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**A PRELIMINARY ASSESSMENT  
OF ENVIRONMENTAL IMPACTS ASSOCIATED WITH  
THE 1997 RED RIVER FLOOD, WITH FOCUS ON  
WATER QUALITY**

**Prepared For:**

**International Red River Basin Task Force**

**Prepared By:**

R.S. Currie, Biologist  
Environmental Explorations and Research  
Services

D.A. Williamson, Manager  
Water Quality Management Section  
Manitoba Environment

and

M.E. Brigham, Environmental Engineer  
Water Resources Division  
United States Geological Survey  
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## ACKNOWLEDGMENTS

The generous provision of flood-related data, information, and assistance is greatly appreciated from the following individuals:

- B. Billeck, B. Franzin, N. Grift, L. Lockhart, M. Stainton, and G. Stern  
Canada Department of Fisheries and Oceans
  - D. Ediger, C.E. Hughes, T. Jaremy, R. Lemoine, R. Sokolowski, E.A. Sorba, and G. Trask  
Manitoba Environment
  - D. Donald, B. Holliday, J. Tisdale, A. Verley, and J. Wood  
Environment Canada
  - W.R. Berkas, K.L. Boespflug, J.B. Kelly, W.W. Larson, L.L. Rutschke, and G.W. Stratton  
United States Geological Survey
  - G. Reetz and G. Skuta  
Minnesota Pollution Control Agency
  - M. Sauer and F. Schwindt  
North Dakota Department of Health
- and
- A. Lang and J. Geidt  
United States Environmental Protection Agency

Currie, R.S., D.A. Williamson, and M.E. Brigham. 1998. A preliminary assessment of environmental impacts associated with the 1997 Red River flood, with focus on water quality. Prepared for the International Red River Basin Task Force jointly by Environmental Explorations and Research Services, Manitoba Environment, and United States Geological Survey.

## SUMMARY

Following the flood in the Red River basin in 1997, the governments of Canada and the United States asked the International Joint Commission (IJC) to examine the causes and effects of the flood and to recommend ways that damages may be reduced in future floods. The IJC was asked to provide governments with an Interim Report by the end of December 1997 identifying measures that may need to be implemented in the near-term. This Interim Report is to be followed by a Final Report once the study has been completed. In September 1997, the IJC appointed an International Red River Basin Task Force to assist with the work. The attached report was commissioned by the International Red River Basin Task Force to assist in preparation of their Interim Report to the IJC for early December 1997, and in particular, to provide an assessment of existing data to gain a better understanding of the short-term environmental impacts due to the flood.

The focus of this report was placed on assessing only readily available data from several key sites within the basin. As new data become available and as additional studies are undertaken, a more complete understanding of the environmental impacts of the 1997 Red River flood will emerge.

Federal, provincial, and state agencies throughout the Red River basin conducted independent, but coordinated water quality studies before, during, and after the flood of 1997 to meet the following objectives:

- to ensure that drinking water treatment facilities could continue to provide potable water to residents in the basin throughout the flood;
- to ensure that the quality of flood waters would not impact other uses in the basin such as recreation and maintenance of habitat for aquatic life and wildlife;
- to gain a better understanding of short-term environmental impacts associated with this unique, high flow event; and
- to ensure collection of sufficient background data to allow for the evaluation of long-term impacts within the basin, particularly in Lake Winnipeg.

This report describes potential sources of contamination during the flood and provides a preliminary assessment of environmental impacts.

Sources of contamination in the basin included household and commercial hazardous wastes, sewage from municipal and private lagoons, septic tanks and septic fields, plus others. Home fuel-oil heating tanks were potentially a major source of contamination throughout the entire Red River basin.

Concentrations of many water quality variables including dissolved solids, some nutrients and metals were correlated with river flow. Concentrations of most physical-chemical variables (e.g., dissolved oxygen, dissolved solids, and trace elements) were found to be within levels normally observed over the period of record. However, maxima, or near maxima, were reached for sediment load, total nitrogen and phosphorus load, fecal coliform, fecal streptococci, nickel, and zinc. Arsenic, lead, and manganese were generally higher than observed over the previous 3 - 5 years. Minima were reached for dissolved solids and conductivity; near minima were reached for sodium and magnesium.

Dieldrin, total DDT, and total chlordane were also correlated with river flow in 1997. As expected, the pesticides 2,4-D, trifluralin, triallate, dicamba, metolachlor, EPTC, pendimethalin, acetochlor, alachlor, metribuzin, malathion, and atrazine were detected at various sites. Dieldrin,  $\gamma$ -chlordane, endrin, *o,p'*-DDT, *p,p'*-DDT, and total PCBs were detected in the Red River in 1997 but were not detected in previous years by Environment Canada at Emerson. It is not known whether these pesticides were detected as a result of improved analytical capabilities or because concentrations increased as a result of the flood. As well, pentachlorophenol, a wood preservative was detected at several sites during the flood. It is thought that this product likely originated from flooded railway ties, fence posts, bridge works, or other flooded wood structures that may have been treated with this preservative.

Flood waters caused the microbiological contamination of a large number of private groundwater wells immediately south and east of the City of Winnipeg. Flood waters moved into the groundwater aquifers through improperly sealed wells. Although the microbiological quality of the flood waters was generally within the normal historical ranges, most groundwater is well protected from microbiological contamination and therefore is often consumed without further treatment. A program were implemented during the summer of 1997 to remedy contaminated groundwater and to properly seal both abandoned and in-use wells.

The southern portion of the Red River basin at Lake Traverse and the northern portion of the Mississippi River basin at Big Stone Lake were connected for a period of time during the flood of 1997. Flow between the two basins during this time was estimated to be small. Interbasin exchange of water is a concern because of the potential transfer of non-indigenous biota.

This preliminary assessment showed that impacts of the flood on water quality of the Red River basin were likely not large; concentrations of most water quality variables were within normally

observed levels. Many potential sources of contaminants were removed from the flood zone prior to the flood and the tremendous volume of relatively clean snow meltwater likely diluted other sources. However, a number of issues remain that could be further explored in future studies. These include the ultimate fate of the detected persistent organochlorines in the basin, particularly in Lake Winnipeg, effects of altered nitrogen - phosphorus ratios on algal communities in the basin, sensitive aquatic life and wildlife habitat that may have been impacted, plus others.

Currie, R. S., D. A. Williamson et M. E. Brigham. 1998. A preliminary assessment of environmental impacts associated with the 1997 Red River flood, with focus on water quality. Préparé conjointement par Environmental Explorations and Research Services, Environnement Manitoba et le United States Geological Survey pour le Groupe de travail international sur le bassin de la rivière Rouge.

## RÉSUMÉ

Suite à l'inondation survenue dans le bassin de la rivière Rouge en 1997, les gouvernements du Canada et des États-Unis ont demandé à la Commission mixte internationale (CMI) d'étudier les causes et les conséquences de l'inondation et de proposer des recommandations pour réduire les dégâts en cas d'inondations futures. Il a été demandé à la CMI de fournir aux gouvernements un rapport provisoire avant la fin décembre 1997 énonçant les mesures pouvant être prises à court terme, ce rapport provisoire devant être suivi d'un rapport définitif une fois l'étude achevée. En septembre 1997, la CMI a nommé le Groupe de travail international sur le bassin de la rivière Rouge afin qu'il l'aide dans cette tâche. Le rapport ci-joint a été réalisé à la demande du Groupe de travail international sur le bassin de la rivière Rouge, afin d'aider ce dernier à préparer pour la CMI un rapport provisoire pour début décembre 1997 et plus particulièrement pour fournir une évaluation des données afin de mieux comprendre les conséquences environnementales à court terme de l'inondation.

Ce rapport a surtout consisté à évaluer des données facilement disponibles provenant de plusieurs sites clés du bassin de la rivière Rouge. Plus nous disposerons de nouvelles données et entreprendrons d'études, mieux nous comprendrons les conséquences de l'inondation de la rivière Rouge de 1997.

Les autorités fédérales, provinciales et gouvernementales de l'ensemble du bassin de la rivière rouge ont réalisé des études indépendantes mais coordonnées sur la qualité de l'eau avant, pendant et après l'inondation de 1997 afin d'atteindre les objectifs suivants :

- s'assurer que les installations de traitement de l'eau de consommation puissent continuer à fournir de l'eau potable aux habitants du bassin pendant toute la durée de l'inondation;
- s'assurer que la qualité des eaux de crue n'interférerait pas avec les autres activités menées dans le bassin de la rivière Rouge, comme par exemple, les loisirs ou la préservation de l'habitat pour les formes de vie aquatiques et la faune sauvage;
- mieux comprendre les effets environnementaux à court terme de cet épisode de crue exceptionnel;
- faire en sorte que suffisamment de données de base soient recueillies pour que l'évaluation des effets de l'inondation à long terme dans le bassin soit possible, en particulier dans le lac Winnipeg.

Ce rapport décrit les sources potentielles de contamination pendant l'inondation et présente une évaluation préliminaire des effets de la crue sur l'environnement.

Parmi les sources potentielles de contamination dans le bassin, il y a entre autres les déchets ménagers et commerciaux dangereux, les eaux usées des lagunes municipales et privées, les fosses septiques et les champs d'épuration. Les réservoirs des appareils de chauffage à mazout domestique étaient à priori les sources de contamination principales dans l'ensemble du bassin de la rivière Rouge.

La concentration de nombreuses variables définissant la qualité de l'eau, y compris celle des matières dissoutes, de certains éléments nutritifs et de métaux était corrélée au débit fluvial. Celle de la plupart des variables physico-chimiques (p. ex. l'oxygène dissous, les matières dissoutes et les éléments à l'état de trace) était, pendant la période étudiée, dans la fourchette des concentrations normalement mesurées. Cependant, la charge solide, la charge totale en polluants azotés et phosphorés ainsi que les teneurs en coliformes et en streptocoques fécaux, en nickel et en zinc étaient soit au maximum, soit très proches du maximum. Les teneurs en arsenic, en plomb et en manganèse étaient en général plus élevées que celles qui avaient été mesurées dans les 3 à 5 années précédentes. Quant aux matières dissoutes et à la conductivité, elles avaient atteint leur minimum et les teneurs en sodium et en magnésium étaient également presque au minimum.

Une corrélation a également été mise en évidence entre le débit fluvial et les concentrations de dieldrine, de DDT et de chlordane totaux en 1997. Comme cela était prévu, les pesticides suivants ont été décelés à plusieurs endroits : le 2,4-D, la trifluraline, le triallate, le dicamba, le metolachlore, l'EPTC, la pendiméthaline, l'acetochlore, l'alachlore, la métribuzine, le malathion et l'atrazine. La dieldrine, le  $\gamma$ -chlordane, l'endrine, le o,p'-DDT, le p,p'-DDT et les PCB totaux ont été détectés dans la rivière Rouge en 1997 alors qu'ils n'avaient pas été décelés par Environnement Canada l'année précédente à Emerson. Nous ne savons pas si ces pesticides ont pu être trouvés suite à une amélioration des capacités analytiques ou parce que leur concentration a augmenté en conséquence de l'inondation. Il en a été de même pour le pentachlorophénol, un préservateur du bois, qui a été mis en évidence dans plusieurs sites pendant les inondations. On pense que ce qui en est probablement la cause, ce sont les traverses de rails, les piquets de clôture, les structures de ponts et tout autre ouvrage en bois, traités avec ce produit, qui ont été couverts par les eaux de crue.

Les eaux de crue ont provoqué une contamination microbiologique de nombreux puits privés situés en bordure immédiate de la ville de Winnipeg, au sud et à l'est. Elles sont également entrées dans les réservoirs aquifères par l'intermédiaire de puits mal scellés. Bien que la qualité microbiologique des eaux de crues soit en général dans la fourchette des valeurs historiques normales, la plupart des puits d'eau souterraine sont bien protégés contre une contamination microbiologique et, de ce fait, leur eau est



souvent consommée sans prendre la peine d'un traitement plus poussé. Afin de remédier au problème de contamination des eaux souterraines, un programme visant à sceller convenablement tous les puits abandonnés ou en service a été mené à bien pendant l'été 1997.

La partie sud du bassin de la rivière Rouge, au Lac Traverse, ainsi que la partie nord du bassin du Mississippi au Lac Big Stone, ont été en communication pendant quelque temps au moment de l'inondation de 1997. On estime que le débit de l'eau entre les deux bassins a été faible pendant cette période. Les échanges d'eau entre bassins est une source d'inquiétude, car il peut y avoir passage de biotes non indigènes d'un bassin à l'autre.

Cette évaluation préliminaire a permis de montrer que les effets de l'inondation sur la qualité de l'eau du bassin de la rivière Rouge sont probablement mineurs. Les concentrations de la plupart des variables définissant la qualité de l'eau se trouvaient dans la fourchette de valeurs normalement observées. De nombreuses sources de contamination potentielle furent supprimées de la zone des inondations avant l'arrivée de la crue et l'incroyable volume d'eau assez propre provenant de la fonte des neiges a probablement dilué les contaminants restants. Il demeure cependant un certain nombre de questions pouvant être examinées à l'occasion de prochaines études. On pourrait ainsi étudier le destin final des organochlorés persistants décelés dans le bassin de la rivière Rouge, et plus particulièrement dans le lac Winnipeg, les conséquences de la modification du rapport entre azote et phosphore sur les communautés algaires du bassin, les formes de vie aquatiques sensibles et les habitats fauniques ayant été touchés et bien d'autres sujets.

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## INTRODUCTION

Due to a combination of factors including excessive snow accumulation, a blizzard during the snow melt period, and wet soil moisture conditions (Warkentin 1997), a major flood occurred in the Red River basin during the spring of 1997. This was the largest flood recorded within the last 100 years (International Red River Pollution Board 1997). Peak discharge was estimated to be 793 m<sup>3</sup>/s on April 17, 1997 at Fargo ND, 3,850 m<sup>3</sup>/s on April 18, 1997 at Grand Forks ND, 3,740 m<sup>3</sup>/s on May 2, 1997 at Emerson MB, and 4,587 m<sup>3</sup>/s on May 4, 1997 at Winnipeg MB. While much of the focus of flood preparedness, response, recovery, and mitigation efforts are appropriately directed towards safeguarding human life and physical structures, both short-term and long-lasting impacts can also occur to the quality of the aquatic environment, particularly from contaminants mobilized during the flood.

The objectives of this report are to: (1) identify potential sources of flood water contamination within the basin; (2) prepare a preliminary assessment of water quality data collected during the flood of 1997 at key sites within the basin; and (3) identify additional issues that may benefit from further study.

## METHODS

Information on water quality was assembled from Manitoba Environment, Environment Canada, Department of Fisheries and Oceans (DFO), United States Geological Survey (USGS), Minnesota Pollution Control Agency (MCPA), and North Dakota Department of Health. Although considerable data are available, this preliminary assessment focused on information generated from a sampling site closest to Lake Winnipeg (Red River at Selkirk MB) for several reasons: (1) water quality at this site represents an integration of basin wide inputs; (2) considerable data were generated at this site during the flood; (3) Manitoba Environment's water quality record at this site started about 1965, thus providing a good historical context; and (4) both water quality data and discharge data were computerized and readily available. The assessment was augmented with other comprehensive data generated at Emerson MB, Pembina ND, Grand Forks ND, and Fargo ND. Linear regression analyses ( $\alpha=0.05$ ) were performed on water quality variables to determine if concentrations were related to river discharge.

The states of North Dakota and Minnesota have water quality standards applicable to the Red River within the U.S. portion of the basin while Manitoba has comparable water quality objectives applicable to the Manitoba portion of the basin. Water quality objectives for five variables have been adopted by the IJC and are applicable at the International border. The IJC has adopted alert levels for a number of materials. In addition, the Canadian Council of Ministers of the Environment (CCME 1987)

have developed water quality guidelines for numerous materials to assist Canadian jurisdictions. Water quality was compared to these objectives, guidelines, standards, or alert levels applicable to the site under consideration. In most cases, Manitoba Surface Water Quality Objectives (Williamson 1988) were referenced since much of the focus of this preliminary assessment was on the sampling site located at Selkirk MB. Although not site specific, the CCME guidelines for organic materials were principally used for comparison since they are generally more current and have been developed for more materials than the Manitoba Surface Water Quality Objectives.

Flow data for the Red River at Selkirk MB were obtained from Environment Canada. Information on sources of contamination as well as identification of other potential environmental issues related to the flood were obtained from interviews and correspondence with key federal, provincial, and state agencies in the basin.

Prior to the flood, most agencies sampled various locations on the Red River at monthly intervals. Sampling frequency was increased at the Selkirk MB site to a minimum of once every 2 - 3 days beginning near the end of April, 1997 to June 12, 1997, then returned to monthly. Amalgamation of Manitoba Environment and DFO data for this site would yield daily coverage throughout much of the flood. At Emerson MB, Environment Canada conducted monthly sampling prior to 1997, sampled weekly in April, twice in May, then returned to monthly sampling in June 1997. United States Geological Survey, MPCA, and North Dakota Department of Health coordinated sample collection in the USA portion of the basin. Samples were collected both bimonthly and monthly at a number of sites in the Fargo/Moorhead, Grand Forks/East Grand Forks, and Pembina areas of Minnesota and North Dakota.

Field and laboratory methods used by Manitoba Environment and Environment Canada for nutrients, sediment loads, trace elements and metals have been described elsewhere (Sorba 1989, Williamson and Hughes 1992, Williamson *et al.* 1992) and are available upon request. Methods for analyses of organics for the historical period of record (1972 to 1994) have been reviewed in Currie and Williamson (1995). Methods have not changed, so will not be repeated here. However, from March, 1997 to June, 1997, methods used by Environment Canada were modified to accommodate the high sediment load expected from a significant flood event. This method change resulted in a lower detection limit for some compounds (Table 1). In the majority of cases detection limits decreased resulting in increased sensitivity.

Canada's Department of Fisheries and Oceans (DFO) collected water samples in 18 L stainless steel containers, extracted using methods in Seastar Instruments Ltd. (1987), then analyzed by GC-ECD.

Table 1. Detection limits for pesticides determined by Environment Canada before and after 1997.

Compound	new DL ( $\mu\text{g/L}$ )	old DL ( $\mu\text{g/L}$ )	change ( $\mu\text{g/L}$ ) <sup>1</sup>
2,3,6-TBA	0.0111	0.03	-0.0189
2,4-D	0.0147	0.03	-0.0153
2,4-DB	0.047	0.05	-0.003
2,4-DP	0.0159	0.03	-0.0141
2,4,5-T	0.0318	0.05	-0.0182
$\alpha$ -chlordane	0.00031	0.003	-0.00269
$\alpha$ -endosulfan	0.00022	0.001	-0.00078
$\alpha$ -HCH	0.0002	0.001	-0.0008
aldrin	0.00061	0.001	-0.00039
atrazine	0.242	0.05	0.192
$\beta$ -endosulfan	0.00088	0.003	-0.00212
barban	NA <sup>2</sup>	0.1	-
bromoxynil	0.0213	0.03	-0.0087
diallate	0.00864	0.1	-0.09136
dicamba	0.0076	0.03	-0.0224
diclofop	NA	0.05	-
dieldrin	0.00035	0.002	-0.00165
endaven	0.0362	0.025	0.0112
endrin	0.00055	0.002	-0.00145
$\gamma$ -chlordane	0.00033	0.002	-0.00167
HCB	0.00062	0.001	-0.00038
heptachlor	0.00082	0.001	-0.00018
heptachlor epoxide	0.00017	0.002	-0.00183
hoegrass	0.0452	NA	-
lindane	0.00015	0.001	-0.00085
MCPA	0.0162	0.03	-0.0138
MCPB	0.0265	0.05	-0.0235
metolachlor	0.116	0.1	0.016
mirex	0.00141	0.001	0.00041
<i>o,p'</i> -DDT	0.00075	0.001	-0.00025
picloram	0.0155	0.05	-0.0345
<i>p,p'</i> -DDD	0.00224	0.002	0.00024
<i>p,p'</i> -DDE	0.00128	0.001	0.00028
<i>p,p'</i> -DDT	0.0013	0.004	-0.0027
<i>p,p'</i> -methoxychlor	NA	0.01	-
silvex	0.0197	0.03	-0.0103
total PCB	0.0112	0.002	0.0092
triallate	0.00864	0.01	-0.00136
trifluralin	0.00838	0.005	0.00338

<sup>1</sup> Negative and positive values indicate increased or decreased analytical sensitivity, respectively.

<sup>2</sup> Not analyzed.

This method resulted in lower detection limits than achievable by other agencies. Further work on pesticides is being conducted by DFO and will be reported elsewhere.

Sampling and analytical methods used by USGS have also been described elsewhere (Tornes, Brigham, and Lorenz 1997; Connor *et al.* 1998).

## **RESULTS AND DISCUSSION**

### **Sources of Potential Contamination**

Water quality could potentially be affected during major flood events by the mobilization of contaminants. For example, hazardous materials are found throughout the basin in urban households, farmyards, both commercial and private service centres, as well as commercial storage facilities. Untreated municipal wastewater could be released through failure of wastewater treatment facilities, flooding of municipal sewage lagoons, intentional bypass of raw sewage to safeguard facilities from hydraulic overload, and flooding of private septic tanks and fields. Similar organic waste may originate from flooded livestock feedlots, holding areas, and manure storage areas during flood events. Industrial facilities, depending upon the nature of the manufacturing or distribution process, may contain relatively large quantities of hazardous materials.

### **Orphaned Containers and Hazardous Materials**

Within Manitoba, a large number and variety of orphaned containers and materials were retrieved from the flooded Red River and from shorelines following the flood. Propane cylinders, home heating fuel tanks, 45 gallon barrels, 5 gallon pails, and assorted smaller containers were reported to Manitoba Environment's Emergency Response team by agencies involved in flood operations, or by property owners within the flooded areas (Table 2). All containers were identified, tested for hazardous material, then labelled. Large containers with hazardous material were emptied and marked as "scrap" for later removal, providing that no further hazard existed, while the residue was removed immediately by licenced haulers to proper storage and treatment facilities. Smaller containers were collected into larger lots and then removed. In addition, residents were instructed to collect all household hazardous wastes and deliver them to depots located throughout areas adjacent to the flooded region.

The origin of the containers listed in Table 2 is unknown. Within Manitoba, a total of 22 5-gallon pails, 39 45-gallon drums, 265 smaller containers, four 20 lb. freon cylinders, 15 propane

Table 2. Orphaned containers retrieved from the Red River and from along shorelines following the flood.

Description	Quantity
five gallon pails	22
45 gallon (Imperial) drums	39
propane cylinders	15
fuel tanks	94
25 kg fertilizer bags	200-300
freon cylinders	4
intermediate bulk containers (IBCs)	1
propane barbeque tanks	4
miscellaneous full containers	130
miscellaneous empty containers	135



cylinders ranging in size from 20 pounds and 250 to 1000 gallons, 94 tanks ranging in size from 150 to 5000 gallons and other miscellaneous containers were collected. A total of 40 containers, ranging in size from 5 to 50 gallons, were also collected between Wahpeton ND and the Canadian border along with a number of empty containers.

Empty, partially full, and full containers were found within the Manitoba portion of the basin. The 5 gallon pails contained waste oil, fire fighting foam, tar, alcohol, and unknown waste. Unknown waste, diesel fuel, tar, solvents, corrosive liquids, gear oil, waste oil, gasoline, lubricating oil, sludge, polyester resin, and flammable liquid were found in the 45 gallon drums. Over 100 of the smaller miscellaneous containers were full and held paint, waste oil, pesticide, or compressed gases such as propane. The remaining 135 smaller containers were empty. Of the 94 tanks found, 55 were empty and 39 were full or partially full fuel tanks containing diesel fuel, home heating fuel, and mineral oil. The contents of the containers collected in the USA are not known, however, they were shipped for disposal at hazardous waste facilities. Whether the empty containers collected in both countries had spilled their contents as a result of the flood or were empty prior to the flood is unclear.

A number of home heating fuel tanks were found in the flood waters in Manitoba. Of the 56 identified home heating fuel tanks, 29 were empty and 27 were full or partially full. Home heating fuel tanks were also a source of potential contamination in Grand Forks ND.

Approximately 1000 of the flooded homes in Grand Forks used heating oil. During the flood, heating oil tanks began to float, breaking pipe connections, and spilling their contents either within home basements or to the external environment. In extreme cases, approximately 7.62 cm (3") of oil could be found on the surface of the water in some basements (U.S. EPA 1997). In Grand Forks, field personnel as well as news media observed petroleum on the surface of the Red River.

After removal of heating oil from 726 flooded homes and businesses in Grand Forks by vacuum trucks, the oil/water mixture was loaded into large fractionation tanks where the oil was allowed to separate. After separation, the water fraction was discharged into the Grand Forks sanitary sewer system at a rate of 13,250 L (3,500 US gallons) per day; in total over 220,665 L (58,300 US gallons) of water was discharged. Hydrocarbons at concentrations of 611, 633, 1150, and 1170 mg/L were detected in the released water (U.S. EPA 1997). Therefore, a total of between 135 and 258 kg of hydrocarbons were released into the Grand Forks sewer system from this source. In total, 274,400 L (72,500 US gallons) of heating oil was collected from the separation process and recycled. In addition, 266 home heating fuel tanks were deposited in the Grand Forks land fill after stabilizing the contents with a material called "floor dry". The potential for ground water contamination in the landfill should be minimal from these tanks.

Estimates of the number of residential fuel oil tanks that spilled in Manitoba are not available. However, as stated above, 56 home heating tanks were retrieved from the Red River within Manitoba. Most of these likely originated in Manitoba.

In addition to home heating fuel, other petroleum products were lost in the flood. Approximately 56,775 L (15,000 US gallons) of gasoline were lost from service stations in Breckenridge MN.

Post-flood clean-up of household hazardous waste from flooded basements and homes resulted in the collection of waste paint, liquid pesticides, waste oil, solvents, aerosols, water putty, detergents, tar, and batteries. Table 3 provides a detailed list of the amounts collected at waste depots in Manitoba.

In the USA, excluding Grand Forks, 86 drums of a mixture of household waste were removed from the flooded areas. In Grand Forks, this waste was mainly comprised of latex paints, paint-related material, compressed gases, caustic alkali liquids, toxic solids and liquids, oil soaked sorbant pads, bulk flammables, and empty drums (Table 4). Other household wastes that were collected pre- and post-flood in Grand Forks are included in Table 4. Containers retrieved after the flood may have lost some of their contents during the flood.

In total, 41,343 kg (90,956 lb) of agricultural waste was accumulated in the USA following the flood. The specific nature of this waste was not available.

### **Flooded Facilities**

Sewage treatment and related facilities may have been sources of potential disease-causing organisms, including bacteria, viruses, and other microorganisms. Numerous feedlots in the Red River basin were also inundated with flood waters resulting in the potential downstream movement of fecal material. Due to the extent of flooding and the fact that most rural dwellers rely on private septic systems for their sewage requirements, the flood likely resulted in the inundation of many private septic systems.

Sewage was bypassed from the collection and treatment systems of many towns, releasing untreated sewage directly into the flood waters. Up to 40 municipal wastewater treatment facilities in Minnesota were either bypassed or were inoperable for varied time periods during the flood. Municipal sewage lagoons at Emerson, St. Jean, Morris and Otterburne MB, and Pembina ND were flooded, but as the flood water receded, the systems were put back in operation. The Grand Forks ND sewage collection system was flooded, but was brought back into service without a significant discharge of raw sewage. Landfill disposal grounds in Gretna and Lettellier MB were also flooded, thus potentially contributing some contaminants to the flood waters.

Table 3. Household hazardous wastes collected at Manitoba depots.

Description	Quantity	Volume (L)	Total Vol. (L)
pesticide	3	20	60
paint	19	205	3895
oil	4	205	820
pesticide	2	205	410
solvent	1	205	205
oil with debris	1.5	205	3075
aerosols	1	205	205
water putty	6	205	1230
detergents	23	20	460
tar	13	20	260
detergents	3	100	300
batteries	-	-	300 kg

Table 4. Household hazardous waste collected in Grand Forks ND.

Materials	# Drums
latex paints	360 bbl and pallets
paint related materials	1452
compressed gas	172
compressed insecticides	37
caustic alkali liquids	162
toxic solids and liquids	175
corrosives	36
landfill drums	20
oxidizers	13
oil soaked sorbant pads	133
batteries	8
bulk flammable	124
asbestos	61
empty drums	286
water reactive material	2
PCB	1
mercury	4
florescence lights (crushed)	10
ethylene glycol	8

Two agricultural storage facilities were flooded in Grand Forks ND and the surrounding area. The basement of the AGSCO facility filled with water along with several inches of floating sunflower oil. The sunflower oil was contaminated with heating oil, toxaphene, and lindane ( $\gamma$ -HCH) and the underlying water was contaminated with toxaphene and lindane (U.S. EPA 1997). Most uses of the insecticide toxaphene were banned in the USA in 1982, however, use of existing stocks was allowed up to 1986 (Glassmeyer *et al.* 1997). Toxaphene has not been registered for use in Canada since 1983. Lindane is used for insect control, especially as a seed treatment for canola. Lindane is registered for use in both Canada and the USA.

Approximately 51,020 L (13,480 US gallons) of toxaphene-contaminated oil was removed from the basement of the AGSCO facility and shipped for disposal to Kansas City MO. Concentrations of toxaphene and lindane in the oil were 170,000  $\mu\text{g/L}$  and 21,000  $\mu\text{g/L}$ , respectively (Al Lang<sup>1</sup>, pers. comm.). Therefore, approximately 8.67 kg of toxaphene and 1.07 kg of lindane were present in the skimmed oil. In the water layer immediately below the oil, toxaphene was found at 2,100  $\mu\text{g/L}$  and lindane at 4,500  $\mu\text{g/L}$  (Al Lang, pers. comm.). Water at the lower depths contained 208  $\mu\text{g/L}$  of lindane (U.S. EPA 1997). Initial concentrations of these compounds in the basement may have been higher as water was likely flushing through the flooded basement during the peak of the flood. Samples from the basement were not taken until April 29, 1997 and peak flow in the area occurred on April 21, 1997.

The contaminated water was pumped through an activated carbon filter system to remove the lindane prior to discharge into either the English Coulee or Red River. Lindane was reduced to  $<0.03$   $\mu\text{g/L}$  following treatment. Fish toxicology studies were performed after the initial release of some water into the English Coulee; these studies showed that the treated water was not toxic to fish. A total of 1,109,000 L (293,000 US gallons) of treated water was discharged to English Coulee or to the Red River.

A large wooden fertilizer building owned by Terra Resources in ND was also flooded, saturating the spring supply of stored fertilizer. It was estimated that approximately 3,632 metric tonnes of urea and 908 metric tonnes of phosphate were lost to the flood waters. A large concrete-enclosed basement filled with various farm chemicals was also flooded. An estimated 556,400 L (147,000 US gallons) of contaminated water [Total organic halogenated compounds (TOX) = 6 mg/L, Total organic carbon (TOC) = 71 mg/L, Total petroleum hydrocarbons (TPH) = 5 mg/L] was collected in fractionation tanks, then pumped through activated carbon prior to discharge (U.S. EPA 1997). All but several pesticide containers in the flooded basement were intact with total loss of an unspecified chemical estimated to be approximately 1 L. Flood waters from this area flowed to the English Coulee through a local drainage

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<sup>1</sup> U.S. EPA, Denver CO.

ditch. Soil collected from this ditch was found to be rich in phosphate fertilizers but no chlorinated compounds were detected.

Approximately 12 livestock storage facilities, numerous concrete storage pits, livestock pens, holding areas, and barns were flooded in the Rural Municipality of Morris MB. Flooded livestock facilities occurred throughout the basin but details are not available for most areas.

### **Miscellaneous Sources**

Insulation and tiles from flooded buildings in Grand Forks may have contained at least some asbestos. However, removal of asbestos is highly regulated in most jurisdictions to protect the health of workers from air-borne asbestos during demolition of buildings.

Table 5 shows that a minimum of 8352 cattle, hogs, poultry, and sheep died directly in flood waters. Over 73% of these occurred in Minnesota, likely as a result of the lack of advance notice for farmers and commercial operators. Many of these animals were contained in the area of origin, however, a number of dead animals were retrieved from flood waters or from flooded areas after flood waters receded. The presence of dead animals in water can result in the release of viruses, bacteria, and other microorganisms such as *Cryptosporidium*.

### **Quality of Red River Flood Waters**

#### **Physical-Chemical Properties**

Total suspended sediment, nitrate-nitrite, total nitrogen, and total phosphorus increased quickly in response to increased river flow in spring 1997 at the Selkirk site. Consequently, sediment load, total phosphorus load, and total nitrogen load increased during this time period. This site at Selkirk is located several kilometres upstream of Lake Winnipeg and, therefore, downstream of all major tributaries; water quality at this site reflects an integration of basin-wide processes. A large increase in many water quality variables was observed on July 13, 1997, corresponding to an increase in river flow due to a large rainfall event in eastern North Dakota and western Minnesota. Three to six inches of rain fell in two days upstream of Grand Forks ND, likely flushing previously sedimented material into the river. During the flood peak, suspended sediment reached maximum concentrations of 480 mg/L on May 13, 1997, then gradually decreased as flow declined. Suspended sediment concentrations then increased substantially again on July 13, 1997 to 570 mg/L in response to the early summer high rainfall event that occurred in

Table 5. Livestock deaths directly attributed to flood waters within Manitoba, North Dakota, and Minnesota.

	Manitoba	North Dakota	Minnesota
Cattle	38	900 (50)	4105
Hogs	210	555	301
Poultry	minimal	300	1403
Sheep	minimal	192	348
Total	248	1947	6157

eastern North Dakota and western Minnesota. Concentrations of suspended sediment at Selkirk were not unusually high in comparison to the historical record (Appendix 1, Figure 1), although they may have remained elevated for a longer period of time in comparison to previous flood events. Suspended sediment were positively correlated with river flow ( $p < 0.05$ ,  $r^2 = 0.87$ ).

Sediment loads moving towards Lake Winnipeg in the Red River at Selkirk during the flood period increased quickly as river flow increased, reaching near-record maxima of 125,660 metric tonnes/day (Appendix 1, Figure 2). At the peak of the flood, sediment loads remained above 50,000 metric tonnes/day from April 22, 1997 to approximately May 20, 1997 when loads subsequently decreased with declining flows to a low of 1,682 metric tonnes/day by August 6, 1997.

Concentrations of dissolved solids decreased quickly at Selkirk as water flow increased (Appendix 1, Figure 3), then increased constantly over the period of the flood until a maximum of 550 mg/L was reached on June 10, 1997. Dissolved solids are comprised of salts such as sodium, chloride, calcium, magnesium, and others. Dissolved solids concentrations were similar to those observed throughout the historical record, however, minimum values were observed in 1997, probably as a result of dilution due to the influx of large quantities of fresh, snow-melt water. Dissolved solids were negatively correlated with flow during the flood period ( $p < 0.05$ ).

Conductivity decreased substantially from 804  $\mu\text{S}/\text{cm}$  on April 3, 1997 to 323  $\mu\text{S}/\text{cm}$  on April 22, 1997. Thereafter, conductivity increased slowly until the end of the sampling record and returned to pre-flood values of approximately 700  $\mu\text{S}/\text{cm}$  by June 8, 1997 (Appendix 1, Figure 4). Conductivity was negatively correlated with flow ( $p < 0.05$ ,  $r^2 = 0.85$ ) during this time period. Decreasing conductivity is generally observed during high flow events; values in 1997 were very close to the historical minimum (249  $\mu\text{S}/\text{cm}$  in 1979). Similar to dissolved solids, conductivity is a surrogate measurement for dissolved salts in the water. As the concentration of dissolved salts increase, a greater electrical current can be passed by the sample.

Chloride concentrations at Selkirk decreased with increased river flow from 53 to 20 mg/L between April 3, 1997 and April 24, 1997. Concentrations then ranged between <10 and 29 mg/L for the duration of the period of record. Chloride was not correlated with river flow during the flood. Chloride concentrations remained within the range normally observed (Appendix 1, Figure 5).

Potassium concentrations decreased slightly from 7.92 to 7.12 mg/L with increased water flow from April 3, 1997 to April 24, 1997. Concentrations fluctuated until reaching a peak of 9.65 mg/L on May 13, 1997, then generally decreased until the end of the period of record. Concentrations were within the same range as normally observed at Selkirk over the period of record (Appendix 1, Figure 6). Potassium concentrations were not correlated with river flow over the period of record.



Sodium concentrations decreased quickly from 52 mg/L to a historical low of 9.75 mg/L from April 3, 1997 to April 29, 1997, respectively, in response to increased river flow (Appendix 1, Figure 7). Subsequently, concentrations increased to 41.3 mg/L on June 12, 1997. In 1997 concentrations appeared to be slightly lower than normally observed at Selkirk. Sodium concentrations were negatively correlated with river flow ( $p < 0.05$ ,  $r^2 = 0.36$ ) over the period of record.

Magnesium concentrations decreased quickly with increased river flow from 33.4 to 14.3 mg/L between April 3, 1997 and April 27, 1997, respectively. Concentrations increased steadily from this point, peaking at 34.8 mg/L on August 6, 1997 (Appendix 1, Figure 8). Over the period of record, magnesium concentrations were negatively correlated with river flow ( $p < 0.05$ ,  $r^2 = 0.51$ ). Concentrations were generally lower than observed previously in the Red River at Selkirk.

Nitrate-nitrite nitrogen concentrations increased quickly with increased river flow up to April 22, 1997, then decreased continuously over the remaining flood period as river flow declined (Appendix 1, Figure 9). Peak spring concentrations were somewhat lower than observed in the previous four years, but were within the normal range shown in the period of record. Nitrate-nitrite was not correlated with river flow during the flood period.

Concentrations of total Kjeldahl nitrogen appeared to decrease quickly with increased river flow in 1997, then declined more gradually during the remainder of 1997 to a minimum of 0.7 mg/L on July 13, 1997 (Appendix 1, Figure 10). Concentrations were within levels normally observed over the period of record. Total Kjeldahl nitrogen was not correlated with flow. Total Kjeldahl nitrogen is comprised of organic forms of nitrogen (*i.e.*, those forms of nitrogen bound in plant or animal cells) and ammonia. Ammonia is often found in relatively high concentrations in municipal wastewater, run-off from animal feedlots, and in water draining recently fertilized agricultural lands.

Total ammonia concentrations decreased with river flow from April 3, 1997 (0.83 mg/L) to April 22, 1997 (0.29 mg/L), and remained low for the duration of the sampling period (Appendix 1, Figure 11). This pattern is usually observed in the spring with concentrations of ammonia decreasing as ice breakup and dilution of ammonia occurs in response to increased water flow. Ammonia concentrations were similar to those observed between 1993 and 1995 in North Dakota (Brigham and Lorenz 1997).

Maximum dissolved nitrate nitrogen concentrations measured during the flood at Fargo, Grand Forks, and Pembina ND were lower than observed in the period 1993 to 1995 (Brigham and Lorenz 1997).

The total nitrogen load (sum of nitrate-nitrite and Kjeldahl nitrogen) in the Red River at Selkirk in 1997 was larger than measured during the previous 30 years (Appendix 1, Figure 12). Total nitrogen load increased quickly with river flow, reaching a maximum of 896 metric tonnes/day on April 24, 1997.

The load generally decreased with river flow but remained above 250 metric tonnes/day until May 27, 1997.

Total phosphorus concentrations also increased sharply with increased river flow, peaking at 0.87 mg/L on April 22, 1997, then declined to approximately 0.20 mg/L by June 2, 1997. The observed concentrations were within the normal range measured at the Selkirk site over the period of record, but were generally higher than observed in the previous three years (Appendix 1, Figure 13). However, total phosphorus measured in North Dakota was similar to concentrations observed in 1993 to 1995. Total phosphorus was positively correlated with river flow ( $p=0.0005$ ,  $r^2=0.60$ ) in 1997 at the Selkirk site.

The total phosphorus load in the Red River at Selkirk in spring 1997 was larger than previously recorded at this site (Appendix 1, Figure 14). The maximum load was 202 metric tonnes/day and remained above 90 tonnes/day until May 22, 1997. The phosphorus load then declined constantly for the duration of the sampling period. As observed during most other spring periods in the historical record, phosphorus loads peaked during high flow conditions, then declined with flow.

Total nitrogen/phosphorus ratios were somewhat lower than normally observed at the Selkirk site, although ratios appeared similar to other periods of high flow, such as those observed during the summer of 1993. Ratios decreased as flow increased and remained below 5.7 until June 2, 1997. Total nitrogen/phosphorus ratios lower than about 10 generally indicate that nitrogen is the plant nutrient that is in limited supply to algae. When this occurs, nuisance blue-green algae tend to proliferate because these species gain a competitive advantage due to their ability to utilize nitrogen from the atmosphere. While blooms of nuisance blue-green algae would not be expected to occur in the Red River during the flood, altered total nitrogen/phosphorus ratios may affect Lake Winnipeg. However, it is not known whether the altered ratios were sustained within Lake Winnipeg, since phosphorus may have been lost from the system through sedimentation at a much faster rate than nitrogen, thus restoring the original balance.

Concentrations of dissolved oxygen during the 1997 flood ranged from 6.3 to 10.8 mg/L (Appendix 1, Figure 15) at the Selkirk sampling location. Concentrations were within the range shown in the historical period of record and did not fall below concentrations necessary to protect aquatic life communities. Dissolved oxygen was not correlated with river flow during the flood, although there was a general downward trend from May 15, 1997 to the end of the period of record. Dissolved oxygen followed a similar pattern at the Emerson site. The IJC's minimum objective for dissolved oxygen was not achieved marginally on one occasion at the boundary in early June 1997.

There was a steady increase in pH from approximately 7.6 to 8.4 from February 5, 1997 to August 6, 1997 (Appendix 1, Figure 16). This pattern is similar throughout the 30 year period of record as pH generally decreases during the fall and winter months, then increases during spring and summer.

## **Bacteria**

Fecal coliform bacteria, an indicator associated with gastrointestinal illness, increased slightly with greater water flow in the Red River, then declined to near normal spring-time densities (Appendix 1, Figure 17). Upstream of Winnipeg, fecal coliform densities briefly exceeded the commonly-used IJC recreational water quality objective of 200 organisms/100 mL then declined to normal densities. At Emerson, record densities of fecal coliform bacteria were detected during the peak of the flood, then densities declined to the normal range. Fecal coliform did not exceed the IJC objective in samples collected by the USGS in the USA portion of the basin. Maximum densities were 81, 149, and 26 fecal coliforms/100 mL at Fargo, Grand Forks, and Pembina, respectively. Downstream of the City of Winnipeg, fecal coliform densities exceeded the recreational water quality guidelines, but did not differ significantly from those normally measured in this reach.

Densities of the general or non-specific fecal streptococci group appeared higher than normal at Emerson near the United States / Canada border in samples collected by Environment Canada (Appendix 1, Figure 18). This is normally expected during flood events since some bacteria measured in the fecal streptococci test are native to soils and plants. These findings were similar to those reported by the USGS during monitoring conducted jointly with MPCA and North Dakota Department of Health. The USGS observed a maximum fecal streptococci density of 2,100 organisms/100 mL at a site upstream of Fargo, 10,900 organisms/100 mL at Grand Forks, and 9,380 organisms/100 mL at Pembina. Recent historical data (1982 - 1994) for the Red River showed a maximum fecal streptococci density of 1,500 organisms/100 mL at Halstad, downstream of Fargo, and 720 organisms/100 mL at Pembina. Thus, fecal streptococci during the flood of 1997 exceeded densities measured in recent years when better sewage treatment was in place.

Although the observed bacteria densities were not unusual for the Red River and many other prairie streams draining populated regions, densities were sufficient to significantly contaminate groundwater in localized areas south-east of the City of Winnipeg.

Bacterial monitoring during the summer months at the major Lake Winnipeg beaches indicated no major impact from flood waters on the quality of these recreational areas.

## Metals and other Trace Elements

Concentrations of extractable aluminum increased quickly with river flow from 0.544 to 2.6 mg/L between April 3, 1997 to April 22, 1997, respectively. Concentrations fluctuated until May 18, 1997 then appeared to decline with decreasing river flow (Appendix 1, Figure 19). The peak concentration of 3.33 mg/L was reached on May 1, 1997. Concentrations were within the range normally observed at Selkirk, but were generally higher than observed in previous years. Aluminum concentrations were positively correlated with river flow ( $p < 0.05$ ,  $r^2 = 0.31$ ) over the period of record. The clay soils located extensively within the Red River basin contain a large proportion of aluminum. Thus, observed concentrations of aluminum appeared to follow closely the concentration of suspended sediments.

Total arsenic concentrations increased quickly with river flow from 0.003 to 0.009 mg/L from April 3, 1997 to April 22, 1997. Concentrations fluctuated between 0.005 and 0.007 mg/L until peak concentrations of 0.01 mg/L were reached on July 3, 1997 (Appendix 1, Figure 20). In 1997, arsenic concentrations were within the upper part of the normal range observed over the period of record. Arsenic concentrations were positively correlated with river flow ( $p < 0.05$ ,  $r^2 = 0.11$ ) over the period of record. The Manitoba Surface Water Quality Objective for domestic consumption is 0.05 mg/L, similar to the water quality standards used by Minnesota and North Dakota. Concentrations did not exceed this level in 1997 or at any time during the period of record.

Extractable boron concentrations decreased quickly with increasing river flow in 1997, dropping from 0.08 to 0.03 mg/L between April 3, 1997 and April 22, 1997. Concentrations steadily increased to a peak of 0.09 mg/L on June 12, 1997 and then decreased to 0.05 mg/L in late summer. Boron concentrations have been steadily decreasing over the period of record, with some of the lowest concentrations observed at Selkirk in 1997 (Appendix 1, Figure 21). Boron concentrations were negatively correlated with river flow ( $p < 0.05$ ,  $r^2 = 0.41$ ) over the period of record. The Manitoba Surface Water Quality Objective for the protection of water used for irrigation is 0.5 mg/L, similar to the Minnesota standard. Concentrations have never reached this level at Selkirk over the period of record.

Extractable cadmium and hexavalent chromium have been detected very infrequently throughout the period of record at Selkirk. Cadmium was not detected in 1997, but hexavalent chromium was measured at 0.04 mg/L on one occasion during the 1997 flood. The Manitoba Surface Water Quality Objective for hexavalent chromium for protection of aquatic life (0.011 mg/L) is similar to the Minnesota standard and was exceeded by the one detection in 1997.

Extractable copper concentrations increased with river flow from 0.006 to 0.012 mg/L between April 3, 1997 and April 22, 1997, was variable until May 13, 1997, then appeared to decrease with river flow. Concentrations increased later in summer, reaching a maximum concentration on August 6, 1997 of 0.028 mg/L (Appendix 1, Figure 22). Copper concentrations were not correlated with river flow and were within the range normally observed over the period of record. The Manitoba Surface Water Quality Objective for the protection of aquatic life, generally equivalent to the standards used in North Dakota and Minnesota, was not exceeded in 1997.

Extractable iron concentrations increased with river flow from 0.34 to 2.42 mg/L between April 3, 1997 and April 24, 1997. Iron then decreased slightly but again increased to reach peak concentrations of 5.46 mg/L on May 13, 1997. Concentrations subsequently decreased with river flow (Appendix 1, Figure 23). Concentrations were similar to levels normally observed at Selkirk. Iron concentrations were positively correlated with river flow ( $p < 0.05$ ,  $r^2 = 0.29$ ) over the period of record. The Manitoba Surface Water Quality Objective for domestic consumption (0.30 mg/L) was exceeded during the flood; this, however, is not unusual during the ice-free period at this site.

Extractable lead concentrations increased quickly with river flow from 0.002 to 0.007 mg/L between April 3, 1997 and April 22, 1997, then fluctuated near 0.003 mg/L until a second peak of 0.007 occurred on July 3, 1997. Lead concentrations were higher during the 1997 flood than normally observed at Selkirk over the period of record (Appendix 1, Figure 24). There was a weak negative correlation with river flow ( $p < 0.05$ ,  $r^2 = 0.08$ ) over the period of record. Non-detections regularly form a large portion of lead data-set, but in 1997 these were limited to four of 28 samples. Observed concentrations of lead did not exceed the Manitoba Surface Water Quality Objective for the protection of aquatic life. The Manitoba Surface Water Quality Objective for lead is generally similar to the standards used by Minnesota and North Dakota.

Extractable manganese concentrations increased quickly with river flow from 0.067 to 0.544 mg/L between April 3, 1997 and April 22, 1997. Subsequently, concentrations decreased quickly, then ranged between 0.111 and 0.275 mg/L until late summer (Appendix 1, Figure 25). During the flood, concentrations were generally higher than normally observed at Selkirk. Manganese concentrations were positively correlated with river flow ( $p < 0.05$ ,  $r^2 = 0.16$ ) over the period of record. Manganese, similar to past years, was consistently higher in 1997 than the Manitoba Surface Water Quality Objective for domestic consumption (0.05 mg/L).

Total mercury in water samples collected at Emerson reached a maximum concentration of 0.015  $\mu\text{g/L}$  during flood stage in 1997 (Appendix 1, Figure 26). Concentrations fluctuated between  $< 0.005$  to 0.015  $\mu\text{g/L}$  during the flood period. The observed mercury concentrations were typical for water rich in

suspended sediment like the Red River and were within levels previously measured at Emerson. Mercury concentrations were weakly negatively correlated with river flow over the period of record ( $p < 0.05$ ,  $r^2 = 0.05$ ). The Manitoba Surface Water Quality Objective for acid soluble mercury is 0.006 µg/L. Concentrations detected at Emerson exceeded this on all but two sampling dates in 1997 (April 2, 1997 and May 5, 1997), however, such exceedances are not unusual for this site. A detection of mercury in water at this site represents an exceedance of the IJC Alert Level.

Extractable nickel concentrations increased with river flow from 0.003 to 0.012 mg/L between April 3, 1997 and April 22, 1997 at the Selkirk site. Concentrations fluctuated thereafter, eventually decreasing to a minimum of 0.004 mg/L by August 6, 1997. The maximum concentration for the entire period of record was observed on July 3, 1997, when nickel reached 0.031 mg/L. Nickel concentrations were generally within the range normally observed at this site, although detection frequencies were higher relative to other years (Appendix 1, Figure 27). Nickel concentrations were not correlated with river flow over the period of record. The Manitoba Surface Water Quality Objective for protection of aquatic life was not exceeded.

Extractable zinc levels increased slightly from 0.01 to 0.02 mg/L with increased river flow (Appendix 1, Figure 28). Concentrations remained at levels normally observed to at least early June, when analytical problems precluded further comparison, at least at the Selkirk MB site.

It appears that concentrations of most metals followed the hydrograph fairly closely. Metals were likely adsorbed to particulates in the water column. As particulate concentrations decreased in response to decreased river, flow metal concentrations also dropped.

### **Pesticides and Industrial Organochlorines**

Concentrations of total DDT increased from 0.21 to 0.40 ng/L between April 28, 1997 and April 30, 1997 at the Selkirk site. Concentrations were correlated with river flow ( $p < 0.05$ ,  $r^2 = 0.91$ ), peaking at 0.40 ng/L and decreasing to 0.04 ng/L by May 20, 1997 (Appendix 1, Figure 29). DDT and metabolites were detected six times at Emerson during the flood by Environment Canada at somewhat higher concentrations (range = 0.61 to 2.3 ng/L) than observed at Selkirk. Environment Canada has only detected DDTs once at Emerson from 1960 to 1996. Increased detection frequency observed at Emerson in 1997 is likely a result of decreased detection limits used by Environment Canada. Detection limit changes are shown in Table 1. The CCME water quality guideline for protection of aquatic life (1.0 ng/L) was not exceeded at Selkirk but was exceeded once at Emerson during the flood.

The ratio of the DDT metabolite (DDE) to parent compound (DDT) can be used to give an indication of the relative age of the DDT source. High ratios are indicative of older, metabolized DDT, while lower ratios indicate newer, parent compound. Ratios found in 1997 by DFO ranged from 0.5 to 1.5 demonstrating that the source was likely older DDT. DDT is not registered for use in either Canada or the United States. However, because of the persistent nature of DDT, trace residues in the environment are still relatively widespread. DDT may have been mobilized from flooded soils during the 1997 flood.

Although concentrations of total PCBs increased with river flow at the Selkirk site, there was no correlation with river flow. Concentrations increased from 0.31 ng/L, peaked at 1.31 ng/L on May 5, 1997, then subsequently decreased to approximately 0.20 ng/L during mid-summer 1997 (Appendix 1, Figure 30). Historical data at the detection limits used by DFO for these observations are not available, therefore, it is not possible to compare these data to previous years.

Total PCBs were detected by Environment Canada at Emerson during the flood of 1997; this is the first detection of total PCBs at this site in the 37 year period of record. The one observation of 25.2 ng/L would have been detected at the older, higher detection limit and, therefore, appears not simply to be an artifact of decreased detection limits. This observation exceeded the CCME guideline of 1 ng/L.

Individual PCB congeners 138, 149, 153, 174, 180 and 187, measured by DFO at Selkirk MB, all had very similar concentration patterns in 1997. Concentrations increased with river flow, peaked on May 5, 1997, then subsequently decreased in mid-summer. Historical data are unavailable for individual PCB congeners, therefore, it is not possible to compare the observed trend during the flood of 1997 to historical patterns. Increases with river flow may be related to the association of these relatively lipophilic compounds with suspended and dissolved organic matter in the river. PCB 49 concentrations fluctuated in 1997 and did not show the same pattern as the other congeners. PCB 49 is more hydrophilic than the other congeners.

Concentrations of dieldrin increased from 0.39 to a maximum of 0.55 ng/L between April 28, 1997 and April 30, 1997, respectively. Concentrations at the Selkirk site decreased to 0.36 ng/L by May 20, 1997 (Appendix 1, Figure 31) and were correlated with river flow ( $p < 0.05$ ,  $r^2 = 0.80$ ). Dieldrin was also detected five times by Environment Canada in samples collected from flood waters at Emerson (range = 0.66 to 2.94 ng/L). Dieldrin is an organochlorine pesticide that is no longer registered in Canada or the United States and has been detected very infrequently in the past. The CCME guideline for protection of aquatic life (4.0 ng/L) was not exceeded.

Total hexachlorocyclohexanes (HCH) increased from 4.14 ng/L and peaked at 4.91 ng/L between April 28, 1997 and May 5, 1997 (Appendix 1, Figure 32). Concentrations decreased with river flow to

3.46 ng/L by mid-summer, 1997. Concentrations, however, were not correlated with river flow ( $p < 0.05$ ). Lindane, one of the HCH isomers, formed approximately 74 to 88% of the total HCH concentrations, ranging from 3.1 to 4.0 ng/L. At Emerson, although  $\alpha$ -HCH and lindane concentrations were within the range observed during the historical period of record (Appendix 1, Figure 33), concentrations were generally higher in 1997 than observed in recent years. Concentrations of lindane at Emerson were not correlated with river flow. The CCME guideline for total hexachlorocyclohexanes of 10 ng/L was not exceeded.

Concentrations of total chlorobenzenes increased from 1.08 to a maximum of 9.55 ng/L during April 28, 1997 to April 30, 1997, then subsequently declined to 0.10 ng/L by mid-summer (Appendix 1, Figure 34). Concentrations were not correlated with river flow. Historical data are not available for comparison. Individual chlorobenzene isomers did not exceed CCME water quality guidelines.

Total chlordanes (sum of heptachlor, oxychlordanes, *trans*-chlordanes, *cis*-chlordanes, *trans*-nonachlor, *cis*-nonachlor, and heptachlor epoxide) increased slightly from 0.29 to a peak of 0.40 ng/L from April 28, 1997 to April 30, 1997, then decreased steadily to 0.18 ng/L by mid-summer at Selkirk (Appendix 1, Figure 35). Concentrations were highly correlated with river flow ( $p < 0.05$ ,  $r^2 = 0.98$ ).  $\gamma$ -chlordanes were detected twice by Environment Canada at Emerson at similar concentrations (0.34 and 0.36 ng/L). Water quality objectives or guidelines were not exceeded by chlordanes or related materials, although detection of any pesticide constitutes an exceedance of the IJC alert levels at the International border. Neither heptachlor nor chlordanes are registered for use in Canada or the USA and have not been detected in the Red River previously. However, the concentrations observed in the Red River during 1997 by both DFO and Environment Canada would not have been detected using their previous analytical methods.

Concentrations of methoxychlor decreased steadily from 0.36 to 0.08 ng/L between April 28, 1997 and May 20, 1997 (Appendix 1, Figure 36). Methoxychlor is rarely detected in Manitoba; prior to 1995 there were only two detections in all of Manitoba. Concentrations were not correlated with river flow. Decreased detection limits likely resulted in the observation of methoxychlor in the Red River in 1997. A water quality guideline for the protection of aquatic life has not been developed by CCME. The Manitoba Surface Water Quality Objective for protection of drinking water sources (0.9 mg/L) was not exceeded during the flood.

Endrin concentrations fluctuated between 0.08 and 0.12 ng/L from April 28, 1997 to May 5, 1997 at Selkirk, then decreased to 0.05 ng/L by May 20, 1997 (Appendix 1, Figure 37). Concentrations were not correlated with river flow. Endrin is rarely detected in the Red River at Selkirk. Endrin was also detected two times by Environment Canada at Emerson at concentrations of 0.69 and 1.45 ng/L.



Endrin has never been detected by Environment Canada over the period of record. Decreased detection limits likely resulted in the increased observation of endrin in the Red River during 1997. The CCME guideline for protection of aquatic life (2.3 ng/L) was not exceeded during the flood at any site.

Concentrations of the commonly used herbicide 2,4-D were within the range historically observed at the Selkirk site (Appendix 1, Figure 38) and were not related to river flow in 1997. Concentrations fluctuated between <0.05 to 0.17 µg/L, with increased detection frequency in early June. Concentrations of 2,4-D at Emerson were also within this range, however, there were more detections earlier in the season than at Selkirk (Appendix 1, Figure 39). Similar to the Selkirk site, 2,4-D concentrations were not correlated with river flow over the period of record at the Emerson site. Over the period of record, 2,4-D concentrations occasionally increased in response to increased river flow (e.g., 1993), but application times coincident with increased water flow likely contributed to the movement of 2,4-D into the Red River. Increased concentrations of 2,4-D, measured in early June at Selkirk in 1997, were likely the result of movement into the river following recent use. Because of the timing of 2, 4-D detections, concentrations measured at Emerson may be flood related whereas those at Selkirk may be related to normal losses from recent use. The CCME guideline of 4.0 µg/L for the protection of aquatic life was not exceeded.

Concentrations of most pesticides currently in use were not detectable in the Red River at the Selkirk site during the flood of 1997. Over the period of record, 2,4-D, dicamba, bromoxynil, trifluralin, atrazine, MCPA, γ-HCH (lindane) and its non-insecticidal isomer α-HCH have been detected at Selkirk. Dicamba was detected two times in 1997 at concentrations similar to those observed previously over the period of record. Bromoxynil, trifluralin, atrazine, MCPA were not detected during the flood of 1997 at Selkirk using conventional sampling and analytical techniques employed by Manitoba Environment. However, 2,4-D, trifluralin, triallate and lindane were detected in the Red River at Emerson. Their detection in water during the flood was not unexpected. However, the maximum atrazine level measured in 1997 at Fargo (0.145 µg/L) was higher than the maximum observed during the 1993-1995 spring period (0.033 µg/L) (Brigham and Lorenz 1997). Atrazine was not detected by Environment Canada at Emerson, likely due to an increase in detection limit from 0.05 to 0.24 µg/L (Table 1).

Atrazine, deethylatrazine, and metolachlor were detected in all samples from the Red River at various sites in North Dakota. Simazine, cyanazine, trifluralin, EPTC, triallate, pendimethalin, acetochlor, alachlor, metribuzin, and malathion were also detected in the Red River at some sites in North Dakota during 1997. These compounds have been routinely detected at trace levels (always < 1 µg/L) in the Red River upstream of Fargo ND and at Emerson MB from 1993 - 1995 (Tornes *et al.* 1997).

Dieldrin,  $\gamma$ -chlordane, endrin, *o,p'*-DDT, *p,p'*-DDT, and total PCBs were detected in the Red River in 1997 by Environment Canada at Emerson but were not detected in previous years by this agency. It is difficult to determine whether these pesticides were detected as a result of decreased detection limits or as a result of their increased presence in the water during the flood. Using older analytical methods heptachlor epoxide,  $\gamma$ -chlordane, endrin, *o,p'*-DDT, and *p,p'*-DDT would not have been detected in 1997 at the higher detection limits. In addition, several other pesticides would not have been observed, including  $\alpha$ -HCH, lindane, dieldrin, and *p,p'*-DDE (Table 6), suggesting that these compounds were detected as a result of increased analytical sensitivity.

Pentachlorophenol concentrations ranged from <0.02 to 0.031  $\mu\text{g/L}$  at the Selkirk site. Pentachlorophenol, a wood preservative, has not been previously detected at this site; it may have been mobilized during the flood from inundation of treated railway ties, fence posts, utility poles, and bridge works.

Pesticides that have been detected in previous years at Emerson but not in 1997 are shown in Table 7. These pesticides were either: 1) diluted with increased volume of water during 1997 and were subsequently not detected; 2) detected infrequently over the period of record; or 3) detected in decreasing quantities over the period of record.

### **Volatile Organic Carbon Compounds**

Petroleum (gasoline or fuel oil) was observed on the river surface throughout the Red River basin. Volatile organic compounds (VOCs) compounds are normally found in various types of fuels, gasolines, or oils. Volatile organic compounds were analyzed by the USGS in samples from Grand Forks and Pembina. A number of VOCs such as alkylbenzenes, naphthalene, and xylenes (ortho, meta, and para) were detected in some samples from North Dakota. Four samples were collected from each site: three samples near the peak of the flood (one from the east overflow, one from the main channel, and one from the west overflow), and one sample was collected about 1 - 2 weeks after the flood peak. Most VOCs targeted in the analysis were not detected, while only a few of those detected were measured at concentrations greater than the detection limit (Table 8). Traces of some VOCs were identified in most samples but at concentrations below detection limits (detection limits ranged from 0.05 to 10  $\mu\text{g/L}$ , depending upon the compound). These are shown in Table 8 as estimated values. Estimated concentrations inherently have greater uncertainty compared to concentrations quantified above the detection limit.

Table 6. Number of detections of pesticides in 1997 by Environment Canada at Emerson compared to the number of detections should older analytical methods with higher detection limits have been used.

Compound	1997 Detections	# Detected using Old DL
$\alpha$ -HCH	4	1
lindane	6	3
hepatachlor epoxide	2	0
$\gamma$ -chlordane	2	0
dieldrin	5	1
<i>p,p'</i> -DDE	4	3
endrin	2	0
<i>o,p'</i> -DDT	1	0
<i>p,p'</i> -DDT	1	0
total PCBs	1	1
2,4-D	2	2
trifluralin	2	2
triallate	2	2

Table 7. Pesticides detected from 1960 to 1996 but not 1997 in the Red River at Emerson by Environment Canada.

Compound	detections	# samples	% detection	min. µg/L.	max. µg/L
HCB	1	209	0.48	0.0007	0.0007
<i>p,p'</i> -TDE	1	208	0.48	0.002	0.002
α-chlordane	1	208	0.48	0.0004	0.0004
mirex	1	208	0.48	0.001	0.001
aldrin	1	208	0.48	0.0007	0.0007
atrazine-total	45	138	32.61	0.05	0.688
2,4,5-T	11	249	4.42	0.002	0.06
2,4-DP	17	250	6.80	0.007	0.41
MCPA	19	249	7.63	0.03	0.36
dicamba	4	150	2.67	0.03	0.2
2,4-DB	2	250	0.80	0.013	0.13
picloram	7	212	3.30	0.05	0.2
bromoxynil	3	105	2.86	0.05	0.27

Table 8. Range of concentrations ( $\mu\text{g/L}$ ) of total volatile organic compounds detected in the Red River in North Dakota in 1997.

	Grand Forks		Pembina	
	Number of Detections	Maximum	Number of Detections	Maximum
<u>Petroleum-related Volatile Organic Compounds</u>				
1,2,3-trimethylbenzene	2	0.07 (estimated)	1	0.004 (estimated)
1,2,4-trimethylbenzene	4	0.23	3	0.02 (estimated)
1,3,5-trimethylbenzene	1	0.05 (estimated)	0	less than detection limit
benzene	2	0.21	1	0.02 (estimated)
ethylbenzene	3	0.1 (estimated)	1	0.007 (estimated)
isodurene	1	0.04 (estimated)	0	less than detection limit
isopropylbenzene	1	0.007 (estimated)	0	less than detection limit
n-butylbenzene	1	0.01 (estimated)	0	less than detection limit
n-propylbenzene	1	0.02 (estimated)	0	less than detection limit
naphthalene	3	0.33	0	less than detection limit
<i>m</i> and <i>p</i> xylene	4	0.42	1	0.02 (estimated)
<i>o</i> -xylene	4	0.1 (estimated)	0	less than detection limit
prehnitene	1	0.05 (estimated)	0	less than detection limit
toluene	3	0.62	1	0.08 (estimated)
<i>o</i> -ethyltoluene	1	0.04 (estimated)	0	less than detection limit
<u>Other Volatile Organic Compounds</u>				
Freon-113	1	0.01 (estimated)	0	less than detection limit
acetone	1	1.0 (estimated)	3	2.0 (estimated)
carbon disulfide	1	0.05 (estimated)	3	0.03 (estimated)
chloroform	1	0.01 (estimated)	0	less than detection limit
methyl chloride	1	0.03 (estimated)	3	0.05 (estimated)
methyl ethyl ketone	3	3.65	1	0.4 (estimated)
methylene chloride	3	0.31	1	0.03 (estimated)
tetrachloroethylene	1	0.002 (estimated)	0	less than detection limit
trichloroethane	2	0.004 (estimated)	1	0.002 (estimated)
trichloroethylene	2	0.007 (estimated)	1	0.009 (estimated)

Most of the VOCs detected were likely from petroleum sources. VOCs were rarely detected upstream of Grand Forks ND (Table 8) suggesting that the source of these compounds was Grand Forks ND when it was flooded. The sample with the greatest number of detected VOC compounds (15) and the greatest total concentration (2.06 µg/L) of petroleum-related VOCs was a composite west overflow sample from Grand Forks. Highest concentrations of VOCs were for the ketone solvents acetone and methyl ethyl ketone (Table 8).

Ortho-, para-, and meta-xylene, toluene, benzene, or ethylbenzene were not detected in the water column in the Red River at Selkirk, nor at a site located upstream of the City of Winnipeg near the South Perimeter highway. Detection limits, however, were slightly higher at the Selkirk site relative to data generated by the USGS in the USA portion of the basin. These compounds either may have volatilized into the atmosphere prior to reaching the northern portion of the basin or may have been present at low concentrations but not detected. Total extractable hydrocarbon concentrations ranged from <50 to 1700 µg/L.

Chlorinated solvents such as methyl chloride, methylene chloride, trichloroethane, and trichloroethylene were found in trace amounts in some samples at concentrations <1 µg/L at various sites in North Dakota (Table 8). Methyl ethyl ketone was detected at 0.4 to 3.7 µg/L at Grand Forks and Pembina ND, respectively, while acetone was measured at 1 to 2 µg/L at these sites. Available water quality objectives for VOCs were not exceeded during the flood.

### **Other Environmental Quality Issues**

#### **Groundwater and Farmstead Reservoir Contamination**

Flood waters contaminated a large number of private wells used for sources of drinking water primarily in the region south and east of the City of Winnipeg (e.g., Grande Point MB). Fecal coliform, *Escherichia coli*, and total coliform densities were elevated, requiring extensive remediation of about 250 wells to meet human consumption guidelines. In Grande Pointe MB, total coliform counts in groundwater ranged from 1 to >2000 organisms/100 mL, with *E. coli* densities ranging from 0 to 95 organisms/100 mL. High bacteria counts were also found in some wells close to private septic fields.

Flood waters entered the aquifer through both in-use and improperly sealed abandoned wells. If not protected, groundwater wells can provide a direct conduit to the underlying aquifers during flood events. Generally, the higher the potential pumping capacity of the well, the greater the potential for aquifer pollution during periods of flooding. Some abandoned wells were covered with up to 2.5 m of

standing water for extended periods. In one instance, flood water flowed into the aquifer through an abandoned well for about four consecutive days at such a rate that a vortex formed over the well casing.

A number of improperly abandoned wells were found in the Grande Pointe MB area. As well, a number of other problem wells were located, such as pit-type wells, well casings damaged by boats during the flood, and wells left outside of constructed sandbag dikes. Immediately after the flood, 36 abandoned wells in the region were permanently sealed, and an additional 17 wells were equipped with proper seals.

Flood waters also resulted in the movement of suspended sediment and plant nutrients (*e.g.*, phosphorus), into farmstead reservoirs. In response, coagulation techniques were used to help mitigate and speed recovery. Coagulation involved the mixing of liquid aluminum sulphate into the affected pond to reduce phosphorus, dissolved organic carbon, and suspended sediment. Treatments provided a temporary measure that resulted in improved water quality for periods as long as 2 to 10 months. It was estimated that about 400 farm reservoirs were affected. Treatment was provided to about 120 of the affected reservoirs.

#### **Red River and Upper Mississippi Basin Hydraulic Connection**

The southern portion of the Red River basin at Lake Traverse and the northern portion of the Minnesota River basin at Big Stone Lake were connected for a period of time during the flood of 1997. Flow between the two basins during this time was estimated to be small. Interbasin exchange of water is a concern because of the increased potential for the transfer of non-indigenous species.

## CONCLUSIONS

A better understanding has been gained of short-term water quality impacts arising from the major flood that occurred in the Red River basin during spring, 1997. Key observations were as follows:

- many water quality variables were correlated with discharge and reached maxima (*e.g.*, suspended sediment) or minima (*e.g.*, major ions) values at peak flood discharge.
- concentrations of most water quality variables remained within ranges previously observed during the approximate 30 year historical record, although the bounds of these ranges were approached.
- when comparisons were made to applicable water quality standards, objectives, guidelines, and alert levels, two patterns emerged. First, those materials that have typically exceeded standards, objectives, guidelines, or alert levels in the past, continued to do so during the spring flood of 1997. Second, with few exceptions, materials not routinely detected but measured during the flood of 1997 did not exceed standards, objectives, guidelines, or alert levels. In those few cases where exceedances did occur, it is thought that water uses would not have been unacceptably affected.
- peak loading of suspended sediment to Lake Winnipeg during the spring flood of 1997 was about 125,000 tonnes/day. Peak loadings of nitrogen and phosphorus were approximately 890 and 200 tonnes/day, respectively.
- peak loadings of the persistent organochlorine compounds chlorobenzene, hexachlorocyclohexane, chlordane, DDT, and PCB in the aqueous phase to Lake Winnipeg were 2.4, 1.5, 0.1, 0.1, and 0.4 kg/day, respectively.
- several organochlorine compounds were detected in the Red River at the international border during the flood of 1997 that had not been detected previously. These arose in some cases because of increased analytical sensitivity utilized in 1997 relative to the methods used previously, and in other cases, likely because of mobilization of persistent residues from previously undisturbed soils.
- pentachlorophenol, a wood preservative, was detected during spring 1997 but had not been detected previously. Pentachlorophenol likely arose from inundation of treated bridges, fence posts, utility poles, railway ties, or other wood structures.
- fecal-related bacteria densities increased initially at most sampling locations, then declined to the range normally observed during the spring-runoff period.
- bacteria densities, although within the normal range previously observed in the Red River, were sufficiently high to contaminate groundwater in the region south and east of the City of Winnipeg. Flood waters entered the aquifers through abandoned wells, improperly sealed in-use wells, or wells with above-ground structures damaged during the flood. Remediation efforts were undertaken to



treat the contaminated aquifers, to permanently seal abandoned wells, and to properly seal in-use wells.

Additional investigations aimed at gaining a better understanding of longer-term impacts are warranted, particularly those that may arise in Lake Winnipeg. Longer-term impacts may result from the large volume of flood water entering Lake Winnipeg containing low nitrogen/phosphorus ratios, from movement of persistent organochlorines such as toxaphene through the aquatic food chain, or from disruption of the lower food web by the large sediment load.

## REFERENCES

- Brigham, M.E., and D.L. Lorenz. 1997. Water quality in the Red River of the north during the spring flood of 1997, pp. 30. In: J.H. Hartman (ed.), Proceedings of the North Dakota Academy of Science, Vol. 51, Suppl. 1. Symposium on the Red River Flood of 1997 Involving Science in Future Watershed Management Decisions. 89<sup>th</sup> Annual Meeting September 15-16, 1997, Grand Forks ND.
- CCME. 1987 (and subsequent updates). Canadian Water Quality Guidelines. Canadian Council of Resource and Environment Ministers. Environment Canada, Ottawa, ON.
- Connor, B.F., D.L. Rose, M.C. Noriega, L.K. Murtagh, and S.R. Abney. 1998. Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory -- Determination of 86 volatile organic compounds in water by gas chromatography/mass spectrometry, including detections less than reporting limits. U.S. Geological Survey Open File Report 97-829.
- Currie, R.S., and D.A. Williamson. 1995. An assessment of pesticide residues in surface waters of Manitoba, Canada. Water Quality Management Section. Manitoba Environment. Report #95-08.
- Glassmeyer, S.T., K. Brice, D.S. DeVault, and R.A. Hites. 1997. Toxaphene in Great Lakes fish and air. Organohalogen Compounds 33:28-33.
- International Red River Pollution Board. 1996. Thirty-sixth Progress Report to the International Joint Commission. Appendix B. Water Quality Objectives and Alert Levels.
- International Red River Pollution Board. 1997. Thirty-seventh Progress Report to the International Joint Commission.
- Seastar Instruments Ltd. 1987. Instruction Manual for Seastar in situ water sampler system model B300. File SR-16. Seastar Instruments Ltd. Sidney, BC.
- Sorba, E.A. 1989. Compendium of approved analytical methods. W.M. Ward Technical Services Laboratory, Manitoba Department of Environment. Winnipeg, Manitoba.
- Tornes, L.H., M.E. Brigham, and D.L. Lorenz. 1997. Nutrients, suspended sediment, and pesticides in streams of the Red River of the North Basin, Minnesota, North Dakota, and South Dakota, 1993-95. U.S. Geological Survey Water-Resources Investigations Report 97-4053.
- U.S. EPA (United States Environmental Protection Agency). 1997. Pollution Report, Red River Valley Floods. POLREP 20 and Final Report. Ref. # 8EPR-ER.

- Warkentin, A.A. 1997. The Red River flood of 1997. pp. 1-4. In: Proceedings of the Red River Valley '97 Flood Symposium "The Flood of the Century". October 22 and 23, 1997, Winnipeg, Manitoba. Canadian Water Resources Association.
- Williamson, D.A. 1988. Manitoba Surface Water Quality Objectives. Water Standards and Studies. Manitoba Environment.
- Williamson, D.A., and C.E. Hughes. 1992. Quality assurance report: paired sampling on the Red River at Selkirk, 1989-1992. Canada-Manitoba Water Quality Monitoring Agreement. Water Quality Management Section Report #92-9. Manitoba Department of Environment.
- Williamson, D.A., M.P. Boychuk, and M.T. Ledoux. 1992. Water quality assessment of the Turtle River and two tributaries, Manitoba, Canada. Manitoba Environment and Turtle River Watershed Conservation District. Water Quality Management Report 92-5.

# **Appendix 1**

**Water Quality Variables in Red River Plotted with Discharge**

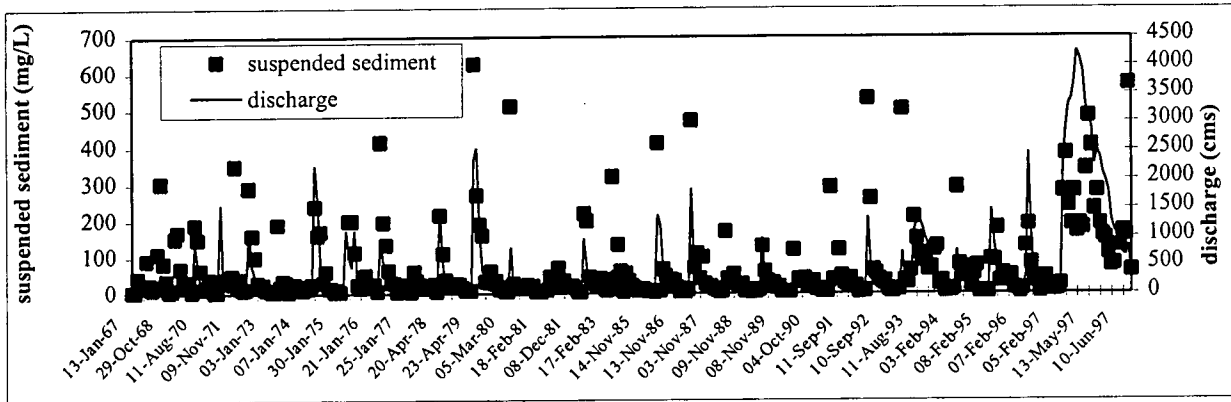


Figure 1: Historical concentrations of suspended sediments in the Red River at Selkirk MB.

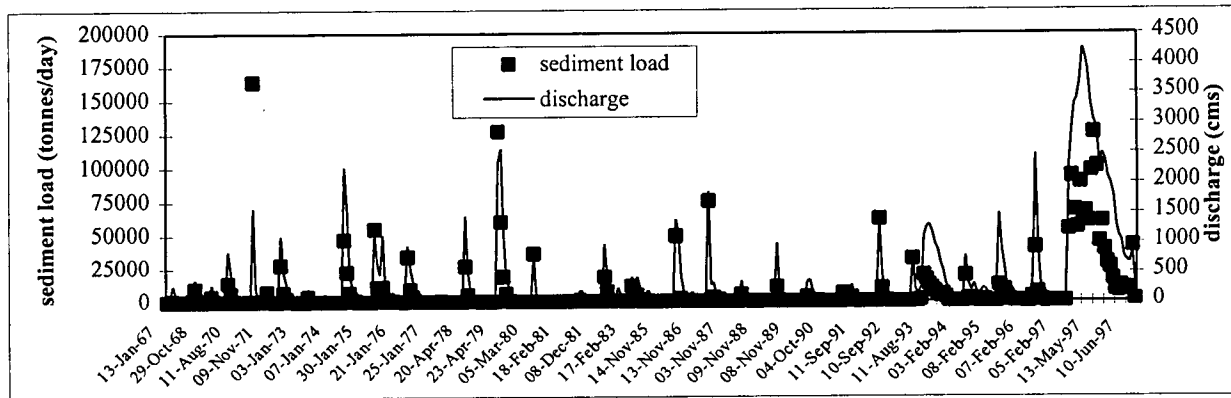


Figure 2: Historical sediment loads in the Red River at Selkirk MB.

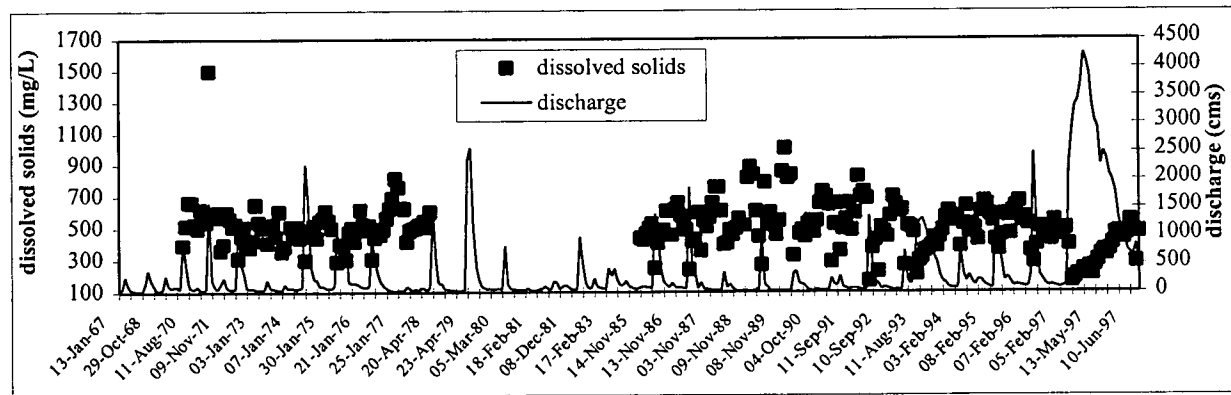


Figure 3: Historical concentrations of dissolved solids in the Red River at Selkirk MB.

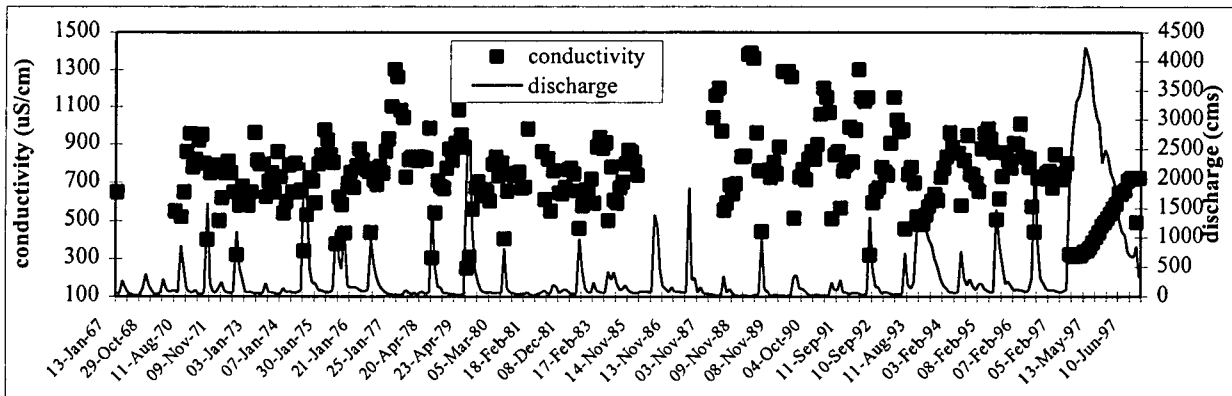


Figure 4: Historical conductivity in the Red River at Selkirk MB.

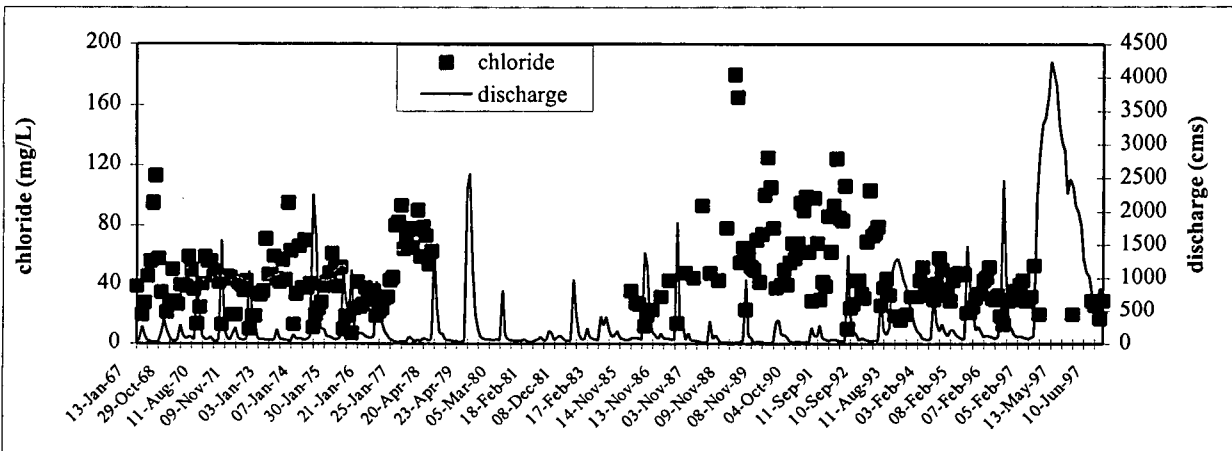


Figure 5: Historical concentrations of chloride in the Red River at Selkirk MB.

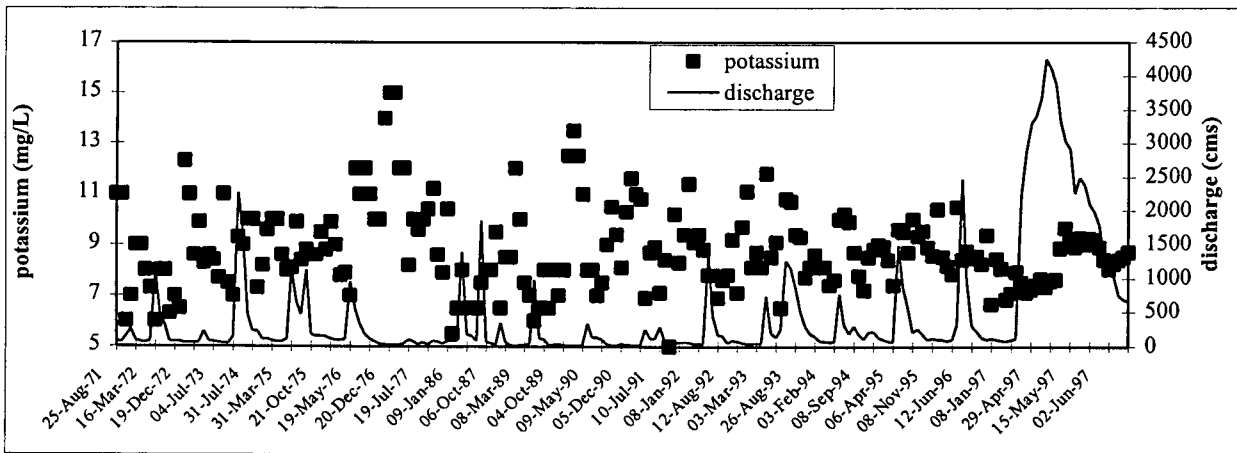


Figure 6: Historical concentrations of potassium in the Red River at Selkirk MB.

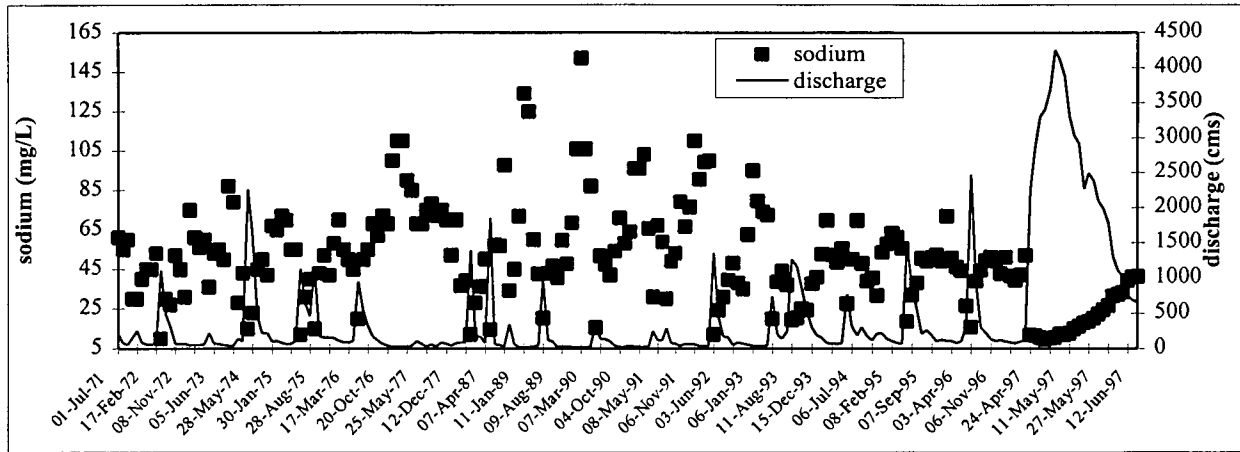


Figure 7: Historical concentrations of sodium in the Red River at Selkirk MB.

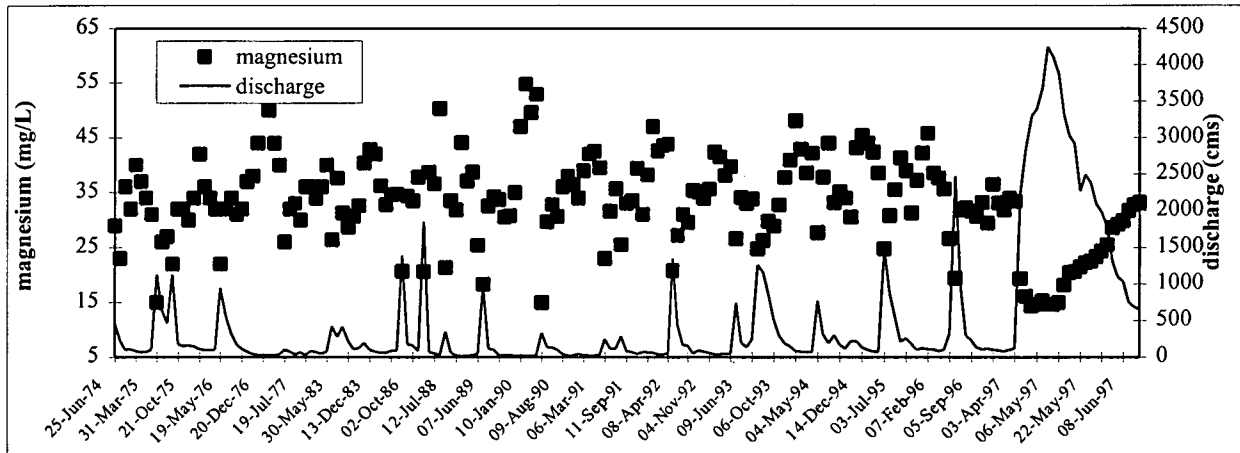


Figure 8: Historical concentrations of magnesium in the Red River at Selkirk MB.

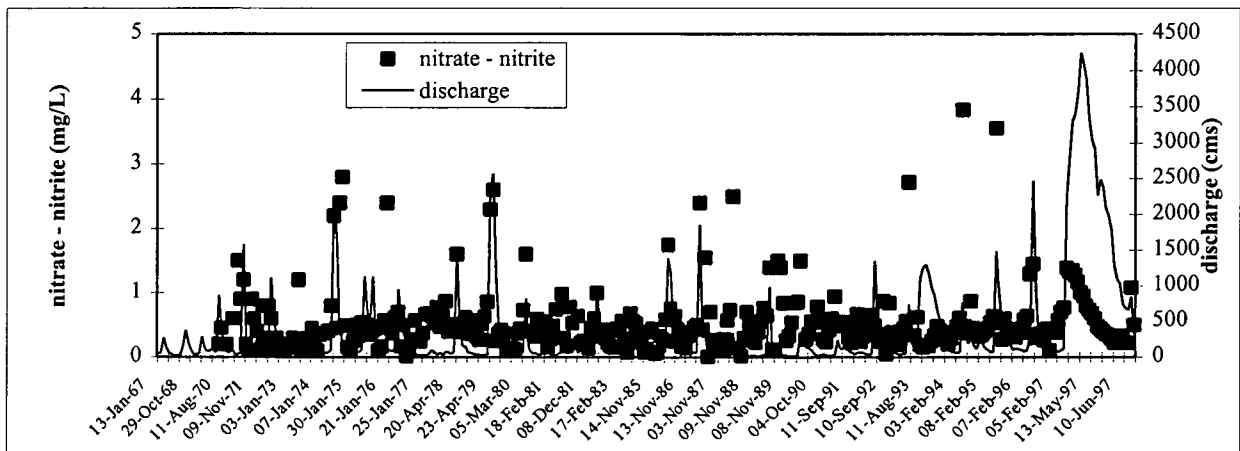


Figure 9: Historical concentrations of nitrate-nitrite in the Red River at Selkirk MB.

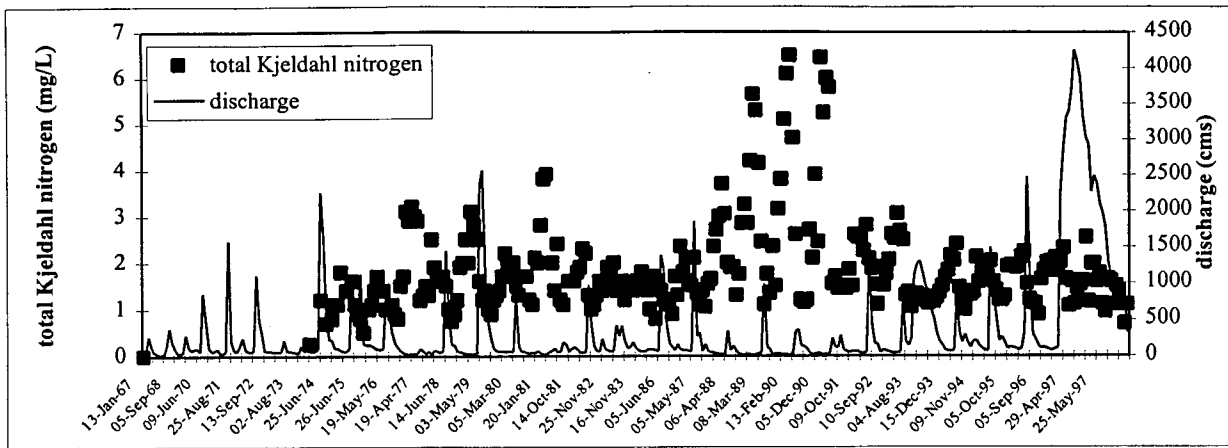


Figure 10: Historical concentrations of total Kjeldahl nitrogen in the Red River at Selkirk MB.

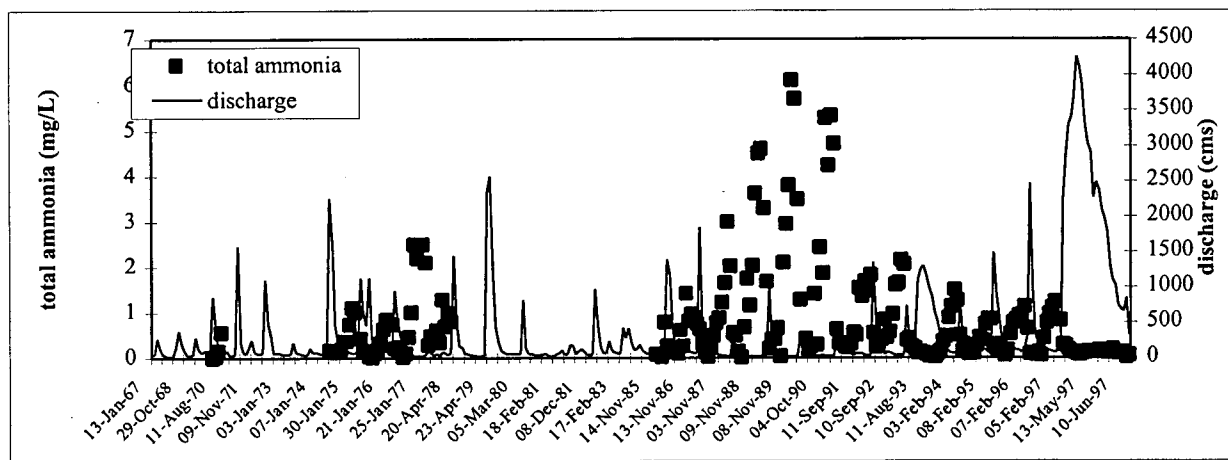


Figure 11: Historical concentrations of total ammonia in the Red River at Selkirk MB.

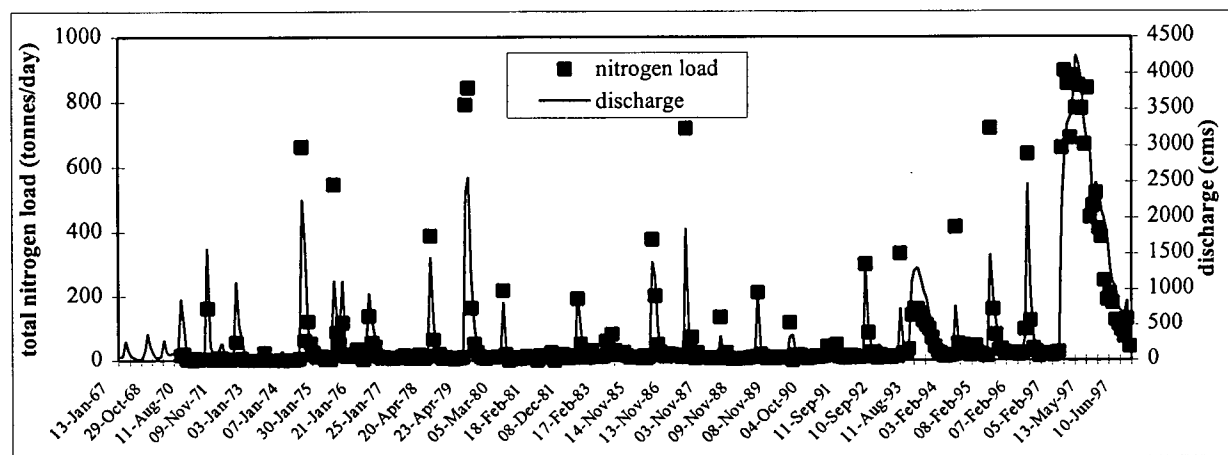


Figure 12: Historical nitrogen loads in the Red River at Selkirk MB.



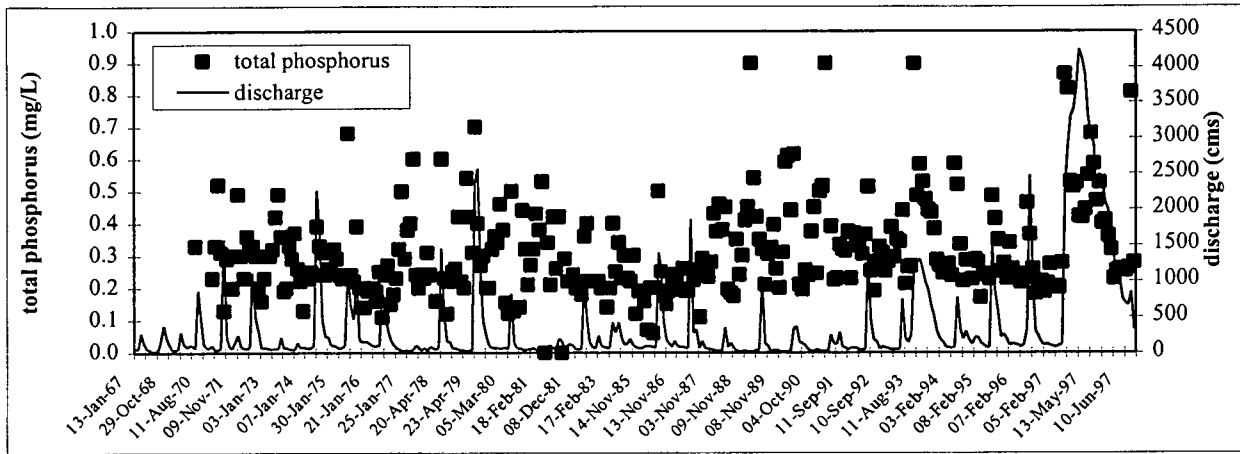


Figure 13: Historical concentrations of total phosphorus in the Red River at Selkirk MB.

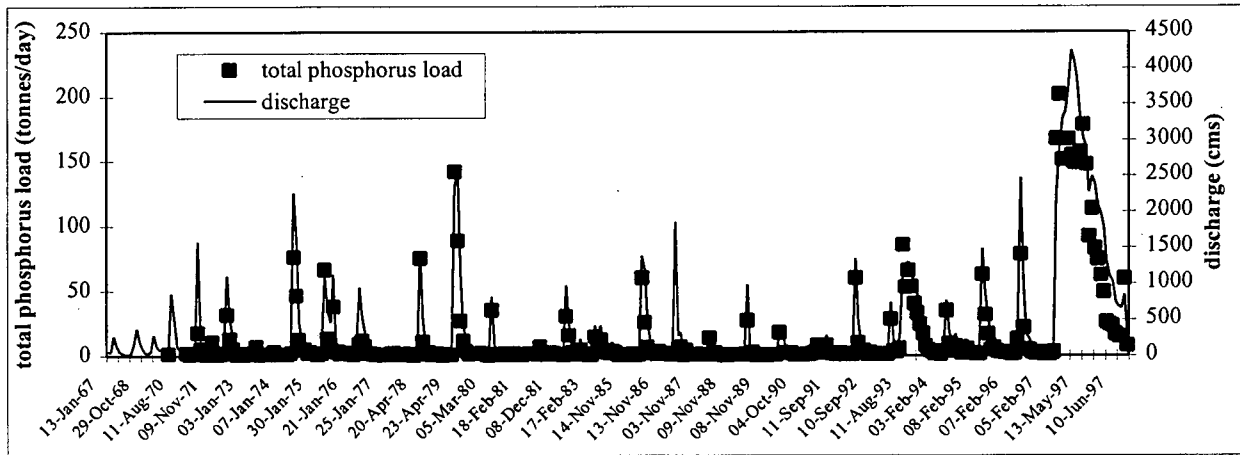


Figure 14: Historical total phosphorus loads in the Red River at Selkirk MB.

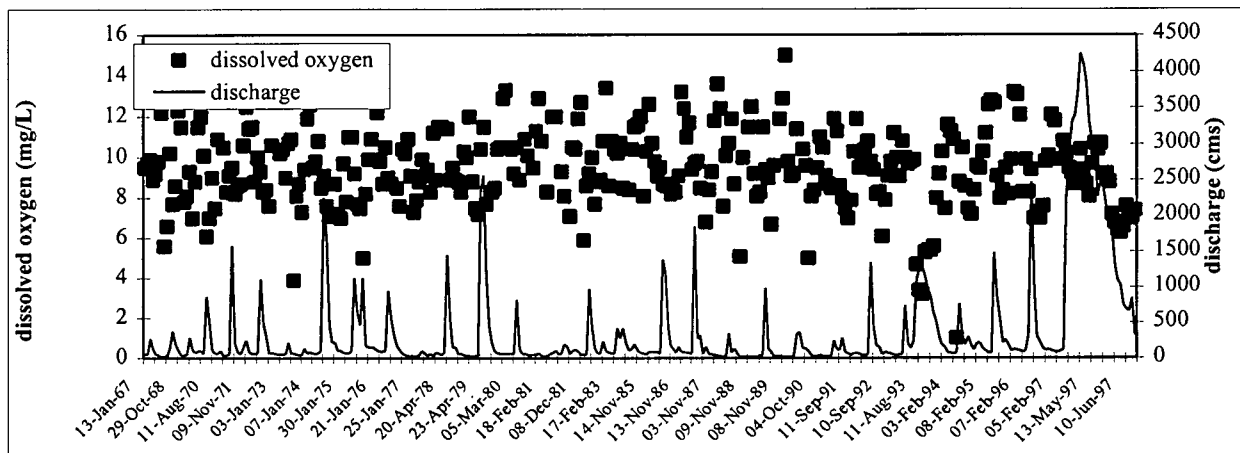


Figure 15: Historical concentrations of dissolved oxygen in the Red River at Selkirk MB.

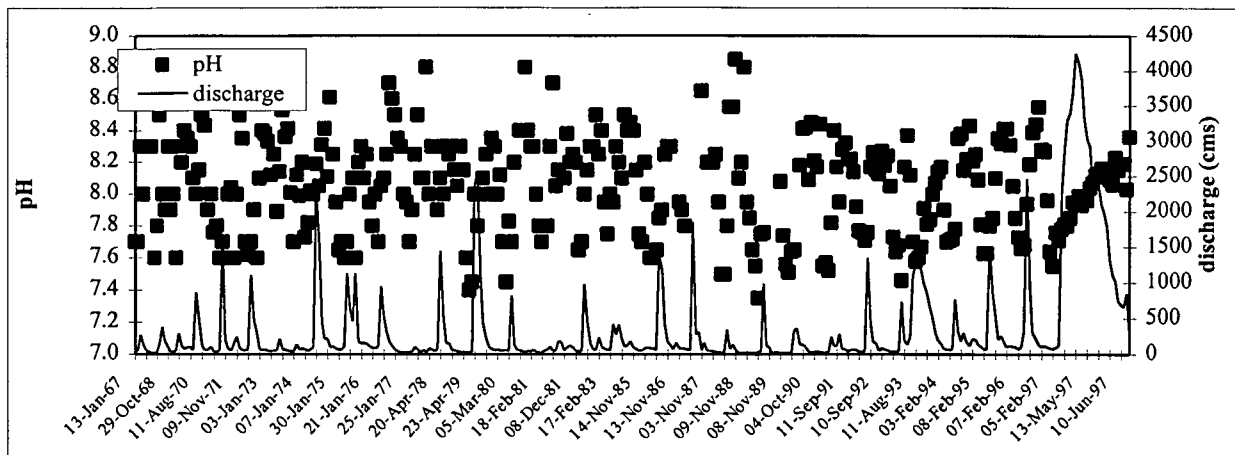


Figure 16: Historical pH in the Red River at Selkirk MB.

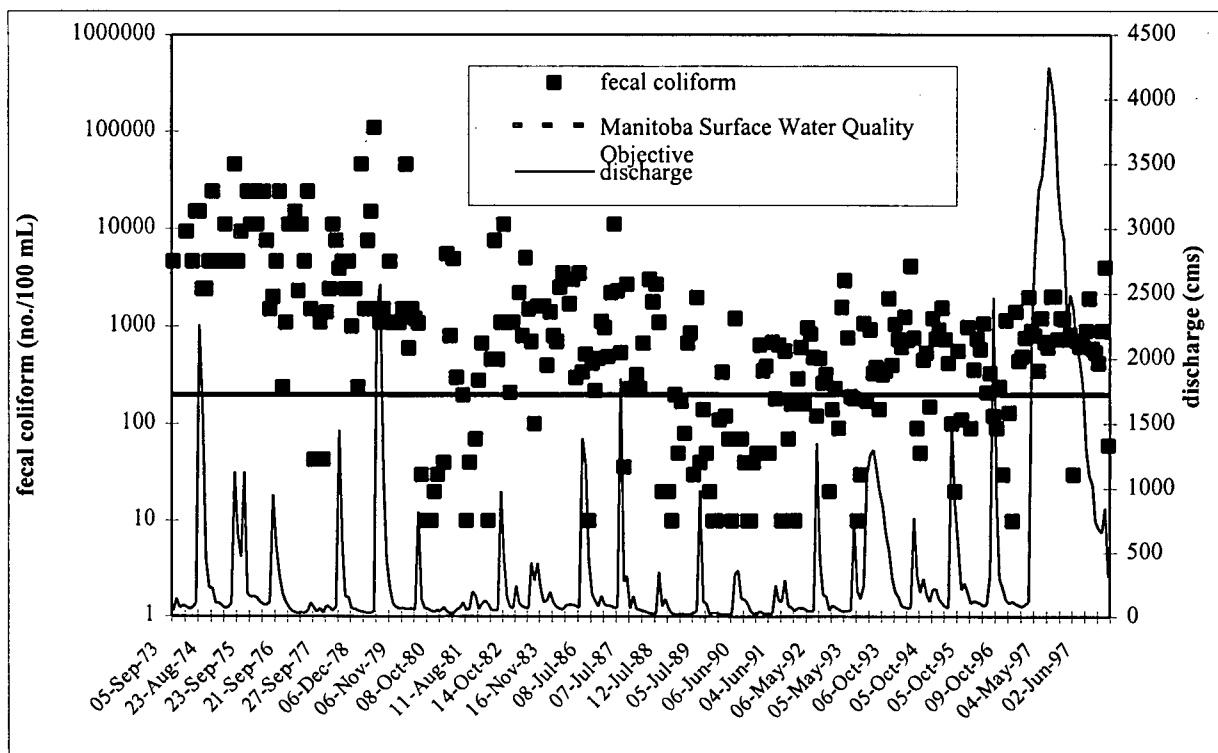


Figure 17: Historical densities of fecal coliform bacteria in the Red River at Selkirk MB.

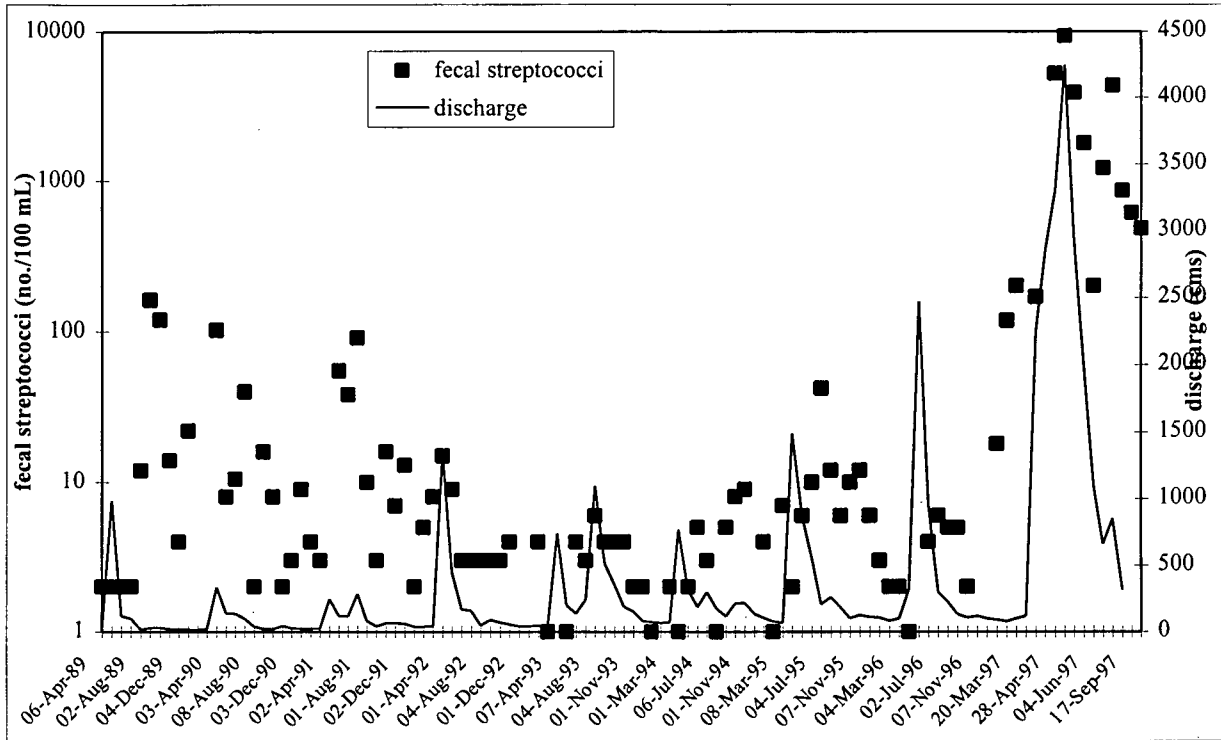


Figure 18: Historical densities of fecal streptococci bacteria in the Red River at Selkirk MB.

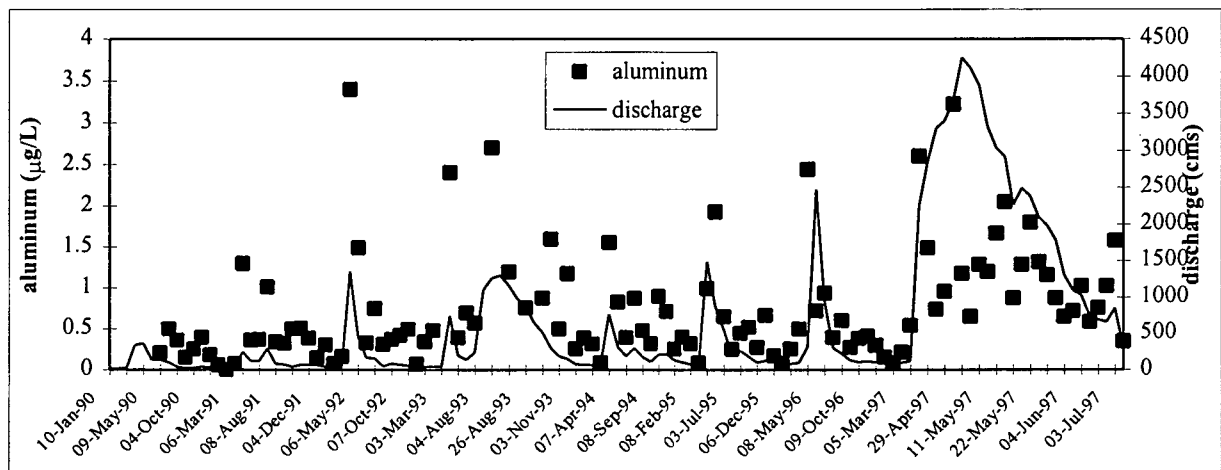


Figure 19: Historical concentrations of aluminum in the Red River at Selkirk MB.

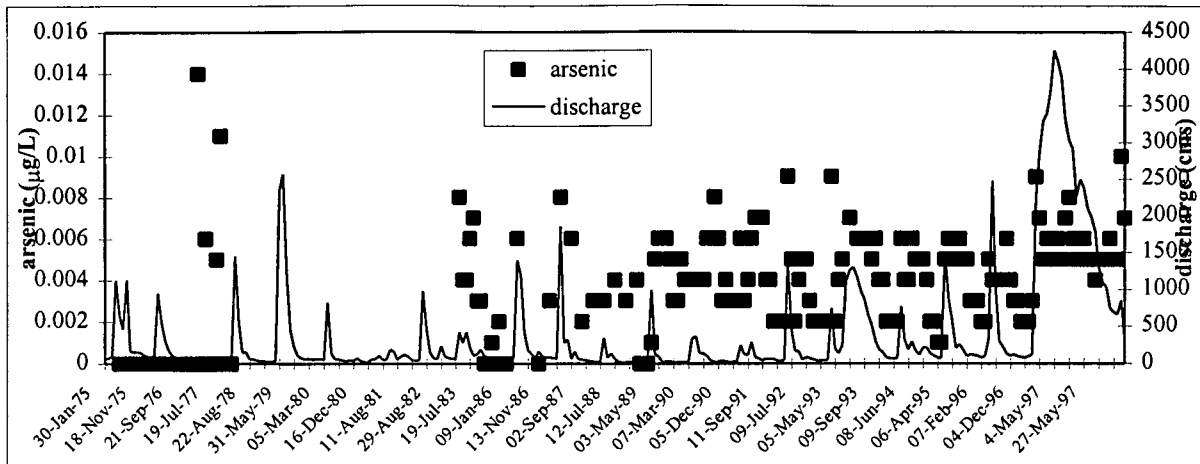


Figure 20: Historical concentrations of arsenic in the Red River at Selkirk MB.

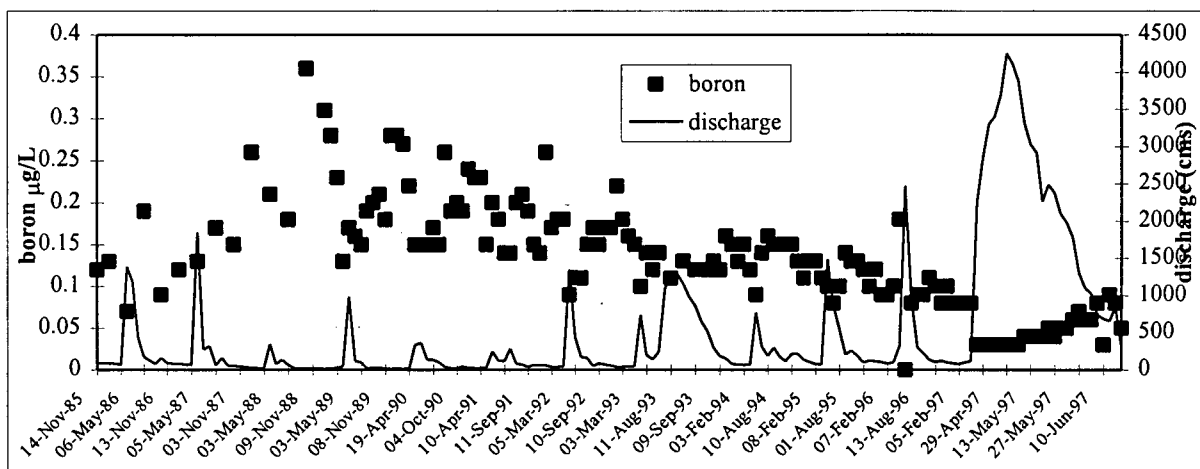


Figure 21: Historical concentrations of boron in the Red River at Selkirk MB.

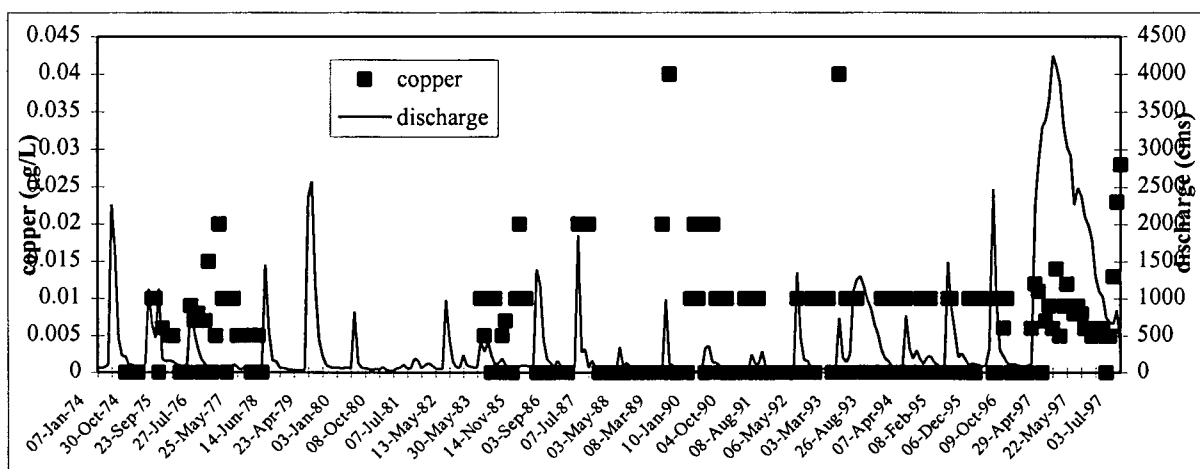


Figure 22: Historical concentrations of copper in the Red River at Selkirk MB.

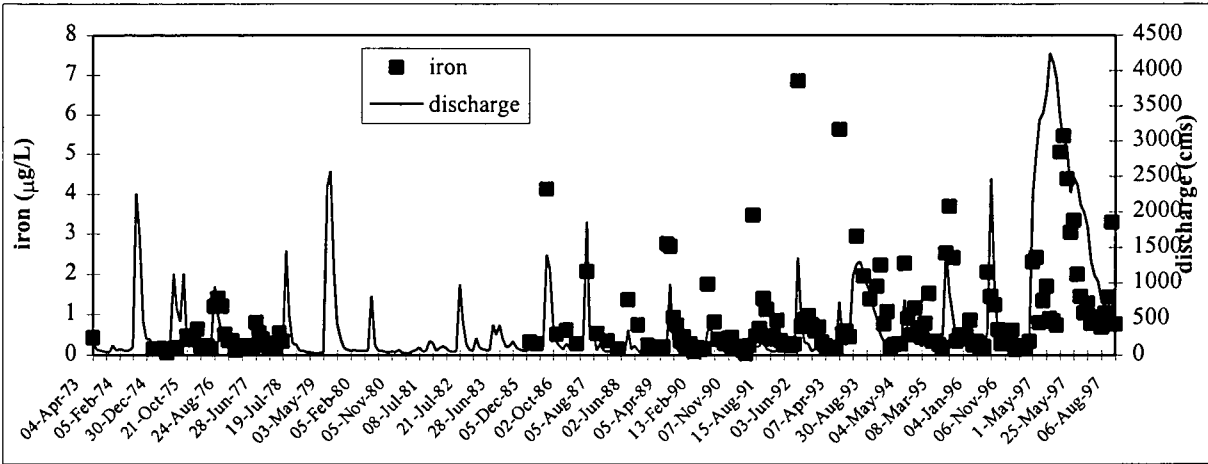


Figure 23: Historical concentrations of iron in the Red River at Selkirk MB.

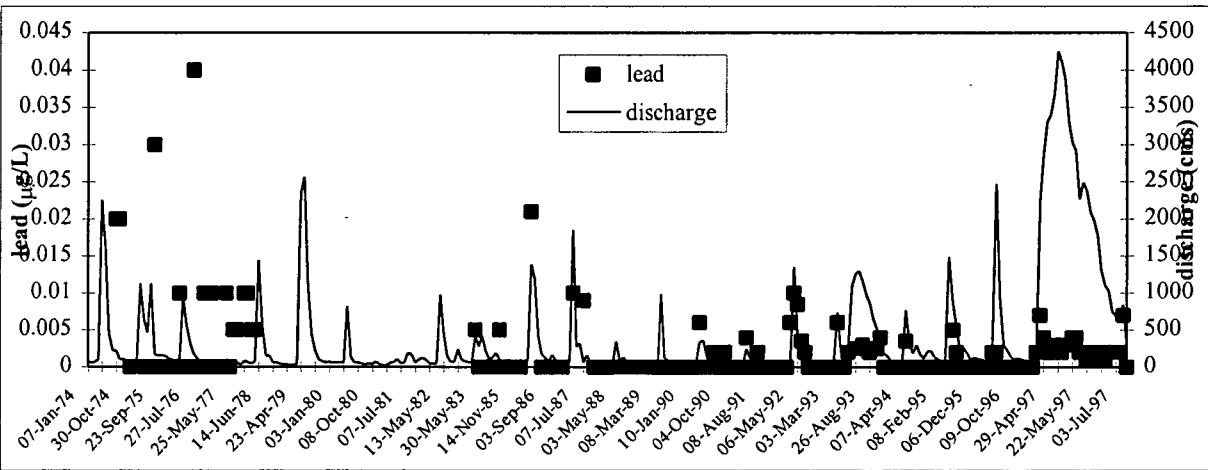


Figure 24: Historical concentrations of lead in the Red River at Selkirk MB.

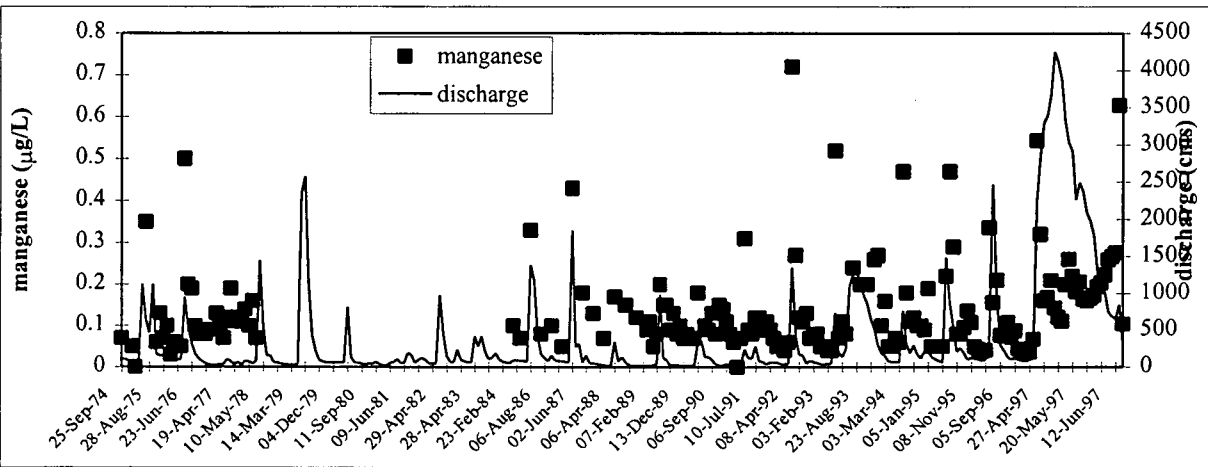


Figure 25: Historical concentrations of manganese in the Red River at Selkirk MB.

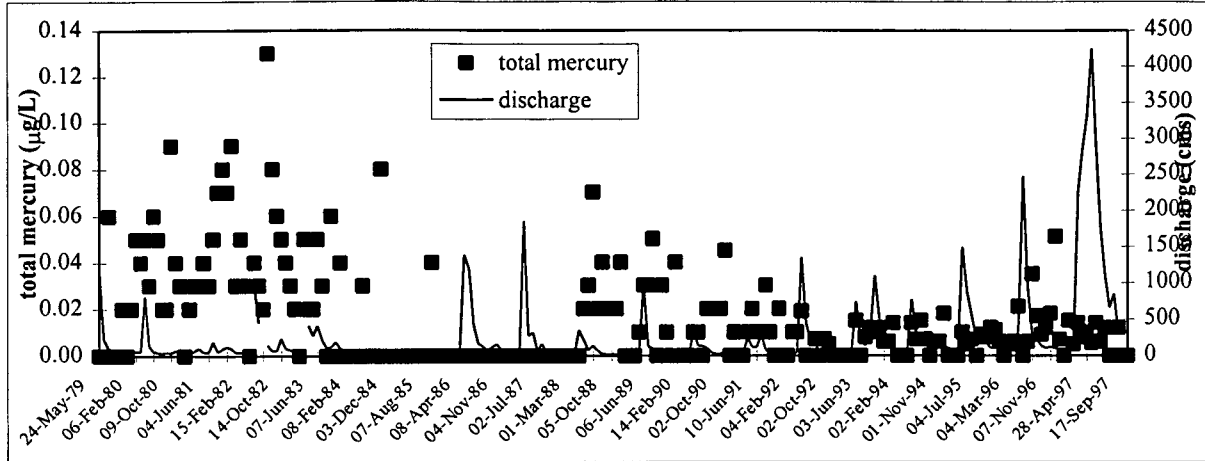


Figure 26: Historical concentrations of mercury in the Red River at Emerson MB.

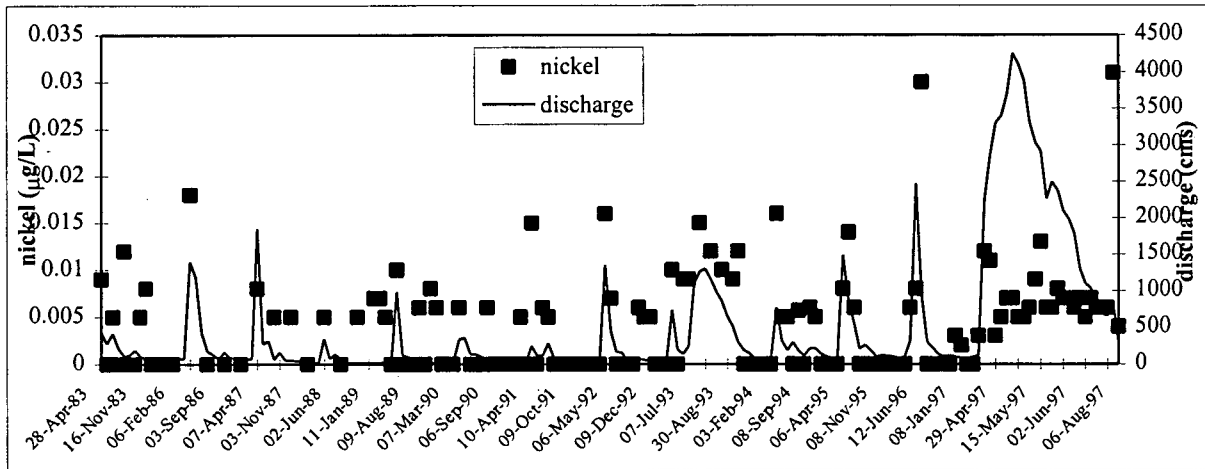


Figure 27: Historical concentrations of nickel in the Red River at Selkirk MB.

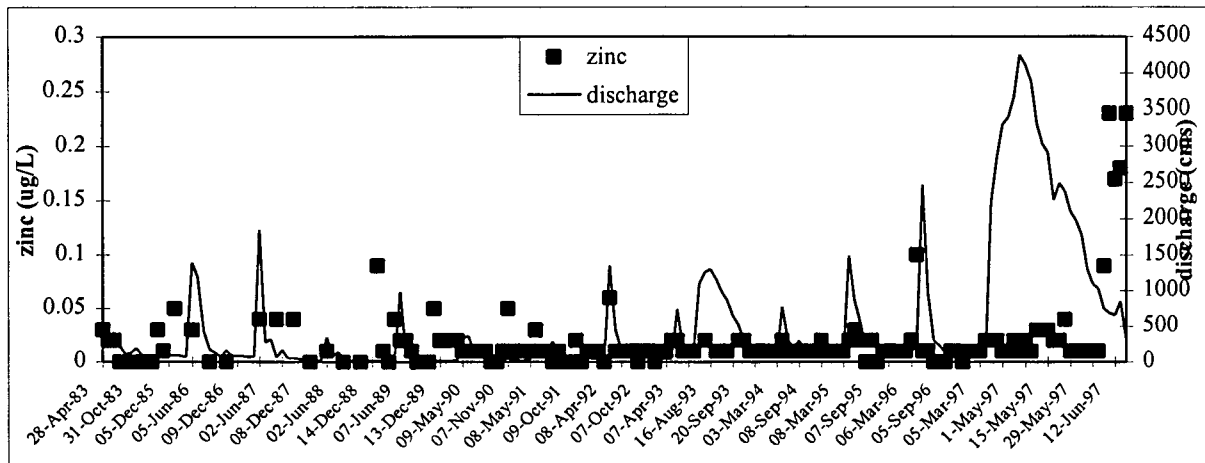


Figure 28: Historical concentrations of zinc in the Red River at Selkirk MB.

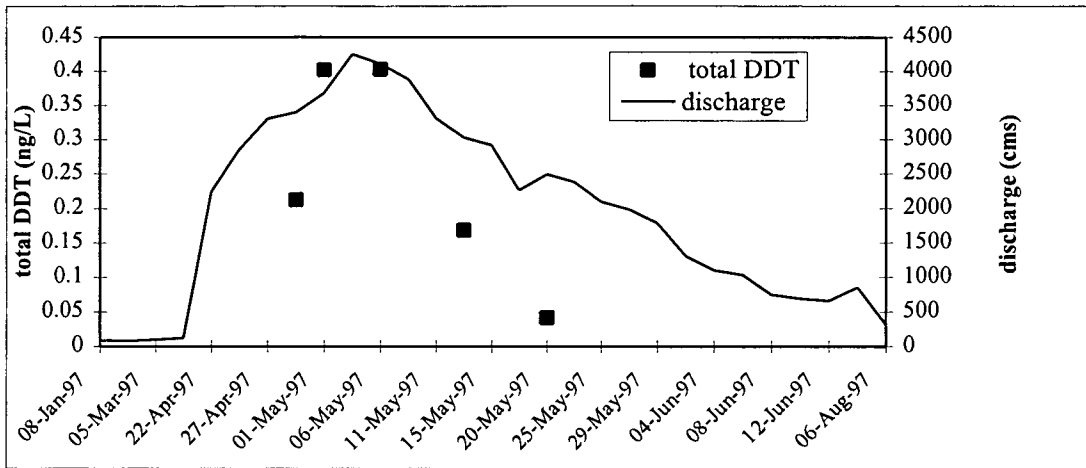


Figure 29: Total DDT in the Red River at Selkirk MB during 1997.

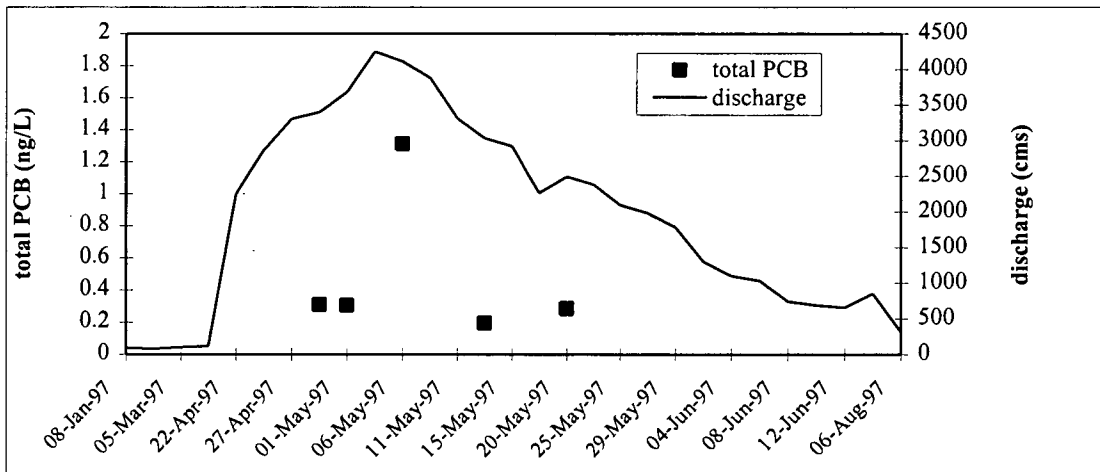


Figure 30: Total PCB in the Red River at Selkirk MB during 1997.

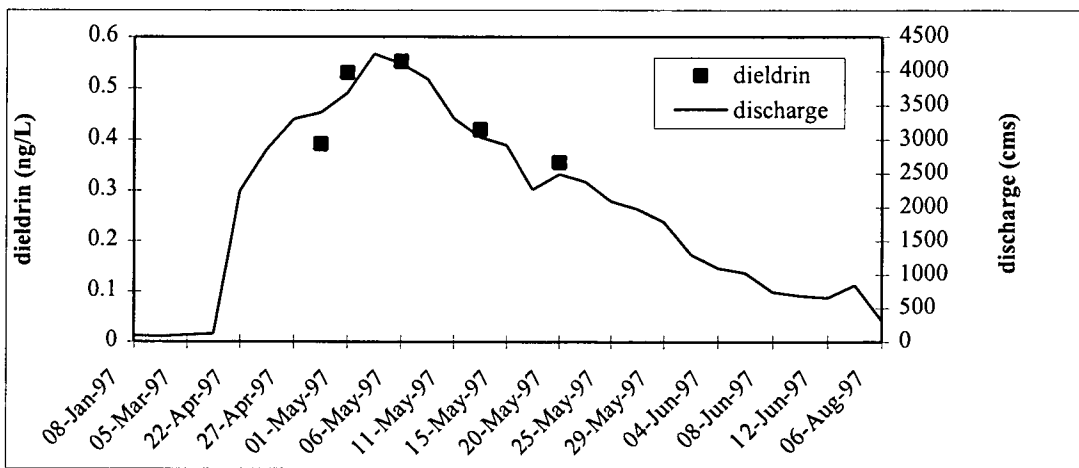


Figure 31: Dieldrin in the Red River at Selkirk MB during 1997.

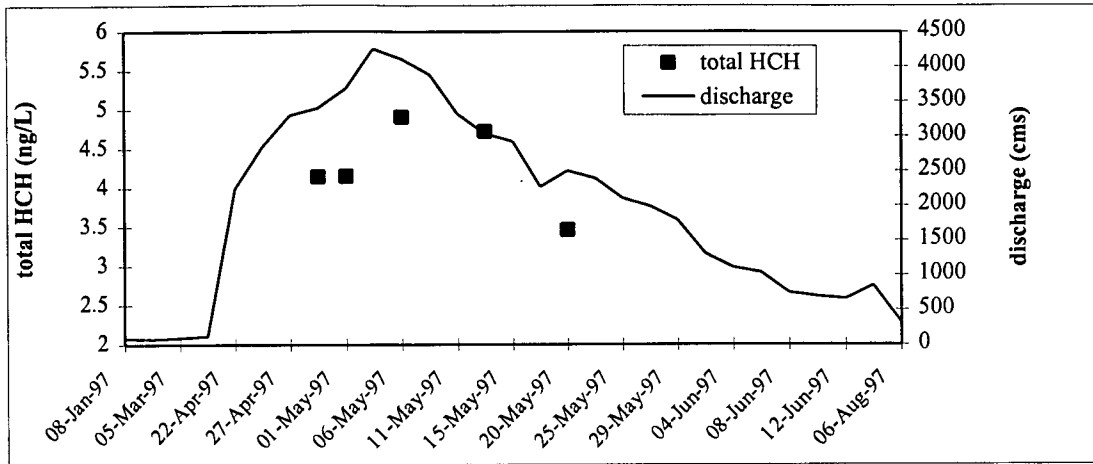


Figure 32: Total HCH in the Red River at Selkirk MB during 1997.

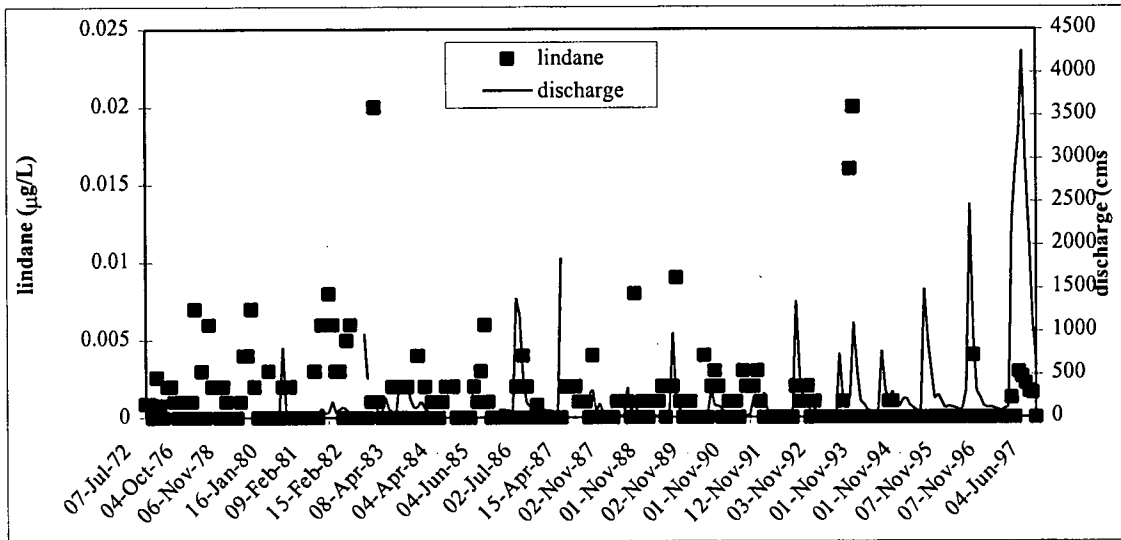


Figure 33: Historical concentrations of lindane in the Red River at Emerson MB.

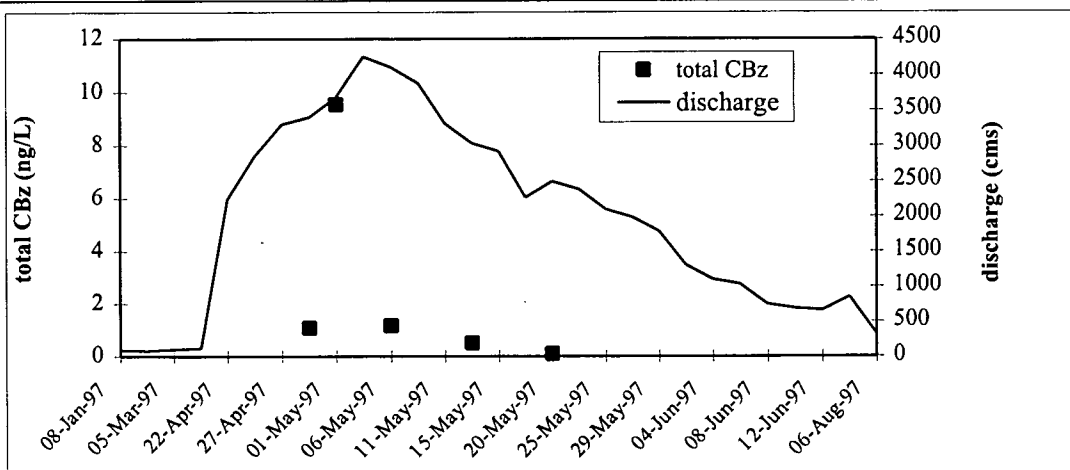


Figure 34: Total chlorobenzenes in the Red River at Selkirk MB during 1997.



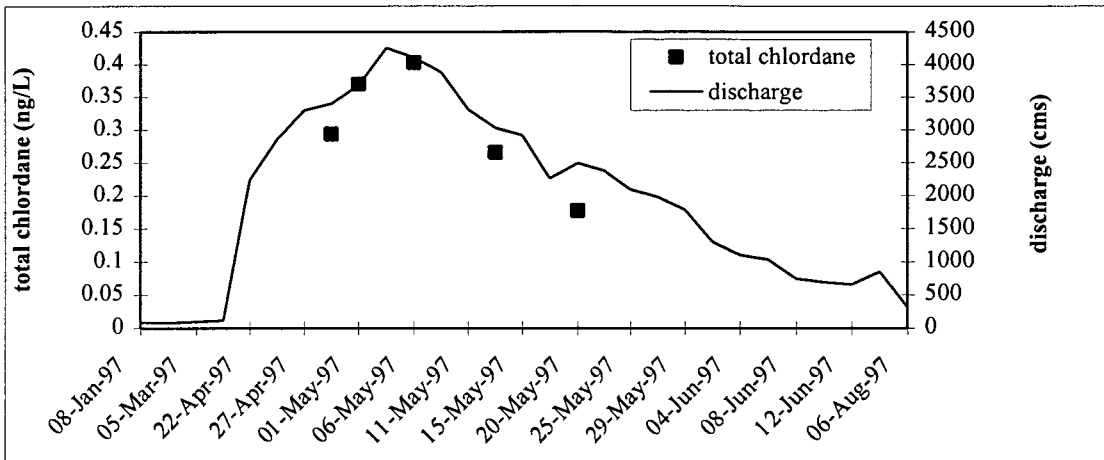


Figure 35: Total chlordane in the Red River at Selkirk MB during 1997.

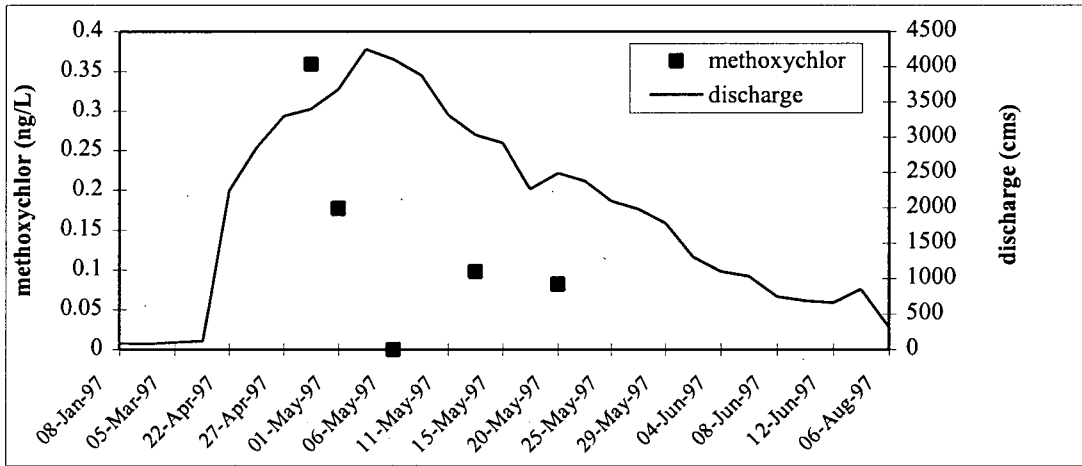


Figure 36: Methoxychlor in the Red River at Selkirk MB during 1997.

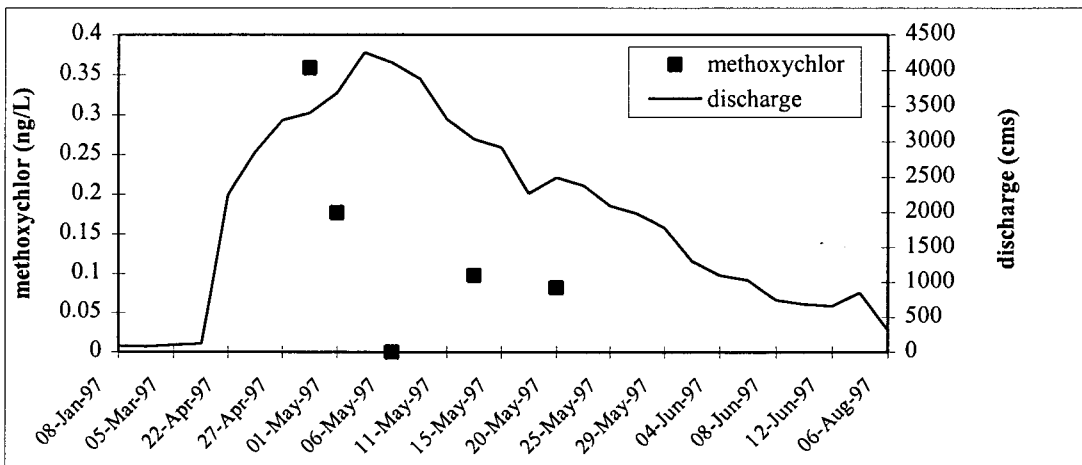


Figure 37: Endrin in the Red River at Selkirk MB during 1997.

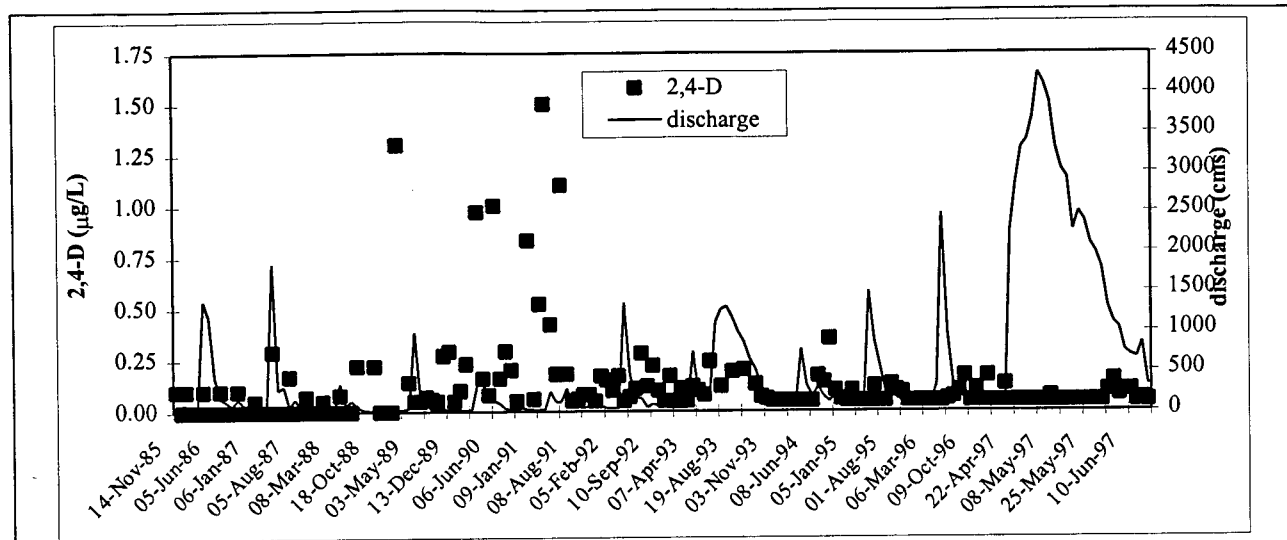


Figure 38: Historical concentrations of 2,4-D in the Red River at Selkirk MB.

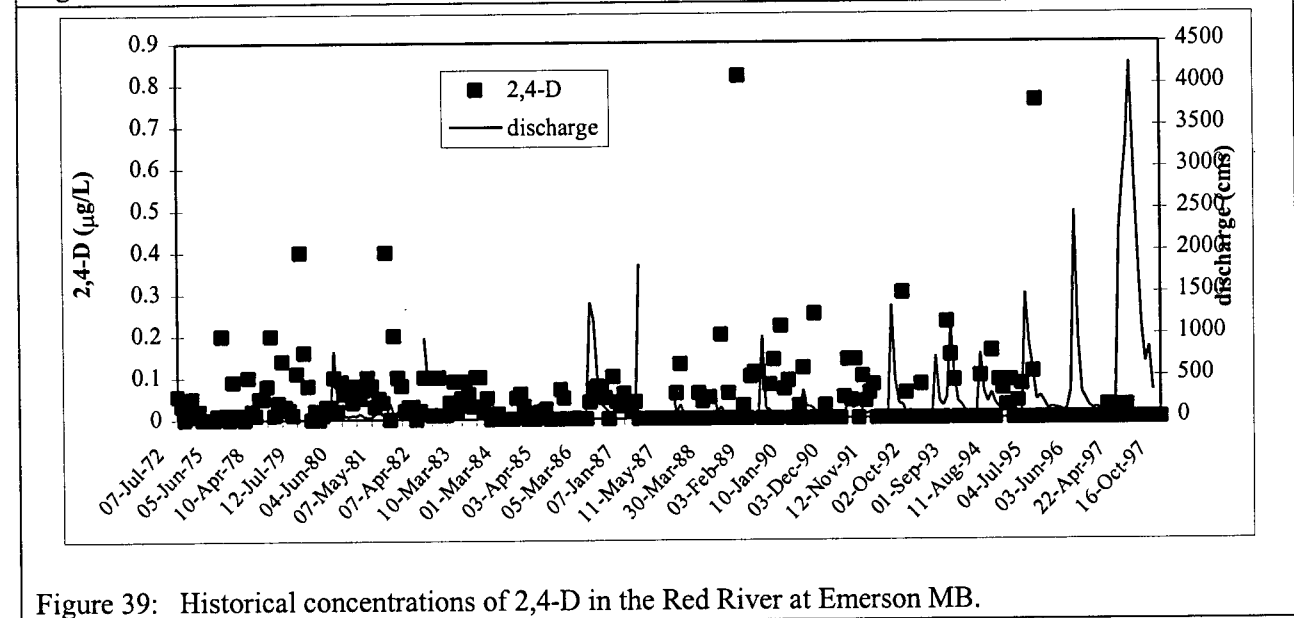


Figure 39: Historical concentrations of 2,4-D in the Red River at Emerson MB.