DETERMINATION OF NATURAL FLOW FOR APPORTIONMENT OF THE RED RIVER

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EXECUTIVE SUMMARY

The Red River basin is a complex basin shared by three states, one province and two countries. More than 80 percent of the surface area of the basin lies in the states of Minnesota and North Dakota. Water use in those states has the potential to affect downstream interests in Canada. At present water consumption in the basin is low in comparison to the median flow of the Red River at the international boundary. In the words of the apocryphal quote, however, the Red River has two problems, too much water and too little. It is diligent for the International joint Commission (IJC) and others in the basin to consider how apportionment may be accomplished in the event of a protracted series of low flow years.

An initial question is whether it is feasible to apportion the waters of the Red River basin and exactly how that may be accomplished. In 2009 a report from Rob de Loë Consulting Services provided a thorough discussion of the Red River basin, presented case studies of interjurisdictional apportionment, and identified principles that could be employed in apportioning the Red River. These include equitable apportionment and consideration of environmental flows. Equitable apportionment in the case of the Red River implies consideration of prior allocation to critical human needs and consideration of seasonal flows.

An important precursor to any apportionment arrangement is the calculation of natural flow. Accordingly R. Halliday & Associates was asked to:

1. Define and review various methodologies that may be used to determine natural flow.
2. Discuss these methods in the context of the Red River basin and recommend a specific method.
3. Review the data requirements of the selected method and compare the requirements to the existing databases. Assume a monthly audit period, but discuss the implications of longer or shorter periods.
4. Identify key data deficiencies and other problem areas and indicate how these could be resolved.
5. Review specific calculation procedures pertaining to international tributaries and recommend an approach.
6. Review considerations related to equitable apportionment and those pertaining to instream flow needs.

This report describes the geographical setting of the Red River basin in the interior plains of North America and provides some general information concerning water apportionment. It then goes on to review natural flow methodologies. The natural flow can be taken to be the flow that would occur if the effects of dams and diversions and other water uses were removed. Considering the effects of land use change and climate change are beyond the scope of the calculation.

Several methods of natural flow calculation can be contemplated, but given the availability of an adequate hydrometric network and a robust system of water permits or licenses, the

Project Depletion Method is recommended. Several agencies are familiar with the method based on apportionment of other interior plains basins.

The report discusses the various approaches to water allocation in the basin and presents detailed information concerning allocation in each of the jurisdictions in the basin. The allocation system throughout the basin is very robust. Allocation should not, however, be confused with actual water use or consumption. Water consumption information for the basin, although available, is not to the same standard as allocation data.

Because of its importance to consideration of equitable apportionment, the question of in-stream flow needs for the Red River and its important tributaries is considered. It is unlikely that hydraulic modelling capability on most important tributaries is sufficient to support in-stream flow calculations, although it may be possible for the mainstem. Despite that, the main in-stream flow concern in the basin relates to water quality and sufficient information to address that concern exists.

The report reviews the actual natural flow calculation and provides information on how the calculation can be accomplished. In terms of the actual natural flow calculation several information gaps were identified.

Hydrometric and Meteorological Networks. The data networks are generally adequate to assist a determination of natural flow in the basin. It should be anticipated, however, that a careful review will identify some gaps and deficiencies. More importantly, natural flow calculations require numerous interim calculations of streamflow at the end of audit periods. This task becomes very demanding during low flow periods when deficits can occur. It is also necessary to monitor releases from storage to make up deficits. Demands on monitoring organizations need to be carefully considered.

Water Allocation. The Red River basin contains a significant percentage of non-contributing drainage. This drainage has been identified by Agriculture Canada. If basin interests agreed on the areas of non-contributing drainage, the water permits or licences in the basin should be geo-referenced so that only the allocations in the effective drainage basin are included in the natural flow calculation.

Water Use. Water consumption in the Red River basin appears to be about 20 percent of the water allocated. Water diversion information and return flow information is available, but there are some indications that the information is incomplete or inaccurate. The task of ensuring that water use information is sufficient to meet natural flow calculation needs could be simplified if a number of assumptions were agreed. Several water use matters could be considered and agreed:

- Urban water use is likely a net contributor to natural flow so this use could be removed from the natural flow calculation.
- Water consumption for cooling thermal generating stations is very small.
- Industrial water use that is allocated separately may be small enough to be ignored, or perhaps only a small number of relatively large allocations may be considered.

- Irrigated agriculture and water management uses appear to be the largest water consumers. These uses should be examined in sufficient detail to ensure an understanding of actual use. It is likely that group average uses could be developed depending on the nature of the mix of projects.
- The significance of return flows to surface water from groundwater withdrawals could be considered. The quantity involved may be small enough to be ignored.

Evaporation. The various jurisdictions in the basin use slightly different methods to calculate evaporation. It may not be necessary to harmonize the methodology, but the effects of using different methods should be understood. Index reservoirs that are representative of many small impoundments that are not routinely monitored should be considered and a small number established. Data on the surface area of Minnesota reservoirs appear to be lacking.

Apportionment. Assuming that a methodology for calculating natural flow can be achieved, it must be agreed by the parties to any apportionment agreement. The method will undoubtedly include assumptions and averaging, but only experience under different flow conditions will reveal the need for changes.

Finally the report briefly reviews some matters related to the apportionment calculation itself. The location at which the Red would be apportioned and hence at which natural flow would be calculated is an early decision. The Red River at Emerson appears to be the most logical apportionment point. There is insufficient water use in the Roseau River and its Canadian tributaries to warrant any consideration of apportioning that river separately. Water consumption in the Pembina River basin in Canada and the Pembina River tributaries that flow north into Canada is also small. There appears to be no reason to apportion the Pembina River separately but it would be necessary to include Pembina River flows in any calculation of natural flow of the Red River at Emerson.

If the apportionment location and natural flow are known, then the attributes of any apportionment arrangement come into play. One can assume that the parties to any agreement would be seeking elements of equitable, as opposed to equal, apportionment. At the current state of institutional development in the Red River basin, it is reasonable to assume a high degree of cooperation among the parties but, at the same time no party would be willing to give up its sovereign rights to another party. Consideration of benefit sharing under an apportionment agreement are likely moot. In considering water apportionment between the United States and Canada, it is difficult to see how this could be accomplished without first coming to an arrangement for the three American states in the basin.

There are a number of matters that must be resolved before natural flow can be calculated and before an apportionment arrangement can be executed. None of them is incapable of being resolved with good will among the parties. It should be noted however that water consumption in the Red River basin is relatively low compared to that in other apportioned basins in the interior plains. It may be preferable to explore whether an international drought contingency plan may be a productive task to pursue rather than considering a traditional apportionment agreement. As an alternative, careful consideration of minimum flow criteria for the Red River could provide additional insights. Such criteria could well be the only element of an apportionment arrangement that is really required at this time.

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INTRODUCTION

In 2009 International Joint Commission's International Watersheds Initiative[1] commissioned a report from Rob de Loë Consulting Services that provided a thorough discussion of the Red River basin, presented case studies of interjurisdictional apportionment, and identified principles that could be employed in apportioning the Red River.[2] These included equitable apportionment and consideration of environmental flows. Equitable apportionment in the case of the Red River implies consideration of prior allocation to critical human needs and consideration of seasonal flows.

An important precursor to any apportionment arrangement is the calculation of natural flow. Accordingly, R. Halliday & Associates was asked to:

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This report provides an overview of the Red River basin, reviews natural flow computation methods, describes water allocation and water use in the basin, describes instream flow requirements and other topics essential to water apportionment, and discusses water apportionment in the context of the Red River basin. In the course of preparation of this report Exel spreadsheets of surface water permits or licenses and of water storage in the Red River basin upstream of the international boundary were created. These spreadsheets have been provided to the International Joint Commission's (IJC) International Red River Board for possible further use.

Geographical Setting

The Red River originates as the Bois de Sioux River in South Dakota. The river flows north forming a portion of the Minnesota-South Dakota boundary, then continues northward to join Minnesota's Otter Tail River to become the Red River. The river forms the boundary between North Dakota and Minnesota and flows north, entering Canada at Emerson, Manitoba (Figure 1). It meanders north to join Lake Winnipeg, the world's 11^{th} largest lake in surface area and thence on to Hudson Bay by way of the Nelson River. The river is known officially as the Red River of the North in the United States of America, but in the basin it is simply called the Red River.

Prairie Pothole Region

The Red River basin – exclusive of the Assiniboine River and its international tributary, the Souris River – covers some 116,500 km^2 (45,000 sq. mi.) from its mouth at Lake Winnipeg. About 103,000 km^2 (39,800 sq. mi.) are in the United States and the remaining 13,000 km^2 (5000 sq. mi.) are in Canada. The drainage basin is distributed with 11 percent in Manitoba, 47 percent in North Dakota, 41 percent in Minnesota and 1 percent in South Dakota.[3]

Much of the Red River basin lies in the prairie pothole region of the North American plains. The central portion of the basin along the Red River maintain, known colloquially as the Red River Valley, is a remnant of glacial Lake Agassiz. Because the basin is so flat not all portions of the basin contribute to surface runoff in a given year. Indeed, it is about 1800 years since the closed Devils Lake basin has naturally contributed flow to the Red River.[4]

Hydrologists have developed the concept of contributing and non-contributing drainage. The contributing drainage is defined as the surface area that would contribute to river flow in a median year, that is, one year in two. The contributing drainage for prairie Canada and the Red River basin in the United States has been determined by Agriculture Canada. Under the auspices of the Prairie Provinces Water Board the three prairie provinces have a process to review and accept the non-contributing drainage calculations and other hydrological data sets provided by Agriculture Canada. Although the calculation has been made for the United States portion of the Red River basin, it has not been formally approved.

The non-contributing drainage at Emerson is shown in Figure 2. Some 37 percent of the drainage basin at the international boundary is non-contributing, including the 3810 sq.-mi. (9870 km^2) Devils Lake sub-basin. Without inclusion of Devils Lake, the non-contributing drainage is 27 percent of the remainder of the basin.[5]

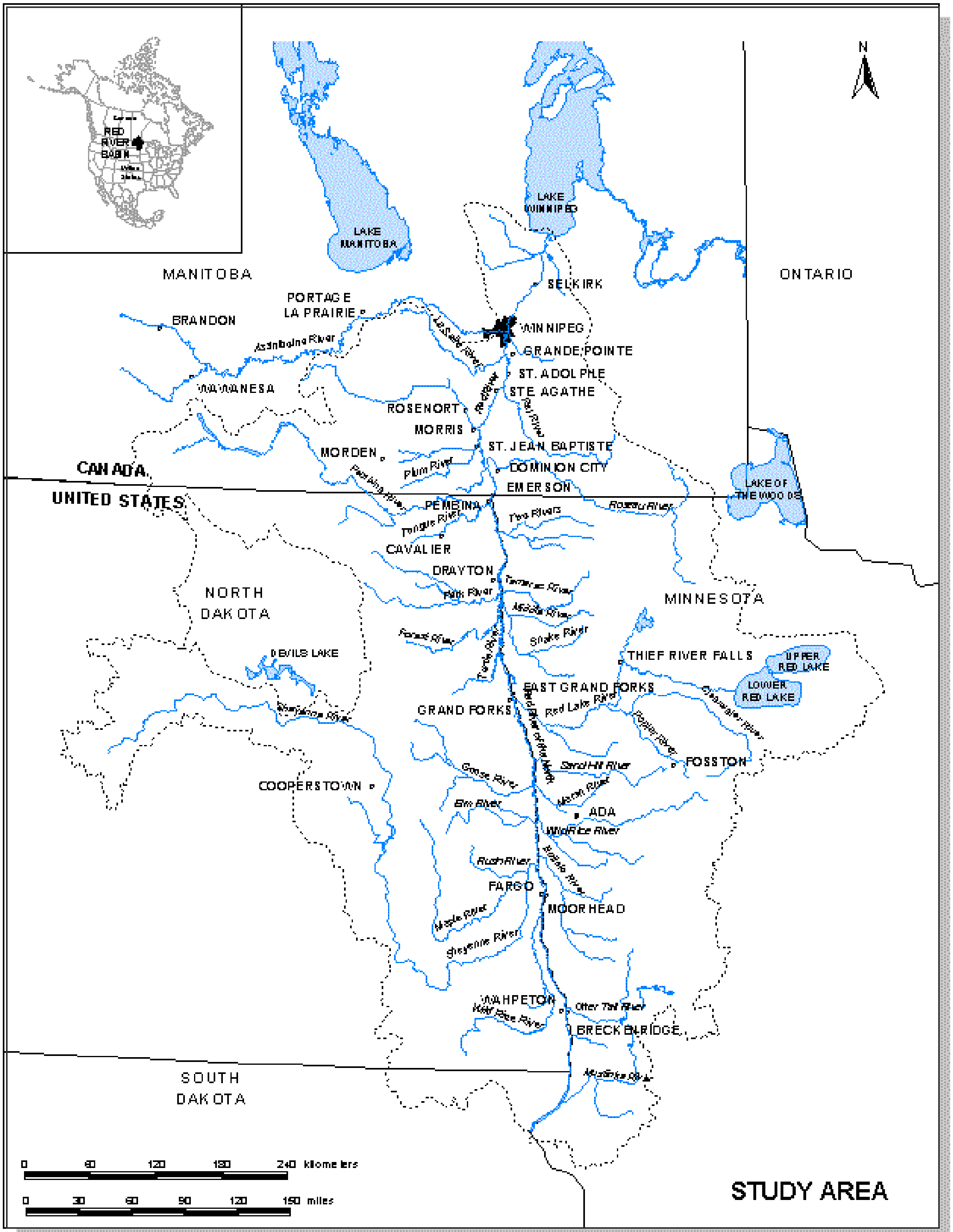

Figure 1. The Red River Basin. *(International Joint Commission, 1998)*[6]

The Red River Valley is remarkably flat and can be up to 100 km (60 mi.) in width. The elevation at Whapeton, North Dakota is 287 m (943 ft.) while that of Lake Winnipeg is 218 m (714 ft.). That is a drop of 71 m (233 ft.) over 872 river kilometres (545 river miles). The longitudinal profile of the mainstem is typically concave upward with relatively high slopes in the headwaters and very low slopes in Manitoba. This low slope provides few natural sites for large reservoirs on the mainstem of the river.

At the margins of the basin, elevations can range from 360 to 480 m (1200 to 1600 ft.) above sea level. Even then the boundaries of the basin are indistinct.

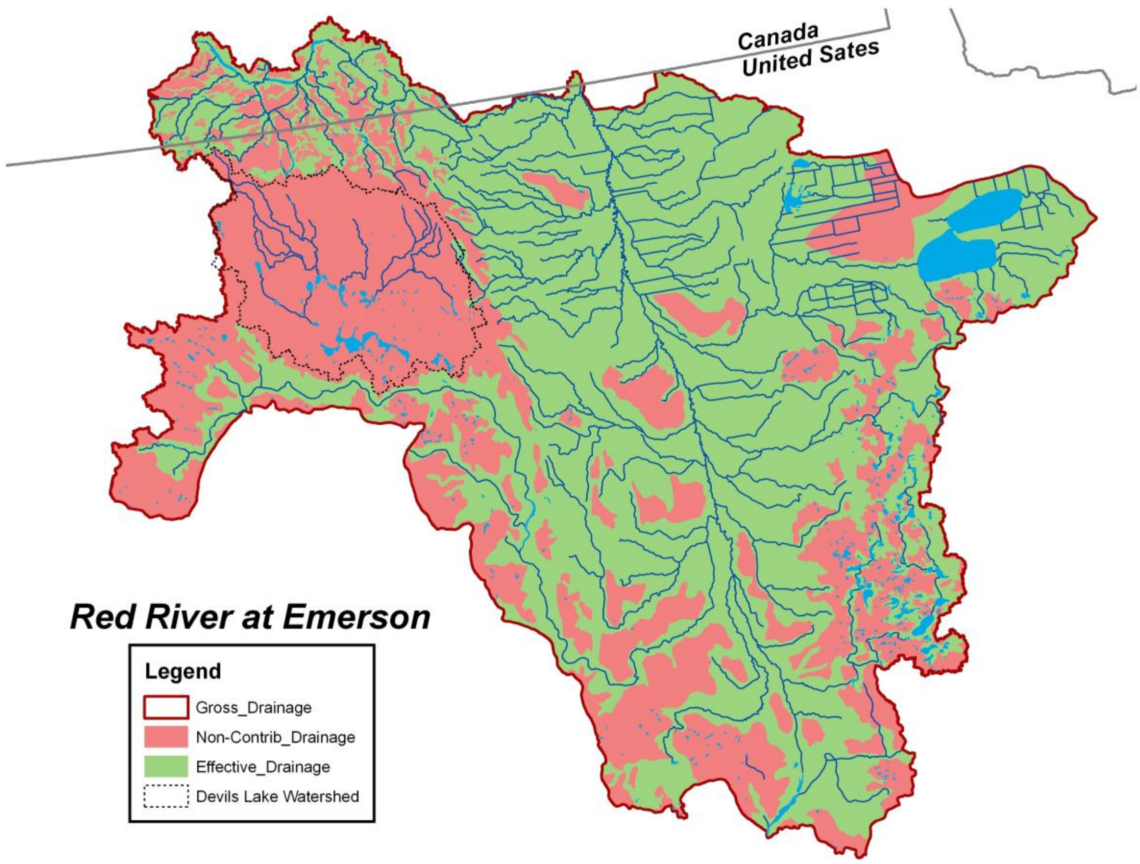

Figure 2. Non-contributing Drainage in the Red River Basin. *(Courtesy of Agriculture Canada)*

The Red River has a humid continental climate featuring modest precipitation, warm summers, cold winters and rapid changes in weather patterns. This is considered Dfb on the Köppen-Geiger classification.[7] About three-quarters of the 500 mm (20 in.) annual precipitation occurs in April through September with almost two-thirds falling in May, June and July. The winter months of November through February are the driest.[8] Evaporation in the basin exceeds precipitation.

Runoff in the basin is primarily the result of snowmelt and rainfall during the snowmelt period although antecedent conditions such as autumn soil moisture play an important role. Summer rains are important is sustaining crop production but only heavy rains result in significant runoff. Runoff is typically dominated by flow from the Minnesota tributaries of the Red River. As shown in Figure 3, the streamflow typically rises to a peak in April and recedes through the remainder of the year. The figure also shows the consistent effect of June and July rains in sustaining flows. (The median hydrograph is a composite, made up of the median monthly flows for the period of record.) As is typical of prairie streams there is considerable variability in streamflow within years and between years. The basin is therefore prone to both floods and droughts. Major floods have occurred as recently as 1997 and 2009. The decade of the 1930s featured a significant hydrological drought.

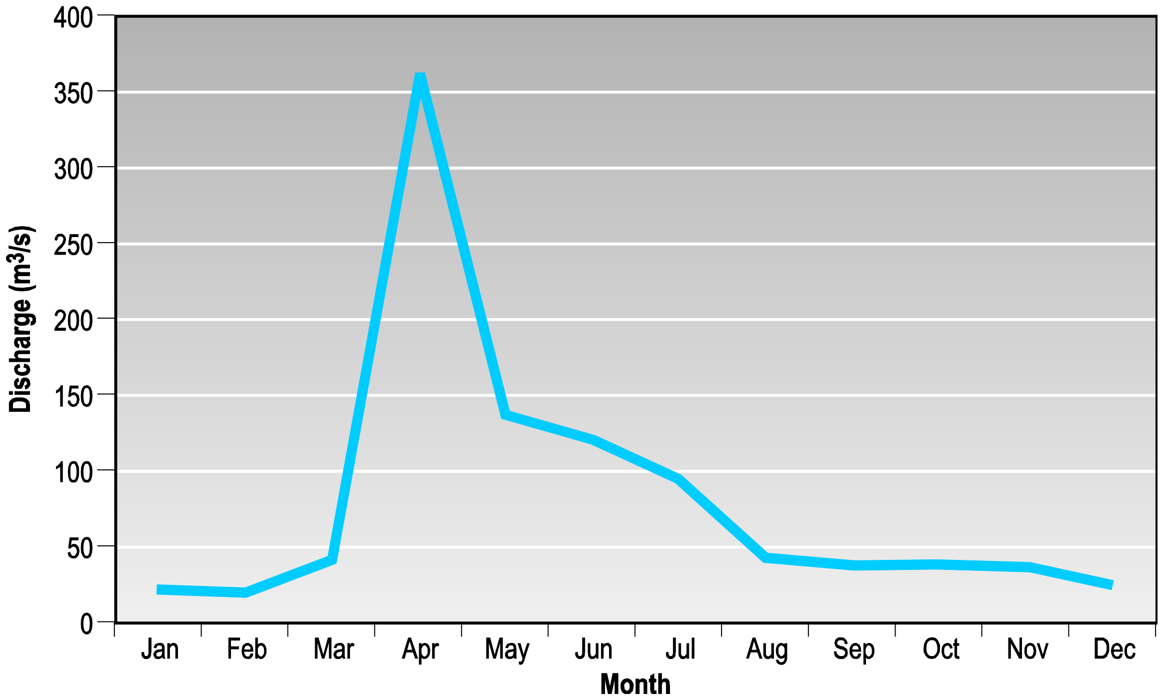

Figure 3. Recorded Monthly Median Discharge at Emerson.

The Red River basin is covered by a layer of glacial drift deposited by ice sheets in the last 2.5 million years. These near surface sands and gravels, particularly in Minnesota, that range in depth from 30 to 90 m (100 to 300 ft.), contain aquifers that supply groundwater to basin residents.[9] Deeper bedrock aquifers are also sources of water. In general the groundwater flow is towards the Red River.

Some 1.3 million people live in the Red River basin, with about 700,000 living in Winnipeg. The Red River basin is home to some 60 percent of North Dakota's population, only 2 percent of Minnesota's, and 70 percent of Manitoba's. The population is largely urban. The two major urban centres in the United States, Fargo-Moorhead and Grand Forks-East Grand Forks, depend on surface water for their municipal supplies while many other smaller communities and some industries depend on groundwater. In Manitoba, the city of Winnipeg draws its water from Shoal Lake, part of Lake of the Woods. The Pembina Valley Water Cooperative, a regional water supply system in southern Manitoba, depends on Red River water.

The United States Geological Survey considers the Red River basin in the United States a hydrological sub-region (0902) and has divided the basin into smaller hydrological units as well.[10] These are shown in Table 1.

Table 1. US Geological Survey Hydrologic Units in the Red River Basin.[11]

Area	Description	State/Province	Area (Sq. Miles)	Area (km^2)
Upper Red 090201 The Red River Basin above the confluence of and including the Goose and Marsh River Basins, excluding the Sheyenne River Basin and the Devils Lake closed basin. 12,200 sq. mi. 31,500 km^2	01 – Bois de Sioux	MN, ND, SD	1140	2950
	02 – Mustinka	MN	825	2140
	03 – Otter Tail	MN	1980	5130
	04 – Upper Red	MN, ND	594	1540
	05 – Western Wild Rice	SD	2380	6160
	06 – Buffalo	MN	1150	2980
	07 – Elm-Marsh	MN	1150	2980
	08 – Eastern Wild Rice	MN	1670	4320
	09 - Goose	ND	1280	3320
Devils Lake-Sheyenne 090202 The Sheyenne River and Devils Lake closed basin 11,000 sq. mi. 28,500 km^2	01 – Devils Lake	ND	3700	9580
	02 – Upper Sheyenne	ND	1940	5020
	03 – Middle Sheyenne	ND	2070	5360
	04 – Lower Sheyenne	ND	1640	4250
	05 – Maple	ND	1620	4200
Lower Red 090203 The Red River basin below the confluence of the Goose and Marsh river basins 16,600 sq. mi. 43,000 km^2	01 – Sandhill-Wilson	MN, ND	1130	2930
	02 – Red Lakes	MN	2040	5280
	03 – Red Lake	MN	1450	3760
	04 – Thief	MN	994	2570
	05 – Clearwater	MN	1350	3500
	06 – Grand Marais-Red	ND	482	1250
	07 – Turtle	ND	714	1850
	08 – Forest	ND	875	2270
	09 – Snake	MN	953	2470
	10 – Park	ND	1080	2800
	11 – Lower Red	MN	1320	3420
	12 – Two Rivers	MN	958	2480
	13 – Pembina	ND, MB	2020	5230
	14 - Roseau	MN, MB	1230	3190

The basin includes two international tributaries: the Pembina River that rises in Manitoba and flows southeast into North Dakota, joining the Red River near Pembina, North Dakota and the Roseau River that rises in Minnesota and flows northwest, joining the Red River near Dominion City, Manitoba. These two rivers also have transboundary tributaries. The apportionment of the Pembina and Roseau rivers and their transboundary tributaries will be discussed in this report.

WATER APPORTIONMENT

Common Elements of Apportionment Agreements

- Parties to the agreement
- Proportion or amount of flow (volume, level) that will be received by each party as measured at specific locations and during certain times, seasons or conditions
- Proportion of benefits from water development that will be received by each party
- Provisions relating to concerns such as water quality, salinity, habitat enhancement, ecosystem flows, riparian users, desired "natural" flows, conjunctive management of transboundary groundwater and surface water resources, and projects and activities that affect flows
- Methods for measuring or estimating flows
- Rules regarding operation of infrastructure
- Requirements for monitoring and reporting
- Contingency plans for situations such as droughts and floods
- Dispute resolution procedures
- Benefit sharing arrangements, including payments and future development rights
- Data sharing arrangements
- Review mechanisms, e.g., mandatory review at defined periods
- Procedures for public consultation and involvement
- Mechanisms for joint decision making

de Loë 2009

The report by Rob de Loë Consulting Services identifies principles that could be employed in apportioning the Red River. These include equitable, rather than equal, apportionment and consideration of environmental flows. Equitable apportionment in the case of the Red River implies consideration of prior allocation to critical human needs and consideration of seasonal flows. This current study builds on the previous work by reviewing the principles identified by de Loë in the context of the Red River basin and identifying other apportionment considerations, providing a detailed methodology for calculation of natural flow of the Red River, and reviewing the necessary steps to apportion the Red River.[12]

The 1909 *Boundary Waters Treaty* provides the framework under which any apportionment arrangement between Canada and the United States would be negotiated. The treaty is founded on the basis of equality between the parties, as exemplified by equality in number of IJC commissioners and membership of boards and task forces.

While some basis of equality may be considered as the point of departure for negotiating an apportionment arrangement, contemporary interjurisdictional water management tends to focus on equitable apportionment. That said, it is interesting to note that Article VI of the *Boundary Waters Treaty* states that the waters of the St. Mary and Milk Rivers are to be divided equally between Canada and the United States. The article then goes on to provide for a prior allocation of St. Mary River water to Canada and Milk River water to the United States. An adjudication of the meaning of the article in 1921 confirmed this arrangement as well as the equal apportionment of important tributaries such as the Frenchman River and Battle and Lodge creeks.[13] One of the tenets of equitable apportionment is the recognition of prior water allocations; it can be argued therefore that international apportionment arrangements between Canada and the United States consider both equal and equitable apportionment. As another example, the arrangement on the Poplar River (between Saskatchewan and Montana) is founded on an asymmetrical arrangement with Canada having a larger share of the East Poplar River and the United States having a larger share on other tributaries.[14] The arrangement on the Souris River provides for equal sharing of water originating in Saskatchewan between Saskatchewan and North Dakota but a 60-40 division when certain flow conditions prevail. The arrangement also contains provision of a riparian flow between North Dakota and Manitoba.[15]

In general, principles of equitable apportionment can be found in language pertaining to prior allocation, provision of riparian flows, protection of water quality, provision for in-stream flows, and consideration of groundwater matters. All of these are clearly within the ambit of the *Boundary Waters Treaty*, even if not explicitly mentioned in the treaty. Groundwater, for example has been considered under both the Souris and Poplar river arrangements.

The text box on the previous page identifies some common attributes of international apportionment arrangements.[16] These contribute to integrated water resources management and are also common to international water arrangements developed in the last 100 years.

The establishment of a process for the development and implementation of surface water apportionment procedures requires a thorough understanding of the natural flow regime on the Red River and how that natural flow can best be calculated. Any acceptance of an apportionment arrangement between the United States and Canada will require agreement on the method of computing the natural flow and documentation of water uses in the basin. Any international apportionment agreement may require, *inter alia*, an apportionment agreement between Minnesota and North Dakota.

NATURAL FLOW METHODOLOGIES

As indicated in the previous section, apportioning water between or among jurisdictions requires that natural flow be calculated. Natural flow may be defined as the *"quantity of water that would flow in any stream had the flow not been subject to human interference"*. Such a definition implies an extremely complex calculation if one is to take into account the effects of land use and land cover change, groundwater and surface water interactions, and the hydrological effects of climatological conditions on the natural flow. Of necessity, the calculation must be simplified.

US Secretary of State Elihu Root, in the course of negotiating the *Boundary Waters Treaty*, in 1907 defined natural flow as *"the flow in the river system in question which would pass the point or points specified if no artificial structure had been placed in the stream channel and if no water had been diverted from or turned into it"*.[17] Variations of this definition continue to be used in determining natural flow for apportionment of streams in the semi-arid interior plains of North America. The Prairie Provinces Water Board, for example, agreed in 1976 by board minute that, *"effects on runoff of changing land use patterns are not considered in the computation of natural flow (changes in land use include land clearing for agriculture, drainage, forestry, industrial and urban development and other land uses). Changes in natural flow due to groundwater inflow or recharge are not considered in the computations"*.

The natural flows calculated for apportionment purposes could best be described as flows subject to apportionment or apportionment flows. Some writers have also used the term "naturalized flows". For the purpose of this report, "natural flow" is used to indicate flows subject to apportionment. In general this calculation involves adjusting the recorded flow at the point of apportionment to take into account diversions into and out of the basin, water uses, net evaporation from constructed storage works, and routing factors. The rigor with which the calculation must be made depends on the extent of water use in the basin. Several methods can be used to calculate natural flow.[18] These will be discussed with respect to Figure 4 on the next page. The figure represents a hypothetical water use unit with an irrigation area, a diversion into the area, including a small reservoir, and a return flow from the area. For the purpose of this discussion the irrigation area could be taken to represent any significant water use.

Project Depletion Method

The project depletion method is highly dependent on hydrometric and other direct measurements and less dependent on meteorological, topographic and land use information than other methods. With reference to Figure 4, streamflow data would be required at Point 1, the diversion from the steam; Point 4, the downstream boundary of the water use unit; and Point 5, the return flow from the water use unit. Natural flow at Point 4 would be calculated as the recorded flow at Point 4 plus the recorded flow at Point 1 less the recorded flow at Point 5. This calculation assumes that the water use area is small enough that natural runoff within the area can be ignored. That is, the area can be considered simply as a black box with water entering and leaving. In the example shown, net evaporation from the small reservoir and conveyance losses in the channel from the point of diversion to the project are subsumed into the water use of the project itself.

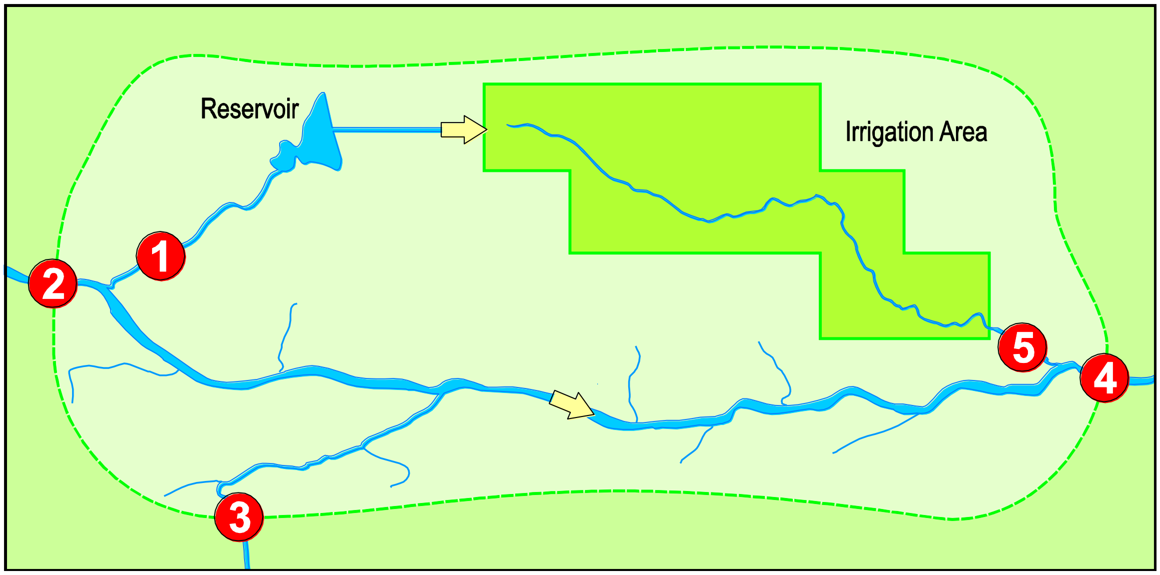

Figure 4. Hypothetical Water Use Unit. *(after PPWB 1976)*[19]

In more complex situations where reservoirs serve multiple purposes and diversion channels serve multiple users, reservoir evaporation and change in storage as well as conveyance losses must be calculated individually. The natural flow could be expressed in the form of an equation.

$$Q_{natural} = Q_{recorded} + diversion + naturalrunoff - returnflow$$

This method is highly dependent on streamflow records. While its accuracy will be influenced by the uncertainty in the streamflow record, accuracy is also influenced by uncertainties in water use and consumption data, evaporation data, and stage-area and stage volume curves for reservoirs.

Stream Depletion Method

This method involves the identification of a bulk area that includes the water use project, the point at which natural flows are to be computed, and points upstream where natural flows are known or can be computed. An example is the area included within the dashed line in Figure 4. The natural flow would be calculated by summing the natural flows at Points 2 and 3 and the natural runoff component from the bulk area. The net depletion for the project is then the difference between the recorded and calculated natural flow at Point 4.

As the bulk area becomes larger and larger it is difficult to monitor all the flows and diversions across the bulk area boundary. It also becomes increasingly difficult to account for all the hydrological processes within the bulk area. Evaporation, ice formation, surface-groundwater interactions may be attributed to change in storage, rather than natural processes. Generally, the uncertainties in this approach are greater than those associated with the Project Depletion Method.

Rimflow Method

This method also uses a bulk area. The method assumes that a robust regression equation can be developed between natural flow at the upstream boundary (Points 2 and 3) and natural flow at the lower boundary (Point 4). This method may be considered prior to the development of significant water uses in the bulk area. It also requires that the areas above the upper and lower boundaries are hydrologically homogeneous. If historical records from pre-development times are used in the regression, this also requires statistical stationarity. Like the Stream Depletion Method, as the bulk area increases in size accounting for the uncertainty consumptive uses on small tributaries increases.

Consumptive Use Method

This method has been considered where irrigation water use is the principle consumptive water use. Assuming storage and diversions can be handled by direct gauging, the method computes actual evapotranspiration by crops using empirical formulas. Again, with reference to Figure 4, the estimated natural flow at Point 4 would be the recorded flow at this point plus project consumptive use. Since evapotranspiration is governed by a large number of factors such as meteorological conditions, crop type, topography, soils, and farming practices, the data requirements are significant. As well, natural hydrologic processes in the project area still have to be taken into account.

MRWRCC Method

The Montana Reserved Water Rights Compact Commission (MRWRCC) developed a method of synthesizing natural flows based on using flow records from selected index gauging stations. Missing streamflow records were first extended to provide monthly values for the desired period of record. The index stations were deemed to have natural flow or, in some cases, natural flows had previously been determined using the project depletion method. The natural flows were then extended to the reach in question using drainage area ratios.[20] The method could be considered adequate for planning purposes, but is not satisfactory for apportionment purposes.

Summary

Several different methods of computing natural flow can be contemplated. Data requirements for all methods are significant and the uncertainty of the result, in some cases, is rather high. There are several factors that influence the decision of which method may be preferred, and these will be discussed later sections in this report. In general, the hydrometric and meteorological networks are relatively dense in the Red River basin. As well, the state and provincial agencies in the basin operate robust water permitting or water licensing systems. Information pertaining to other aspects of water use, such as water diverted, consumption or return flows, while not as detailed as the water allocation information, is often available.

One of the challenges in calculating natural flow in the basin is that there is no single major water use, such as irrigated agriculture, or a handful of major dams that would dominate the natural flow calculation. Instead, there are a myriad small water projects and dozens of relatively small structures. The data demands of dealing rigorously with each use or each structure could make the calculation complex and time consuming.

One other consideration is that the states and provinces of the interior plains tend to use the project depletion method of calculating natural flow. This applies not only for interprovincial streams in prairie Canada and for international basins but also for basins such as that of the Colorado River. It is reasonable to assume that there is a certain comfort level and some expertise in various federal, North Dakota and Manitoba agencies in using the project depletion method.

The next several sections of this report are written with the project depletion method in mind. The question of the selection of a preferred method of natural flow calculation for the Red River will be re-visited following that discussion.

WATER ALLOCATION

Water is allocated in the Red River basin in accordance with riparian doctrine in Minnesota and in accordance with western water law – the doctrine of prior appropriation – in North Dakota, South Dakota, and Manitoba. This situation plus the differences in water administration in the western water law jurisdictions add complexity to consideration of water apportionment in the Red River basin.

Riparian doctrine is rooted in Roman water law (code of Justinian, 500 A.D.) and English common law.[21] In effect, riparian water rights are vested in landowners of lands through, or adjacent to, which a stream flows. These rights are automatic and water may be used for domestic and other reasonable purposes irrespective of the effect on downstream riparians. If water is used for extraordinary purposes such as industrial use it must be returned to the stream substantially undiminished in quality and quantity. The right does not have to be exercised, pertains directly to the land through which a defined channel flows, and does not pertain to a specific quantity of water. Landowners who are not adjacent to a stream have no water rights and no means of obtaining a right. It should be noted as well that English common law covers percolating water (groundwater) that doesn't flow in a defined channel in a different manner. Persons with access to percolating water have little responsibility to other existing or potential water users. The concept of interconnections between surface and groundwater is absent from English common law. This may, in part, account for the differing water management regimes for surface and groundwater in some jurisdictions.

States and provinces of eastern North America allocate water in accordance with what has become known as a regulated riparian system.[22] Regulated riparian jurisdictions will have laws or regulations covering many of the following aspects of water allocation:[23]

- requirements for registration of water withdrawals
- permits for water withdrawals
- water withdrawal and usage reporting requirements
- permit requirements for interbasin transfers
- limits on water withdrawals
- procedures for water allocation during drought
- recognition of rights of non-riparian water users
- water well construction limitations, and
- regulatory requirements for water intakes and other water infrastructure

The 1848 California gold rush led to needs to allocate scarce water supplies among competing miners. The system that evolved simply rejected riparian doctrine and provided an enforceable water right to the first person to put either surface or groundwater to beneficial use. The needs of the first appropriator had to be met before the next person's and so on. This is the doctrine of prior appropriation.[24,25] An appropriator acquires a right to a specific quantity of water for a specified purpose. A right holder who does not use the water may forfeit his right. This concept became the norm in the American west. Mining, agriculture and other water developments could proceed with the knowledge of security of supply. Two mantras apply, "first in time, first in right" and "use it or lose it". California developed a legal system to appropriate water in 1873. The Colorado Constitution of 1876 abolished riparian water rights stating that, *"The right to divert the unappropriated waters of any natural stream to beneficial uses shall never be denied."* [26] Other western American states were quick to enact statutes in support of the doctrine. The doctrine was also adopted in the Canadian west and in Australia in the 1890s.

Another element of water law in the United States pertains to federal reserved water rights. These relate to federal lands and date to when the land became federal, or earlier in the case of Indian lands. They exist whether that water has been put to beneficial use, or not. They are superior to state water rights.

Water appropriation is often seen in the western water law states of the United States as a property right with the water permit system being simply an administrative mechanism. Once water has been taken or abstracted and the water put to beneficial use the right may be considered 'perfected'. The right to water will be absolute and during times of shortage cannot be overturned by more junior rights, even if they are considered more socially important, valuable or water efficient. Appropriation implies some physical diversion although some states provide permits for in-stream uses. In some states the water appropriation can be separated from the land and traded commercially.

In contrast to prior appropriation in the western United States, the system in western Canada is rooted in the concept of water rights being vested in the Crown, *i.e.*, the government. This originated with the *North-west Irrigation Act* of 1894 in prairie Canada (federal legislation) and statutes at about the same time in British Columbia (federal and provincial legislation). The principle of "first in time, first in right" thus became a key element in western Canadian water management. Water governance in western Canada developed on the basis of government-issued licences to divert and use water for a specified purpose. Senior licence holders had higher priority than junior ones. As in the western United States water developments could take place with some certainty of supply. The concept of putting water to beneficial use is not engrained in the western Canadian system. Priority of use is determined based on when the licence application was made, not when water was put to beneficial use. Issuing a water licence confers or acknowledges no property rights and in recent years it is customary to issue a water licence for a specified period such as 20 years. The licence would not be renewed if it has not been used.

Some writers identify the American system as prior appropriation and the Canadian system as prior allocation.[27] This implies that there may be differences as well as similarities between the two systems. Irrespective of constitutional rights to water and differences among the various jurisdictions in the Red River basin, it is important to emphasize that throughout the basin water is allocated by statute. Specific laws related to water allocation will be described later in this section.

All jurisdictions in the Red River basin allow an annual withdrawal of water, without licence or permit, to meet domestic requirements. This can be considered as a vestige of the riparian doctrine in western water law jurisdictions. Minnesota, the only riparian doctrine jurisdiction in the basin, can be considered a regulated riparian state.

South Dakota

When South Dakota became a state in 1889 a prior appropriation system for allocating surface water in Dakota Territory had been in place since 1881.[28] The state engineer was authorized to administer appropriation of surface water following enabling legislation in 1907.[29] A law was introduced making groundwater subject to prior appropriation in 1955. In 1972 withdrawals from groundwater that exceed the average annual recharge were prohibited. Water permits are issued under the authority of Chapter 46 of the *South Dakota Codified Laws* and associated *Administrative Rules of South Dakota*.[30]

Authority to issue water permits rests with a seven-member Water Management Board appointed by the Governor. A chief engineer of the water rights program in the Department of Environment and Natural Resources provides technical assessments. Applications for use of more than 10,000 ac.-ft. (12,233 dam^3) a year require legislative approval. (One cubic decametre or dam^3 is 1000 cubic metres.)

Permits are required for all uses exceeding 25,920 U.S. gallons a day (29 ac.-ft. or 35.8 dam^3 a year). Any use requiring a peak pumping rate of 25 U.S. gallons a minute or greater also requires a permit. (The daily use limit is equivalent to 18 U.S. gallons a minute for 24 hours.)

South Dakota has no designated list of water use priorities, other than domestic use takes precedence over other uses, provided this is exercised in the public interest. Domestic use is defined to include household use, watering of livestock, non-commercial irrigation and uses by public institutions such as schools. Riparian rights established prior to July 1, 1955 and beneficial uses established prior to 1907 are considered vested rights.[31]

South Dakota law provides for appropriations for instream flows, although this provision has rarely been used. The matter of federal reserved water rights has not been an issue in South Dakota. No adjudication process related to federal reserved rights exists.[32]

As indicated earlier, South Dakota comprises only one percent of the Red River basin. As one would expect, water allocation is small compared to that in other basin jurisdictions. For the purposes of this report no attempt has been made to determine water allocation in the Red River basin portion of the state. One source indicates that the total water allocation is 21,174 ac.-ft. (26,100 dam^3), 6,945 ac.-ft. (8,566 dam^3) from surface water and 14,229 ac.-ft. (17,550 dam^3) from groundwater.[33]

North Dakota

Water in North Dakota is appropriated under the terms of the state's *Century Code*. This code is the compilation of all general and permanent laws since statehood in 1889. Each area of law is covered by a division called a Title and each title is subdivided into Chapters. Title 61 - Waters contains Chapter 04 – Appropriation of Water. A related *Administrative Code* contains specific rules pertaining to implementing the *Century Code*. North Dakota formally repealed riparian doctrine in 1963 but riparian rights acquired prior to that time are recognized.[34]

A water permit from the State Engineer's Office is required to put surface or groundwater to beneficial use unless that use relates to domestic, livestock, or fish, wildlife and other recreational uses. However, any use that requires impounding more that 12.5 acre-feet (15.4 dam^3) of water using constructed works, dams or dugouts requires a permit. Landowners using less than 12.5 acre-feet may still apply for a permit to clearly establish a priority date. An individual may not apply for a permit for irrigation if that would enable the individual to hold permits for more than 720 acre-feet (888 dam^3) of water that has not been applied to beneficial use.

Water permits are issued under Chapter 61-04 of the *Century Code* in accordance with the principle of prior appropriation under western water law. That is, the priority of the water permit is based on the date of application. When applications are on the same date or are competing for the same water supply, water use priorities come into play. The order of priority of the purposes for which water may be used or diverted, or works constructed, established or maintained, in accordance with the Chapter 61 is as follows:

1. **Domestic Use.** This means the use of water by an individual, or by a family unit, or household, for personal needs and for household purposes, including heating, drinking, washing, sanitary, and culinary uses; irrigation of land not exceeding five acres (2.0 ha) in area for non-commercial gardens, orchards, lawns, trees, or shrubbery; and for household pets or animals kept for household sustenance and not for commercial use, when the water is supplied by the individual or family unit. This includes domestic rural uses.
2. **Municipal or Public Use.** This means the use of water by the state through its political subdivisions, institutions, facilities, and properties, and the inhabitants thereof, or by unincorporated communities, subdivision developments, rural water systems, and other entities, whether supplied by the government or by privately owned public utility or other agency or entity, for primarily domestic purposes.
3. **Livestock Use.** This means the use of water for drinking purposes by heards, flocks, or bands of animals, kept for commercial purposes.
4. **Irrigation Use.** This means the use of water for application to more than five acres (2.0 ha) of land to stimulate the growth of agricultural crops, including gardens, orchards, lawns, trees, shrubbery, or the maintenance of recreation areas such as athletic fields, golf courses, parks, and similar types of areas, except when the water for the facility is provided by a municipal water system.
5. **Industrial Use.** This means the use of water for the furtherance of a commercial enterprise wherever located, including but not limited to manufacturing, mining, or processing.
6. **Fish, Wildlife, and Other Outdoor Recreational Uses.** This means the use of water for the purposes of propagating and sustaining fish and wildlife resources and for the development and maintenance of water areas necessary for outdoor recreation activities.

All holders of a water permit are required to install a measuring device and to report annual water usage to the State Engineer on or before February 1 of the following year. A permit can only be acquired for water to be put to beneficial use. Wasting water is not considered a beneficial use.

North Dakota law does not provide for appropriations for instream flows. The matter of federal reserved water rights has not been a significant issue in North Dakota. No adjudication process related to federal reserved rights exists.

According to an HDR Engineering report, the state has issued water permits for 296,624 ac.-ft. (365,880 dam^3) of surface water and 152,311 ac.-ft. (187,872 dam^3) of groundwater annually.[35] A recent retrieval from the North Dakota water permit database indicates that 290,470 ac.-ft. (358,289 dam^3) of surface water has been allocated in the Red River basin – a similar figure to that in the HDR Engineering report. The distribution of surface water permits by use is shown in Figure 5. The dominant use is municipal.

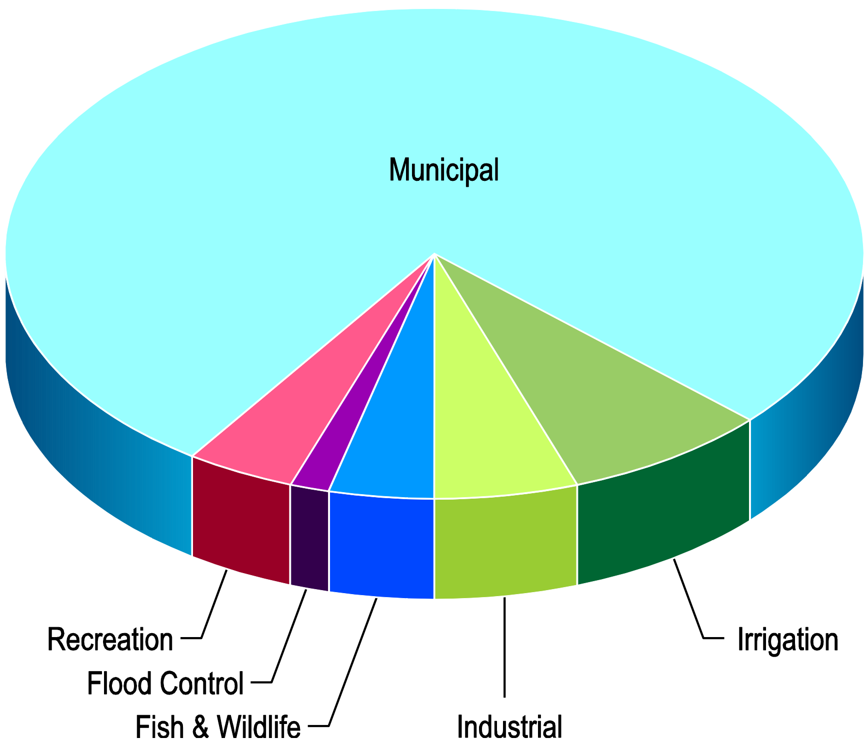

Figure 5. Appropriation from Surface Water in North Dakota.

Minnesota

Minnesota is the only jurisdiction in the Red River basin whose water administration is founded in riparian law. When Minnesota became a state in 1858, one early piece of legislation was an act to encourage drainage, a reflection of water abundance, if not excess. During the 1930s drought, which was particularly severe in the Red River basin, the state passed a law making it illegal to withdraw groundwater or surface water without first obtaining written permission from the Commissioner of Conservation. For the most part water is covered under Chapters 103A-114B of the *Minnesota Statutes* and Chapters 103A through G comprise the water law of the state.

Chapter 103G.261 establishes priorities for consumptive use and appropriation of surface and groundwater. These are:

1. **Domestic and Power Production.** This means domestic water supply, excluding industrial and commercial uses of municipal water supply, and use for power production that meets the contingency planning provisions of the chapter.

2. **Low Consumption.** This means any use of water that involves consumption of less than 10,000 [US] gallons of water per day [11.2 ac.-ft or 13.8 dam^3 a year].

3. **Agricultural Irrigation and Processing.** This means any agricultural irrigation, and processing of agricultural products involving consumption in excess of 10,000 gallons per day [11.2 ac.-ft. or 13.8 dam^3 a year].

4. **Power Production**. This means power production in excess of the use provided for in the contingency plan developed under this chapter.

5. **Other Uses**. This means uses, other than agricultural irrigation, processing of agricultural products, and power production, involving consumption in excess of 10,000 gallons per day [11.2 ac.-ft. or 13.8 dam^3 a year].

6. **Nonessential uses.**

In addition to the listed priorities, Minnesota statutes and rules also provide for natural resources protection.

Water permits are obtained by application to the Department of Natural Resources. Permits may be suspended during low water level conditions to protect higher priority users as well as natural resources. Excluding temporary permits, Minnesota has issued 765 permits for appropriations from surface water. The annual quantity of water appropriated in September 2009 is 605,682 ac.-ft. (747,098 dam^3). The distribution by water use is shown in Figure 6. Similarly the state has issued 941 permits for appropriations from groundwater. The annual quantity appropriated in September 2009 was 219,340 ac-ft. (270,551 dam^3). The groundwater wells in the Red River basin do not exceed 500 ft. (150 m) in depth and are typically 125 ft. (40 m) deep. In times past Minnesota had allocated large quantities of water for cooling purposes. That use has been eliminated as an inappropriate use of high quality water. Water permit applications are considered public documents in Minnesota. Details concerning permits are available on-line at http://www.dnr.state.mn.us/waters/watermgmt_section/appropriations/wateruse.html

It should be noted that the Minnesota water allocation figures used in this report are significantly higher than those shown in a report produced by HDR Engineering for the Red River Basin Commission.[36] The differences cannot be accounted for simply by the timing of retrievals from the DNR database. The difference may lie in the allocated quantity of water versus that permitted for use at a given time.

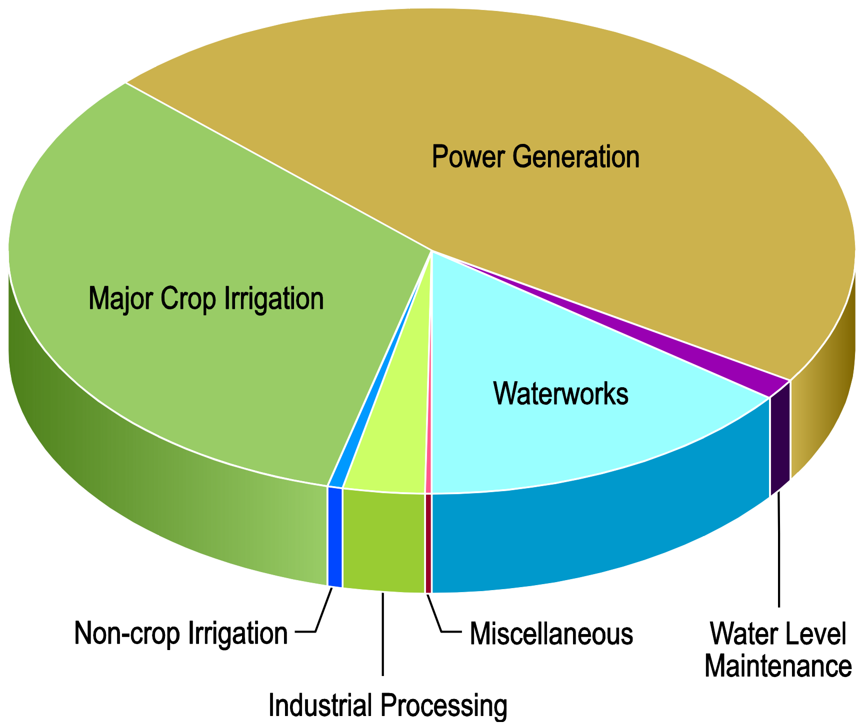

Figure 6. Appropriation from Surface Water in Minnesota.

Any person or organization appropriating or using water must measure the use and report annual water usage to the Commissioner of Natural Resources on or before February 15 of the following year.

Manitoba

When Manitoba became a province in 1870 it was known as the postage stamp province – the small province extending 177 km (110 miles) northward from the international boundary to the southern tip of Lake Winnipeg and 209 km (130 miles) along the international boundary scarcely covered the Red River basin. The province was extended in 1881 and again in 1912. Natural resources administration in the new province continued to be vested in the federal government. The federal government allocated water rights under the provisions of the *North-west Irrigation Act*. The act defined priorities of water use and used the first-in-time, first-in-right principle. Natural resources administration became a provincial responsibility under the *Constitution Act*, 1930 and Manitoba enacted water rights legislation soon after this. Groundwater allocations were not covered by the legislation until 1959.

In Manitoba water is currently allocated under *The Water Rights Act (C.C.S.M. c. W80)*, which came into force in June 13, 2006. The act and related regulations establish a framework for water licensing in the province that is grounded in western water law although surface and groundwater rights related to domestic use are recognized.

Licensing is in accordance with the principle of prior allocation under western water law. That is, the priority of the licence is based on the date of application. When applications are on the same date, water use priorities come into play. The order of priority of the purposes for which water may be used or diverted, or works constructed, established or maintained, in accordance with the Act is as follows:

1. **Domestic Purposes.** This means the use of water, obtained from a source other than a municipal or community water distribution system, for household and sanitary purposes, for watering lawns and gardens, and watering livestock and poultry. A licence is not required unless use is more than 25,000 litres a day. This rate is equivalent to 25 cubic metres a day or 9.125 dam^3 (7.4 ac.-ft.) a year.
2. **Municipal Purposes.** This means the use of water by a municipality or a community for the purpose of supplying a municipal or community water distribution system for household and sanitary purposes, for industrial use or uses related to industry, for watering streets, walks, paths, boulevards, lawns and gardens, for protection of property, for flushing sewers and for other purposes usually served by a municipal or community water distribution system.
3. **Agricultural Purposes.** This means the use of water at a rate of more than 25 cubic metres a day for the production of primary agricultural products, but does not include the use of water for irrigation purposes.
4. **Industrial Purposes.** This means the use of water obtained from a source other than a municipal or community water distribution system, for operation of an industrial plant producing goods or services other than primary agricultural products. It does not include the sale or barter of water for those purposes or the use of water for recreation.
5. **Irrigation Purposes.** This means the use of water at a rate of more than 25 cubic metres a per day for the artificial application to soil to supply moisture essential to plant growth. This criterion also applies to non-agricultural irrigators such as golf courses and sports fields. Typical irrigation licences consider a 300 mm (12 inch) duty under drought (one in ten year risk) conditions, but smaller quantities may also be licenced. (Most of the irrigated land in Manitoba is used to grow potatoes.)
6. **Other Purposes.** This means the use of water for purposes that do not fit into any of the above noted categories. Some examples include Ducks Unlimited Canada projects, recreation, some commercial uses, fire fighting and heating/cooling systems.

Licences are issued for a specific purpose for specified period, usually 20 years for municipal purposes and currently 10 years for other uses. The licences indicate the annual withdrawal volume and rate, water source and diversion location, and whether the source is surface or ground water. Instream needs may be covered by conditional clauses in the licence. Withdrawal volumes may be reduced when instream needs warrant. Indeed, irrigation licences based on spring runoff sources typically include a clause indicating the volume may only be available 80 percent of the time.

Regulations under the Water Rights Act require that the proponent install a meter or timing device on the water source and that records of water use to be kept. The licence itself contains a provision that water use records be submitted to the Water Licensing Branch, Manitoba Water Stewardship, either upon request or by February 1st of the following year. Depending on the type of project, records must be kept on a daily, weekly, or monthly basis, and tallied to provide yearly consumption. In the case of industrial use not connected to a municipal system and 'other' purposes, water use charges are assessed based on the quantity of the diversion. These range from one dollar a cubic decametre a year for the first 100 dam^3 and increase in steps to two dollars as annual diversion exceeds 20,000 dam^3. Industrial users are charged for their entire allocation if they do not submit water use reports so reporting of water use in that sector is good. Municipal users tend to report water use, but many other users do not. Submission of water use records is a condition of water licence renewals or transfer of licences when project ownership changes. Irrigation licences not used for three consecutive years may be cancelled.

The Pembina River basin is the only significant Canadian basin upstream of the Red River at the international boundary. The total quantity of surface water allocated in the basin in Manitoba is 1354 dam^3 (1670 ac.-ft.). About 70 percent of the use is for municipal purposes with most of the remainder being allocated to irrigation. The groundwater allocation is 1942 dam^3 (1575 ac.-ft.). One municipal surface water licence for 580 dam^3 (470 ac.-ft.) is being converted to groundwater. The annual water allocations can be compared to the median annual flow of some 168,000 dam^3 (208,000 ac.-ft.).

Summary

All jurisdictions within the Red River basin operate a robust water appropriation or allocation system under which persons using water must obtain a permit or licence. All have a minimum quantity for which no permit is required. This quantity is relatively high for South Dakota, but is similar for the other three jurisdictions in the basin. All jurisdictions place the highest priority on meeting domestic water needs by not subjecting small domestic use to the allocation process. Table 2 summarizes the water use priorities in each state or province. In the western water law jurisdictions, *i.e.*, all but Minnesota, these priorities come in to play when applications for use are made on the same day.

Table 2. Water Use Priorities by Jurisdiction.

Priority	South Dakota	North Dakota	Minnesota	Manitoba
1	Domestic	Domestic	Domestic/Power	Domestic
2	All Other	Municipal/Public	Low Consumption	Municipal
3		Livestock	Irrigation and Ag. Processing	Agricultural, other than irrigat.
4		Irrigation	Power Production	Industrial
5		Industrial	Industrial	Irrigation
6		Fish/Wildlife/Other	Non-Essential	Other

Note: Quantities not requiring a permit or licence are 29 ac.-ft. (35.8 dam^3) in South Dakota, 12.5 ac.-ft. (15.4 dam^3) in North Dakota, 11.2 ac.-ft. (13.8 dam^3) in Minnesota, and 7.4 ac.-ft. (9.125 dam^3) in Manitoba.

The quantity of surface or groundwater appropriated for various purposes is known. In the case of Minnesota the information is available on line. Despite the doctrine of beneficial use that is a fundamental part of water administration in the western United States, many water users withdraw less than their entitlement in a given year. This also is the case in Manitoba and Minnesota. Using water appropriation data to support a natural flow calculation for the Red River will lead to an overestimate of natural flow as appropriation data represent an upper limit on consumptive use. One must therefore consider the actual quantity of water withdrawn and returned to the aquatic system.

WATER USE

The terminology related to water use varies from one agency or practitioner to the other. In this report the term water allocation or appropriation is used to identify the quantity of water set aside under a permit or licence for a particular purpose by a specified user. This quantity may include a consumptive use component and a return flow that would be available to downstream users. Water withdrawal or water diversion is the quantity of surface or groundwater that a water user removes from the aquatic system. Water consumption is water consumed by a user that does not return to the aquatic system. Water consumption includes losses to seepage, in industrial processes or to evaporation. Return flow is the difference between water withdrawal and water consumption. These concepts are illustrated in Figure 7.

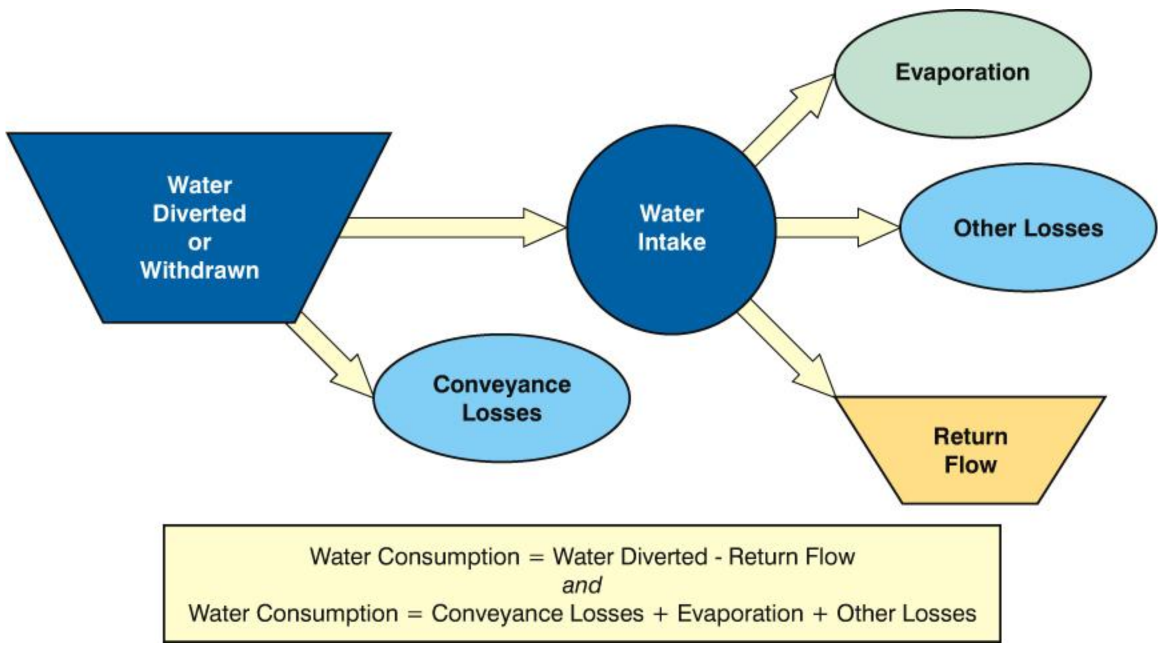

Figure 7. Water Use Terminology. *(PFSRB, 2009)*[37]

In considering Figure 7, it must be kept in mind that the quantity of water diverted or withdrawn is not identical to the quantity allocated under a permit or licence. In some cases it will be substantially lower than the licensed allocation. Conveyance losses are most commonly associated with surface water uses as water may be conveyed by an open ditch from the point of diversion to the point of use. Groundwater extraction most often involves piped systems so there are no conveyance losses other than leakage. Industrial water uses often involve considerable recirculation and re-use of water. Some water will be lost during such processes thus requiring “top-up” water from the water supply. The process losses are considered as consumption. Finally, water will evaporate from any free surface. Any evaporation from reservoirs, or other impoundments such as tailings ponds, associated with a water use is deemed to be consumption. Evaporation represents an important water use; it will be discussed separately later in this report.

All jurisdictions in the basin have defined water use categories that are used in their permit or licence system. These uses are also consistent with the water use priorities identified in legislation. These uses consist of major use categories and various sub uses. Minnesota, for example has identified more than 60 sub uses in its permit system. Examining the various water use categories allows inferences to be drawn concerning actual water use. Table 3 summarizes the water allocations ranked by volume in the Red River basin. As discussed earlier, on-farm domestic use does not represent an allocation as such. While there are many domestic water users, the actual volume used is not known.

Table 3. Major Water Allocation Categories by Jurisdiction

South Dakota	North Dakota	Minnesota	Manitoba
Municipal	Municipal/Public	Power Generation	Municipal
	Irrigation	Major Crop Irrigation	Irrigation
	Industrial	Water Works	Other
	Recreation	Industrial Processing	Agricultural
	Fish and Wildlife	Water Level Maintenance	
	Flood Control	Non-crop Irrigation	

These water use categories and the consequence to natural flows calculations are reviewed below. The analytical framework is in the context of surface water withdrawals and return flows.

Almost without exception water withdrawn from an aquifer is lost to that aquifer, at least in the short term. From a groundwater perspective then, withdrawals from an aquifer are considered as entirely a consumptive use unless the water is returned directly to the aquifer. An open-loop geothermal system may be one example of a non-consumptive groundwater use. On the other hand, groundwater may be withdrawn from an aquifer and any effluent returned to the surface water system, as is the case for Moorhead, Minnesota. The return flow from the city's wastewater treatment system represents an addition to the natural flow of the receiving stream. From the perspective of natural flow calculations a groundwater withdrawal that returns effluent or returns flows to surface water is a credit to the system. (Some groundwater supplies are closely linked to surface water so a depletion of groundwater represents a depletion of surface water.) If the same system were supplied by surface water with return flows discharging to a nearby stream, this would represent a depletion of the natural flow. Determining natural flow therefore requires careful attention to water sources and receiving waters.

One further complication can be considered. As mentioned earlier in this report, 27 percent of the Red River basin (exclusive of the Devils Lake sub-basin) does not contribute to flow in a typical year. In determining natural flow, one can consider that a water use in the non-contributing drainage does not represent a depletion of the natural flow of the Red River at the international boundary. One can start to deal with this situation by including information in water permit or water licence databases indicating whether the permit is in the contributing or non-contributing drainage. Figure 2 illustrates portions of the basin where this should be considered.

Domestic. Domestic water use is not covered by permits or licences. Generally this use applies in rural or very small communities. A typical rural household will use 2 acre-feet (2 dam^3) of water to meet its needs for and entire year. As the quantity of water exempt from water appropriation rules is much larger than that, a rural operation could also water small number of cattle or irrigate a small plot of land without exceeding the minimum requirement. As this use is not subject to permits, it is difficult to determine how much water is used for domestic purposes in the basin. The quantity is likely to be small, however.

Municipal. This consists of water distributed by communities for domestic, commercial, industrial, and public users. Community-scale use is usually covered by one or more licenses or permits. The water source could be either surface or groundwater. Municipal water supply tends to be a significant part of water permits in the Red River basin. Indeed, it represents the largest appropriation from surface water in North Dakota. From the perspective of natural flow calculations, the water consumed tends to be negligible so municipal uses do not enter into the natural flow calculation. Large cities, at least, tend to be water sources rather than water consumers. Table 4 provides some figures for Grand Forks and Winnipeg. Winnipeg's situation is provided for comparison purposes although the city does not draw its water from the Red River.

Table 4. Urban Water Supply and Consumption

City	Water Withdrawn	Unaccounted For Water	Return Flow	Stormwater	Outdoor Use
Grand Forks	8,984 acre-ft.	7 percent	7,791 acre-ft.	n/a	n/a
Winnipeg	77,300 dam^3	13 percent	112,800 dam^3	n/a	6-10 percent

Even if the return flow from wastewater treatment plants for a city is less than the quantity of water diverted, the impervious surfaces of urban centres will produce more stormwater runoff than would naturally occur. Return flows from cities can be reduced, however, if the treated effluent is used as an input to an industrial process. Urban centres will also have some unaccounted for water lost in the distribution system. (Unaccounted for water can be considered as the difference between the quantity of water diverted from a source and the quantity metered at households and other consumers.) Some of that water will find its way into groundwater, which in turn may replenish surface water. Outdoor water use may also find its way into the groundwater system. Lethbridge, Alberta in western Canada has a two-metre high groundwater dome under it – the result largely of excessive outdoor water use.[38] During drought periods outdoor water use is usually significantly restricted so the general approach of urban water use not being a factor in natural flow calculations should continue to hold true.

Industrial. This consists of water used by industrial users who are not connected to an urban distribution system. These users tend to have individual permits or licences. Examples of such uses include food processing, mining or manufacturing. Industrial water usage in the Red River basin is relatively small. Consumption is low because industrial water is generally recycled. While it is believed that industrial water use is not important to natural flow calculations, examination of consumption pertaining to a sample of some of the larger permits in the basin may be useful.

Power Generation. This category is identified separately in Minnesota – the only jurisdiction having thermal generating stations in the Red River basin upstream of the international boundary. (Manitoba Hydro has a thermal generating station at Selkirk, Manitoba.) The quantity of surface water appropriated to power generation is very large, almost 50 percent of the total for Minnesota. The stations in the basin use once-through cooling so although a large quantity of water is used, only a very small portion – less than three percent – is consumed. This use is inconsequential to natural flow calculations for apportionment purposes.

Irrigation. Irrigation represents a significant water consumer in the basin. This can include crop irrigation or other irrigation uses such as sod farms or golf courses. About one-third of the appropriations in Minnesota are for irrigation. With the exception of some relatively large acreages devoted to wild rice production, irrigated lands for each permit are rarely more than a quarter section in size. In western Canada, the quantity of water consumed in large irrigation districts is in the order of 80-90 percent of the water diverted. Over the years irrigators have adopted increasingly more water efficient systems, moving from spring backflood to gravity to sprinklers to low pressure sprinklers. Technological improvements lead to improved water use efficiency and further reductions in return flow.

Irrigation water use will be a significant factor in any natural flow calculation for the Red River basin. It would be important to understand the extent to which water withdrawn in a typical year matches the quantity appropriated and the quantity of return flow, if any, from individual projects. The pattern of water withdrawal could also be significant. In at least some parts of the basin water is withdrawn during the spring to off-stream storage for use later in the season.

Other. This includes a number of miscellaneous categories. Water level maintenance (a separate major category in Minnesota and North Dakota) serves water and wildlife management functions. Depending on the project design, the water diverted for this purpose may be entirely lost to evaporation so the entire diversion may be considered a consumptive use. Other uses may include uses that just don't fit elsewhere such as heating and cooling. From the perspective of natural flow calculations, it could be assumed that all water diverted for water management purposes of some description is consumed. It would be important to verify whether the quantity diverted annually is similar to the allocated quantity and to identify any projects believed to have significant return flows.

Return Flows

By 1972, responding to concerns about municipal and industrial wastewater pollution of the rivers, streams, and lakes, the United States Congress passed the *Clean Water Act*. Section 402 of the act created the National Pollutant Discharge Elimination System (NPDES) Permit Program. The main goals of the NPDES Program are to control the amount of pollution that can enter waters of the United States and to protect the beneficial uses of all streams and lakes. The NPDES program covers all point discharges from water users, including storm water runoff from urban centres. The United States Environmental Protection Agency has delegated administration of the program to states. Under state programs, water users must obtain a permit to release return flows into the aquatic system and they must report the quantity of flow released. Industrial users in an urban centre may be required to pre-treat their effluents to reduce effects on the sanitary treatment system.

The South Dakota Department of Environment and Natural Resources issues Surface Water Discharge permits. In North Dakota return flows from water users are covered under Chapter 61-28 of the *Century Code,* which is aimed at control, prevention and abatement of pollution of surface waters. The law regulates wastes such as industrial, municipal and agricultural effluents discharged into state waters. It is the state response to section 402 of the federal *Clean Water Act*, 1972. Any person discharging waste as a point source into surface water requires a permit from the North Dakota Department of Health. Details of the permit system are covered by Article 33-16 of the *Administrative Code*. The Minnesota Pollution Control Agency operates its NPDES as part of an integrated water quality management system. Permit applicants are encouraged to identify water conservation and effluent reduction measures.

Summary

Analysis of water licences or permits provides only a rough indication of actual water use and consumption in a river basin. Further, although by law or by conditions imposed in the water allocation process, projects are required to report actual water withdrawals and return flows, there are many uncertainties in the available data. Some water users simply report that they use their appropriation every year – a rather unlikely scenario. Some water uses such as thermal power station cooling or municipal use are not significant water consumers while others like irrigated agriculture or water management projects are.

Annual water withdrawal data as reported by permit holders for Minnesota is available on line and can be compared to permit information. Although, as mentioned earlier in this report, the allocation information reviewed by this writer was much higher than that provided in a recent report by HDR Engineering, the withdrawal information is almost identical. Annual withdrawals from surface water in the state are in the order of 100,000 to 125,000 ac.-ft. (125,000 to 150,000 dam^3) a year. Considering calculations by this writer and HDR Engineering, maximum annual surface water withdrawal for the Red River basin in Minnesota is about 20 to 25 percent of permitted allocation. HDR Engineering also indicates that the ratio in North Dakota, considering both surface and groundwater is about the same.[39] It should be noted that water use reports for North Dakota take into account evaporative losses from reservoirs; this does not seem to be the case in Minnesota. If return flows are also taken into account, actual water consumption represents an even lower percentage of allocation.

Water allocation and use for urban municipal purposes and for cooling of thermal power stations in the Red River basin can safely be ignored in determining natural flow. Industrial water uses subject to separate permits can likely be ignored, but it would be useful to spot check the actual use and consumption associated with the larger permits. Water consumption for irrigated agriculture will require detailed analysis as will some of the 'other' uses that are significant water consumers. Among the considerations related to irrigation is the area irrigated, the typical annual duty – often 12 inches or 300 mm, the nature of the operation, and the return flow. It should be possible based on existing information to develop average or typical annual consumptive uses that would be sufficient for the natural flow calculation.

Water used by water management structures, including fish and wildlife uses, is largely consumed by evaporation. The nature of these structures and their water consumption should be examined as part of any natural flow calculation for the basin.

In addition to the consumptive uses previously discussed, evaporative losses must also be taken into account. Loses from the many artificial impoundments in the basin may represent a significant water use.

INSTREAM FLOWS

The robust water allocation system used in the Red River basin serves human needs very well, but may not meet ecosystem needs. Of the four jurisdictions in the basin only South Dakota has a provision for issuing permits for instream flows, and this provision is rarely used. Surface water permits or licences issued by the various jurisdictions in the basin may contain provisions related to in-stream flow needs.

The science pertaining to instream riverine flows is relatively new. As it pertains to naturally flowing streams as opposed to regulated rivers, much of the science was conducted in the last 20 years. Even the terminology is not completely established. For the purpose of this study instream flows will be taken to mean a scientifically derived flow regime designed to sustain aquatic and related ecosystems. Some writers call this an ecological flow. This must be distinguished from conservation flows, sometimes called environmental flows, which tend to be administratively derived minimum flows aimed at maintaining ecosystems. Such flows, while sometimes based on science, more often could be considered as "rules of thumb"

The benchmark for instream flows is the natural flow regime of the stream. This is not to say that the natural flow regime always provides the 'best' riverine environment. It does, however, provide the within year and between year variability needed to sustain healthy aquatic ecosystems.[40,41] Flow variability is one of the necessary requirements for ecosystem health. Very little work has been conducted with specific reference to instream flow requirements for the Red River and its tributaries. This is likely on account of two factors: the flow regime for the most part is almost identical to the natural regime and water quality matters, of themselves, have been considered a higher priority. As discussed later in this section, water quality is an important component of instream flow requirements.

As water consumption in the Red River basin increases or if the basin is struck by a severe and protracted drought, instream flow requirements will become a more important consideration. It is unlikely that a formal water apportionment arrangement for the Red River basin could be negotiated without some consideration of instream flows. The following discussion, which is drawn in large part from a report by Alberta Environment provides one approach to determining instream flows.[42] Although the methodology is applied to the South Saskatchewan River basin, a large basin in a semi-arid region of western Canada having high irrigation water use, similar methods could be applied to the Red River basin.

Definitions of biodiversity or ecological integrity usually consider three levels: genetic, taxonomic and ecosystem. As such, they consider structure, function, processes, and the relation to the natural regime. The physical, chemical and biological regimes under which aquatic ecosystems function can be linked to the natural flow regime and instream flows can be expressed in terms of deviations from that regime. Relating broadly-based ecosystem function to the natural flow regime is enormously complex. Data requirements alone make the problem intractable. The approach taken in Alberta was to consider four aspects of instream flows: fish habitat, water quality, riparian vegetation, and channel maintenance.

The general approach to fish habitat studies is to use the physical habit simulation system (PHABSIM) developed by the U.S. Fish and Wildlife Service.[43] In this approach a hydraulic model is used to define the characteristics of the stream, in terms of depth and velocity, as a function of discharge for specified reaches. In general:[44]

- A flow that is beneficial to one life stage may be detrimental to another life stage.
- A flow that is beneficial to one species may be detrimental to another.
- Various life stages and species may require different amounts of water at different times of the year.
- A flow that maximizes usable habitat in one part of the stream may not provide very much usable habitat in another part of the same stream.
- More water does not necessarily mean more habitat.

With reference to the Red River, the mainstem has eight low-head dams or weirs that provide obstructions to fish passage. Although the dams submerge at high flows, the three at Wahpeton-Brekenridge, Fargo-Moorhead and one at Grand Forks-East Grand Forks have been modified to enable fish passage under most stream conditions. The ones at Wolverton, Hickson and Drayton have not.[45] When the Red River Floodway at Winnipeg was expanded, consideration was given to avoiding fatal traps for fish and such considerations will also affect the design of the Fargo-Moorhead Floodway, should that project proceed. There are many obstructions to flow on tributaries, some of which are submerged during spring flows. In general, the Red River is a cool water fishery and the fish species composition and the flow regime needs of each species are known. The extensive hydraulic modelling conducted for the Red River mainstem since 1997 may be sufficient to apply PHABSIM. This is clearly not the case for many tributaries that provide spawning habitat. The high water flow regime of the Red River and its tributaries is close to natural, however. Factors such as habitat, streamflow regime, water temperature, nutrients and suspended sediment account for about 60 percent of the variability in fish community composition. Additional variation can be attributed to land use practices and to biological interactions.[46]

More than 50 species of fish have been identified in the Red River and its major tributaries including game species such as channel catfish, muskellunge, northern pike, sauger, walleye, smallmouth bass, goldeye, mooneye, and carp. Other species include fresh-water drum, bullhead and lake sturgeon.[47] Target species for any Red River instream flow needs related to fisheries could be selected among these species. Species composition in the Red River basin tends to be more diverse in the headwaters of tributaries than lower down on the tributaries or on the mainstem.[48]

Water quality has been monitored at many long-term sites throughout the Red River basin, including sites on tributaries and the mainstem. Parameters monitored can be grouped as physicals (such as temperature or dissolved oxygen), major ions, nutrients, metals, bacteria, and pesticides. International water quality objectives have been established on the Red River at Emerson for dissolved oxygen, total dissolved solids, chloride, sulphate, and fecal coliform bacteria. The IJC's International Red River Board monitors compliance with these objectives and maintains a system of alert levels for other parameters, particularly pesticides.[49]

Water quality is also a function of the geology and landscape through which a stream flows. Water quality of the Red River is dominated by the predominately agricultural landscape. In the United States portion of the basin 64 percent of the land is cropland. Water quality in the lower main stem is also influenced by saline seeps from sedimentary bedrock aquifers.[50] From an instream flow needs perspective the most significant water quality parameters are water temperature, dissolved oxygen, and suspended sediment. Upsets at wastewater treatment facilities that lead to raw or partially treated sewage entering the river can also be a concern. Low flows can influence temperature, dissolved oxygen and waste assimilation. Sediment concentrations increase with flow.

The riparian vegetation of the Red River and its tributaries is adapted to the natural patterns of streamflow variability. Since the current streamflow pattern is very close to natural, the natural foliage and associated habitat is healthy. The main effect on riparian areas has been land clearing and drainage for agricultural and urban development purposes rather than streamflow modification. Trends towards permanent cover of riparian areas and towards riparian buffer strips are a positive influence on the health of riparian zones. The development of greenways on the Red River since 1997 is also a positive step. Dense natural riparian vegetation also enhances riverine habitat.

To some extent riparian zones and aquatic ecosystems can be considered as pulse-stabalized. A constant flow will lead to degradation. If water uses increase on the river, it is important that major dams be operated to mimic the natural hydrograph to the extent possible. Under current water use patterns, the most significant threat to riparian ecosystems from an instream flow perspective would be a lengthy drought.

The Red River mainstem is a low gradient meandering river having a fine-grained bed made up of silts and clays. River bank slumping is the principle morphological change; the river channel itself is quite stable. The headwaters of the Red River tributaries tend to have more slope and some, like the Pembina River, have more erodible beds than the Red River itself. Instream flow requirements pertaining to channel maintenance are likely more important for tributaries. This is because of morphological conditions and the greater likelihood of dams being constructed on the tributaries. The sediment regime of the basin is also affected by agricultural development and land drainage.

In general any natural river requires sufficient channel maintenance flows that conserve the hydraulic characteristics of the river. These flows suspend small particles and reset the aquatic system by scouring channels and re-establishing habitat. Given the recent flood history of the Red River, it is difficult to make a case for development of instream flows for channel maintenance on a high priority basis. Nonetheless there is a need to be aware of the effects of hydraulic structures on the flow regime and on river morphology.

In summary, instream flows can be considered as ecological-based flows pertaining to fish habitat, water quality, riparian vegetation, and channel maintenance. Such flows are not constant, rather they mimic the natural hydrograph. Given the current water use situation in the Red River basin, it would be useful to consider instream flow requirements pertaining to a lengthy drought. Water quality concerns would be the main priority.

NATURAL FLOW DETERMINATION

As an initial step in determining natural flows for the Red River the U.S. Geological Survey calculated historic monthly streamflows at 35 sites on the Red River, on the mainstem and at the mouth of key tributaries, for the years 1931-2001. Of the 35 sites, 4 had continuous streamflow records for the entire period, 10 had partial records and 21 had no record. Missing record was estimated using drainage area ratios, regression, and water balance methods. The method used varied from stream to stream. Naturalized streamflow for the 35 sites was then estimated by eliminating the effects of Orwell Dam (Ottertail River), Reservation Dam and Whiterock Dam (Bois de Sioux River), and Baldhill Dam (Sheyenne River). Surface water withdrawals and return flows were also eliminated.[51] The method used could be considered as a first order approximation using the project depletion method.

Determining detailed natural flow for the Red River requires water use and consumption data for the larger uses such as irrigation. If consideration of smaller uses is required, allocation data could form the basis of the calculation. For example, consumption for thermal station cooling could be taken to be three percent of allocation.

There are other considerations as well. Evaporation is a significant water consumer so determining evaporation from various impoundments in the basin is necessary. Since not all structures in the basin are monitored there is a need to develop a procedure to deal with minor diversions, evaporation and other consumptive uses at small projects. Finally, water diversions or water releases to make up deficits will incur some channel losses. A procedure for determining time of travel and channel losses under various flow conditions is needed.

The natural flow calculations can take on varying degrees of complexity. Additional complexity also implies additional time and effort required for the calculation. Procedures that can be performed relatively quickly using interim or unapproved data will allow flow adjustments to be made in a timely manner. It is almost inevitable that interim procedures will be used during the year, with a final accounting once all the data are available. No matter how the calculation is performed it is important that the methodology be approved by the various parties to any apportionment agreement. Any agreement should also contain provisions that allow the calculations to be improved as experience is gained.

Evaporation

Evaporation is significant in the Red River basin. Indeed, in some sub-basins, evaporation could be the single largest consumer of water. As part of any natural flow calculation reservoir net evaporation (gross evaporation less precipitation) must be taken into account as a consumptive use of water. Although technology now exists for measuring evaporation directly using eddy covariance (eddy correlation, eddy flux) technology, the equipment is expensive and there are no routine monitoring sites in the Red River basin where such equipment is deployed. (The method requires measurement of vertical turbulent air movements and fluctuations in atmospheric water vapour density.) One must therefore rely on indirect measures or estimates of evaporation.

Historically, one of the common means by which evaporation has been determined is through the operation of evaporation pans. The Class A pan consists of a 4 foot (1.22 m) diameter by 10 inch (0.25 m) deep pan mounted on a wooden pallet allowing air to flow beneath the pan and around its sides. The pan is serviced daily adding water to make up for evaporative loss or removing water to account for rainfall, rain being measured at an adjacent gauge. Because of energy exchange with the atmosphere through the pan walls, a pan coefficient of 0.7 is applied. Pan-derived evaporation values will tend to overestimate reservoir evaporation early in the season and underestimate evaporation late in the season. This is because of the differing heat storage characteristics of a pan versus a larger impoundment.[52] Attempts to resolve these problems by sinking the pan in the ground or floating it in a reservoir lead to other problems. Traditionally, evaporation pans are serviced in the morning; it has been demonstrated that afternoon servicing leads to less data loss due to ice effects in April and October.

One of the main factors controlling evaporation is the temperature of the evaporating surface. This is controlled by the energy balance at the surface including energy exchanges in the process of evaporation. In a simplistic sense this can be expressed as:

Energy Input = Energy Output +/- Energy Storage

Measures of incoming short wave radiation, long wave reflected radiation, and sensible and latent heat can be used to determine evaporation. The instrumentation for energy budget measures is not often available. As a result various equations based on more common meteorological observations such as precipitation, air temperature and wind speed are frequently used. The US Geological Survey compared 11 equations to the results from evaporation calculated at two highly instrumented energy balance sites in North Dakota and Minnesota. They found that a modified DeBruin-Keijman equation, the Priestly-Taylor equation, and a modified Penman equation produced evaporation results for Lake Ashtabula, Orwell Lake and Lake Traverse that are most comparable to those obtained by energy balance. Annual gross evaporation from these lakes was in the order of 2.5 ft. (0.75 m).[53] As well as measurements of air temperature, the equations identified require measurements of net radiation, wind speed, and relative humidity. Because net radiation, wind speed, and relative humidity are not measured routinely at most climate stations, the equations could not be used routinely in natural flow calculations.

North Dakota uses the Soil Conservation Service's Hydrology Manual for North Dakota as the basis for evaporation calculations. The manual provides a map of mean annual evaporation from shallow lakes and reservoirs based on calculations by Adolph F. Meyer of Minnesota Resources Commission.[54] Meyer's seminal work on evaporation from lakes and reservoirs was published in 1942.

In prairie Canada, Agriculture Canada periodically calculates 30-year average annual potential evaporation using the Meyer equation. The calculated values of gross evaporation for the Red River basin in Manitoba are in the order of 0.8 m (2.6 ft).[55] (Note the similarity to the figures obtained by the USGS.) The province of Manitoba uses these calculated values for water management purposes. Considering that average annual precipitation at Fargo, for example, is 0.538 m (1.77 ft.), the net evaporative loss from reservoirs in the basin can be significant.

The Meyer equation can be expressed in metric units as:

$$PE = 7.58(V_w - V_a)(1+6.21x10^{-2}W)(1+3.28\ x10^{-5}A)$$

where PE is the monthly gross evaporation in millimeters; V_w is the monthly saturated vapour pressure corresponding to the estimated monthly mean water temperature (mbar); V_a is the actual monthly mean vapour pressure in the atmosphere at 7.62 m (25 ft.) above ground level (mbar); W is the monthly mean wind speed at 7.62 m (25 ft.) above ground level (km/hr); and A is the elevation above mean sea level of the ground level (m).

From the equation, PE is affected by the difference between water vapour pressure and air vapour pressure (vapour pressure deficit, VPD), wind speed and the elevation of the site. Agriculture Canada estimates the monthly saturated vapour pressure based on water temperature, which is estimated from monthly mean air temperature. The actual monthly mean vapour pressure in the atmosphere is estimated from monthly mean dew point temperature.[56] Evaporation could therefore be calculated using available climatological data although, at least in Manitoba and North Dakota, the calculations are already available although it would be desirable to update the calculations for North Dakota.

According to the US Army Corps of Engineers on-line National Inventory of Dams there are 501 dams in the Red River basin in the United States, including a few in the Roseau River basin. In Manitoba, there are also six dams in the Pembina River basin and none in the Roseau basin. An Excel spreadsheet pertaining to the structures in the basin is described in Appendix 1 of this report. Table 5 provides a brief summary.

Table 5. Reservoir Surface Area and Capacity – Red River Basin.

State/Province	**Number of Dams**	**Total Surface Area**		**Total Storage**	
		acres	**km^2**	**acre-feet**	**dam^3**
South Dakota	12	252	1	5,015	6,186
North Dakota	205	25,331	103	221,900	273,709
Minnesota	284 (plus 111 not in NID)	51,821*	210*	1,210,000	3,320,987
Manitoba	6	11,922	48	71,439	88,119
Totals	507	89,326	362	1,508,354	3,689,001

* Red Lake, a regulated natural lake is not included in these totals.

Some structures in the basin simply stabilize the level of a naturally existing lake. Pelican Lake in Manitoba and Red Lake in Minnesota are examples. As these lakes existed in a state of nature, the evaporative loss from them could be considered as natural and should not be included in the natural flow calculation. The calculation could be further refined if stabilization of the lake level has led to a significant increase in surface area, in which case a portion of the evaporation should be included in the natural flow calculation.

Although Red Lake information has been deleted from the total surface area, surface area data for Minnesota reservoirs is often not available, other natural lakes are included in the totals, and no account is taken whether a project is in the effective drainage area, one can use the data in Table 5 for a back-of-the-envelope calculation of evaporative loss in the Red River basin to demonstrate the potential significance of this consumptive use of water. Based on net evaporation data presented earlier in this report, reservoir evaporation for the basin would be in the order of 60,000 ac.-ft. or 75,000 dam^3. This figure is fraught with uncertainty and should be considered with extreme caution. Suffice to say, the evaporative loss from basin reservoirs could well be greater than actual water consumption in the basin.

A natural flow calculation will require agreement on the method used to calculate evaporative losses. At a first level of approximation, simply using the methodology that each jurisdiction customarily employees should be sufficient but a consensus on consistent approach for the entire basin would be desirable. One important data gap is the apparent lack of surface areas for Minnesota reservoirs.

Many of the reservoirs in the basin have riparian outlets that are operated for water management purposes such as flood control or water supply. Evaporation must be taken into account along with diversions into or out of the reservoirs. This task is simplified if there are water level gauges on the reservoir and stream gauges downstream. Smaller reservoirs, however, often are not closely monitored. Some sort of index method should be established to deal with consumptive use from these so-called minor projects.

Minor Projects

Many of the smaller structures listed in the USACE National Dam Inventory are not individually monitored. That is, neither the water level nor the discharge from the structure is routinely measured. There are also smaller structures in the basin built to capture runoff that have received water permits but, again, have no monitoring facilities. Water diversion and consumption information may be reported annually, but no information is available during the year. These types of project are considered minor projects. While the water consumption and evaporation from any single project is small, the aggregate total may be significant. There are two ways in which these projects may be handled.

First, if the project is subject to a water permit and the annual water consumption is reported annually, the average annual water use could be including in interim apportionment balances, with the reported use for the current year being used in the final year-end balance. In addition to the use reported by the project operator, a calculation of annual evaporation would also have to be carried out.

Secondly, for projects where water use is not reported, the projects may be grouped by type and a small number of monitoring index stations established, each being representative of a certain type of operation. The considerable special variation in prairie rainfall means that operating an evaporation pan in conjunction with the index reservoir may be required to determine net evaporation. The findings from the index stations can then be applied to the aggregate of the related type of project. If one assumes that the monitoring results from the index stations would be available throughout the period of operation of the structure – likely the open water season, the results can be applied to both interim and final apportionment balances.

Channel Losses

Any apportionment arrangement for the Red River must consider that, at some time, delivery of water at the apportionment point say, the Red River at Emerson, will be in deficit, and water must be released from an upstream reservoir to make up this shortage. The larger reservoirs currently in the basin are a considerable distance from the international boundary and a portion of any releases aimed at making up a deficit would be lost to priming the channel. Taking into account that deficits will most probably occur during low flow or drought conditions, the losses to the channel may be considerable. In other apportioned river basins in the interior plains channel loss studies aimed at determining losses under various flow conditions have been conducted. The losses can be considered for high, medium or low flows. In the case of the eastern tributaries of the Milk River, where reservoirs are in Alberta and the stream flows through Saskatchewan to Montana, under low or zero flow conditions, the channel loss can be 100 percent. That is, a release from an upstream reservoir will never reach the international boundary.

Given the locations of major Red River basin reservoirs are a considerable distance from the boundary and that there would be very little public sympathy for reservoir releases for the conduct of channel loss studies during drought conditions, the preferred approach might be to examine the flow records during past low flow periods to obtain some understanding of channel losses. For example, during 1977 and in the 1980s when flows were low, releases were made from Red Lake to meet downstream needs. Analysing the quantity of water released and the quantity reaching the international boundary could be instructive.

Travel Times

Aside from consideration of channel losses from any reservoir release needed to make up an international deficit, it is also important that the travel time for any release from reservoir storage to reach the international boundary be known. At present there is no information available on travel times of the Red River or its tributaries. One USGS report, however, does calculate travel times in the Fargo-Moorhead reach of the river. The study was aimed at calibrating a WASP (Water quality Analysis Simulation Program) model of the river. Based on dye transport measurements in 2003 and field studies done in the 1990s when flows ranged from 150 to 250 cfs (4 to 7 m^3/s), the velocities over a relatively short reach of the Red River were typically 0.4 to 0.5 ft/s (0.12 to 0.15 m/s) although both higher and lower velocities were calculated.[57] It is likely that releases to make up deficits would be made when flows are much lower and therefore travel times would be even longer than those calculated by the USGS. Travel times under ice conditions would be still longer.

Studies aimed at meeting provisions of the Clean Water Act pertaining to improving wastewater treatment at urban centres will in the long term lead to improved understanding of travel times on the Red River and its tributaries. In addition, travel time information is required to understand the movement of chemical spills that may result from upsets at industrial or wastewater facilities. There is currently a proposal to produce a REMM (Riparian Ecosystem Management Model) model for the Red River for this purpose.

Considering that the total length of the Red River to the international boundary is about 395 miles (635 km), it is not unreasonable to assume that it would take more than a month for a release from a headwaters reservoir to travel the mainstem to the international boundary. Obtaining reasonable estimates of travel times under low flow conditions will be required if Red River apportionment were to be implemented. This could be accomplished by hydraulic modelling studies. Some preliminary estimates could be obtained by hydrograph comparison.

Selection of a Natural Flow Method

The discussion earlier in this report identified several natural flow calculation methodologies. Of the methods identified earlier in this report, the stream depletion method and the rimflow method tend to rely on having a few large projects in a basin rather that a large number of widely distributed projects as is the case in the Red River basin. The consumptive use method has been applied where water use is dominated by large irrigation districts.

Although using the project depletion method may present challenges, it appears that the monitoring networks and the water use data in the basin would support such an approach. Adding to that is the fact that several agencies in the basin are familiar with the method and have applied it in other basins. The discussion earlier in this report indicates that the method be recommended. The key challenge will be to reach consensus on the many simplifying assumptions that would have to be made.

APPORTIONMENT OF THE RED RIVER

As a preface to the discussion of Red River apportionment it must be emphasized that this is a theoretical discussion. At present there is no advocate for such an apportionment and based on current water use in the basin there does not appear to be a compelling case for traditional surface water apportionment. Consider Figure 8, which presents flow duration data of annual volume at Emerson based on over 100 years of streamflow record. Current water consumption is lower than the 98th percentile of the volume shown in the figure. It could be argued that with the present water use in the Red River basin, a basin-wide contingency plan to deal with the effects of rare droughts may be preferable to calculating annual apportionment balances under a formal arrangement.

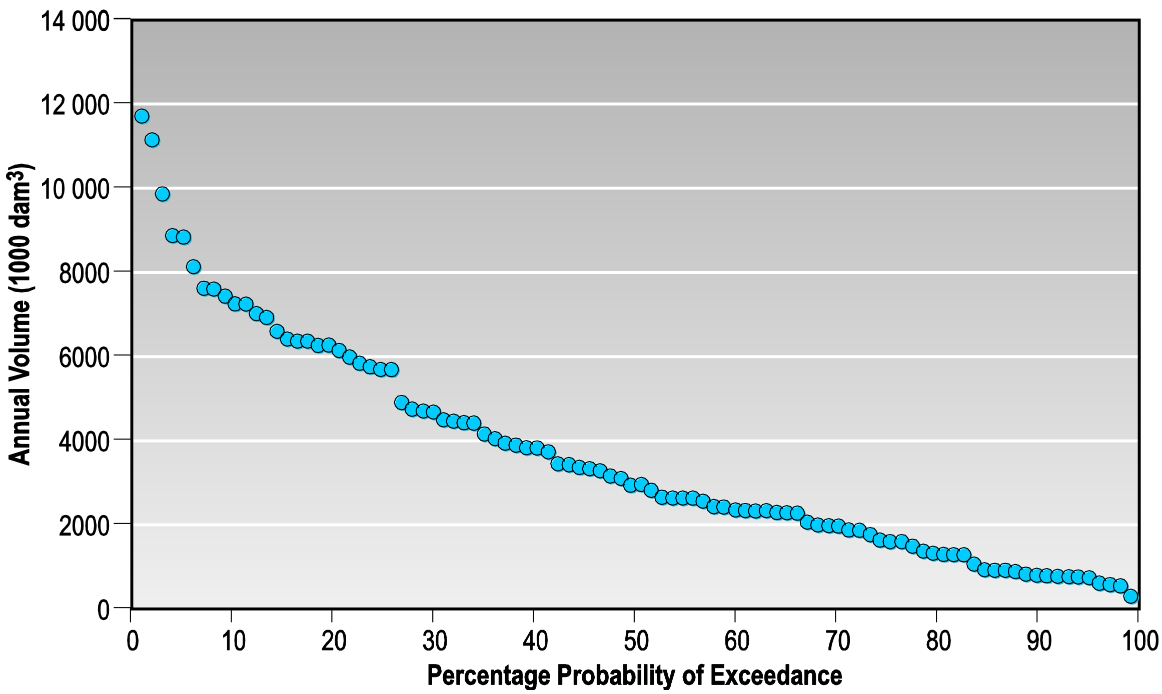

Figure 8. Annual Flow Duration for the Red River at Emerson.

In addition to annual flows, monthly flows can also be considered. The decade of the 1930s contains many of the lowest flow years for the Red River at Emerson, 1960 and 1977 being the most significant low flow years since that time. Each month in the period from October 1936 to March 1937 is the lowest on record. April 1938 provides the lowest spring runoff and May through September 1934, the lowest summer streamflow. Based on experience since the 1930s, the extremely low winter flows of that period are unlikely to reoccur as releases from reservoirs constructed by the Corps of Engineers in the 1940s (Lake Traverse) and 1950s (Lake Ashtabula, Orwell Lake and Red Lake) are used to augment winter flows. Winter flows in low flow years since that time are some 25 times greater than the flows of the 1930s.

River regulation during very low flows on the Red River make it more difficult to apply other low flow criterion such as 7-day 10-year low flows (7Q10). Often used in water quality studies, this is the minimum flow averaged over seven days that is expected to occur on average once in any 10-year period. That is, the 7Q10 flow has a one in 10 chance of occurring in any given year. Calculating a 7Q10 flow based on the recorded flows of the Red River would give a misleadingly low figure because of low flow augmentation in the last 60 years.

Considering annual flow patterns and water consumption (including reservoir evaporation) as identified in this report, one would also have to consider the pattern of water withdrawal to determine how difficult it would be to meet water demands in a series of low flow years like those of the 1930s. The general pattern of use is to store water in the spring for subsequent use. Demands during a drought would be different than those during normal conditions as some water infrastructure would be inoperable and some water use curtailed.

Given that the natural flow of the Red River can be calculated using the Project Depletion Method, one can then turn to the question of how that natural flow is to be divided and at what location. The location question can be resolved fairly easily. The options are whether to apportion the transboundary tributaries of the Red River separately and, if so how, or simply apportion the Red River at the international boundary while taking into account international tributary flows.

Considering the Roseau and Pembina rivers, the water consumption in the Roseau River in Minnesota is trivial, as is the water consumption in tributaries such as Pine and Sprague creeks that flow from Manitoba to join the Roseau River in Minnesota. There appears to be no reason to consider apportionment of the Roseau River, either of itself or as part of the apportionment of the Red River.

Turning to the Pembina River, water consumption in that basin in Manitoba is small as is water consumption from tributaries such as Badger, Snowflake and Mowbry creeks that flow from North Dakota into Manitoba. Water use in North Dakota in these tributaries is small. Considering water consumption in the Pembina basin in Manitoba, annual water consumption could be a little as 500 dam^3 and evaporation from artificial impoundments about 1000 dam^3. On this basis there does not appear to be a need under current water usage to apportion the Pembina River separately where it crosses from Manitoba into North Dakota. The median (50 percent probability of excedance) annual volume of the Pembina River is in the order of 168,000 dam^3. Figure 9 illustrates annual recorded flow duration for the period of record.

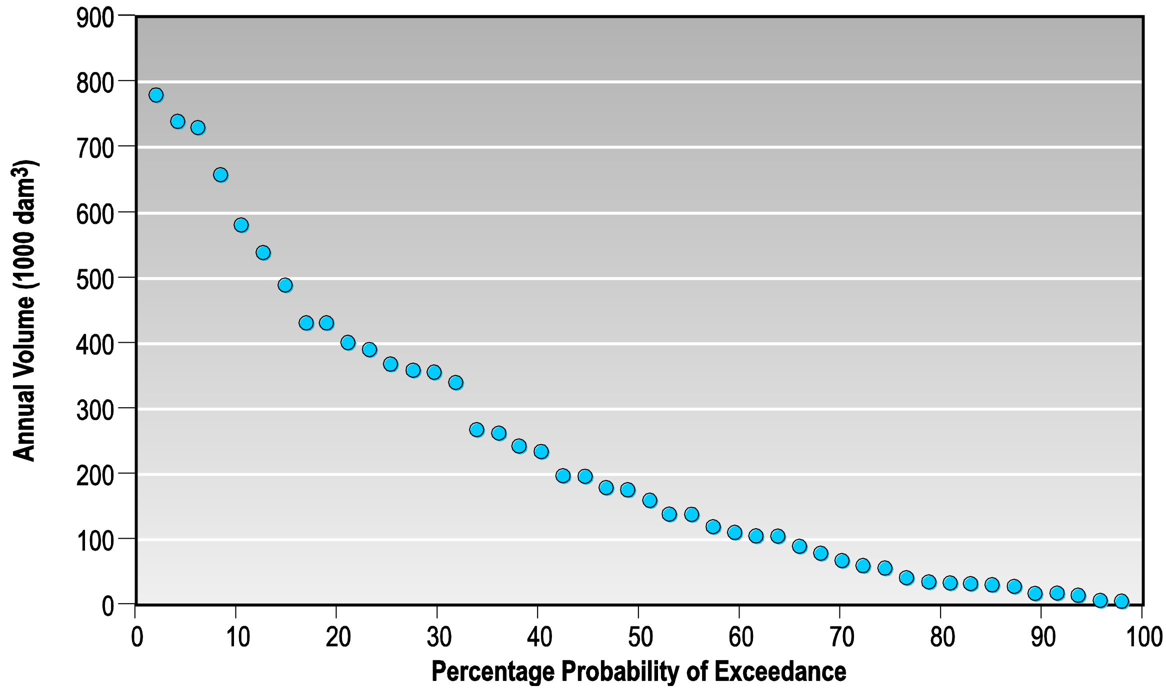

Figure 9. Annual Flow Duration for the Pembina River at Windygates.

Unlike the case of the Roseau River, Pembina River flows must be taken into account in any Red River apportionment. As a first order approximation it appears sufficient to simply use the recorded flows of the Pembina River near Windygates, Manitoba or, if deemed necessary, adjust the flows for water allocation plus change in storage and evaporation from the reservoirs in Manitoba to obtain a natural flow for apportionment.

With its two transboundary tributaries considered as in the previous paragraphs, the apportionment location for the Red River could be taken as the gauging station on the Red River at Emerson, Manitoba. The simplest procedure would be to divide the natural flow at this point equally between the United States and Canada. (One-half of the Pembina River natural flow determined at Windygates would have to be subtracted before dividing the flow between the two countries.)

The concept of equitable apportionment means that other divisions of the natural flow can be contemplated. For example the United States could argue that it is entitled to some sort of prior allocation to satisfy water needs that have been established over time. If this is agreed, it is critical that any apportionment agreement explicitly specify whether the prior allocation is part of the United States share or in addition to. There are precedents for these sorts of considerations in the apportionment of the St. Mary and Milk rivers between the United States and Canada and of the South Saskatchewan River between the Canadian provinces of Alberta and Saskatchewan.[58,59]

In his 2009 report, de Loë discusses the need for a prior apportionment to meet critical human and environmental needs, particularly in the context of drought and climate change. This implies consideration of what constitutes critical human needs and of instream flows. In determining what quantity of water may be required to meet critical human needs, it is important to recognize that not all of domestic water use constitutes a critical need. It can be argued that the exemption of domestic uses from water licensing or permitting requirements accomplishes the critical human need in a rural context, provided water is available. Indeed, an annual allocation of about 2 ac.-ft. or dam^3 for a rural household is sufficient for that purpose. Accommodating critical human needs during droughts of various severities should be part of any drought response plan.[60] In an urban setting it is natural to assume that water use, particularly outdoor use, would be curtailed during drought periods in order to meet critical human needs.

Similarly, instream flow needs, when developed for the Red River, should also consider requirements under drought conditions. Drought in the interior plains is a natural phenomena so consideration of instream flows should include reductions during drought. It would be reasonable in an apportionment agreement for the Red River to include specific language related to drought contingencies and how water would be apportioned under various levels of drought. A prior apportionment may or may not be required. It should be noted that there are elements of reduced water use that arise almost automatically during a drought. Urban outdoor water use is curtailed and many smaller water intakes cannot be operated during very low flows.

Water quality is a key issue on the Red River. It is important that any apportionment agreement recognize the water quality objectives and alert levels currently in place at the international boundary and any future water quality arrangements.

One particularly difficult challenge for any apportionment arrangement on the Red River between the United States and Canada can be implemented without some similar arrangement between Minnesota and North Dakota. For instance how would any prior apportionment be shared between the two states? Would deficits, when they occur, also be apportioned and how would they be made up? In an American context it may be that a full-fledged water compact involving South Dakota, North Dakota and Minnesota could be required as a precursor to any traditional international apportionment arrangement.

Apportionment Period

Water is managed in the Red River basin on an annual basis with water being captured in hundreds of small reservoirs in the spring being used to meet most water requirements for the year. It appears logical to consider an annual apportionment with neither surpluses nor deficits being carried over to the following year. An annual apportionment could, under some low flow conditions, lead to water shortages downstream. The highly seasonal flows of the river, however, mean that equitable apportionment would call for periodic audits of apportionment results and an opportunity for correction. This could be carried out on a monthly, quarterly or on some other basis. Unless water consumption in the basin increases significantly, a quarterly or less frequent audit period can be considered.

Considering each quarter in turn, it is evident that January, February, March flows will be small under any circumstances. Indeed, early spring runoff in March, especially in low flow years, will likely ensure that this quarter is almost always in surplus. Winter water supply augmentation from storage also means that a deficit is unlikely.

If a deficit is incurred in this quarter it could be made up during spring runoff in the following quarter. The April, May, June quarter accounts for about two-thirds of the annual natural flow of the Red River in a typical year and this is the period during which reservoirs are filled. A deficit at the end of the first six months of the year would be rare, except during very low runoff years. During the July, August, September quarter water demands may be relatively high and water supplies relatively modest, barring summer rains. It is likely that if a deficit is going to occur it will be at the end of this quarter. This means that interim natural flow calculations to the end of the quarter will have to be carried out expeditiously so that corrective action, if needed can be taken before winter sets in. Flows in the October, November, December quarter are usually small, water demand is low and flows may be increased by releases from storage. Even if there were a deficit at the end of year it is unlikely that a large winter release would effective.

Considering an annual apportionment with periodic audit periods, the main concern in the Red River basin will be to ensure that apportionment status is known during the course of the summer so that corrective measures can be taken before freeze-up. Some sort of asymmetric audit periods may be the most useful. For example, the entire January to May period could comprise the first audit period. This could be followed by a June-September period. This would allow a deficit, if any to be made up. No interim status report would be done at year end; instead the final calculation would be made based on approved records.

Make-up Water

Any discussion of apportionment deficits leads to the question of how and when or even if deficits would be made up. The usual source of make-up water is upstream reservoirs. In the case of the Red River the larger reservoirs in the basin are a considerable distance upstream of the international boundary. Time of travel and channel loss studies would have to be undertaken to see what would be a reasonable time during which deficits would have to be made up. Given that all of the larger reservoirs in the basin are upstream of Grand Forks and that make-up water would likely be released under relatively dry conditions, the travel time involved would likely be measured in weeks. If conditions are such that most of the water released would be taken up in conveyance losses and there is no compelling use for the water further downstream, the pragmatic decision may be not to attempt to make up the deficit. This situation could well occur during a prolonged drought.

Dispute Resolution

One can assume that any apportionment agreement developed for the Red River would be administered by the International Joint Commission and monitored on the IJC's behalf by the International Red River Board. This should be an explicit decision by the parties to the agreement, however. Nevertheless, it would appear reasonable no matter how the agreements is administered that any disputes under the agreement be referred to the IJC for resolution.

Summary

It is feasible to calculate the natural flow of the Red River and apportion that flow between the United States and Canada. The calculations required for the natural flow calculation are extensive and time consuming while current water demands are small in comparison to the natural flow. Equitable apportionment would require consideration of audit periods and likely apportioning the river between Minnesota and North Dakota. A particular challenge will be the sourcing of make-up waters should a deficit occur and the logistics of releasing that water to Canada. Given the current water use situation, it may be preferable to consider an international drought contingency plan for the Red River basin.

Another approach may be to consider apportionment only in the context of minimum flow criteria for the Red River. One could determine minimum flow needs based, for example, on the flows required to allow water intakes to operate, instream flow needs for sustainability of the aquatic environment, instream flow needs related only to water quality, the need for flushing flows, or other criteria. Certainly the overarching objective would be to maintain a live stream under almost any circumstance. Having determined an annual minimum flow regime, the question of whether that flow could be met through reservoir releases, water use efficiency or some other means could be addressed.

Considering the historical record for the Red River at Emerson, the minimum flow in February 1937 was 0.03 m^3/s (1 cfs). In the last 50 years, however, minimum winter flows have been in the order of 5 m^3/s (175 cfs) or better. This improvement in minimum flows is likely the result of low flow augmentation by releases from reservoirs. The available storage in the basin can be compared to the annual minimum flow regime to determine how long such a flow can be maintained. A continuous flow of 5 m^3/s (175 cfs), if provided solely from reservoir storage is a significant water demand.

CONCLUSIONS

The Red River basin is a complex basin shared by three states, one province and two countries. More than 80 percent of the surface area of the basin lies in the states of Minnesota and North Dakota. Water use in those states has the potential to affect downstream interests in Canada. The IJC's International Red River Board provides one forum to consider matters of mutual concern. One concern is the question of whether it is feasible to apportion the waters of the Red River basin and exactly how that may be accomplished.

A precursor to considering water apportionment is the need to calculate the natural flow of the river. In this case the natural flow is taken to be the flow that would occur if the effects of dams and diversions and other water uses were removed. Considering the effects of land use change and climate change are beyond the scope of the calculation.

Several methods of natural flow calculation can be contemplated, but given the availability of an adequate hydrometric network and a robust system of water permits or licenses, the Project Depletion Method is recommended. Several agencies are familiar with the method based on apportionment of other interior plains basins. There are a number of considerations or data gaps that must be addressed before the Project Depletion Method could be applied routinely.

Hydrometric and Meteorological Networks. The data networks are generally adequate to assist a determination of natural flow in the basin. It should be anticipated, however, that a careful review will identify some gaps and deficiencies. More importantly, natural flow calculations require numerous interim calculations of streamflow at the end of audit periods. This task becomes very demanding during low flow periods when deficits can occur. It is also necessary to monitor releases from storage to make up deficits. Demands on monitoring organizations need to be carefully considered.

Water Allocation. The Red River basin contains a significant percentage of drainage that would contribute to flow one year in two, or less. This drainage has been identified by Agriculture Canada. If basin interests agreed on the areas of non-contributing drainage, the water permits or licences in the basin should be geo-referenced so that only the allocations in the effective drainage basin are included in the natural flow calculation. It is understood that some agencies are already doing this.

Water Use. Water consumption in the Red River basin appears to be about 20 percent of the water allocated. Water diversion information and return flow information is available, but there are some indications that the information is incomplete or inaccurate. The task of ensuring that water use information is sufficient to meet natural flow calculation needs could be simplified if a number of assumptions were agreed. Several water use matters could be considered and agreed:

- Urban water use is likely a net contributor to natural flow so this use could be removed from the natural flow calculation.

- Industrial water use that is allocated separately may be small enough to be ignored, or perhaps only a small number of relatively large allocations may be considered.
- Irrigated agriculture and water management uses appear to be the largest water consumers. These uses should be examined in sufficient detail to ensure an understanding of actual use. It is likely that group average uses could be developed depending on the nature of the mix of projects.
- The significance of return flows to surface water from groundwater withdrawals could be considered. The quantity involved may be small enough to be ignored.

Evaporation. The various jurisdictions in the basin use different methods to calculate evaporation. It may not be necessary to harmonize the methodology, but the effects of using different methods should be understood. Index reservoirs that are representative of many small impoundments that are not routinely monitored should be considered, and a small number established.

Apportionment. Assuming that a methodology for calculating natural flow can be achieved, it must be agreed by the parties to any apportionment agreement. The method will undoubtedly include assumptions and averaging, but only experience under different flow conditions will reveal the need for changes.

There are several considerations pertaining to apportionment itself. The location at which the Red River would be apportioned and hence at which natural flow would be calculated is an early decision. The Red River at Emerson appears to be the most logical apportionment point. There is insufficient water use in the Roseau River and its Canadian tributaries to warrant any consideration of apportioning that River separately. Water consumption in the Pembina River basin in Canada and the Pembina River tributaries that flow north into Canada is also small. There appears to be no reason to apportion the Pembina River separately but it would be necessary to include Pembina River flows in any calculation of natural flow of the Red River at Emerson.

If the apportionment location and natural flow are known, then the attributes of any apportionment arrangement come into play. One can assume that the parties to any agreement would be seeking elements of equitable as opposed to equal apportionment. At the current state of institutional development in the Red River basin, it is reasonable to assume a high degree of cooperation among the parties but, at the same time no party would be willing to give up its sovereign rights to another party. Consideration of benefit sharing under an apportionment agreement are likely moot.

In an earlier report for the IJC, Rob de Loë Consulting Services identified several common elements of any apportionment arrangement. These are all applicable to the Red River basin.

Parties to the Agreement. The parties would include the United States, Canada, Manitoba, Minnesota, North Dakota and South Dakota. While an apportionment arrangement could be executed by federal governments, implementing it without the cooperation of state or provincial governments would be problematic. It is much superior to ensure the states and province are engaged from the start.

Apportionment Formula. A starting point for apportioning the calculated natural flow is to share equally between Canada and the United States. To achieve equity, matters such as apportioning flow between Minnesota and North Dakota, prior apportionment to long-standing uses, seasonal flows, and other elements of equitable apportionment would have to be considered. This would also involve consideration of flows to meet critical human needs, instream flows and the international water quality objectives for the Red River.

Data Sharing and Availability. There are long-standing arrangements for sharing hydrometeorological data between Canada and the United States. In the case of hydrometric data, the arrangements began in the very early days of the 1909 *Boundary Waters Treaty*. Administering apportionment will require some new arrangements and some preliminary studies. This would include an examination of travel times and channel losses.

Audit Periods. Periods for which the apportionment balance is calculated would have to be determined. There could be as few as two audit periods a year, with a final balance once the year is complete. Annual surpluses or deficits would not be refunded. Audit requirements would become more demanding in low flow years.

Make-up Water. Any apportionment arrangement requires a means of making up deficits. This is a particular problem for the Red River, where reservoirs are relatively small and a long distance from the international boundary.

Dispute Resolution. The apportionment agreement should specify a dispute resolution mechanism. The IJC would be one logical entity.

Public Consultation. There is a high level of public engagement in water matters in the Red River basin. Implementing an apportionment arrangement will require that the public be involved in the process.

As can be seen there are a number of matters that must be resolved before natural flow can be calculated and before an apportionment arrangement can be executed. None of them are incapable of being resolved with good will among the parties. It should be noted however that water consumption in the Red River basin is relatively low compared to that in other apportioned basins in the interior plains. It may be preferable to explore whether an international drought contingency plan may be a productive task to pursue rather than considering an apportionment agreement. As an alternative, careful consideration of minimum flow criteria for the Red River could provide additional insights. Such criteria could well be the only element of an apportionment arrangement that is really required at this time.

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ENDNOTES

[1] International Joint Commission 2009. *The International Watersheds Initiative: Implementing a New Paradigm for Transboundary Basins*. Third Report to Governments on the International Watersheds Initiative. International Joint Commission, Washington and Ottawa.
[2] de Loë R.C. 2009. *Sharing the Water of the Red River Basin: A Review of Options for Transboundary Water Governance*. Prepared for the International Red River Board, International Joint Commission. Rob de Loë Consulting Services, Guelph, ON.
[3] Krenz, G and J. Leitch 1998. *A River Runs North – Managing an International River*. Red River Water Resources Council, 2nd Printing.
[4] Bluemle, J.P 2005. *The Origin and Behavior of Devils Lake*. North Dakota Geological Survey. Accessed on-line.
[5] Personal communication 2010. Richard Rickwood and Gord Bell, Agriculture Canada.
[6] International Joint Commission 1997. *Short Term Measures*. International Joint Commission, Ottawa, ON and Washington, DC
[7] Kottek, M., J. Grieser, C. Beck, B. Rudolf, and F. Rubel 2006. World Map of the Köppen-Geiger Climate Classification Updated. *Meteorologishe Zeitschrift*. 15:3 259-263
[8] Jensen, Ray E. No Date. *Climate of North Dakota*. National Weather Service, North Dakota State University, Fargo, North Dakota. 48pp.
[9] Reppe, T.H.C. 2005. Ground-water Availability from Surficial Aquifers in the Red River of the North Basin, Minnesota. Scientific Investigations Report 2005-5204, United States Geological Survey, Washington, DC.
[10] Seaber, P.R., F. Kapinos, G.L. Knapp 1987. *Hydrologic Unit Maps*. Water Supply Paper 2294. United States Geological Survey, Washington, DC.

[12] de Loë R.C. 2009. *Sharing the Water of the Red River Basin: A Review of Options for Transboundary Water Governance. supra*
[13] Halliday, R.A. and G. Faveri 2007. The St. Mary and Milk Rivers: The 1921 Order Revisited. *Canadian Water Resources Journal*, 32:1 75-92
[14] International Joint Commission 1978. *Water Apportionment in the Poplar River Basin*. An IJC Report to the Governments of Canada and the United States. International Joint Commission, Washington and Ottawa.
[15] de Loë R.C. 2009. *Sharing the Water of the Red River Basin: A Review of Options for Transboundary Water Governance. supra*

[16] de Loë R.C. 2009. *Sharing the Water of the Red River Basin: A Review of Options for Transboundary Water Governance. supra*

[17] International Joint Commission 1917. *Supplemental Argument in the Matter of the Measurement and Apportionment of the Waters of the St. Mary and Milk Rivers and their Tributaries in the United States and Canada under Article VI of the Treaty of January 11, 1909, between the United States and Great Britain, Detroit, Michigan.* International Joint Commission, Washington and Ottawa.

[18] Prairie Provinces Water Board 1976. *Determination of Natural Flow for Apportionment Purposes.* Report 48. Prairie Provinces Water Board. Regina, SK.

[19] Prairie Provinces Water Board 1976. *Determination of Natural Flow for Apportionment Purposes.* Report 48. *ibid*

[20] Cary, L.E. and C. Parrett 1995. *Synthesis of Natural Flows at Selected Sites in and Near the Milk River Basin, Montana, 1928-89.* Water Resources Investigations Report 95-4022. In Cooperation with the Bureau of Reclamation. U.S. Geological Survey, Helena, MT.

[21] Lucas, A.R. 1990. *Security of Title in Canadian Water Rights.* Canadian Institute of Resources Law, The University of Calgary, Calgary, AB.

[22] Dellapenna, J.W. (ed.) 2004. *The Regulated Riparian Model Water Code.* EWRI/ASCE 40-03. Water Law Committee, American Society of Civil Engineers, Washington, DC.

[23] Water Wiki, http://sogweb.sog.unc.edu/Water/index.php/Regulated_riparianism, accessed July, 2010.

[24] Lucas, A.R. 1990. *ibid*

[25] Wolfe, M.E. 1996. *A Landowner's Guide to Western Water Rights.* Roberts Rinehart Publishers, Boulder, CO.

[26] Schorr, D.B. 2005. Appropriation as Agrarianism: Distributive Justice in the Creation of Property Rights. *Ecological Law Quarterly.* 32:3 1-71.

[27] AMEC 2008. *Comparison of the Water Allocation Process in Alberta to Other Jurisdictions.* Report EE27048. Report for Alberta Environment, Edmonton, AB

[28] Wolfe, M.E. 1996. *A Landowner's Guide to Western Water Rights. supra*

[29] Red River Basin Board 2000. *Inventory Team Report: Water Law.* Red River Basin Board, Fargo , ND.

[30] Department of Environment and Natural Resources 2008. *Summary of South Dakota Water Laws and Rules.* Department of Environment and Natural Resources, South Dakota, Pierre, SD.

[31] Department of Environment and Natural Resources 2007. *Environmental Permitting and Regulation Guide.* Department of Environment and Natural Resources, South Dakota, Pierre, SD.

[32] Wolfe, M.E. 1996. *A Landowner's Guide to Western Water Rights. supra*

[33] HDR Engineering Inc. 2009. *Red River Basin Immediate Drought Response Process.* Report for the Red River Basin Commission. HDR Engineering Inc. Minneapolis, MN.

[34] Red River Basin Board 2000. *Inventory Team Report: Water Law. supra*

[35] HDR Engineering 2009. *Red River Basin Immediate Drought Response Process. supra*

[36] HDR Engineering Inc. 2009. *Red River Basin Immediate Drought Response Process. supra*

[37] Partners FOR the Saskatchewan River Basin 2009. *From the Mountains to the Sea: The State of the Saskatchewan River Basin.* Partners FOR the Saskatchewan River Basin, Saskatoon, SK.

[38] Berg, A.A and J.M. Byrne 1998. Water Table Development Due to Household and Park Irrigation in Lethbridge, Alberta. *Canadian Water Resources Journal* 23(1): 61-75.

[39] HDR Engineering Inc. 2009. *supra*
[40] Poff, N.L., J.D. Allan, M.B. Bain, J.R. Karr, K.L. Pretegaard, B.D. Richter, R.E. Sparks and J.C. Stromberg 1997. The Natural Flow Regime: a Paradigm for River Conservation and Restoration. *BioScience* 47:11 769-784
[41] Richter, B.D. and H.E. Richter 2000. Prescribing Flood Regimes to Sustain Riparian Ecosystems along Meandering Rivers. *Conservation Biology* 14:5 1467-1478.
[42] Clipperton, G.K., C.W. Koning, A.G.H. Locke, J.M. Mahoney, and B. Quazi 2003. *Instream Flow Needs Determinations for the South Saskatchewan River Basin, Alberta, Canada*. Report for Alberta Environment, Edmonton, Alberta.
[43] Bovee, K.D. 1982. *A Guide to Stream Habitat Analysis Using the Instream Flow Incremental Methodology.* Western Energy and Land Use Team, Office of Biological Services, Fish and Wildlife Service, U.S. Dept. of the Interior, Washington, D.C. Instream Flow Information Paper 12.
[44] Clipperton, G.K. *et al.* 2003. *Instream Flow Needs Determinations for the South Saskatchewan River Basin, Alberta, Canada. supra.*
[45] North Dakota Game and Fish Department. *North Dakota Angler's Guide*. Minnesota Department of Natural Resources and the North Dakota Game and Fish Department. Accessed on-line, March 10, 2010.
[46] Stoner, J.D., D.L Lorenz, R.M. Goldstein, M.E. Brigham, and T.K. Cowdery 1998. *Water Quality in the Red River of the North Basin, Minnesota, North Dakota, and South Dakotas, 1992-95.* U.S. Geological Survey Circular 1169. United States Geological Survey, St. Paul, MN.
[47] North Dakota Game and Fish Department. *North Dakota Angler's Guide. ibid*
[48] Stoner, J.D., D.L Lorenz, R.M. Goldstein, M.E. Brigham, and T.K. Cowdery 1998. *Water Quality in the Red River of the North Basin, Minnesota, North Dakota, and South Dakotas, 1992-95. supra.*
[49] International Red River Board 2008. *Ninth Annual Progress Report.* International Joint Commission, Ottawa and Washington.
[50] Stoner, J.D., D.L Lorenz, R.M. Goldstein, M.E. Brigham, and T.K. Cowdery 1998. *Water Quality in the Red River of the North Basin, Minnesota, North Dakota, and South Dakotas, 1992-95. supra.*
[51] 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.* Scientific Investigations Report 2005-5092. In Cooperation with the bureau of Reclamation. U.S. Geological Survey, Bismarck, ND.
[52] Hopkinson, R. 2003. *Status Report on Studies and Research to Address "Guidelines for Evaporation Estimates Required by the Prairie Provinces Water Board".* Report 162. Prairie Provinces Water Board, Regina, SK.
[53] Vining, K.C. 2003. *Estimation of monthly Evaporation from Lake Ashtabula in North Dakota, Orwell Lake in Minnesota, and Lake Traverse in Minnesota and South Dakota, 1931-2001.* Water-Resources Investigations Report 03-4282. In Cooperation with the Bureau of Reclamation. United States Geological Survey, Bismarck, ND.
[54] Soil Conservation Service 1979. *Hydrology Manual for North Dakota.* Soil Conservation Service, Department of Agriculture, Bismarck, ND.
[55] Martin, F.R.J. 2002. *Gross Evaporation for the 30-Year Period 1971-2000 in the Canadian Prairies.* Hydrology Report #143, Agriculture and Agri-Food Canada, Prairie Farm

Rehabilitation Administration, Regina, Saskatchewan.
[56] Burn, D.H. and N.M. Hesch 2006. A Comparison of Trends in Potential and Pan Evaporation for the Canadian Prairies. *Canadian Water Resources Journal,* 31:3 173-184
[57] Lundgren, R.F. and R.A. Nustad 2008. *Calibration of a Water-Quality Model for Low-Flow Conditions on the Red River of the North at Fargo, North Dakota and Moorhead, Minnesota, 2003*. Scientific Investigations Report 2008-5007. Prepared in cooperation with the North Dakota Department of Health, and the Minnesota Pollution control Agency, and the cities of Fargo, North Dakota and Moorhead, Minnesota. US Geological Survey, Reston, VA.
[58] Halliday, R.A. and G. Faveri 2007. The St. Mary and Milk Rivers: The 1921 Order Revisited. *supra*
[59] Partners FOR the Saskatchewan River Basin 2009. *From the Mountains to the Sea: The State of the Saskatchewan River Basin*. *supra*
[60] HDR Engineering 2009. *Red River Basin Immediate Drought Response Process. supra*

Appendix – Dams in the Red River

Water storage and water consumption from that storage plays an important role in calculating natural flow for apportionment. The number, size, operating plan, and net evaporation from storage of the many reservoirs in the Red River basin will have a bearing on the calculation of natural flow. An Exel spreadsheet of dams in the Red River basin upstream of the international boundary was created as a means of assisting analysis of water consumption in the basin. The spreadsheet contains a list drawn from the US Army Corps of Engineers National Inventory of Dams (NID), plus other information from Minnesota and Manitoba. The NID contains a wealth of information, but its primary focus is dam safety so hydrological content is not a major concern. The NID often uses '0' to indicate lack of information.

The remainder of this Appendix describes the column headings used in the spreadsheet and points out information gaps where they occur. The spreadsheet has been delivered to the IJC's International Red River Board. The board may wish to consider developing a process for reviewing the information and updating it where necessary. Maintaining an inventory of all structures in the basin may be of value to the board for a number of purposes. Such an inventory could include all Manitoba structures. If that is the case, the information contained in the spreadsheet could be further modified.

Spreadsheet Headings

County, State or Rural Municipality, Province. The spreadsheet is organized by state and county in the United States or province and rural municipality in Manitoba. In the interests of completion, structure in the Roseau River basin in Minnesota are included although they are not upstream of the Red River at Emerson.

NID ID. The identification number used in the National Inventory of Dams is given. This is simply a sequence number for each project in a state, starting at 0000. The number is based on when the project was submitted to the NID.

State ID. In some cases there is a state identification number. This has been included where it is known. In the case of state projects that have been identified, but that are not part of the NID, the particulars are shown in italics.

Project Name. This is the commonly used name for the project. Any alternative names are given in the Comments column.

Stream. This is the stream on which the project is located.

Hydrologic Unit. A column has been provided in which the USGS hydrologic unit in which the project is located can be listed. In the case of projects in the Pembina River basin in Canada, the Water Survey of Canada identifier is used. This would allow sorting the list by hydrologic unit so that analysis for specific watersheds could be performed. This assignment of hydrologic units is incomplete, but this information could be completed by the USGS.

Effective Area. This column has been provided so that a yes/no indication of whether the project is in the effective drainage area can be made. The effective drainage area, as identified for the entire basin by Agriculture Canada, is the area that would contribute to Red River flow in a median year, that is, one year in two. Project found in the effective area are particularly significant from a natural flow calculation perspective. This information is incomplete at present.

Natural Lake. This column has been provided so that a yes/no indication of whether the structure is used to stabalize a natural lake can be made. Net evaporation from a natural lake would not be included in natural flow calculations unless the structure has led to a significantly larger water surface area. This information is incomplete at present.

Coordinates. These columns provide the latitude and longitude of the project in decimal degrees to four decimal places. This provides a resolution of 100 feet (30 m) or better, more than sufficient to find a project with handheld geographic positioning devices. It is assumed, but not verified, that the horizontal datum is NAD83. This is the standard horizontal datum used in North America and for the purposes of this task is close enough to WGS84, the datum used by most GPS devices. Other co-ordinate systems exist, notably UTM coordinates, but geographic coordinates can be readily converted to these other coordinate systems.

Land Description. The land description column is provided as this is a familiar means of locating projects in both the United States and Canada. This column could be deleted as geographic coordinates are more useful.

Year. This is the year in which the project was constructed. The NID also includes information on the year when a project was significantly modified. This has not been included in the spreadsheet.

Owner. The organization owning the project is given. In the case of ownership by individuals, the word ‘private’ is used to protect privacy.

Purpose. The primary purpose of the project is given. This may provide insights into how the project may be operated.

Type. This is the type of structure. Most dams in the basin are earth fill.

Drainage Area. This column gives the gross drainage area upstream of the structure.

Height. This column gives the total height, as opposed to the hydraulic height of the structure. The NID provides both figures.

Surface Area. This is the surface area of water retained by the structure, presumably at full supply level. This information tends to be incomplete for Minnesota structures and is very useful for consideration of net evaporation from reservoirs.

Storage. Both the Maximum Storage – the total storage at full supply level – and the Normal Storage – the quantity of water usually stored by the project – are given. These quantities, which include both live storage and dead storage, are useful from a dam safety perspective. A more useful number for calculation of natural flow and administration of apportionment would be the live storage.

Maximum Discharge. This is the maximum quantity of water that can be released from a dam, either from the riparian outlet or by gates, as the case may be. It may be a useful number for some major projects used to provide river regulation or make up water, but is not that important for smaller projects.

Monitoring. These columns indicate the degree to which monitoring is in place for each project. That is, reservoir water level monitoring, and inflow or outflow monitoring. The information is largely incomplete, but could be provided by the USGS and other agencies.

Comments. This column includes any other information deemed relevant.