Laughing Water Arts & Science, Inc.

1006 Kilkenny Drive

Winnipeg, MB, R3T 5A5

Ph: 204 219 9018

Email: franzin@shaw.ca

Information Available

for an

Instream Flow Analysis of the Red River

for

Water Apportionment Purposes

By

William G. Franzin

Laughing Water Arts & Science, Inc.

1006 Kilkenny Drive

Winnipeg, MB, R3T 5A5

Laughing Water Arts & Science, Inc. Report 2 - 2011 – December 2011

Acknowledgments

Many people made it possible for me to locate data files and studies that were not immediately located on the internet or in library catalogues. I especially thank Aaron Buesing of the US Army Corps of Engineers, Signe Snortland, Sharon Taylor, Greg Hiemenz and Zachary Sutphin of the US Bureau of Reclamation and Ron Sutton (formerly USBR); Candace Bostwick and Chris Laveau of the US Geological Survey; Rick Gunderson of Houston Engineering, Inc,; Ron Kaatz of MB Infrastructure and Transportation, Akinbola George, Bob Harrison, Eugene Kozera, Greg Shippam, Michele Methot and Jeff Long of MB Water Stewardship, and Lindsay Donnelly (formerly MB WS); Tanya Dixon of MB Conservation; Lynn Shlueter of ND Dept. of Game and Fish, Luther Aadland, Ann Kuitunen and Tom Groshens of MN Dept. of Natural Resources, Chuck Fritz of the International Water Institute and ND State University; Steve Kelsch and Isaac Schlosser of University of North Dakota and the librarians at MB Conservation, North Dakota State University and University of North Dakota; Grant Mohr of City of Winnipeg Water and Waste Dept.; Doug Watkinson of Dept. of Fisheries and Oceans and Brian Parker and Minzhen Su of Environment Canada for providing information and assistance. Bernard Beckhoff at the International Joint Commission in Ottawa provided the map in Figures 1 and 7. Without the assistance of all these people this project would not have been feasible.

Executive Summary

The contract requested that information be gathered with respect to eleven specific areas of information. These are provided below with summaries of data discovered followed by recommendations for the future.

- **Geo-referenced bathymetric data that defines river bed topography**
    - Geo-referenced cross sections are available over the length of the river that define cross channel topography at about intervals of one to a few kilometres. It is possible with available HEC RAS models to interpolate the cross sections to approximate longitudinal topography. For detailed 2D modelling, river habitat surveys would be required at selected IFN sites, however River2D could be run in a coarse configuration using interpolated data.
- **Surveyed transects and cross sections**
    - There are hundreds of surveyed cross sections over the length of the river from Wahpeton to Lake Winnipeg. Longitudinal transects may be limited to those collected by Terry Dick and students within the City of Winnipeg and those created in River2D modelling by the USBR at their Frog Point site. Terry Dick collected data using Questar Tangent equipment from Emerson to Breezy Point but the data may be lost. Longitudinal water surface profiles for any flow can be output from the HEC RAS models. These data will be extremely useful in identifying possible IFN study sites.
- **Any previous IFN studies**
    - It appears that four IFN studies have been done in the RRN (USBR 1999, 2003 and Houston Engineering, Inc 1997a,b) with study reaches in the Sheyenne River and the RRN. USBR (1999) calculated monthly flow regimes for aquatic life maintenance at all of the major USGS gauging stations from Wahpeton to Emerson

using flow data from 1931-1984. USBR (2003) used River2D to model fish habitat at Frog Point, near Grand Forks. These study sites should be examined for utility in further habitat modelling with additional species and life stages.

- **Discharge, velocity, water surface and depth measurements in open water and ice-covered conditions**
    - There are good discharge records at several gauging stations for long periods of record (up to more than 100 years) both in the US and Canada for summer and winter. Depth measurements are available from a great many cross sections in the US and Canada (in HEC RAS morphometry files) at the time and discharge of measurement. The HEC RAS models will output depths for any given discharge at those cross section locations in the river. Similarly water surface profiles are available from the HEC RAS for any given flow. Only average cross sectional velocity data can be output from HEC RAS models but by interpolation it is possible to produce simulated cross sectional velocities and channel long lines that may be useful in 1D habitat modelling using PHABSIM.
- **Substrate, cover and water temperature data**
    - There is little substrate and cover data available for the RRN but there is much temperature data collected at gauging stations in the US portion of the river and at Emerson in Canada. Fish habitat distribution in the river is undescribed and a large data gap. However long reaches in the river may be of similar, rather plain, habitat.
- **Natural flow hydrographs**
    - The hydrographs at the several gauging stations in the RRN are not natural and are influenced by dams and land drainage throughout the watershed. There has been some effort to synthesize natural flows in the US portion of the river.

- **Identification of representative fish species and life stages for the RRN**
    - The fish species and their life histories in the RRN are reasonably well known but details of spawning locations and larval and juvenile life histories are poorly known for the RRN. Two theses provide timing and location data for larval fish occurrence from drift sampling in the RRN in the US. Considerable fish distribution and biological data are available from which to identify representative species. The fact that the major common large fish species appear to be present in good numbers throughout the mainstem river suggest that the same suite of representative species could be used at all mainstem RRN sites.
- **Data on distribution, habitat use, and habitat availability of representative fish species and life stages in reference sites where bathymetry and flow data were recorded**
    - Good fish distributional information is available for the US portion of the RRN but in Canada these data are limited to two studies, one focussed on Winnipeg in 1972-74 (Clarke et al MS1980) and the other comprised of three seasonal longitudinal electrofishing surveys of the Canadian portion of the river in 2002-03 (Watkinson and Franzin unpublished data). Habitat preference data is limited to that found in Aadland and Kuitunen (2006). Habitat availability data is poor in the US portion and non-existent in the Canadian portion of the river. Fish presence data collected by standardized sampling over about 25 years at about 5y intervals are available in the US portion of the river including sites where flow data are available and HEC RAS model cross sections can provide bathymetry. A River2D model has been developed and operated in sites near Fargo-Moorhead and Grand Forks to test fish habitat-flow relationships.

- **Determination of biologically sensitive periods**
    - A tentative set of BSPs is provided with input from regional biologists but a workshop should be held to provide the definitive BSPs for the species in the RRN. Aadland and Kuitunen (2006) provide BSP-related habitat use data for a number of fish species in the RRN.
- **Temperature and velocity preferences for the different fish species**
    - There are ample data on temperature preferences of the commoner fish species of the RRN some of which are compiled in an unpublished DFO report (Watkinson et al MS 2011). Data also are reported in most books on the fishes of states and provinces. Velocity preference data are available for some species in the RRN in Aadland and Kuitunen (2006). Velocity preference data also are available from IFN studies elsewhere on the prairies and in the US.
- **Any available reports on validating habitat suitability curves (HSC) for representative fish species in the RRN**
    - There are none. This is a data gap that frequently has not been addressed in most published IFN studies.
- **Recommendations:**
    - The large amount of detailed hydrological, hydraulic and modelling data will require a significant amount of processing time by an engineer with specialization in hydraulic modelling and GIS to determine if the development of instream flow needs for fish and other organisms in the various segments of the RRN is feasible with the available data. It is estimated that this could take one person year to complete.
    - The completion of IFN studies elsewhere suggests that a RRN IFN study would require a Steering Committee, presumably the IRRB, and one or more technical task groups. A RRN Technical Task Group including hydrologists, hydraulic engineers, biologists, ecologists, and water quality specialists from Minnesota, North

Dakota, South Dakota, the province of Manitoba and from the Canadian and the United States federal governments would carry out the detailed data analyses required in an IFN study. An experienced IFN specialist proficient in the use of Excel spreadsheets should be sought to lead the Technical Task Group either from within the group or by contract. It is estimated that an IFN study on the RRN would take from three to five years to complete, depending on the person year and financial commitment of the parties involved.

Table of Contents

	Page
Acknowledgments	ii
Executive Summary	iii
Table of Contents	viii
List of Figures	x
List of Tables	x
1.0 Introduction and History	1
1.1 Objectives	1
1.2 History and context of the RRN	2
1.3 Components of an IFN analysis	5
2.0 Data required for an IFN determination	6
2.1 Hydrology	7
2.1.1 Hydrology of the Red River	7
2.1.2 Hydrology data for the Red River in Canada	12
2.1.3 Hydrology data for the Red River in USA	22
2.1.4 Hydrology Summary	37
2.2 Geomorphology	40
2.2.1 Introduction to concepts of river segmentation	41
2.2.2 Preliminary Red River Segmentation	42
3.0 Fish Habitat Analysis	47
3.1 Physical habitat	47
3.2 Biology	48

Page

3.2.1 Fisheries Resources of the Red River 48

3.2.2 Other aquatic fauna of the Red River 53

3.2.3 Fish HSC from, or adaptable for, use in the Red River 53

3.3 Fisheries of the RRN 54

3.4 Instream Flow and Fish Habitat Modelling in the RRN 54

3.4.1 Macrohabitat & Mesohabitat Modelling 55

3.5 Fish water quality and temperature requirements 57

3.6 Fish Species Periodicity 57

4.0 Connectivity 60

5.0 Water Quality 61

5.1 Water Quality in Canada 61

5.2 Water Quality in the USA 63

6.0 Water Use 64

7.0 Summary 64

8.0 Literature Cited 69

List of Figures

		Page
Figure 1.	Map of the Red River basin in Canada and the United States.	3
Figure 2.	Daily discharge in the Red River at Emerson from 1913 to 2000.	38
Figure 3.	Mean annual flows in the Red River at Emerson.	39
Figure 4.	Flow duration curve for mean annual flow of the Red River at Emerson for the period 1912-2000.	40
Figure 5.	Four management reaches (segments) used by MN DNR fish managers for fish sampling programs (from Groshens 2010, with permission).	44
Figure 6.	Longitudinal profile of the RRN in the United States showing locations of MN DNR management reaches (segments).	45
Figure 7.	Suggested preliminary segments in the RRN based on hydrology.	46

List of Tables

Table 1.	Stream hydrology gauges for the entire Red River of the North Basin in the United States and Canada.	8
Table 2.	Detailed hydrology data from stream gauges in the Red River and its major tributaries in Canada from the International Boundary to Lake Winnipeg.	12
Table 3.	Detailed hydrologic and water quality data available for the Red River of the North and major tributaries within the United States.	21

Page

Table 4. Fish species reported in the US (1962-2000; Aadland et al 2004) and Canadian (1967-2004; Stewart and Watkinson 2004) portions of the Red River of the North not including tributaries. 51

Table 5. Fish species relative abundances by Reaches in the US (MN DNR 1983-84, 2010) and by Segments in the Canadian (DFO 2002-03) portions of the Red River of the North. 52

Table 6. Tentative species periodicity table for fishes commonly found in the mainstem of the Red River of the North. 59

Table 7. Average, maximum and minimum values for dissolved oxygen, pH, temperature and turbidity in NTU in the RRN at Emerson from 1960 to the present. 62

Appendices

Data files and public domain documents are in named folders in the included DVD: **IWI Red River Data Repository Disk**

1.0 Introduction and History

1.1 Objectives

The objectives of this report are to present all relevant available information and data that would be useful in the development of an instream flow needs (IFN) recommendation for the Red River (of the North; hereafter the RRN) that would maintain the aquatic ecosystem, including fish and fish habitat, relative to quantitative water apportionment of this international river. The work includes identification of data gaps and necessary work that would be required to fill them. Specific types of information have been identified as integral to such an analysis including but not limited to:

- Geo-referenced bathymetric data that defines river bed topography
- Surveyed transects and cross sections
- Any previous IFN studies
- Discharge, velocity, water surface and depth measurements in open water and ice-covered conditions
- Substrate, cover and water temperature data
- Natural flow hydrographs
- Identification of representative fish species and life stages for the RRN
- Data on distribution, habitat use, and habitat availability of representative fish species and life stages in reference sites where bathymetry and flow data were recorded
- Determination of biologically sensitive periods
- Temperature and velocity preferences for the different fish species
- Any available reports on validating habitat suitability curves (HSC) for representative fish species in the RRN

1.2 History and context of the RRN

The RRN is a young river occupying the central north-south axis of the exposed lake bed of former glacial Lake Agassiz. Lake Agassiz was a huge pro-glacial lake that occupied much of south central Manitoba, northwestern Minnesota and eastern North Dakota for several thousand years. Early in its history the outflow of the lake was southward to the Mississippi River system through Brown's Valley, MN but with the melting of the ice sheet forming its northern boundary, the lake finally drained northward to Hudson Bay about 6500 years ago. Lakes Winnipeg, Winnipegosis, Manitoba and Lake of the Woods are familiar remnant water bodies of this once great lake (Figure 1).

The modern RRN begins at the confluence of the Otter Tail and Bois de Sioux rivers at Breckenridge, MN and Wahpeton, ND at about latitude 46.16 degrees north. The river flows for about 877 kilometres to its mouth at Lake Winnipeg, MB at about latitude 50.27 degrees about 2.25 times the direct distance between source and mouth. The catchment has an area of about 116,500 km^2 upstream of the Assiniboine River, the largest tributary of the river. The Assiniboine River has a catchment of approximately 162,000 km^2 and flows for about 1266 km from Preeceville, SK to enter the RRN at Winnipeg approximately 78 km from its mouth at Lake Winnipeg. Other major tributaries include the Sheyenne River that enters the RRN near Fargo, ND, the Wild Rice River joining the RRN near Hendrum, MN, the Red Lake River that joins the RRN at East Grand Forks, MN, the Pembina River that flows from Canada into the US with its confluence at Neche, ND, just south of the International Boundary, and the Roseau River that flows from the US into Manitoba and joins the RRN near Letellier, MB. There also are several smaller tributaries along the length of the river in both the US and Canada. Approximately 102,000 km^2 of the RRN watershed (87.5% of the watershed above the Assiniboine River) lies upstream of the International Boundary hydrometric station at Emerson, MB.

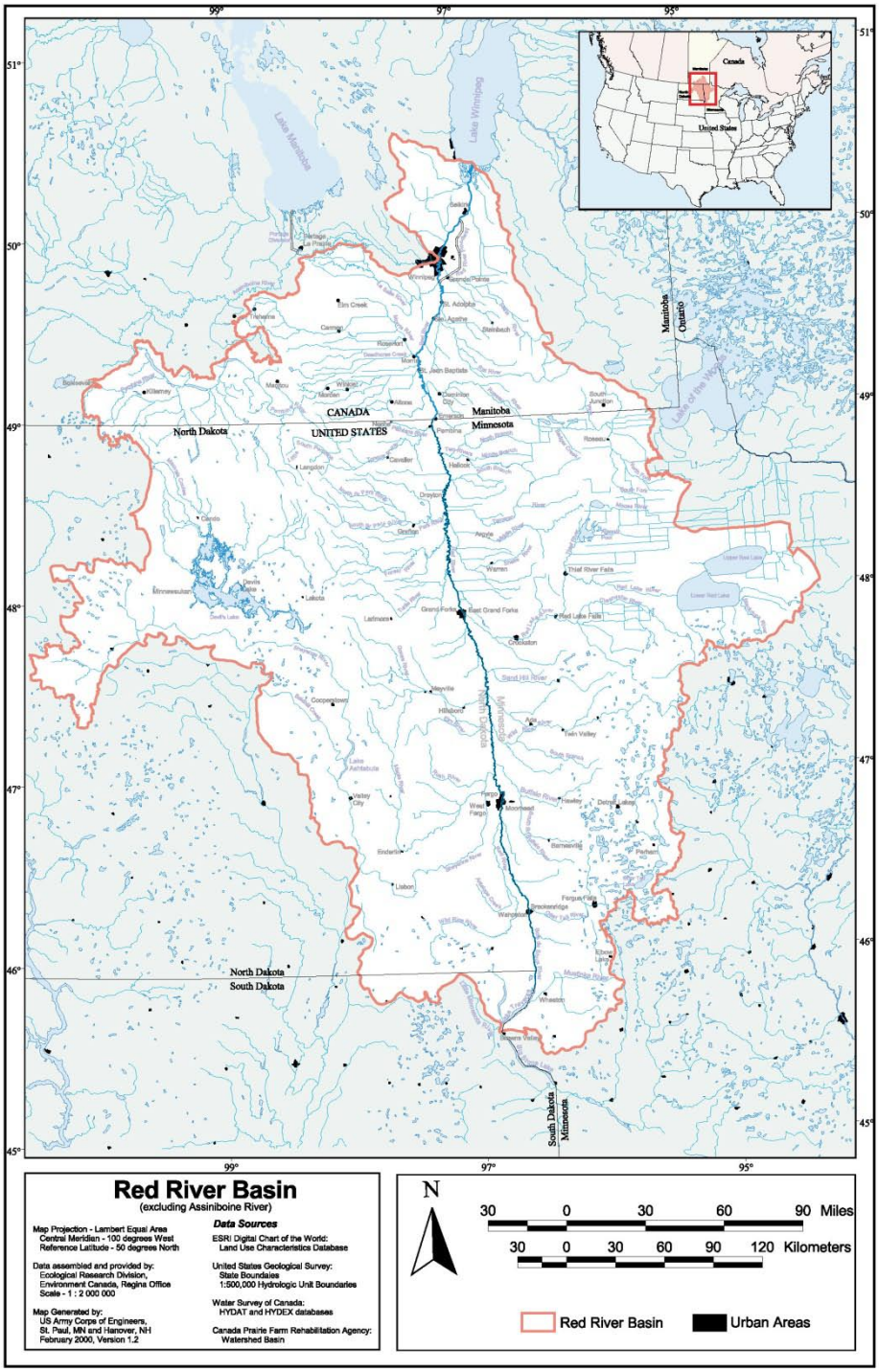

Figure 1. Map of the Red River basin in Canada and the United States. Reproduced from IJC (2000) with permission.

The RRN has a long history of catastrophic flooding, most frequently following the spring snowmelt, but in wet years overbank floods can happen anytime from March to early December. This attribute of the river is a result of a cyclical alternation of wet and dry periods of about 25-30 years duration known as the prairie drought cycle. The severity and duration of the wet and dry periods can vary from a few extremely wet or dry years to several years. The 1930s and the late 1990s – early 2000s are examples of particularly long dry and wet periods respectively. While there is no doubt that the floods that occur relatively frequently in the RRN basin occasionally have caused extreme damage to property and livelihoods, a long period of drought may have much more devastating consequences considering the number of communities, farms, businesses, and wildlife that depend on the RRN and its tributaries for water. The summers of the drought years of the 1930s caused extremely low flows in the river in summer, and during the winters, the RRN at the International Boundary was reduced to a trickle of <1 m^3/s for many days at a time in consecutive years.

A consequence of the RRN flowing hundreds of kilometres down the gently northward sloping bed (total relief; 70m, average slope; 8cm/km) of former Lake Agassiz is that it has eroded through many meters of poorly consolidated, fine-grained sediments that were deposited on the bottom of the ancient lake. The low slope and erodible soils of the valley have produced a river that is greatly meandering over most of its length and generally turbid (except in winter). Having cut through the surficial Lake Agassiz sediments, the bed of the modern river lies mainly on the harder compacted sediments of the lakebed with occasional outcrops of till or old beach ridges in the upper valley and some exposed bedrock in the most downstream reaches. The present day sediment supply is derived mainly from bank erosion in the outside meander bends and from tributaries and drainage ditches.

The flat, fine grained soils of the RRN valley are highly suited to agriculture and most of the area of the old lake bed is in annual cultivation. The soils of the region, once cultivated, are prone to both wind and water erosion. The river and its tributaries are

important as an international watershed of high biodiversity, for fisheries and recreation, and as a source of water for municipal, agricultural and industrial uses throughout the valley.

Comprehensive accounts of the general geography, hydrology, and water quality of the Red River basin are provided by Stoner et al (1993), Thorleifson et al (1998), Rosenberg et al (2005) and in online resources such as Minnesota Pollution Control Agency (MN PCA), the US Environmental Protection Agency (USEPA), US Geological Survey National Water-Quality Assessment Program (USGS NAWQA), ND State Water Commission, US Bureau of Reclamation USBR), and the US Army Corps of Engineers (USACE).

1.3 Components of an IFN analysis

There are many ways to develop an IFN, from relatively simple desktop methods that consider only stream or toe width (e.g. wetted perimeter method), percent of mean monthly flow, the Tennant (Tennant 1976) or Tessman's modification (Tessman 1979) of Tennant's method (used as a desktop method in several provinces and states), to data rich incremental methods that include extensive hydrologic and hydraulic modelling of fish habitat such as the Instream Flow Incremental Methodology (IFIM) (Bovee et al 1998). Reviews of these methods may be found in Annear et al (2002, 2004), Tharme (2003) and Acreman and Dunbar (2004). The more holistic incremental methods generally are preferred when time and resources permit.

A modern incremental IFN study needs to consider the interaction of five main riverine components; hydrology, geomorphology, water quality, biology, and connectivity of a river, all in the context of three policy components; legal, institutional policy frameworks and public involvement (Locke et al 2008). The IFC (http://www.instreamflowcouncil.org/) is an organization of state and provincial biologists representing 41 state and provincial fish and wildlife agencies in North America. The IFC is dedicated to fostering and improving the instream flow programs of its member

agencies and to promoting responsible riverine resource stewardship on the continent. The Fish and Wildlife agencies of four of the states and provinces that include the Red River watershed (Manitoba, Minnesota, North Dakota and South Dakota) are members of the IFC and subscribe to the organization's mission and vision. Saskatchewan is not a member of IFC but the portion of the Red River watershed in SK is in the Assiniboine River watershed and excluded from this report.

The overarching tenet of the IFC is that instream flows should emulate, as closely as possible, the natural flow regime of a river with allowance for human uses. The goal is to preserve intra- and inter- annual flow variability, base flows, high and low flow pulses such as out-of-bank flows and extremely low flows, thereby maintaining the ecological health of the river (Annear et al 2002).

The fact that many members of the river science community in Canada, the US, and other countries around the world subscribe to this view of rivers is testament to the scientific acceptance of the approach. Also, two major scientific reviews of large instream flow programs in the US completed recently by the US National Research Council of the US National Academy of Sciences emphasize the IFC approach to river science (NRC 2005, 2008). With that background the data presented here follow the framework of the IFC approach to instream flows.

2.0 Data required for an IFN determination

A robust instream flow program requires an immense amount of data, but for most instream flow studies data requirements are only partially realized. Many times there will be gaps in the data that must be either recognized and accepted or addressed by additional data collection. Frequently it is the biological data that is in short supply because of the expense of collecting it. However, the detailed hydrographic data required for robust habitat analyses also are expensive and time consuming to collect

and analyze. As a result, IFN programs often are able to model only a few relatively small sites to represent the IFN of a whole river.

2.1 Hydrology

Hydrology needs for an IFN study are provided by stream gauge data, preferably discharge records as long as possible and not less than about 50 years in order to include high and low flows and the effects on flow of a variable climate. Preferably these data should be available from several sites within a river system. Hydrology is the master variable in rivers, converting precipitation and groundwater to river flows which form and reform the bed forms within the available geomorphology. Hydrology is comprised of four dimensions; longitudinal from headwaters to mouth, vertical between stream and groundwater below the river bed, lateral between the river and its floodplain and chronological with the changes of flows over the years.

2.1.1 Hydrology of the Red River

The RRN watershed is blessed with an abundance of stream gauges both in the tributaries and in the mainstem of the river. Several gauges have been in place for over 50 years, some more than 100 years. These data provide a good understanding of the variability of flows within and between years over time as the watershed has changed in response to human habitation and alterations.

Table 1 provides a list of all the gauges that exist in the RRN watershed on both sides of the International Boundary. Each gauge's data may be investigated by activating the link emphasized by the blue underlined text by merely mousing over the link and hitting "CTRL Left Click". All the available gauges are included here should it be desirable to sum up the incremental addition of tributary flows for streams between the major gauging stations on the RRN. Table 2 contains the gauging stations in the RRN mainstem and larger tributaries in Canada with records of more than 20 years, a total of 12 gauges including gauges at the upstream and downstream ends of the Red River

Floodway Channel around Winnipeg. Three gauges in the Canadian portion of the watershed have records nearing 100 years; Emerson (shared with the US), Roseau River and the Assiniboine River. The station on the RRN at Letellier has 48 years of record and that at Ste. Agathe, 53 years. None of the downstream stations have records as long as 50 years.

Table 3 includes the gauging stations in the RRN mainstem and larger tributaries in the United States, a total of 14 gauges with records of more than 20 years. The gauge on the Bois de Sioux River closest to the RRN had a relatively short period of record so the next upstream station was included as well. Four gauges in the US portion of the RRN had records longer than 100 years, Fargo, Grand Forks, the Red Lake River at Crookston and the Pembina River. Other stations with long records include the RRN at Wahpeton (68 years) and Drayton (74 years), the Sheyenne River at West Fargo (61 years), the Wild Rice River near Hendrum, (65 years) and the Otter Tail River below Orwell Dam (80 years).

Table 1. Stream hydrology gauges for the entire Red River of the North Basin in the United States and Canada. Links are active with "CTRL Left Click". Data from public websites of USGS NWIS (http://waterdata.usgs.gov/nwis) and Environment Canada (http://www.wateroffice.ec.gc.ca) accessed August to October 2011.

Stream gauges in the Red River Basin from the headwaters to Fargo, North Dakota
05030500 OTTER TAIL RIVER NEAR ELIZABETH
05046000 OTTER TAIL RIVER BL ORWELL D NR FERGUS FALLS
05046475 OTTER TAIL RIVER DIVERSION AT BRECKENRIDGE
05049000 MUSTINKA RIVER ABOVE WHEATON
05050000 BOIS DE SIOUX RIVER NEAR WHITE ROCK
05051300 BOIS DE SIOUX RIVER NEAR DORAN
05051500 RED RIVER OF THE NORTH AT WAHPETON
0505152130 RED RIVER OF THE NORTH AT ENLOE
05051522 RED RIVER OF THE NORTH AT HICKSON
464129096453101 WOLVERTON CREEK NEAR COMSTOCK
05051600 WILD RICE RIVER NR RUTLAND
05052000 WILD RICE RIVER NEAR MANTADOR
05052500 ANTELOPE CREEK AT DWIGHT
05053000 WILD RICE RIVER NR ABERCROMBIE

464243096495100	WILD RICE RIVER AT I-29 NEAR ST BENEDICT
05054000	RED RIVER OF THE NORTH AT FARGO

Stream gauges in the Sheyenne River watershed of the Red River Basin, North Dakota	
05054500	SHEYENNE RIVER ABOVE HARVEY
05055260	SHEYENNE RIVER AT ST RTE 30 SOUTH OF MADDOCK
05055300	SHEYENNE R AB DEVILS LK STATE OUTLET NR FLORA
05055400	SHEYENNE R BL DEVILS LK STATE OUTLET NR BREMEN
05056000	SHEYENNE RIVER NR WARWICK
05056060	MAUVAIS COULEE TRIB NO. 3 NR CANDO
05056100	MAUVAIS COULEE NR CANDO
05056200	EDMORE COULEE NR EDMORE
05056215	EDMORE COULEE TRIB NR WEBSTER
05056222	MORRISON LAKE NEAR WEBSTER
05056239	STARKWEATHER COULEE NEAR WEBSTER
05056241	DRY LAKE NEAR PENN
05056255	LAKE ALICE-IRVINE CHANNEL NEAR CHURCHS FERRY
05056265	BIG COULEE AT HWY 2 NEAR CHURCHS FERRY
05056340	LITTLE COULEE NEAR LEEDS
05056500	DEVILS LAKE NEAR DEVILS LAKE
05056665	EASTERN STUMP LAKE NEAR LAKOTA
05056995	SHEYENNE RIVER ON HWY 200 NEAR COOPERSTOWN
05057000	SHEYENNE RIVER NEAR COOPERSTOWN
05057200	BALDHILL CREEK NEAR DAZEY
05058000	SHEYENNE RIVER BELOW BALDHILL DAM
05058500	SHEYENNE RIVER AT VALLEY CITY
05058600	SHEYENNE RIVER NEAR KATHRYN
05058700	SHEYENNE RIVER AT LISBON
05058980	SHEYENNE RIVER ON GOL ROAD NEAR KINDRED
05059000	SHEYENNE RIVER NEAR KINDRED
05059300	SHEYENNE RIVER ABOVE SHEYENNE R DIVERSION NR HORACE
05059310	SHEYENNE RIVER DIVERSION NEAR HORACE
05059480	SHEYENNE RIVER DIVERSION AT WEST FARGO
05059500	SHEYENNE RIVER AT WEST FARGO
05059600	MAPLE RIVER NEAR HOPE
05059700	MAPLE RIVER NEAR ENDERLIN
05059715	MAPLE RIVER ABOVE MAPLE RIVER DAM NR SHELDON
05060000	MAPLE RIVER NEAR MAPLETON
05060100	MAPLE RIVER BL MAPLETON
05060400	SHEYENNE RIVER AT HARWOOD
05060500	RUSH RIVER AT AMENIA
05060550	RUSH RIVER NEAR PROSPER

05060570	LOWER BRANCH RUSH RIVER NEAR PROSPER

Stream gages in the Red River Basin from Fargo to Grand Forks, North Dakota	
05061000	BUFFALO RIVER NEAR HAWLEY
05061500	SOUTH BRANCH BUFFALO RIVER AT SABIN
05062000	BUFFALO RIVER NEAR DILWORTH
465839096412800	BUFFALO RIVER EAST OF KRAGNES
471446097001701	ELM RIVER AT GRANDIN
471924097014701	NORTH BRANCH ELM RIVER AT KELSO
05062500	WILD RICE RIVER AT TWIN VALLEY
05063398	S. BR. WILD RICE RIVER AT CO. RD. 27 NR FELTON
05064000	WILD RICE RIVER AT HENDRUM
05064500	RED RIVER OF THE NORTH AT HALSTAD
05065500	GOOSE RIVER NEAR PORTLAND
05066500	GOOSE RIVER AT HILLSBORO
05067500	MARSH RIVER NEAR SHELLY
05069000	SAND HILL RIVER AT CLIMAX
05070000	RED RIVER OF THE NORTH NEAR THOMPSON
05074500	RED LAKE RIVER NEAR RED LAKE
05075000	RED LAKE RIVER AT HIGH LANDING NR GOODRIDGE
05076000	THIEF RIVER NEAR THIEF RIVER FALLS
05078000	CLEARWATER RIVER AT PLUMMER
05078230	LOST RIVER AT OKLEE
05078500	CLEARWATER RIVER AT RED LAKE FALLS
05078720	CO DITCH 140 ABV BR-6 IMP NR TILDEN JCT
05078770	JUDICIAL DITCH 66 NEAR MARCOUX CORNERS
05079000	RED LAKE RIVER AT CROOKSTON
05080000	RED LAKE RIVER AT FISHER
05082500	RED RIVER OF THE NORTH AT GRAND FORKS

Stream gauges in the Red River Basin from Grand Forks to the International Border	
05082625	TURTLE RIVER AT TURTLE R STATE PARK NR ARVILLA
05083500	RED RIVER OF THE NORTH AT OSLO
05084000	FOREST RIVER NR FORDVILLE
05085000	FOREST RIVER AT MINTO
05085450	SNAKE RIVER ABOVE WARREN
05087500	MIDDLE RIVER AT ARGYLE
05090000	PARK RIVER AT GRAFTON
05092000	RED RIVER OF THE NORTH AT DRAYTON
05094000	SOUTH BRANCH TWO RIVERS AT LAKE BRONSON

05099400	LITTLE SOUTH PEMBINA RIVER NR WALHALLA
05099600	PEMBINA RIVER AT WALHALLA
05100000	PEMBINA RIVER AT NECHE
05101000	TONGUE RIVER AT AKRA
05102490	RED RIVER OF THE NORTH AT PEMBINA
05104500	ROSEAU RIVER BELOW SOUTH FORK NEAR MALUNG
05106000	SPRAGUE CREEK NEAR SPRAGUE
05107500	ROSEAU RIVER AT ROSS
05112000	ROSEAU RIVER BELOW STATE DITCH 51 NR CARIBOU

Stream gauges in the Red River Basin from the International Border to Lake Winnipeg, Manitoba	
05MJ001	ASSINIBOINE RIVER AT HEADINGLEY [MB]
05OA006	LONG RIVER NEAR HOLMFIELD [MB]
05OA007	BADGER CREEK NEAR CARTWRIGHT [MB]
05OA010	PEMBINA RIVER ABOVE LORNE LAKE [MB]
05OB001	PEMBINA RIVER NEAR LA RIVIERE [MB]
05OB007	PEMBINA RIVER NEAR WINDYGATES [MB]
05OB010	CYPRESS CREEK NEAR CLEARWATER [MB]
05OB016	SNOWFLAKE CREEK NEAR SNOWFLAKE [MB]
05OB021	MOWBRAY CREEK NEAR MOWBRAY [MB]
05OB023	PEMBINA RIVER BELOW CRYSTAL CREEK [MB]
05OB027	ROCK LAKE NEAR GLENORA [MB]
05OC001	RED RIVER AT EMERSON [MB]
05OC006	RED RIVER AT MORRIS [MB]
05OC008	RED RIVER NEAR ST. NORBERT [MB]
05OC009	RED RIVER AT ST. JEAN BAPTISTE [MB]
05OC010	RED RIVER NEAR LETELLIER [MB]
05OC012	RED RIVER NEAR STE. AGATHE [MB]
05OC016	DEADHORSE CREEK NEAR ROSENFELD [MB]
05OC017	RED RIVER FLOODWAY NEAR ST. NORBERT [MB]
05OC019	BUFFALO CREEK NEAR ROSENFELD [MB]
05OC020	RED RIVER BELOW FLOODWAY CONTROL STRUCTURE [MB]
05OC022	RIVIERE AUX MARAIS NEAR CHRISTIE [MB]
05OC024	KRONSGART DRAIN NEAR SEWELL [MB]
05OC026	RED RIVER ABOVE RED RIVER FLOODWAY [MB]
05OC028	RED RIVER AT ST. ADOLPHE [MB]
05OC029	RED RIVER FLOODWAY AT TRANS CANADA HIGHWAY [MB]
05OD001	ROSEAU RIVER NEAR DOMINION CITY [MB]
05OD004	ROSEAU RIVER AT GARDENTON [MB]
05OD028	MAIN DRAIN NEAR DOMINION CITY [MB]
05OE001	RAT RIVER NEAR OTTERBURNE [MB]
05OE004	RAT RIVER NEAR SUNDOWN [MB]

05OE006	MANNING CANAL NEAR ILE DES CHENES [MB]
05OE007	JOUBERT CREEK AT ST. PIERRE-JOLYS [MB]
05OE009	TOUROND CREEK NEAR TOUROND [MB]
05OE010	MARSH RIVER NEAR OTTERBURNE [MB]
05OE011	SEINE RIVER DIVERSION NEAR ILE DES CHENES [MB]
05OE014	PANSY DRAIN NEAR SARTO [MB]
05OE015	JOUBERT CREEK NEAR PANSY [MB]
05OF003	BOYNE RIVER NEAR CARMAN [MB]
05OF009	ROSEISLE CREEK NEAR ROSEISLE [MB]
05OF014	SHANNON CREEK NEAR MORRIS [MB]
05OF017	SOUTH TOBACCO CREEK NEAR MIAMI [MB]
05OF018	TOBACCO CREEK NEAR ROSEBANK [MB]
05OF020	MORRIS RIVER NEAR ROSENORT [MB]
05OF023	SOUTH BRANCH OF SOUTH TOBACCO CREEK NEAR MIAMI [MB]
05OF024	LITTLE MORRIS RIVER NEAR ROSENORT [MB]
05OF025	MORRIS RIVER AT BRUNKILD [MB]
05OF026	NORQUAY CHANNEL NEAR HOMEWOOD [MB]
05OG001	LA SALLE RIVER NEAR SANFORD [MB]
05OG005	ELM CREEK CHANNEL NEAR ELM CREEK [MB]
05OG008	LA SALLE RIVER NEAR ELIE [MB]
05OH007	SEINE RIVER NEAR STE. ANNE [MB]
05OH009	SEINE RIVER SOUTH OF PRAIRIE GROVE [MB]
05OJ005	RED RIVER AT SELKIRK [MB]
05OJ008	NETLEY CREEK NEAR PETERSFIELD [MB]
05OJ015	RED RIVER AT JAMES AVENUE PUMPING STATION [MB]
05OJ016	DEVILS CREEK NEAR LIBAU [MB]
05OJ017	GRASSMERE CREEK DRAIN NEAR MIDDLECHURCH [MB]
05OJ019	COOKS CREEK BELOW COOKS CREEK DIVERSION [MB]
05OJ021	RED RIVER UPSTREAM OF ST. ANDREWS DAM AT LOCKPORT [MB]
05OJ022	RED RIVER AT BREEZY POINT [MB]

Emerson (2005) reviewed the existing US Red River of the North watershed data and updated missing records using a variety of techniques (Emerson et al 2005) to provide more complete mean monthly streamflow records for many of the US gauging stations both in tributaries and in the mainstem RRN. No similar published work was encountered for stations with missing records in Canada.

2.1.2 Hydrology data for the Red River in Canada

Table 2. Detailed hydrology data from stream gauges in the Red River and its major tributaries in Canada from the International Boundary to Lake Winnipeg. Data from public website of Environment Canada (http://www.wateroffice.ec.gc.ca) accessed 21 October 2011. Links are active with "CTRL Left Click". Record lengths updated to 2010 from 2006. Stations have a minimum of 20 years of data except for Breezy Point which was retained only because it is the lowest station on the river.

05OC001 RED RIVER AT EMERSON [MB]

Station Information

Active or discontinued: Active
Province / Territory: MB
Latitude: 49° 00' 18'' N
Longitude: 97° 12' 54'' W
Gross drainage area: 102000 km^2
Regulation type: Regulated
Record length: 99 Years
Period of record: 1912 – 2010
Real-time data available: Yes
Sediment data available: Yes
Type of water body: River
RHBN: No
EC Regional Office: WINNIPEG
Data contributed by: N/A
Datum of published data: GEODETIC SURVEY OF CANADA DATUM (LOCAL 1929 ADJ.)

05OC001 Data Collection History

Period of record	Type	Operation schedule	Gauge type
1912 – 1952	Flow	Continuous	Manual
1953 – 2001	Flow	Continuous	Recorder
2002 – 2010	Flow & Level	Continuous	Recorder

05OC010 RED RIVER NEAR LETELLIER [MB]

Station Information

Active or discontinued: Active
Province / Territory: MB

Latitude: 49° 07’ 54’’ N
Longitude: 97° 15’ 11’’ W
Gross drainage area: 103000 km^2
Regulation type: Regulated
Record length: 48 Years
Period of record: 1952 – 2010
Real-time data available: Yes
Sediment data available: No
Type of water body: River
RHBN: No
EC Regional Office: WINNIPEG
Data contributed by: N/A
Datum of published data: GEODETIC SURVEY OF CANADA DATUM (LOCAL 1953 ADJ.)

05OC010 Data Collection History

Period of record	Type	Operation schedule	Gauge type
1952 – 1952	Flow	Miscellaneous	Manual
1959 – 1960	Level	Seasonal	Manual
1963 – 1968	Level	Seasonal	Manual
1969 – 1972	Level	Seasonal	Recorder
1974 – 1976	Level	Seasonal	Recorder
1978 – 1980	Level	Seasonal	Recorder
1982 – 2010	Level	Seasonal	Recorder

05OC006 RED RIVER AT MORRIS [MB]

Station Information

Active or discontinued: Active
Province / Territory: MB
Latitude: 49° 21’ 18’’ N
Longitude: 97° 20’ 56’’ W
Gross drainage area: 111000 km^2
Regulation type: Natural
Record length: 20 Years
Period of record: 1912 – 2010
Real-time data available: Yes
Sediment data available: No
Type of water body: River
RHBN: No
EC Regional Office: WINNIPEG
Data contributed by: N/A

Datum of published data: GEODETIC SURVEY OF CANADA DATUM (LOCAL 1979 ADJ.)

05OC006 Data Collection History

Period of record	Type	Operation schedule	Gauge type
1912 – 1918	Level	Seasonal	Manual
1950 – 1950	Level	Seasonal	Manual
1952 – 1952	Level	Seasonal	Manual
2000 – 2001	Level	Seasonal	Recorder
2002 – 2010	Level	Seasonal	Recorder

05OC012 RED RIVER NEAR STE. AGATHE [MB]

Station Information

Active or discontinued: Active
Province / Territory: MB
Latitude: 49° 33’ 13’’ N
Longitude: 97° 11’ 05’’ W
Gross drainage area: 115000 km^2
Regulation type: Regulated
Record length: 53 Years
Period of record: 1958 – 2010
Real-time data available: Yes
Sediment data available: Yes
Type of water body: River
RHBN: No
EC Regional Office: WINNIPEG
Data contributed by: N/A
Datum of published data: GEODETIC SURVEY OF CANADA DATUM (LOCAL 1953 ADJ.)

05OC012 Data Collection History

Period of record	Type	Operation schedule	Gauge type
1958 – 1959	Flow	Seasonal	Manual
1960 – 1960	Flow	Continuous	Manual
1961 – 2001	Flow	Continuous	Recorder

Period of record	Type	Operation schedule	Gauge type
2002 – 2010	Flow & Level	Continuous	Recorder

05OC008 RED RIVER NEAR ST. NORBERT [MB]

Station Information

Active or discontinued: Active
Province / Territory: MB
Latitude: 49° 47' 06'' N
Longitude: 97° 08' 00'' W
Gross drainage area: 122000 km^2
Regulation type: Regulated
Record length: 43 Years
Period of record: 1948 – 2010
Real-time data available: Yes
Sediment data available: Yes
Type of water body: River
RHBN: No
EC Regional Office: WINNIPEG
Data contributed by: N/A
Datum of published data: GEODETIC SURVEY OF CANADA DATUM (LOCAL 1929 ADJ.)

05OC008 Data Collection History

Period of record	Type	Operation schedule	Gauge type
1948 – 1948	Level	Seasonal	Manual
1950 – 1950	Level	Seasonal	Manual
1962 – 1962	Flow	Miscellaneous	N/A
1965 – 1965	Flow	Miscellaneous	N/A
1967 – 1967	Flow	Seasonal	Manual
1969 – 1972	Flow	Seasonal	Manual
1974 – 1976	Flow	Seasonal	Manual
1978 – 1979	Flow	Seasonal	Manual
1982 – 2001	Flow	Seasonal	Manual
2002 – 2010	Flow & Level	Seasonal	Recorder

05OC026 RED RIVER ABOVE RED RIVER FLOODWAY [MB]

Station Information

Active or discontinued: Active

Province / Territory: MB
Latitude: 49° 43’ 26’’ N
Longitude: 97° 07’ 49’’ W
Gross drainage area: 119000 km^2
Regulation type: Regulated
Record length: 29 Years
Period of record: 1982 – 2010
Real-time data available: Yes
Sediment data available: No
Type of water body: River
RHBN: No
EC Regional Office: WINNIPEG
Data contributed by: N/A
Datum of published data: GEODETIC SURVEY OF CANADA DATUM (LOCAL 1929 ADJ.)

05OC026 Data Collection History

Period of record	Type	Operation schedule	Gauge type
1982 – 2010	Level	Seasonal	Recorder

05OJ015 RED RIVER AT JAMES AVENUE PUMPING STATION [MB]

Station Information

Active or discontinued: Active
Province / Territory: MB
Latitude: 49° 53’ 45’’ N
Longitude: 97° 07’ 50’’ W
Gross drainage area: 285000 km^2
Regulation type: Regulated
Record length: 40 Years
Period of record: 1971 – 2010
Real-time data available: Yes
Sediment data available: No
Type of water body: River
RHBN: No
EC Regional Office: WINNIPEG
Data contributed by: N/A
Datum of published data: GEODETIC SURVEY OF CANADA DATUM (LOCAL 1929 ADJ.)

05OJ015 Data Collection History

Period of record Type Operation schedule Gauge type

Period of record	Type	Operation schedule	Gauge type
1971 – 2010	Level	Continuous	Recorder

05OC020 RED RIVER BELOW FLOODWAY CONTROL STRUCTURE [MB]

Station Information

Active or discontinued: Active
Province / Territory: MB
Latitude: 49° 45’ 20’’ N
Longitude: 97° 08’ 10’’ W
Gross drainage area: 119000 km^2
Regulation type: Regulated
Record length: 38 Years
Period of record: 1970 – 2010
Real-time data available: Yes
Sediment data available: No
Type of water body: River
RHBN: No
EC Regional Office: WINNIPEG
Data contributed by: N/A
Datum of published data: GEODETIC SURVEY OF CANADA DATUM (LOCAL 1929 ADJ.)

05OC020 Data Collection History

Period of record	Type	Operation schedule	Gauge type
1970 – 1976	Level	Seasonal	Recorder
1978 – 1979	Level	Seasonal	Recorder
1982 – 2010	Level	Seasonal	Recorder

05OJ022 RED RIVER AT BREEZY POINT [MB]

Station Information

Active or discontinued: Active
Province / Territory: MB
Latitude: 50° 16’ 58’’ N
Longitude: 96° 51’ 30’’ W
Gross drainage area: 288000 km^2
Regulation type: Regulated
Record length: 11 Years
Period of record: 2000 – 2010
Real-time data available: Yes

Sediment data available: No
Type of water body: River
RHBN: No
EC Regional Office: WINNIPEG
Data contributed by: N/A
Datum of published data: GEODETIC SURVEY OF CANADA DATUM (MAN. GOVT. EXT.)

05OJ022 Data Collection History

Period of record	Type	Operation schedule	Gauge type
2000 – 2010	Level	Seasonal	Recorder

05OC017 RED RIVER FLOODWAY NEAR ST. NORBERT [MB]

Station Information

Active or discontinued: Active
Province / Territory: MB
Latitude: 49° 45’ 24’’ N
Longitude: 97° 07’ 36’’ W
Gross drainage area: N/A
Regulation type: Regulated
Record length: 42 Years
Period of record: 1969 – 2010
Real-time data available: Yes
Sediment data available: Yes
Type of water body: River
RHBN: No
EC Regional Office: WINNIPEG
Data contributed by: N/A
Datum of published data: GEODETIC SURVEY OF CANADA DATUM (LOCAL 1929 ADJ.)

05OC017 Data Collection History

Period of record	Type	Operation schedule	Gauge type
1969 – 2001	Flow	Seasonal	Recorder
2002 – 2010	Flow & Level	Seasonal	Recorder

05MJ001 ASSINIBOINE RIVER AT HEADINGLEY [MB]

Station Information

Active or discontinued: Active
Province / Territory: MB
Latitude: 49° 52’ 09’’ N
Longitude: 97° 24’ 10’’ W
Gross drainage area: 162000 km^2
Regulation type: Regulated
Record length: 97 Years
Period of record: 1913 – 2010
Real-time data available: Yes
Sediment data available: Yes
Type of water body: River
RHBN: No
EC Regional Office: WINNIPEG
Data contributed by: N/A
Datum of published data: GEODETIC SURVEY OF CANADA DATUM (LOCAL 1929 ADJ.)

05MJ001 Data Collection History

Period of record	Type	Operation schedule	Gauge type
1913 – 1952	Flow	Continuous	Manual
1953 – 2001	Flow	Seasonal	Recorder
2002 – 2010	Flow & Level	Seasonal	Recorder

05OD001 ROSEAU RIVER NEAR DOMINION CITY [MB]

Station Information

Active or discontinued: Active
Province / Territory: MB
Latitude: 49° 11’ 28’’ N
Longitude: 96° 59’ 02’’ W
Gross drainage area: 5020 km^2
Regulation type: Natural
Record length: 97 Years
Period of record: 1913 – 2010
Real-time data available: Yes
Sediment data available: Yes
Type of water body: River
RHBN: No
EC Regional Office: WINNIPEG
Data contributed by: N/A
Datum of published data: GEODETIC SURVEY OF CANADA DATUM (LOCAL 1929 ADJ.)

05OD001 Data Collection History

Period of record	Type	Operation schedule	Gauge type
1913 – 1913	Flow	Continuous	Manual
1914 – 1914	Flow	Seasonal	Manual
1916 – 1916	Flow	Seasonal	Manual
1917 – 1927	Flow	Continuous	Manual
1928 – 1948	Flow	Seasonal	Manual
1949 – 1962	Flow	Continuous	Manual
1963 – 1996	Flow	Continuous	Recorder
1997 – 2001	Flow	Seasonal	Recorder
2002 – 2010	Flow & Level	Seasonal	Recorder

2.1.3 Hydrology data for the Red River of the North in the USA

Table 3. Detailed hydrologic and water quality data available for the Red River of the North and major tributaries within the United States. Accessed at USGS National Water Information System public website (http://waterdata.usgs.gov/nwis) 12 August 2011. Embedded links jump to data sources with "CTRL Left Click". Stations have a minimum of 20 years of flow data.

USGS 05051500 RED RIVER OF THE NORTH AT WAHPETON, ND

Stream Site

DESCRIPTION:

Latitude 46°15'58", Longitude 96°35'54" NAD27
Richland County, North Dakota, Hydrologic Unit 09020104
Drainage area: 4,010 square miles
Datum of gage: 942.97 feet above NGVD29.

AVAILABLE DATA:

Data Type	Begin Date	End Date	Count
Real-time	-- Previous 120 days --		
Daily Data			
Discharge, cubic feet per second	1942-05-01	2010-09-30	24870
Discharge, cubic feet per second – Red River Only	2004-10-01	2011-08-11	2504
Gage height, feet – Red River Only	2000-10-01	2011-08-11	3917
Daily Statistics			
Discharge, cubic feet per second	1942-05-01	2010-09-30	24870
Discharge, cubic feet per second – Red River Only	2004-10-01	2010-10-14	2205
Gage height, feet – Red River Only	2000-10-02	2010-10-14	3621
Monthly Statistics			
Discharge, cubic feet per second	1942-05	2010-09	
Discharge, cubic feet per second – Red River Only	2004-10	2010-10	
Gage height, feet – Red River Only	2000-10	2010-10	
Annual Statistics			
Discharge, cubic feet per second	1942	2010	
Discharge, cubic feet per second – Red River Only	2005	2011	
Gage height, feet – Red River Only	2001	2011	
Peak streamflow	1897	2010-03-16	70
Field measurements	1901-01-01	2011-07-25	997

Field/Lab water-quality samples	1971-10-05	2011-04-28	362
Additional Data Sources	**Begin Date**	**End Date**	**Count**
Annual Water-Data Report (pdf) **offsite**	2006	2010	5

OPERATION:

Record for this site is maintained by the USGS North Dakota Water Science Center
Email questions about this site to North Dakota Water Science Center Water-Data Inquiries

USGS 05051522 RED RIVER OF THE NORTH AT HICKSON, ND

Stream Site

DESCRIPTION:

Latitude 46°39'35", Longitude 96°47'44" NAD27
Cass County, North Dakota, Hydrologic Unit 09020104
Drainage area: 4,300 square miles
Datum of gage: 876.38 feet above NGVD29.

AVAILABLE DATA:

Data Type	Begin Date	End Date	Count
Real-time	-- Previous 120 days --		
Daily Data			
Discharge, cubic feet per second	1975-10-01	2011-08-11	13099
Gage height, feet	2000-10-01	2011-08-11	3918
Daily Statistics			
Discharge, cubic feet per second	1975-10-01	2010-10-20	12804
Gage height, feet	2000-10-01	2010-10-20	3626
Monthly Statistics			
Discharge, cubic feet per second	1975-10	2010-10	
Gage height, feet	2000-10	2010-10	
Annual Statistics			
Discharge, cubic feet per second	1976	2011	
Gage height, feet	2001	2011	
Peak streamflow	1976-03-31	2010-03-19	35
Field measurements	1975-09-25	2011-08-05	419
Field/Lab water-quality samples	1975-11-03	2011-04-27	370
Additional Data Sources	**Begin Date**	**End Date**	**Count**
Annual Water-Data Report (pdf) **offsite**	2006	2010	5

OPERATION:

Record for this site is maintained by the USGS North Dakota Water Science Center
Email questions about this site to North Dakota Water Science Center Water-Data Inquiries

USGS 05054000 RED RIVER OF THE NORTH AT FARGO, ND

Stream Site

DESCRIPTION:

Latitude 46°51'40", Longitude 96°47'00" NAD27
Cass County, North Dakota, Hydrologic Unit 09020104
Drainage area: 6,800 square miles
Datum of gage: 861.8 feet above NGVD29.

AVAILABLE DATA:

Data Type	Begin Date	End Date	Count
Real-time	-- Previous 120 days --		
Daily Data			
Temperature, water, degrees Celsius	1998-09-26	2011-08-11	12998
Discharge, cubic feet per second	1901-06-01	2011-08-11	40249
Gage height, feet	2000-10-01	2011-06-09	3854
Specific conductance, water, unfiltered, microsiemens per centimeter at 25 degrees Celsius	1998-09-26	2011-08-11	11877
Dissolved oxygen, water, unfiltered, milligrams per liter	2003-10-26	2011-08-11	7326
pH, water, unfiltered, field, standard units	2003-10-26	2011-08-11	7468
Turbidity, water, unfiltered, monochrome near infra-red LED light, 780-900 nm, detection angle 90 +/ -2.5 degrees, formazin nephelometric units (FNU)	2003-10-26	2011-08-11	7075
Daily Statistics			
Temperature, water, degrees Celsius	1998-09-26	2010-11-18	4112
Discharge, cubic feet per second	1901-06-01	2010-10-11	39945
Gage height, feet	2000-10-01	2010-10-11	3613
Specific conductance, water, unfiltered, microsiemens per centimeter at 25 degrees Celsius	1998-09-26	2010-11-18	3737
Dissolved oxygen, water, unfiltered, milligrams per liter	2003-10-26	2010-11-18	2221
Turbidity, water, unfiltered, monochrome near infra-red LED light, 780-900 nm, detection angle 90 +/ -2.5 degrees, formazin nephelometric units (FNU)	2003-10-26	2010-11-18	2144
Monthly Statistics			

Temperature, water, degrees Celsius	1998-09	2010-11	
Discharge, cubic feet per second	1901-06	2010-10	
Gage height, feet	2000-10	2010-10	
Specific conductance, water, unfiltered, microsiemens per centimeter at 25 degrees Celsius	1998-09	2010-11	
Dissolved oxygen, water, unfiltered, milligrams per liter	2003-10	2010-11	
Turbidity, water, unfiltered, monochrome near infra-red LED light, 780-900 nm, detection angle 90 +/ -2.5 degrees, formazin nephelometric units (FNU)	2003-10	2010-11	
Annual Statistics			
Temperature, water, degrees Celsius	1998	2011	
Discharge, cubic feet per second	1901	2011	
Gage height, feet	2001	2011	
Specific conductance, water, unfiltered, microsiemens per centimeter at 25 degrees Celsius	1998	2011	
Dissolved oxygen, water, unfiltered, milligrams per liter	2004	2011	
Turbidity, water, unfiltered, monochrome near infra-red LED light, 780-900 nm, detection angle 90 +/ -2.5 degrees, formazin nephelometric units (FNU)	2004	2011	
Peak streamflow	1897-04-07	2010-03-21	110
Field measurements	1901-05-04	2011-08-04	1351
Field/Lab water-quality samples	1949-05-16	2011-07-12	968
Additional Data Sources	**Begin Date**	**End Date**	**Count**
Annual Water-Data Report (pdf) **offsite**	2006	2010	5

OPERATION:

Record for this site is maintained by the USGS North Dakota Water Science Center
Email questions about this site to North Dakota Water Science Center Water-Data Inquiries

USGS 05064500 RED RIVER OF THE NORTH AT HALSTAD, MN

Stream Site

DESCRIPTION:

Latitude 47°21'07", Longitude 96°50'36" NAD27
Traill County, North Dakota, Hydrologic Unit 09020107
Drainage area: 21,800 square miles
Datum of gage: 826.65 feet above NGVD29.

AVAILABLE DATA:

Data Type	Begin Date	End Date	Count
Real-time	-- Previous 120 days --		
Daily Data			
Temperature, water, degrees Celsius	1997-10-01	2011-08-11	10863
Discharge, cubic feet per second	1961-06-01	2011-08-11	18323
Gage height, feet	2000-10-01	2011-08-11	3876
Specific conductance, water, unfiltered, microsiemens per centimeter at 25 degrees Celsius	1997-09-21	2011-08-11	9326
Daily Statistics			
Temperature, water, degrees Celsius	1997-10-01	2010-11-07	3350
Discharge, cubic feet per second	1961-06-01	2010-10-11	18030
Gage height, feet	2000-10-01	2010-10-11	3583
Specific conductance, water, unfiltered, microsiemens per centimeter at 25 degrees Celsius	1997-10-01	2010-11-07	2827
Monthly Statistics			
Temperature, water, degrees Celsius	1997-10	2010-11	
Discharge, cubic feet per second	1961-06	2010-10	
Gage height, feet	2000-10	2010-10	
Specific conductance, water, unfiltered, microsiemens per centimeter at 25 degrees Celsius	1997-10	2010-11	
Annual Statistics			
Temperature, water, degrees Celsius	1998	2011	
Discharge, cubic feet per second	1961	2011	
Gage height, feet	2001	2011	
Specific conductance, water, unfiltered, microsiemens per centimeter at 25 degrees Celsius	1998	2011	
Peak streamflow	1936-04-15	2010-03-22	71
Field measurements	1936-04-15	2011-08-04	928
Field/Lab water-quality samples	1961-07-08	2011-04-26	642
Additional Data Sources	**Begin Date**	**End Date**	**Count**
Annual Water-Data Report (pdf) **offsite**	2006	2010	5

OPERATION:

Record for this site is maintained by the USGS North Dakota Water Science Center
Email questions about this site to North Dakota Water Science Center Water-Data Inquiries

USGS 05082500 RED RIVER OF THE NORTH AT GRAND FORKS, ND

Stream Site

DESCRIPTION:

Latitude 47°55'37", Longitude 97°01'44" NAD27
Grand Forks County, North Dakota, Hydrologic Unit 09020301
Drainage area: 30,100 square miles
Contributing drainage area: 26,300 square miles,
Datum of gage: 779.0 feet above NGVD29.

AVAILABLE DATA:

Data Type	Begin Date	End Date	Count
Real-time	-- Previous 120 days --		
Daily Data			
Temperature, water, degrees Celsius	1956-10-02	1973-09-30	6330
Temperature, water, degrees Celsius – Sorlie Bridge	2007-03-31	2011-08-11	4311
Discharge, cubic feet per second	1904-01-01	2011-08-11	39277
Gage height, feet	1979-03-01	2011-08-11	7935
Specific conductance, water, unfiltered, microsiemens per centimeter at 25 degrees Celsius	2007-03-31	2011-08-11	4107
Dissolved oxygen, water, unfiltered, milligrams per liter	2007-03-31	2011-08-11	4059
pH, water, unfiltered, field, standard units	2007-03-31	2011-08-11	4113
Turbidity, water, unfiltered, monochrome near infra-red LED light, 780-900 nm, detection angle 90 +/ -2.5 degrees, formazin nephelometric units (FNU)	2007-05-11	2011-08-11	3936
Daily Statistics			
Temperature, water, degrees Celsius – Sorlie Bridge	2007-03-31	2010-11-08	1183
Discharge, cubic feet per second	1904-01-02	2010-10-12	39001
Gage height, feet	1989-02-17	2010-10-12	5419
Specific conductance, water, unfiltered, microsiemens per centimeter at 25 degrees Celsius	2007-03-31	2010-11-08	1139
Dissolved oxygen, water, unfiltered, milligrams per liter	2007-03-31	2010-11-08	1123
Turbidity, water, unfiltered, monochrome near	2007-05-11	2010-11-08	1086

infra-red LED light, 780-900 nm, detection angle 90 +/ -2.5 degrees, formazin nephelometric units (FNU)			
Monthly Statistics			
Temperature, water, degrees Celsius – Sorlie Bridge	2007-03	2010-11	
Discharge, cubic feet per second	1904-01	2010-10	
Gage height, feet	1989-02	2010-10	
Specific conductance, water, unfiltered, microsiemens per centimeter at 25 degrees Celsius	2007-03	2010-11	
Dissolved oxygen, water, unfiltered, milligrams per liter	2007-03	2010-11	
Turbidity, water, unfiltered, monochrome near infra-red LED light, 780-900 nm, detection angle 90 +/ -2.5 degrees, formazin nephelometric units (FNU)	2007-05	2010-11	
Annual Statistics			
Temperature, water, degrees Celsius – Sorlie Bridge	2007	2011	
Discharge, cubic feet per second	1904	2011	
Gage height, feet	1989	2011	
Specific conductance, water, unfiltered, microsiemens per centimeter at 25 degrees Celsius	2007	2011	
Dissolved oxygen, water, unfiltered, milligrams per liter	2007	2011	
Turbidity, water, unfiltered, monochrome near infra-red LED light, 780-900 nm, detection angle 90 +/ -2.5 degrees, formazin nephelometric units (FNU)	2007	2011	
Peak streamflow	1882-04-18	2010-03-20	129
Field measurements	1901-05-24	2011-08-08	1804
Field/Lab water-quality samples	1949-06-22	2011-07-12	1014
Additional Data Sources	**Begin Date**	**End Date**	**Count**
Annual Water-Data Report (pdf) **offsite**	2006	2010	5

OPERATION:

Record for this site is maintained by the USGS North Dakota Water Science Center
Email questions about this site to North Dakota Water Science Center Water-Data Inquiries

USGS 05092000 RED RIVER OF THE NORTH AT DRAYTON, ND

Stream Site

DESCRIPTION:

Latitude 48°34'20", Longitude 97°08'50" NAD27
Pembina County, North Dakota, Hydrologic Unit 09020311
Drainage area: 34,800 square miles
Datum of gage: 755.0 feet above NGVD29.

AVAILABLE DATA:

Data Type	Begin Date	End Date	Count
Real-time	-- Previous 120 days --		
Daily Data			
Temperature, water, degrees Celsius	1956-12-14	1975-09-30	8215
Discharge, cubic feet per second	1936-04-01	2011-08-11	23667
Gage height, feet	2000-10-01	2011-08-11	3616
Daily Statistics			
Discharge, cubic feet per second	1936-04-02	2010-10-13	23415
Gage height, feet	2000-10-01	2010-10-13	3394
Monthly Statistics			
Discharge, cubic feet per second	1936-04	2010-10	
Gage height, feet	2000-10	2010-10	
Annual Statistics			
Discharge, cubic feet per second	1936	2011	
Gage height, feet	2001	2011	
Peak streamflow	1897-04	2010-03-28	73
Field measurements	1936-04-18	2011-08-05	1190
Field/Lab water-quality samples	1971-11-18	2011-04-20	439
Additional Data Sources	**Begin Date**	**End Date**	**Count**
Annual Water-Data Report (pdf) **offsite**	2006	2010	5

OPERATION:

Record for this site is maintained by the USGS North Dakota Water Science Center
Email questions about this site to North Dakota Water Science Center Water-Data Inquiries

USGS 05102500 RED RIVER OF THE NORTH AT EMERSON, MANITOBA

Stream Site

DESCRIPTION:

Latitude 49°00’30”, Longitude 97°12’40” NAD27
000, 93,
Drainage area: 40,200 square miles
Datum of gage: 700 feet above NGVD29.

AVAILABLE DATA:

Data Type	Begin Date	End Date	Count
Daily Data			
Discharge, cubic feet per second	1912-06-01	2009-12-31	35643
Daily Statistics			
Discharge, cubic feet per second	1912-06-01	2009-12-31	35643
Monthly Statistics			
Discharge, cubic feet per second	1912-06	2009-12	
Annual Statistics			
Discharge, cubic feet per second	1912	2010	
Peak streamflow	1861	2009-04-15	98
Field measurements	1994-01-11	2011-01-13	128
Field/Lab water-quality samples	1974-07-09	2004-05-10	433
Additional Data Sources	**Begin Date**	**End Date**	**Count**
Annual Water-Data Report (pdf) **offsite**	2006	2009	4

OPERATION:

Record for this site is maintained by the USGS North Dakota Water Science Center
Email questions about this site to North Dakota Water Science Center Water-Data Inquiries

USGS 05079000 RED LAKE RIVER AT CROOKSTON, MN

Stream Site

DESCRIPTION:

Latitude 47°46’32”, Longitude 96°36’33” NAD27
Polk County, Minnesota, Hydrologic Unit 09020303
Drainage area: 5,270 square miles
Datum of gage: 832.72 feet above NGVD29.

AVAILABLE DATA:

Data Type	Begin Date	End Date	Count
Real-time	-- Previous 120 days --		
Daily Data			
Temperature, water, degrees Celsius	1977-10-01	1983-04-04	1738
Discharge, cubic feet per second	1901-06-01	2011-08-11	40236

Specific conductance, water, unfiltered, microsiemens per centimeter at 25 degrees Celsius	1980-10-30	1983-04-04	1094
Daily Statistics			
Temperature, water, degrees Celsius	1977-10-02	1983-04-04	962
Discharge, cubic feet per second	1901-06-02	2010-11-17	39981
Specific conductance, water, unfiltered, microsiemens per centimeter at 25 degrees Celsius	1980-10-31	1983-04-04	302
Monthly Statistics			
Temperature, water, degrees Celsius	1977-10	1983-04	
Discharge, cubic feet per second	1901-06	2010-11	
Specific conductance, water, unfiltered, microsiemens per centimeter at 25 degrees Celsius	1980-10	1983-04	
Annual Statistics			
Temperature, water, degrees Celsius	1978	1983	
Discharge, cubic feet per second	1901	2011	
Specific conductance, water, unfiltered, microsiemens per centimeter at 25 degrees Celsius	1981	1983	
Peak streamflow	1897-04-11	2010-03-15	110
Field measurements	1964-09-11	2011-06-29	536
Field/Lab water-quality samples	1962-04-11	2001-04-20	214
Additional Data Sources	**Begin Date**	**End Date**	**Count**
Instantaneous-Data Archive **offsite**	1993-10-01	2010-09-30	93371
Annual Water-Data Report (pdf) **offsite**	2006	2010	5

OPERATION:

Record for this site is maintained by the USGS Minnesota Water Science Center
Email questions about this site to Minnesota Water Science Center Water-Data Inquiries

USGS 05046000 OTTER TAIL RIVER BL ORWELL D NR FERGUS FALLS, MN

Stream Site

DESCRIPTION:

Latitude 46°12’35”, Longitude 96°11’05” NAD27
Otter Tail County, Minnesota, Hydrologic Unit 09020103
Drainage area: 1,740 square miles
Datum of gage: 1,029.65 feet above COE1912.

AVAILABLE DATA:

Data Type	Begin Date	End Date	Count
Real-time	-- Previous 120 days --		
Daily Data			
Discharge, cubic feet per second	1930-10-01	2011-08-11	29534
Daily Statistics			
Discharge, cubic feet per second	1930-10-01	2010-10-04	29224
Monthly Statistics			
Discharge, cubic feet per second	1930-10	2010-10	
Annual Statistics			
Discharge, cubic feet per second	1931	2011	
Peak streamflow	1931-05-18	2010-09-15	80
Field measurements	1949-04-07	2011-05-18	567
Field/Lab water-quality samples	1960-10-12	1995-08-24	47
Additional Data Sources	**Begin Date**	**End Date**	**Count**
Instantaneous-Data Archive **offsite**	1993-10-01	2010-09-30	147107
Annual Water-Data Report (pdf) **offsite**	2006	2010	5

OPERATION:

Record for this site is maintained by the USGS Minnesota Water Science Center
Email questions about this site to Minnesota Water Science Center Water-Data Inquiries

USGS 05050000 BOIS DE SIOUX RIVER NEAR WHITE ROCK, SD

Stream Site

DESCRIPTION:

Latitude 45°51'45", Longitude 96°34'25" NAD27
Roberts County, South Dakota, Hydrologic Unit 09020101
Drainage area: 1,160 square miles

AVAILABLE DATA:

Data Type	Begin Date	End Date	Count
Real-time	-- Previous 120 days --		
Daily Data			
Discharge, cubic feet per second	1941-10-01	2011-08-11	25497
Daily Statistics			
Discharge, cubic feet per second	1941-10-01	2010-10-13	25215
Monthly Statistics			

Discharge, cubic feet per second	1941-10	2010-10	
Annual Statistics			
Discharge, cubic feet per second	1942	2011	
Peak streamflow	1942-07-11	2010-04-05	69
Field measurements	1950-04-04	2011-06-28	715
Field/Lab water-quality samples	1963-10-30	1966-11-15	15
Additional Data Sources	**Begin Date**	**End Date**	**Count**
Instantaneous-Data Archive **offsite**	1991-10-14	2010-09-30	170972
Annual Water-Data Report (pdf) **offsite**	2006	2010	5

OPERATION:

Record for this site is maintained by the USGS Minnesota Water Science Center
Email questions about this site to Minnesota Water Science Center Water-Data Inquiries

USGS 05051300 BOIS DE SIOUX RIVER NEAR DORAN, MN

Stream Site

DESCRIPTION:

Latitude 46°09'08", Longitude 96°34'44" NAD27
Wilkin County, Minnesota, Hydrologic Unit 09020101
Drainage area: 1,880 square miles

AVAILABLE DATA:

Data Type	Begin Date	End Date	Count
Real-time	-- Previous 120 days --		
Daily Data			
Discharge, cubic feet per second	1989-10-01	2011-08-11	7981
Daily Statistics			
Discharge, cubic feet per second	1989-10-01	2010-10-13	7683
Monthly Statistics			
Discharge, cubic feet per second	1989-10	2010-10	
Annual Statistics			
Discharge, cubic feet per second	1990	2011	
Peak streamflow	1990-03-16	2010-03-18	21
Field measurements	1989-10-26	2011-06-28	223
Field/Lab water-quality samples	1993-03-27	1995-08-24	26
Additional Data Sources	**Begin Date**	**End Date**	**Count**
Instantaneous-Data Archive **offsite**	1993-10-01	2010-09-30	190417

Annual Water-Data Report (pdf) **offsite**	2006	2010	5

OPERATION:

Record for this site is maintained by the USGS Minnesota Water Science Center
Email questions about this site to Minnesota Water Science Center Water-Data Inquiries

USGS 05064000 WILD RICE RIVER AT HENDRUM, MN

Stream Site

DESCRIPTION:

Latitude 47°16'05", Longitude 96°47'50" NAD27
Norman County, Minnesota, Hydrologic Unit 09020108
Drainage area: 1,560 square miles
Datum of gage: 836.75 feet above NGVD29.

AVAILABLE DATA:

Data Type	Begin Date	End Date	Count
Real-time	-- Previous 120 days --		
Daily Data			
Discharge, cubic feet per second	1944-04-01	2011-10-26	24468
Daily Statistics			
Discharge, cubic feet per second	1944-04-01	2010-10-31	24108
Monthly Statistics			
Discharge, cubic feet per second	1944-04	2010-10	
Annual Statistics			
Discharge, cubic feet per second	1944	2011	
Peak streamflow	1944-07-15	2010-03-17	67
Field measurements	1964-09-30	2011-10-18	464
Field/Lab water-quality samples	1962-10-01	2010-05-06	372
Additional Data Sources	**Begin Date**	**End Date**	**Count**
Instantaneous-Data Archive **offsite**	1997-10-01	2010-09-30	140676
Annual Water-Data Report (pdf) **offsite**	2006	2010	5

OPERATION:

Record for this site is maintained by the USGS Minnesota Water Science Center
Email questions about this site to Minnesota Water Science Center Water-Data Inquiries

USGS 05059500 SHEYENNE RIVER AT WEST FARGO, ND

Stream Site

DESCRIPTION:

Latitude 46°53'28", Longitude 96°54'24" NAD27
Cass County, North Dakota, Hydrologic Unit 09020204
Drainage area: 8,870 square miles
Contributing drainage area: 3,090 square miles,
Datum of gage: 877.19 feet above NGVD29.

AVAILABLE DATA:

Data Type	Begin Date	End Date	Count
Real-time	-- Previous 120 days --		
Daily Data			
Discharge, cubic feet per second	1903-05-01	2011-05-02	30867
Gage height, feet	2000-10-01	2011-10-26	3841
Daily Statistics			
Discharge, cubic feet per second	1903-05-01	2010-10-03	30656
Gage height, feet	2000-10-01	2010-10-03	3457
Monthly Statistics			
Discharge, cubic feet per second	1903-05	2010-10	
Gage height, feet	2000-10	2010-10	
Annual Statistics			
Discharge, cubic feet per second	1903	2011	
Gage height, feet	2001	2011	
Peak streamflow	1903-04-11	2010-04-01	85
Field measurements	1929-09-16	2011-09-19	1278
Field/Lab water-quality samples	1969-09-16	2010-08-05	363
Additional Data Sources	**Begin Date**	**End Date**	**Count**
Annual Water-Data Report (pdf) **offsite**	2006	2010	5

OPERATION:

Record for this site is maintained by the USGS North Dakota Water Science Center
Email questions about this site to North Dakota Water Science Center Water-Data Inquiries

USGS 05100000 PEMBINA RIVER AT NECHE, ND

Stream Site

DESCRIPTION:

Latitude 48°59'23", Longitude 97°33'24" NAD27
Pembina County, North Dakota, Hydrologic Unit 09020313
Drainage area: 3,410 square miles
Datum of gage: 809.69 feet above NGVD29.

AVAILABLE DATA:

Data Type	Begin Date	End Date	Count
Real-time	-- Previous 120 days --		
Daily Data			
Discharge, cubic feet per second	1903-05-01	2011-08-11	38029
Gage height, feet	2000-10-01	2011-08-11	3713
Daily Statistics			
Discharge, cubic feet per second	1903-05-01	2010-11-01	37746
Gage height, feet	2000-10-01	2010-11-01	3461
Monthly Statistics			
Discharge, cubic feet per second	1903-05	2010-11	
Gage height, feet	2000-10	2010-11	
Annual Statistics			
Discharge, cubic feet per second	1903	2011	
Gage height, feet	2001	2011	
Peak streamflow	1904-05-02	2010-04-04	103
Field measurements	1903-04-29	2011-07-06	1243
Field/Lab water-quality samples	1971-11-17	2011-07-11	400
Additional Data Sources	**Begin Date**	**End Date**	**Count**
Annual Water-Data Report (pdf) **offsite**	2006	2010	5

OPERATION:

Record for this site is maintained by the USGS North Dakota Water Science Center
Email questions about this site to North Dakota Water Science Center Water-Data Inquiries

2.1.4 Hydrology Summary

The RRN watershed contains a great number of dams, 10 on the mainstem RRN and approximately 500 dams on tributaries in the US and Canada (Goldstein 1995, Aadland et al 2005). In addition to flow modifications from dams, the entire stream network of the agricultural portion of the RRN basin has been altered by construction of ditches and channelization of natural streams to improve drainage.

The net result of the dams, ditches and channelized streams in the basin is that mainstem RRN flows cannot be considered natural flows. Naturalized flows would require considerable effort by hydrologists to synthesize natural hydrographs for each station by removing effects of upstream dams and land drainage. Emerson (2005) estimated natural stream flow for a number of RRN gauges including the Emerson gauge for the period 1931 – 2001 by eliminating the hydrologic effects of Orwell Dam, Reservation Dam, White Rock Dam, Baldhill Dam, surface water withdrawals, and return flows. Apparently effects of Red Lake River dams were not included and it is uncertain if the impacts of land drainage were removed by the methods used.

Daily and mean annual flows at the Emerson gauge illustrate how variable the river flows are and how they have changed over time (Figures 2 and 3). The flow duration curve for annual mean flow (Figure 4) displays the recurrence probability of annual mean flows at Emerson. The usual time step for an IFN study would be weekly flows. These will have to be calculated from the daily flows at each gauge.

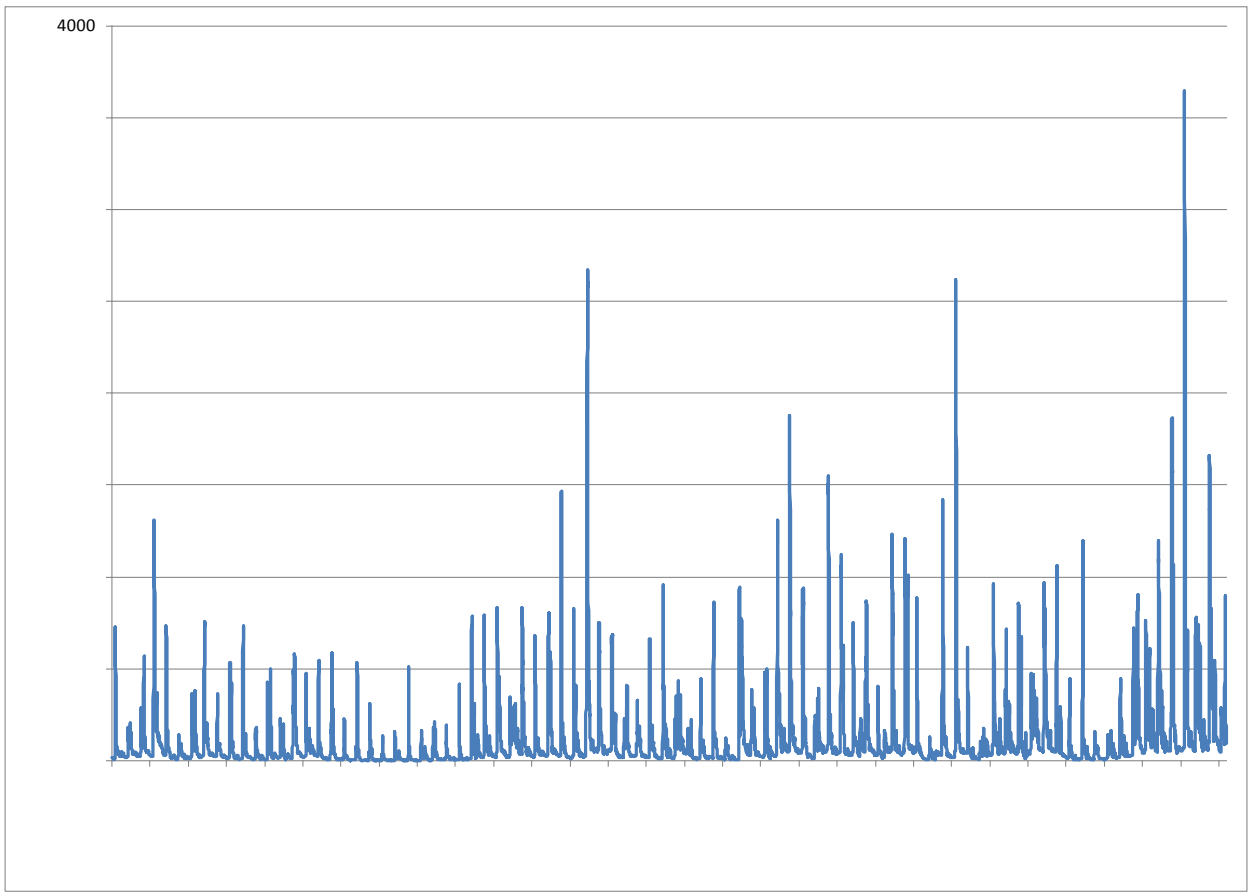

Figure 2. Daily discharge in the Red River at Emerson from 1913 to 2000.

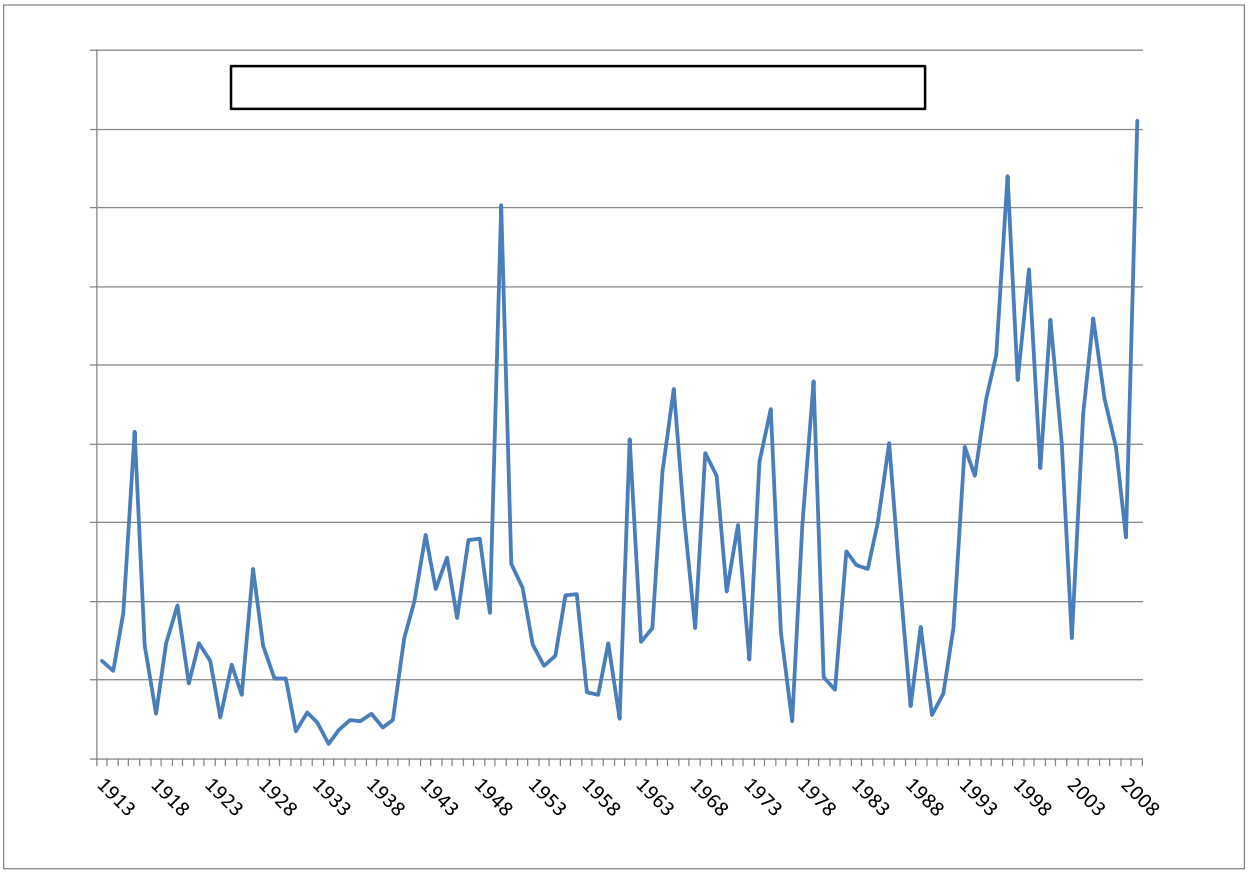

Figure 3. Mean annual flows in the Red River at Emerson.

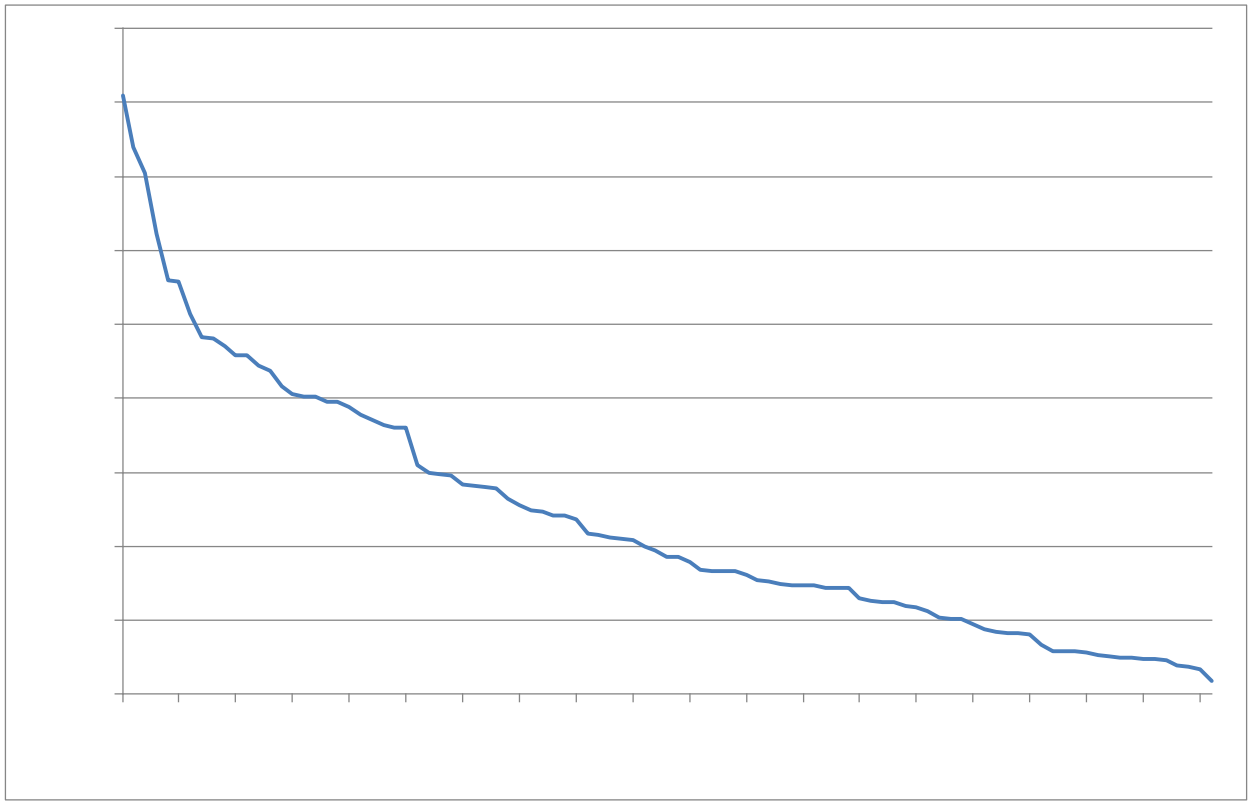

Figure 4. Flow duration curve for mean annual flow of the Red River at Emerson for the period 1912-2009.

2.2 Geomorphology

A natural river exhibits a wide range in flows both within and among years. This natural flow regime maintains riverine processes, including erosion, transport and deposition of sediments, provides varying degrees of flooding and drying of the river channel and controls ice formation and breakup. The ecological integrity of a river is maintained by the natural flow regime (Annear et al 2004).

The physical structure of an alluvial river, like the RRN, is the result of a range in flows from low flows to extremely high flows both within and among years. High peak flows are channel forming flows; powerful events that may scour new channels, modify stream banks, and create or modify side channels. Frequent, seasonally high flows

maintain gross channel morphology and provide the energy for most sediment transport. Moderate, flushing flows remove fine sediments out of coarse material that may be important habitat for fish and benthos. The magnitude, frequency, duration and distribution of moderate, bankfull, and overbank flows largely determine the stability and distribution of instream habitats for fish and other aquatic organisms. Channel maintenance flows occur relatively frequently, in the Red River in recent time, perhaps as often as once or twice a year. The range of flows from about 60% to about 160% of bankfull typically account for about 80% of sediment transport (Andrews and Nankervis 1995).

2.2.1 Introduction to concepts of river segmentation

A fundamental unit of any IFN study is the river segment, a basic habitat unit comprised of a relatively long section of a river that has a relatively homogeneous discharge, i.e. the outflow from the segment is approximately equal to the inflow. Given this homogeneity, it is expected that the geomorphology of the channel will remain about the same in terms of slope, sinuosity and channel pattern and structure (Bovee et al 1998). The flow regime is the primary driver of habitat and the major determinant of segment boundaries. In that regard it is a rule of thumb that a 10% or greater change in base flow is sufficient to indicate a potential segment boundary (Bovee et al 1998). Usually a boundary will be at the junction of a major tributary but an incremental change in discharge due to multiple inputs that total about 10% also may be taken as justification for a segment boundary. Incremental increases in flow make deciding exactly where a boundary should be more difficult. Alternatively, one can place a segment boundary at a point where there has been more than a 10% increase in drainage area. Other segment boundaries may be indicated by major changes in slope, channel configuration, valley type or as a result of human structures such as dams which may affect habitat structure in the river.

2.2.2 Preliminary Red River Segmentation

The USGS has not done a river segmentation analysis on the RRN (Chris Laveau Supervisory Hydrologist, USGS Grand Forks Field Office, personal communication) nor was one found for the Canadian portion of the river. MN DNR fisheries managers segmented the river in the US for fish management purposes (Renard et al 1986). The segmentation was based on a videotaped over flight of the river from Wahpeton to the International Boundary, on-river inspection by boat, and availability of access points (Figure 5). The 14 sectors were based mainly on changes in slope of the river (Figure 6) and sites of eight dams that were known to be impassable barriers to fish movements except during flood flows. Later MN DNR amalgamated these sectors into four sampling segments which fairly closely align with possible segments based on hydrology of the river. The current MN DNR four segments are as follows: Breckenridge to Fargo, Fargo to Grand Forks, Grand Forks to Drayton and Drayton to the mouth of the Pembina River (Groshens 2010).

Suggested segments for the RRN based solely on hydrology (mean annual flow for the periods of record) would be 1) from the confluence of the Otter Tail and Bois de Sioux rivers at Wahpeton/Breckenridge to just above the mouth of the Sheyenne River, 2) from below the mouth of the Sheyenne to just above the mouth of Red Lake River, 3) from below the mouth of the Red Lake River to the below the mouth of the Roseau River (with the Pembina River an accumulated 10%+), 4) from below the mouth of the Roseau River to the floodgates above Winnipeg, 5) from below the floodgates to just above the mouth of Assiniboine River, 6) from the mouth of Assiniboine River to Lockport Dam, 7) from below the Lockport Dam to Lake Winnipeg (Figure 7). Operation of the Lockport Dam confounds the hydrological segments through the City of Winnipeg because when the dam is in operation the river is backwatered to near the floodgates suggesting a single segment from the floodgates to Lockport Dam. For the rest of the year a segment boundary at the mouth of the Assiniboine River is clearly indicated but the floodgates and Lockport Dam still would affect fish movements. A purely hydrological Segment 4 would extend from the below the mouth of the Roseau River to

the above the mouth of the Assiniboine River and likewise Segment 5 would extend from the mouth of the Assiniboine River to Lake Winnipeg. However that fact of the International Boundary may dictate a segment boundary at the Emerson gauge.

This is a suggested preliminary segmentation; a more thorough examination of the river via an aerial photography survey and an on-river survey by a knowledgeable international team would be required to provide final RRN segmentation. During the aerial survey potential IFN sites could be chosen and confirmed during the on-river survey. There are a number of rapids in the river both in the US and Canada that offer potential IFN sites because the hardened substrates and stable channel configurations often are favoured by many fish species. A complete long profile of the RRN from Wahpeton to Lake Winnipeg would provide geomorphic indications of segment boundaries to augment the hydrology based segmentation. These data may be extracted from the HEC RAS (US Army Corps of Engineers Hydrologic Engineering Center River Analysis System) models operated by the USACE and MB WS. Mr. Akinbola George can provide this in Manitoba and operation of the USACE models accompanying this report should provide the profile for the US portion (USACE HEC RAS project is available in the accompanying Data Disk). Existing modelled sites in the US portion of the RRN (USACE HEC RAS (2011) and USBR 1D (1999) and 2D (2003)), in the MB portion of the river (MB WS HEC RAS), and within the City of Winnipeg (HEC-2; Grant Mohr personal communication) and MB WS HEC RAS) offer opportunities for IFN study sites (see Data Disk for files). Interpolation of stream bed long lines between the cross sections in the HEC RAS models may provide sufficient habitat structure to operate the 1D version of the USGS Instream Flow Incremental Methodology (IFIM) Physical Habitat Simulation Model (PHABSIM). Fish habitat modelling has been conducted by US Bureau of Reclamation (USBR) at Fargo-Moorhead and at Frog Point near Grand Forks (River 2D files for Frog Point are in the Data Disk) but no fish habitat modelling has been done on the Red River in Manitoba.

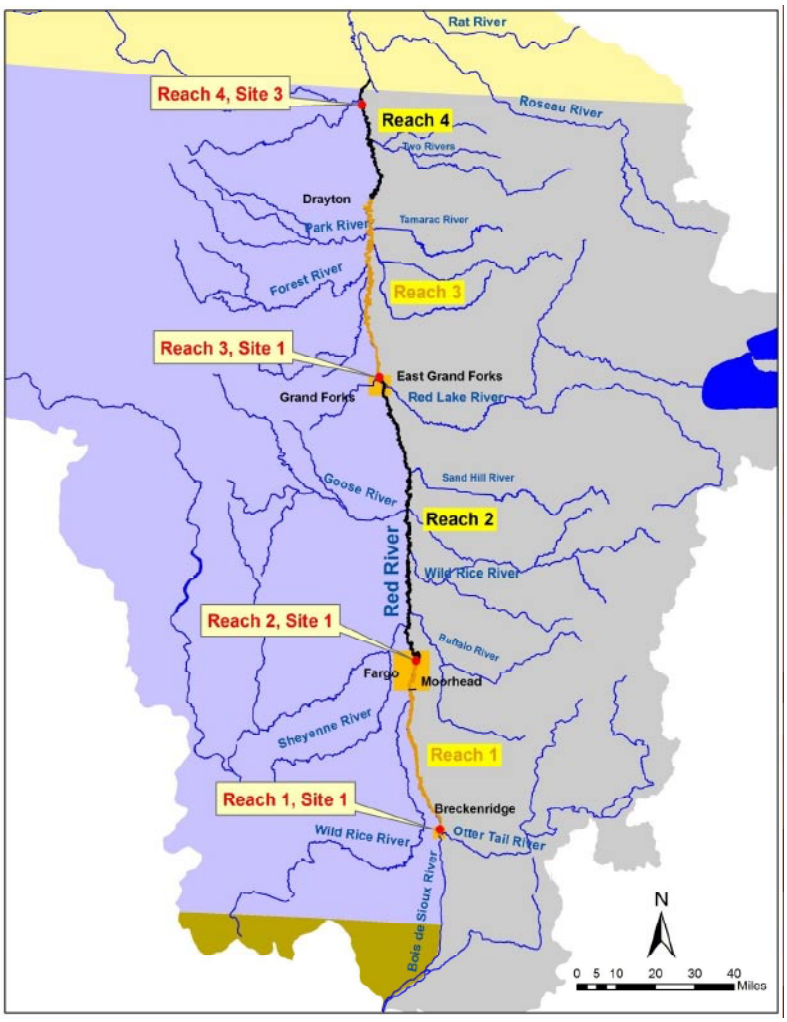

Figure 5. Four management reaches (segments) used by MN DNR fish managers for fish sampling programs (from Groshens 2010, with permission).

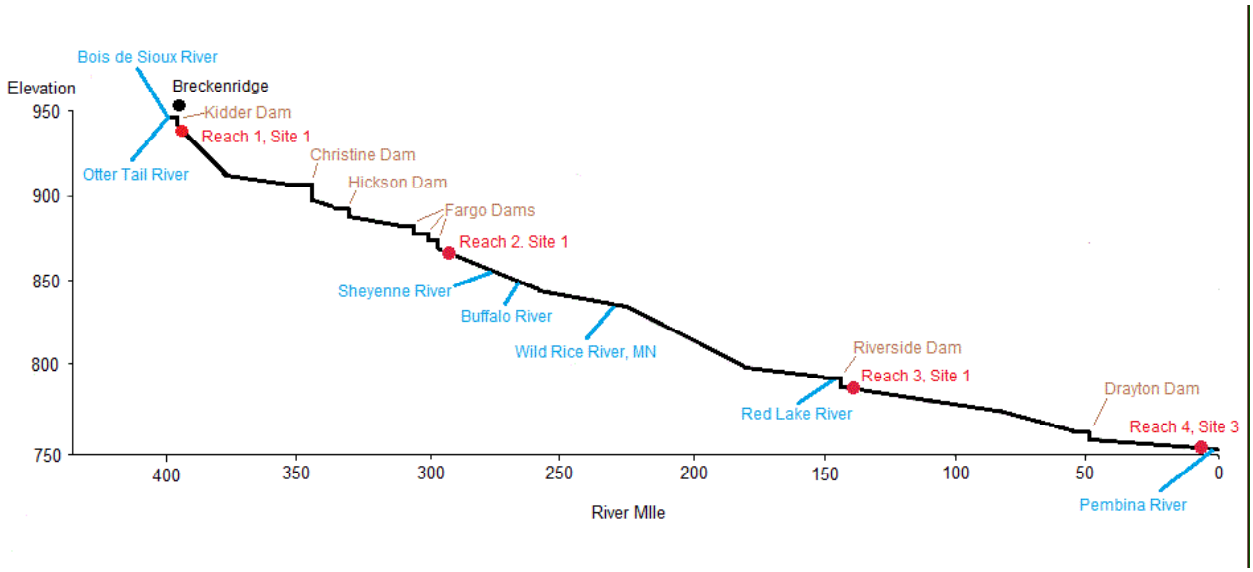

Figure 6. Longitudinal profile of the RRN in the United States showing locations of MN DNR management reaches (segments) (from Groshens 2010 with permission).

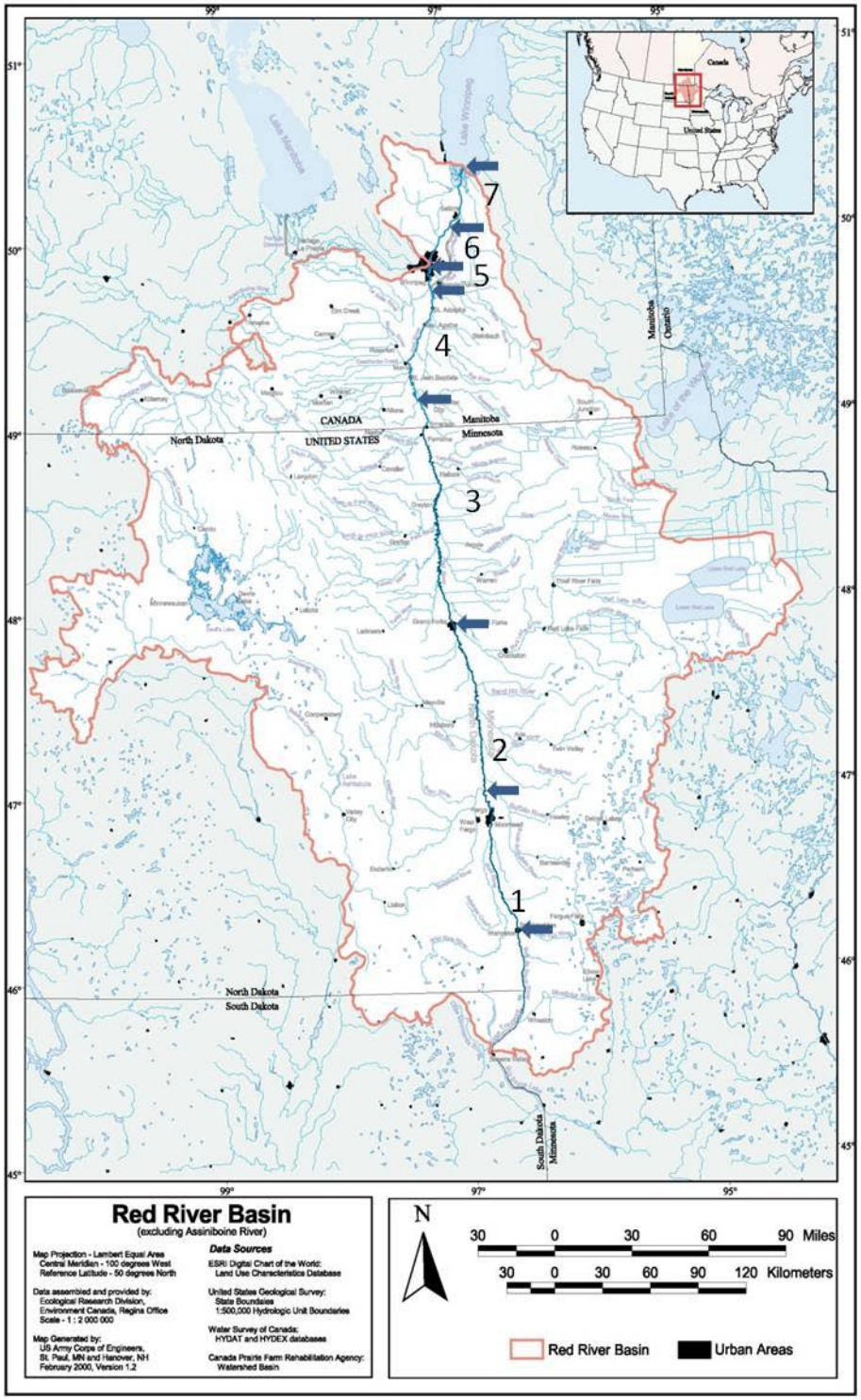

Figure 7. Suggested preliminary segments in the RRN based on hydrology.

3.0 Fish Habitat Analysis

The most frequently used fish habitat analysis system worldwide is the IFIM developed by the USFWS/USGS. IFIM is an integrative, multidisciplinary decision support system aimed at providing solutions to human use of water while preserving river ecology. The fish habitat analysis part of IFIM uses time series hydrology, hydraulic habitats and fish habitat suitability criteria to understand change in habitat quantity in relation to flow over time. This allows practitioners to contrast effects of low and high flows and water use scenarios on availability and quality of fish habitat for the period of record.

3.1 Physical habitat

The PHABSIM group of models are designed to calculate an index of the amount of habitat available for various life stages of fish or other aquatic organisms in relation to flow. PHABSIM has two basic components; the first is a hydraulic model to provide the physical habitat features of a stream in terms of depth and velocity as a function of discharge. Second, hydraulic habitat is integrated with HSC to provide measures of suitable habitat in relation to flow. Together, hydraulic habitat and HSC are referred to as a hydraulic-habitat model. A basic assumption of habitat modelling in IFIM is that there is a direct relationship between available suitable habitat and fish populations. There has been much discussion in the scientific literature on the validity of this assumption but it is generally believed to be true, often with qualifications. This discussion is outside of the purview of this report. Another general assumption generally held to be true is that the quantity, quality, and location of suitable habitat may change with discharge both in space and time. Finally use of the PHABSIM models assumes that the channel geometry does not change significantly with discharge over the timeframe of the analysis. The outputs from PHABSIM usually are restricted to relatively short reaches of a river and various methods are used to extrapolate the results to unobserved river stages and to the rest of the river.

Hydraulic habitat models may be one dimensional (e.g. IFG4, HEC-2, HEC RAS), two dimensional (e.g. River2D) or even three dimensional (very expensive). The more complex the model the more detailed is the model of habitat but this is countered by higher costs associated with more detailed survey work in the river. Whatever model is used, composite suitabilities are derived from combining individual HSC for depth, velocity and some indication of substrate or other habitat features collectively known as channel index for each cell. All of the similar cells are aggregated to provide the total amount of suitable (from >0 to 100%) or unsuitable habitat in the sample site at a given discharge. This sum of suitable habitat cells in relation to flow weighted by quality is known as weighted usable area (WUA) expressed as m^2/km of stream. WUA in combination with a hydrology time series provides a habitat time series, the variability in WUA over the period of record. Habitat duration curves are created in the same way as flow duration curves to provide exceedence values for habitat.

3.2 Biology

3.2.1 Fisheries Resources of the Red River

Aadland et al (2005) provided the most recent comprehensive assessment of the fish fauna of the RRN Basin. This paper was a collaboration of fish biologists in both the Canadian and US portions of the watershed. The authors identified a total of about 60 species in the main stem of the RRN although some of these are rare and several are introduced (Table 4). Lake Sturgeon is the only species essentially extirpated from the river. Lake Sturgeon occasionally are caught by anglers in the lower Red River below Lockport but have been virtually unknown above Winnipeg for nearly 100 years. The MN DNR and aboriginal groups have been working to recover Lake Sturgeon in the upper Red River watershed in the US while MB WS has stocked juvenile fish into the Assiniboine River, both for several years. Common Carp is the only truly exotic species (not of North American origin) established in the river and it was introduced deliberately beginning around the early 20th century. Several other species are exotic to the drainage but native in North America, such as White Bass, White Crappie, Largemouth

Bass and Rainbow Smelt. None of these species have become well established within the RRN. A smaller group of about 35 species could be considered common in the RRN and even then determined sampling would be required to collect more than about 20 of the commonest species.

The RRN has been sampled adequately in the US (Renard et al 1986, Hegrenes 1992, Goldstein et al 1995 Topp (1996), Henry (1996), Huberty (1996), Koel and Peterka 1998, Martini and Stewig (2000), Henry (2007), Groshens (2010), Yoder (2011 In Review). However some of these surveys targeted large bodied game fish using gear that was unlikely to sample small fish species very well. Resseguie (2002) provides some data on larval fish drift in the RRN. Biological sampling for fish in the river in Canada can only be described as rudimentary and there are no published data. Two unpublished studies have been done by DFO staff; Clarke et al (MS1980) completed three years of comprehensive sampling at Winnipeg in 1972-1974, and Watkinson and Franzin completed three stratified random sample runs of the entire river from Emerson to Lake Winnipeg in 2002-03 (Watkinson DFO, unpublished data). The former study used mainly trapnets and gillnets with some trawling and seining while the latter samples were collected entirely by boat electroshocking.

Fish catches in the four management reaches sampled by MN DNR in two different years (1983-84 and 2010) are compared with the 2002-03 catches in three preliminary segments in the Canadian portion of the river (Table 5) (data from Menard et al 1986, Groshens 2010, and Watkinson, unpub. Data 2003). The preliminary Segment 4 for these catches began at the International Boundary rather than at the mouth of the Roseau River. The different complement of fishing gears and effort among these samples affects the similarity of catches. However it is evident from the table that the abundance of large fish species is similar throughout the river. Gears used to sample mainly game fish obviously were biased against representative sampling of small bodied species and they are under-represented in these catches. Comparison of the earlier data collected in Winnipeg (Clarke et al MS1980) with the catches of Watkinson and Franzin for Segments 5 and 6 indicates the large fish community remains much the

same. Two changes in the recent catches in the lower RRN are the presence of *Ictiobus cyprinelus*, the Smallmouth Buffalo and *Cyprinella spiloptera*, the Spotfin Shiner. These species apparently colonized the lower RRN from the Assiniboine River and upper Red River respectively. Both species were known from those areas for a long time but expanded their ranges into the lower Red River quite suddenly in the 1980s.

Many of the larger species of fish in the RRN make quite long distance movements as demonstrated by mark-recapture studies of Channel Catfish and other species (Clarke et al MS1980, Hegrenes 1992, MacDonald 1992, Tyson 1996, Wendel 1999). Recaptures of fish tagged in the Winnipeg area have been caught in Lake Winnipeg and in the US portion of the river and fish tagged in the US portion of the river have been caught in Lake Winnipeg. The fact that the majority of the larger species are found in abundance from Wahpeton to Lake Winnipeg suggests most of these species probably have panmictic populations in the river with gene flow throughout the system. DNA evidence would be required to confirm this speculation.

Table 4. Fish species reported in the US (1962-2000; Aadland et al 2004) and Canadian (1967-2004; Stewart and Watkinson 2004) portions of the Red River of the North not including tributaries. Highlighted species are known to commonly occur in the mainstem of the Red River (D.Watkinson, DFO and Franzin, Unpub. Data; Koel 1997, Koel and Peterka 1998; Yoder MS2011).

Country	USA	Canada		Country	USA	Canada
Taxon				Taxon		
Petromyzontidae				**Esocidae**		
Ichthyomyzon castaneus	X	X		*Esox lucius*	X	X
Ichthyomyzon unicuspis	X	X		**Umbridae**		
Amiidae				*Umbra limi*	X	X
Amia calva [R]	X			**Osmeridae**		
Acipenseridae				*Osmerus mordax* [1R]	X	X
Acipenser fulvescens [R]	X	X		**Salmonidae**		
Hiodontidae				*Coregonus artedi*		X
Hiodon alosoides	X	X		*Coregonus clupeaformis*		X
Hiodon tergisus	X	X		**Percopsidae**		
Cyprinidae				*Percopsis omiscomaycus*	X	X
Carassius auratus [1]	X	X		**Gadidae**		
Cyprinella spiloptera	X	X		*Lota lota*	X	X
Cyprinus carpio [1]	X	X		**Cyprinodontidae**		
Luxilus cornutus	X	X		*Fundulus diaphanus* [R]	X	X
Macrhybopsis storeriana	X	X		**Gasterosteidae**		
Nocomis biguttatus	X			*Culaea inconstans*	X	X
Notemigonus crysoleucas	X	X		**Moronidae**		
Notropis atherinoides	X	X		*Morone chrysops* [1]	X	X
Notropis blennius	X	X		**Centrarchidae**		
Notropis dorsalis	X			*Ambloplites rupestris*	X	X
Notropis hudsonius	X	X		*Lepomis cyanellus*	X	
Notropis stramineus	X	X		*Lepomis gibbosus* [R]	X	X
Pimephales notatus	X			*Lepomis humilis*	X	
Pimephales promelas	X	X		*Lepomis macrochirus*	X	
Platygobio gracilis	X	X		*Micropterus dolomieu*	X	X
Rhinichthys obtusus	X	X		*Pomoxis annularis* [R]	X	X
Rhinichthys cataractae	X	X		*Pomoxis nigromaculatus*	X	X
Semotilus atromaculatus	X	X		**Percidae**		
Catostomidae				*Etheostoma exile*		X
Carpiodes cyprinus	X	X		*Etheostoma nigrum*	X	X
Catostomus commersonii	X	X		*Perca flavescens*	X	X
Ictiobus cyprinellus	X	X		*Percina caprodes*	X	X
Moxostoma anisurum	X	X		*Percina maculata*	X	X
Moxostoma erythrurum	X	X		*Percina shumardi*		X
Moxostoma macrolepidotum	X	X		*Sander canadensis*	X	X
Moxostoma valenciennesi	X			*Sander vitreus*	X	X
Ictaluridae				**Sciaenidae**		
Ameiurus melas	X	X		*Aplodinotus grunniens*	X	X
Ameiurus natalis	X					
Ameiurus nebulosus	X	X		Species Richness	57	55
Ictalurus punctatus	X	X		[R]Rare		
Noturus flavus	X	X		[1]Introduced species		
Noturus gyrinus	X	X				

Table 5. Fish species relative abundances by Reaches in the US (MN DNR 1983-84, 2010) and by Segments in the Canadian (DFO 2002-03) portions of the Red River of the North.

	USA				USA				Canada		
	Reach Totals 1983-84				Reach Totals 2010				Segment Totals		
	1	2	3	4	1	2	3	4	4	5 + 6	7
Taxon											
Petromyzontidae											
Ichthyomyzon castaneus		2							1		2
Ichythyomyzon unicuspis		4									
Acipenseridae											
Acipenser fulvescens											
Hiodontidae											
Hiodon alosoides		250	82	46	162	274	131	122	1703	1559	488
Hiodon tergisus	1	44	17	16				3	4	3	1
Cyprinidae											
Carassius auratus [1]											
Cyprinella spiloptera	115	23	9						65	4	1
Cyprinus carpio [1]	164	92	68	25	18	6	36	6	119	128	214
Luxilus cornutus		2							2		
Macrhybopsis storeriana		7	7	10			4		18	22	37
Nocomis biguttatus											
Notemigonus chrysoleucas											
Notropis atherinoides	1	10	15	511					54	54	256
Notropis blennius		2	11	45					3		
Notropis dorsalis											
Notropis hudsonius											4
Notropis stramineus		14		1					1		
Pimephales notatus											
Pimephales promelas		2	1						19	1	1
Platygobio gracilis		1									
Rhinichthys obtusus											
Rhinichthys cataractae		1									
Semotilus atromaculatus											
Catostomidae											
Carpiodes cyprinus	26	27	20	3	14	16	40	129	58	84	40
Catostomus commersoni	10	40	6	3	13	8	1	20	32	31	59
Ictiobus cyprinellus	41	7	2			1	1		3	19	8
Moxostoma anisurum	32	49	5	2	5			6	13	24	5
Moxostoma erythrurum	34	7	2	2	6	2	4	4	6		12
Moxostoma macrolepidotum	197	157	9	1	37	34	11	36	146	14	17
Moxostoma valenciennesi	1				3	2					
Ictaluridae											
Amieurus melas	1	6				28	4	1	2	1	
Amieurus natalis					1						
Amieurus nebulosus						17					
Ictalurus punctatus	108	47	9	5	2239	691	27	152	57	15	17
Noturus flavus		2			6	36	35	10	5		
Noturus gyrinus											
Esocidae											
Esox lucius	19	4	3	1	1	4	22	42	49	29	10
Umbridae											
Umbra limi											
Osmeridae											
Osmerus mordax [R]											
Salmonidae											
Coregonus artedii											2
Coregonus clupeaformis											
Cyprinodontidae											
Fundulus diaphanus [R]											
Gasterosteidae											
Culaea inconstans											
Gadidae											
Lota lota		8	1				1				
Percopsidae											
Percopsis omiscomaycus	15	4							5	2	1
Moronidae											
Morone chrysops [1]		1							3	4	40
Centrarchidae											
Ambloplites rupestris	16	19	2		8	4	3	1	18	9	2
Lepomis cyanellus	4										
Lepomis humilis											
Lepomis macrochirus							7				
Micropterus dolomieui					1				1	1	
Pomoxis annularis											
Pomoxis nigromaculatus	1	1	1	1	2		4		43	30	10
Percidae											
Etheostoma exile											
Etheostoma nigrum											
Perca flavescens										1	10
Percina caprodes	3										
Percina maculata	11										
Percina shumardi											
Sander canadensis		6	10	48	6	33	40	48	682	322	575
Sander vitreus	35	28		1	12	14	12	14	68	44	35
Sciaenidae											
Aplodinotus grunniens	17	40	12	11	21	67	50	35	119	24	82
Totals	852	907	292	732	2555	1237	433	629	3299	2425	1929

3.2.2 Other aquatic fauna of the Red River

In addition to fish, the RRN is habitat for several species of amphibians, two species of turtles, about a dozen species of mussels (Cvancara 1970, Renard et al 1986), and a great many invertebrates. Aquatic and semi-aquatic mammals such as beaver, muskrat, otter, mink and raccoons inhabit the river and its margins. Where significant riparian forests remain along the river mast species of trees such as burr oak, green ash, basswood and cottonwood provide important habitat for songbirds. The river also is a source of water for terrestrial mammals such as deer, fox, rabbits and several species of squirrels and small rodents. Many species of waterfowl and raptors use the river valley as a migration corridor and as nesting habitat (Rosenberg et al 2005).

3.2.3 Fish HSC from, or adaptable for, use in the Red River

The MN DNR is the only source of RRN specific habitat suitability criteria (HSC) for fish (Aadland et al 1991, Aadland and Kuitunen 2006). Aadland and Kuitunen have assembled HSC for many of the species that occur in the RRN drainage basin but have developed HSC for at least one life stage for only 14 species in the RRN. Data have been gathered for four other species but not enough to provide HSC curves. Kelsch and Wendel (2004) also reported habitat availability and use by Channel Catfish in the RRN that could be used to augment Channel Catfish HSC.

HSC from elsewhere may be used in place of locally derived data but usually a group of expert fish habitat biologists would be gathered in a workshop to fine tune imported HSC to be applied in a local case. Aadland and Kuitunen report HSC for many species in other rivers that could be adapted for use in the RRN. Similarly 11 HSC are available from the Assiniboine River (Nelson and Franzin 2000) and several species curves could be imported from the Saskatchewan River (Watkinson et al 2009), but all would have to be adjusted to reflect conditions in the RRN. Given that the RRN below Grand Forks is mainly a single deep channel, the important habitat features are depth, velocity and cover with bottom roughness from substrate playing a minor role except perhaps in the

few “rapids” areas. Aadland and Kuitunen (2006) also provide some HSC for mussels but not from the RRN. Mussel experts would have to determine applicability of those HSC to the mussels of the RRN.

3.3 Fisheries of the RRN

The RRN provides important recreational fisheries in both the US and Canada, mainly for Channel Catfish, Walleye and Sauger. The three states MN, ND, SD and the Province of MB established a management plan for the river in 2008 that provides fisheries objectives for the US portion of the river (Red River of the North Fisheries Management Plan 2008). Manitoba has no fisheries management plan specific to the RRN at this time (Derek Kroeker, MB WS, personal communication) but the general recreational fishing regulations specify size and catch limits in the RRN for all three species. The RRN recreational fishery is the single most important recreational fishery in MB, accounting for about 20% of the total value ($80M) of recreational fishing in the province (http://www.gov.mb.ca/waterstewardship/water_info/transboundary/manitoba.html). There also is an important commercial bait fishery in the lower RRN in MB below Lockport valued at approximately $200K annually.

Recreational fisheries on the RRN in MN and ND had a combined value in 2010 of approximately $8.3M (Lynn Schlueter, NDGF Devils Lake, personal communication).

3.4 Instream Flow and Fish Habitat Modelling in the RRN

Fish habitat modelling in the RRN is limited to studies undertaken by the USBR (1999, 2003) and Houston Engineering (1997a) in the Sheyenne River and in sections of the RRN between Fargo and the Buffalo River. The 1999 USBR study was comprehensive and compared multiple methodologies for providing instream flows for aquatic life maintenance, riparian corridor maintenance, water quality, and recreational usage in the RRN. Seasonal instream flow regimes were evaluated using 1) hydrologic methods

(comparisons of annual mean flows; mean flows for all years with high and low flows for spawning and maintenance, the Tennant method, a comparison of 25% of annual mean flow comparison, and water year type (dry-average-wet) comparisons with high and low flows for spawning and maintenance) 2) wetted perimeter versus the MN flow method of O'Shea (1995), 3) the hydraulic rating method using the wetted perimeter technique after Nelson (1980), 4) modified habitat preference method (modified PHABSIM). A goal oriented methodology also was employed to help establish a seasonal instream flow regime for aquatic life maintenance. IFN methods for seasonal aquatic life maintenance for high (March to June) and low (July to February) flow periods were compared at Wahpeton, Hickson, Fargo, Halstead, Grand Forks, Drayton and Emerson (Table 3 in USBR 1999). Proposed monthly flows with high flows for spawning in March to June and maintenance flows for July to February for these same stations are reported in Table 5 of the report. Houston Engineering, Inc. (1997b) also completed an IFN study for water quality in the Sheyenne River and in the RRN from Fargo to the Buffalo River.

The USBR (1999) study reach for the modified PHABSIM analysis was from Fargo to the mouth of the Buffalo River near Halstad, MN. A study site was selected near Fargo, just downstream of the Interstate-94 highway bridge. Hydrology data from 1931 to 1984 in monthly timesteps were used as the basis of the comparisons of the IFN methods. HSC were selected from Aadland et al 1991 and other literature was used to affirm that the chosen five species occurred in the study area. The USBR (2003) study compared 1D and 2D modelling using PHABSIM at a site near Grand Forks called Frog Point. Again the HSC were derived from Aadland et al 1991.

3.4.1 Macrohabitat & Mesohabitat Modelling

Aadland and Kuitunen (2006) provide tables of fish preferences for combinations of depths and velocities known as mesohabitats or macrohabitats depending on scale. Mesohabitat HSC may be constructed of three-way combinations of different hydraulic habitats, e.g. slow velocity, deep depth, fine substrate or fast velocity, shallow depth and coarse substrate. Examples of mesohabitats or macrohabitats based on stream

characteristics can include pools, riffles, and runs at varying depths or velocities such as large pools with moderate depths, slow current and fine substrates or rapids with shallow depths, fast current and coarse substrate. Using groups of fish species occurrence data for such habitats is a convenient way to encompass larger habitat units and to guild fishes into common habitat requirements. These approaches may be considered to be closer to the real world than the calculated microhabitat preferences derived from combining individual species life stage occurrence data for depth, velocity and substrate (HSC), but modelling them is much the same as for microhabitats. The USBR (2003) included small scale mesohabitats with fish guilding as part of their study of fish habitat at Frog Point near Grand Forks.

The availability of long river segments in HEC RAS models in the US (USACE 2011) and in MB (MB WS) may make it possible to categorize macrohabitats in terms of larger scale features which may be appropriate for much of the RRN. These two models each include hundreds of cross sections spaced in the range of one to a few kilometres apart. Mr. Akinbola George of MB WS advises that it is possible to interpolate longlines for depth between these cross sections by following the thalweg channel and the river banks. Average velocities for any flow can be computed at the measured cross sections and also could be interpolated between the cross sections. In areas where the cross sections are more densely place (possibly in the Fargo-Moorhead area and within the City of Winnipeg (Acres Manitoba Ltd. 2004 HEC-2 cross sections) it is possible that 1D fish hydraulic-habitat models like PHABSIM could use interpolated river topography to provide a basis for physical habitat modelling. There are short occurrences of coarse substrates which may form rapids at low flows dispersed over the upstream portion of the RRN above Grand Forks mainly and below the City of Winnipeg for which HEC RAS derived topography may be too coarse to be useful. These rare and possibly important habitats would require careful surveys to be included in habitat modelling efforts.

3.5 Fish water quality and temperature requirements

Water quality in the RRN is generally adequate for the resident fish communities. Fish require waters that are not extremely turbid, have sufficient oxygen for a full range of physiological function, a circum-neutral pH, low levels of toxic chemicals and water temperatures in the range suitable for normal activity (usually less than about 35C for a cool-water to warm-water fish community such as that of the RRN). Kjartanson et al (MS2009) compiled environmental tolerances for temperature, pH, dissolved oxygen and turbidity for Manitoba fishes including all of the commoner species in the RRN. Resseguie (2002) also collected data on spawning responses of several species of fish in the upper RRN in relation to flow, temperature and photoperiod.

All of the jurisdictions in the RRN watershed have water quality criteria for aquatic life which are designed to protect aquatic species including fish. The RRN has had episodes of poor water quality that have included fish kills both in response to extreme low water and high temperatures in summer and due to wastewater spills resulting from accidental discharges during high precipitation events.

3.6 Fish Species Periodicity

Instream flow models using fish habitat suitability criteria (HSC) for modelling fish habitat in a river system must be appropriate for the life stages present in the river at the location and time of modelling. These lifestage times are referred to as biologically sensitive periods (BSP). Table 6 provides a tentative set of BSPs for the life stages of the commoner fishes of the RRN. This set of BSPs was developed from consulting regional literature (Stewart and Watkinson 2004, Scott and Crossman 1973, Becker 1983) in combination with personal knowledge and consultations with fish biologists working in Manitoba, Minnesota and North Dakota. The BSPs used in any IFN setting exercise should be re-examined in a workshop setting including knowledgeable fish biologists to arrive at an accepted set of BSPs for each river segment. The appropriate

time step for BSPs is weeks; therefore daily discharge records used in hydraulic-habitat modelling need to be configured into weekly time steps for the years of record.

Table 6. Tentative species periodicity table for fishes commonly found in the mainstem of the Red River of the North. A = Adult; J = Juvenile; F = Fry; S = Spawning; I = Incubation. Adult fish are fish that either are of adult size or juveniles in a second year of life or greater; Juveniles are fish post fry stage in their first year of life; Fry are fish that are just hatched and just becoming free swimming but not fully developed into the juvenile stage (i.e. don't yet look like small adult fish). Biologically sensitive periods (BSP) were chosen to represent important times of an average year in the Red River mainstem: BSP 1; winter ice cover, BSP 2; spring break up and spawning for early spring spawners; BSP 3; late spring spawning, early summer spawning and the beginning of the major growing season; BSP 4; summer spawning and peak of summer growing season; BSP 5; late summer growing season and falling light levels; BSP 6; fall spawning and cool down to winter. Juveniles are included in BSP 6 only to reflect the fall/winter periods of ice cover. Most species are known to use tributaries of the Red River for spawning; it is not well known whether or not the mainstem of the river is used for spawning.

Scientific Name	Common Name	BSP 1 Weeks 48 - 13 (Nov 28 - Apr 3)	BSP 2 Weeks 14 - 19 (Apr 4 - May 15)	BSP 3 Weeks 20 - 23 (May 16 - Jun 12)	BSP 4 Weeks 23 - 28 (Jun 13 - Jul 17)	BSP 5 Weeks 29 - 38 (Jul 18 - Sep 25)	BSP 6 Weeks 39 - 47 (Sep 26 - Nov 27)
Petromyzontidae							
Ichthyomyzon castaneus	Chestnut Lamprey	A, J	A, J	A, J	A, J, S, F	A, J	A, J
Ichthyomyzon unicuspis	Silver Lamprey	A, J	A, J	A, J	A, J, S, F	A, J	A, J
Acipenseridae							
Acipenser fulvescens (endangered)	Lake Sturgeon	A, J	A, S	A, S, F	A, J, F	A, J	A, J
Hiodontidae							
Hiodon alosoides	Goldeye	A, J	A, S	A, F	A, J	A, J	A, J
Hiodon tergisus;	Mooneye	A, J	A	A, S	A, F	A, J	A, J
Cyprinidae							
Cyprinella spiloptera	Spotfin Shiner	A, J	A	A, S	A, S, F	A, S, F	A, J
Cyprinus carpio [1]	Common Carp	A, J	A	A, S	A, S, F	A, J	A, J
Luxilus cornutus	Common Shiner	A, J	A	A, S	A, S, F	A, S, F	A, J
Macrhybopsis storeriana	Silver Chub	A, J	A	A	A, S	A, S, F	A, J
Notropis atherinoides	Emerald Shiner	A, J	A	A	A, S, F	A, S, F	A, J
Notropis blennius	River Shiner	A, J	A	A, S	A, S, F	A, S, F	A, J
Notropis hudsonius	Spottail Shiner	A, J	A	A, S	A, F	A, J	A, J
Notropis stramineus	Sand Shiner	A, J	A	A, S	A, S, F	A, S, F	A, J
Pimephales promelas	Fathead Minnow	A	A, S	A, S	A,S,F	A, J	A
Catostomidae							
Carpiodes cyprinus	Quillback	A, J	A, S	A, F	A, J	A, J	A, J
Catostomus commersonii	White Sucker	A, J	A, S	A, F	A, J	A, J	A, J
Ictiobus cyprinellus	Bigmouth Buffalo	A, J	A	A, S	A, F, J	A, J	A, J
Moxostoma anisurum	Silver Redhorse	A, J	A, S	A, S, F	A, F	A, J	A, J
Moxostoma erythrurum	Golden Redhorse	A, J	A, S	A, S, F	A, F	A, J	A, J
Moxostoma macrolepidotum	Shorthead Redhorse	A, J	A, S	A, S, F	A, F	A, J	A, J
Ictaluridae							
Ameiurus melas	Black Bullhead	A, J	A	A, S	A, S, F	A, J	A, J
Ameiurus nebulosus	Brown Bullhead	A, J	A	A, S	A, S, F	A, J	A, J
Ictalurus punctatus	Channel Catfish	A, J	A	A	A, S	A, F, J	A, J
Noturus flavus	Stonecat	A, J	A	A	A, S	A, F, J	A, J
Noturus gyrinus	Tadpole Madtom	A, J	A	A	A, S	A, F, J	A, J
Esocidae							
Esox lucius	Northern Pike	A, J	A, S	A, F	A, J	A, J	A, J
Salmonidae							
Coregonus artedi	Cisco	A, I	A, F	A, J	A, J	A, J	A, S, J
Gasterosteidae							
Culaea inconstans	Brook Stickleback	A, J	A, S	A, S, F	A, S, F	A, J	A, J
Gadidae							
Lota lota	Burbot	A, S, I	A, F	A, J	A, J	A, J	A, J
Percopsidae							
Percopsis omiscomaycus	Troutperch	A, J	A	A, S	A, S, F	A, J	A, J
Moronidae							
Morone chrysops [1]	White Bass	A, J	A	A, S	A, F	A, J	A, J
Centrarchidae							
Ambloplites rupestris	Rock Bass	A, J	A	A, S, F	A, F	A, J	A, J
Pomoxis nigromaculatus	Black Crappie	A, J	A	A	A, S, F	A, J	A, J
Percidae							
Etheostoma nigrum	Johnny Darter	A, J	A	A, S	A, F	A, J	A, J
Perca flavescens	Yellow Perch	A, J	A	A, S	A, F	A, J	A, J
Percina maculata	Blackside Darter	A, J	A	A, S	A, F	A, J	A, J
Sander canadensis	Sauger	A, J	A, S	A,S,F	A, J	A, J	A, J
Sander vitreus	Walleye	A, J	A, S	A,S,F	A, J	A, J	A, J
Sciaenidae							
Aplodinotus grunniens	Freshwater Drum	A, J	A	A, S	A, S, F	A, J	A, J

[1] Introduced

4.0 Connectivity

Connectivity in an IFN context is the river's connection with its floodplain (lateral), with its subsurface groundwater (vertical), with the upper and lower parts of the watershed (longitudinal) and its hydrology over time (chronological). Hydrology is the main driving variable in all aspects of connectivity, connecting fish with floodplain habitats, maintaining base flows during winter, providing the high and low flows that shape habitats and providing access for fish to the length of the river. The main physical manifestation of connectivity for fish within the RRN is the ability of fish to move freely up and down the length of the river without physical barriers.

There are barriers to fish passage in the RRN; 10 dams in the mainstem river. Five of the eight weir-type dams in the US portion of the RRN mainstem have been converted to rapids by constructed rock-arch rapids that backwater the weir crest to enable fish passage, reduce erosion and improve public safety (Groshens 2010). In the winter of 2011-12 two of the remaining dams near Christine and Hixon ND will be converted to rock-arch rapids. Alternatives for modifying the last intact dam, Drayton Dam, presently are being evaluated by a multi-agency team (T. Groshens, MN DNR, personal communication). The two remaining structures in the mainstem RRN are the floodgates above Winnipeg and the St. Andrews Lock and Dam at Lockport, MB. Both structures are known impediments to fish passage (City of Winnipeg Ammonia Criteria Study: Other Physical Stressors 2000). Options for a fishway at the floodgates have been considered but nothing has been constructed to date (KGS Group 2008).

All of the larger RRN tributaries also have had or still have dams; some have been removed or backwatered with rock-arches. Van Offelen (USFWS 2005) includes these dams as part of an overall assessment of dams in the RRN drainage in MN. Construction of fishways to enable fish passage from the RRN to ND tributaries entering the river in the Fargo area is part of the plan for the Fargo-Moorhead Diversion (USACE 2011). In Manitoba, the Assiniboine River control structure at Portage la Prairie 160 km

upstream of the confluence is the only tributary dam of consequence for RRN fishes. This dam is an absolute fish barrier except during winter when the dam is opened to drain the headpond. As van Offelen points out there also are many culverts under roads in the RRN watershed that often are fish barriers blocking access to suitable habitats upstream.

Connectivity of the river with its riparian zone also is important to the maintenance of many species that occupy the banks and immediate valley of the RRN. Modeling done for channel maintenance (USBR 1999) suggests that channel maintenance flows in the RRN probably provide sufficient connection of the riparian zone to the river.

5.0 Water Quality

The most important water quality parameters for aquatic life are temperature, pH, dissolved oxygen and turbidity (aside from toxic chemicals such as ammonia and chlorine associated with some sewage treatment plants). Also, other biohazardous materials occasionally may be introduced into the river by spills. These four parameters and many others are monitored routinely in the RRN at several gauging stations in the US and Canada. Table 3 provides linked access to the US gauges but easy public access to water quality monitoring stations in Canada is nonexistent. Requests must be made to Environment Canada for water quality data from the International Border station at the Emerson gauge. The period of record for water quality parameters is from 1960 to the present (Brian Parker, EC personal communication). The Red River Basin Board Water Quality group reviewed water quality concerns, regulations and standards of all of the jurisdictions in the RRN basin (RRBB 2001 (now part of the Red River Basin Commission)) and reported that water quality in the RRN was generally good.

5.1 Water Quality in Canada

Environment Canada monitors International Border gauging stations such as that at Emerson monitor water quality and reports the data to MB WS and the International Red River Board (IRRB) of the IJC. Criteria for aquatic life are provided by the Canadian Council of Ministers of Environment (CCME) Guidelines for the Protection of Aquatic Life (accessible on the internet at: http://www.waterquality.ec.gc.ca/EN/navigation/3297/3301/3307.htm)
In addition to the Emerson station, water quality in the RRN also is monitored by MB WS at St. Norbert and Selkirk for compliance with Manitoba Water Quality Standards, Objectives, and Guidelines (2011). The City of Winnipeg Department of Water and Wastes also regularly monitors river water quality at bridge crossings on the Red and Assiniboine rivers (http://winnipeg.ca/waterandwaste/sewage/monitoring/2011RiversReports.stm). Other years can be accessed by changing the year in the URL.

Paquette (2009) analyzed statistical trends in selected water quality parameters in the Manitoba portion of the RRN from Emerson and at the MB WS monitoring stations near St. Norbert and at Selkirk. Manitoba water quality data must be requested from MB WS. Data for the period of record from the water quality station at Emerson were reviewed for average, maximum and minimum of temperature, dissolved oxygen, pH and turbidity for the period of record (Table 7). Ten of 559 dissolved oxygen values were less than the aquatic life guideline of 5mg/l. Temperature and pH were within guidelines and for NTU, 353 observations were greater than the guideline of 10% above background levels (here taken as the average) (Data provided by Environment Canada, Water Quality Monitoring and Surveillance, Winnipeg).

Table 7. Average, maximum and minimum values for dissolved oxygen, pH, temperature and turbidity in NTU in the RRN at Emerson from 1960 to the present.

	Dissolved Oxygen	pH	Temperature	NTU Turbidity
Average	10.0	8.1	16.5	106.4
Maximum	20.8	9.2	29.0	1862.0
Minimum	2.3	6.7	-0.2	0.1
Observations	559	1235	1185	1113

5.2 Water Quality in the USA

Tornes (2005) recently reviewed water quality at gauging stations on the RRN and tributaries in the Red River of the North Basin of Minnesota, North Dakota, and South Dakota, for the period 1970-2001. He found that pH ranged from 7.2-8.9, dissolved oxygen ranged from 1.3-18.2 mg/l, solids residue on evaporation ranged from 245 – 1100 mg/l and temperature ranged from 0-29 C in the RRN at Emerson. The data generally were within water quality criteria for aquatic life with the exceptions of occasional low dissolved oxygen and frequent high TSS and TDS observations. Approximately 25 other constituents also were reported. Macek-Rowland and Dressler (2002) provide statistical summaries of water quality data for all of the RRN gauging stations from Emerson upstream to Wahpeton for the period generally from about 1970 to 2000 except at Fargo and Grand Forks where data collection began in 1949 and at Emerson in 1960. The data for Emerson includes approximately 14 pages of parameters ranging from discharge to an amazing array of organic contaminants.

Real time and historic water quality data for the RRN in the US are available by clicking on the USGS gauge of interest in Table 3. Because of potential future population growth and risks associated with drought in the Red River valley in ND/MN the USGS and USBR developed a water quality model to better understand constituent transport dynamics in the RRN from upstream of Fargo to the International Boundary for eight water supply options developed by the USBR (Nustad and Bales 2005). The modification of the USACE HEC-5Q model provided potential effects on water quality of the various water supply options including effects of low river flows on dissolved oxygen.

USEPA (Guidelines for Deriving Numerical National Water Quality Criteria for the Protection Of Aquatic Organisms and Their Uses), MN PCA (Minnesota Rules Chapter

7050) and ND Dept of Health (Chapter 33-16-02.1 Standards Of Quality For Waters Of The State) all have water quality standards for aquatic life similar to those of EC and MB. These standards usually are met by waters of the RRN.

6.0 Water Use

Rules for international, state and provincial water licensing and allocation in the RRN are discussed fully by de Loë (2009) and are not considered in this report. Only known water uses of RRN water are reported here. Macek-Rowland et al (2004) provided water use and return flow data for the RRN basin for the period 1979-2001. RRBC (2008) updated this information to include water use data for the RRN valley in Manitoba as well as average daily use data for people living throughout the RRN valley. USBR completed a large comprehensive water demand and supply study for the RRN of ND and MN with eight options for increasing water supply in times of shortage and with different population increase scenarios (USBR 2008). The Dakota Water Resources Act under which the study was funded specifically included flows in rivers for aquatic needs for fish and wildlife and channel maintenance; hence the habitat modelling that was done in the RRN (USBR 1999, 2003).

The potential for serious drought in the RRN valley is real, and in spite of several years of flooding, the possible impact of extended drought conditions cannot be underestimated. Basin communities know this and are preparing (albeit slowly) for that eventuality.

7.0 Summary

Data discovered and data gaps:

- **Geo-referenced bathymetric data that defines river bed topography**
    - Geo-referenced cross sections are available over the length of the river that define cross channel topography at about intervals of one to a few kilometres. It is possible with available HEC RAS models

to interpolate the cross sections to approximate longitudinal topography. For detailed 2D modelling, river habitat surveys would be required at selected IFN sites, however River2D could be run in a coarse configuration using interpolated data.

- **Surveyed transects and cross sections**
    - There are hundreds of surveyed cross sections over the length of the river from Wahpeton to Lake Winnipeg. Longitudinal transects may be limited to those collected by Terry Dick and students within the City of Winnipeg and those created in River2D modelling by the USBR at their Frog Point site. Terry Dick collected data using Questar Tangent equipment from Emerson to Breezy Point but the data may be lost. Longitudinal water surface profiles for any flow can be output from the HEC RAS models. These data will be extremely useful in identifying possible IFN study sites.
- **Any previous IFN studies**
    - It appears that four IFN studies have been done in the RRN (USBR 1999, 2003 and Houston Engineering, Inc 1997a,b) with study reaches in the Sheyenne River and the RRN. USBR (1999) calculated monthly flow regimes for aquatic life maintenance at all of the major USGS gauging stations from Wahpeton to Emerson using flow data from 1931-1984. USBR (2003) used River2D to model fish habitat at Frog Point, near Grand Forks. These study sites should be examined for utility in further habitat modelling with additional species and life stages.
- **Discharge, velocity, water surface and depth measurements in open water and ice-covered conditions**
    - There are good discharge records at several gauging stations for long periods of record (up to more than 100 years) both in the US and Canada for summer and winter. Depth measurements are available from a great many cross sections in the US and Canada (in HEC RAS morphometry files) at the time and discharge of

measurement. The HEC RAS models will output depths for any given discharge at those cross section locations in the river. Similarly water surface profiles are available from the HEC RAS for any given flow. Only average cross sectional velocity data can be output from HEC RAS models but by interpolation it is possible to produce simulated cross sectional velocities and channel long lines that may be useful in 1D habitat modelling using PHABSIM.

- **Substrate, cover and water temperature data**
    - There is little substrate and cover data available for the RRN but there is much temperature data collected at gauging stations in the US portion of the river and at Emerson in Canada. Fish habitat distribution in the river is undescribed and a large data gap. However long reaches in the river may be of similar, rather plain, habitat.
- **Natural flow hydrographs**
    - The hydrographs at the several gauging stations in the RRN are not natural and are influenced by dams and land drainage throughout the watershed. There has been some effort to synthesize natural flows in the US portion of the river.
- **Identification of representative fish species and life stages for the RRN**
    - The fish species and their life histories in the RRN are reasonably well known but details of spawning locations and larval and juvenile life histories are poorly known for the RRN. Two theses provide timing and location data for larval fish occurrence from drift sampling in the RRN in the US. Considerable fish distribution and biological data are available from which to identify representative species. The fact that the major common large fish species appear to be present in good numbers throughout the mainstem river suggest that the same suite of representative species could be used at all mainstem RRN sites.

- **Data on distribution, habitat use, and habitat availability of representative fish species and life stages in reference sites where bathymetry and flow data were recorded**
    - Good fish distributional information is available for the US portion of the RRN but in Canada these data are limited to two studies, one focussed on Winnipeg in 1972-74 (Clarke et al MS1980) and the other comprised of three seasonal longitudinal electrofishing surveys of the Canadian portion of the river in 2002-03 (Watkinson and Franzin unpublished data). Habitat preference data is limited to that found in Aadland and Kuitunen (2006). Habitat availability data is poor in the US portion and non-existent in the Canadian portion of the river. Fish presence data collected by standardized sampling over about 25 years at about 5y intervals are available in the US portion of the river including sites where flow data are available and HEC RAS model cross sections can provide bathymetry. A River2D model has been developed and operated in sites near Fargo-Moorhead and Grand Forks to test fish habitat-flow relationships.
- **Determination of biologically sensitive periods**
    - A tentative set of BSPs is provided with input from regional biologists but a workshop should be held to provide the definitive BSPs for the species in the RRN. Aadland and Kuitunen (2006) provide BSP-related habitat use data for a number of fish species in the RRN.
- **Temperature and velocity preferences for the different fish species**
    - There are ample data on temperature preferences of the commoner fish species of the RRN some of which are compiled in an unpublished DFO report (Watkinson et al MS 2011). Data also are reported in most books on the fishes of states and provinces. Velocity preference data are available for some species in the RRN in Aadland and Kuitunen (2006). Velocity preference data also are available from IFN studies elsewhere on the prairies and in the US.

- **Any available reports on validating habitat suitability curves (HSC) for representative fish species in the RRN**
    - There are none. This is a data gap that frequently has not been addressed in most published IFN studies.

8.0 Literature Cited

Aadland, L.P., C.M. Cook, M.T. Negus, H.G. Drewes, and C.S. Anderson. 1991. Microhabitat preferences of selected stream fishes and a community-oriented approach to instream flow assessment. Minnesota Department of Natural Resources, Section of Fisheries, Investigational Report No. 406. St. Paul. 125 pp. Available online: http://www.dnr.state.mn.us/publications/fisheries/investigational_reports.html

Aadland, L.P., T.M. Koel, W.G. Franzin, K.W. Stewart, and P. Nelson. 2005. Changes in fish assemblage structure of the Red River of the North. pp 293-321 IN *Historical Changes in Large River Fish Assemblages of the Americas*. J. N. Rhine, R.M. Hughes, and B. Calamusso, Eds. American Fisheries Society Symposium 45, Bethesda, Maryland.

Aadland, L.P. and A. Kuitunen. 2006. Habitat suitability criteria for stream fishes and mussels of Minnesota. MN DNR Section of Fisheries Special Publication 162.167p. Available online: http://files.dnr.state.mn.us/publications/fisheries/special_reports/162.pdf

Acres Manitoba Ltd. 2004. Re-computation of natural water levels at the Floodway Inlet (Final Report). Report prepared for Manitoba Water Stewardship, plus appendices. Available online at: http://www.gov.mb.ca/waterstewardship/reports/floodway_inlet.html

Acreman, M. and M.J. Dunbar. 2004. Defining environmental river flow requirements – a review. Hydrology and Earth System Sciences 8: 861-876.

Andrews, E.D. and J. M. Nankervis. 1995. Effective Discharge and the Design of Channel Maintenance Flows for Gravel Bed Rivers. Geophysical Monograph 89, pp 151 - 164.

Annear, T., I. Chisholm, H. Beecher, A. Lock and 12 other authors. 2002. Instream flows for riverine resource stewardship. Instream Flow Council. 410p.

Annear, T., I. Chisholm, H. Beecher, A. Lock and 12 other authors. 2004. Instream flows for riverine resource stewardship, Revised Edition. Instream Flow Council. 267p.

Becker, G.C. 1983. Fishes of Wisconsin. University of Wisconsin Press, Madison, Wisconsin. 1052p.

Bovee, K.D., B.L. Lamb, J.M. Bartholow, C.B Stalnaker, J. Taylor, and J. Henriksen. 1998. Stream habitat analysis using the Instream Flow Incremental Methodology. USGS Biological Resources Division Information and Technology Report USGS/BRD-1998-0004. Viii + 131p.

Clarke, R.McV., R.W. Boychuck and D.A. Hodgins. 1980. Fishes of the Red River at Winnipeg, Manitoba. Unpublished Manuscript Report, Western Region, Department of Fisheries and Oceans: 42pp.

City of Winnipeg Ammonia Criteria Study: Other Physical Stressors. 2000. Phase 2 Technical Memorandum for Red and Assiniboine Ammonia Criteria Study accessed online:
http://www.gov.mb.ca/conservation/eal/registries/4864wpgww/cow_ammonia/ospc-01.pdf

City of Winnipeg Water and Waste website accessed October 30/11.
http://winnipeg.ca/waterandwaste/sewage/monitoring/2011RiversReports.stm

Cvancara, A. M. 1970. Mussels (Unionidae) of the Red River Valley in North Dakota and Minnesota. Malacologia 10: 57-92.

de Loë, R.C. 2009. Sharing the Waters of the Red River Basin: A Review of Options for Transboundary Water Governance. Prepared for International Red Rivers Board,

International Joint Commission. Guelph, ON: Rob de Loë Consulting Services

Emerson, D.G. 2005. Historic and naturalized monthly streamflow for selected sites in the Red River of the North Basin in North Dakota, Minnesota, and South Dakota, 1931-2001. USGS Scientific Investigations Report 2005–5092. 228p.

Emerson, D.G., A.V. Vecchia, and A.L. Dahl. 2005. Evaluation of drainage-area ratio method used to estimate streamflow for the Red River of the North Basin, North Dakota and Minnesota. USGS Scientific Investigations Report 2005–5017. 13p.

Goldstein, R.M. 1995. Aquatic communities and contaminants in fish from streams of the Red River of the North Basin, Minnesota and North Dakota. U.S.G.S. Water Resources Investigations Report 95-4047. 34p.

Goldstein, R.M., J. C. Stauffer, P.R. Larson, and D.L. Lorenz. 1995. Relation of physical and chemical characteristics of streams to fish communities in the Red River of the North Basin, Minnesota and North Dakota, 1993-95. U.S. Geological Survey Water-Resources Investigations Report 96-4227. 57p.

Groshens, T. 2010. Red River of the North Channel Catfish population assessment summer 2010, River mile 0.0 to 400.4. Minnesota Dept. Natural Resources Division of Fish and Wildlife. 70p.

Hegrenes, S. 1992. Age, growth, and reproduction of Channel Catfish in the Red River of the North. Unpub. MS thesis. University of North Dakota. 104p.

Henry, M. 1996. Red River of the North stream fish population assessment Reach 1. Minnesota Dept. Natural Resources Division of Fish and Wildlife. 36p.

Henry, M. 2007. Red River of the North fisheries population assessment summer 2005 Combined Reach Report. Reaches 1 – 4, River mile 0.0 – 400.4. Minnesota Dept. Natural Resources Division of Fish and Wildlife. 62p.

Houston Engineering, Inc. December 1997a. Instream flow needed for aquatic life. White Paper. Prepared for the Garrison Diversion Conservancy District. Houston Engineering, Inc., Fargo, North Dakota and Minneapolis, MN. 17 pp. plus appendices.

Houston Engineering, Inc. 1997b. White Paper Methodology - In-stream flow requirements for maintaining water quality. Prepared for Garrison Diversion Conservancy District. Houston Engineering, Inc., Fargo, ND and Minneapolis, MN.

Huberty, G. 1996. Stream fish population assessment of the Red River Reach two from East Grand Forks upstream to Moorhead, Polk, Norman and Clay counties. Minnesota Dept. Natural Resources Division of Fish and Wildlife. 70p.

International Joint Commission. 2000. Living with the Red. A report to the governments of Canada and the United States on reducing flood impacts in the Red River Basin. Int. Joint Comm. Washington/Ottawa. November 2000. 82p + Map.
Kelsch, S. and J. L. Wendell. 2005

KGS Group. 2008. Final Report: Conceptual engineering study for fish passage Red River Floodway Inlet Control Structure Manitoba Floodway Authority. 223p.

Kjartanson, S.L., Watkinson, D.A., Backhouse, S.M., Franzin, W.G., and Milani, D.W. MS2009. Environmental Tolerances of Manitoba's Freshwater Fishes. Can. Tech. Rep. Fish. Aquat. Sci. XXX: vi + XX. 117p.

Kelsch, S.W. and J.L. Wendel. 2004. Lotic habitat availability and use by Channel Catfish in the Red River of the North. Journal of Freshwater Ecology 19: 473-484.

Koel, Todd Marvin. 1997. Distribution of fishes in the Red River of the North Basin on Multivariate environmental gradients. Ph.D. thesis, North Dakota State University, Fargo, North Dakota. Northern Prairie Wildlife Research Center Online. http://www.npwrc.usgs.gov/resource/fish/norbasin/index.htm (Version 03JUN98).

Koel, T. M., and J. J. Peterka. 1998. Stream fishes of the Red River of the North Basin, United States: a comprehensive review. Canadian Field-Naturalist 11:631-646.

Locke, A., C. Stalnaker, S. Zellmer, K. Williams and 6 other authors. 2008. Integrated approaches to riverine resource stewardship: Case studies, Science, Law, People and Policy. Instream Flow Council. 429p.

MacDonald, D.A. 1992. The Channel Catfish sport fishery of the lower Red River. Unpub. MNRM Practicum. University of Manitoba Natural Resources Institute. 160p.

Macek-Rowland, K.M., A.D. Arntson, K.R. Ryberg, A.L. Dahl and, A.Lieb. 2004. Water-Use Data for the Red River of the North Basin, North Dakota, Minnesota, and South Dakota, 1979-2001. USGS Open-File Report 2004-1308. 255p.

Macek-Rowland, K.M. and V.M. Dressler. 2002. Statistical summaries of water-quality data for selected streamflow-gaging stations in the Red River of the North Basin, North Dakota, Minnesota and South Dakota. USGS Open File Report 02-390. 234p.

Manitoba water quality standards, objectives, and guidelines. 2011. Manitoba Water Stewardship Report 2011-01. 72p.

Martini, K.J. and J.D. Stewig. 2000. Red River of the North fisheries population assessment summer 2000 including the 1990-2000 assessment summaries. Combined Reach Report. Minnesota Dept. Natural Resources Division of Fish and Wildlife. 54p.

Nelson, F. A. 1980. Evaluation of selected instream flow methods in Montana. MT Dept. Fish Wildlife and Parks. 24p.

Nelson, P. A. and W. G. Franzin. 2000. Habitat availability and its utilization by 11 species of fish from the Assiniboine River, Manitoba with special reference to habitat processes. Can. Tech. Rep. Fish. Aquat. Sci. 2313: vi + 55p.

NRC (National Research Council). 2005. The science of instream flows: a review of the Texas Instream Flow Program. Washington, DC. The National Academies Press. 149p.

NRC (National Research Council). 2008. Hydrology, ecology, and fishes of the Klamath River Basin. Washington, DC. The National Academies Press. 249p.

Nustad, R.A. and J.D. Bales. 2005. Simulation of Conservative-Constituent Transport in the Red River of the North Basin, North Dakota and Minnesota, 2003-04. USGS Scientific Investigations Report 2005–5273. 89p.

O'Shea, Daniel T. 1995. Estimating minimum instream flow requirements for Minnesota streams from hydrologic data and watershed characteristics. North American Journal of Fisheries Management 15:569-578.

Paquette, C.B. 2009. Statistical analysis of trends in Red River water quality over a 45-year period. M.Sc. Thesis. University of Manitoba. 133 p.

Red River Basin Board. 2001. Water Quality. RRBB Inventory Team Report. 90p. (now amalgamated in Red River Basin Commission)

Red River Basin Commission. 2008. Water Supply Update. January 2008. Online: http://www.redriverbasincommission.org/WaterSupply_Update_2008.pdf

Red River of the North Fisheries Management Plan. 2008 – 2012. Minnesota Department of Natural Resources, North Dakota Game and Fish Department, Manitoba Water Stewardship, South Dakota Department of Game, Fish and Parks April 2008 – 2012. 25p.

Renard, P.A., S.R. Hanson, and J.W. Emblom. 1986. Biological survey of the Red River of the North. Minnesota Dept. Nat. Res. Fish and Wildlife Div. Special Publication No. 142. 60p. + maps.

Resseguie, T.J. 2002. Distribution, relative abundance, and reproductive seasonality of larval fish in the Red River of the North. B.S. thesis. University of North Dakota.

Rosenberg, D.M., P.A. Chambers, J.M. Culp, W.G. Franzin, P.A. Nelson, A.G. Salki, M.P. Stainton, R.A. Bodaly, and R.W. Newbury. Nelson and Churchill Rivers. 2005. Nelson and Churchill River Basins. Pp 853-902 *In* Rivers of North America, A.C. Benke and C.E. Cushings, Eds. Elsevier Academic Press. Burlington, San Diego and London.
Scott, W.B. and E.J. Crossman. 1973. Freshwater Fishes of Canada. Bulletin 184, Fisheries Research Board of Canada. 966p.

Stewart, K.W. and D.A. Watkinson. 2004. Freshwater fishes of Manitoba. University of Manitoba Press, Winnipeg Manitoba. 276p.

Stoner, J.D., D.L. Lorenz, G.J. Wiche, and R.M. Goldstein. 1993. Red River of the North Basin, Minnesota, North Dakota, and South Dakota. Wat. Res. Bull. 29: 575-615.

Tennant, D.L. (1976). Instream flow regimens for fish, wildlife, recreation and related environmental resources. Fisheries, 1, 6-10.

Tessmann, S. A. 1979. Environmental Assessment. Technical Appendix E, in “Reconnaissance Elements” of the Western Dakotas Region of South Dakota Study. Water Resources Research Institute, South Dakota University. 18 p.

Tharme, R.E. 2003. A global perspective on environmental flow assessment: emerging trends in the development and application of environmental flow methodologies for rivers. River Research and Applications 19: 397-441.

Thorleifson, H., G. Brooks, I. Hanuta, S. Kroker, G. Matile, E. Nielsen, C. Prévost, and W. Rannie. 1998. Red River flooding: evolutionary geomorphic trends and evidence for major floods in recent centuries (NTS 62H/W). *In* Manitoba Energy and Mines, Geological Services, report of Activities, 1998: 186-195.

Topp, D. 1998. Red River of the North stream fish population assessment Reaches 3 and 4. Minnesota Dept. Natural Resources Division of Fish and Wildlife. 16p.

Tornes, L.H. 2005. Water Quality of Streams in the Red River of the North Basin, Minnesota, North Dakota, and South Dakota, 1970-2001. Scientific Investigations Report 2005-5095. 81p.

Tyson, J.D. 1996. The effect of thermal effluent on overwintering Channel Catfish (*Ictalurus punctatus*) in the lower Red River, Manitoba. Unpub. M.Sc. thesis. University of Manitoba Zoology Department. 121p.

US Bureau of Reclamation. 1999. Final appraisal report Red River Valley municipal, rural, and industrial water needs assessment. Phase 1, Part B Instream flow needs assessment. Main Report. U.S. Department of the Interior, Bureau of Reclamation, Great Plains Region, Dakotas Area Office. 88p + 11 appendices.

US Bureau of Reclamation. 2003. Report on Red River Valley Water Supply Project Needs and Options, Aquatic Needs Assessment Final Report, Instream Flows for Aquatic Life and Riparian Maintenance. U.S. Department of the Interior, Bureau of Reclamation, Great Plains Region, Dakotas Area Office. 41p.

US Bureau of Reclamation. 2008. Comprehensive Report Red River Valley Water Supply Project. U.S. Department of the Interior, Bureau of Reclamation, Great Plains Region. Dakotas Area Office. 39p.

U.S. Fish & Wildlife Service. 2005. Final environmental assessment for fish passage in the Red River of the North Basin, Minnesota. United States Fish and Wildlife Service La Crosse Fishery Resource Office 555 Lester Avenue Onalaska, Wisconsin 54650. 49p.

U.S. Geological Survey, 2011, National Water Information System data available on the World Wide Web (Water Data for the Nation), accessed [August 12, 2011], at URL http://waterdata.usgs.gov/nwis/.

Watkinson, D.A., H.K. Ghamry, W.G. Franzin, and C. Katopodis. 2009. E.B. Campbell Hydroelectric Station Aquatic Assessment Study Report. Prepared for: SaskPower/DFO/SE/SWA Steering Committee.134 pp.

Wendell, J.L. 1999. Habitat use and movements of Channel Catfish in the Red River of the North. Unpub. M.S. thesis. University of North Dakota. 169p.

Yoder, C.O., V.L. Gordon, and E.T. Rankin. MS2011. Assessment of the Fish Assemblages and Habitat Quality in the Red River of the North, 2010 U.S. Mainstem Portion: Wahpeton to Pembina, ND. USEPA Report xxxx. yyp.