99	4	5843	135.000	532	10.980	44.780	0.169	2.960	0.011
16-Sep-99	4	5050	107.000	791	6.380	43.460	0.198	2.870	0.013
16-Sep-99	5	150		180	0.940				
16-Sep-99	5	1869	39.000	206	9.070	44.600	0.192	3.070	0.013
16-Sep-99	5	1919	38.000	306	6.270	41.010	0.178	2.820	0.012

Table D-5
ALGAE PRODUCTIVITY TESTS RAW DATA

DATE	STATION	NH_3/NH_4^+-N g/L µg/L	NH_3-N mg/L µg/L	PO_4 µg/L	N/P	P-MAX	ALPHA	SPMAX	SALPHA
16-Sep-99	5	4446	102.000	518	8.580	44.000	0.188	3.030	0.013
16-Sep-99	5	8656	184.000	777	11.140	45.050	0.205	3.100	0.014
5-Oct-99	3	706	8.000			87.620	0.440	3.100	0.015
5-Oct-99	3	647	7.500						
5-Oct-99	3	673	7.600			88.620	0.437	3.140	0.015
5-Oct-99	3	1069	12.300			87.300	0.506	3.090	0.018
5-Oct-99	3	1319	14.500			89.120	0.424	3.150	0.015
5-Oct-99	3	2341	26.800			85.120	0.494	3.010	0.017
5-Oct-99	3	4800	54.900			74.590	0.377	2.640	0.013
5-Oct-99	3	6489	73.200			64.140	0.376	2.270	0.013
5-Oct-99	4	84	0.900			94.340	0.456	3.090	0.015
5-Oct-99	4	566	6.600			94.610	0.491	3.100	0.016
5-Oct-99	4	673	7.600			91.110	0.438	2.990	0.014
5-Oct-99	4	965	11.100			118.420	0.486	3.880	0.016
5-Oct-99	4	1966	21.600			91.900	0.341	3.010	0.011
5-Oct-99	4	2549	29.200			89.020	0.511	2.920	0.017
5-Oct-99	4	4675	53.500			78.280	0.386	2.570	0.013
5-Oct-99	4	6426	72.500			65.750	0.372	2.160	0.012
5-Oct-99	5	80	0.900			94.550	0.467	3.040	0.015
5-Oct-99	5	472	5.500			93.620	0.521	3.010	0.017
5-Oct-99	5	736	8.300			93.860	0.464	3.020	0.015
5-Oct-99	5	840	9.700			93.750	0.544	3.020	0.018
5-Oct-99	5	1549	17.000			91.910	0.448	2.950	0.014
5-Oct-99	5	2633	30.100			89.560	0.525	2.880	0.017
5-Oct-99	5	4592	52.500			80.960	0.393	2.600	0.013
5-Oct-99	5	6530	73.700			65.840	0.385	2.100	0.012
20-Oct-99	3	455	7.400			312.420	1.245	4.260	0.017
20-Oct-99	3	442	6.200			248.870	1.422	3.390	0.019
20-Oct-99	3	768	12.100			260.280	1.176	3.550	0.016
20-Oct-99	3	899	13.100			253.810	1.444	3.460	0.020
20-Oct-99	3	1731	25.100			255.980	1.191	3.490	0.016
20-Oct-99	3	1948	28.200			198.280	1.155	2.700	0.016
20-Oct-99	3	4050	62.000			196.340	0.969	2.670	0.013
20-Oct-99	3	6259	95.900			168.260	0.887	2.290	0.012
20-Oct-99	4	260	3.400			344.240	1.310	4.190	0.016
20-Oct-99	4	425	4.800			254.830	1.388	3.100	0.017
20-Oct-99	4	689	8.600			272.410	1.228	3.320	0.015
20-Oct-99	4	893	10.400			257.110	1.424	3.130	0.017
20-Oct-99	4	1560	18.000			267.060	1.257	3.250	0.015
20-Oct-99	4	2332	26.800			196.290	1.200	2.390	0.015
20-Oct-99	4	3716	45.100			202.510	0.995	2.430	0.012
20-Oct-99	4	6780	82.300			164.280	0.905	1.980	0.011
20-Oct-99	5	90	1.500			336.100	1.339	3.950	0.016
20-Oct-99	5	407	5.700			261.060	1.429	3.070	0.017
20-Oct-99	5	689	10.900			273.320	1.257	3.210	0.015
20-Oct-99	5	893	13.000			264.990	1.469	3.110	0.017
20-Oct-99	5	1460	21.100			270.640	1.275	3.180	0.015
20-Oct-99	5	2252	32.600			190.990	1.250	2.230	0.015
20-Oct-99	5	3883	59.500			203.840	1.053	2.390	0.012
20-Oct-99	5	6447	98.800			175.580	0.895	2.040	0.011
21-Oct-99	3	446		107.000	4.170				
21-Oct-99	3	1919	30.100	215.000	8.930	357.880	1.542	4.340	0.019
21-Oct-99	3	2994	46.200	335.000	8.940	307.980	1.666	3.730	0.020
21-Oct-99	3	4300	66.400	566.000	7.600	320.630	1.461	3.890	0.018
21-Oct-99	3	6384	95.500	765.000	8.350	256.400	1.521	3.110	0.018
21-Oct-99	4	230		89.000	2.580				
21-Oct-99	4	1911	30.000	205.000	9.320	376.760	1.609	4.440	0.019
21-Oct-99	4	2832	43.700	317.000	8.930	313.880	1.578	3.700	0.019
21-Oct-99	4	5030	77.700	537.000	9.370	338.340	1.475	3.990	0.017
21-Oct-99	4	6301	94.300	786.000	8.020	261.390	1.660	3.080	0.020
21-Oct-99	5	37		62.000	0.600				
21-Oct-99	5	1848	29.000	201.000	9.190	365.200	1.620	4.470	0.020
21-Oct-99	5	2786	43.000	335.000	8.320	325.610	1.620	3.980	0.020
21-Oct-99	5	4800	74.100	556.000	8.630	332.040	1.542	4.060	0.019
21-Oct-99	5	6405	95.800	772.000	8.300	269.480	1.633	3.300	0.020
2-Nov-99	3	313	2.400			174.780	1.258	1.640	0.012
2-Nov-99	3	448	3.500			189.210	1.314	1.770	0.012
2-Nov-99	3	722	5.900			189.900	1.224	1.780	0.011
2-Nov-99	3	955	8.700			210.650	1.295	1.970	0.012
2-Nov-99	3	1942	17.100			196.400	1.022	1.840	0.010
2-Nov-99	3	2817	24.400			143.680	1.042	1.350	0.010
2-Nov-99	3	4707	43.400			112.970	0.755	1.060	0.007
2-Nov-99	3	6812	63.400			100.400	0.664	0.940	0.006
2-Nov-99	4	158	1.500			185.330	1.260	1.740	0.012
2-Nov-99	4	423	4.100			204.500	1.385	1.930	0.013

Table D-5
ALGAE PRODUCTIVITY TESTS RAW DATA

DATE	STATION	NH_3/NH_4^+-N g/L μg/L	NH_3-N mg/L μg/L	PO_4 μg/L	N/P	P-MAX	ALPHA	SPMAX	SALPHA
2-Nov-99	4	712	7.400			209.980	1.231	1.980	0.012
2-Nov-99	4	910	10.300			227.060	1.428	2.050	0.014
2-Nov-99	4	1846	20.100			233.230	1.025	2.150	0.010
2-Nov-99	4	2759	30.500			148.900	0.973	1.400	0.009
2-Nov-99	4	4936	56.800			130.820	0.753	1.230	0.007
2-Nov-99	4	6728	78.000			114.540	0.705	1.080	0.007
2-Nov-99	5	24	0.200			167.710	1.179	1.590	0.011
2-Nov-99	5	423	4.100			181.620	1.274	1.720	0.012
2-Nov-99	5	705	7.300			192.600	1.194	1.830	0.011
2-Nov-99	5	903	10.200			211.800	1.287	2.000	0.012
2-Nov-99	5	1942	21.100			202.150	0.971	1.910	0.009
2-Nov-99	5	2767	30.600			135.910	0.898	1.290	0.009
2-Nov-99	5	4832	55.600			113.720	0.651	1.080	0.006
2-Nov-99	5	6624	76.800			97.690	0.601	0.930	0.006
3-Nov-99	3	538		85.400	6.300				
3-Nov-99	3	823	6.500	85.400	9.640	193.840	1.464	2.010	0.015
3-Nov-99	3	1004	8.000	92.400	10.810	211.190	1.336	2.180	0.014
3-Nov-99	3	1831	15.600	196.700	9.310	216.360	1.306	2.230	0.014
3-Nov-99	3	2882	24.500	289.300	9.960	222.240	1.376	2.320	0.014
3-Nov-99	3	5050	44.900	506.200	9.980	215.620	1.283	2.210	0.013
3-Nov-99	3	6926	59.400	700.800	9.880	125.900	0.746	1.320	0.008
3-Nov-99	4	206		46.500	4.430				
3-Nov-99	4	814	6.500	79.900	10.190	199.020	1.469	2.010	0.015
3-Nov-99	4	974	7.800	96.600	10.080	224.840	1.485	2.250	0.015
3-Nov-99	4	1998	17.000	196.700	10.160	230.200	1.369	2.310	0.014
3-Nov-99	4	2790	23.700	311.600	8.950	234.710	1.515	2.370	0.015
3-Nov-99	4	4571	40.700	515.500	8.870	232.120	1.406	2.340	0.014
3-Nov-99	4	6780	58.200	697.100	9.730	143.770	0.893	1.450	0.009
3-Nov-99	5	39		33.500	1.160				
3-Nov-99	5	713	5.700	72.500	9.830	182.400	1.451	1.770	0.014
3-Nov-99	5	954	7.600	92.900	10.270	205.670	1.377	1.990	0.013
3-Nov-99	5	1827	15.500	191.100	9.560	213.090	1.370	2.050	0.013
3-Nov-99	5	2648	22.500	296.800	8.920	220.000	1.451	2.090	0.014
3-Nov-99	5	4988	44.400	502.500	9.930	212.520	1.378	2.020	0.014
3-Nov-99	5	6676	57.300	691.600	9.650	129.790	0.891	1.260	0.009

TABLE D-6
EFFECTS OF NITRATE SPIKING ON PRIMARY PRODUCTIVITY

DATE	STATION	NO$_3$-N µg/L	PO$_4$ µg/L	N/P	PMAX	ALPHA	SPMAX	SALPHA
with Phosphorus Spiking								
6-Oct-00	3		166.000					
6-Oct-00	3	1,930	203.000	9.570	110.140	0.544	3.590	0.018
6-Oct-00	3	3,000	323.000	9.290	109.380	0.500	3.570	0.016
6-Oct-00	3	5,170	545.000	9.440	101.680	0.544	3.310	0.018
6-Oct-00	3	7,900	776.000	10.180	109.550	0.517	3.570	0.017
6-Oct-00	4		154.000					
6-Oct-00	4	2,030	211.000	9.620	116.500	0.546	3.570	0.017
6-Oct-00	4	3,070	325.000	9.450	117.200	0.526	3.590	0.016
6-Oct-00	4	5,070	562.000	9.020	106.760	0.520	3.270	0.016
6-Oct-00	4	7,700	818.000	9.410	112.650	0.522	3.450	0.016
6-Oct-00	5		138.000					
6-Oct-00	5	2,000	211.000	9.480	111.500	0.556	3.310	0.016
6-Oct-00	5	3,000	325.000	9.230	109.320	0.524	3.240	0.015
6-Oct-00	5	5,100	570.000	8.950	101.680	0.518	3.020	0.015
6-Oct-00	5	7,170	847.000	8.470	102.740	0.511	3.050	0.015
without Phosphorus Spiking								
6-Oct-00	**3**	**340**			**100.220**	**0.546**	**3.260**	**0.018**
6-Oct-00	3	530			106.630	0.599	3.470	0.020
6-Oct-00	3	900			99.130	0.489	3.230	0.016
6-Oct-00	3	1,100			99.080	0.514	3.230	0.017
6-Oct-00	3	2,170			91.510	0.495	2.980	0.016
6-Oct-00	3	3,270			89.260	0.500	2.910	0.016
6-Oct-00	3	5,570			90.070	0.488	2.930	0.016
6-Oct-00	3	6,670			69.970	0.363	2.280	0.012
6-Oct-00	**4**	**320**			**109.220**	**0.575**	**3.340**	**0.018**
6-Oct-00	4	570			103.480	0.537	3.170	0.016
6-Oct-00	4	800			100.320	0.501	3.070	0.015
6-Oct-00	4	1,100			97.950	0.512	3.000	0.016
6-Oct-00	4	2,100			91.620	0.534	2.800	0.016
6-Oct-00	4	3,170			97.880	0.521	3.000	0.016
6-Oct-00	4	5,070			98.590	0.501	3.020	0.015
6-Oct-00	4	7,100			76.380	0.368	2.310	0.011
6-Oct-00	**5**	**300**			**105.200**	**0.564**	**3.120**	**0.016**
6-Oct-00	5	530			104.010	0.600	3.090	0.018
6-Oct-00	5	830			94.250	0.509	2.800	0.015
6-Oct-00	5	1,000			93.600	0.533	2.780	0.016
6-Oct-00	5	2,100			86.010	0.524	2.530	0.016
6-Oct-00	5	3,070			84.310	0.514	2.500	0.015
6-Oct-00	5	5,200			90.870	0.469	2.700	0.014
6-Oct-00	5	7,200			64.290	0.403	1.910	0.012

TABLE D-7
EFFECTS OF AMMONIA SPIKING ON PRIMARY PRODUCTIVITY

DATE	STATION	NO_3-N µg/L	NH_3-N µg/L	PO_4 µg/L	N/P	PMAX	ALPHA	SPMAX	SALPHA
22-Jun-99	3	360	15			68.580	0.193	4.690	0.013
22-Jun-99	3	510	19			56.430	0.163	3.850	0.011
22-Jun-99	3	841	39			71.790	0.179	4.900	0.012
22-Jun-99	3	1075	63			68.490	0.188	4.680	0.013
22-Jun-99	3	1762	133			66.060	0.170	4.510	0.012
22-Jun-99	3	3036	190			56.370	0.162	3.850	0.011
22-Jun-99	3	818	35			50.090	0.133	3.420	0.009
22-Jun-99	3	2430	85			33.420	0.091	2.280	0.006
22-Jun-99	4	90	3			67.420	0.188	4.400	0.012
22-Jun-99	4	173	6			62.140	0.195	4.050	0.013
22-Jun-99	4	504	29			70.400	0.185	4.600	0.012
22-Jun-99	4	855	50			60.830	0.173	3.970	0.011
22-Jun-99	4	844	51			63.950	0.167	4.170	0.011
22-Jun-99	4	2351	147			51.090	0.148	3.330	0.010
22-Jun-99	4	3363	145			46.280	0.122	3.020	0.008
22-Jun-99	4	2304	100			33.810	0.092	2.190	0.006
6-Jul-99	3	123	5			60.850	0.206	33.740	0.013
6-Jul-99	3	503	24			60.300	0.202	3.710	0.012
6-Jul-99	3	909	57			64.230	0.184	3.950	0.011
6-Jul-99	3	1064	53			64.000	0.222	3.940	0.014
6-Jul-99	3	2232	140			68.430	0.215	4.210	0.013
6-Jul-99	3	2568	102			62.600	0.219	3.850	0.013
6-Jul-99	3	3413	213			62.180	0.188	3.820	0.012
6-Jul-99	3	2828	111			52.890	0.171	3.250	0.011
6-Jul-99	4	117	5			51.260	0.164	3.120	0.010
6-Jul-99	4	505	20			57.750	0.198	3.510	0.012
6-Jul-99	4	946	38			53.630	0.200	3.260	0.012
6-Jul-99	4	1131	70			71.970	0.290	4.380	0.018
6-Jul-99	4	1569	79			67.660	0.218	4.110	0.013
6-Jul-99	4	3761	232			56.120	0.194	3.410	0.012
6-Jul-99	4	2416	121			52.990	0.169	3.220	0.010
6-Jul-99	4	4079	199			51.160	0.167	3.110	0.010
6-Jul-99	5	358	1			58.060	0.168	4.280	0.012
6-Jul-99	5	340	17			49.360	0.198	3.640	0.015
6-Jul-99	5	502	25			58.730	0.212	4.330	0.016
6-Jul-99	5	744	37			64.710	0.233	4.440	0.017
6-Jul-99	5	1925	149			64.750	0.205	4.440	0.015
6-Jul-99	5	3132	193			60.110	0.203	4.430	0.015
6-Jul-99	5	2177	136			51.950	0.170	3.830	0.012
6-Jul-99	5	3191	194			62.100	0.131	4.570	0.010
7-Jul-99	3	98	5	205	0.480	103.370	0.298	7.630	0.022
7-Jul-99	3	497	25	205	2.420	111.590	0.356	8.230	0.026
7-Jul-99	3	720	37	205	3.510	103.030	0.262	7.600	0.019
7-Jul-99	3	1018	53	205	4.970	116.550	0.344	8.600	0.025
7-Jul-99	3	1670	86	205	8.150	109.390	0.261	8.070	0.019

TABLE D-7
EFFECTS OF AMMONIA SPIKING ON PRIMARY PRODUCTIVITY

DATE	STATION	NO_3-N μg/L	NH_3-N μg/L	PO_4 μg/L	N/P	PMAX	ALPHA	SPMAX	SALPHA
7-Jul-99	3	2610	137	309	8.450	98.870	0.303	7.290	0.022
7-Jul-99	3	3246	175	389	8.340	83.190	0.200	6.140	0.015
7-Jul-99	3	3858	203	469	8.230	60.180	0.166	4.440	0.012
7-Jul-99	4	44	2	198	0.220	93.430	0.287	5.900	0.018
7-Jul-99	4	469	23	198	2.370	84.770	0.266	5.350	0.017
7-Jul-99	4	687	36	198	3.470	105.410	0.248	6.660	0.016
7-Jul-99	4	907	47	198	4.580	105.680	0.318	6.680	0.020
7-Jul-99	4	1674	87	198	8.450	97.710	0.225	6.170	0.014
7-Jul-99	4	2744	144	303	9.060	83.240	0.225	5.260	0.016
7-Jul-99	4	3233	174	385	8.400	83.130	0.198	5.250	0.012
7-Jul-99	4	4191	221	520	8.060	49.940	0.122	3.160	0.008
7-Jul-99	5	47	2	119	0.390	95.770	0.284	4.340	0.013
7-Jul-99	5	304	15	119	2.550	102.240	0.345	4.640	0.016
7-Jul-99	5	450	23	119	3.780	106.040	0.262	4.810	0.012
7-Jul-99	5	944	49	119	7.930	97.020	0.357	4.400	0.016
7-Jul-99	5	1729	89	119	14.530	105.650	0.251	4.790	0.011
7-Jul-99	5	2814	147	286	9.840	94.110	0.286	4.270	0.013
7-Jul-99	5	3013	162	424	7.110	80.670	0.187	3.660	0.008
7-Jul-99	5	3547	187	471	7.530	53067.000	0.150	2.440	0.007
21-Jul-99	3	158	8			45.610	0.138	3.150	0.010
21-Jul-99	3	401	21			38.840	0.140	3.060	0.011
21-Jul-99	3	612	34			46.860	0.130	3.600	0.010
21-Jul-99	3	670	37			52.460	0.108	3.040	0.009
21-Jul-99	3	1452	83			48.180	0.128	3.700	0.010
21-Jul-99	3	2316	131			42.090	0.132	3.390	0.010
21-Jul-99	3	3294	187			49.800	0.160	3.820	0.012
21-Jul-99	3	5493	311			46.390	0.124	3.560	0.010
21-Jul-99	4	152	8			35.060	0.120	2.740	0.009
21-Jul-99	4	370	20			33.670	0.106	2.630	0.008
21-Jul-99	4	653	36			36.720	0.121	2.870	0.009
21-Jul-99	4	704	39			37.700	0.119	2.950	0.009
21-Jul-99	4	1482	85			37.910	0.123	2.960	0.010
21-Jul-99	4	2047	116			38.650	0.104	3.020	0.008
21-Jul-99	4	3520	199			44.210	0.121	3.460	0.009
21-Jul-99	4	4441	251			35.990	0.111	2.810	0.009
21-Jul-99	5	109	6			37.780	0.126	3.050	0.010
21-Jul-99	5	373	20			36.410	0.122	2.940	0.010
21-Jul-99	5	615	34			35.980	0.121	2.910	0.010
21-Jul-99	5	794	44			49.430	0.106	4.000	0.008
21-Jul-99	5	1485	85			41.120	0.124	3.320	0.010
21-Jul-99	5	2179	123			38.190	0.106	3.090	0.009
21-Jul-99	5	3221	182			56.390	0.125	4.550	0.010
21-Jul-99	5	5046	286			36.760	0.122	2.970	0.010
22-Jul-99	3	126		199					
22-Jul-99	3	1679	118	239	7.030	52.990	0.164	3.420	0.011

TABLE D-7
EFFECTS OF AMMONIA SPIKING ON PRIMARY PRODUCTIVITY

DATE	STATION	NO_3-N µg/L	NH_3-N µg/L	PO_4 µg/L	N/P	PMAX	ALPHA	SPMAX	SALPHA
22-Jul-99	3	3012	210	337	8.940	54.540	0.162	3.520	0.010
22-Jul-99	3	5346	365	493	10.840	52.820	0.166	3.400	0.011
22-Jul-99	4	83		195					
22-Jul-99	4	1663	144	247	6.730	52.940	0.164	3.660	0.011
22-Jul-99	4	3403	294	331	10.280	56.550	0.174	3.160	0.011
22-Jul-99	4	4850	409	493	9.840	55.950	0.166	3.570	0.010
22-Jul-99	5	35		185					
22-Jul-99	5	1501	130	247	6.080	55.890	0.162	3.790	0.011
22-Jul-99	5	3217	277	331	9.720	51.350	0.159	3.480	0.011
22-Jul-99	5	4833	408	467	10.350	54.520	0.160	3.700	0.011
10-Aug-99	3	236	19.000			176.550	0.529	6.320	0.019
10-Aug-99	3	547	45.000			186.020	0.502	6.660	0.018
10-Aug-99	3	749	62.000			181.040	0.483	6.490	0.017
10-Aug-99	3	921	77.000			172.070	0.494	6.160	0.018
10-Aug-99	3	1980	165.000			198.080	0.601	7.100	0.021
10-Aug-99	3	3069	259.000			212.070	0.820	7.600	0.029
10-Aug-99	3	4573	383.000			187.480	0.693	6.720	0.025
10-Aug-99	3	7327	623.000			140.260	0.455	5.030	0.016
10-Aug-99	4	160	13.000			234.380	0.658	8.910	0.025
10-Aug-99	4	431	35.000			223.600	0.622	10.330	0.022
10-Aug-99	4	795	66.000			228.480	0.607	8.690	0.023
10-Aug-99	4	982	82.000			232.990	0.645	8.860	0.025
10-Aug-99	4	1958	163.000			251.700	0.789	9.570	0.030
10-Aug-99	4	3045	257.000			267.690	0.386	10.180	0.015
10-Aug-99	4	4777	400.000			251.970	0.894	9.580	0.034
10-Aug-99	4	7231	615.000			181.780	0.598	6.910	0.021
10-Aug-99	5	34	3.000			219.390	0.667	6.910	0.021
10-Aug-99	5	447	37.000			224.430	0.642	7.070	0.020
10-Aug-99	5	748	62.000			216.270	0.612	6.810	0.019
10-Aug-99	5	995	83.000			213.090	0.610	6.710	0.019
10-Aug-99	5	1929	160.000			234.460	0.770	7.390	0.024
10-Aug-99	5	3153	266.000			255.060	0.593	8.031	0.019
10-Aug-99	5	4872	408.000			230.880	0.856	7.270	0.027
10-Aug-99	5	6816	579.000			171.610	0.522	5.404	0.016
11-Aug-99	3	289		161	1.800				
11-Aug-99	3	1832	150	219	8.370	186.650	0.573	4.900	0.015
11-Aug-99	3	2107	175	335	6.290	200.850	0.552	5.280	0.015
11-Aug-99	3	4744	398	580	8.190	160.060	0.507	4.210	0.013
11-Aug-99	3	6032	505	833	7.240	170.710	0.443	4.490	0.012
11-Aug-99	4	164		172	0.940				
11-Aug-99	4	1927	158	190	10.140	222.470	0.653	4.140	0.012
11-Aug-99	4	1963	163	306	6.420	235.280	0.681	4.380	0.013
11-Aug-99	4	4487	376	546	8.220	200.280	0.613	3.730	0.011
11-Aug-99	4	6973	584	795	8.770	214.700	0.573	4.000	0.011
11-Aug-99	5	33		149	0.220				

TABLE D-7
EFFECTS OF AMMONIA SPIKING ON PRIMARY PRODUCTIVITY

DATE	STATION	NO$_3$-N µg/L	NH$_3$-N µg/L	PO$_4$ µg/L	N/P	PMAX	ALPHA	SPMAX	SALPHA
11-Aug-99	5	1943	159	199	9.760	196.040	0.632	5.000	0.016
11-Aug-99	5	1987	165	317	6.270	205.080	0.574	5.230	0.015
11-Aug-99	5	4558	382	555	8.210	189.180	0.594	4.820	0.015
11-Aug-99	5	6399	536	791	8.090	203.840	0.525	5.200	0.013
31-Aug-99	3	162	7.000			136.110	0.367	4.790	0.013
31-Aug-99	3	450	19.000			125.330	0.370	4.410	0.013
31-Aug-99	3	759	31.000			130.600	0.402	4.590	0.014
31-Aug-99	3	894	36.000			120.680	0.662	4.240	0.023
31-Aug-99	3	1922	79.000			129.500	0.387	4.550	0.014
31-Aug-99	3	2943	121.000			126.400	0.366	4.450	0.013
31-Aug-99	3	5202	215.000			128.370	0.355	4.510	0.012
31-Aug-99	3	7395	296.000			100.270	0.348	3.520	0.012
31-Aug-99	4	93	4.000			129.680	0.358	4.950	0.014
31-Aug-99	4	450	19.000			127.450	0.371	4.860	0.014
31-Aug-99	4	750	31.000			134.150	0.382	5.120	0.015
31-Aug-99	4	954	38.000			134.280	0.392	5.120	0.015
31-Aug-99	4	2022	83.000			133.580	0.421	5.100	0.016
31-Aug-99	4	2914	119.000			127.660	0.388	4.870	0.015
31-Aug-99	4	5256	217.000			127.360	0.359	4.860	0.014
31-Aug-99	4	7545	302.000			102.480	0.328	3.920	0.012
31-Aug-99	5	32	1.000			125.390	0.402	5.510	0.018
31-Aug-99	5	442	18.000			131.350	0.410	5.780	0.018
31-Aug-99	5	744	31.000			134.760	0.425	5.930	0.019
31-Aug-99	5	964	39.000			136.290	0.428	5.990	0.019
31-Aug-99	5	1976	81.000			140.790	0.435	6.190	0.019
31-Aug-99	5	3001	123.000			126.420	0.390	5.560	0.017
31-Aug-99	5	5002	206.000			122.770	0.393	5.400	0.017
31-Aug-99	5	5736	229.000			102.260	0.353	4.500	0.016
1-Sep-99	3	411		189					
1-Sep-99	3	844		189					
1-Sep-99	3	1785	72	196		148.100	0.459	4.580	0.014
1-Sep-99	3	225		200					
1-Sep-99	3	693		200					
1-Sep-99	3	3891	159	308		146.430	0.434	4.530	0.013
1-Sep-99	3	5298	214	540		134.250	0.449	4.160	0.014
1-Sep-99	3	7915	315	750		127.200	0.378	3.940	0.012
1-Sep-99	4	632		175					
1-Sep-99	4	120		183					
1-Sep-99	4	433		183					
1-Sep-99	4	953		185					
1-Sep-99	4	2156	87	200		164.710	0.511	6.200	0.019
1-Sep-99	4	3415	140	316		149.820	0.420	5.640	0.016
1-Sep-99	4	5932	240	556		153.150	0.500	5.760	0.019
1-Sep-99	4	7698	306	744		136.520	0.390	5.140	0.014
1-Sep-99	5	646		159					

TABLE D-7
EFFECTS OF AMMONIA SPIKING ON PRIMARY PRODUCTIVITY

DATE	STATION	NO_3-N µg/L	NH_3-N µg/L	PO_4 µg/L	N/P	PMAX	ALPHA	SPMAX	SALPHA
1-Sep-99	5	32		171					
1-Sep-99	5	410		171					
1-Sep-99	5	793		179					
1-Sep-99	5	1969	79	208		121.530	0.420	4.910	0.017
1-Sep-99	5	3307	136	318		120.190	0.390	4.850	0.016
1-Sep-99	5	5825	236	530		113.270	0.400	4.570	0.016
1-Sep-99	5	8257	328	768		107.340	0.340	4.340	0.014
15-Sep-99	3	69	2.000			30.920	0.169	2.120	0.012
15-Sep-99	3	491	13.000			39.940	0.154	2.740	0.011
15-Sep-99	3	765	18.000			35.950	0.164	2.970	0.011
15-Sep-99	3	995	26.000			37.100	0.164	2.540	0.011
15-Sep-99	3	2046	52.000			37.870	0.156	2.600	0.011
15-Sep-99	3	3205	85.000			36.590	0.157	2.510	0.011
15-Sep-99	3	9874	148.000			29.960	0.154	2.030	0.011
15-Sep-99	3	8271	218.000			26.380	0.101	1.810	0.007
15-Sep-99	4	187	5.000			33.130	0.171	2.360	0.012
15-Sep-99	4	471	12.000			36.900	0.147	2.650	0.011
15-Sep-99	4	750	17.000			37.960	0.170	2.690	0.012
15-Sep-99	4	973	25.000			35.550	0.231	2.550	0.017
15-Sep-99	4	1525	39.000			37.610	0.159	2.700	0.011
15-Sep-99	4	3059	81.000			36.450	0.152	2.610	0.011
15-Sep-99	4	5799	145.000			32.750	0.150	2.350	0.011
15-Sep-99	4	8417	222.000			27.770	0.104	1.960	0.008
15-Sep-99	5	42	1.000			30.980	0.160	2.680	0.014
15-Sep-99	5	481	13.000			38.290	0.159	3.310	0.014
15-Sep-99	5	750	17.000			37.870	0.171	3.270	0.015
15-Sep-99	5	1020	27.000			35.150	0.166	3.040	0.014
15-Sep-99	5	1971	51.000			35.950	0.162	3.060	0.014
15-Sep-99	5	2771	73.000			36.680	0.153	3.170	0.013
15-Sep-99	5	5978	150.000			32.660	0.141	2.820	0.012
15-Sep-99	5	8417	222.000			25.310	0.124	2.180	0.011
16-Sep-99	3	132							
16-Sep-99	3	1956	40.000				0.199	2.680	0.011
16-Sep-99	3	2011	40.000				0.178	2.390	0.010
16-Sep-99	3	5050	116.000				0.180	2.350	0.010
16-Sep-99	3	6051	128.000				0.197	2.080	0.011
16-Sep-99	4	179							
16-Sep-99	4	1956	40.000				0.192	2.960	0.013
16-Sep-99	4	2190	44.000				0.182	2.960	0.012
16-Sep-99	4	5843	135.000				0.169	2.960	0.011
16-Sep-99	4	5050	107.000				0.198	2.870	0.013
16-Sep-99	5	150							
16-Sep-99	5	1869	39.000				0.192	3.070	0.013
16-Sep-99	5	1919	38.000				0.178	2.820	0.012
16-Sep-99	5	4446	102.000				0.188	3.030	0.013

TABLE D-7
EFFECTS OF AMMONIA SPIKING ON PRIMARY PRODUCTIVITY

DATE	STATION	NO_3-N µg/L	NH_3-N µg/L	PO_4 µg/L	N/P	PMAX	ALPHA	SPMAX	SALPHA
16-Sep-99	5	8656	184.000				0.205	3.100	0.014
5-Oct-99	3	706	8.000			87.620	0.440	3.100	0.015
5-Oct-99	3	647	7.500						
5-Oct-99	3	673	7.600			88.620	0.437	3.140	0.015
5-Oct-99	3	1069	12.300			87.300	0.506	3.090	0.018
5-Oct-99	3	1319	14.500			89.120	0.424	3.150	0.015
5-Oct-99	3	2341	26.800			85.120	0.494	3.010	0.017
5-Oct-99	3	4800	54.900			74.590	0.377	2.640	0.013
5-Oct-99	3	6489	73.200			64.140	0.376	2.270	0.013
5-Oct-99	4	84	0.900			94.340	0.456	3.090	0.015
5-Oct-99	4	566	6.600			94.610	0.491	3.100	0.016
5-Oct-99	4	673	7.600			91.110	0.438	2.990	0.014
5-Oct-99	4	965	11.100			118.420	0.486	3.880	0.016
5-Oct-99	4	1966	21.600			91.900	0.341	3.010	0.011
5-Oct-99	4	2549	29.200			89.020	0.511	2.920	0.017
5-Oct-99	4	4675	53.500			78.280	0.386	2.570	0.013
5-Oct-99	4	6426	72.500			65.750	0.372	2.160	0.012
5-Oct-99	5	80	0.900			94.550	0.467	3.040	0.015
5-Oct-99	5	472	5.500			93.620	0.521	3.010	0.017
5-Oct-99	5	736	8.300			93.860	0.464	3.020	0.015
5-Oct-99	5	840	9.700			93.750	0.544	3.020	0.018
5-Oct-99	5	1549	17.000			91.910	0.448	2.950	0.014
5-Oct-99	5	2633	30.100			89.560	0.525	2.880	0.017
5-Oct-99	5	4592	52.500			80.960	0.393	2.600	0.013
5-Oct-99	5	6530	73.700			65.840	0.385	2.100	0.012

Table D-8
Average of NH3/NH4+-N µg/L at all Three Stations
From June through November 1999

	DATE											
Test Level	22-Jun-99	6-Jul-99	21-Jul-99	10-Aug-99	31-Aug-99	16-Sep-99	5-Oct-99	20-Oct-99	2-Nov-99	Average	Geometric Mean	Standard Deviation
1	225	199	140	143	96	99	290	268	165	181	170	70
2	342	449	381	475	447	481	519	425	431	439	436	53
3	673	786	627	764	751	755	694	715	713	720	718	50
4	965	980	723	966	937	996	958	895	923	927	924	82
5	1,303	1,909	1,473	1,956	1,973	1,847	1,611	1,584	1,910	1,730	1,715	243
6	2,694	3,154	2,181	3,089	2,953	3,012	2,508	2,177	2,781	2,727	2,706	370
7	2,091	2,669	3,345	4,741	5,153	7,217	4,689	3,883	4,825	4,290	4,068	1520
8	2,367	3,366	4,993	7,125	6,892	8,368	6,482	6,495	6,721	5,868	5,538	1925

Table D-9
Average of SPMAX at all Three Stations
From June through November 1999

	DATE											
Test Level	22-Jun-99	6-Jul-99	21-Jul-99	10-Aug-99	31-Aug-99	16-Sep-99	5-Oct-99	20-Oct-99	2-Nov-99	Average	Geometric Mean	Standard Deviation
1	4.55	3.71	2.98	7.38	5.08	2.39	3.08	4.13	1.66	3.88	3.60	1.69
2	3.95	3.62	2.88	8.02	5.02	2.90	3.06	3.19	1.81	3.83	3.56	1.80
3	4.75	3.85	3.13	7.33	5.21	2.98	3.05	3.36	1.86	3.95	3.71	1.61
4	4.33	4.25	3.33	7.24	5.12	2.71	3.33	3.23	2.01	3.95	3.73	1.54
5	4.34	4.25	3.33	8.02	5.28	2.79	3.04	3.31	1.97	4.04	3.77	1.78
6	3.59	3.90	3.17	8.60	4.96	2.76	2.94	2.44	1.35	3.74	3.37	2.08
7	3.22	3.62	3.94	7.86	4.92	2.40	2.60	2.50	1.12	3.58	3.20	1.93
8	2.24	3.64	3.11	5.78	3.98	1.98	2.18	2.10	0.98	2.89	2.62	1.42

Table D-10
Average of SALPHA
From June through November 1999

	DATE											
Test Level	22-Jun-99	6-Jul-99	21-Jul-99	10-Aug-99	31-Aug-99	16-Sep-99	5-Oct-99	20-Oct-99	2-Nov-99	Average	Geometric Mean	Standard Deviation
1	0.0125	0.0117	0.0097	0.0217	0.0150	0.0127	0.0150	0.0163	0.0117	0.0140	0.0137	0.0035
2	0.0120	0.0130	0.0097	0.0200	0.0150	0.0120	0.0165	0.0177	0.0123	0.0142	0.0139	0.0033
3	0.0120	0.0130	0.0097	0.0197	0.0160	0.0127	0.0147	0.0153	0.0113	0.0138	0.0136	0.0030
4	0.0120	0.0163	0.0087	0.0207	0.0190	0.0140	0.0173	0.0180	0.0127	0.0154	0.0150	0.0038
5	0.0115	0.0137	0.0100	0.0250	0.0163	0.0120	0.0133	0.0153	0.0097	0.0141	0.0136	0.0047
6	0.0105	0.0133	0.0090	0.0210	0.0150	0.0117	0.0170	0.0153	0.0093	0.0136	0.0131	0.0039
7	0.0085	0.0113	0.0103	0.0287	0.0143	0.0113	0.0130	0.0123	0.0067	0.0129	0.0120	0.0063
8	0.0060	0.0103	0.0097	0.0177	0.0133	0.0087	0.0123	0.0113	0.0063	0.0106	0.0101	0.0036

Table D-11
Average of NH3/NH4+-N µg/L In 1999
At Three Sample Stations

	STATION			
Test Level	3	4	5	Average
1	287	145	96	179
2	474	424	423	440
3	755	719	686	722
4	949	930	894	925
5	1821	1641	1780	1746
6	2694	2757	2736	2729
7	4526	4273	4320	4375
8	5923	5995	6101	6002

Table D-12
Average of SPMAX in 1999
At Three Sample Stations

	STATION			
Test Level	3	4	5	Grand Total
1	3.76	3.94	3.88	3.86
2	3.70	4.02	3.82	3.85
3	3.89	3.95	3.91	3.92
4	3.68	4.10	4.04	3.94
5	3.91	4.11	4.06	4.02
6	3.63	3.79	3.84	3.75
7	3.41	3.64	3.74	3.59
8	2.77	2.90	3.09	2.91

Table D-13
Average of SALPHA
At Three Sample Stations

	STATION			
Test Level	3	4	5	Grand Total
1	0.0138	0.0139	0.0146	0.0141
2	0.0134	0.0140	0.0154	0.0142
3	0.0130	0.0138	0.0150	0.0139
4	0.0153	0.0158	0.0155	0.0155
5	0.0136	0.0141	0.0150	0.0142
6	0.0144	0.0124	0.0143	0.0137
7	0.0127	0.0131	0.0136	0.0131
8	0.0103	0.0107	0.0115	0.0108

Table D-14

Statistical Significance Tests for Figure 6-4

a) Figure 6-4 a

NOTE Gradient is significant for t and P test

SUMMARY OUTPUT

Regression Statistics	
Multiple R	*0.296144579*
R Square	*0.087701612*
Adjusted R Square	*0.083251376*
Standard Error	*22.75475414*
Observations	*207*

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	*1*	*10203.96176*	*10203.96*	*19.70718201*	*1.47385E-05*
Residual	*205*	*106144.6614*	*517.7788*		
Total	*206*	*116348.6231*			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	*1.155811077*	*2.241280223*	*0.515692*	*0.606625004*	*-3.263102871*	*5.574725026*	*-3.263102871*	*5.574725026*
X Variable 1	***-3.282238833***	*0.739363344*	*-4.43928*	***1.47385E-05***	*-4.739969536*	*-1.82450813*	***-4.739969536***	***-1.82450813***

b) Figure 6-4 b

NOTE Gradient is significant for t and P test

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.159667357
R Square	0.025493665
Adjusted R Square	0.017634743
Standard Error	34.66154437
Observations	126

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	3897.31141	3897.311	3.243913692	0.074119474
Residual	124	148976.4096	1201.423		
Total	125	152873.721			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	7.437375334	4.763733706	1.561249	0.12101358	-1.99138156	16.86613223	-1.99138156	16.86613223
X Variable 1	-2.494082591	1.384765342	-1.801087	0.074119474	-5.234919207	0.246754024	-5.234919207	0.246754024

Table D-15

Statistical Significance Tests for Figure 6-5

Figure 6-5 a *NOTE Gradient is significant for t and P test*

SUMMARY OUTPUT

Regression Statistics	
Multiple R	*0.402783271*
R Square	*0.162234363*
Adjusted R Square	*0.158147701*
Standard Error	*16.8646621*
Observations	*207*

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	*1*	*11290.92323*	*11290.92*	*39.69850632*	*1.77946E-09*
Residual	*205*	*58305.44968*	*284.4168*		
Total	*206*	*69596.37292*			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	*4.678780682*	*1.66112248*	*2.816638*	*0.005327166*	*1.403707257*	*7.953854107*	*1.403707257*	*7.953854107*
X Variable 1	*-3.452633623*	*0.547978365*	*-6.30068*	*1.77946E-09*	*-4.5330292*	*-2.372238046*	*-4.5330292*	*-2.372238046*

Figure 6-5 b *NOTE Gradient is significant for t and P test*

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.308219895
R Square	0.094999504
Adjusted R Square	0.087701113
Standard Error	27.00320029
Observations	126

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	9491.277691	9491.278	13.01649946	0.000446152
Residual	124	90417.43038	729.1728		
Total	125	99908.70807			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	17.75149768	3.711203806	4.783218	4.80505E-06	10.40599085	25.09700451	10.40599085	25.09700451
X Variable 1	-3.892159385	1.0788064	-3.607839	0.000446152	-6.027417968	-1.756900803	-6.027417968	-1.756900803

Table D-16

Statistical Significance Tests for Figure 6-6

Figure 6-6 a NOTE Gradient is significant for t and P test

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.87002066
R Square	0.756935948
Adjusted R Square	0.745361469
Standard Error	6.194473741
Observations	23

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	2509.380535	2509.381	65.39698	6.92338E-08
Residual	21	805.8016034	38.3715		
Total	22	3315.182139			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	5.328501664	1.90279192	2.80036	0.010721	1.371428557	9.285574771	1.371428557	9.285574771
X Variable 1	**-4.928292273**	0.609421272	-8.08684	6.92E-08	**-6.195653408**	**-3.660931138**	**-6.195653408**	**-3.660931138**

Figure 6-6 b NOTE Gradient is significant for t and P test

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.814182779
R Square	0.662893597
Adjusted R Square	0.647570579
Standard Error	6.463679714
Observations	24

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	1807.420317	1807.42	43.26129	1.29335E-06
Residual	22	919.1414199	41.77916		
Total	23	2726.561737			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-1.123929037	1.971249783	-0.570161	0.574346	-5.21205526	2.964197186	-5.21205526	2.964197186
X Variable 1	**-3.78945197**	0.576138179	-6.577332	1.29E-06	**-4.984290704**	**-2.594613235**	**-4.984290704**	**-2.594613235**

Table D-17

Statistical Significance Tests for Figure 6-7

Figure 6-7 a *NOTE Gradient is significant for t and P test*

SUMMARY OUTPUT

Regression Statistics	
Multiple R	*0.606977085*
R Square	*0.368421182*
Adjusted R Square	*0.338346*
Standard Error	*10.8026625*
Observations	*23*

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	*1*	*1429.545379*	*1429.545*	*12.25000682*	*0.002132342*
Residual	*21*	*2450.647858*	*116.6975*		
Total	*22*	*3880.193237*			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	*7.368964944*	*3.318315611*	*2.220694*	*0.037505474*	*0.468148662*	*14.26978123*	*0.468148662*	*14.26978123*
X Variable 1	***-3.719736415***	*1.062781537*	*-3.5*	*0.002132342*	***-5.929911997***	***-1.509560833***	***-5.929911997***	***-1.509560833***

Figure 6-7 b *NOTE Gradient is significant for t and P test*

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.776988933
R Square	0.603711801
Adjusted R Square	0.585698701
Standard Error	7.593550912
Observations	24

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	1932.551272	1932.551	33.51515304	7.98526E-06
Residual	22	1268.56434	57.66202		
Total	23	3201.115612			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0.528110884	2.315830339	0.228044	0.82171833	-4.274632442	5.330854209	-4.274632442	5.330854209
X Variable 1	**-3.918432226**	0.676848913	-5.789227	7.98526E-06	**-5.322132465**	**-2.514731987**	**-5.322132465**	**-2.514731987**

APPENDIX E

CALIBRATION OF WIN/WASP+ MODEL

E.1 THE WIN/WASP+ MODEL

WIN/WASP+ is an enhanced Windows version of the US EPA Water-Quality Analysis Simulation Program (WASP5), which is a dynamic water-quality model for lakes, rivers and reservoirs. This Windows version, developed and distributed by ASCII Corporation of the United States, has the same algorithms as the DOS-based WASP5. These algorithms provide a generalized framework for modelling contaminate fate and transport in surface water, using a flexible compartmental modelling approach that can be applied in 1, 2 or 3-dimensions. The model can be used to study surface-water quality including BOD, DO-dynamics, nutrients and eutrification (algal productivity), bacterial contamination and organic and heavy-metal contamination. WIN/WASP+ has features including a pre-processor, a rapid data-processor, and a graphical post-processor that enables the model to be run more quickly and easily to evaluate results both numerically and graphically through comparison of simulation results with field data.

To model water quality in the Red and Assiniboine rivers, the rivers were broken into segments as indicated in Table E-1. Within each segment, the model calculates transport of chemicals from one segment to the next and interactions between chemicals and algae within each segment. Figure 10-1 illustrates the state variables and processes in the eutrification module of WIN/WASP+. As indicated in Figure 10-1, the model calculates the concentrations of each of the parameters illustrated in the figure. The model does not estimate changes in pH and this must be done outside the model using relationships developed in this study. The model was calibrated to 1988 conditions as shown in the figures and tables in this Apendix.

E.2 CALIBRATION ASSUMPTIONS AND OBSERVATIONS

The following are assumptions and observations made during the calibration of the WASP model for the Red and Assiniboine rivers:

- the period of calibration was June 1, 1988 to October 31, 1988, during which it was assumed the St. Andrews Lock and Dam was in operation;

Table E-1
WASP MODEL STRUCTURE

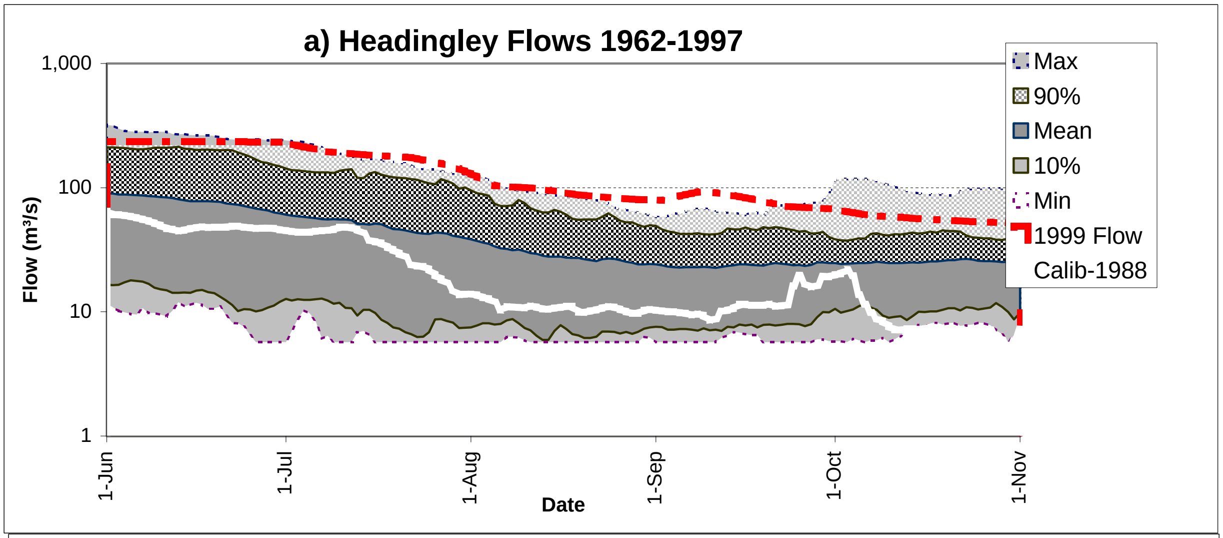
Segment	End Kilometre from Sugar Island	Starte Kilometre from Sugar Island	Key Locations	Exact Location From Lake Winnipeg Kilometres	End Kilometres from LW	Start Kilometres from LW	Sement Length (Km)	Volume in m^3
RED RIVER								
1	0.00	0.50			28.6	29.1	0.5	708,755
1b	0.50	1.00			29.1	29.6	0.5	751,454
2	1.00	1.75			29.6	30.3	0.8	794,154
2b	1.75	2.50			30.3	31.1	0.8	726,255
3	2.50	3.25			31.1	31.8	0.8	658,355
3b	3.25	4.00			31.8	32.6	0.8	721,198
4	4.00	5.00			32.6	33.6	1.0	784,041
4b	5.00	6.00			33.6	34.6	1.0	840,703
5	6.00	7.00			34.6	35.6	1.0	897,364
5b	7.00	8.00			35.6	36.6	1.0	846,120
6	8.00	9.00			36.6	37.6	1.0	794,875
6b	9.00	10.00			37.6	38.6	1.0	821,855
7	10.00	11.50			38.6	40.1	1.5	848,834
7b	11.50	13.00			40.1	41.6	1.5	859,891
8	13.00	14.25			41.6	42.8	1.3	870,948
8b	**14.25**	**15.50**	**Lockport (14.915 Km)**	**43.5**	**42.8**	**44.1**	**1.3**	777,441
9	15.50	16.25			44.1	44.8	0.8	683,934
9b	16.25	17.00			44.8	45.6	0.8	720,197
10	17.00	17.75			45.6	46.3	0.8	756,460
10b	17.75	18.50			46.3	47.1	0.8	785,438
11	18.50	19.50			47.1	48.1	1.0	814,415
11b	19.50	20.50			48.1	49.1	1.0	855,536
12	20.50	21.75			49.1	50.3	1.3	896,657
12b	21.75	23.00			50.3	51.6	1.3	876,210
13	23.00	24.25			51.6	52.8	1.3	855,763
13b	24.25	25.50			52.8	54.1	1.3	810,391
14	25.50	26.75			54.1	55.3	1.3	765,018
14b	26.75	28.00			55.3	56.6	1.3	779,512
15	28.00	29.25			56.6	57.8	1.3	794,005
15b	29.25	30.50			57.8	59.1	1.3	762,575
16	30.50	31.50			59.1	60.1	1.0	731,145
16b	31.50	32.50			60.1	61.1	1.0	765,713
17	**32.50**	**33.50**	**North Perimeter Bridge (33.31 Km)**	**61.9**	**61.1**	**62.1**	**1.0**	800,280
17b	33.50	34.50			62.1	63.1	1.0	772,521
18	34.50	35.50			63.1	64.1	1.0	744,762
18b	35.50	36.50			64.1	65.1	1.0	784,527
19	**36.50**	**37.50**	**NEWPCC (36.75 Km)**	**65.3**	**65.1**	**66.1**	**1.0**	824,291
19b	37.50	38.50			66.1	67.1	1.0	748,136
20	38.50	39.50			67.1	68.1	1.0	671,981
20b	39.50	40.50			68.1	69.1	1.0	738,265
21	40.50	41.50			69.1	70.1	1.0	804,549
21b	**41.50**	**42.50**	**Redwood Bridge (41.66 Km)**	**70.3**	**70.1**	**71.1**	**1.0**	816,742
22	42.50	43.75			71.1	72.3	1.3	828,936
22b	43.75	45.00			72.3	73.6	1.3	787,733
23	45.00	46.25			73.6	74.8	1.3	746,530
23b	**46.25**	**47.50**	**Assiniboine River (47.3 Km)**	**75.9**	**74.8**	**76.1**	**1.3**	608,771
24	**47.50**	**48.25**	**Norwood Bridge (47.59 Km)**	**76.2**	**76.1**	**76.8**	**0.8**	471,011
24b	48.25	49.00			76.8	77.6	0.8	517,919
25	49.00	50.00			77.6	78.6	1.0	564,827
25b	50.00	51.00			78.6	79.6	1.0	539,915
26	51.00	52.00			79.6	80.6	1.0	515,003
26b	52.00	53.00			80.6	81.6	1.0	512,434
27	53.00	54.00			81.6	82.6	1.0	509,866
27b	54.00	55.00			82.6	83.6	1.0	515,199
28	55.00	56.00			83.6	84.6	1.0	520,532
28b	56.00	57.00			84.6	85.6	1.0	501,435
29	57.00	58.00			85.6	86.6	1.0	482,338

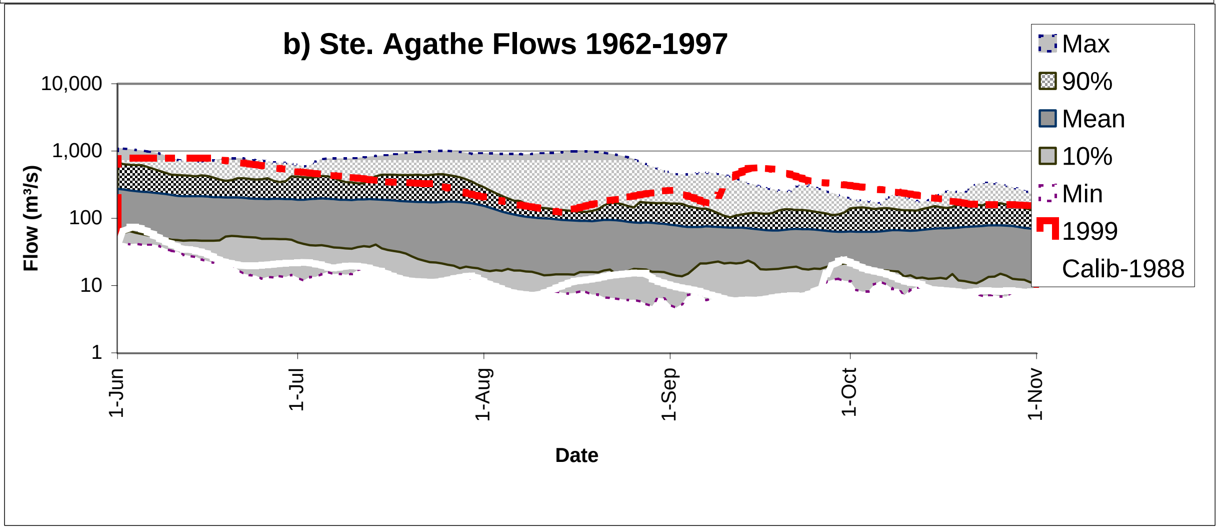
Table E-1
WASP MODEL STRUCTURE

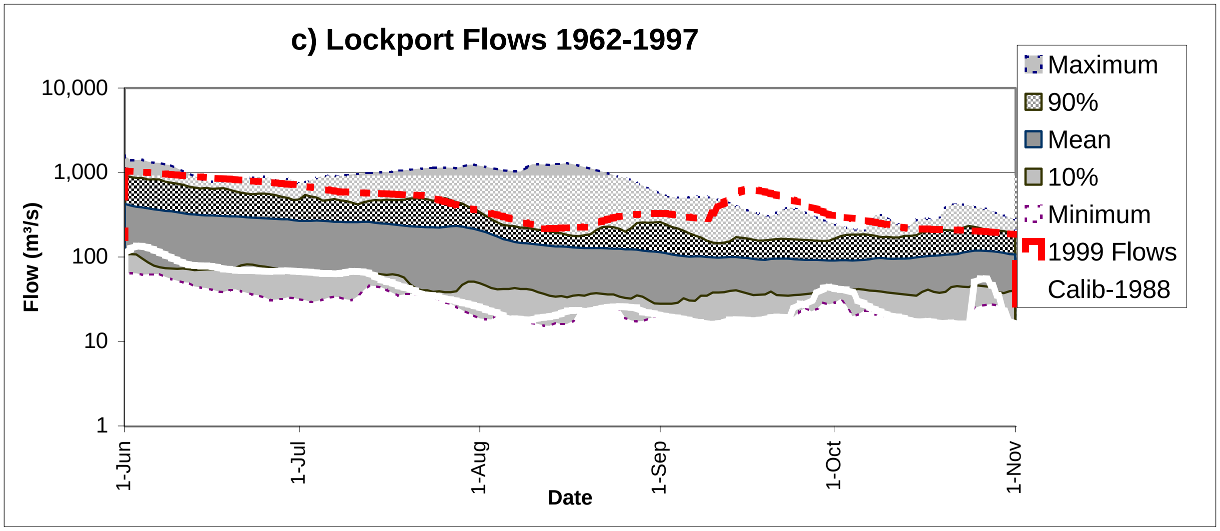
Segment	End Kilometre from Sugar Island	Starte Kilometre from Sugar Island	Key Locations	Exact Location From Lake Winnipeg Kilometres	End Kilometres from LW	Start Kilometres from LW	Sement Length (Km)	Volume in m^3
			RED RIVER					
29b	58.00	59.00			86.6	87.6	1.0	473,774
30	59.00	60.00			87.6	88.6	1.0	465,210
30b	60.00	61.00			88.6	89.6	1.0	474,003
31	**61.00**	**62.00**	**Fort Garry Bridge (62.00 Km)**	**90.6**	**89.6**	**90.6**	**1.0**	482,796
31b	62.00	63.00			90.6	91.6	1.0	471,373
32	63.00	64.00			91.6	92.6	1.0	459,950
32b	64.00	65.00			92.6	93.6	1.0	471,715
33	65.00	66.00			93.6	94.6	1.0	483,480
33b	66.00	67.00			94.6	95.6	1.0	447,573
34	67.00	68.00			95.6	96.6	1.0	411,665
34b	**68.00**	**69.00**	**SEWPCC (68.47 Km) b**	**97.1**	**96.6**	**97.6**	**1.0**	442,506
35	69.00	70.00			97.6	98.6	1.0	473,346
35b	70.00	71.00			98.6	99.6	1.0	461,231
36	71.00	72.00			99.6	100.6	1.0	449,115
36b	72.00	73.00			100.6	101.6	1.0	428,715
37	73.00	74.00			101.6	102.6	1.0	408,316
37b	74.00	75.00			102.6	103.6	1.0	447,235
38	75.00	76.00			103.6	104.6	1.0	486,155
38b	76.00	77.00			104.6	105.6	1.0	466,559
39	**77.00**	**78.00**	**Floodway control (77.76 Km)**	**106.4**	**105.6**	**106.6**	**1.0**	446,962
39b	78.00	79.00			106.6	107.6	1.0	447,020
40	79.00	80.00			107.6	108.6	1.0	447,078
40b	80.00	81.00			108.6	109.6	1.0	451,970
41	81.00	82.00			109.6	110.6	1.0	456,862
41b	82.00	83.00			110.6	111.6	1.0	448,240
42	83.00	84.00			111.6	112.6	1.0	439,618
42b	84.00	85.00			112.6	113.6	1.0	433,356
43	85.00	85.63			113.6	114.2	0.6	427,095
43b	85.63	86.25			114.2	114.8	0.6	423,411
44	86.25	87.13			114.8	115.7	0.9	419,727
44b	87.13	88.00			115.7	116.6	0.9	451,579
45	88.00	89.00			116.6	117.6	1.0	483,431
45b	89.00	90.00			117.6	118.6	1.0	458,589
46	90.00	91.00			118.6	119.6	1.0	433,746
46b	91.00	92.00			119.6	120.6	1.0	474,671
47	92.00	93.00			120.6	121.6	1.0	515,595
47b	93.00	94.00			121.6	122.6	1.0	579,432
48	94.00	95.50			122.6	124.1	1.5	643,270
48b	**95.50**	**97.00**	**St. Adolphe (96.3)**	**124.9**	**124.1**	**125.6**	**1.5**	643,270

Segment	End Kilometre from Forks	Start Kilometre from Forks	Key Locations	Exact Location Kilometres from LW	End KM from LW	Start KM from LW	Sement Length (Km)	Volume in m^3
			ASSINIBOINE RIVER					
49	**0.00**	**1.25**	**Main Street Bridge (0.31 Km)**	**76.2**	**75.9**	**77.1**	**1.25**	**189,128**
49b	1.25	2.50			77.1	78.4	1.25	188,571
50	2.50	3.75			78.4	79.6	1.25	188,014
50b	3.75	5.00			79.6	80.9	1.25	183,126
51	5.00	6.75			80.9	82.6	1.75	178,238
51b	6.75	8.50			82.6	84.4	1.75	185,166
52	8.50	10.75			84.4	86.6	2.25	192,094
52b	10.75	13.00			86.6	88.9	2.25	191,703
53	13.00	14.75			88.9	90.6	1.75	191,312
53b	14.75	16.50			90.6	92.4	1.75	195,554
54	**16.50**	**18.75**	**West Perimeter Bridge (18.39 Km)**	**94.3**	**92.4**	**94.6**	**2.25**	**199,796**
54b	**18.75**	**21.00**	**WEWPCC (19.87 Km)**	**95.8**	**94.6**	**96.9**	**2.25**	**186,290**
55	21.00	22.38			96.9	98.3	1.375	172,784
55b	22.38	23.75			98.3	99.6	1.375	175,328
56	23.75	24.88			99.6	100.8	1.125	177,873
56b	**24.88**	**26.00**	**Headingley Bridge (25.61 Km)**	**101.5**	**100.8**	**101.9**	**1.125**	**88,936**

- the bathymetric information was based on 1951 hydrographic survey data for the Red and Assiniboine rivers conducted by the Department of Resources and Development of Canada;
- stream flow;
  - the historic stream flow data was obtained by gauging stations at Headingley on the Assiniboine River, St. Agathe on the Red River, and Lockport on the Red River;
  - Assiniboine River flows at Headingley were below average, but generally above the 10th percentile none exceedance flow for the corresponding period of the year (see Figure E-1);
  - Red River flows at St. Agathe and Lockport were typically below the 10th percentile for flows for the corresponding period of the year (see Figure E-1).
- hydraulic relationships;
  - flow versus velocity and flow versus depth relationships were developed on MIKE11 hydraulic simulations and were described in Section 2 of the main Technical Memorandum;
  - flow velocities correspond to the following time of travel through the model section of the river system (i.e., St. Agathe and Headingley to Selkirk);
    - minimum of about 8 days during early June when the stream flow was high;
    - maximum of 78 days during mid-September when the stream flow was very low.
- loads from the WPCCs
  - no effluent data was available for the NEWPCC in August and September (see Figure E-2);
  - no effluent data for the SEWPCC was available from September 23 to October 9;
  - when no effluent data was available, data is interpolated between the last two points;
  - nitrogen and phosphorus effluent loads are higher and more variable at the NEWPCC than at the SEWPCC and WEWPCC;
  - during June through October, 1998, approximately 80% of nitrogen load from the NEWPCC and SEWPCC was ammonia;
  - nitrogen loads from the WEWPCC comprises 40% ammonia, 40% nitrate, and 20% organic nitrogen;
  - mean nutrient loads from the three WPCCs are shown in Table E-2;
  - loads from the SEWPCC and WEWPCC had much lower N:P ratio (5.5 and 4.4 respectively) than load from the NEWPCC (16).
- light data;
  - used solar radiation data at Winnipeg Airport;

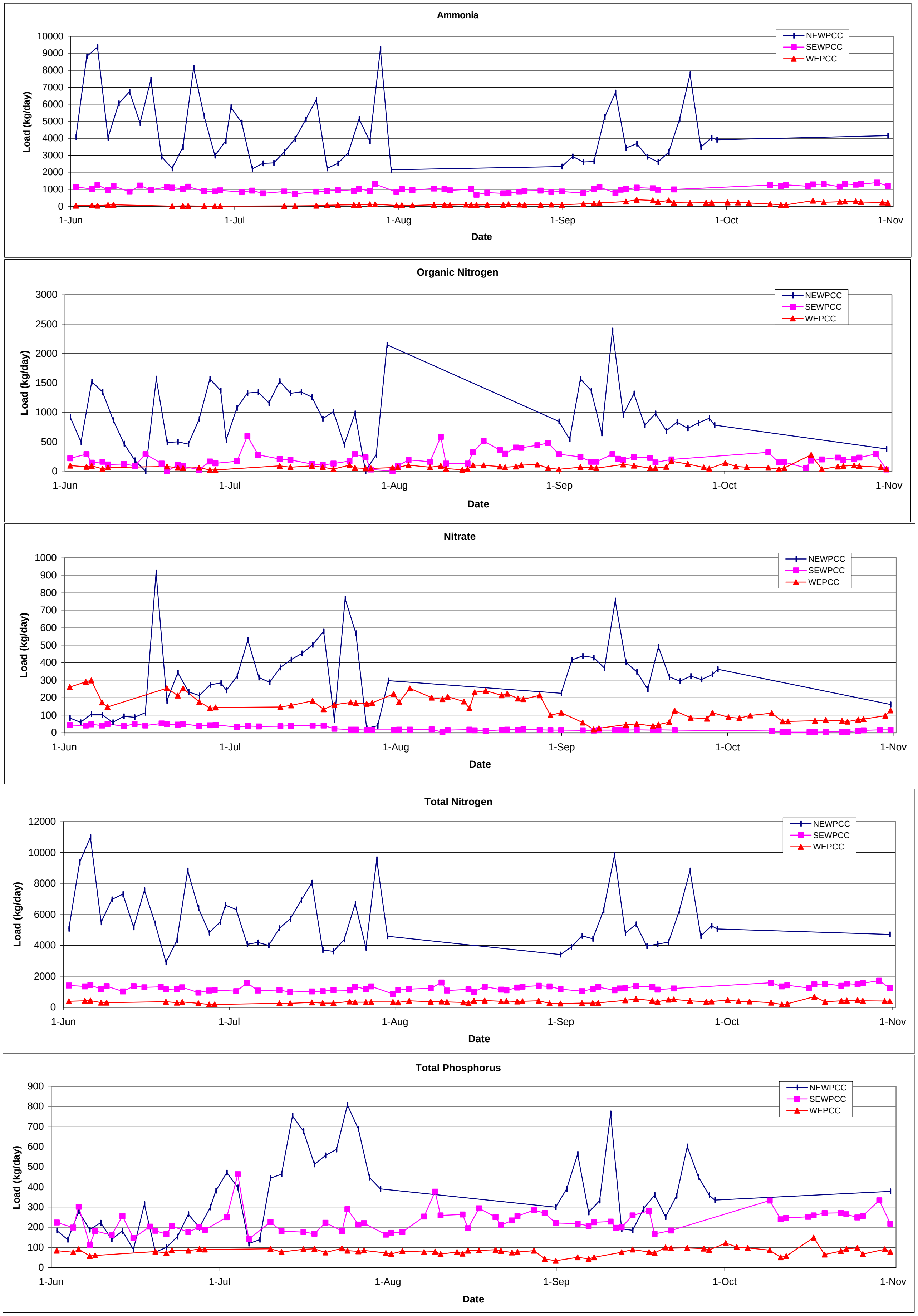

a) Headingley Flows 1962-1997


b) Ste. Agathe Flows 1962-1997


c) Lockport Flows 1962-1997

Comparison of 1988 Flows used in Calibration to Historic Flows

Figure E-1

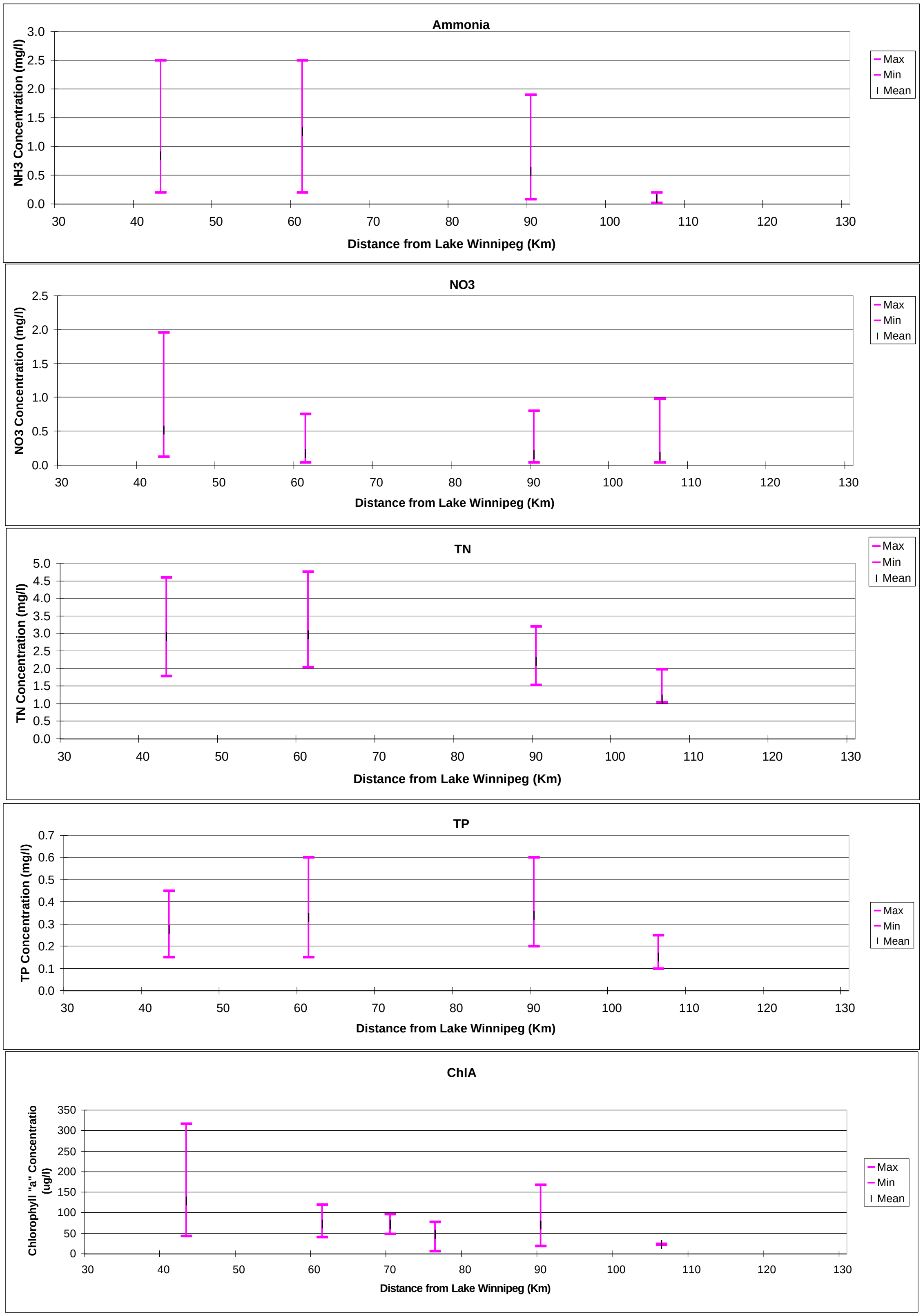


WPCC Inputs for Calibration Period
Figure E-2

Table E-2
Plant Effluent Loads during Calibration Period
(1988 June Through October)

		NEWPCC	SEWPCC	WEWPCC
Flow (m3/s)	Mean	3.042	0.622	0.228
	Stdev	0.774	0.046	0.039
TKN (Kg/day)	Mean	5372	1226	212
	Stdev	1926	183	116
NH3 (Kg/day)	Mean	4418	1017	139
	Stdev	1990	174	98
Org. N (Kg/day)	Mean	954	210	73
	Stdev	503	128	39
NO3 (Kg/day)	Mean	316	23	143
	Stdev	196	15	71
TN (Kg/day)	Mean	5688	1249	354
	Stdev	1893	179	90
TP (Kg/day)	Mean	355	229	81
	Stdev	190	58	18

  - 7-day average radiation was typically above 800 langleys/day from June to mid-August, but decreased with time to about 300 langleys/day in late October;
  - fraction of daylight hours is approximately 0.67 from June to mid-August, but decreased gradually to 0.42 by late October;
  - the light attenuation co-efficient was obtained through calibration.
- water-quality data;
  - water-quality data for comparison to the model was obtained by two sources in the City of Winnipeg Database; bi-weekly monitoring data and special surveys done in August 1988;
  - observed concentrations of ammonia, nitrate, total nitrogen, total phosphorus, and chlorophyll ‘a’ from June 1 through October 31, 1988, as shown in Figures E-3 and E-4;
  - the range of temperatures are shown on profiles (see Figure E-5) and at key stations (see Figure E-6);
  - there is significant temporal variability in water temperature, but very little variability throughout the region;
  - water temperatures typically are above 20°C from June through mid-August, but steadily decrease with time to about 5°C by late October.
- calibration results which show the model prediction versus the data are shown in a series of figures:
  - at Lockport (Figure E-7a and b);
  - at the North Perimeter Bridge (Figure E-8a and b);
  - at the Fort Garry Bridge (Figure E-9a and b); and
  - at the Main Street Bridge (Figure E-10a and b).
- longitudinal concentration profiles for specific single days do not match the observed historical concentration profiles as closely as the agreement between model and observed temporal profiles. We have shown profiles on the Red and Assiniboine rivers for one day on July 19 (see Figure E-11a and b).
- A summary of the parameters used in the calibrated WASP model is shown on Table E-3.



Range of Data for Red River Profiles
Figure E-3

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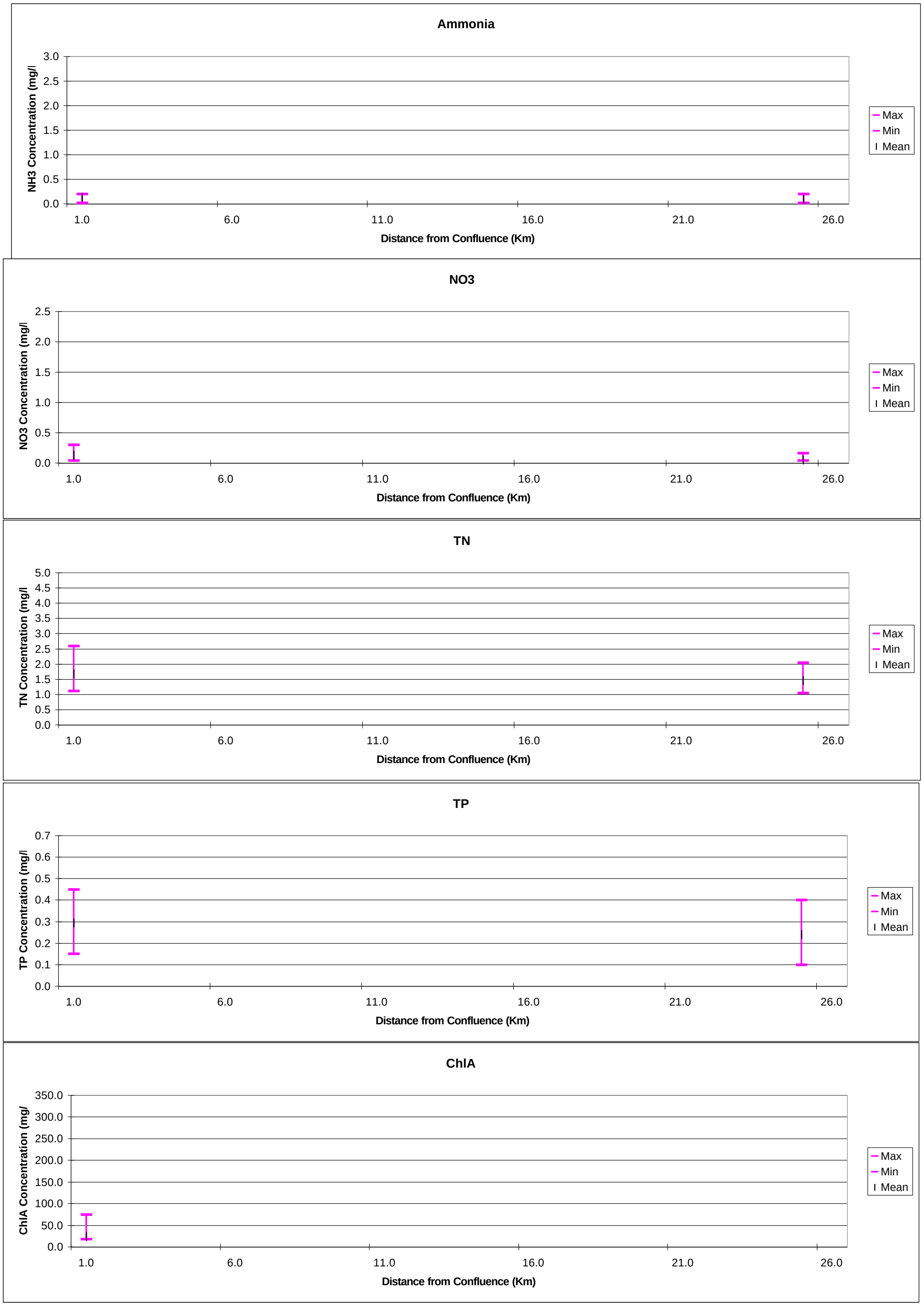
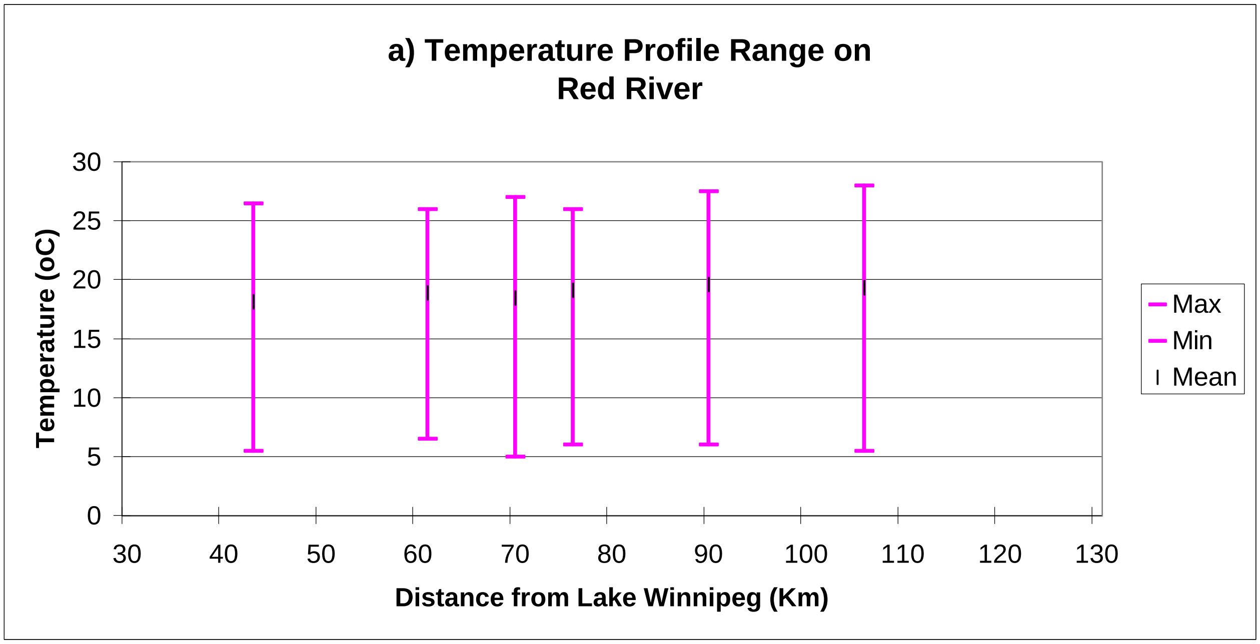
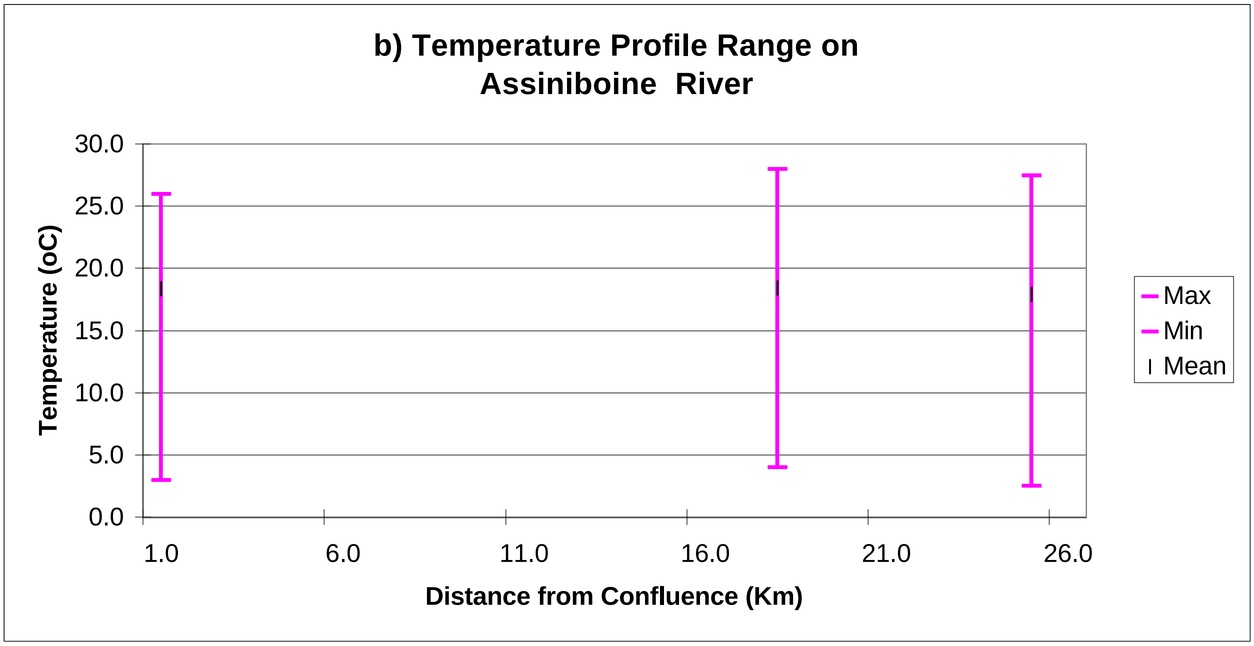


Range of Data for Assiniboine River Profiles
Figure E-4



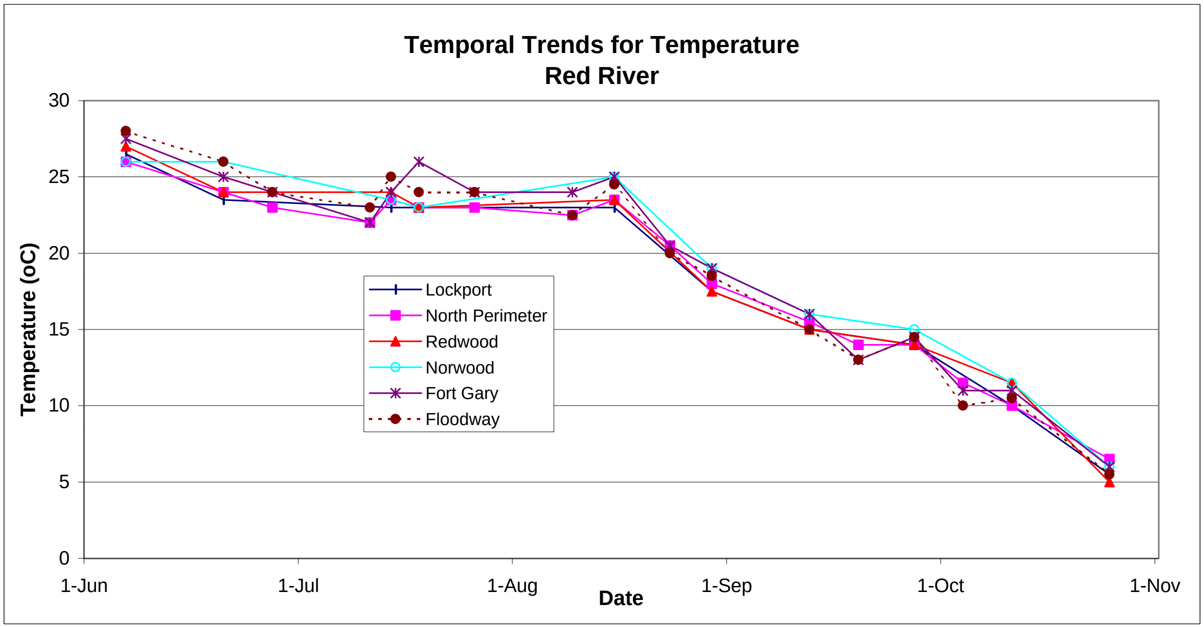
a) Temperature Profile Range on Red River

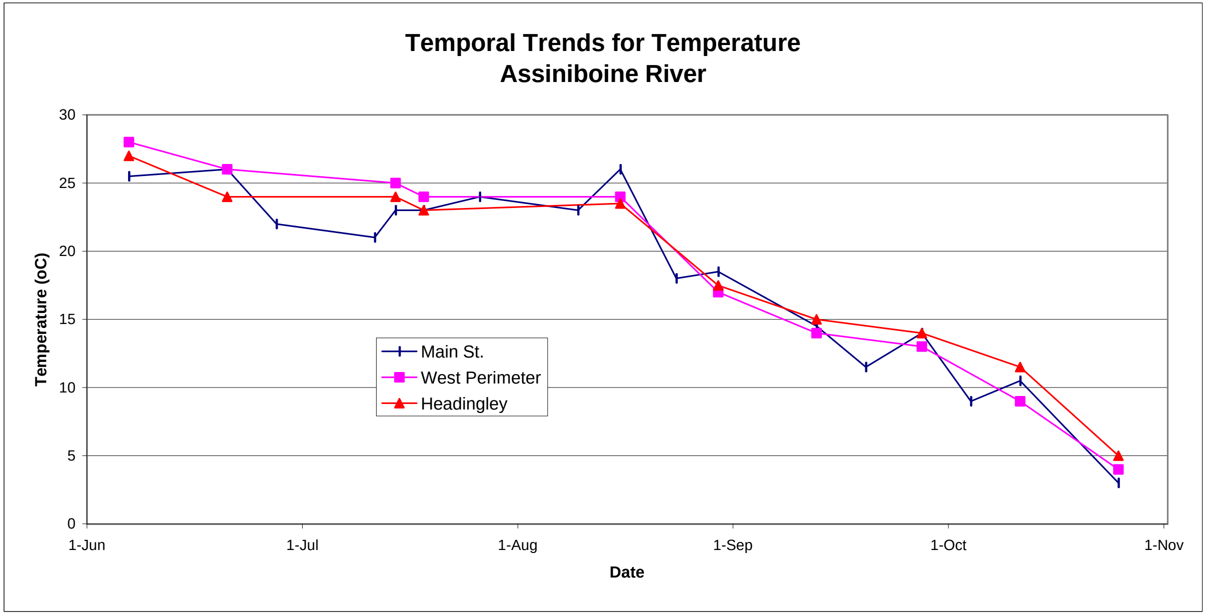


b) Temperature Profile Range on Assiniboine River

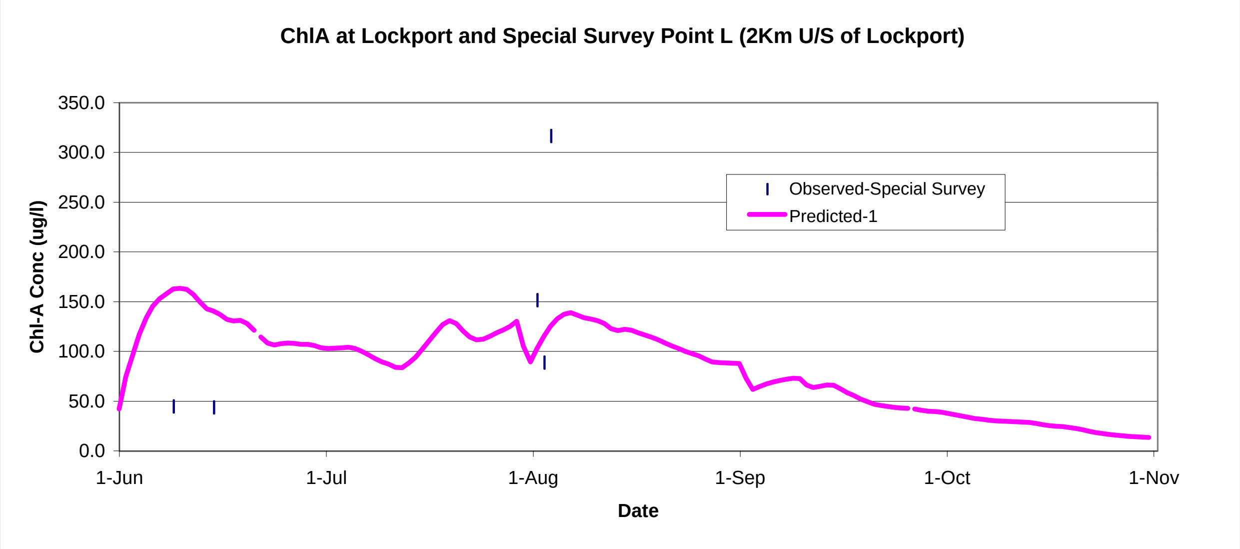
Range of Temperature for Assiniboine River Profiles

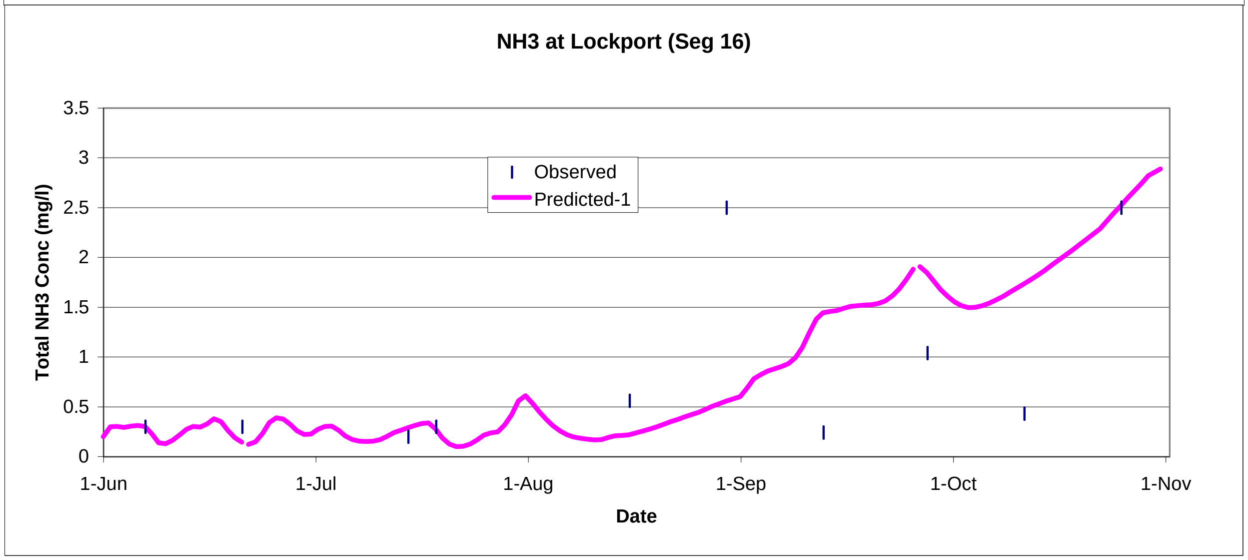
Figure E-5

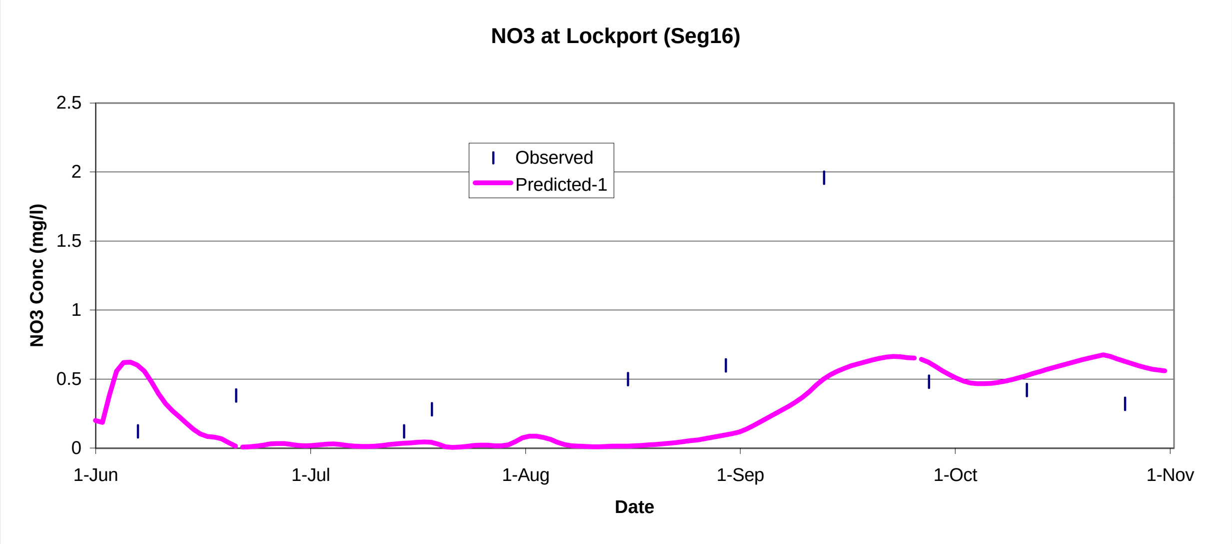




Range of Data for Assiniboine River Profiles
Figure E-6

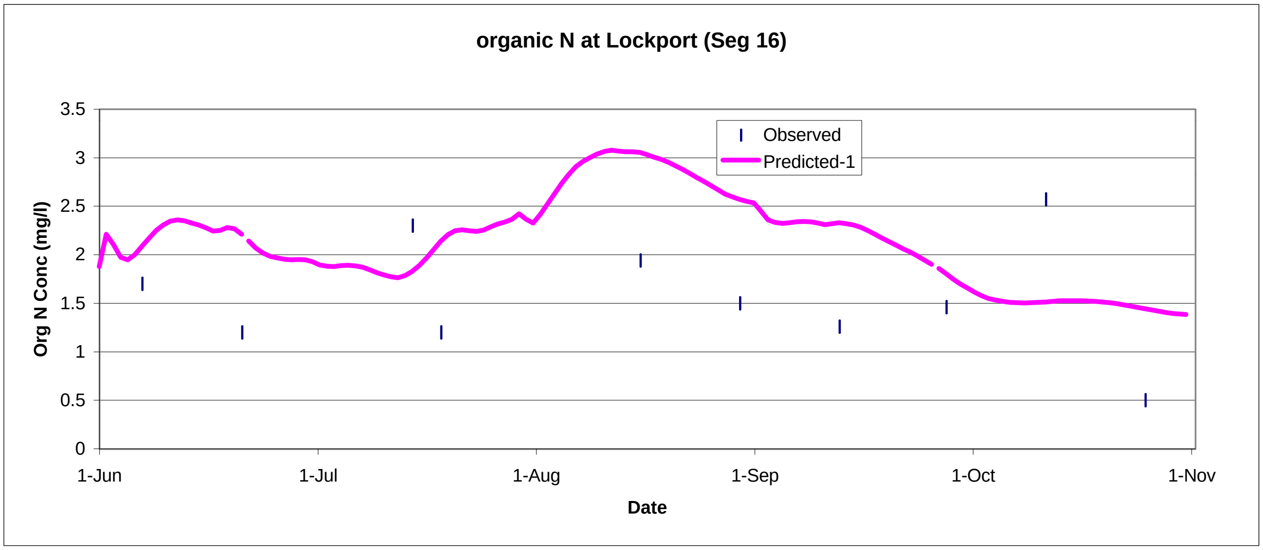


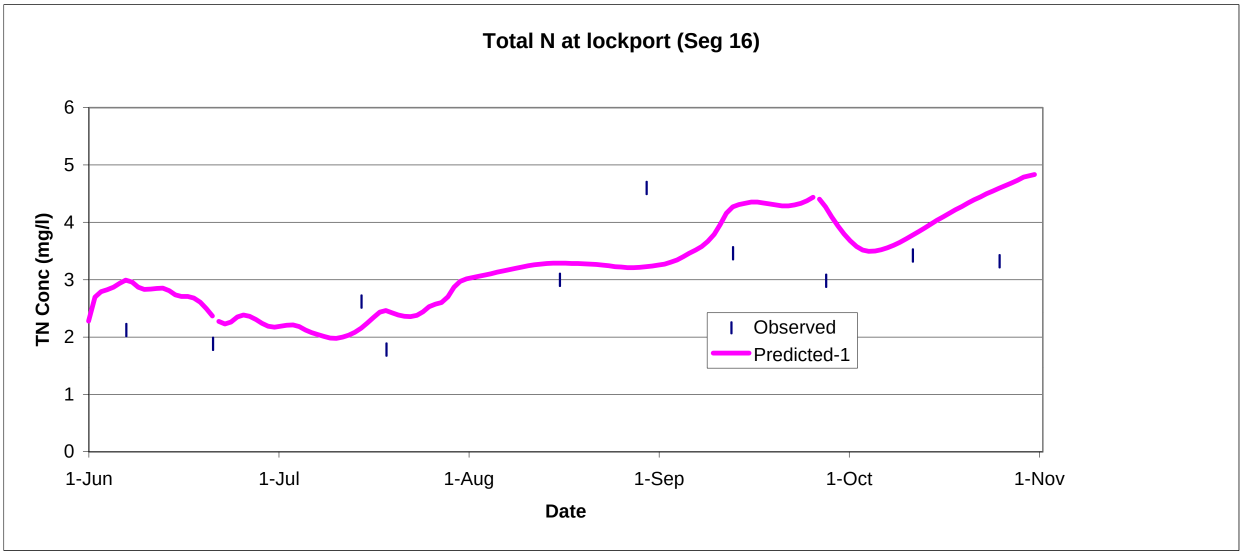


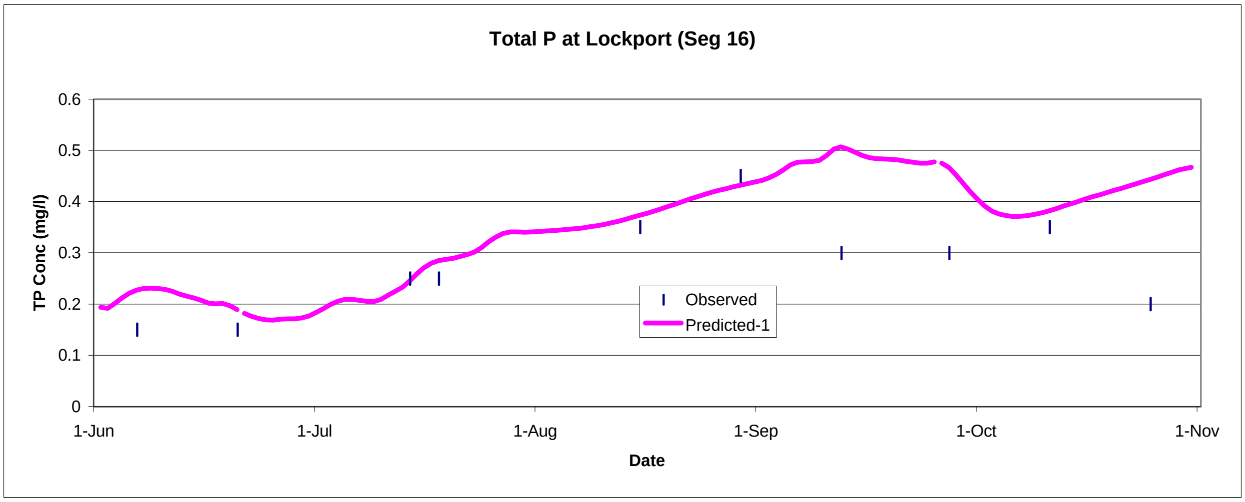


Algae and Nutrients at Lockport

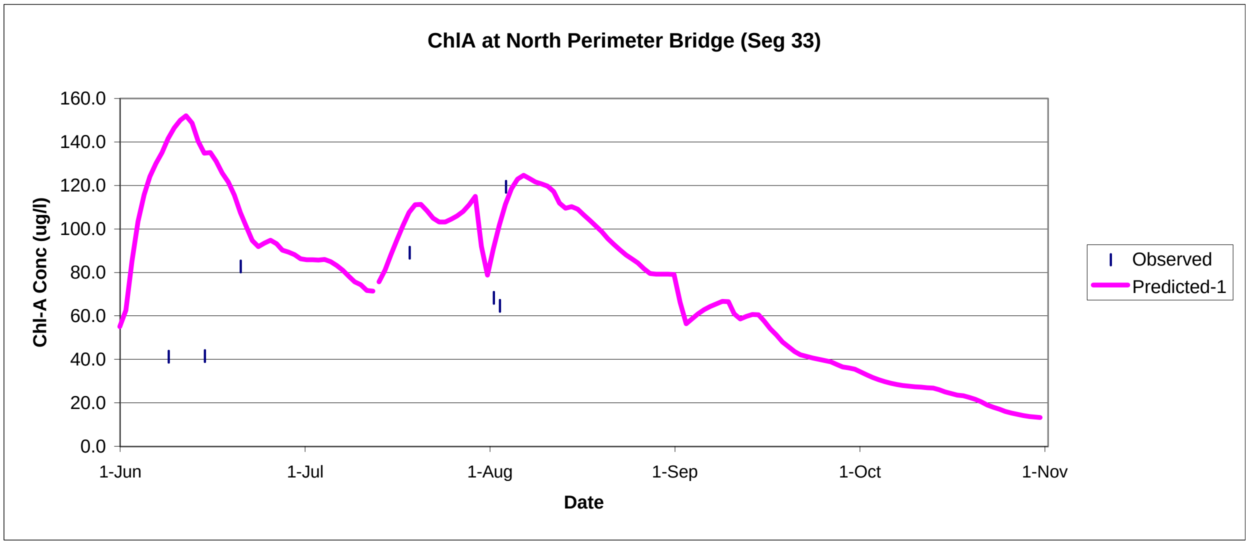
Figure E- 7a

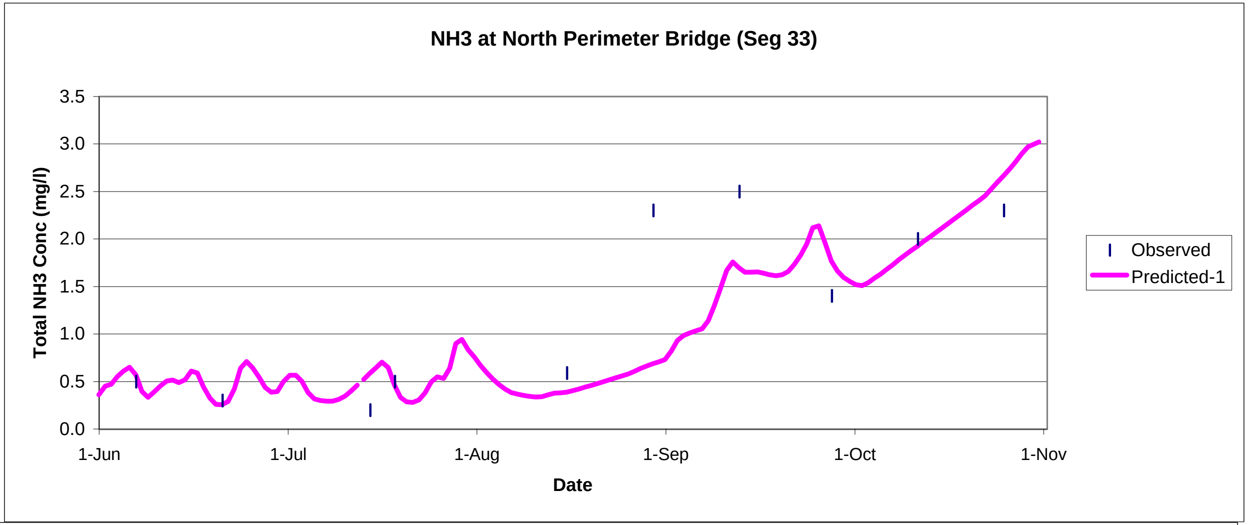


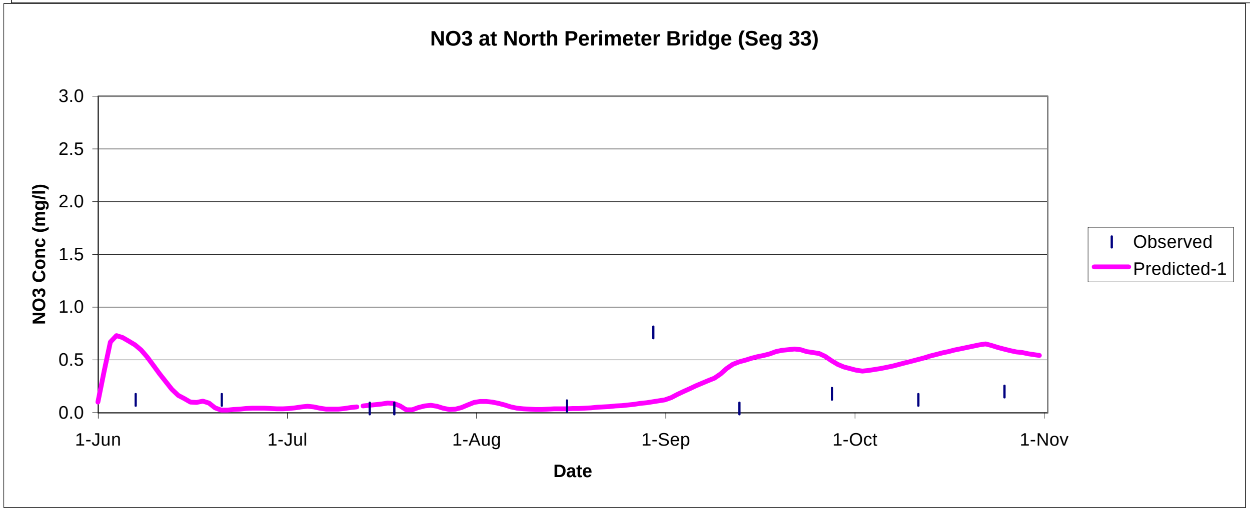




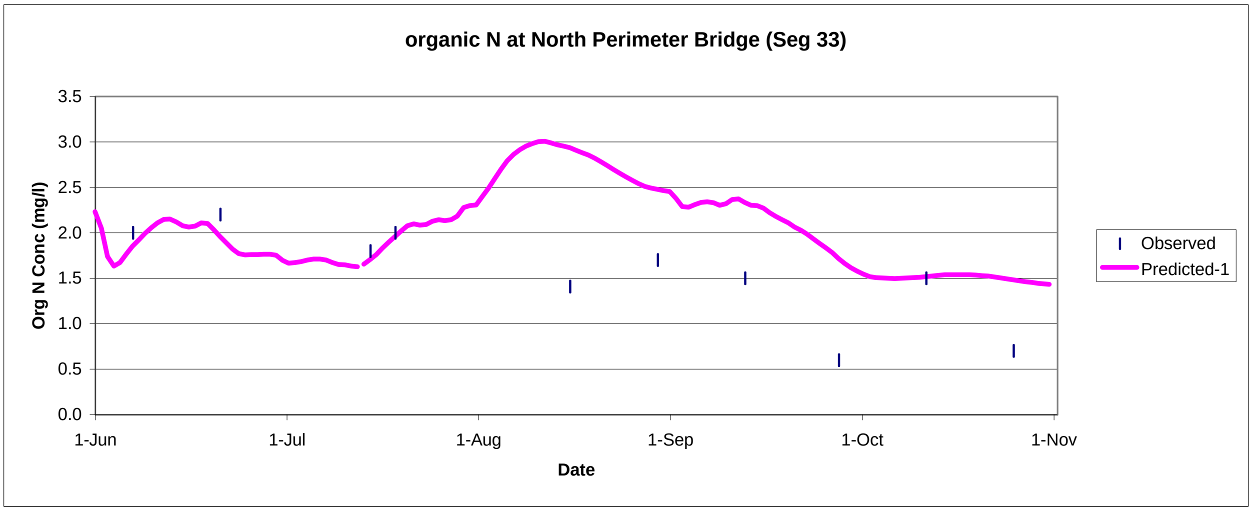
Algae and Nutrients at Lockport
Figure E- 7b

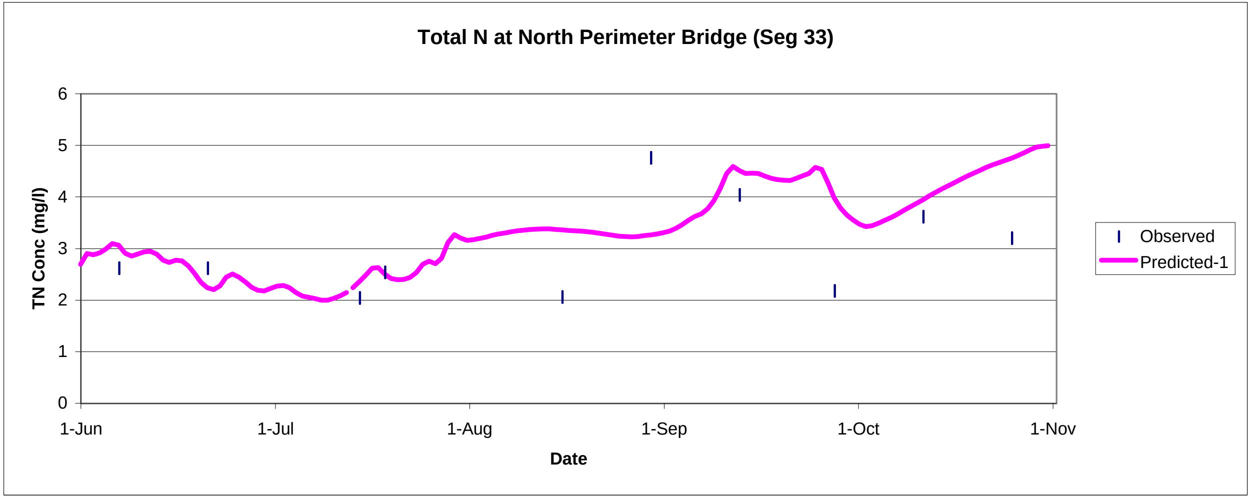


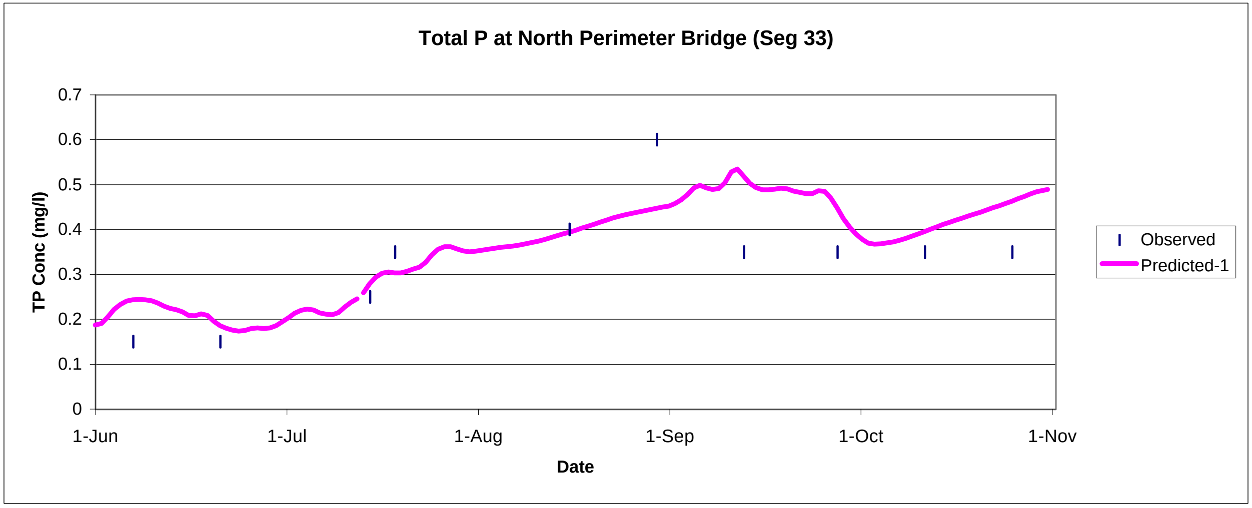




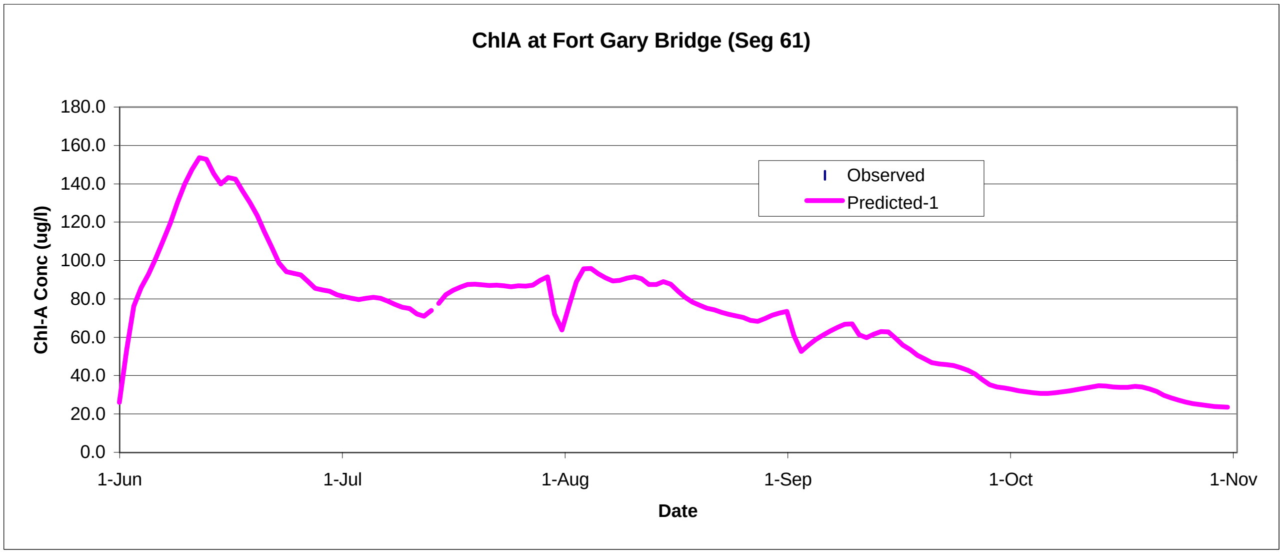
Algae and Nutrients at North Perimeter Bridge
Figure E- 8a

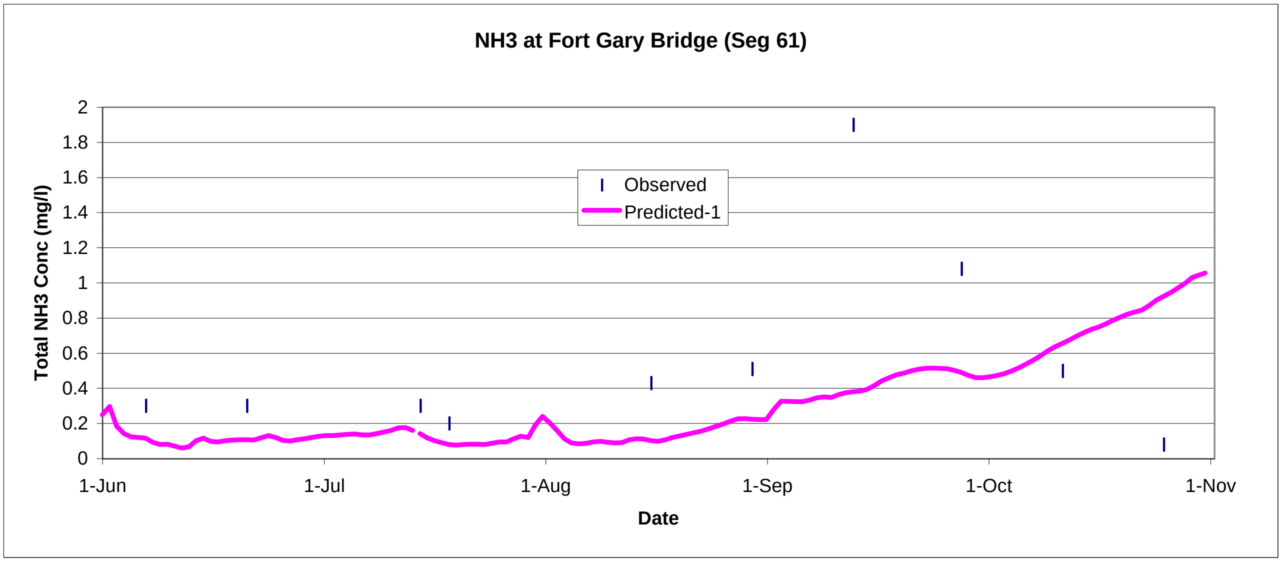


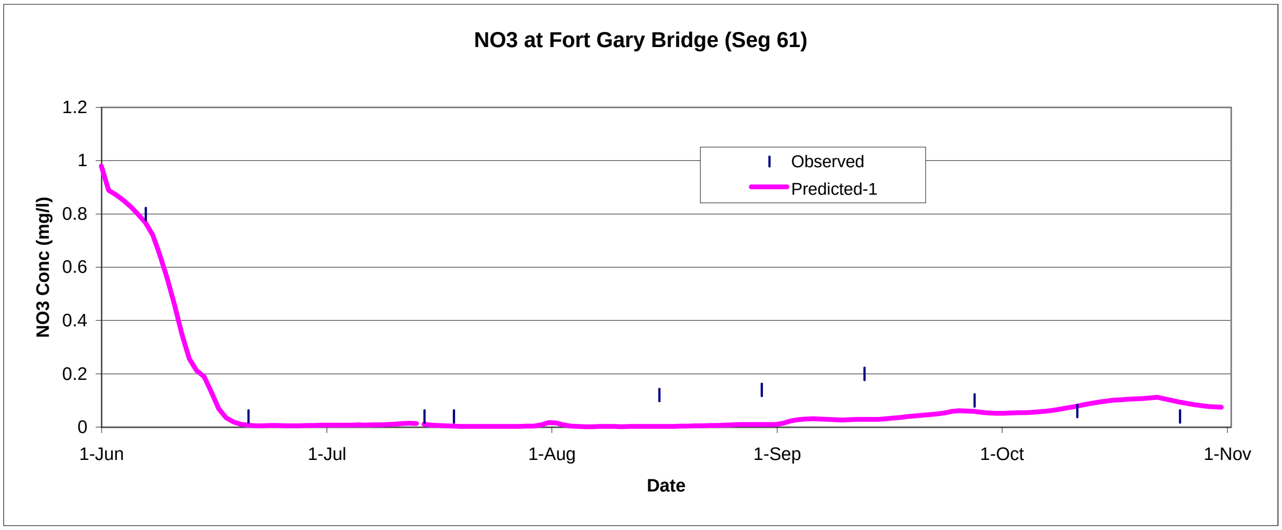




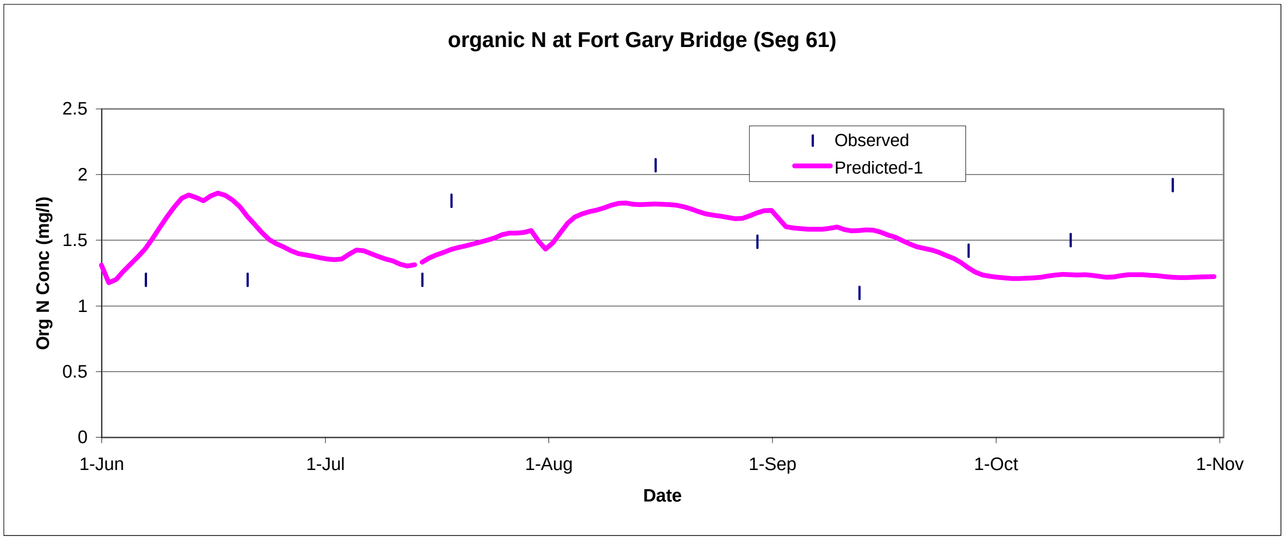
Algae and Nutrients at North Perimeter Bridge
Figure E- 8b

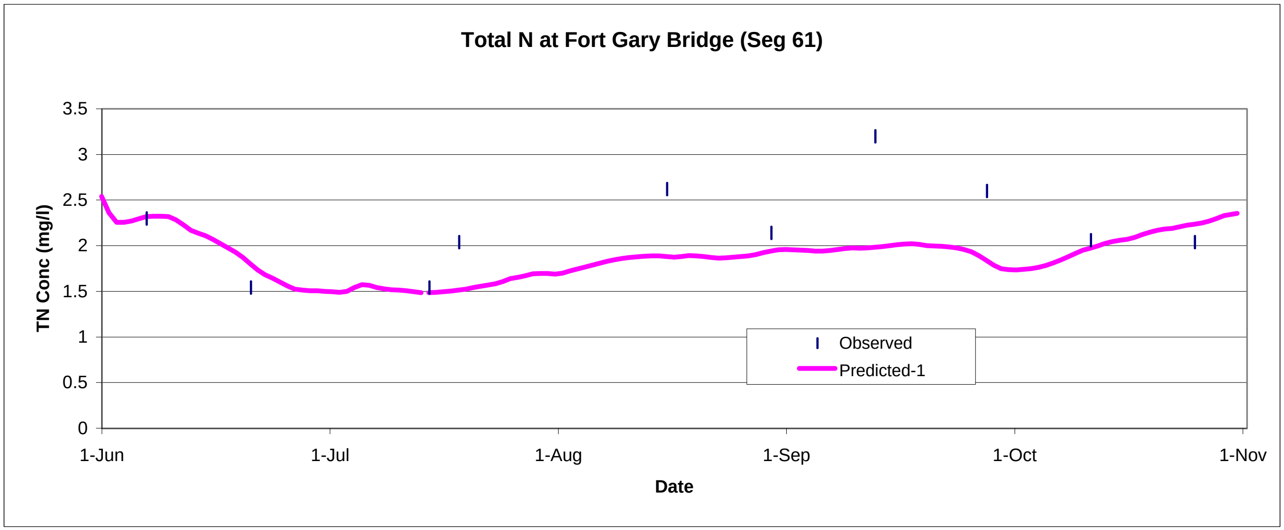


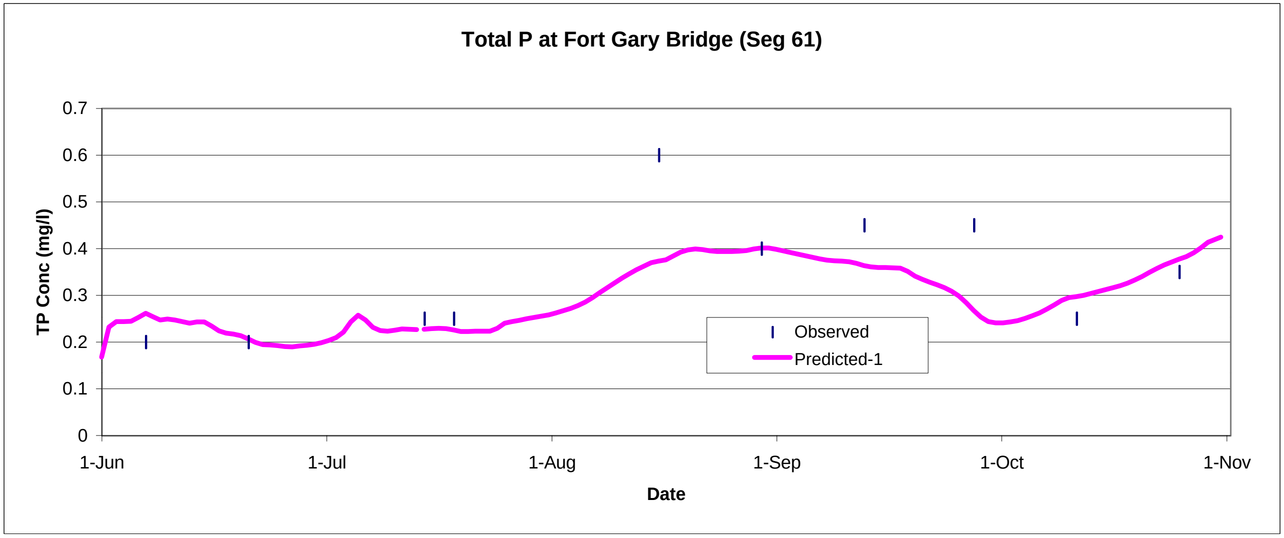




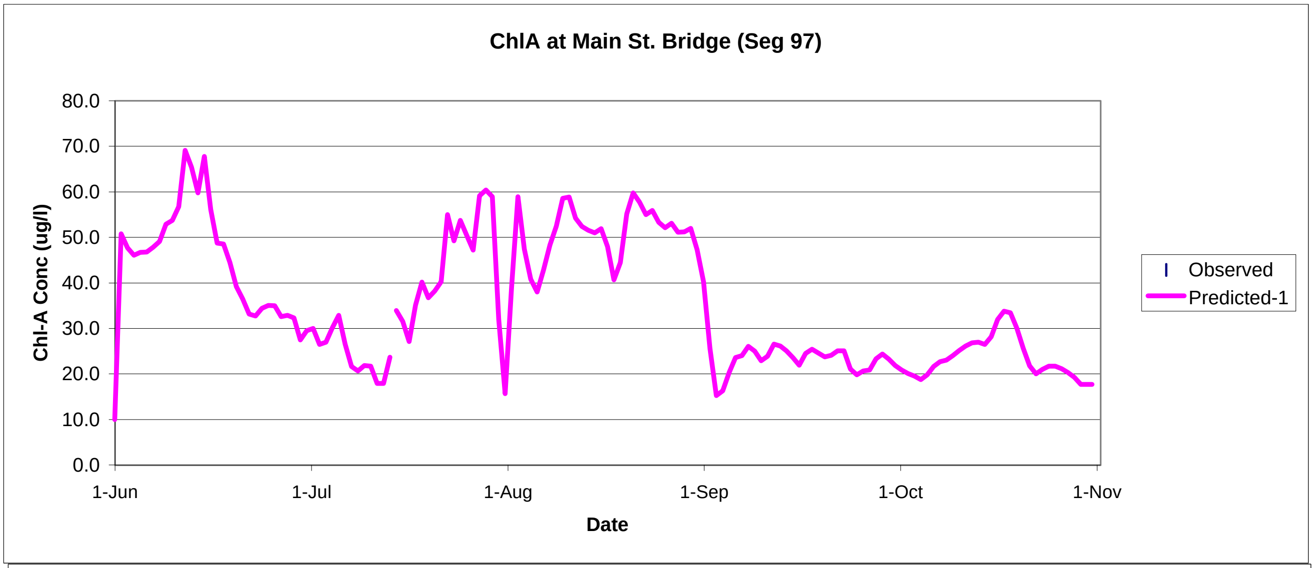
Algae and Nutrients at Fort Garry Bridge
Figure E- 9a

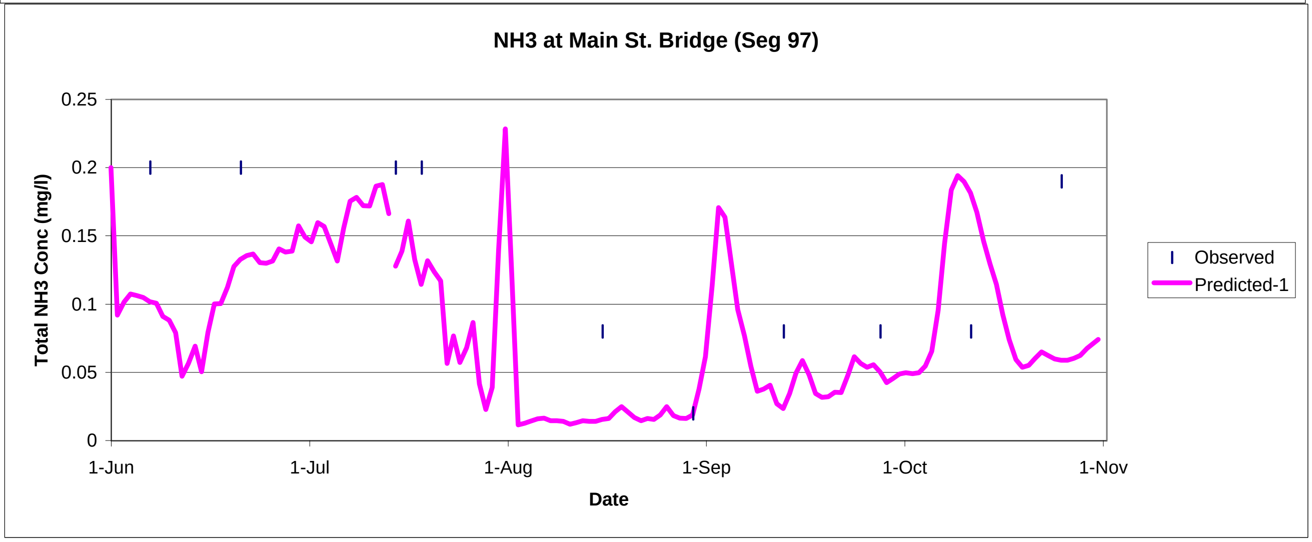


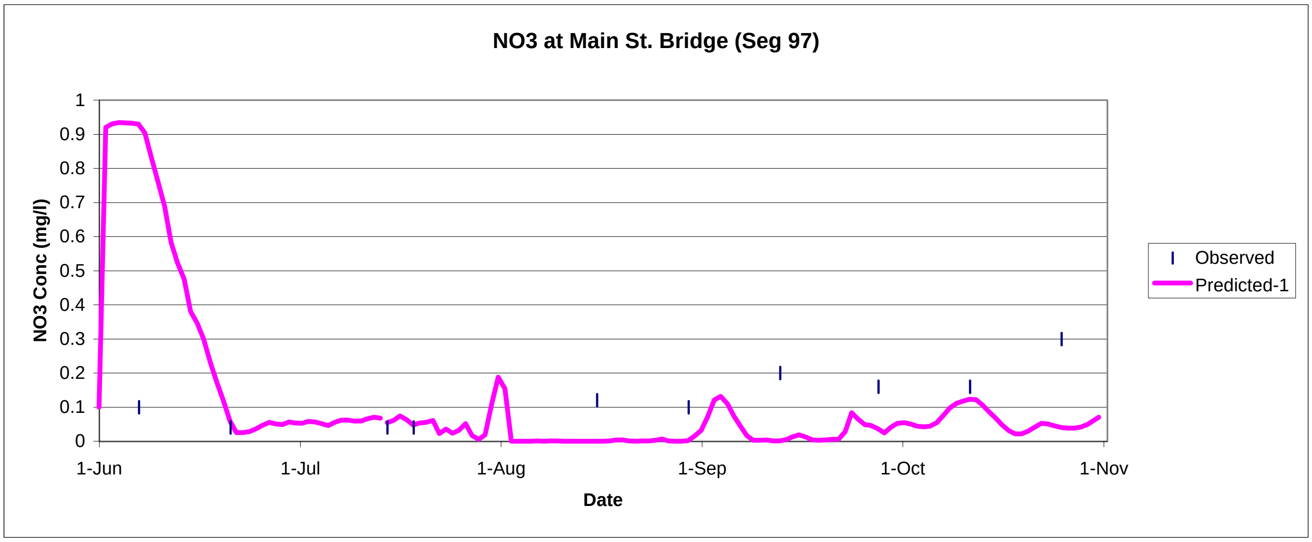




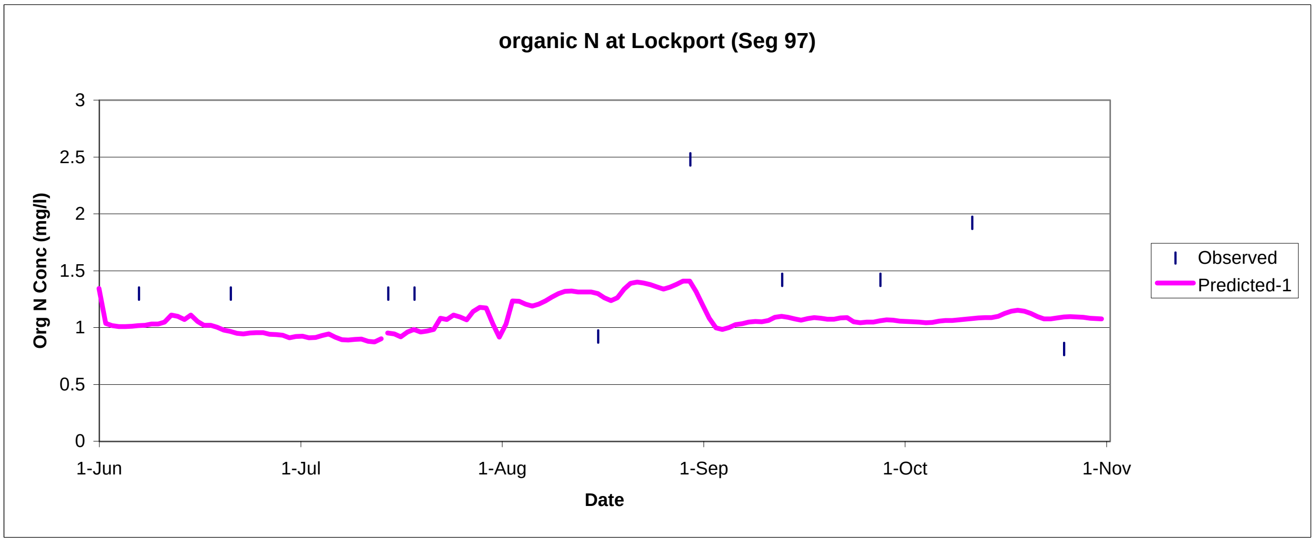
Algae and Nutrients at Fort Garry Bridge
Figure E- 9b

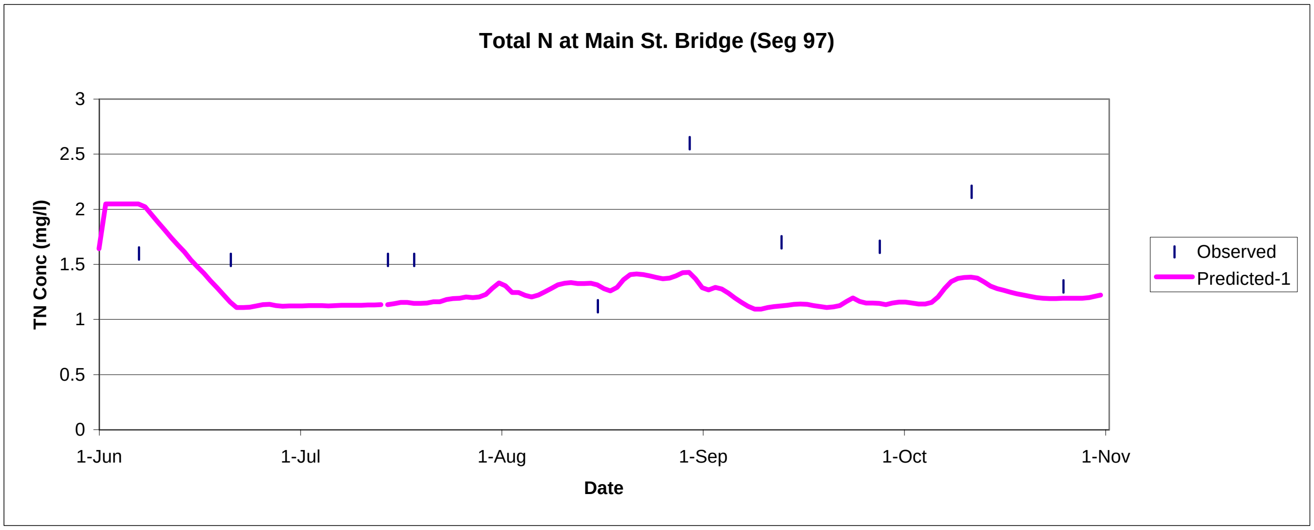


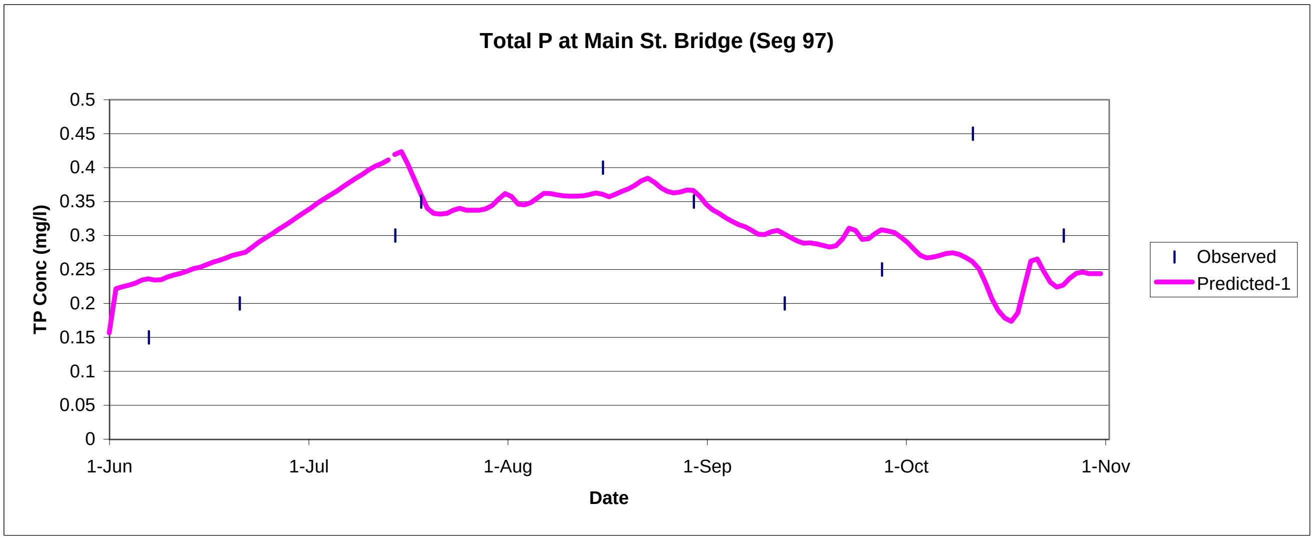




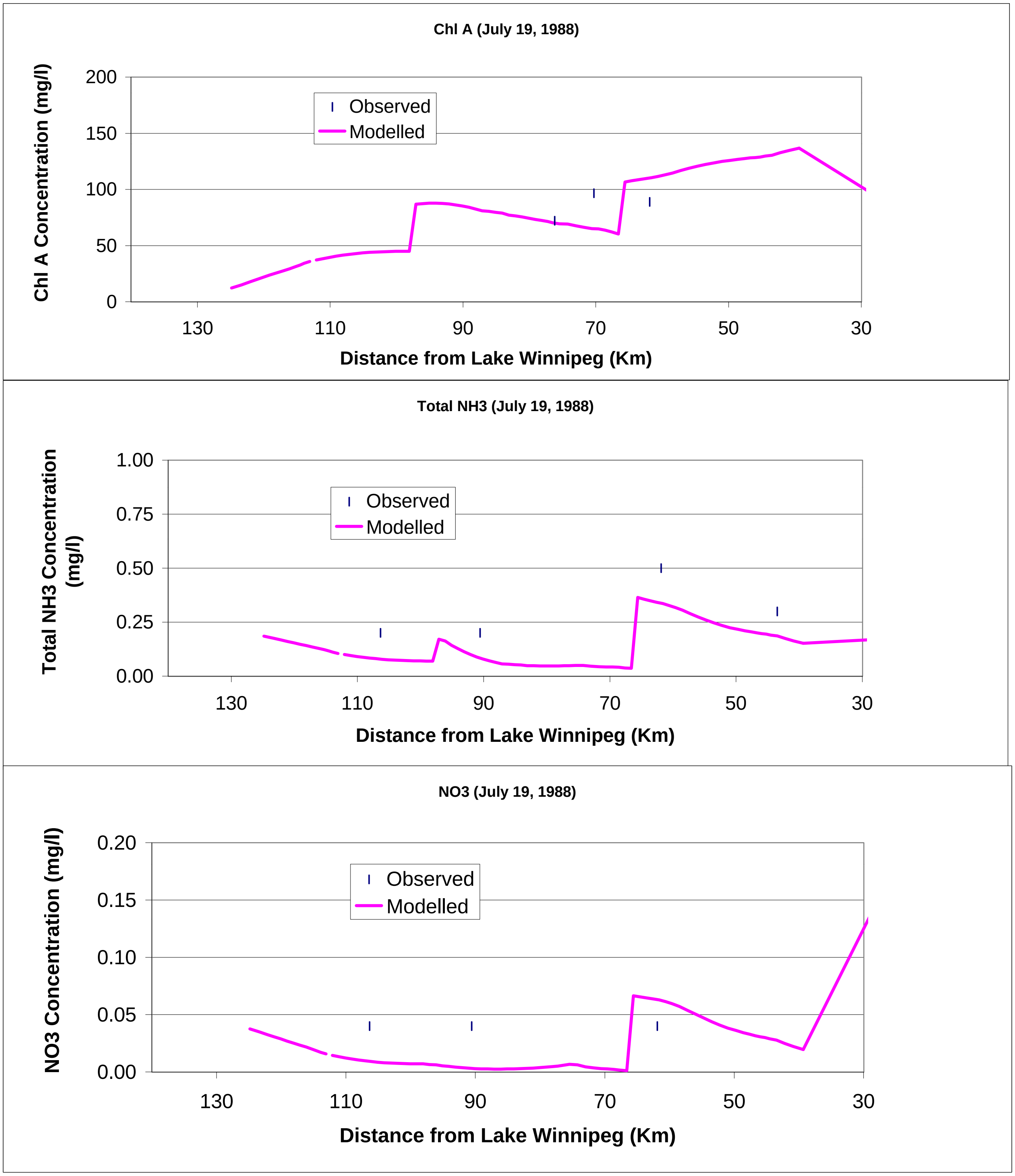
Algae and Nutrients at Main Street Bridge
Figure E- 10a





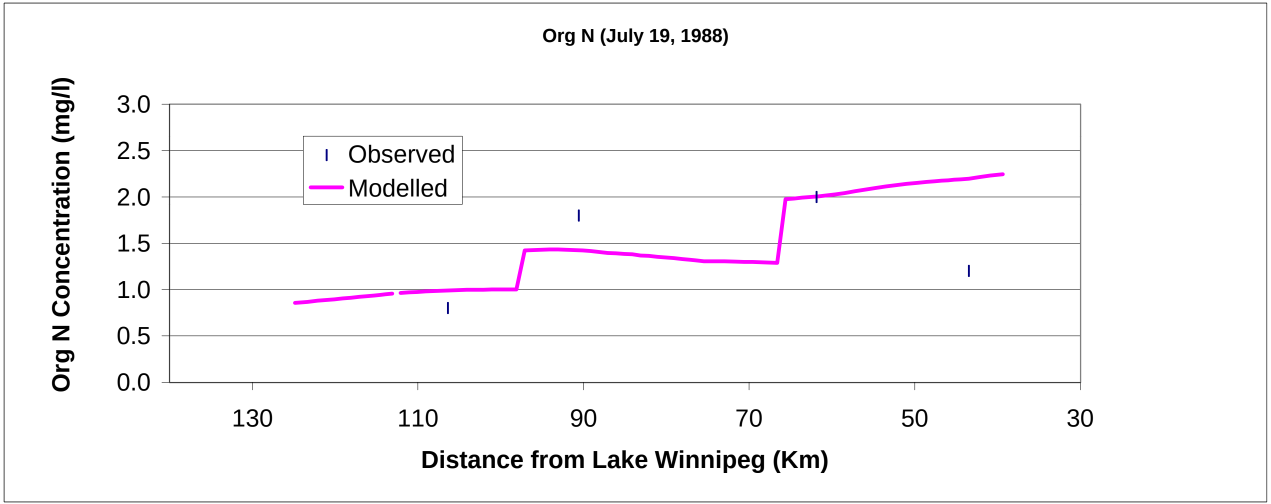


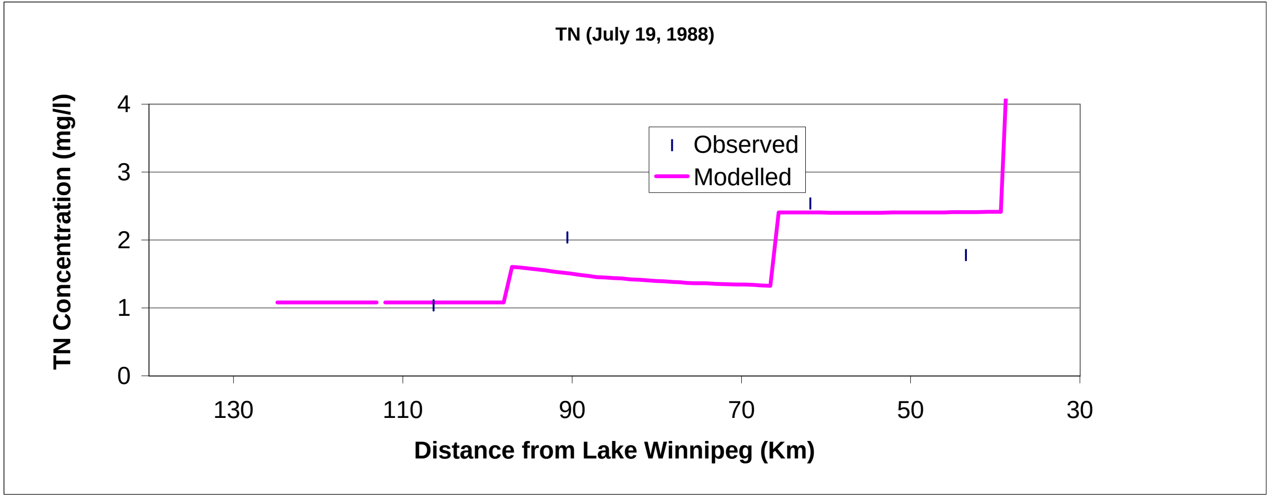
Algae and Nutrients at Main Street Bridge
Figure E- 10b

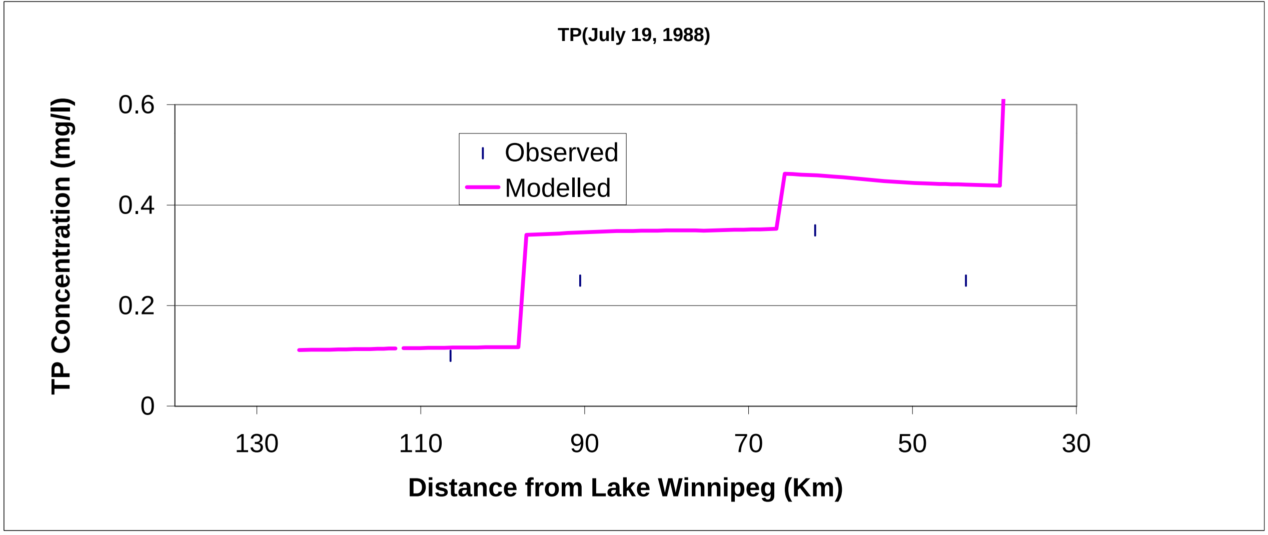


Comparison of Modelled and Monitored Parameters on the Red River for July 19,1988

Figure E-11a







Comparison of Modelled and Monitored Parameters on the Red River for July 19,1988

Figure E-11b

Table E-3
WASP5 Parameters used in Calibrated Model

Parameter	Units	Simulated	Constant Used	Documented Range	
				Minimum	Maximum
CARBONACEOUS BIOCHEMICAL OXYGEN DEMAND					
BOD Decay Rate @20c	day^{-1}	Yes	0.18000001	0.008	5.6
BOD Decay Rate Temperature Correction		Yes	1.08000004	1.02	1.075
BOD Decay Rate in Sediments	day-1	No	0	0	0.0004
BOD Decay Rate in Sediments Temperature Correction	O_2/L	No	0	0	1.08
BOD Half Saturation Oxygen Limit		No	0	-	0.5
DISSOLVED OXYGEN					
Waterbody Type Used for Wind Driven Reaeration Rate		No	0	0	3
Oxygen::Carbon Stoichiometeric Ratio		Yes	2.67000008	0	2.67
Reaeration Rate	day-1	No	0	0.05	10
Reaeration Option (Sums Wind and Hydraulic Ka)		Yes	1	0	1
ORGANIC NITROGEN					
Dissolved Organic Nitrogen Mineralization Rate @20c	day-1	Yes	0.05	0.001	1.08
Dissolved Organic Nitrogen Mineralization Temperature Coefficient		Yes	1.07000005	1.02	1.08
Organic Nitrogen Decay in Sediments	day-1	No	0	0.0004	0.0025
Organic Nitrogen Decay in Sediment Temperature Coefficient		No	0	1.02	1.14
Fraction of Phytoplankton Death Recycled to Organic Nitrogen		Yes	1	0	1
AMMONIA					
Nitrification Rate @20c	day-1	Yes	0.04	0.1	10
Nitrification Temperature Coefficient		Yes	1.08000004	1.047	1.103
Half Saturation: Nitrification Oxygen Limit	O_2/L	Yes	2	0.5	2
NITRATE AND NITRITE					
Denitrificatin Rate @20c	day-1	Yes	0.09	0.002	1
Denitrification Temperature Coefficient		Yes	1.03999996	1.02	1.09
Half Saturaturation:Denitrification Oxygen Limit	O_2/L	Yes	0.1	-	0.1
ORGANIC PHOSPHORUS					
Mineralization Rate of Dissolved Organic Phosphorus @20c	day-1	Yes	0.27000001	0.003	0.8
Dissolved Organic Phosphorus Mineralization Temperature Coefficient		Yes	1.07000005	1.02	1.14
Organic Phosphoru Decay Rate in Sediments	day-1	No	0	0.0004	0.0025
Organic Phosphorus Decay in Sediments Temperature Coefficient		No	0	1.02	1.14
Fraction of Phytoplankton Death Recycled to Organic Phosphorus		Yes	1	0	1
ALGAL DYNAMICS					
Phytoplankton Maximum Growth Rate @20c	day-1	Yes	4	0.2	9.2
Phytoplankton Growth Temperature Coefficient		Yes	1.08	1.01	1.068
Phytoplankton Light Formulation Switch (1=DiToro, 2=Smith)		Yes	1	1	2
Phytoplankton Maximum Quantum Yield Constant	mg C/mole photons	Yes	720	600	1020
Phytoplankton Self Shading Extinction	$(\text{mg Chl-a/m}^3)^{-1}$/m	Yes	0.02	0.007	0.07
Phytoplankton Carbon::Chlorophyll Ratio	mg PO_4-P/mg-C	Yes	25	200	500
Phytoplankton Optimal Light Saturation	langleys/day	Yes	200	-	350
Phytoplankton Half-Saturation Constant for Nitrogen	mg N / L	Yes	5.00E-02	0.0014	0.4
Phytoplankton Half-Saturation Constant for Phosphorus	mg P / L	Yes	1.00E-03	0.0005	0.08
Phytoplankton Endogenous Respiration Rate @20c	day-1	Yes	0.3	0.005	0.8
Phytoplankton Respiration Temperature Coefficient		Yes	1.04999995	1.04	1.08
Phytoplankton Death Rate Non-Zooplankton Predation	day-1	Yes	0.003	0.003	0.25
Phytoplankton Zooplankton Grazing Rate	day-1	No	0	0	5
Nutrient Limitation Option		No	0	0	1
Phytoplankton Decay Rate in Sediments	day-1	Yes	0.02	0.003	0.17
Phytoplankton Temperature Coefficient for Sediment Decay		Yes	1.08000004	-	1.08
Phytoplankton Carbon::Phosphorus Ratio		Yes	0.027	0.024	0.05
Phytoplankton Carbon:: Nitrogen Ratio		Yes	0.17	0.05	0.43
Phytoplankton Half-Sat. for Recycle of Nitrogen and Phosphorus		Yes	1	0	1
SETTLING					
Dead Organic	m/day	No	0	0.001	0.1
Phytoplankton	m/day	Yes	0.43	0.07	18
Inorganic	m/day	No	0	-	-

APPENDIX F

POTENTIAL NUTRIENT LOADING SCENARIOS

Table F-1
Upstream and Plant Nutrient Loads for each Scenario

	Scenario 1- Base Case					Scenario 2 - COW Phosphorus Control				
	NEWPCC	SEWPCC	WEWPCC	Floodway Control	Headingly	NEWPCC	SEWPCC	WEWPCC	Floodway Control	Headingly
Flow (Ml/d)	267.1	87	34.7	Variable Historic	Variable Historic	267.1	87	34.7	Variable Historic	Variable Historic
Total P (mg/L)	**2.6**	**4.0**	**4.2**	Variable Historic	Variable Historic	**1.0**	**1.0**	**1.0**	Variable Historic	Variable Historic
Ratio of Dissolved P to Total P	0.80	0.57	0.22	0.65	0.65	0.80	0.57	0.22	0.65	0.65
Total P (kg/day)	560	198	33	Variable Historic	Variable Historic	213	50	8	Variable Historic	Variable Historic
Orgainic P (kg/day)	143	149	114	Variable Historic	Variable Historic	54	37	27	Variable Historic	Variable Historic
Total Ammonia (mg/L)	28.6	23	23.5	Variable Historic	Variable Historic	28.6	23	23.5	Variable Historic	Variable Historic
Total Ammonia (kg/day)	7,639	2,001	815	Variable Historic	Variable Historic	7,639	2,001	815	Variable Historic	Variable Historic
Nitrate (mg/L)	0.08	0.04	0.22	Variable Historic	Variable Historic	0.08	0.04	0.22	Variable Historic	Variable Historic
Nitrate (kg/day)	21	3	8	Variable Historic	Variable Historic	21	3	8	Variable Historic	Variable Historic
Organic N (mg/L)	12.8	13.9	10.3	Variable Historic	Variable Historic	12.8	13.9	10.3	Variable Historic	Variable Historic
Organic N (kg/Day)	3,419	1,209	357	Variable Historic	Variable Historic	3,419	1,209	357	Variable Historic	Variable Historic

	Scenario 3 - COW Nitrification (P Increase)					Scenario 4- COW and Upstream P Control				
	NEWPCC	SEWPCC	WEWPCC	Floodway Control	Headingly	NEWPCC	SEWPCC	WEWPCC	Floodway Control	Headingly
Flow (Ml/d)	267.1	87	34.7	Variable Historic	Variable Historic	267.1	87	34.7	Variable Historic	Variable Historic
Total P (mg/L)	**4.6**	**6.0**	**6.2**	Variable Historic	Variable Historic	**1.0**	**1.0**	**1.0**	**0.1**	**0.1**
Ratio of Dissolved P to Total P	0.80	0.57	0.22	0.65	0.65	0.80	0.57	0.22	0.65	0.65
Total P (kg/day)	985	298	49	Variable Historic	Variable Historic	213	50	8	Variable Historic	Variable Historic
Orgainic P (kg/day)	252	223	168	Variable Historic	Variable Historic	54	37	27	Variable Historic	Variable Historic
Total Ammonia (mg/L)	1	1	1	Variable Historic	Variable Historic	28.6	23	23.5	Variable Historic	Variable Historic
Total Ammonia (kg/day)	267	87	35	Variable Historic	Variable Historic	7,639	2,001	815	Variable Historic	Variable Historic
Nitrate (mg/L)	27.6	22	22.5	Variable Historic	Variable Historic	0.08	0.04	0.22	Variable Historic	Variable Historic
Nitrate (kg/day)	7,372	1,914	781	Variable Historic	Variable Historic	21	3	8	Variable Historic	Variable Historic
Organic N (mg/L)	12.8	13.9	10.3	Variable Historic	Variable Historic	12.8	13.9	10.3	Variable Historic	Variable Historic
Organic N (kg/Day)	3,419	1,209	357	Variable Historic	Variable Historic	3,419	1,209	357	Variable Historic	Variable Historic