Interaction of Groundwater and Surface Water in the Williston and Powder River Structural Basins

by

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Abstract

Groundwater and surface water supplies in the Williston and Powder River structural basins are necessary for future development in these regions. To help determine if these water supplies will be sustainable during projected development, the interaction of surface water and groundwater was examined. This study will help quantify these interactions in both basins. The objectives of this thesis were to estimate base flow as groundwater discharge to streams, identify and quantify gaining and sinking reaches of streams, and quantify reservoir interaction in the Williston and Powder River structural basins.

The analysis used the base-flow software program, PART, along with 525 stream gauge records. The base-flow estimates were used to determine if stream reaches gained water from the underlying aquifer, or lost water thereby recharging the underlying aquifer. A water budget was completed for the three Missouri River mainstem reservoirs. The final estimate of gain from the underlying aquifers was 9230 ft^3/s, while the loss to underlying aquifers was 7790 ft^3/s. Both the Powder River and Williston basins contain gaining and sinking streams. The glacial aquifer system in the Williston basin primarily discharges into streams. The Upper Fort Union aquifer primarily discharges into overlying streams, whereas results pertaining to the rest of the bedrock hydrogeologic units were less conclusive as to whether they discharge into or receive recharge from streams. The values for the reservoir budget were inconclusive because they were within the range of error for the data.

The estimates provide a starting point for understanding these interactions. Additional field data are needed for calibration of modeling efforts. As energy production increases in the Williston and Powder River structural basins, the use and demand for groundwater and surface water will increase, along with emphasizing the importance of accurately quantifying these interactions.

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Introduction

As energy production increases in the Powder River and Williston structural basins, the use and demand for groundwater and surface water increases as well. Although the Powder River basin has long been a source of energy production, the increase in production in the Williston basin is relatively recent. The energy production is not only economically important to the people living in these basins, but to the United States as a whole. The production boom could be cut short if there is a shortage of water or a political impasse regarding these supplies. This raises questions about how sustainable the groundwater and surface water supplies are. To answer these questions, an assessment of the interactions of these sources was completed.

The interaction of surface water and groundwater in these regions is not well understood. Several studies have been performed on the Powder River structural basin, but only limited studies have been performed on the Williston structural basin. In this work, the Williston structural basin will be referred to as the Williston basin, while the Powder River structural basin will be referred to as the Powder River basin. This study will help quantify the groundwater and surface water interactions in both basins.

Objectives

The objectives of this study are to estimate base flow as groundwater discharge to streams, identify and quantify gaining and sinking reaches of streams, and quantify the three mainstem Missouri River reservoirs interactions in the Williston and Powder River structural basins. The analysis will use a base-flow software program, along with streamflow records. The base-flow estimates will be used to determine if a stream reach

is gaining water from the underlying aquifer or is sinking and recharging the underlying aquifer. The gaining and sinking estimates were summed, and net gains and losses were computed as part of a water balance for both basins. The quantification of reservoir interaction was dependent on evidence of groundwater discharge to the reservoir or recharge from the reservoir to the underlying aquifers. The water balance was estimated for the Upper Cretaceous, Lower Tertiary, and glacial aquifer systems in the study area. Several limitations and assumptions in calculating base flow were addressed in this thesis. The project was completed with the South Dakota School of Mines and Technology and the U.S. Geological Survey.

Previous Work

Base-flow estimates have been completed at gauges on several streams across the United States. Wolock (2003) calculated average annual base-flow, average annual streamflow, and annual base-flow index for more than 19,000 stream gauges in the continental United States. Several streams in the Powder River and Williston basins were included in this study.

Base-flow estimates were generated for a majority of streams in the Powder River basin, as part of a groundwater systems analysis and water quality study completed in the 1980's (Rankl and Lowry, 1990; Druse and others, 1981). Base-flow estimates were generated using carbon-13 isotope data for Otter Creek in the Powder River basin (Meredith and Kuzara, 2012). Several streams in the northern part of the Powder River basin were studied for low flows in streamflow records prior to 1980 (Armentrout and Wilson, 1987). Shallow aquifers, including deposits of alluvial and clinker, were studied for base flow, seepage, infiltration, and recharge potential (Lenfest, 1987; Cannon, 1985;

Lowry and Rankl, 1987). A groundwater model of the Upper Cretaceous and Lower Tertiary units in the Powder River basin was created in the 1980s in a study performed by Hotchkiss and Levings (1986). A result of that study was contour maps of the groundwater potentiometric surface. These maps of the potentiometric surfaces were very helpful in correlating areas of gaining streamflow and sinking streamflow.

Stream statistics have been described in the northeastern part of the Williston basin for North Dakota, Minnesota, Manitoba, and Saskatchewan (Williams-Sether, 2012).

Study Area

The study area encompasses the Lower Tertiary and Upper Cretaceous aquifer systems, as defined by Thamke and others (2013), within the Williston and Powder River structural basins, as shown on Figure 1. The Powder River basin is herein defined as the extent of the boundary of the Lower Tertiary and Upper Cretaceous aquifers systems and is located in parts of Montana and Wyoming. The Williston basin is herein defined as the extent of the boundary of the Lower Tertiary and Upper Cretaceous aquifers systems and is located in parts of Montana, North Dakota, and South Dakota in the United States, and Manitoba and Saskatchewan in Canada. The study includes the extents of the Upper Cretaceous and lower Tertiary units, as defined in the hydrology section, along with glaciated portions that extend outside of these boundaries.

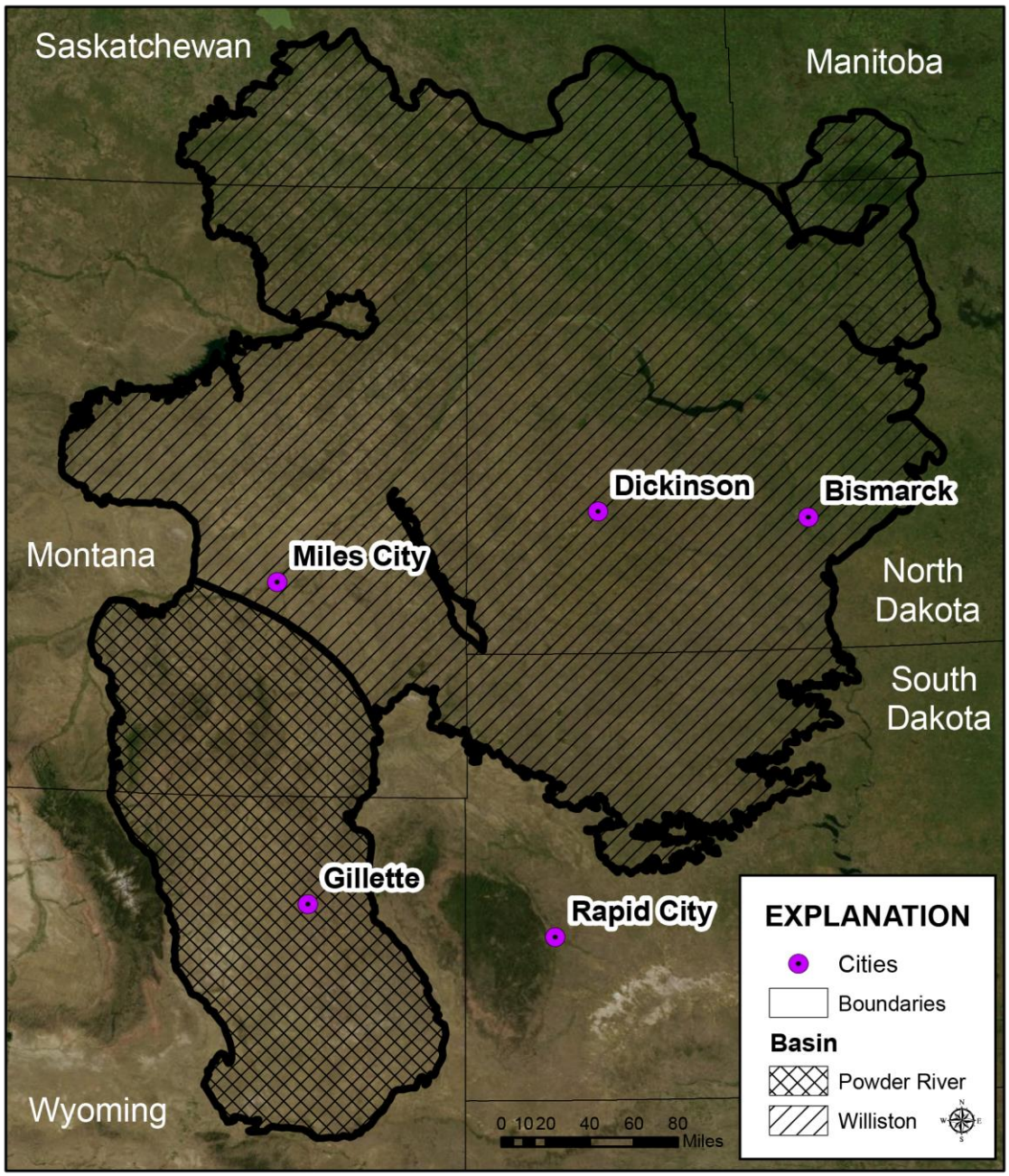

Figure 1. Study area.

Geographic and Physiographic Provinces

The study area lies in a part of North America that is known as the Great Plains, with a majority of the area on the Missouri Plateau (Trimble, 1980). The Missouri Plateau contains two regions, a glaciated part and an unglaciated part. The northeastern part of

the Williston basin is located on the Central Lowlands, an area consisting primarily of rolling, glaciated landscape (Bluemle and Biek, 2007). The main features associated with the Central Lowlands are the Turtle Mountain region and the Prairie Pothole region (Figure 2). The region known as the Turtle Mountains is dominated with hummocky hills, generally less than 200 feet high (Keefer, 1974). The northeastern part of the Williston basin is covered by thousands of kettle lakes, known as the Prairie Pothole region. The Prairie Pothole region is located primarily in the Saskatchewan and North Dakota, with a minor amount located in Manitoba. This region contains glacial features and has very little surface stream drainage in comparison to the rest of the basin. The glaciated and unglaciated portion of the Missouri Plateau is separated by the Missouri Escarpment (Figure 2). The Missouri Escarpment is a very steep and rugged region with glaciation (Bluemle and Biek, 2007). To the west of the Missouri Escarpment is a region known as the Missouri Coteau (Figure 2), which stretches from Saskatchewan, through North Dakota, and into South Dakota. This is an area underlain by glacial till that has no integrated drainage in the region because of the large amount of clay in the till. The Missouri River, in North Dakota and South Dakota, parallels the Missouri Coteau to the west. West of the Missouri Coteau and east of the Missouri River is a region known as the Coteau Slope, consisting of rolling to hill plains (Bluemle and Biek, 2007). The Peerless Plateau is an area in the northwestern part of the Williston basin where bedrock is exposed and surrounded by glacial deposits (Figure 2). The Peerless Plateau extends from Saskatchewan into Montana. In the unglaciated part of the Missouri Plateau covers the rest of the Williston basin and Powder River basin. The southern part of the Williston basin, primarily in South Dakota, contains a region known as the Cretaceous table lands

(Figure 2). The table lands are a region dominated by flat topped buttes, primarily of sandstone composition (Rothrock, 1943). In western North Dakota, a region known as the Little Missouri Badlands contains rugged, deeply eroded topography (Bluemle and Biek, 2007). A region absent of the Lower Tertiary and Upper Cretaceous lithologic units of interest is the Cedar Creek anticline (Figure 2), located in southeastern Montana and the very southwest corner of North Dakota. The majority of the unglaciated Missouri Plateau in the Williston basin, in southeastern Montana and southwestern North Dakota, and the Powder River basin consists of a topography that is dominated with clinker deposits in regions where stream incision and valley floors are surrounded by terrace remnants of older deposits (Trimble, 1980). The Powder River basin is dominated by structural highs, and although separated structurally by the Miles City arch (Figure 2), topographically cannot be differentiated from the adjacent part of the Williston basin (Keefer, 1974).

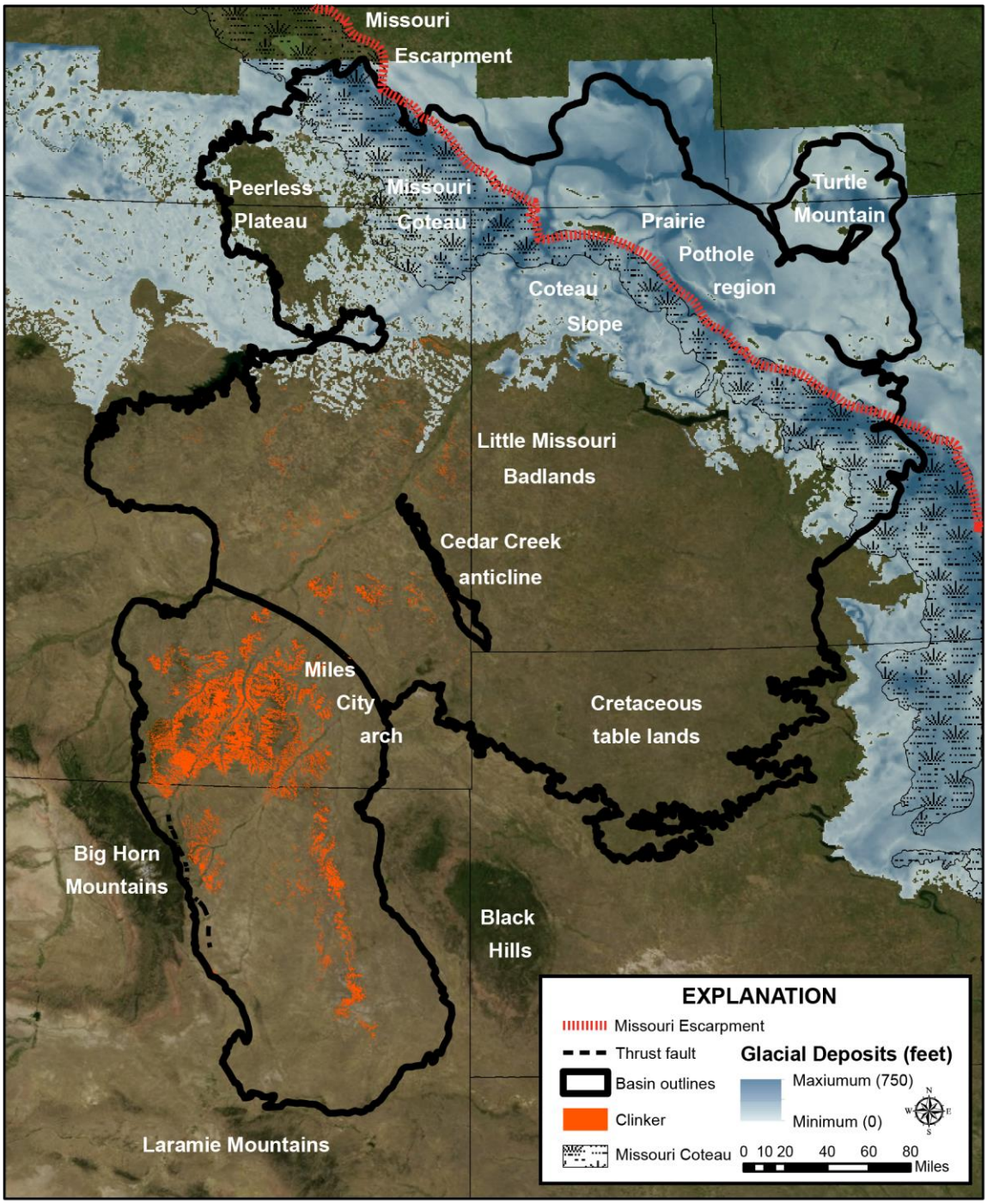

Figure 2. Important physiographic provinces, structural features, glacial deposit thickness, and clinker deposit extents.

Geologic Setting

Powder River Structural Basin

The Powder River basin (Figure 2) is an intermontane basin that is bounded by the Black Hills uplift, Hartville uplift, Laramie Mountains, Casper arch, Bighorn Mountains, Miles City arch, and the Ashland syncline (Beikman, 1962). The basin was formed as a result of crustal deformation from the Laramide orogeny, and formed during Upper Cretaceous and Lower Tertiary time (Beikman, 1962). The basin consists of more than 18,000 feet of Paleozoic, Cenozoic, and Mesozoic sediments (Dolton and others, 1990). The basin is approximately 100 miles wide by 230 miles long with an asymmetrical syncline axis and a trough that is parallel to the Bighorn Mountains (Beikman, 1962).

The basin contains the following units: Pierre Shale, Lewis Shale, Bearpaw Shale, Fox Hills Formation, Lance Formation, and the Hell Creek Formation from the Upper Cretaceous epoch. The Lower Tertiary units include the Fort Union (Figure 3) and Wasatch formations, as defined by Thamke and others (2013).

Figure 3. Photo of clinker-capped Tongue River Member of the Fort Union Formation south of Colstrip, Montana.

Williston Structural Basin

The Williston basin is bounded by the Black Hills uplift, Miles City arch, Bowdoin dome, Porcupine dome, Bow Island arch, Canadian Shield, and the Transcontinental arch; these features are resultant or rejuvenated from the Laramide Orogeny (Anna and others, 2011). The basin contains more than 16,000 feet of sedimentary rocks of Cambrian through Holocene time periods and is considered to be tectonically inactive (Peterson, 1988; Anna and others, 2011). The basin is thought to be a result of structural deformation and block faulting from Precambrian rooted structures, and deformation related to the Trans-Hudson orogenic belt (Anna and others, 2011). The Cedar Creek anticline is a large structural feature located in the southwestern part of the basin (Figure 2).

The basin contains the following units from the Upper Cretaceous period: Pierre Shale[1], Bearpaw Shale, Bearpaw Formation, Fox Hills Formation, Eastend Formation, Boissevain Formation, and Hell Creek Formation (Figure 4). The Lower Tertiary units include the Fort Union Formation, Ravenscrag Formation, Turtle Mountain Formation, Bullion Creek Formation, Golden Valley Formation, and overlying glacial deposits, as defined by Thamke and others (2013).

Figure 4. Photo of the Hell Creek Formation near Buffalo, South Dakota.

General Lithologies and Depositional Environments

In the Powder River basin, the Pierre and Lewis Shales are present in Wyoming and are equivalent to the Bearpaw Shale found in Montana. In the Williston basin, the Bearpaw Formation in Saskatchewan, the Pierre Formation in Manitoba, the Bearpaw Shale in Montana, and the Pierre Shale in North and South Dakota are equivalent (Thamke and others, 2013). These units are Upper Cretaceous and are considered part of

[1] The Pierre Shale is also called the Pierre Formation in parts of the Williston basin.

the Montana Group. The shales are generally medium to dark gray in color, with lithologies primarily of claystone and shale, with interbedded siltstone and sandy siltstone (Hotchkiss and Levings, 1986). These units were formed during the last transgression of the Cretaceous period and are marine units (Anna, 1986). They vary in thickness but can be up to 1,300 feet thick parts of the Powder River basin, and up to 3,000 feet thick in the Williston basin (Hotchkiss and Levings, 1986; Whitehead, 1996).

The Fox Hills Formation, of the Upper Cretaceous epoch, is found in both Montana and Wyoming in the Powder River basin and is the uppermost formation in the Montana Group. In the Williston basin, the Fox Hills Formation also is found in Montana, North Dakota, and South Dakota. It is equivalent to the Eastend Formation in Saskatchewan and, the Boissevain Formation and the Coulter Member of the Pierre Formation in Manitoba (Thamke and others, 2013). The Fox Hills and equivalents represent the final regression of the Late Cretaceous seaway, and consist of deltaic, interdeltaic, and shoreline deposits (Anna, 1986). The lithology is primarily fine to medium grained sandstone and siltstone, and shale; thicknesses range up to 700 feet in the Powder River basin but on average are around 300 feet (Hotchkiss and Levings, 1986; Anna, 1986).

The Hell Creek Formation of Montana and equivalent Lance Formation of Wyoming in the Powder River basin are from the Upper Cretaceous epoch. The Hell Creek Formation in Montana, South Dakota, and North Dakota, the Frenchman Formation in Saskatchewan, and the Boissevain Formation in Manitoba are equivalent in the Williston basin (Thamke and others, 2013). The Hell Creek Formation and its counterparts are primarily fluvial, nonmarine deposits (Anna, 1986). The primarily

lithologies include sandstone, siltstone, carbonaceous and bentonitic sandy shale, and claystone, along with lenticular coal beds, with thicknesses ranging from 350 to 2,000 feet (Anna, 1986; Hotchkiss and Levings, 1986).

The Paleocene Fort Union Formation[2] consists of the Tullock Member, the Lebo Shale Member, and the Tongue River Member, and is present in both Montana and Wyoming in the Powder River basin. The equivalents in the Williston basin consist of the members of the Fort Union Formation throughout Montana, North Dakota, and South Dakota, the Bullion Creek Formation in North Dakota, the Ravenscrag Formation in Saskatchewan, and Turtle Mountain Formation in Manitoba. The Fort Union consists of the following members: Ludlow, Tullock, Lebo, and Tongue River in Montana; Cannonball, Ludlow, and Lebo Shale in North Dakota and South Dakota; and the Tongue River Member in North Dakota (Thamke and others, 2013). The Fort Union Formation was deposited primarily in alluvial, lacustrine, and fluvial environments, with the exception of the Cannonball Member and the Ludlow Member in in North Dakota, which were marine and marginal marine, respectively (Anna, 1986). The lithologies are primarily sandstone, siltstone, and claystone with thicknesses of up to several thousands of feet. The Fort Union is primarily known for its coal deposits, ranging from lignite to subbituminous in grade (Anna, 1986; Hotchkiss and Levings, 1986).

The Eocene Wasatch Formation is found primarily in Wyoming, with a limited extent in Montana. The Wasatch Formation is a continental deposit, consisting primarily of sandstone with shale and coal interbedded, and thicknesses up to 1,000 feet (Anna, 1986; Hotchkiss and Levings, 1986). The Golden Valley Formation is present solely in North Dakota and consists of up to 150 feet of claystone, mudstone, micaceous

[2] The Fort Union Formation is commonly known as the Fort Union Group in parts of the study area.

sandstone, and lignite (Anna, 1986). The Sentinel Butte Member of the Fort Union is present in North Dakota and Montana. The unit was deposited in fluvial and deltaic environments, up to 26 feet in thickness with lithology primarily consisting of sandstone and mudstone with interbedded zones of coal (Flores and others, 1999).

Clinker deposits occur throughout both basins, although are primarily found in the Powder River basin. Clinker is metamorphosed rocks resultant from burned coal deposits (Figure 5). The exposed coal beds can ignite and burn, leaving ash deposits in an empty cavern. The convection from the heat of the burning coal bed “bakes” the overlying rocks until they are hardened and brittle. The overburden tends to collapse into the

Figure 5. Photo of clinker-capped Fort Union Formation with a coal zone located west of Ashland, Montana.

empty caverns where the coal beds once resided (Heffern and Coates, 1999). Clinker is typically harder than the parent rock (Heffern and others, 2013). Heffern and Coates (2004) found that these deposits can be a few hundred feet in thickness in the Powder

River basin. Clinker deposits in North Dakota are improperly known as “scoria” deposits. Sigsby (1966) found that these deposits are typically thin in North Dakota, but can be greater than 45 feet thick. Clinker deposits in the Williston basin are very sparse in comparison to the deposits in the Powder River basin. Clinker deposits in the Powder River basin cover an area of 1,472 mi^2 with 1094 mi^2 in Montana and 378 mi^2 in Wyoming (Heffern and others, 2013). Clinker deposits have been found to be reworked in alluvium (Heffern and Coates, 1999).

Pleistocene glacial deposits, consisting of till and outwash, are present primarily north of the Missouri River. The glaciated region of the Williston basin was last affected by Late Wisconsin glaciation approximately 12,000 years ago (Fullerton and others, 2004). These deposits range up to 750 feet thick in parts of the basin (Thamke and others, 2013). Some of the thickest deposits are within the boundary of the Missouri Coteau (Figure 2). The deposits thin west of the Missouri Coteau and are almost nonexistent south of the Missouri River. Northeast of the Missouri Coteau deposits vary with thickness. The thickest deposits are along the eastern boundary of the Missouri Coteau, the center of Turtle Mountain, and the northern most part of the Prairie Pothole Region. Dominant remnants resultant from glaciation includes moraines, buried channels, and erratics (Fullerton and others, 2004).

Hydrology

Surface Water Systems

The majority of the surface drainage in the study area is toward the Missouri River and terminally to the Gulf of Mexico. Streamflow in the Williston basin is primarily perennial, with most terminal drainage to the Missouri River (Figure 1). Most streams northeast of the Missouri River drain to the Red River and into the Hudson Bay. The Missouri River is the longest river in the study area and in the United States (U.S. Army Corps of Engineers, 2006). The Missouri River enters the study area on the western side of the Williston basin in Montana, and then flows eastward into North Dakota and southerly into South Dakota, where it flows out of the study area. The Missouri River flows through three mainstem reservoirs, which are discussed in the reservoir section in more depth.

The streamflow in the Powder River basin is east to northeast, flowing primarily toward the Yellowstone River with a terminal drainage into the Missouri River. Streams in the Powder River basin are a mix of ephemeral and perennial with most small headwater tributaries primarily ephemeral in nature.

The study area contains three major dams and reservoirs: Fort Peck Dam on Fort Peck Lake, Garrison Dam on Lake Sakakawea, and Oahe Dam on Lake Oahe. These three mainstem reservoirs are some of the longest and largest dams and reservoirs, not only in the United States, but in the world. Understanding these reservoirs is very important to understanding the entire interaction of surface water and groundwater in the study area. Although the reservoirs are located along the Missouri River, the vastness of the reservoirs could allow them to develop a “lake type” environment with respect to the

underlying aquifers. Each of the reservoirs contains a large delta in the headwaters (U.S. Army Corps of Engineers, 2012).

Fort Peck Lake (Figure 6) is in northwestern Montana near Glasgow and resides on part of the western boundary of the Williston basin. Fort Peck Lake is the largest hydraulic fill reservoir in the world (U.S. Army Corps of Engineers, 2012). The reservoir is underlain by glacial deposits and Bearpaw Shale, with a length of 134 miles, gross volume of 18,688,000 acre-feet, and surface area of 240,000 acres[3] (U.S. Army Corps of Engineers, 2006).

Lake Sakakawea (Figure 6) is in western North Dakota near Garrison and is centrally located in the Williston basin. The reservoir is underlain by Fort Union clay and shale and by glacial till deposits, with a length of 178 miles, gross volume of 23,821,000 acre-feet, and surface area of 364,000 acres. (Michael Swenson, written commun., 2013; U.S. Army Corps of Engineers, 2006).

Lake Oahe (Figure 6) is in south-central North Dakota and north-central South Dakota near Pierre, South Dakota. The reservoir is underlain by Pierre Shale, with a length of 231 miles, gross volume of 23,137,000 acre-feet, and surface area of 360,000 acres (U.S. Army Corps of Engineers, 2006).

[3] The gross volume and surface areas of the mainstem reservoirs are calculated when the reservoir is at pool level (U.S. Army Corps of Engineers, 2006).

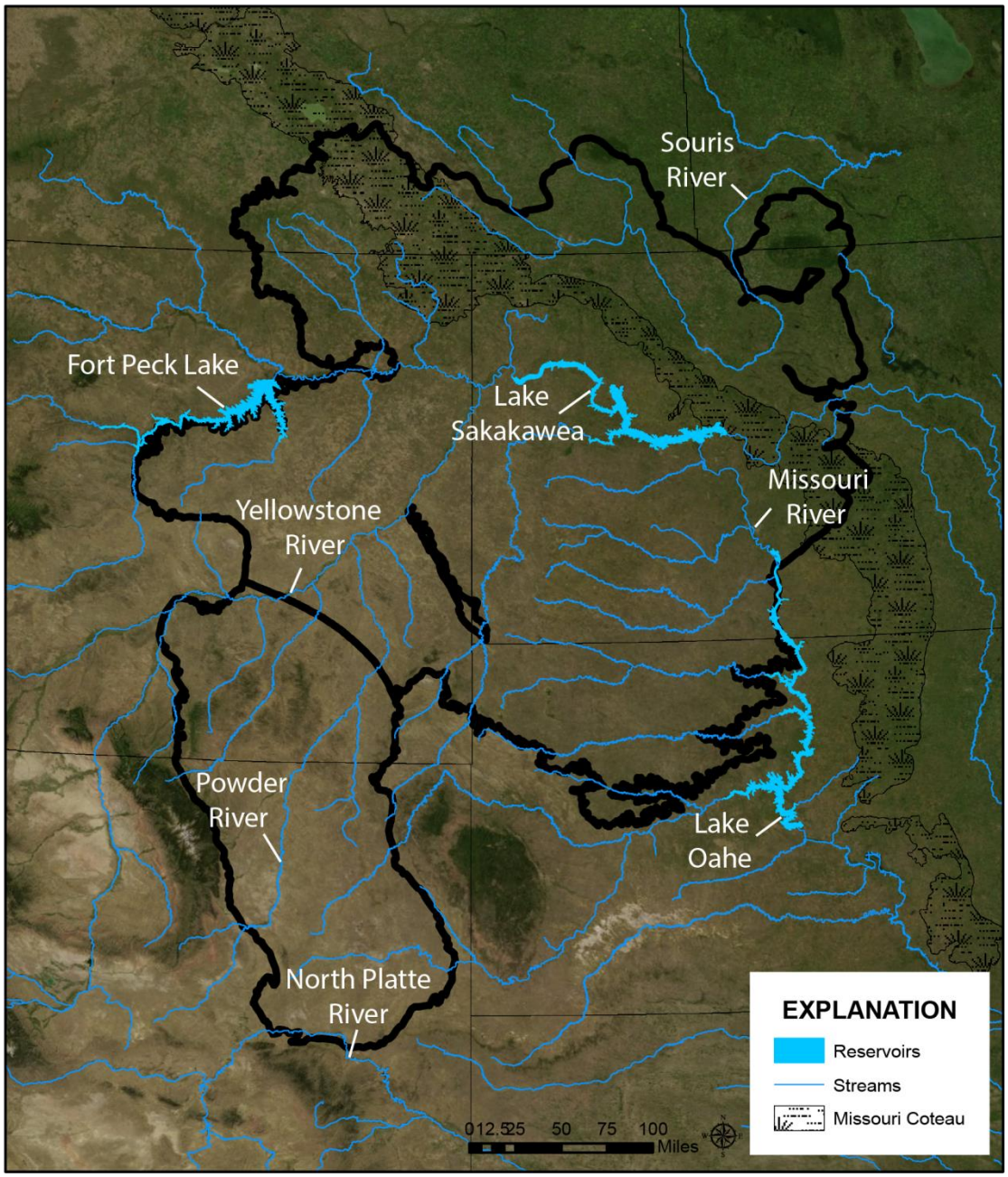

Figure 6. Major surface water features of the study area.

Groundwater Systems

The study area contains six hydrogeologic units (Figure 7), as defined by Thamke and others (2013, in review). The Lower Tertiary unit consists of the Upper Fort Union (UFU) aquifer, Middle Fort Union (MFU) hydrogeologic unit, and Lower Fort Union (LFU) aquifer. The Upper Cretaceous units consist of the Upper Hell Creek (UHC)

hydrogeologic unit, Lower Hell Creek (LHC) aquifer, Fox Hills (FH) aquifer, and the basal confining unit. These units are consistent across the study area, but each basin has varying correlative and grouped lithostratigraphic units. The basal confining unit is not considered to exchange flow with the principal aquifer systems. The term aquifer implies that the unit is more transmissive and has greater hydraulic properties than the units above or below. The term hydrogeologic unit can be considered an aquifer in some units, while a confining layer in others.

The Upper Fort Union aquifer, in the Powder River basin, consists of the Wasatch Formation and Tongue River Member of the Fort Union Formation, while in the Williston basin the Ravenscrag Formation, the Golden Valley Formation, the Sentinel Butte and Tongue River members of the Fort Union Formation, and the Bullion Creek Formation are included. The Middle Fort Union hydrogeologic unit, in the Powder River basin, consists of the Lebo Shale Member of the Tongue River Formation, while in the Williston basin the Ravenscrag Formation, Slope Formation, and the Lebo Shale Member of the Fort Union Formation are included. The Lower Fort Union aquifer in the Powder River basin contains the Tullock Member of the Tongue River Formation, while in the Williston basin the Ravenscrag Formation, Turtle Mountain Formation, and the Cannonball, Ludlow and Tullock members of the Fort Union Formation are included.

The Upper Hell Creek hydrogeologic unit in the Powder River basin consists of the upper part of the Hell Creek Formation the upper part of the Lance Formation, while in the Williston basin the Boissevain Formation, Frenchman Formation, and the upper part of the Hell Creek Formation are included. The Lower Hell Creek aquifer, in the Powder River basin, consists of the lower part of the Hell Creek Formation and the lower

part of the Lance Formation, while in the Williston basin the Boissevain Formation, Frenchman Formation, and the lower part of the Hell Creek Formation are included. The Fox Hills aquifer in the Powder River basin consists of the Fox Hills Formation, while in the Williston basin the Boissevain Formation, the Coulter Member of the Pierre Formation, the Eastend Formation, and the Fox Hills Formation are included. The basal confining unit in the Powder River basin consists of the Bearpaw Shale, Pierre Shale, and Lewis Shale, while in the Williston basin the Pierre Shale and Bearpaw Shale are the confining units.

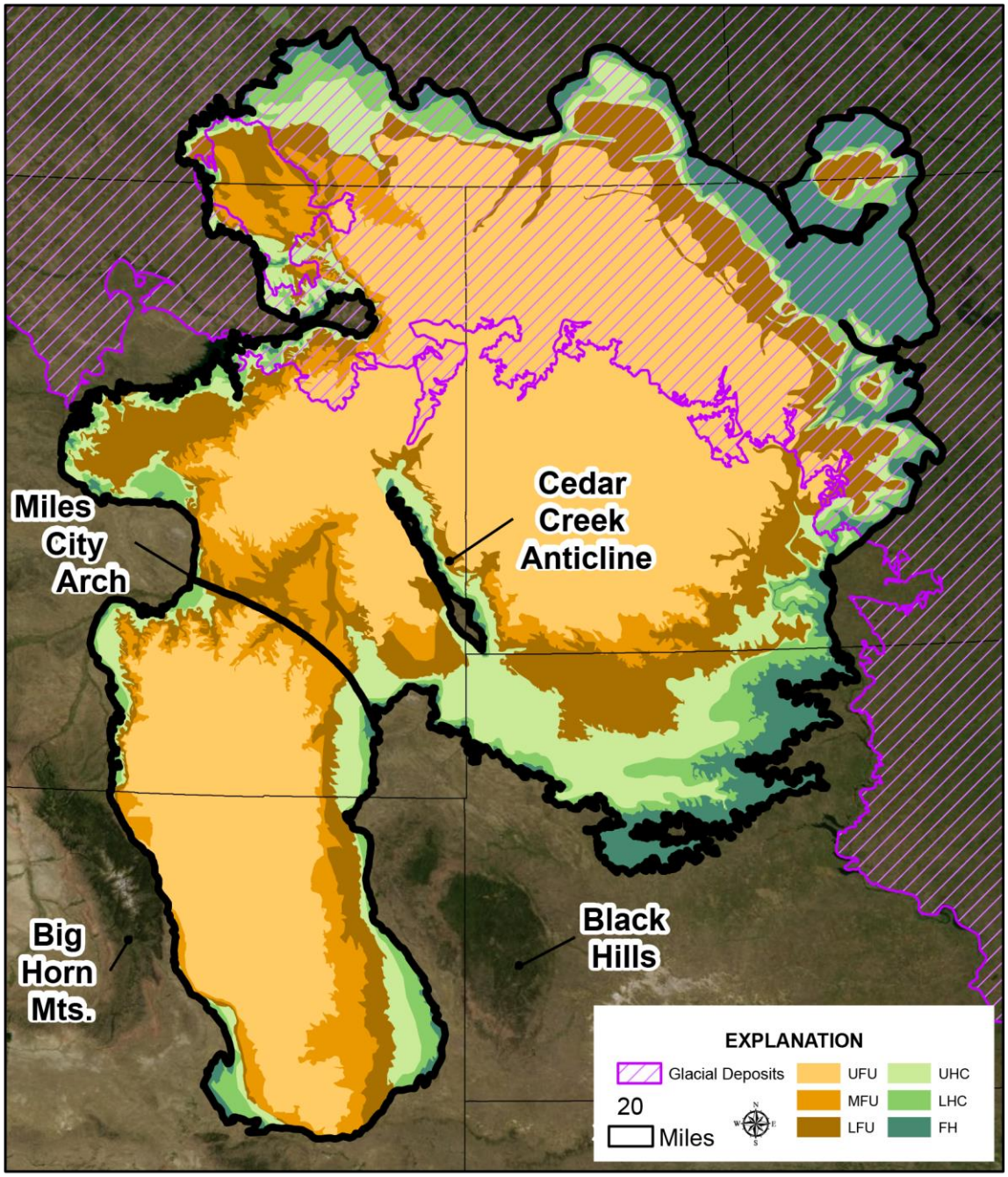

Figure 7. Hydrogeologic units as defined by Thamke and others (2013) along with important structural features [UFU, Upper Fort Union aquifer; MFU, Middle Fort Union hydrogeologic unit; LFU, Lower Fort Union aquifer; UHC, Upper Hell Creek hydrogeologic unit; LHC, Lower Hell Creek hydrogeologic unit; FH, Fox Hills aquifer].

Method of Study

Base-Flow Estimates from PART

Most base-flow estimates use graphical hydrograph separation techniques, although techniques such as base-flow index, isotope tracers, and chemical hydrograph separation can be used as well (Neff and others, 2005; Meredith and Kuzara, 2012; Sanford and others, 2012). In this work, base-flow estimates were generated by using the hydrograph separation program, PART, developed by the U.S. Geological Survey (USGS) (Rutledge, 1998). PART analyzes streamflow record files downloaded from the USGS National Water Information System (NWIS; URL: http://waterdata.usgs.gov/nwis) and the Environment Canada Water HYDAT database (URL: http://www.wsc.ec.gc.ca/applications/H2O/index-eng.cfm). The amount of time it takes for water to drain from the headwaters to the gauge site is called antecedent recession. The program generates three conditions of antecedent recession based on the days preceding the time when the condition was met. The number of days for antecedent recession is assumed to be proportional to the drainage area and is calculated by PART from the following equation:

$$N=A^{0.2} \qquad (1)$$

where N= number of days and A= drainage area (square miles) of the basin upstream of the gauge site (Rutledge, 1998). One condition is that a basin has to be larger than one square mile for the minimum conditions of antecedent recession to be met. This means that the minimum N value is one day. The maximum condition of antecedent recession that was suggested in the PART manual is a drainage area of 500 square miles (Rutledge, 1998), which results in an N value of 3.5 days. Based on the unit hydrograph theory,

results from drainage areas of up to 2000 square miles can be used confidently (Linsley and others, 1982; Chow, 1988), which results in an N value of 4.6 days. PART generates three output files, where output number one uses N rounded down to the nearest integer as the antecedent recession condition, and output files number two and three use the next highest integers, respectively. The third output for the antecedent recession condition was chosen for this study. An example of recession conditions for a drainage basin of 500 square miles is shown in Table 1.

Table 1. Time for antecedent conditions to have been met for the three output files from PART.

Antecedent Recession	#1	#2	#3
3.5 days	3 days	4 days	5 days

Although this study used antecedent recession condition number three, the variation between all output files is minimal. The third condition was chosen to ensure that all runoff from the precipitation event had a long enough period of time to get to the gauge and flow downstream and out of the system. The first output files from PART of antecedent recession conditions have larger base flow values than the second and third. This estimates the largest amount of base flow among the three. The second and third choices are very similar and contain fewer hydrograph peaks than the first output file. PART considers streamflow and baseflow to be equal unless when plotted on a logarithmic scale the streamflow declines of more than 0.1 log cycle (Rutledge, 1998). The software runs a linear interpolation where the streamflow is not equal to base flow (Rutledge, 1998). Figure 8 shows an example of streamflow hydrograph (red) and base flow (green) hydrograph.

The full-year periods of record were used as input in the PART software, and the output files were full-year records. Output files consisted of daily values, monthly averages, and water-year averages.

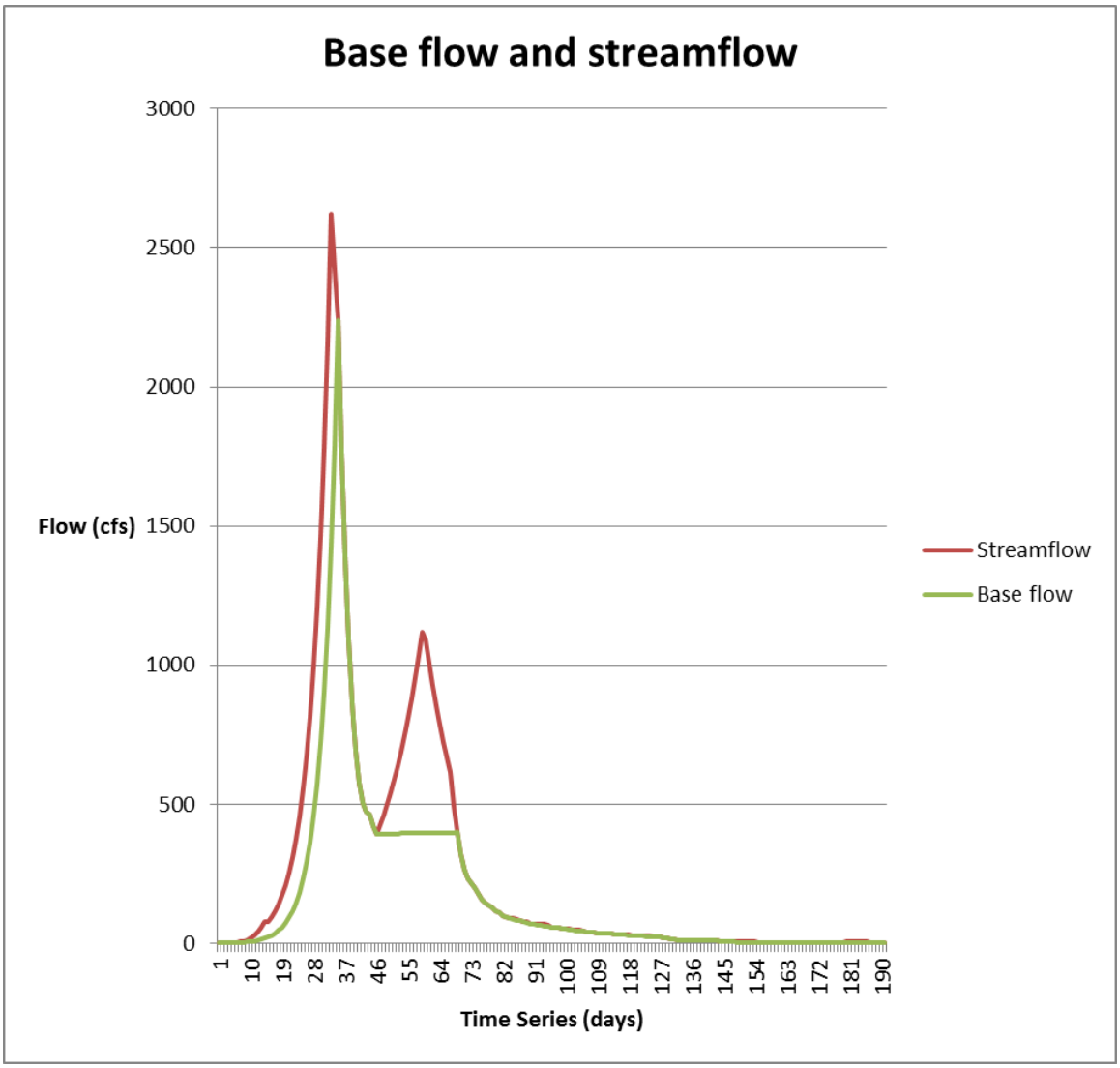

Figure 8. Hydrograph of streamflow and estimated base-flow from PART.

The water year averages are for the period of October 1 to September 30. Averages for the fall period (September and October) were used for the final analysis for the period of record 1903-2011.

Gauge Selection Criteria and Assumptions

The stream gauge locations that were chosen for the study were based on a set of criteria to ensure consistency and the most accurate interpretation of the data. Some assumptions could lessen the accuracy of the results, but on the scale at which the study was performed, this lower accuracy was acceptable.

The following items were considered as criteria in selecting a gauge: consecutive period of record, overall length of that period of record and location. The PART program cannot operate with daily values missing; therefore it has to have a minimum of one year of consecutive daily streamflow record to operate. To be used in this study streamflow records had to contain a minimum of three consecutive years, to eliminate any unusual hydrologic seasons and to create a better average in the analysis. The longer a stream gauge record, the better averaged the results will be for streamflow. The last criterion was the location of the stream gauge. The study area includes the entire area outlined by the Lower Tertiary and Upper Cretaceous boundaries in Figure 1. Streams that flow outside of the extent of the Lower Tertiary and Upper Cretaceous boundary are also included in the study area. The extent of the study area is dependent on the location of the closest upstream or downstream stream gauge on each river. Additional stream reaches and stream gauges were included in the northern and eastern parts of the Williston basin. These additional stream gauges were included because of the extent of the underlying glacial deposits, as shown in Figure 2.

The assumptions were all presumed to have enhanced accuracy because the September and October time frame. Although the program output is a full year of daily records, only the low-flow months of September and October were used for analysis.

This time frame was chosen to eliminate several physical factors that could provide interference in the base-flow results, because low flows are generally derived from groundwater discharge (Smakhtin, 2001). The interference from the following were minimized by using the fall period: dams and regulations, diversion for irrigation, flowback from irrigation, evapotranspiration, precipitation, ice damming, ground freeze and snow cover, minimal bank storage, and backwater effects from the reservoirs and flooding.

The effects from dams and regulations on the streams, with the exception of the three mainstem reservoirs on the Missouri River, were thought to be minimized by using the fall period. Minimal releases from the reservoirs should occur during this time period versus other high flow times of the year.

Crops that are irrigated in the study area are generally harvested by early September. This means that diversions and return flow from irrigation are negligible. This also means that evapotranspiration rates should be trending downward and should be nearly negligible.

Minimal precipitation occurs during the fall period which allows for larger drainage areas to be used with more confidence. PART operates best when the drainage area is less than 500 square miles, although as previously discussed it can be used confidently up to 2000 square miles. Drainage areas larger than 2000 square miles can be used with lower accuracy (Neff and others, 2005). This study used every stream gauge that met the other criteria, regardless of drainage area. Base-flow estimates from stream gauges with drainage areas larger than 20,000 square miles were substituted, when there

was uncertainty, with the difference between upstream and downstream streamflow averages and not through PART estimates.

Ice damming, ground freeze and snow cover are, for the most part, eliminated by using a fall time frame. Although streamflow records are corrected for ice damming, these are only estimated flow rates, and may not be as accurate. Ground freezing might immobilize pore water that is then not able to drain. Snow cover, while in the solid state, is not able to recharge the groundwater system or the stream.

Antecedent recession output number three from the PART output files was chosen to minimize any contribution from bank storage. The distance that the in-flow penetrates into the bank is usually rather limited, and the recession of bank outflow is steep because the strip length involved is very small as compared with that of base flow (Singh, 1968). The peak of base flow is also minimized by the choice of antecedent recession number three. Singh (1968) reported that bank storage is largely depleted by the time that the base flow occurs. The base flow peaks below the hydrograph peak after a runoff event. With PART interpolation of base flow, this cuts off the peak part of the hydrograph that is related to these events. Therefore, the bank storage or interflow is theoretically eliminated.

Backwater effects are negligible during non-winter and non-flooding time frames. Therefore, choosing a time frame free of flooding contributes to a steadier hydrograph. During times of flooding, higher rates of streamflow are observed, in large part because of reservoir releases and overland runoff.

Data

Stream gauge records for the United States were retrieved from the USGS National Water Information Systems (NWIS) online database (U.S. Geological Survey, 2013). Canadian gauges were retrieved from the Environment Canada HYDAT online database. These records were formatted to fit the NWIS file structure and converted from metric to English units (Water Survey of Canada, 2013). 525 stream gauges were located in the study area, but only 143 were used in analysis (Figure 9).

Stream gauge data were simulated along the Missouri River by the U.S. Army Corps of Engineers (Corps). This information consisted of inflow and outflow data on Fort Peck Lake, Lake Sakakawea, and Lake Oahe. The averages of the inflow or outflow were used to simulate stream gauges at those inflow or outflow locations. The data also were used in a reservoir budget. The simulated data from the Corps data consisted of model simulation outputs of inflow, outflow, evaporation, and storage.

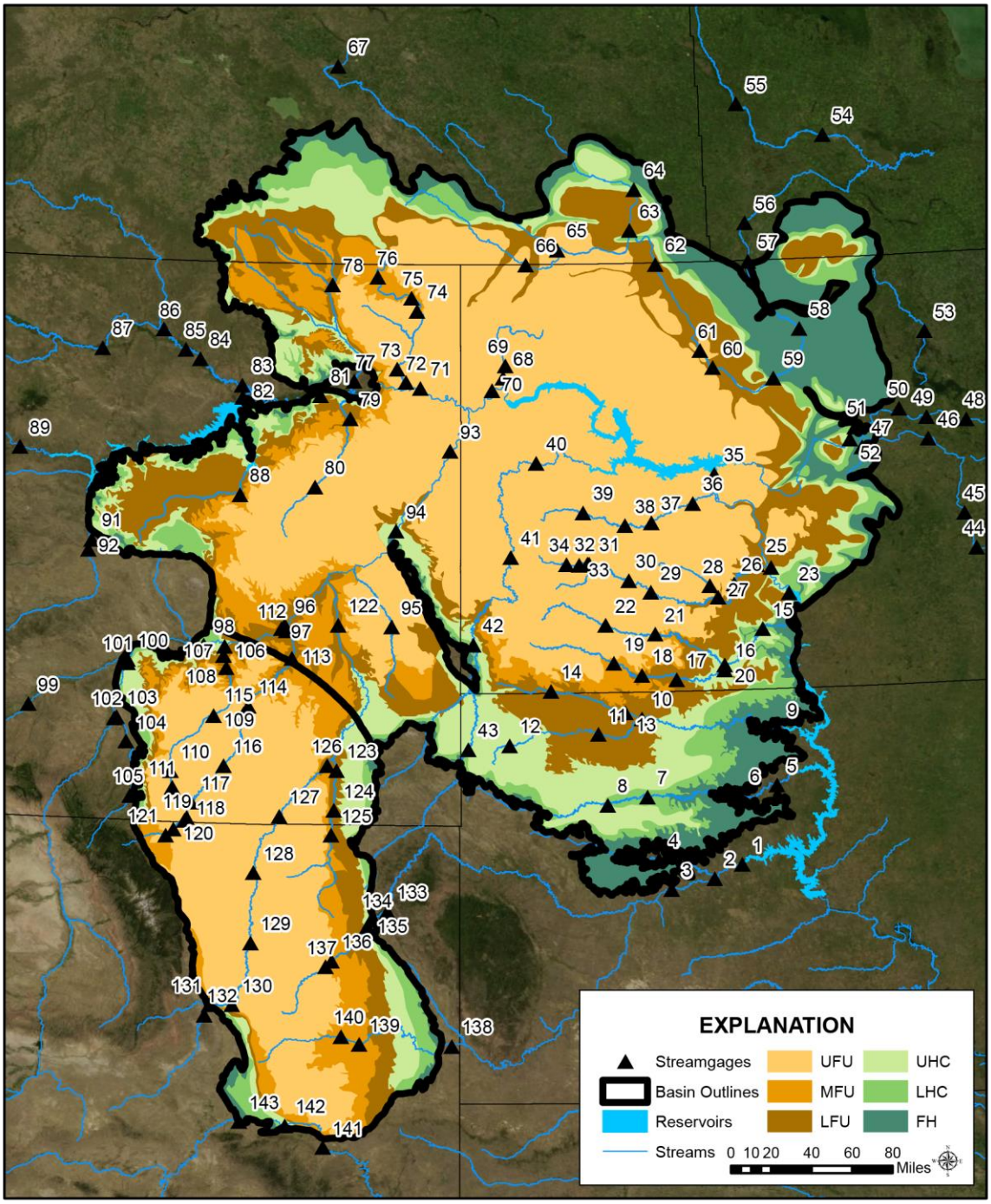

Figure 9. Locations of stream gauges that were included in the study [UFU, Upper Fort Union aquifer; MFU, Middle Fort Union hydrogeologic unit; LFU, Lower Fort Union aquifer; UHC, Upper Hell Creek hydrogeologic unit; LHC, Lower Hell Creek hydrogeologic unit; FH, Fox Hills aquifer].

Base-Flow Index

The base-flow index (BFI) is a number indicating how much of streamflow is considered base flow. The BFI is calculated by taking the estimated base-flow divided by the streamflow. It can be shown as a fraction of one or as a percentage. The BFI is dependent on period of record. Wolock (2005) calculated the BFI at more than 19,000 stream gauge locations in the continental United States. This included several streams in the study area. The BFI was calculated for annual records and for a different time frame than the period of records used in this study. The BFI was calculated for all gauges in the study area that had a PART analysis. The average of the September/October PART analysis was calculated and then divided by the streamflow average for the same time period. The length of record used was the full available length for each stream gauge through September 2011, generally beginning to earlier than 1900.

BFI is useful in comparing streamflow and streams from different parts of the study area, because it is used as an indicator of catchment geology (Institute of Hydrology, 1980). Neff and others (2005) used the BFI of gauges in their study area to extrapolate results to ungauged areas of the basin.

Base-Flow Estimates from Streamflow Records

Base-flow also was estimated by using averaged September and October streamflow records. Fall estimates can be considered useful periods of time for low flows, as previously discussed. In most of the gauges that were calculated using PART, the fall streamflow averages were fairly close to the resultant estimated base-flow values. This correlation was expected, as the streamflow should consist of mainly base flow

during low flow periods. The estimated base-flow values from PART correlate with the fall streamflow values and therefore the fall streamflow values are acceptable to use as substitutes in losing reaches.

Estimating Gaining and Losing Stream Reaches

A gaining stream reach is considered to be receiving discharge from the underlying aquifer. Adjacent to the steam, the water table is at a higher elevation than the stream and slopes down to the stream elevation (Figure 10).

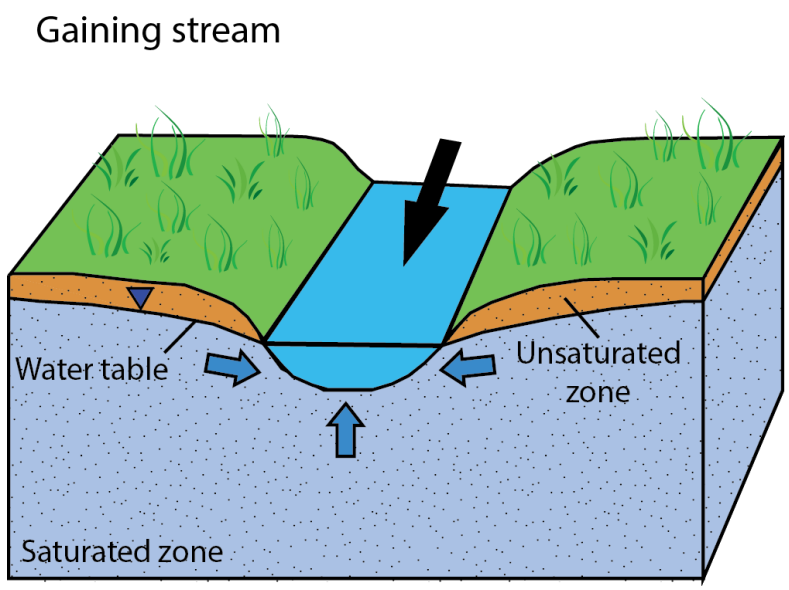

Figure 10. Conceptual model of gaining and losing stream systems (modified from Winter and others, 1998).

A losing stream reach is considered to be losing flow into the underlying aquifer(s). There are two types of losing stream reaches. The first type is a stream reach that is hydraulically connected with the underlying aquifer (Figure 11) and the stream is losing flow directly to the underlying aquifer. The second type is a stream reach that is losing flow into the underlying aquifer, but is separated by an unsaturated zone (Figure 12). Losses may occur in this zone, such that the flow lost from the stream never actually

reaches the underlying aquifer. If flow does reach the underlying aquifer there may be a mounding affect underneath the stream bed (Figure 12).

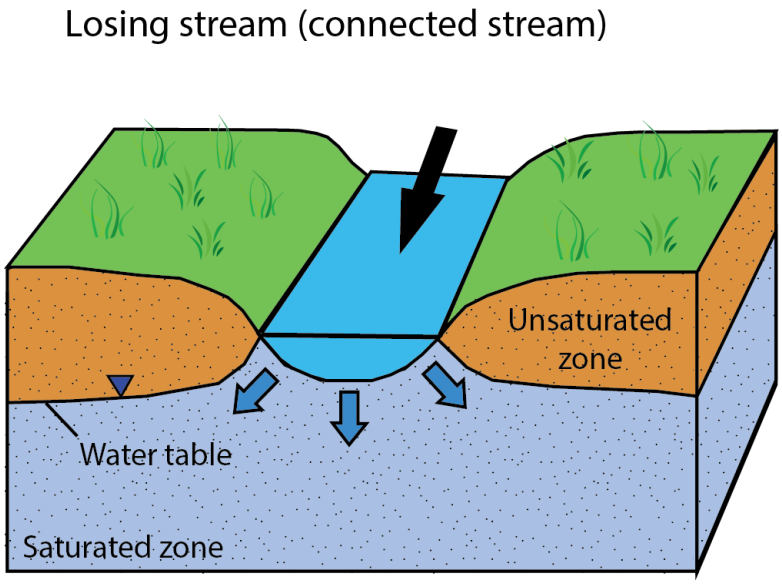

Figure 11. Conceptual model of losing stream system that is connected hydraulically to the underlying aquifer (modified from Winter and others, 1998).

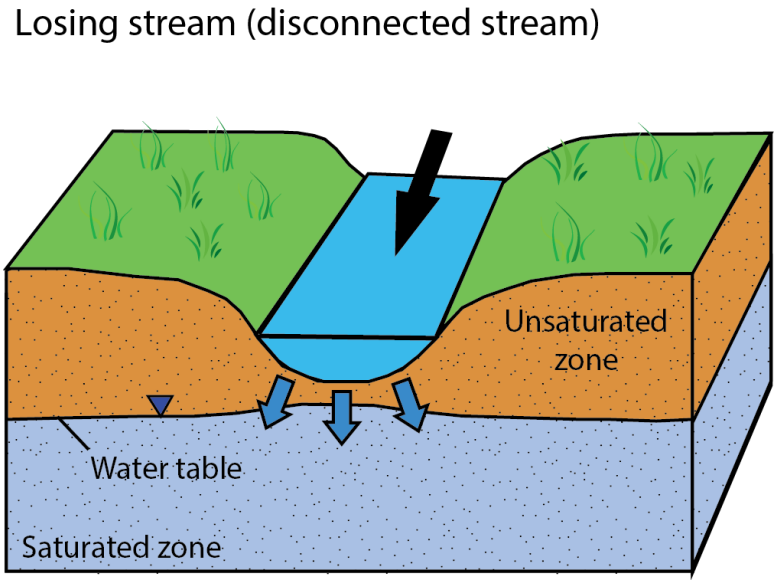

Figure 12. Conceptual model of losing stream system that is disconnected hydraulically to the underlying aquifer (modified from Winter and others, 1998).

Streams can either be gaining flow, losing flow or a mixture of both gaining and losing reaches (Winter and others, 1998). Most streams tend to be a mixture of gaining and losing stream reaches.

Although base-flow estimation at individual stream gauges is calculated from PART and streamflow values, these are only point values. The drainage area for each stream gauge extends to the headwaters of the watershed for that point. In order to estimate the recharge to or discharge from the underlying aquifer(s), the gains or losses along each stream reach must be quantified. The difference of base flow between each stream gauge was calculated and was attributed to the drainage area between the stream gauges. Figure 13 shows the delineation necessary for every point in the study area to be included. Table 2 shows the calculations for each reach in Figure 13. In cases where there were no stream gauges upstream only the headwaters, recharge and discharge were assumed to be zero at the point where the headwaters start.

Table 2. Example of recharge estimation using difference in base flow estimates at each stream gauge.

Reach	**Recharge estimate**
Reach 1	Gauge 1 - Gauge 2
Reach 2	Gauge 2- Gauge 3
Reach 3	Gauge 3 - 0

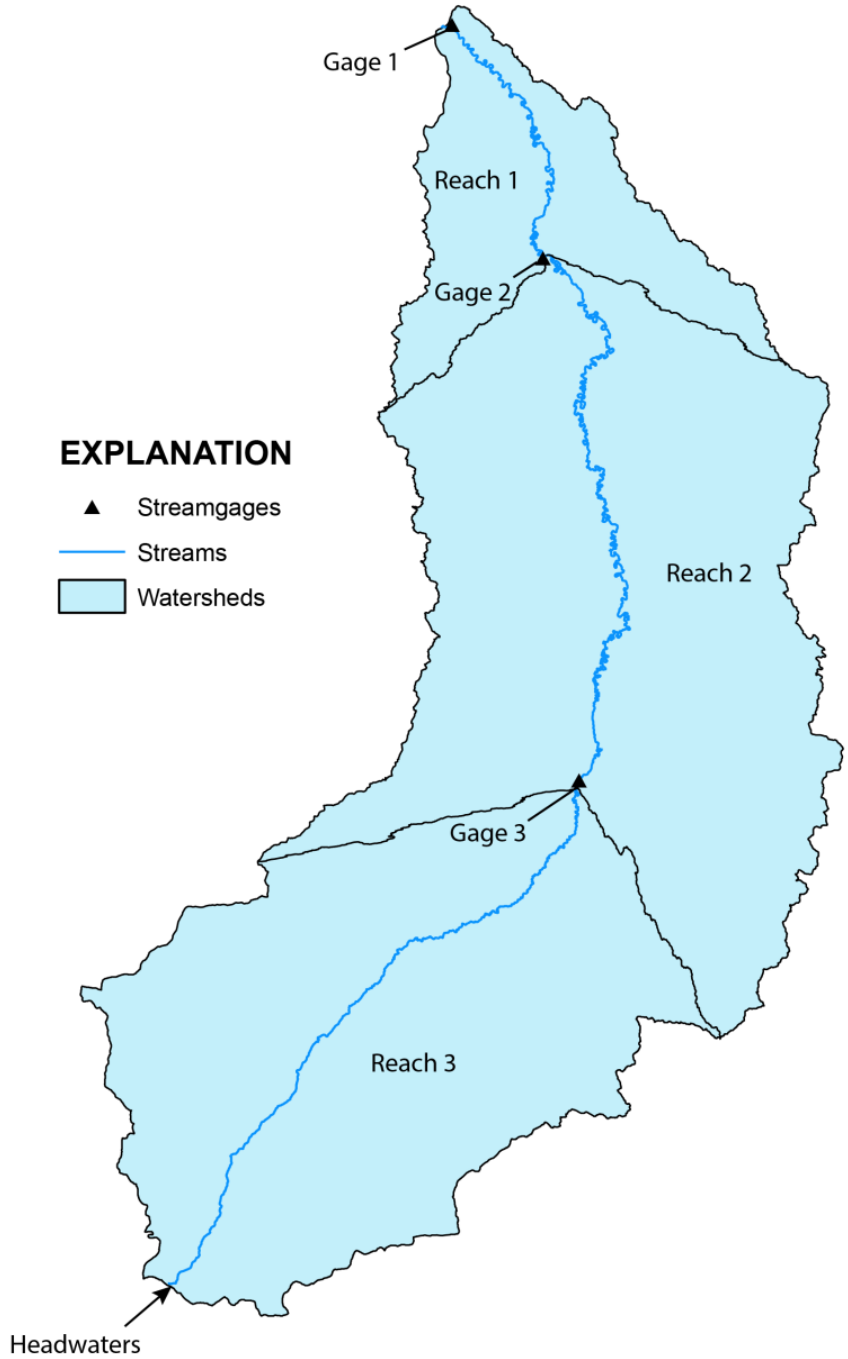

Figure 13. Watershed delineation between stream gauges.

PART was developed for base-flow estimation in humid regions where the majority of streams are perennial. The study area is a semi-arid region, with a large amount of the ephemeral and intermittent stream systems. Throughout the entire study

area perennial streams account for a very small percentage of streams with these mainly limited to mainstem tributaries. The software may not behave as expected in regions where ephemeral and intermittent streams dominate the landscape.

Streams in the study area were separated into reaches defined by upstream and downstream stream gauges. Long-term average base-flow estimates for each stream reach were calculated as the difference between the upstream and downstream average base flow. The farthest upstream gauge on each stream defined the downstream end of a reach, and streamflow at the headwater was assumed to be zero. If the estimated base flow for any reach was negative, this indicated a sinking reach. If a stream does not gain flow from the underlying aquifers, the amount of streamflow being lost to underlying aquifers cannot be separated from the runoff component of the hydrograph properly (Rutledge, 1998). PART is valid only for gaining streams, however, and was not used to estimate stream recharge for these reaches. For these sinking reaches that were identified by negative base-flow estimates, the difference between long-term average upstream and downstream streamflow measurements for September and October were used as estimates of stream recharge. The appropriateness of using September and October data for sinking reaches is less certain than for gaining reaches, but this was done for consistency with the base-flow estimates. Studies have shown that the fall period is a common time for low flows, although they can occur during other parts of the year. In some cases, the September and October streamflow values indicated a sinking reach, whereas the PART estimates indicated a gaining reach; these were assumed to be sinking reaches, and therefore, the streamflow values were used to estimate stream recharge. The streamflow values were used in cases where there was uncertainty as to whether the

stream reach was gaining or losing flow to the underlying aquifers. Since the streamflow was very close to most PART base-flow estimates it was assumed to portray a fairly accurate representation of the base-flow in cases of uncertainty. The values from these are shown in Appendix B.

The estimated recharge to and discharge from the underlying aquifers were summed to find the total for each structural basin and ultimately the study area.

Additional Recharge to Aquifers

Base-flow estimates from PART are only acceptable for use on streams that gain flow from the underlying aquifers. The fall streamflow measurements were substituted where PART estimates were inadequate. PART estimates were determined to be inadequate in areas where the PART estimates were negative, indicating sinking streams. They were also inadequate where streamflow averages were negative, even if the PART results were positive, as this indicated uncertainty. Full-year sinking rates were examined in both basins, because there might have been a larger amount of recharge from periods of higher flow, which would result in additional recharge not accounted for by fall estimates.

Climate Variability and Analysis

When a study area is large enough, climate can be a large variable that must be considered. Precipitation, temperature, and humidity can vary widely across a study area. The length of streamflow record varies with each gauge in the study area. The entire period of record was used, to average out any outlier years, but a smaller period of record should be examined to see how climate affects the length of record or the position of the

gauge within the study area. The period of 1978-1980 was chosen because 54% of the gauge records contained that period. The BFI was utilized to compare the full period of record to the isolated period of record for these gauges. If climatic effects are not a large, the BFI should be similar for both time frames.

Reservoir Analysis

A reservoir budget was completed for each of the three mainstem reservoirs in the study area (Figure 14). This helps analyze the seepage from the reservoirs to the underlying aquifer(s) or the discharge from the underlying aquifer(s) to the reservoirs. The following equation was used in quantifying the reservoir interaction:

$$\text{Inflow-Outflow-Evaporation-}\Delta\text{Storage} = \text{Residuals} \qquad (2)$$

where inflow (ft^3/s) is equal to all flow into a reservoir including tributaries and canals, outflow (ft^3/s) is equal to the discharge at the dam, evaporation (ft^3/s) is the estimated amount of water lost to the atmosphere over the entire surface area of the reservoir, and Δstorage is the change in storage in the reservoir over a-24 hour period. The change in storage is calculated from stage record data.

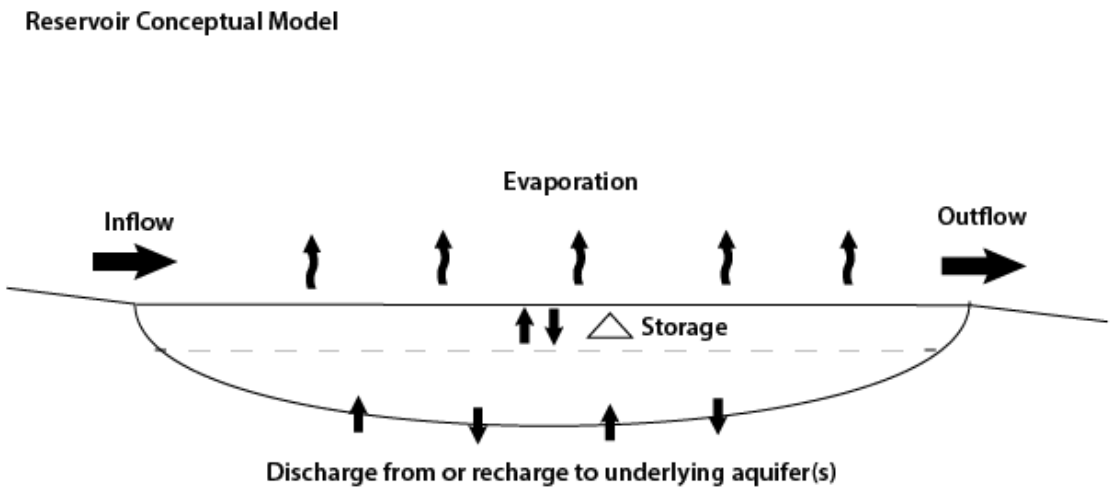

Figure 14. Conceptual model of reservoir system.

The term, residuals, encompasses the discharge or recharge to underlying aquifers, withdrawals, and error. The discharge or recharge to underlying aquifers is the most important term in this equation, and is the term that is assumed as the majority of the value. The withdrawals for the mainstem reservoirs of the Missouri River are not currently tracked (Michael Swenson, written commun., 2013). The withdrawals, in comparison to the vast quantities of water in these reservoirs, are most likely negligible. The error is a source of uncertainty and will be addressed in the latter part of this thesis, under error and uncertainty.

Results

Base-Flow Estimates and Streamflow Values

There were 525 stream gauges analyzed in the study area with only 143 stream gauges used in the final study. Appendix A lists all of the stream gauges assessed for the study. The base-flow estimates and streamflow values at select stream gauge locations

are shown in Appendix B**.** The values included in the table are the fall months of September and October as well as the annual averages. The values of base-flow at each stream gauge ranged from 0 to 13,234 ft^3/s for the PART estimates, while the streamflow averages ranged from 0 to 19,853 ft^3/s. The values typically fell in three categories: large rivers (thousands of ft^3/s), large tributaries to large rivers (hundreds of ft^3/s), and small tributaries and headwaters (single to tens of ft^3/s).

Gaining and Sinking Stream Reaches

The values of gaining and sinking for stream reaches between gauges are shown in Appendix C. The table contains values of PART estimates, streamflow, and the final cumulative values of losing and gaining estimates generated for each basin and for the entire study area. The values of PART estimates per reach for sinking streams for the fall period range from -1 to -1221 ft3/s, while the values for gaining streams range from 1 to 1594 ft^3/s. The values of streamflow per reach for sinking streams for the fall period range from -1 to -2220 ft^3/s, while the values for gaining streams range from 1 to 1944 ft^3/s. All streams were included in the analysis that flowed into or out of the extent of the Lower Tertiary and Upper Cretaceous aquifer systems boundary. These streams are primarily in the Williston basin and were included, because they are connected hydraulically to the glacial aquifers, which cover approximately one third of the Williston basin. No interpretation was performed between stream gauges; therefore if the stream reach extended outside the basin boundary it was used in the analysis (Figure 15).

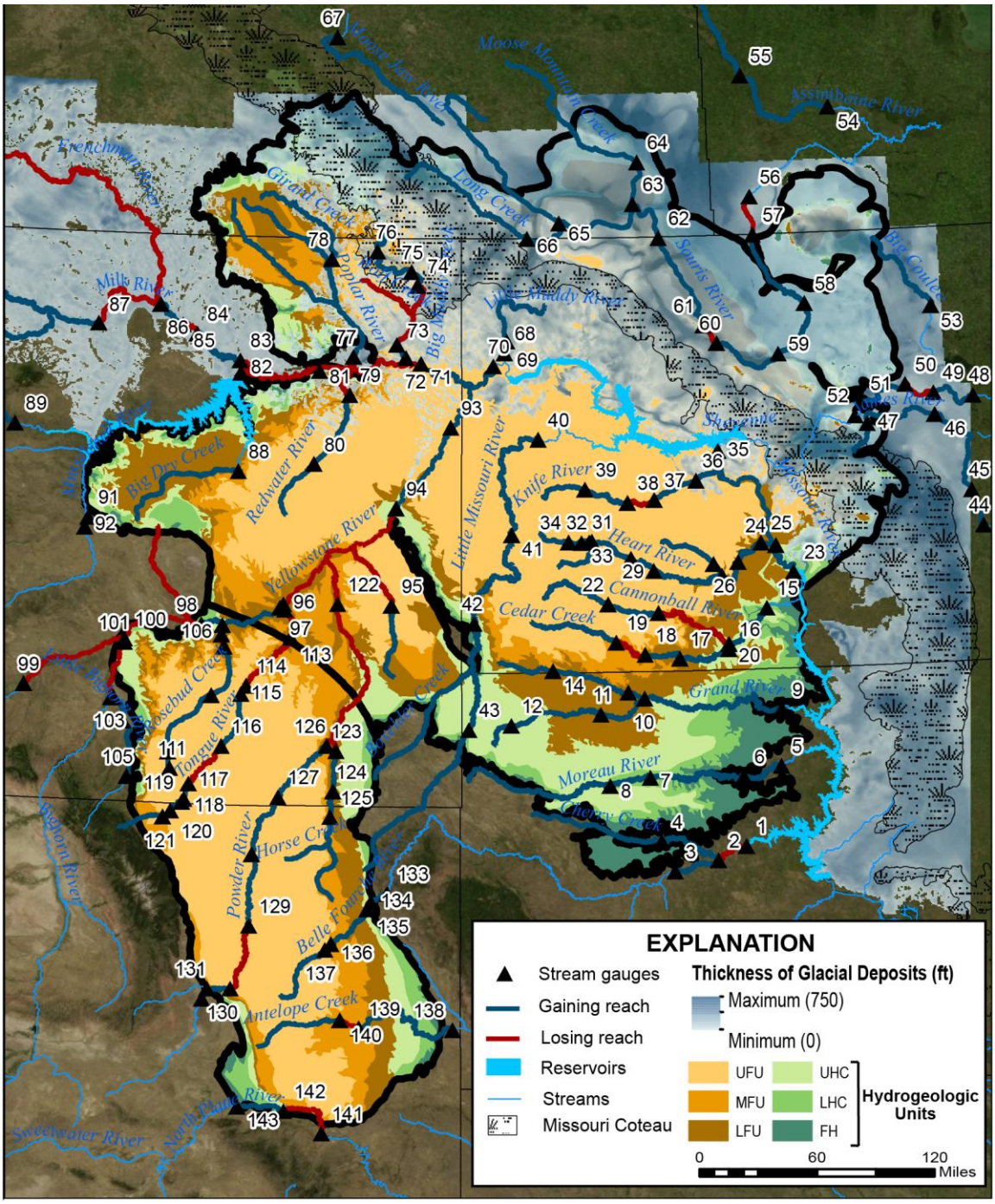

Figure 15. Gaining and sinking stream reaches in the study area [UFU, Upper Fort Union aquifer; MFU, Middle Fort Union hydrogeologic unit; LFU, Lower Fort Union aquifer; UHC, Upper Hell Creek hydrogeologic unit; LHC, Lower Hell Creek hydrogeologic unit; FH, Fox Hills aquifer].

Powder River Basin

North Platte River

The North Platte River flows across the southern part of the Powder River basin and cuts across all Upper Cretaceous and Lower Tertiary units. The stream gains flow from the underlying aquifers where it is underlain by the Upper Cretaceous units, primarily the Lower Hell Creek aquifer. The stream loses flow to the underlying Lower Tertiary Middle Fort Union hydrogeologic unit.

Antelope Creek

Antelope Creek flows across the southern part of the Powder River basin. The headwaters are on the western side of the basin and the stream flows across the basin until it joins the Cheyenne River on the eastern side of the basin. Antelope Creek is underlain by Lower Tertiary units and gains flow from the underlying aquifers.

Cheyenne River

The Cheyenne River flows out of the southeastern side of the Powder River basin. The river loses a small amount of flow to the underlying Middle Fort Union unit as it flows across it after Antelope Creek joins it. The Cheyenne River gains flow from the underlying Lower Fort Union and Fox Hills aquifers. The Cheyenne River flows northward from the Powder River basin and flows across the southern part of the Williston basin.

Belle Fourche River

The Belle Fourche River flows from the south-central part of the Powder River basin toward the Williston basin before it joins the Cheyenne River (Figure 16). The river flows across all Lower Tertiary and Upper Cretaceous units and gains flow from the

underlying aquifers in most of the area. This is with the exception of a reach along the Upper Hell Creek hydrogeologic unit where the reach is losing flow.

Figure 16. Photo of the Belle Fourche River in northern South Dakota.

Little Powder River

The Little Powder River flows north on the eastern side of the Powder River basin until it joins the Powder River. The river steadily gains flow as it crosses the Upper Fort Union aquifer, Middle Fort Union hydrogeologic unit, and the Lower Fort Union aquifer.

Rosebud Creek

Rosebud Creek flows across the northwestern part of the Powder River basin toward the Williston basin, where it joins the Yellowstone River in the vicinity of the Miles City Arch. Rosebud Creek steadily gains flow from the underlying Upper Tertiary units. As Rosebud Creek nears the Yellowstone River it flows across the Upper Hell Creek hydrogeologic unit and loses flow. As Rosebud Creek reaches its confluence with

the Yellowstone River, it gains a very small amount, while flowing over the Upper Hell Creek hydrogeologic unit.

Powder River

The Powder River flows from the southwestern side of the Powder River basin, across the Miles City Arch, and into the Williston basin, where it joins the Yellowstone River. The Powder River flows across most of the Lower Tertiary and Upper Cretaceous units. The Powder River primarily gains discharge across the Upper Fort Union aquifer, and loses discharge to the underlying aquifer as it crosses the Middle Fort Union hydrogeologic unit, the Lower Fort Union aquifer, and the Upper Hell Creek hydrogeologic unit in the region of the Miles City Arch.

Tongue River

The Tongue River flows from the western part of the Powder River basin, across the Miles City Arch, and into the southeastern side of the Williston basin, where it joins the Yellowstone River. The Tongue River flows across all of the Lower Tertiary and Upper Cretaceous units before it reaches its confluence with the Yellowstone River. The river is primarily gaining flow from the underlying aquifers on the western side of the Powder River basin. Losses occur to the Upper Fort Union aquifer in the central part of the basin, and also as the river flows across the Middle Fort Union hydrogeologic unit and the Lower Fort Union aquifer across the Miles City Arch.

Bighorn River

The Bighorn River flows northward along the northwestern outskirts of the Powder River basin until it joins the Yellowstone River. The Bighorn River gains flow from the underlying aquifers outside of the Powder River basin, but it starts to lose flow

to the underlying Upper Cretaceous aquifers before its confluence with the Yellowstone River.

Yellowstone River

The Yellowstone River flows across the northern part of the Powder River basin and crosses the Miles City Arch, where it enters the Williston basin and flows into the Missouri River. The Yellowstone River gains flow from the underlying aquifer as it enters the north side of the basin and flows across the Miles City Arch. In the Williston basin, the river loses flow until it reaches the Cedar Creek Anticline, where it starts gaining flow again.

Additional Recharge

The results show sinking rates approximately three times greater than the initial estimates in the Powder River basin for the full year average, results found in Appendix D, while the Williston basin showed a slight decrease in sinking rates.

Williston Basin

O'Fallon Creek

O'Fallon Creek flows into the Yellowstone River in the southwestern part of the Williston basin and cuts across all of the Lower Tertiary units. The creek gains a small amount from the underlying aquifers.

Big Dry Creek

Big Dry Creek flows on the western side of the Williston basin into Fort Peck Lake. The river gains flow from the underlying Lower Fort Union aquifer.

Redwater River

The Redwater River flows north on the western part of the Williston basin until it reaches the Missouri River. The river gains discharge as it flows across the Upper Fort Union aquifer, Middle Fort Union hydrogeologic unit, and Lower Fort Union aquifer. It gains the most flow from the Upper Fort Union aquifer.

Musselshell River

The Musselshell River is west of the Williston basin and flows into Lake Fort Peck and the Missouri River. The stream is losing discharge the underlying aquifers.

Milk River

The Milk River flows from the northwest into the Missouri River just east of Fort Peck Lake. The Milk River is outside of the Williston basin, but is underlain in most areas by glacial material. A few reaches of the Milk River lose flow to the underlying aquifers and are not underlain by glacial material. The areas of the Milk River that gain from underlying aquifers are underlain by thick glacial material.

Poplar River

The Poplar River flows along the northwestern part of the Williston basin until it joins the Missouri River. Girard Creek, the Middle Fork Polar River, and the West Fork Poplar River all contribute to the mainstem Poplar River. The river flows mainly over the Middle Fort Union hydrogeologic unit, the Lower Fort Union aquifer, and the Upper Hell Creek hydrogeologic unit, and gains flow along the way. Glacial aquifers might contribute to Girard Creek and mainstem of the Poplar River.

Big Muddy Creek

The Big Muddy Creek flows southward on the northwestern part of the Williston basin until it reaches the Missouri River. The creek gains discharge from the underlying

units where it flows over the Lower Fort Union aquifer and Middle Fort Union hydrogeologic unit, while losing discharge primarily where it flows over the underlying Upper Fort Union aquifer.

The upper reach of Big Muddy Creek gains discharge where glacial deposits are spotty, but where it flows over areas of thicker glacial materials the river loses discharge to the glacial aquifers.

Moose Jaw River

The Moose Jaw River flows northward and gains flow from the underlying glacial aquifers.

Little Muddy River

The Little Muddy River flows southward into the Missouri River in the north-central part of the Williston basin. The river flows through glacial deposits >100 feet in thickness and gains flow from the glacial aquifers. The river flows over the Upper Fort Union aquifer and gains discharge from it.

Long Creek

Long Creek flows across the northern part of the Williston basin and into the Souris River. Long Creek gains flow from the underlying glacial aquifers.

Souris River

The Souris River flows southward into the Williston basin and then out of the basin on its way to the confluence with the Assiniboine River. The river mainly gains flow from the underlying glacial aquifers in areas where the glacial material is >100 feet thick. The river loses flow in areas of thinner glacial material and could be influenced by dams on the river.

Moose Mountain Creek

Moose Mountain Creek flows southward until it reaches the Souris River and gains flow from the underlying glacial aquifers. Glacial thickness appears to be >100 feet.

Assiniboine River

The Assiniboine River flows southward until it reaches its confluence with the Souris River. The stream gains flow from the underlying glacial aquifers.

Big Coulee

Big Coulee gains flow from the underlying glacial aquifers. The stream flows southward into a lake.

Sheyenne River

The Sheyenne River flows out of the eastern part of the Williston basin and ultimately discharges into the Red River. The Sheyenne River is the only stream in the entire study area to flow across the Missouri Coteau. The stream is in a glaciated region of the basin and some reaches lose flow where the areas of glacial deposits are thin or eroded away. The stream gains flow in most other reaches where glacial deposits are thick.

James River

The James River flows eastward out of the eastern part of the Missouri Coteau and southward out of the Williston basin until it joins the Missouri River south of the study area. The James River primarily gains flow from the underlying glacial units.

Knife River

The Knife River flows eastward in the south-central part of the Williston basin, until it reaches the Missouri River. The stream is underlain by the Upper Fort Union

aquifer and in areas near the confluence with the Missouri, potentially glacial units. Knife River primarily gains flow.

Little Missouri River

The Little Missouri River flows out of the eastern side of the Powder River basin and northeastward toward the Williston basin. Boxelder Creek flows into the Little Missouri River just south of the Cedar Creek Anticline and is the only stream to flow across the anticline, where all units are absent, before it flows northward and into Lake Sakakawea. The stream flows across all hydrogeologic units in the study area and gains flow from the underlying aquifers the entire length.

Cannonball River

The Cannonball River flows eastward in the Williston basin and joins with the Missouri River. The stream flows across all hydrogeologic units and gains discharge as it flows across the Upper Fort Union aquifer, and also where it flows across all the Upper Cretaceous hydrogeologic units. The stream loses discharge along a reach that crosses the Middle Fort Union hydrogeologic unit, the Lower Fort Union aquifer, and the Upper Hell Creek hydrogeologic unit.

Cedar Creek

Cedar Creek flows eastward in the Williston basin until it reaches its confluence with the Cannonball River. Cedar Creek flows across all Lower Tertiary units and the Upper Hell Creek hydrogeologic unit. The stream primarily gains flow, with the exception of a reach flowing over the Middle Fort Union hydrogeologic unit and the Lower Fort Union aquifer.

Grand River

The Grand River flows eastward in the Williston basin until it joins the Missouri River (Figure17). The river flows across the lower Fort Union aquifer and all hydrogeologic units of the Upper Cretaceous. The stream gains flow from all underlying units.

Figure 17. Photo of the South Fork Grand River near Bison, South Dakota.

Moreau River

The Moreau River flows eastward across the southern part of the Williston basin until it reaches the Missouri River. The stream flows across all Upper Cretaceous hydrogeologic units and gains discharge from these units.

Cherry Creek

Cherry Creek flows southeastward across the southern part of the Williston basin, until it joins the Cheyenne River. Cherry Creek gains discharge from the underlying Fox Hills aquifer.

Climate Variability

The climate analysis was performed on the isolated period from 1978 to1980 and compared the full period available for each gauge. The comparison of the Base Flow Index for each of these periods showed that there was little to no variability with an average change in BFI of approximately -5.5%, as shown in Appendix F.

Reservoir Budget

The reservoir budget was completed for the time period of 1967 to 2011, for the fall periods of September and October and the full year of record. Fort Peck Lake showed the most variability, as it received recharge from the underlying aquifers in the full year and seepage to the underlying aquifers for the fall period. Lake Sakakawea and Lake Oahe estimates showed seepage to the underlying aquifers for the full year and fall estimates, although the fall period rates were three to four times higher.

Table 3. Results of the reservoir water budget [Negative values indicate flow being lost to underlying units].

Reservoir	**Annual seepage estimates from 1967-2011 (ft^3/s)**	**Fall seepage estimates from 1967-2011 (ft^3/s)**
Fort Peck Lake	37	-500
Lake Sakakawea	-104	-424
Lake Oahe	-188	-531

Discussion

The final estimate of gain from the underlying aquifers in the study area was approximately 9230 ft^3/s, while the loss to underlying aquifers was about 7790 ft^3/s. The Williston basin gained approximately 6980 ft^3/s and lost about 6200 ft^3/s to the underlying units. The Powder River basin gained approximately 2250 ft^3/s and lost about 1590 ft^3/s to the underlying units. The study area contains six hydrogeologic units and the discharge from and recharge to these units has not been differentiated in this study. These estimates were for all streams in the study area, as well as a few streams outside the study area that were in the glacial areas, in the northern half of the Williston basin. The Powder River basin contains a mixture of gaining and losing streams because of the ephemeral and intermittent nature of the streams. The Williston basin primarily gains flow from the underlying aquifers. The greater aridity in the Powder River basin and the glacial material in the Williston basin contribute to the difference in total flow between the basins. It should be noted that the gaining or sinking estimates are a net balance for each stream. When a stream crosses multiple hydrogeologic units, there is no way to differentiate where the gains or loss occurs. Even on reaches that are crossing one unit, there is no possibility with current data to isolate the gaining or losing parts.

Powder River Basin

The Powder River basin contains both gaining and sinking streams. Calculations show the streams gained about 2250 ft^3/s from the underlying aquifers, while about 1590 ft^3/s was lost from the streams to the underlying aquifers. Each stream and hydrogeologic unit has sinking reaches with no preferential area of loss. The mix of gaining and losing

may be related to the higher amount of ephemeral streams compared to perennial. The basin contains higher amounts of clinker than the Williston basin and clinker can have higher rates of infiltration, and also can contribute to base flow. These may allude to higher rates of recharge to the underlying aquifers. The recharge also may flow into the alluvium and discharge at a later point.

Rankl and Lowry (1990) estimated base flow for selected streams in the Powder River structural basin from 1944-1977, which are similar to estimates in Appendix B for the same locations. Druse and others (1981) calculated base flow during the months of October and November for the Powder River basin from 1977-1978. These values are close in range to the values that were calculated for this study. Both of these studies were performed on smaller tributaries that were not used in the final analysis. Base flow was analyzed for these streams and is shown along with the values from Rankl and Lowry (1990) and Druse and others (1981) in Appendix C. The monthly time frame chosen for the Rankl and Lowry study was for the “non-growing” months of October-March, while the Druse and others study used August-October. The period of record varied, with this study using additional data from 1980 to 2011. The methodology varied as well, with both studies using field measurements of solely base flow, while this study used graphical separation methods and streamflow records. Even with these differences in methodology, the base flow estimates for each gauge were fairly close.

Additional Recharge

In this study the initial estimates in the Powder River basin for sinking streams were about 650 ft^3/s. These could have been underestimates in the basin. Full-year gauge records were examined for the entire study area from the period of 1903-2011. In the

Powder River basin recharge to the underlying units was as much as three times greater during the full year period versus the September/October period (Appendix E). This was in contrast to the Williston basin, which primarily stayed at the same rate of recharge for the full-year analysis. This additional recharge is potentially from clinker deposits and ungauged streams flowing off the Bighorn Mountains.

Clinker deposits cover 6 to 7% of the Powder River basin and are known to have higher infiltration rates than non-clinker drainage basins (Heffern, 1999; Lowry and Rankl, 1987). Recharge from infiltration is greater over areas of clinker, compared to areas of unbaked sediment (Heffern and Coates, 1999). It should be noted that clinker can hold greater amounts of water than the sedimentary formations it resulted from, as was evident from pumping tests performed at several mine locations (Heffern and Coates, 1999). Pumping tests conducted in the Powder River basin drew several hundred gallons per minute with essentially no drawdown, indicating to large amounts of water held in clinker-dominated regions (Heffern and Coates, 1999).

The other source potential for additional recharge exists from the ungauged streams flowing into the basin from the Bighorn Mountains. For the full-year analysis of sinking stream reaches, the streams with the highest amounts of increased recharge were located along the western part of the Powder River basin. A large amount of recharge occurs along the western boundary of the Powder River basin and the Bighorn Mountains (Downie and Dinwiddie, 1988). An extensive fault (Figure 2) trends north to south along the border of the Bighorn Mountains and the basin, which could contribute to the greater rate of sinking streams and recharge to the underlying aquifer in that region (Love and Christianson, 1985).

In a study done on a catchment basin in Australia, McCallum and others (2013) found that higher rates of recharge to an aquifer, due to sinking streams, occur during higher periods of flow

Williston Basin

The Williston basin contains streams that primarily gain flow from the underlying aquifers. The streams that are underlain by glacial deposits appear to be gaining in the areas of greatest thickness, and in areas of thinning material, losing flow to underlying aquifers. There is a lot of variability in the large river systems, like the Missouri River and the Yellowstone River. To the author's knowledge, there have been no previous base flow studies in the Williston basin.

Diversions and withdrawals for multiple purposes affect streamflow in the Williston basin. The Big Muddy Creek flows southward into the Missouri River and is gaining flow from underlying aquifers until the point of stream gauge 74 (Figure 15, Appendix D). From reach 73-74 the stream loses approximately one third to one half of its flow (Figure 15, Appendix D). The tributary Wolf Creek drains into the Bid Muddy Creek along the reach that is losing flow. The stream then gains flow from reach 72-73 right before it flows into the Missouri River (Figure 15, Appendix D). The Medicine Lake National Wildlife Refuge Complex (MLNWRC) is approximately one mile to the east of Big Muddy Creek. Large amounts of flow from the Big Muddy Creek are diverted into Medicine Lake which is located in the MLNWRC (U.S. Fish and Wildlife Service, 2007; U. S. Geological Survey, 2013). This diversion of flow could be the reason why the Big Muddy Creek gains flow, then loses large amounts of flow, and then gains flow.

Without the diversion it is suggested that the stream is gaining flow from the underlying aquifers. Diversions also appear to affect the Milk River along reach 84-85 and 86-87 (Figure 15; Appendix D). There are two canals located along these reaches which divert water from the Milk River (U.S. Geological Survey, 2013).

Withdrawals are not tracked for any water system in the Williston or Powder River basin. Along reaches 94-96 and 96-97 of the Yellowstone River, base flow estimates indicate that the river is recharging the groundwater at very high rates (Figure 15; Appendix D). On the contrary evidence from potentiometric maps, in both the deep and shallow hydrologic units in the vicinity of the Yellowstone River, southwest of the Miles City arch, indicates that groundwater is discharging into the river (LaFave, 1998; Smith, 1998; and Patton and others, 1998). There are several surface water withdrawals permitted in the region of the Yellowstone River (Montana Department of Natural Resources and Conservation, 2013). There is a strong possibility that these withdrawals have affected the Yellowstone River streamflow and the current base-flow estimates for the reaches in this vicinity are not accurate.

Limitations, Error, and Uncertainty

Using most of the available data for each stream gauge was assumed to provide the best long-term estimates of average base flow and stream recharge for the entire control volume. This approach, however, sometimes resulted in different periods of record for the upstream and downstream stream gauges used for each reach, which could affect the accuracy of estimates for individual reaches. Neff and others (2005) used a similar approach in that they did not use a common time period for streamflow records. Annual values were not estimated because this would greatly decrease the number of

reaches that could be estimated. Although the September and October period was assumed to provide the best estimates of base flow and stream recharge, seasonal variability can exist, especially for sinking reaches. There also is uncertainty in the estimates for large watersheds, as previously described, and rivers with controlled flow, such as the Missouri River, because PART was designed for uncontrolled streamflow with natural variability. River reaches that include controlled reservoirs were not included in this analysis.

The fall period of record used was assumed to be a period of solely base-flow. This was presumed to be an indicator of the average base-flow for the year. However, it was shown, in some reaches, that the full year of record had higher rates of sinking streams in the Powder River basin. This indicates that the estimates in this study might underestimate rates of sinking streams. The streamflow values that were used in conjunction with the PART estimates were always greater than PART estimates for gaining streams. This seems to be an indicator that the assumption of fall PART estimates, as solely base-flow, could be an oversimplification.

The software was developed for humid regions with primarily gaining streams, and although that was addressed with the supplement of streamflow values, the validity of the estimates could be questioned. Although observed streamflow was used to calculate gaining and sinking reaches, no other field data were used.

The reservoir component was a source of significant error and the results were deemed to be unusable. These results could be reasonably accurate but the only available data were from model output.

The length of record was variable for each stream gauge. Although this was addressed in the climate variability section, there is still the uncertainty that error could exist in these estimates, based on the large range of stream gauge records and the size of the basin.

The study area covered more than 100,000 square miles. The scale at which the estimates were made is much larger than the PART program suggests. This introduces error, but the degree is unknown. Approximately 70% of gauges were deemed unusable because of gauge selection criteria, which eliminated a great deal of data. Time constraints and necessity for detail also were factors in the amount of error associated with the estimates. There is the possibility that human error exists as well, although the author tried to be as diligent and thorough as possible.

Reservoirs

The results from the three mainstem reservoirs in this study were very minimal in comparison to the amount of flow through the reservoirs. This does not indicate that the reservoirs are not recharging the underlying units or getting discharge from the underlying units, but only that the results were not conclusive. The amount of flow that is being lost to the underlying aquifers does increase in the fall period as shown in Table 3. Some evidence from a recent study indicates that reservoirs “silt” up and lose hydraulic connection with the underlying units. Rosenberry and Healy (2012) found, during a recent study on the South Platte River in Colorado, that fine-grained sedimentation occurred during low flow conditions. This could be occurring in these large mainstem reservoirs.

Conclusions

As energy production increases in the Williston and Powder River basins and as technology allows us to become more efficient, the need for greater accuracy in water-use and availability estimates will increase. This study quantified the flow from and to the underlying aquifers. The gain to stream systems from the underlying aquifers in the study area was approximately 9230 ft^3/s, while the loss from the stream systems to underlying aquifers was about 7790 ft^3/s. This study showed that the Williston basin primarily gained flow from the glacial aquifers systems. This study also showed that there were greater rates of recharge to the underlying aquifers during higher flow periods in the Powder River basin.

The estimates provide a starting point for understanding these surface water and groundwater interactions. This study illustrates the need for more accurate methods in estimating base flow and gaining and sinking stream reaches. The methodology for estimating base flow and gaining and losing reaches on large streams where diversions and withdrawal of the surface water sources occurs is currently inadequate. The PART software is limited by many factors including drainage size, length of record, and streamflow diversions. The software should be used when the stream is in its most natural environment. With the amount of surface water withdrawals occurring for in the study area, there is no adequate way to accommodate this at this time.

Further research is needed to enhance these methodologies. The methods used in this work were based on assumptions that could be modified. In addition, more field data are needed. Although this study could not quantify all interactions between the Missouri River reservoirs and underlying aquifers, it provided insight into what additional data are

necessary to complete such a study. Additional field data are necessary for calibration of modeling work.

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Appendix A: All Stream Gauges Located in the Study Area

Station number	Stream gauge name	Initial year of record	Last year of record	Years of Record	Drainage Area (mi^2)	Latitude (in NAD 83 decimal degrees)	Longitude (in NAD 83 decimal degrees)	Regulated[a]
05054500	Sheyenne River above Harvey, ND	1956	2011	56	154.0	47.70277750	-99.94901450	U
05055000	Sheyenne River near Harvey, ND	1946	1955	10	174.0	47.79027940	-99.89068150	U
05055100	North Fork Sheyenne River near Wellsburg, ND	1958	1966	9	207.0	47.87611636	-99.71845990	U
05055200	Big Coulee near Maddock, ND	1957	1966	10	90.0	47.91945178	-99.58013040	U
05055300	Sheyenne River above Devils Lake state outlet near Flora, ND	2005	2012	8	591.0	47.90777778	-99.41555560	U
05055400	Sheyenne River below Devils Lake state outlet near Bremen, ND	-	-	-	622.0	47.82138889	-99.27611110	U
05055500	Sheyenne River at Sheyenne, ND	1940	1950	11	660.0	47.83916540	-99.12512270	U
05055520	Big Coulee near Fort Totten, ND	1966	1974	9	7.7	47.88249809	-98.96761800	U
05056000	Sheyenne River near Warwick, ND	1950	2011	62	760.0	47.80555340	-98.71621720	U
05056060	Mauvais Coulee tributary no. 3 near Cando, ND	-	-	-	60.2	48.45750080	-99.22430370	U
05056085	Mauvais Coulee tributary no. 4 near Cando, ND	1994	1994	1	109.0	48.45777810	-99.24708170	U
05056100	Mauvais Coulee near Cando, ND	1957	1981	25	377.0	48.44805880	-99.10263540	Y
05056225	Webster Coulee at Webster, ND	1988	1993	6	670.0	48.28250308	-98.91901670	U
05056239	Starkweather Coulee near Webster, ND	1980	1986	7	210.0	48.32055910	-98.94068510	Y
05056244	St. Joe Coulee near Webster, ND	1986	1987	2		48.32305850	-99.00568790	U
05056247	Calio Coulee near Starkweather, ND	1987	1993	7	130.0	48.39944800	-99.04652290	U
05056270	Big Coulee below Churchs Ferry, ND	1998	1999	2	1,120.0	48.25916510	-99.20041220	U
05056300	Little Coulee at Leeds, ND	1956	1966	11	140.0	48.28749939	-99.44902410	U
05056340	Little Coulee near Leeds, ND	-	-	-	170.0	48.24333220	-99.37291250	U
05056390	Little Coulee near Brinsmade, ND	1976	1981	6	350.0	48.18749810	-99.24319040	U
05056400	Big Coulee near Churchs Ferry, ND	1951	1996	46	1,462.0	48.17777620	-99.22124550	U
05056403	Comstock Coulee near Minnewaukan, ND	-	-	-	58.0	48.10916548	-99.22846770	U
05056410	Channel A near Penn, ND	1984	1997	14	790.0	48.16666750	-98.98012770	U
05113360	Long Creek at West Crossing of international boundary	1960	2007	48	1,320.0	49.00031148	-103.35268940	U

05113500	Long Creek near Crosby, ND	1945	1964	20	780.0	48.97503358	-103.26824280	U
05113600	Long Creek near Noonan, ND	1960	2010	51	630.0	48.98114170	-103.07657340	U
05113700	West Branch Short Creek near Columbus, ND	1978	1980	3	80.0	48.96780930	-102.85156640	U
05114000	Souris River near Sherwood, ND	1931	2011	81	3,040.0	48.99001560	-101.95822090	Y
05116000	Souris River near Foxholm, ND	1950	2011	62	3,270.0	48.37223570	-101.50544140	Y
05116150	Des Lacs River near Kenmare, ND	1988	1992	5	687.0	48.58974490	-101.99738460	U
05116500	Des Lacs River at Foxholm, ND	1946	2011	66	539.0	48.37056947	-101.57016330	Y
05117500	Souris River above Minot, ND	1904	2000	97	3,900.0	48.24584280	-101.37127450	Y
05120000	Souris River near Verendrye, ND	1938	2011	74	4,400.0	48.15972928	-100.72958630	Y
05120200	Wintering River near Bergen, ND	1957	1977	21	126.0	47.93056058	-100.67125460	U
05120500	Wintering River near Karlsruhe, ND	1938	2011	74	285.0	48.13833739	-100.53986230	Y
05121001	Souris River east oufall at Eaton Dam near Towner, ND	2005	2006	2	-	48.27583330	-100.48805560	Y
05122000	Souris River near Bantry, ND	1938	2011	74	4,700.0	48.50555109	-100.43485340	Y
05122500	Willow Creek at Dunseith, ND	1954	1969	16	91.0	48.82000140	-100.06291190	U
05123100	Oak Creek at Lake Metigoshe outlet near Bottineau, ND	1954	1980	27	59.0	48.96556590	-100.36347460	U
05123400	Willow Creek near Willow City, ND	1957	2010	54	730.0	48.58888750	-100.44207870	U
05123500	Stone Creek near Kramer, ND	-	-	-	168.0	48.67834240	-100.71153100	U
05123510	Deep River near Upham, ND	1958	1979	22	370.0	48.58417950	-100.86264520	U
05123600	Egg Creek near Granville, ND	1957	1980	24	139.0	48.35500886	-100.82236390	U
05123700	Cut Bank Creek at Lake Outlet near Granville, ND	1957	1979	23	244.0	48.38611740	-100.76708240	U
05123750	Cut Bank Creek at Upham, ND	1975	1979	5	272.0	48.57472866	-100.74458250	U
05123900	Boundary Creek near Landa, ND	1958	1980	23	170.0	48.81279500	-100.86320720	U
05124000	Souris River near Westhope, ND	1931	2011	81	6,600.0	48.99640790	-100.95848890	Y
06115000	Missouri River Power Plant Ferry near Zortman, MT	1935	1967	33	40,763.0	47.73000000	-108.93472200	U
06115200	Missouri River near Landusky, MT	1935	2011	77	40,987.0	47.63138900	-108.68750000	Y
06115270	Armells Creek near Landusky, MT	2001	2003	3	397.0	47.61055600	-108.69555600	U

06115300	Duval Creek near Landusky, MT	2001	2003	3	3.3	47.74888900	-108.70277800	U
06115350	Rock Creek near Landusky, MT	2000	2003	4	72.9	47.70444400	108.54805600	U
06127500	Musselshell River at Musselshell, MT	1946	1978	33	4,568.0	46.52222200	-108.10861100	Y
06127600	Musselshell River near Mosby, MT	1963	1965	3	5,941.0	46.92222200	-107.91916700	U
06127900	Flatwillow Creek near Flatwillow, MT	1935	1955	21	188.0	46.79111100	-108.61388900	U
06128200	Flatwillow Creek near Winnett, MT	1922	1928	7	642.0	46.93805600	-108.19750000	U
06129000	Box Elder Creek near Winnett, MT	1959	1971	13	684.0	47.01250000	-108.15527800	U
06129500	McDonald Creek at Winnett, MT	1935	1944	10	421.0	46.99861100	-108.35138900	U
06130000	Flatwillow Creek near Mosby, MT	1965	1965	1	1,855.0	46.92861100	-107.93277800	U
06130500	Musselshell River at Mosby, MT	1935	2011	77	7,846.0	46.99444400	-107.88888900	Y
06130650	Hell Creek near Jordan, MT	2001	2003	3	70.6	47.57889410	-106.92757030	U
06130700	Sand Creek near Jordan, MT	1958	1966	9	317.0	47.25244167	-106.84900280	U
06130950	Little Dry Creek near Van Norman, MT	1980	1980	1	1,224.0	47.33944250	-106.36364740	U
06131000	Big Dry Creek near Van Norman, MT	1971	2005	35	2,554.0	47.34944268	-106.35781380	Y
06131120	TiMBer Creek near Van Norman, MT	1983	1984	2	287.0	47.40555540	-106.17419400	U
06131200	Nelson Creek near Van Norman, MT	1976	1984	9	100.2	47.53555760	-106.15363560	Y
06132000	Missouri River below Fort Peck Dam, MT	1944	1999	56	57,556.0	48.04418477	-106.35642120	Y
06155500	Milk River at Malta, MT	1911	1921	11	11,762.0	48.36166700	-107.86277800	U
06155900	Milk River at Cree Crossing near Saco, MT	-	-	-	13,118.0	48.54055600	-107.51972200	U
06156000	Whitewater Creek near international boundary	-	-	-	458.0	48.95250000	-107.86194400	U
06164000	Frenchman River at international boundary	-	-	-	2,120.0	49.00001990	-107.30284820	Y
06164500	Frenchman Canal near Saco, MT	1921	1968	48	-	48.60000000	107.25000000	U
06164510	Milk River at Juneberg Bridge near Saco, MT	1988	2011	24	17,670.0	48.50916700	-107.21861100	U
06164800	Beaver Creek above Dix Creek near Malta, MT	1976	1981	6	929.0	48.08833300	-107.55527800	U
06165000	Beaver Creek near Malta, MT	1918	1920	3	1,010.0	48.16083300	-107.52555600	U
06165500	Beaver Creek overflow near Bowdoin, MT	1904	1911	8	-	48.36694400	-107.61805600	U
06166000	Beaver Creek below Guston Coulee near Saco, MT	-	-	-	1,208.0	48.35666700	-107.58194400	U
06166500	Beaver Creek near Saco, MT	1909	1911	3	1,224.0	48.40000000	-107.53333300	U

06167000	Beaver Creek near Brady's Ranch at Ashfield, MT	-	-	-	1,327.0	48.43333300	-107.53333300	U
06167500	Beaver Creek near Hinsdale, MT	-	-	-	1,785.0	48.42027800	-107.17111100	U
06168500	Rock Creek at international boundary	1915	1960	46	241.0	48.98891220	-106.79227050	U
06169000	Horse Creek at international boundary	1915	1960	46	73.5	48.98891190	-106.83671690	U
06169500	Rock Creek below Horse Creek near international boundary	1979	2011	33	328.0	48.96946720	-106.83949470	Y
06169600	South Creek tributary near Opheim, MT	1984	1986	3	2.2	48.87613480	-106.63837420	U
06169700	South Creek tributary No. 2 near Opheim, MT	1984	1986	3	1.6	48.88863466	-106.66031970	U
06169800	South Creek tributary No. 3 near international boundary	1984	1986	3	0.3	48.94002260	-106.81671580	U
06170000	McEachern Creek at international boundary	1945	1975	31	182.0	48.99168918	-106.92838760	U
06170050	Rock Creek below McEachern Creek near international boundary	1984	1986	3	650.0	48.88140980	-106.89894170	U
06170080	Starbuck Coulee near international boundary	1984	1986	3	4.2	48.86046940	-106.90002500	U
06170200	Willow Creek near Hinsdale, MT	1966	1972	7	283.0	48.56472200	-106.98222200	U
06171000	Rock Creek near Hinsdale, MT	-	-	-	1,313.0	48.45250000	-107.03638900	U
06171500	Milk River at Hinsdale, MT	-	-	-	20,897.0	48.40000000	-107.06667000	U
06172000	Milk River near Vandalia, MT	1915	1924	10	20,926.0	48.37277800	-106.97305600	U
06172200	Buggy Creek near Tampico, MT	1958	1966	9	105.0	48.36055600	-106.77777800	U
06172310	Milk River at Tampico, MT	1988	1992	5	21,078.0	48.30777800	-106.82222200	Y
06174000	Willow Creek near Glasgow, MT	1954	1986	33	538.0	48.11446200	-106.67143800	U
06174000	Willow Creek near Glasgow, MT	1954	1986	33	538.0	48.11416700	-106.67138900	U
06174500	Milk River at Nashua, MT	1940	2011	72	22,332.0	48.12974210	-106.36447640	Y
06175000	Porcupine Creek at Nashua, MT	1982	1991	10	725.0	48.13586667	-106.34228890	U
06175500	Little Porcupine Creek at Frazer, MT	1909	1910	2	280.0	48.06852778	-106.03903060	U
06175540	Prairie Elk Creek near Oswego, MT	1976	1984	9	352.0	47.99890559	-105.86723340	U
06176000	Wolf Point ditch at Wolf Point, MT	1909	1909	1	-	48.11668509	-105.68389170	U
06176500	Wolf Creek near Wolf Point, MT	1982	1991	10	251.0	48.09640700	-105.67861380	U
06177000	Missouri River near Wolf Point, MT	1929	2011	83	82,290.0	48.06668410	-105.53249640	Y

06177400	McCune Creek near Circle, MT	1983	1984	2	29.9	47.35000797	-105.58388880	U
06177500	Redwater River at Circle, MT	1975	2003	29	547.0	47.41417510	-105.57555480	Y
06177650	Redwater River near Richey, MT	1983	1984	2	1,071.0	47.63084615	-105.32859850	U
06177700	Cow Creek Tributary near Vida, MT	1983	1984	2	1.7	47.71667919	-105.48388290	U
06177825	Redwater River near Vida, MT	1976	1984	9	1,974.0	47.90196098	-105.21553760	U
06178000	Poplar River at international boundary	1936	1936	1	358.0	48.99030160	-105.69667390	Y
06179000	East Fork Poplar River near Scobey, MT	1976	1978	3	722.0	48.85224645	-105.42138300	U
06180000	West Fork Poplar River near Richland, MT	1939	1939	1	428.0	48.80712220	-106.02119720	U
06180500	Poplar River near Bredette, MT	-	-	-	2,940.0	48.40619440	-105.21008890	U
06181000	Poplar River near Poplar, MT	1982	2011	30	3,174.0	48.17085238	-105.17886980	Y
06182000	Beaver Creek near international boundary	1950	1951	2	224.0	48.98891379	-105.01164310	U
06182500	Big Muddy Creek at Daleview, MT	1948	1971	24	279.0	48.91087500	-104.93909720	U
06183000	Big Muddy Creek at Plentywood, MT	1949	1952	4	850.0	48.76608056	-104.57809440	U
06183450	Big Muddy Creek near Antelope, MT	1982	2010	29	967.0	48.67280480	-104.51217750	Y
06183500	Big Muddy Creek at Reserve, MT	1951	1952	2	1,044.0	48.60697060	-104.45884190	U
06183700	Big Muddy Creek diversion canal near Medicine Lake, MT	1986	2009	24	-	48.50946920	-104.54912320	Y
06183750	Lake Creek near Dagmar, MT	-	-	-	101.0	48.56419230	-104.17771870	Y
06183800	Cottonwood Creek near Dagmar, MT	-	-	-	126.0	48.50974740	-104.17355200	U
06183850	Sand Creek near Dagmar, MT	-	-	-	122.0	48.49391370	-104.27355620	N
06184000	Wolf Creek near Medicine Lake, MT	1918	1919	2	165.0	48.56669160	-104.70051800	U
06184500	Smoke Creek near Poplar, MT	1918	1918	1	283.0	48.36119167	-104.74761940	U
06185000	Big Muddy Creek near Culbertson, MT	1909	1920	12	2,447.0	48.25713889	-104.72359720	U
06185110	Big Muddy Creek near mouth near Culbertson, MT	1982	1991	10	2,684.0	48.16446458	-104.62968170	U
06185500	Missouri River near Culbertson, MT	1959	2011	53	91,557.0	48.12502000	-104.47273100	Y
06214500	Yellowstone River at Billings, MT	1929	2011	83	11,408.0	45.80000000	-108.46777800	Y
06217950	Buffalo Creek near Custer, MT	1980	1982	3	221.0	46.13388900	-107.63083300	U
06218000	Yellowstone River at Custer, MT	-	-	-	14,427.0	46.14305600	-107.55138900	U

06288400	Bighorn River at Two Leggins Bridge, near Hardin, MT	-	-	-	-	45.64416700	-107.65750000	U
06288500	Bighorn River near Hardin, MT	1905	1924	20	20,722.0	45.72916700	-107.58083300	U
06288600	Little Bighorn River below Dayton Gulch near Burgess Junction, WY	1983	1986	4	15.9	44.83972200	-107.75500000	U
06288700	DF Little Bighorn River Below Lick Creek near Burgess Junction, WY	1983	1986	4	54.1	44.88750000	-107.61583300	U
06288975	Elkhorn Creek above Fuller Ranch ditch near Parkman, WY	-	-	-	4.6	44.98361100	-107.61472200	U
06288990	West Fork Little Bighorn River near Parkman, WY	1983	1985	3	38.2	44.99833300	-107.63277800	U
06289000	Little Bighorn River at State Line near Wyola, MT	1940	2011	72	182.0	45.00694400	-107.61527800	Y
06289100	Red Canyon Creek near Parkman, WY	-	-	-	3.2	44.97833300	-107.58583300	U
06289500	Little Bighorn River near Wyola, MT	-	-	-	251.0	45.10083300	-107.44000000	U
06289600	West Pass Creek near Parkman, WY	1983	2011	29	15.4	44.98774410	-107.48286850	Y
06289800	East Pass Creek near Parkman, WY	1975	1975	1	11.6	44.94357696	-107.48536760	U
06289820	East Pass Creek near Dayton, WY	1983	2011	29	21.7	44.99052258	-107.42286650	Y
06289870	Twin Creek near Parkman, WY	1988	1989	2	27.0	44.99357889	-107.35564190	U
06290000	Pass Creek near Wyola, MT	1983	2008	26	111.0	45.05611100	-107.35583300	Y
06290500	Little Bighorn River below Pass Creek near Wyola, MT	1977	2003	27	428.0	45.17694400	-107.39444400	U
06291000	Owl Creek near Lodge Grass MT	1980	1991	12	163.0	45.26802240	-107.30147900	U
06292500	Lodge Grass Creek near Lodge Grass, MT	-	-	-	143.0	45.26833300	-107.45166700	U
06293000	Lodge Grass Creek at Lodge Grass, MT	-	-	-	170.0	45.30944400	-107.36194400	U
06293500	Little Bighorn River near Crow Agency, MT	1939	1959	21	1,181.0	45.56722200	-107.45333300	U
06293900	Little Bighorn River at Crow Agency, MT	-	-	-	1,190.0	45.59722200	-107.46027800	U
06294000	Little Bighorn River near Hardin, MT	1954	2011	58	1,294.0	45.73555600	-107.55722200	Y
06294500	Bighorn River above Tullock Creek near Bighorn, MT	1946	2011	66	22,414.0	46.12444400	-107.46861100	Y
06294600	East Cabin Creek Tributary Near Hardin MT	1982	1984	3	8.6	45.79776190	-107.26172900	U

06294690	Tullock Creek near Bighorn, MT	1975	1981	7	446.0	46.08555600	-107.40611100	U
06294700	Bighorn River at Bighorn, MT	1946	1980	35	22,885.0	46.14694400	-107.46722200	U
06294940	Sarpy Creek near Hysham, MT	1974	1983	10	453.0	46.23859968	-107.13727900	U
06294950	Starved to Death Creek near Sanders, MT	1980	1984	5	36.9	49.33194400	-107.05472200	U
06294995	Amrells Creek near Forsyth, MT	1975	1983	9	370.0	46.24971480	-106.80670720	U
06295000	Yellowstone River at Forsyth, MT	1978	2011	34	39,455.0	46.26610550	-106.69059090	Y
06295100	Rosebud Creek near Kirby MT	1982	1984	3	35.5	45.24580840	-106.96784670	U
06295113	Rosebud Creek at Reservation Boundary near Kirby MT	1980	2010	31	123.0	45.36108850	-106.99034170	Y
06295250	Rosebud Creek near Colstrip MT	1975	2005	31	799.0	45.76749635	-106.57002120	Y
06295500	Rosebud Creek near Rosebud MT	1939	1942	4	1,193.0	46.11277536	-106.45279870	U
06296000	Rosebud Creek near Forsyth, MT	1948	1951	4	1,279.0	46.19809167	-106.48402780	U
06296003	Rosebud Creek at mouth near Rosebud, MT	1975	2005	31	1,302.0	46.26471980	-106.47558050	U
06296100	Snell Creek near Hathaway, MT	1982	1984	3	10.5	46.29867220	-106.15409170	U
06296120	Yellowstone River near Miles City, MT	1975	1983	9	42,847.0	46.39805820	-105.89556020	U
06296500	North Fork Tongue River near Dayton, WY	1946	1956	11	32.4	44.75694400	-107.62222200	U
06298500	Little Tongue River near Dayton, WY	1956	1973	18	25.1	45.81055600	-107.28388900	U
06299000	Tongue River at Dayton, WY	1903	1903	1	259.0	44.87774638	-107.26452460	U
06299500	Wolf Creek at Wolf, WY	1946	1970	25	37.8	44.77246889	-107.23424300	N
06299980	Tongue River at Monarch, WY	2005	2011	7	478.0	44.90024930	-107.02090500	Y
06302500	Goose Creek at Sheridan, WY	-	-	-	182.0	44.79719380	-106.96451280	U
06305500	Goose Creek below Sheridan, WY	1942	1983	42	392.0	44.82358286	-106.96173530	U
06305700	Goose Creek near Acme, WY	1985	2006	22	413.0	44.88636070	-106.98895930	U
06306000	Tongue River near Acme, WY	1939	1956	18	894.0	44.94427778	-106.94425000	U
06306100	Squirrel Creek near Decker, MT	1976	1984	9	33.6	45.05136258	-106.92729160	U
06306200	Prairie Dog Creek at Wakeley Siding near Sheridan, WY	2005	2011	7	87.9	44.84219467	-106.88117760	Y
06306250	Prairie Dog Creek near Acme, WY	2001	2011	11	358.0	44.98386286	-106.83978920	Y
06306300	Tongue River at State Line near Decker, MT	1961	2011	51	1,453.0	45.00886320	-106.83617800	Y

06306500	Tongue River near Decker, MT	1929	1937	9	1,585.0	45.03053059	-106.81451000	U
06306950	South Fork Leaf Rock Creek near Kirby, MT	1982	1984	3	4.5	45.18330897	-106.91728910	U
06307500	Tongue River at Tonge River Dam near Decker, MT	1940	2011	72	1,770.0	45.14136700	-106.77144940	Y
06307525	Prairie Dog Creek above Jack Creek near Birney, MT	1980	1982	3	6.6	45.33553825	-106.77421910	U
06307528	Prairie Dog Creek near Birney, MT	1979	1983	5	19.6	45.29109546	-106.68282700	U
06307560	East Trail Creek near Otter, MT	1977	1980	4	31.3	45.06915330	-106.41031740	U
06307600	Hanging Woman Creek near Birney, MT	2004	2011	8	470.0	45.29554566	-106.50392640	Y
06307616	Tongue River at Birney Day School Brook near Birney, MT	1980	2011	32	2,621.0	45.41166026	-106.45780750	Y
06307717	Otter Creek below Fifteenmile Creek near Otter, MT	1983	1984	2	453.0	45.40305170	-106.14251310	U
06307740	Otter Creek at Ashland, MT	1973	1984	12	707.0	45.58388900	-106.25529180	Y
06307800	Tongue River near Ashland, MT	1967	1972	6	3,830.0	45.78333490	-106.27000940	U
06307830	Tongue River below Brandenberg Bridge near Ashland, MT	1974	1983	10	3,948.0	45.83972350	-106.21973000	U
06307990	Tongue River above T&Y Div Dam near Miles City, MT	2005	2010	6	4,508.0	46.18750218	-105.77999600	Y
06308000	Tongue River near Miles City, MT	1930	1931	2	4,539.0	46.23333560	-105.75055100	U
06308400	Pumpkin Creek near Miles City, MT	1973	1984	12	697.0	46.22833557	-105.69054870	Y
06308500	Tongue River at Miles City, MT	1947	2011	65	5,397.0	46.38472495	-105.84528000	Y
06309000	Yellowstone River at Miles City, MT	1929	2011	83	48,253.0	46.42166950	-105.86111490	Y
06309460	Beaver Creek above White Panther Ditch near Barnum, WY	1975	1988	14	24.2	43.69774310	-106.94839260	U
06309500	Middle Fork Powder River above Kaycee, WY	1950	1969	20	450.0	43.64746830	-106.80866420	U
06310000	Red Fork near Barnum, WY	1951	1952	2	142.0	43.64996926	-106.76727340	U
06310500	Middle Fork Powder River at Kaycee, WY	-	-	-	647.0	43.71663927	-106.61726600	U
06312000	North Fork Powder River near Kaycee, WY	1930	1931	2	244.0	43.76664006	-106.60059860	U
06312500	Powder River near Kaycee, WY	1941	1970	30	980.0	43.69302950	-106.53059510	U
06313000	South Fork Powder River near Kaycee, WY	1951	1968	18	1,150.0	43.61941675	-106.57726400	U

06313180	Dugout Creek Tributary near Midwest, WY	1975	1982	8	0.8	43.43663820	-106.42031040	U
06313400	Salt Creek near Sussex, WY	1983	1992	10	769.0	43.62191829	-106.36836390	U
06313500	Powder River at Sussex, WY	1986	1997	12	3,090.0	43.69708610	-106.30619440	Y
06313590	Powder River above Burger Draw near Buffalo, WY	2004	2011	8	4,290.0	44.14442367	-106.13919100	Y
06313700	Dead Horse Creek near Buffalo, WY	1972	2000	29	151.0	44.21497995	-106.11196800	U
06314500	North Fork Crazy Woman Creek below Spring Draw near Buffalo, WY	1949	1970	22	51.7	44.19386110	-106.78032820	U
06315000	North Fork Crazy Woman Creek near Greub, WY	1951	1967	17	174.0	44.08052966	-106.66310130	U
06316000	Crazy Woman Creek near Buffalo, WY	1930	1931	2	464.0	44.08886538	-106.53115160	U
06316400	Crazy Woman Creek at upper station near Arvada, WY	1964	2011	48	937.0	44.49109050	-106.17780750	Y
06316500	Crazy Woman Creek near Arvada, WY	1951	1963	13	956.0	44.48694440	-106.13944440	U
06317000	Powder River at Arvada, WY	1935	2011	77	6,050.0	44.64998226	-106.12752780	Y
06317020	Wild Horse Creek near Arvada, WY	2001	2011	11	250.0	44.63248210	-106.03196710	Y
06318500	Clear Creek near Buffalo, WY	1918	1991	74	120.0	44.33275055	-106.77727350	U
06320200	Clear Creek below Rock Creek near Buffalo, WY	1976	1980	5	322.0	44.36219670	-106.65421400	U
06320400	Clear Creek at Ucross, WY	1977	1980	4	409.0	44.55247600	-106.53560160	U
06323000	Piney Creek at Kearny, WY	1941	1996	56	118.0	44.53552818	-106.82227830	Y
06323500	Piney Creek at Ucross, WY	1950	1981	32	267.0	44.56192046	-106.53949080	U
06324000	Clear Creek near Arvada, WY	1940	1981	42	1,110.0	44.87165220	-106.08280160	Y
06324500	Powder River at Moorhead, MT	1975	2011	37	8,086.0	45.05776485	-105.87806700	Y
06324710	Powder River at Broadus, MT	1976	1980	5	8,748.0	45.42693600	-105.40193500	U
06324890	Little Powder River below Corral Creek near Weston, WY	1978	1982	5	-	44.50472220	-105.45444440	U
06324925	Little Powder River near Weston, WY	1978	1980	3	-	44.64750000	-105.31027780	U
06324970	Little Powder River above Dry Creek near Weston, WY	1973	2010	38	1,237.0	44.92692880	-105.35332680	Y
06325000	Little Powder River at Biddle, MT	1939	1942	4	1,541.0	45.10468330	-105.33073610	U
06325500	Little Powder River near Broadus, MT	1963	1971	9	1,974.0	45.39026830	-105.30471090	U

06326000	Powder River near Mizpah, MT	1929	1930	2	12,132.0	46.25000190	-105.26720220	U
06326300	Mizpah Creek near Mizpah, MT	1975	1985	11	797.0	46.26083538	-105.29331400	U
06326500	Powder River near Locate, MT	1939	2011	73	13,068.0	46.43000386	-105.30998300	Y
06326555	Cherry Creek near Terry, MT	1991	1993	3	358.0	46.85000730	-105.32470950	U
06326600	O'Fallon Creek near Ismay MT	1978	1991	14	669.0	46.42139319	-104.76162660	U
06326850	O'Fallon Creek at Mildred, MT	1976	1977	2	1,396.0	46.67222905	-104.96858100	U
06326952	Clear Creek near Lindsay, MT	1983	1984	2	101.0	47.07889900	-105.10275550	U
06327000	Upper Sevenmile Creek near Glendive, MT	1921	1922	2	-	47.11667806	-104.89885710	U
06327450	Cains Coulee at Glendive, MT	-	-	-	3.7	47.09417867	-104.71329310	U
06327500	Yellowstone River near Glendive, MT	2003	2010	8	66,739.0	47.10584540	-104.71912670	Y
06328000	Deer Creek near Glendive, MT	1921	1922	2	197.5	47.16223477	-104.70273710	U
06328200	Lower Sevenmile Creek near Bloomfield, MT	1983	1984	2	25.2	47.32779060	-104.91719150	U
06329200	Burns Creek near Savage, MT	1976	1983	8	233.0	47.37223700	-104.42994700	U
06329500	Yellowstone River near Sidney, MT	1934	2010	77	68,392.0	47.67835000	-104.15660300	Y
06329597	Charbonneau Creek near Charbonneau, ND	1967	1980	14	149.0	47.85085328	-103.79409070	U
06330000	Missouri River near Williston, ND	1929	1964	36	164,500.0	48.10807920	-103.71464460	Y
06331000	Little Muddy River below Cow Creek near Williston, ND	1955	1982	28	775.0	48.28446830	-103.57297180	Y
06331500	Little Muddy Creek near Williston, ND	1947	1953	7	1,020.0	48.19750000	-103.59722220	U
06331570	Stony Creek near Williston, ND	1978	1980	3	146.0	48.15446848	-103.57463960	U
06331680	Tobacco Garden Creek near Watford City, ND	1977	1981	5	135.0	47.99252460	-103.16629890	U
06331850	Beaver Creek near Ray, ND	1978	1981	4	102.0	48.18113268	-103.02435080	U
06332000	White Earth River at White Earth, ND	1955	1981	27	490.0	48.37640910	-102.76712640	U
06332500	Missouri River at Sanish, ND	1929	1931	3	-	47.97834930	-102.55434890	U
06332515	Bear Den Creek near Madnaree, ND	1967	2010	44	74.0	47.78723690	-102.76852560	U
06332520	Shell Creek near Parshall, ND	1966	1980	15	465.0	48.05306950	-102.13655770	U
06332523	East Fork Shell Creek near Parshall, ND	1992	2010	19	360.0	47.94862396	-102.21489300	U
06332770	Deepwater Creek at mouth near Raub, ND	1992	2010	19	220.0	47.73778499	-102.10766870	U
06334500	Little Missouri River at Camp Crook, SD	1957	2010	54	1,974.0	45.54813430	-103.97123860	Y

06335000	Little Beaver Creek near Marmarth, ND	1939	1978	40	587.0	46.27472780	-103.97631920	U
06335500	Little Missouri at Marmarth, ND	1939	2010	72	4,640.0	46.29777778	-103.91750000	Y
06335750	Deep Creek near Amidon, ND	1978	1982	5	250.0	46.57695587	-103.55769000	U
06336000	Little Missouri at Medora, ND	1946	1974	29	6,190.0	46.91945839	-103.52824260	U
06336447	Duck Creek near Wibaux, MT	1983	1984	2	46.5	46.87501280	-104.15548980	U
06336500	Beaver Creek at Wibaux, MT	1939	1968	30	351.0	46.99001356	-104.18382440	U
06336510	Hay Creek No. 2 near Wibaux, MT	1979	1981	3	11.4	46.99195810	-104.10382120	U
06336515	Hay Creek near Wibaux, MT	1979	1981	3	11.4	47.04056946	-104.13493360	U
06336545	Little Beaver Creek near Wibaux, MT	1979	1980	2	96.2	47.06223630	-104.09215400	U
06336600	Beaver Creek near Trotters, ND	1978	1982	5	616.0	47.16307028	-103.99270570	U
06337000	Little Missouri River near Watford City, ND	1935	2010	76	8,310.0	47.59029320	-103.25185720	U
06338490	Missouri River at Garrison Dam, ND	1970	2008	39	181,400.0	47.50222180	-101.43099530	Y
06339000	Missouri River below Garrison Dam, ND	1949	1968	20	181,400.0	47.38555467	-101.39377080	U
06339100	Knife River at Manning, ND	1968	2010	43	205.0	47.23612590	-102.76990740	U
06339180	Stray Creek near Manning, ND	1979	1980	2	30.3	47.21306840	-102.62323990	U
06339300	Knife River at Marshall, ND	1971	1980	10	722.0	47.13806467	-102.33378930	U
06339490	Elm Creek near Golden Valley, ND	1968	1980	13	82.0	47.10695265	-102.05183490	U
06339500	Knife River near Golden Valley, ND	1944	2010	67	1,230.0	47.15445300	-102.05989200	U
06339550	Coyote Creek near Zap, ND	1978	1982	5	65.2	47.19917470	-101.91211250	U
06339560	Brush Creek near Beulah, ND	1975	1990	16	23.9	47.17861810	-101.78516480	U
06339800	Spring Creek below Lake Ilo near Dunn Center, ND	1978	1980	3	104.0	47.34279020	-102.61796200	U
06339900	Spring Creek near Halliday, ND	1978	1982	5	235.0	47.36556497	-102.37684600	U
06340000	Spring Creek at Zap, ND	1946	2011	66	549.0	47.28611880	-101.92572600	Y
06340010	Knife River near Beulah, ND	2011	2011	1	1,880.0	47.25388889	-101.78555560	Y
06340200	West Branch Otter Creek near Beulah, ND	1966	1981	16	26.5	47.13472660	-101.66015890	U
06340500	Knife River at Hazen, ND	1938	2010	73	2,240.0	47.28528160	-101.62210930	Y
06340520	Antelope Creek above Hazen, ND	1978	1985	8	47.2	47.33528210	-101.69516740	U
06340524	West branch Antelope Creek no. 5 near Zap, ND	1978	1981	4	4.4	47.36306158	-101.90767080	U

06340528	West branch Antelope Creek no. 4 near Zap, ND	1977	1985	9	8.5	47.35583900	-101.85489240	U
06340536	West branch Antelope Creek no. 2 near Beulah, ND	1977	1979	3	28.3	47.32917230	-101.78544700	U
06340540	West branch Antelope Creek near Hazen, ND	1978	1981	4	37.7	47.31667127	-101.69127820	U
06340580	Coal Creek near Stanton, ND	1978	1980	3	15.8	47.33416830	-101.52766300	U
06340780	Alderin Creek near Fort Clark, ND	1978	1982	5	20.8	47.26916360	-101.30987870	U
06340890	Missouri River tributary no. 2 near Hensler, ND	1979	1980	2	9.8	47.27527270	-101.19737490	U
06340905	Coal Lake Coulee near Hensler, ND	1978	1988	11	70.5	48.38611740	-100.76708240	U
06340930	Buffalo Creek near Washburn, ND	1979	1982	4	57.3	47.30332750	-101.08931500	U
06341400	Turtle Creek near Turtle Lake, ND	1957	1975	19	115.0	47.45833010	-100.92125440	U
06341410	Turtle Creek above Washburn, ND	1987	2002	16	155.0	47.38499540	-100.91236400	U
06341800	Painted Woods Creek near Wilton, ND	1983	2002	20	117.0	47.27499418	-100.79207910	U
06342040	Square Butte Creek near Hannover, ND	1978	1980	3	16.9	47.13499899	-101.42570820	U
06342100	Square Butte Creek above tributary no. 2 near Center, ND	1966	1975	10	13.0	47.11110600	-101.25181530	U
06342200	Square Butte Creek above Nelson Lake near Center, ND	1978	1981	4	75.8	47.10221720	-101.25653720	U
06342230	Hagel Creek near Center, ND	1978	1981	4	45.6	47.06610570	-101.23681280	U
06342260	Square Butte Creek below Center, ND	1966	2011	46	146.0	47.05749409	-101.19570010	Y
06342450	Burnt Creek near Bismarck, ND	1968	1981	14	108.0	46.91499220	-100.81374190	U
06342500	Missouri River at Bismarck, ND	1929	2011	83	186,400.0	46.81416667	-100.82138890	Y
06342850	Norwegian Creek near Belfield, ND	1979	1980	2	39.8	46.85334570	-103.14795540	U
06342900	South Branch Heart River near South Heart, ND	1979	1981	3	132.0	46.84001180	-103.02045530	U
06342970	North Creek near South Heart, ND	1979	1980	2	40.8	46.89556786	-102.99906730	U
06343000	Heart River near South Heart, ND	1947	1969	23	311.0	46.86556000	-102.94851160	U
06344000	Heart River below Dickinson Dam near Dickinson, ND	1952	1971	20	404.0	46.86195350	-102.81656800	U
06344300	Heart River at Dickinson, ND	1984	1995	12	440.0	46.86723026	-102.73517970	U
06344500	Heart River at Lehigh, ND	1944	1951	8	443.0	46.86945237	-102.71017990	U
06344600	Green River near New Hradec, ND	1965	2010	46	152.0	47.02779158	-103.05323550	U

06344610	Green River Tributary near New Hradec, ND	1979	1980	2	22.4	47.00695780	-102.99045810	U
06345000	Green River near Gladstone, ND	1964	1974	11	356.0	46.89445210	-102.62406990	U
06345500	Heart River near Richardton, ND	1944	2011	68	1,240.0	46.74555556	-102.30833330	Y
06345780	Heart River above Lake Tschida near Glen Ullin, ND	1989	2010	22	1,530.0	46.65695060	-102.07932790	Y
06346500	Heart River below Heart Butte Dam near Glen Ullin, ND	1943	1972	30	1,710.0	46.59722860	-101.80181450	U
06347000	Antelope Creek near Carson, ND	1949	1974	26	221.0	46.54528390	-101.64542280	U
06347100	Wilson Creek near Glen Ullin, ND	1965	1969	5	41.4	46.83139198	-101.65681580	U
06347500	Big Muddy Creek near Almont, ND	1946	1969	24	456.0	46.69444606	-101.46736650	U
06348000	Heart River near Lark, ND	1947	1980	34	2,750.0	46.61027956	-101.38208940	U
06348300	Heart River at Stark Bridge near Judson, ND	1989	2010	22	2,930.0	46.70333330	-101.21361110	U
06348500	Sweetbriar Creek near Judson, ND	1952	1978	27	157.0	46.85110718	-101.25319720	Y
06349000	Heart River near Mandan, ND	1938	2012	75	3,310.0	46.83388270	-100.97457890	U
06349215	Long Lake Creek above Long Lake near Moffit, ND	1989	2003	15	280.0	46.63304455	-100.24177800	U
06349275	Long Lake Creek below Long Lake near Moffit, ND	1989	1990	2	700.0	46.69165615	-100.28650120	U
06349280	Long Lake Creek at Highway 83 bridge near Moffit, ND	2010	2011	2	-	46.69916667	-100.29083330	U
06349500	Apple Creek near Menoken, ND	1946	2011	66	1,180.0	46.79443787	-100.65734590	U
06349580	Hay Creek at 43rd Ave. near Bismarck, ND	-	-	-	20.7	46.85249286	-100.75873920	U
06349590	Hay Creek at Divide Ave. in Bimarck, ND	-	-	-	29.9	46.82277098	-100.73734900	U
06349600	Hay Creek at Main Ave. in Bismarck, ND	-	-	-	31.2	46.80721560	-100.73401530	U
06349900	Cannonball River at New England, ND	1979	1980	2	285.0	46.54306420	-102.88822330	U
06349930	Coal Bank Creek near Havelock, ND	1975	1982	8	70.0	46.46389550	-102.73933060	U
06350000	Cannonball River at Regent, ND	1951	2010	60	580.0	46.42667116	-102.55183030	U
06351000	Cannonball River below Bentley, ND	1944	1982	39	1,140.0	46.35833830	-102.04209780	U
06351200	Cannonball River near Raleigh, ND	2002	2011	10	1,640.0	46.12694760	-101.33318700	U
06351680	White Butte Fork Cedar Creek near Scranton, ND	1966	1982	17	42.9	46.32223090	-102.99627600	U

06352000	Cedar Creek near Haynes, ND	1951	2011	61	553.0	46.15528136	-102.47571330	U
06352300	Cedar Creek near Lemmon, SD	1960	1962	3	901.0	46.06666910	-102.18376560	U
06352400	Timber Creek near Bentley, ND	1978	1980	3	100.0	46.10139250	-101.95764620	U
06352500	Cedar Creek near Pretty Rock, ND	1944	1975	32	1,340.0	46.03194920	-101.83236130	U
06352525	Hay Creek near Morristown, SD	1991	1992	2	86.0	45.96083720	-101.64485540	U
06353000	Cedar Creek near Raleigh, ND	1963	2010	48	1,750.0	46.09166988	-101.33374200	U
06353500	Cannonball River near Timmer, ND	1903	1903	1	3,650.0	46.32305480	-101.00429960	U
06354000	Cannonball River at Breien, ND	1935	2010	76	4,100.0	46.37611110	-100.93444440	U
06354480	South Branch Creek near Zeeland, ND	2011	2011	1	106.0	46.11388889	-99.83694440	U
06354500	Beaver Creek at Linton, ND	1950	1988	39	617.0	46.25749005	-100.23316950	U
06354580	Beaver Creek below Linton, ND	1990	2010	21	665.0	46.26860150	-100.25261420	U
06354815	Porcupine Creek near Ft. Yates, ND	1992	1998	7	220.0	46.19332999	-100.75179600	U
06354825	One-Mile Creek near Ft. Yates, ND	1978	1979	2	19.8	46.06555266	-100.66985020	U
06354860	Spring Creek near Herreid, SD	1963	1985	23	565.0	45.81443669	-100.10817450	U
06354880	Spring Creek near Pollock, SD	1960	1961	2	1,530.0	45.88332710	-100.23373300	U
06354882	Oak Creek near Wakpala, SD	1985	2010	26	354.0	45.71194220	-100.55930150	U
06355000	North Fork Grand River at Haley, ND	1946	1994	49	509.0	45.96083639	-103.11961700	U
06355310	Buffalo Creek Tributary near Gascoyne, ND	1975	1986	12	15.7	46.11111690	-103.03933490	U
06355500	North Fork Grand River near White Butte, SD	1946	2011	66	1,202.0	45.80222000	-102.36237950	Y
06356000	South Fork Grand River at Buffalo, SD	1956	1993	38	148.0	45.57610790	-103.54435830	U
06356500	South Fork Grand River near Cash, SD	1946	1994	49	1,305.0	45.64868830	-102.64332590	U
06357500	Grand River at Shadehill, SD	1944	1987	44	2,996.0	45.75638450	-102.19598880	U
06357800	Grand River at Little Eagle, SD	1959	2010	52	5,322.0	45.65777405	-100.81819330	Y
06358000	Grand River near Wakpala, SD	1935	1963	29	5,423.0	45.66110780	-100.63930300	Y
06358500	Missouri River near Mobridge, SD	1929	1961	33	208,700.0	45.52360529	-100.47374850	U
06359000	Moreau River at Bixby, SD	1949	1968	20	1,570.0	45.14359700	-102.55877200	U
06359500	Moreau River near Faith, SD	1944	2010	67	2,596.0	45.19775826	-102.15654720	U
06360000	Moreau River near Eagle Butte, SD	1944	1957	14	4,320.0	45.18886930	-101.21848440	U

06360500	Moreau River near Whitehouse, SD	1955	2009	55	4,878.0	45.25581710	-100.84292140	U
06361000	Moreau River at Promise, SD	1934	1957	24	5,223.0	45.34498798	-100.60291870	U
06364300	Porcupine Creek near Teckla, WY	2004	2005	2	78.6	43.57802568	-105.33915130	U
06364700	Antelope Creek near Teckla, WY	1978	1980	3	959.0	43.48552560	-105.22803510	U
06365300	Dry Fork Cheyenne River near Bill, WY	1977	1980	4	128.0	43.22467180	-105.66721730	U
06365900	Cheyenne River near Dull Center, WY	2005	2010	6	1,527.0	43.42913690	-105.04580650	U
06375600	Little Thunder Creek near Hampshire, WY	1988	1997	10	434.0	43.65472220	-104.90944440	U
06376300	Black Thunder Creek near Hampshire, WY	1973	1989	17	535.0	43.58164019	-104.72024060	U
06378300	Lodgepole Creek near Hampshire, WY	1978	1980	3	-	43.56111100	-104.56111100	U
06386500	Cheyenne River near Spencer, WY	1949	1973	25	5,349.0	43.42083300	-104.13138900	Y
06425720	Belle Fourche River below Rattlesnake Creek near Piney, WY	2002	2011	10	495.0	43.98442105	-105.38832500	Y
06425750	Coal Creek near Piney, WY	1981	1982	2	71.8	43.97275430	-105.33193320	U
06425780	Belle Fourche River above Dry Creek near Piney, WY	1976	1982	7	597.0	44.02497745	-105.32693340	U
06425900	Caballo Creek at mouth near Piney, WY	1978	1982	5	260.0	44.07997827	-105.26693100	U
06425950	Raven Creek near Moorcroft, WY	1978	1982	5	-	44.16775780	-105.08692500	U
06426000	Belle Fourche River near Moorcroft, WY	1924	1929	6	1,380.0	44.27498160	-104.97692160	U
06426095	Burlington Lake ditch above Gillette, WY	1989	1989	1	-	44.30081406	-105.51361000	U
06426100	Stonepile Creek at Gillette, WY	-	-	-	11.2	44.28831370	-105.47694160	U
06426130	Donkey Creek near Gillette, WY	2001	2010	10	63.4	44.26664698	-105.43860630	Y
06426400	Donkey Creek near Moorcroft, WY	1978	1980	3	238.0	44.28275907	-105.06386960	U
06426500	Belle Fourche River below Moorcroft, WY	1944	1969	26	1,690.0	44.32192645	-104.94053130	Y
06427500	Belle Fourche River below Keyhole Reservoir, WY	1952	1994	43	1,954.0	44.38472200	-104.78055600	U
06428000	Belle Fourche River at Hulett, WY	1930	1950	21	2,800.0	44.68166700	-104.60138900	U
06428200	Belle Fourche River near Alva, WY	-	-	-	2,948.0	44.78944400	-104.48083300	U
06429905	Sand Creek near Ranch A near Beulah, WY	1977	2011	35	275.0	44.52027800	-104.08333300	U
06438500	Cheyenne River near Plainview, SD	1951	1980	30	21,414.0	44.52943040	-101.93015310	Y

06439000	Cherry Creek near Plainview, SD	1990	2004	15	1,190.0	44.74304495	-102.05349480	U
06439300	Cheyenne River at Cherry Creek, SD	1961	1993	33	23,642.0	44.59970657	-101.49792540	U
06439430	Cottonwood Creek near Cherry, SD	1983	1998	16	120.0	44.67442838	-101.40487140	U
06439500	Cheyenne River near Eagle Butte, SD	1935	1966	32	24,300.0	44.69637199	-101.21737110	Y
06467600	James River near Manfred, ND	1958	1981	24	56.0	47.64444497	-99.82817900	U
06467900	Big Slough at Hamberg, ND	1958	1967	10	42.0	47.75555940	-99.51206970	U
06468000	James River at New Rockford, ND	1951	1968	18	279.0	47.68472059	-99.12539490	U
06468170	James River near Grace City, ND	1969	2010	42	410.0	47.55805250	-98.86288500	U
06468250	James River above Arrowwood Lake near Kensal, ND	1986	2011	26	450.0	47.39971890	-98.79760570	U
06468300	Kelly Creek below Niccum reservoir near Bordulac, ND	1987	1988	2	188.0	47.40138560	-98.82955090	U
06468500	James River near Pingree, ND	1953	1967	15	670.0	47.14166070	-98.78371680	U
06469400	Pipestem Creek near Pingree, ND	1974	2011	38	260.0	47.16749480	-98.96899980	U
06469500	Pipestem Creek near Buchanan, ND	1951	1973	23	298.0	47.06638140	-98.91899800	U
06469825	Pipestem Creek below Pipestem Dam, ND	1984	1985	2	-	46.94998950	-98.75760460	U
06470000	James River at Jamestown, ND	1944	2011	68	1,170.0	46.88972220	-98.68166670	U
06643000	Bates Creek near Alcova, WY	1936	1953	18	393.0	42.67611100	-106.60250000	U
06643500	North Platte River near Goose Egg, WY	1951	1959	9	10,744.0	42.71194400	-106.55805600	U
06644000	Poison Spider Creek near Goose Egg, WY	1951	1954	4	301.0	42.77888900	-106.52944400	U
06644500	Casper Creek at Casper, WY	1947	1955	9	570.0	42.84777800	-106.36444400	U
06645000	North Platte River below Casper, WY	1930	1958	29	11,743.0	42.85888900	-106.21138900	U
06645500	North Platte River at Parkerton, WY	-	-	-	12,011.0	42.84996589	-105.98112000	U
06646500	Deer Creek at Glenrock, WY	1936	1960	25	212.0	42.86163300	-105.86778180	U
06646600	Deer Creek below Millar Wasteway at Glenrock, WY	1962	1991	30	213.0	42.86385525	-105.86611500	U
06646780	Sand Creek near Glenrock, WY	1978	1980	3	-	42.85746670	-105.76694410	U
06646800	North Platte River near Glenrock, WY	1960	1991	32	12,365.0	42.83607780	-105.75888820	U
06647000	Running Dutchman Canal near Careyhurst, WY	1936	1949	14	-	42.86663350	-105.66721770	U

06647810	Box Elder Creek at Converse County Park near Careyhurst, WY	1982	1983	2	138.0	42.76972200	-105.77250000	U
06648000	Box Elder Creek near Careyhurst, WY	1936	1968	33	202.0	42.83552240	-105.67388470	U
06648500	Douglas Canal near Orpha, WY	1936	1949	14	-	42.84691150	-105.48859930	U
06649200	La Prele Creek below La Prele Reservoir, WY	1962	1967	6	152.0	42.73138900	-105.61638900	U
06649500	La Prele Creek near Orpha, WY	1936	1969	34	177.0	42.83663370	-105.49082160	U
06650000	North Platte River near Douglas, WY	1947	1958	12	13,199.0	42.68333300	-105.39055600	U
06650500	Wagonhound Creek near La Bonte, WY	1940	1968	29	112.0	42.65972200	-105.36944400	U
06651500	La Bonte Creek near La Bonte, WY	1936	1968	33	287.0	42.65000000	-105.35722200	U
06652000	North Platte River at Orin, WY	1959	2011	53	13,822.0	42.65250000	-105.15861100	Y
44385510-6051201	Wild Horse Creek tributary 0.2 miles above mouth near Arvada, WY	2005	2005	1	-	44.64897220	-106.08819440	Y
47573010-6550702	Lone Tree Creek tributary near Glasgow, MT	1984	1985	2	-	47.95834468	-106.91923350	U
05HA003	Bear Creek near Piapot, SK	-	-	-	97.7	49.89944400	-109.10611100	Y
05HC005	Antelope Creek near Cabri, SK	-	-	-	94.2	50.66194400	-108.38138900	Y
05HD036	Swift Current Creek below Rock Creek, SK	1979	2010	32	552.1	49.84444400	-108.47944400	N
05HD039	Swift Current Creek near Leinan, SK	1973	2002	30	1,003.9	50.49388900	-107.65861100	Y
05JA002	Wood River near LaFleche, SK	-	-	-	1,826.3	49.66694400	-106.69250000	Y
05JA003	McDonald Creek near McCord, SK	-	-	-	100.0	49.43722200	-106.83472200	N
05JA005	Wood River near McCord, SK	-	-	-	-	-	-	U
05JA006	Six Mile Creek near Glentworth, SK	-	-	-	-	-	-	U
05JB001	Notukeu Creek near Vanguard, SK	-	-	-	1,366.8	49.91750000	-107.18555600	Y
05JB004	Notukeu Creek above Admiral Reservoir, SK	-	-	-	175.3	49.70888900	-108.12527800	N
05JB007	Mosquito Creek near PaMBrun, SK	-	-	-	48.3	49.97694400	-107.43666700	N
05JC004	Rushlake Creek above Highfield Reservoir, SK	-	-	-	125.5	50.25333300	-107.46833300	N
05JE006	Moose Jaw River near Burdick, SK	1973	2010	38	1,339.8	50.40027800	-105.39777800	Y
05JF001	Qu'appelle River below Lumsden, SK	1968	2010	43	2,683.4	50.65027800	-104.86666700	Y
05JF005	Wascana Creek near Lumsden, SK	1973	2010	38	671.8	50.63611100	-104.90972200	Y

05JF006	Boggy Creek near Lumsden, SK	-	-	-	120.5	50.59861100	-104.81805600	Y
05JF011	Cottonwood Creek near Lumsden, SK	-	-	-	86.5	50.59055600	-104.90861100	N
05JG006	Elbow Diversion Canal at Drop Structure, SK	-	-	-	0.0	50.97777800	-106.39861100	Y
05JG013	Ridge Creek near Bridgeford, SK	-	-	-	72.6	50.95138900	-106.32944400	N
05JH004	Last Mountain Lake at Rowan's Ravine, SK	1965	2011	47	1,081.1	50.99777800	-105.18555600	Y
05JK002	Qu'appelle River below Craven Dam, SK	1955	2010	56	4,015.4	50.70638900	-104.79777800	Y
05JK004	Jumping Deer Creek near Lipton, SK	-	-	-	65.6	50.91944400	-103.89916700	Y
05JK007	Qu'appelle River below Loon Creek, SK	1971	2010	40	4,285.7	50.78638900	-104.28916700	Y
05JL005	Pheasant Creek near Abernethy, SK	-	-	-	133.2	50.73416700	-103.32777800	Y
05JM001	Qu'appelle River near Welby, SK	1975	2010	36	6,602.3	50.49111100	-101.55777800	Y
05JM010	Ekapo Creek near Marieval, SK	-	-	-	424.7	50.52972200	-102.71027800	N
05JM015	Cutarm Creek near Spy Hill, SK	-	-	-	153.7	50.59083300	-101.74277800	Y
05ME006	Assiniboine River near Miniota, MB	1962	2009	48	32,509.6	50.11027800	-101.03583300	Y
05ME007	Smith Creek near Marchwell, SK	-	-	-	22.3	50.83277800	-101.57861100	N
05MF018	Little Saskatchewan River near Rivers, MB	1956	1996	41	1,501.9	50.02361100	-100.20750000	Y
05MF020	Lake Wahtopanah near Rivers, MB	1960	2010	51	1,501.9	50.02944400	-100.20333300	Y
05MG001	Arrow River near Arrow River, MB	-	-	-	234.0	50.09250000	-100.95583300	N
05MG003	Gopher Creek near Virden, MB	-	-	-	116.2	49.78333300	-100.96638900	N
05MG004	Oak River near Rivers, MB	1969	1982	14	451.7	50.02555600	-100.39416700	Y
05MG014	Assiniboine River east of Virden, MB	2012	2012	1	33,437.8	49.87527800	-100.84888900	Y
05MG015	Baileys Creek near Oak Lake, MB	2012	2012	1	0.0	49.87138900	-100.67222200	N
05MH006	Little Souris River near Brandon, MB	-	-	-	248.6	49.73194400	-99.84861100	N
05MH013	Assiniboine River near Brandon, MB	1974	2010	37	36,177.6	49.87055600	-100.10000000	Y
05NA003	Long Creek at Western Crossing of International Boundary, SK	1959	2007	49	1,239.4	49.00027800	-103.35222200	Y
05NA005	Gibson Creek near Radville, SK	-	-	-	203.9	49.48388900	-104.33638900	Y
05NB001	Long Creek near Estevan, SK	1960	2010	51	1,868.7	49.10416700	-103.01333300	Y
05NB011	Yellow Grass Ditch near Yellow Grass, SK	-	-	-	1,023.2	49.78638900	-104.03777800	Y
05NB014	Jewel Creek near Goodwater, SK	-	-	-	81.5	49.38611100	-103.71166700	Y

05NB017	Souris River near Halbrite, SK	-	-	-	-	-	-	U
05NB018	Tatagwa Lake Drain Near Weyburn, SK	-		-	92.7	49.59944400	-103.94722200	Y
05NB020	Nickle Lake near Weyburn, SK	-	-	-	1,428.6	49.57555600	-103.76888900	Y
05NB021	Short Creek near Roche Percee, SK	1960	2010	51	467.2	49.03111100	-102.84916700	Y
05NB032	Rafferty Reservoir near Estevan, SK	-	-	-	2,390.0	49.14611100	-103.09388900	Y
05NB033	Moseley Creek near Halbrite, SK	-	-	-	22.6	49.49444400	-103.62944400	N
05NB034	Roughbark Creek Near Goodwater, SK	-	-	-	-	-	-	U
05NB035	Cooke Creek Near Goodwater, SK	-	-	-	49.8	49.35194400	-103.61305600	N
05NB036	Souris River Below Rafferty Reservoir, SK	-	-	-	2,393.8	49.14333300	-103.08222200	Y
05NB038	Boundary Reservoir Diversion Canal Near Estevan, SK	-	-	-	-	49.14750000	-103.10861100	Y
05NB039	Tributary near Outram, SK	-	-	-	36.4	49.17305600	-103.30333300	Y
05NB040	Souris River Near Ralph, SK	-		-	-	49.53111100	-103.67777800	Y
05NB041	Roughbark Creek Above Rafferty Reservoir, Sk	-	-	-	-	49.46388900	-103.68333300	Y
05NC002	Moose Mountain Lake (Reservoir) Near Corning, SK	-	-	-	768.3	49.89361100	-103.03027800	Y
05ND004	Moose Mountain Creek near Oxbow, SK	1991	2010	20	2,335.9	49.23277800	-102.22805600	Y
05ND010	Moose Mountain Creek above Alameda Reservoir, SK	1992	2010	19	1,818.5	49.52277800	-102.16972200	Y
05ND011	Shepherd Creek near Alameda, SK	-	-	-	67.6	49.34722200	-102.25694400	N
05ND012	Alameda Reservoir near Alameda, SK	-	-	-	2,332.0	49.26027800	-102.22861100	Y
05NE002	Moosomin Lake near Moosomin, SK	-	-	-	1,405.4	50.05027800	-101.69027800	Y
05NE003	Pipestone Creek above Moosomin Reservoir, SK	-	-	-	1,054.1	50.15250000	-101.83583300	N
05NF001	Souris River at Melita, MB	1915	1917	3	19,266.4	49.26666700	-100.97694400	Y
05NF002	Antler River near Melita, MB	1978	1996	19	1,243.2	49.05722200	-101.04916700	N
05NF006	Lightning Creek near Carnduff, SK	-	-	-	288.8	49.22138900	-101.71888900	N
05NF007	Gainsborough Creek near Lyleton, MB	-	-	-	444.0	49.09472200	-101.18277800	Y
05NF008	Graham Creek near Melita, MB	-	-	-	286.1	49.26250000	-100.99805600	N
05NF010	Antler River near Wauchope, SK	-	-	-	134.4	49.58416700	-101.84777800	N

05NG001	Souris River At Wawanesa, MB	-	-	-	23,590.7	49.59777800	-99.68138900	Y
05NG003	Pipestone Creek near Pipestone, MB	1957	1993	37	1,637.1	49.59527800	-100.94333300	N
05NG007	Plum Creek near Souris, MB	1957	1981	25	2,092.7	49.62583300	-100.30333300	Y
05NG010	Oak Creek Near Stockton, MB	-	-	-	397.7	49.56194400	-99.51166700	N
05NG012	Elgin Creek near Souris, MB	-	-	-	204.6	49.59000000	-100.23555600	N
05NG020	Medora Creek near Napinka, MB	-	-	-	385.3	49.32583300	-100.70361100	N
05NG021	Souris River at Souris, MB	-	-	-	22,934.3	49.61944400	-100.24583300	Y
05NG023	Whitewater Lake near Boissevain, MB	1970	2011	42	260.2	49.26611100	-100.35277800	Y
05NG023	Whitewater Lake, MB	-	-	-	-	-	-	Y
05NG024	Pipestone Creek near Saskatchewan Boundary, MB	-	-	-	-	-	-	U
05OA001	Pembina River north of Killarney, MB	1921	1928	8	175.7	49.22083300	-99.72055600	N
05OA006	Long River near Holmfield, MB	-	-	-	221.6	49.14750000	-99.41416700	Y
05OA007	Badger Creek near Cartwright, MB	1972	1996	25	586.9	49.10444400	-99.32555600	N
05OA010	Pembina River above Lorne Lake, MB	-	-	-	221.2	49.26333300	-99.46388900	Y
05OA017	Tributary Creek near Ninette, MB	2012	2012	1	70.7	49.40361100	-99.64000000	N
05OB010	Cypress Creek near Clearwater, MB	-	-	-	153.3	49.08861100	-98.98277800	N
05OB023	Pembina River below Crystal Creek, MB	1964	1996	33	1,729.7	49.22138900	-99.03444400	Y
05OB027	Rock Lake near Glenora, MB	1988	2010	23	1,401.5	49.20750000	-99.13416700	Y
11AC017	Frenchman River near Ravenscrag, SK	-	-	-	466.0	49.49166700	-109.08861100	Y
11AC025	Denniel Creek near Val Marie, SK	-	-	-	190.7	49.30722200	-107.70333300	N
11AC052	Eastend Canal near Eastend, SK	-	-	-	-	49.50583300	-108.84833300	Y
11AC054	Newton Lake Main Canal, SK	-	-	-	-	49.30500000	-107.80138900	Y
11AC055	Eastend Reservoir, SK	-	-	-	617.8	49.50722200	-108.85138900	Y
11AC056	Newton Lake, SK	-	-	-	1,347.5	49.30333300	-107.80555600	Y
11AC063	Huff Lake, SK	-	-	-	-	49.37111100	-107.88527800	Y
11AC065	Huff Lake Gravity Canal, SK	-	-	-	-	49.36944400	-107.88500000	Y
11AC066	Huff Lake Pumping Canal, SK	-	-	-	-	49.37222200	-107.88333300	Y
11AC068	Val Marie Pump No. 1, SK	-	-	-	-	49.36222200	-107.84750000	Y

Appendix B: Selected Stream Gauges Used in Analysis

ID	Station number	Stream gauge name	Total years of record	September/ October baseflow estimates (ft^3/s)	September/ October streamflow (ft^3/s)	September /October BFI	Drainage area (mi^2)	Regulated[a]
1	06439500	Cheyenne River near Eagle Butte, SD	32	178.01	295.20	60.3%	24,300.0	Y
2	06439300	Cheyenne River at Cherry Creek, SD	33	214.34	344.50	62.2%	23,642.0	U
3	06438500	Cheyenne River near Plainview, SD	30	185.83	290.51	64.0%	21,414.0	Y
4	06439000	Cherry Creek near Plainview, SD	62	0.92	4.74	19.4%	1,190.0	U
5	06360500	Moreau River near Whitehouse, SD	55	9.15	39.07	23.4%	4,878.0	U
6	06360000	Moreau River near Eagle Butte, SD	14	11.29	28.29	39.9%	4,320.0	U
7	06359500	Moreau River near Faith, SD	67	7.49	24.36	30.7%	2,596.0	U
8	06359000	Moreau River at Bixby, SD	20	1.97	5.09	38.7%	1,570.0	U
9	06357800	Grand River at Little Eagle, SD	52	52.69	87.64	60.1%	5,322.0	Y
10	06357500	Grand River at Shadehill, SD	44	39.00	49.81	78.3%	2,996.0	U
11	06356500	South Fork Grand River near Cash, SD	49	9.51	18.45	51.5%	1,305.0	U
12	06356000	South Fork Grand River at Buffalo, SD	38	1.93	4.62	41.8%	148.0	U
13	06355500	North Fork Grand River near White Butte, SD	66	2.58	4.48	57.6%	1,202.0	Y
14	06355000	North Fork Grand River at Haley, ND	49	1.33	2.09	63.6%	509.0	U
15	06354000	Cannonball River at Breien, ND	76	17.72	32.73	54.1%	4,100.0	U
16	06353000	Cedar Creek near Raleigh, ND	48	4.96	9.26	53.6%	1,750.0	U
17	06352500	Cedar Creek near Pretty Rock, ND	32	2.63	4.22	62.3%	1,340.0	U
18	06352300	Cedar Creek near Lemmon, SD	3	0.25	0.46	54.3%	901.0	U
19	06352000	Cedar Creek near Haynes, ND	61	2.60	3.98	65.3%	553.0	U
20	06351200	Cannonball River near Raleigh, ND	10	7.00	9.93	70.5%	1,640.0	U
21	06351000	Cannonball River below Bentley, ND	39	7.56	11.65	64.9%	1,140.0	U
22	06350000	Cannonball River at Regent, ND	60	3.99	6.38	62.5%	580.0	U
23	-	Missouri River inflow at Lake Oahe, ND[b]	44	-	21,364.00	-	-	Y
24	06342500	Missouri River at Bismarck, ND	83	13,233.51	20,528.00	64.5%	186,400.0	Y

25	06349000	Heart River near Mandan, ND	75	47.31	65.41	72.3%	3,310.0	U
26	06348300	Heart River at Stark Bridge near Judson, ND	22	39.72	58.85	67.5%	2,930.0	U
27	06348000	Heart River near Lark, ND	34	36.10	53.63	67.3%	2,750.0	U
28	06347500	Big Muddy Creek near Almont, ND	24	0.86	1.91	45.0%	456.0	U
29	06345780	Heart River above Lake Tschida near Glen Ullin, ND	22	12.81	19.71	65.0%	1,530.0	Y
30	06345500	Heart River near Richardton, ND	68	10.01	16.79	59.6%	1,240.0	Y
31	06344500	Heart River at Lehigh, ND	8	2.00	3.71	53.9%	443.0	U
32	06344300	Heart River at Dickinson, ND	12	2.62	5.26	49.8%	440.0	U
33	06344000	Heart River below Dickinson dam near Dickinson, ND	20	0.46	1.29	35.7%	404.0	U
34	06343000	Heart River near South Heart, ND	23	0.39	1.02	38.2%	311.0	U
35	-	MIssouri River outflow at Garrison Dam, ND[b]	44	-	19,853.00	-	-	Y
36	06340500	Knife River at Hazen, ND	73	25.73	37.25	69.1%	2,240.0	Y
37	06339500	Knife River near Golden Valley, ND	67	6.36	14.08	45.2%	1,230.0	U
38	06339300	Knife River at Marshall, ND	10	6.82	14.99	45.5%	722.0	U
39	06339100	Knife River at Manning, ND	43	0.75	3.45	21.7%	205.0	U
40	06337000	Little Missouri River near Watford City, ND	76	53.01	156.60	33.9%	8,310.0	U
41	06336000	Little Missouri at Medora, ND	29	38.90	114.83	33.9%	6,190.0	U
42	06335500	Little Missouri at Marmarth, ND	72	24.52	85.93	28.5%	4,640.0	Y
43	06334500	Little Missouri River at Camp Crook, SD	54	9.54	35.53	26.9%	1,974.0	Y
44	06470000	James River at Jamestown, ND	68	82.04	116.08	70.7%	1,170.0	U
45	06468500	James River near Pingree, ND	15	5.85	8.36	70.0%	670.0	U
46	06468000	James River at New Rockford, ND	18	1.84	2.20	83.6%	279.0	U
47	06467600	James River near Manfred, ND	24	0.17	0.27	63.0%	56.0	U
48	05056000	Sheyenne River near Warwick, ND	62	19.96	27.16	73.5%	760.0	U
49	05055500	Sheyenne River at Sheyenne, ND	11	1.15	3.53	32.6%	660.0	U
50	05055300	Sheyenne River above Devils Lake state outlet near Flora, ND	8	22.07	28.06	78.7%	591.0	U
51	05055000	Sheyenne River near Harvey, ND	10	0.38	0.73	52.1%	174.0	U
52	05054500	Sheyenne River above Harvey, ND	56	2.75	3.69	74.5%	154.0	U

53	05056100	Mauvais Coulee near Cando, ND	25	2.33	3.16	73.7%	377.0	Y
54	05MH013	Assiniboine River near Brandon, MB	37	630.40	715.41	88.1%	36,178.0	Y
55	05ME006	Assiniboine River near Miniota, MB	48	286.50	442.50	64.7%	32,510.0	Y
56	05NF001	Souris River at Melita, MB	3	12.04	29.50	40.8%	19,266.4	Y
57	05124000	Souris River near Westhope, ND	81	68.20	101.23	67.4%	6,600.0	Y
58	05122000	Souris River near Bantry, ND	74	70.47	85.77	82.2%	4,700.0	Y
59	05120000	Souris River near Verendrye, ND	74	46.62	66.81	69.8%	4,400.0	Y
60	05117500	Souris River above Minot, ND	97	23.74	34.41	69.0%	3,900.0	Y
61	05116000	Souris River near Foxholm, ND	62	28.89	44.28	65.2%	3,270.0	Y
62	05114000	Souris River near Sherwood, ND	81	16.79	22.92	73.3%	3,040.0	Y
63	05ND004	Moose Mountain Creek near Oxbow, SK	20	4.71	13.43	35.1%	2,335.9	Y
64	05ND010	Moose Mountain Creek above Alameda Reservoir, SK	19	3.12	4.10	76.1%	1,818.5	Y
65	05NB001	Long Creek near Estevan, SK	51	1.51	5.98	25.3%	1,868.7	Y
66	05NA003	Long Creek at Western Crossing of International Boundary, SK	49	0.55	1.52	36.2%	1,239.4	Y
67	05JE006	Moose Jaw River near Burdick, SK	38	5.38	9.64	55.8%	1,340.0	Y
68	06331500	Little Muddy Creek near Williston, ND	7	9.02	10.98	82.1%	1,020.0	U
69	06331000	Little Muddy River below Cow Creek near Williston, ND	28	7.98	9.00	88.7%	775.0	Y
70	06330000	Missouri River near Williston, ND	36	10,367.66	18,403.38	56.3%	164,500.0	Y
71	06185500	Missouri River near Culbertson, MT	53	6,876.25	8,848.46	77.7%	91,557.0	Y
72	06185110	Big Muddy Creek near mouth near Culbertson, MT	10	6.09	11.45	53.2%	2,684.0	U
73	06185000	Big Muddy Creek near Culbertson, MT	12	5.46	10.32	52.9%	2,447.0	U
74	06183450	Big Muddy Creek near Antelope, MT	29	15.93	18.48	86.2%	967.0	Y
75	06183000	Big Muddy Creek at Plentywood, MT	4	2.54	6.62	38.4%	850.0	U
76	06182500	Big Muddy Creek at Daleview, MT	24	1.05	1.95	53.8%	279.0	U
77	06181000	Poplar River near Poplar, MT	30	16.19	20.03	80.8%	3,174.0	Y
78	06179000	East Fork Poplar River near Scobey, MT	3	2.18	3.37	64.7%	722.0	U
79	06177825	Redwater River near Vida, MT	9	3.21	4.93	65.1%	1,974.0	U

80	06177500	Redwater River at Circle, MT	29	0.71	3.12	22.8%	547.0	Y
81	06177000	Missouri River near Wolf Point, MT	83	5,988.78	9,894.75	60.5%	82,290.0	Y
82	06132000	Missouri River below Fort Peck Dam, MT	56	7,435.20	11,555.90	64.3%	57,556.0	Y
83	06174500	Milk River at Nashua, MT	72	147.47	282.36	52.2%	22,332.0	Y
84	06172310	Milk River at Tampico, MT	5	25.34	106.35	23.8%	21,078.0	Y
85	06172000	Milk River near Vandalia, MT	10	80.40	207.02	38.8%	20,926.0	U
86	06164510	Milk River at Juneberg Bridge near Saco, MT	24	104.60	171.46	61.0%	17,670.0	U
87	06155500	Milk River at Malta, MT	11	105.54	214.02	49.3%	11,762.0	U
88	06131000	Big Dry Creek near Van Norman, MT	35	4.63	14.71	31.5%	2,554.0	Y
89	06115200	Missouri River near Landusky, MT	77	5,234.55	6,354.98	82.4%	40,987.0	Y
90	06115000	Missouri River Power Plant Ferry near Zortman, MT	33	4,477.32	5,974.72	74.9%	40,763.0	U
91	06130500	Musselshell River at Mosby, MT	77	61.10	99.31	61.5%	7,846.0	Y
92	06127600	Musselshell River near Mosby, MT	3	94.91	134.02	70.8%	5,941.0	U
93	06329500	Yellowstone River near Sidney, MT	77	5,014.57	7,335.16	68.4%	68,392.0	Y
94	06327500	Yellowstone River near Glendive, MT	8	4,975.64	6,372.60	78.1%	66,739.0	Y
95	06326600	O'Fallon Creek near Ismay, MT	14	0.22	0.90	24.4%	669.0	U
96	06309000	Yellowstone River at Miles City, MT	83	5,696.34	7,371.62	77.3%	48,253.0	Y
97	06296120	Yellowstone River near Miles City, MT	9	6,888.41	8,756.23	78.7%	42,847.0	U
98	06295000	Yellowstone River at Forsyth, MT	34	5,663.24	6,970.02	81.3%	39,455.0	Y
99	06214500	Yellowstone River at Billings, MT	83	3,464.96	3,971.98	87.2%	11,408.0	Y
100	06294700	Bighorn River at Bighorn, MT	35	2,035.94	3,074.21	0.0%	22,885.0	U
101	06294500	Bighorn River above Tullock Creek near Bighorn, MT	66	2,057.80	2,946.48	0.0%	22,414.0	Y
102	06288500	Bighorn River near Hardin, MT	20	2,345.21	2,919.36	0.0%	20,722.0	U
103	06294000	Little Bighorn River near Hardin, MT	58	110.53	140.00	0.0%	1,294.0	Y
104	06293500	Little Bighorn River near Crow Agency, MT	21	95.69	125.95	0.0%	1,181.0	U
105	06290500	Little Bighorn River below Pass Creek near Wyola, MT	27	98.36	107.22	0.0%	428.0	U
106	06296003	Rosebud Creek at mouth near Rosebud, MT	31	3.94	7.66	51.4%	1,302.0	U
107	06296000	Rosebud Creek near Forsyth, MT	4	2.02	7.52	26.9%	1,279.0	U

108	06295500	Rosebud Creek near Rosebud MT	4	0.06	9.31	0.6%	1,193.0	U
109	06295250	Rosebud Creek near Colstrip MT	31	5.77	7.17	80.5%	799.0	Y
110	06295113	Rosebud Creek at Reservation Boundary near Kirby, MT	31	1.76	2.18	80.7%	123.0	Y
111	06295100	Rosebud Creek near Kirby MT	3	0.00	0.00	0.0%	35.5	U
112	06308500	Tongue River at Miles City, MT	65	163.63	209.40	78.1%	5,397.0	Y
113	06307990	Tongue River above T&Y Div Dam near Miles City, MT	6	192.77	230.55	83.6%	4,508.0	Y
114	06307830	Tongue River below Brandenberg Bridge near Ashland, MT	10	263.72	301.63	87.4%	3,948.0	U
115	06307800	Tongue River near Ashland, MT	6	319.52	375.48	85.1%	3,830.0	U
116	06307616	Tongue River at Birney Day School Brook near Birney, MT	32	218.71	258.63	84.6%	2,621.0	Y
117	06307500	Tongue River at Tongue River Dam near Decker, MT	72	245.14	278.96	87.9%	1,770.0	Y
118	06306500	Tongue River near Decker, MT	9	95.59	140.16	68.2%	1,585.0	U
119	06306300	Tongue River at State Line near Decker, MT	51	184.05	229.12	80.3%	1,453.0	Y
120	06306000	Tongue River near Acme, WY	18	140.14	178.08	78.7%	894.0	U
121	06299980	Tongue River at Monarch, WY	7	81.92	100.36	81.6%	478.0	Y
122	06326500	Powder River near Locate, MT	73	95.79	203.06	47.2%	13,068.0	Y
123	06325500	Little Powder River near Broadus, MT	9	3.94	9.77	40.3%	1,974.0	U
124	06325000	Little Powder River at Biddle, MT	4	0.39	7.77	5.0%	1,541.0	U
125	06324970	Little Powder River above Dry Creek near Weston, WY	38	1.51	6.66	22.7%	1,237.0	Y
126	06324710	Powder River at Broadus, MT	5	123.76	216.65	57.1%	8,748.0	U
127	06324500	Powder River at Moorhead, MT	37	101.96	206.45	49.4%	8,086.0	Y
128	06317000	Powder River at Arvada, WY	77	36.86	102.07	36.1%	6,050.0	Y
129	06313590	Powder River above Burger Draw near Buffalo, WY	8	38.35	77.75	49.3%	4,290.0	Y
130	06313500	Powder River at Sussex, WY	12	62.49	128.57	48.6%	3,090.0	Y
131	06312500	Powder River near Kaycee, WY	30	35.14	50.51	69.6%	980.0	U
132	06313000	South Fork Powder River near Kaycee, WY	18	7.59	24.51	31.0%	1,150.0	U
133	06427500	Belle Fourche River below Keyhole Reservoir, WY	43	6.31	8.89	71.0%	1,954.0	U

134	06426500	Belle Fourche River below Moorcroft, WY	26	0.39	2.71	14.4%	1,690.0	Y
135	06426000	Belle Fourche River near Moorcroft, WY	6	2.96	8.78	33.7%	1,380.0	U
136	06425780	Belle Fourche River above Dry Creek near Piney, WY	7	0.23	0.94	24.5%	597.0	U
137	06425720	Belle Fourche River below Rattlesnake Creek near Piney, WY	10	0.25	0.43	58.1%	495.0	Y
138	06386500	Cheyenne River near Spencer, WY	25	0.87	16.31	5.3%	5,349.0	Y
139	06365900	Cheyenne River near Dull Center, WY	35	0.00	0.01	28.6%	1,527.0	U
140	06364700	Antelope Creek near Teckla, WY	3	0.20	0.29	69.0%	959.0	U
141	06650000	North Platte River near Douglas, WY	12	701.67	1,164.95	60.2%	13,199.0	U
142	06646800	North Platte River near Glenrock, WY	32	1,051.37	1,379.06	76.2%	12,365.0	U
143	06645000	North Platte River below Casper, WY	29	776.98	1,047.96	74.1%	11,743.0	U

[a] Regulated is if known diversions, withdrawals, or dams are upstream of the stream gauge [Y, yes; N, no; U, unknown].
[b] Simulated stream gauges from U.S. Army Corps of Engineer data.

Appendix C: Base-Flow Analysis of Selected Stream Gauges in the Powder River Basin

Appendix C: Base-Flow Analysis of Selected Stream Gauges in the Powder River basin

Station Number	Station Name	Drainage Area (mi^2)
06307740	Otter Creek at Ashland, Montana	707
06308400	Pumpkin Creek near Miles City, Montana	697
06324970	Little Powder River above Dry Creek near Weston, Wyoming	1,230
06376300	Black Thunder Creek near Hampshire, Wyoming	535

	Lowry and Rankl (1990)		Druse and others (1981)				Base-flow estimates from this study (2013)		
Station Number	**Base-Flow Estimates (ft^3/s)**	**Period of Record (years)**	**Base-Flow Estimates (ft^3/s)**	**Period of Record**	**Base-Flow Estimates (ft^3/s)**	**Period of Record**	**PART Estimates (ft^3/s)**	**Streamflow Averages (ft^3/s)**	**Period of Record (years)**
06307740	4.00	1972-1977	1.82	August - September 1978	4.23	October 1978	0.89	1.84	1973-1984
06308400	0.00	1972-1977	0.03	August - September 1978	0.27	October 1978	0.06	0.02	1973-1984
06324970	1.00	1972-1977	3.44	August - September 1978	1.82	October 1978	1.51	6.66	1973-2010
06376300	0.00	1972-1977	0.12	August - September 1978	--	October 1978	0.06	0.38	1973-1989

Appendix D: Individual Stream Reach Analysis Results

Powder River structural basin					
River Systems	**Downstream stream gauge**	**Upstream stream gauge**	**Flow rate, in ft^3/s (values from streamflow data)[a]**	**Flow rate, in ft^3/s (values from PART)[a]**	**Flow rate, in ft^3/s (final estimated value)[a]**
Antelope Creek					
	140	None	-0.29	-0.2	-0.2
Belle Fourche River					
	133	134	-6.18	-5.92	-5.92
	134	135	6.07	2.57	6.07 [b]
	135	136	-7.84	-2.73	-2.73
	136	137	-0.51	-0.02	-0.02
	137	None	-0.43	-0.25	-0.25
Bighorn River					
	100	101	-127.73	21.86	-127.73
	101	102, 103	112.88	397.94	852.88 [b]
	103	104	-14.05	-14.84	-14.84
	104	105	-18.73	2.67	-18.73
Cheyenne River					
	138	139	-16.3	-0.87	-0.87
	139	140	0.28	0.2	11.28 [b]

Little Powder River					
	123	124	-2	-3.55	-3.55
	124	125	-1.11	1.12	-1.11
	125	None	-6.66	-1.51	-1.51
North Platte River					
	141	142	214.11	349.7	214.11
	142	143	-331.1	-274.39	-274.39
Powder River					
	122	126, 123	23.36	31.91	23.36
	126	127	-10.2	-21.8	-21.8
	127	128	-104.38	-65.1	-65.1
	128	129	-24.32	1.49	-24.32
	129	130	50.82	24.14	50.82
	130	131, 132	-53.55	-19.76	-19.76
Rosebud Creek					
	106	107	-0.14	-1.92	-1.92
	107	108	1.79	-1.96	1.79
	108	109	-2.14	5.71	-2.14
	109	110	-4.99	-4.01	-4.01
	110	111	-2.18	-1.76	-1.76
	111	None	0	0	0

Tongue River						
	113	114	71.08	70.95	71.08	
	114	115	73.85	55.8	145.85	b
	115	116	-116.85	-100.81	-100.81	
	116	117	20.33	26.43	47.33	b
	117	118	-138.8	-149.55	-149.55	
	118	119	88.96	88.46	88.96	
	119	120	-51.04	-43.91	-43.91	
	120	121	-77.72	-58.22	-58.22	
	121	None	-100.36	-81.92	-81.92	
Yellowstone River						
	97	98, 106	-1778.55	-1221.23	-1221.23	
	98	99, 100	76.17	-162.34	76.17	
Total stream recharge to groundwater for study area					1590	
Total discharge to streams from groundwater for study area					-2248	

Williston structural basin					
River systems	**Downstream stream gauge**	**Upstream stream gauge**	**Flow rate, in ft^3/s (values from streamflow data)[a]**	**Flow rate, in ft^3/s (values from PART)[a]**	**Flow rate, in ft^3/s (final estimated value)[a]**
Assiniboine River					
	54	55	272.91	-343.5	-343.5
	55	None	-442.5	-286.5	-286.5
Big Coulee					
	53	None	-3.16	-2.33	-2.33
Big Dry Creek					
	88	None	-14.71	-4.63	-4.63
Big Muddy Creek					
	72	73	-1.32	-0.66	-0.66
	73	74	8.16	10.47	8.16
	74	75	-11.86	-13.39	-13.39
	75	76	-4.67	-1.49	-1.49
	76	None	-1.95	-1.05	-1.05
Cannonball River					
	15	20, 16	-13.54	-5.76	-5.76
	20	21	1.73	0.56	1.73
	21	22	-5.27	-3.57	-3.57
	22	None	-6.38	-3.99	-3.99

Cedar Creek					
	16	17	-5.04	-2.33	-2.33
	17	18	-3.76	-2.38	-2.38
	18	19	3.52	2.35	3.52
	19	None	-3.98	-2.6	-2.6
Cherry Creek					
	4	None	-4.74	-0.92	-0.92
Cheyenne River					
	1	2	49.3	36.33	49.3
	2	3, 4	-49.25	-27.59	-27.59
Grand River					
	9	10	-37.65	-13.69	-13.69
	10	11, 13	-26.88	-29.49	-29.49
	11	12	-13.83	-7.58	-7.58
	12	None	-4.62	-1.93	-1.93
	13	14	-2.39	-1.25	-1.25
	14	None	-2.09	-1.33	-1.33
Heart River					
	25	26	-6.563	-7.59	-7.59
	26	27	-5.22	-3.62	-3.62
	27	28, 29	-32.01	-22.43	-22.43
	29	30	-2.92	-2.8	-2.8
	30	31	-13.08	-8.01	-8.01
	31	32	1.55	0.62	1.55

	32	33	-3.97	-2.16	-2.16
	33	34	-0.27	-0.07	-0.07
	34	None	-1.02	-0.39	-0.39
	28	None	-1.91	-0.86	-0.86
James River					
	44	45	-107.72	-76.19	-76.19
	45	46	-6.16	-4.01	-4.01
	46	47	-1.93	-1.67	-1.67
	47	None	-0.22	-0.17	-0.17
Knife River					
	36	37	-23.17	-19.37	-19.37
	37	38	0.91	0.46	0.91
	38	39	-11.54	-6.07	-6.07
	39	None	-3.45	-0.75	-0.75
Little Missouri River					
	40	41	-41.77	-14.11	-14.11
	41	42	-28.9	-14.38	-14.38
	42	43	-50.4	-15	-15
	43	None	-35.53	-9.54	-9.54
Little Muddy River					
	68	69	-1.98	-1.04	-1.04
	69	None	-9	-7.98	-7.98

Long Creek					
	65	66	-4.46	-0.96	-0.96
	66	None	-1.52	-0.55	-0.55
Missouri River					
	23	24, 25	-770.59	-	-770.59
	24	35, 36	-637.75	-	-637.75
	35	71, 93	-2219.76	1523.16	-2219.76
	70	86, 72, 79, 77	1082.7	-861.98	1082.7
	71	86, 72, 79, 77	1082.7	-861.98	541.35
	81	82, 83	1943.51	1593.89	1943.51
	82	82, 83	1943.51	1593.89	0
	89	90	-380.26	-757.23	-757.23
Milk River					
	83	84	-176.01	-122.13	-122.13
	84	85	100.67	55.06	100.67
	85	86	-35.56	24.2	-35.56
	86	87	42.56	0.94	42.56
	87	None	-380.26	-105.54	-105.54
Moose Jaw River					
	67	None	-9.64	-5.38	-5.38
Moose Mountain Creek					
	63	64	-9.33	-1.59	-1.59
	64	None	-4.1	-3.12	-3.12

Moreau River					
	5	6	-10.78	2.14	-10.78
	6	7	-3.93	-3.8	-3.8
	7	8	-19.27	-5.52	-5.52
	8	None	-5.09	-1.97	-1.97
Musselshell River					
	91	92	34.71	33.81	34.71
O'Fallon Creek					
	95	None	-0.9	-0.22	-0.22
Poplar River					
	77	78, None	-13.36	-14.01	-14.01
	78	None	-3.37	-2.18	-2.18
Redwater River					
	79	80	-1.81	-2.5	-2.5
	80	None	-3.12	-0.71	-0.71
Sheyenne River					
	48	49	-23.63	-18.81	-18.81
	49	50	24.53	20.92	24.53
	50	51	-27.33	-21.69	-21.69
	51	52	2.96	2.37	2.96
Souris River					
	56	57	71.73	56.16	71.73

	57	58	-15.46	2.27	-15.46
	58	59	-18.96	-23.85	-23.85
	59	60	-32.4	-22.88	-22.88
	60	61	9.87	5.15	9.87
	61	62	-21.36	-12.1	-12.1
	62	65, 63, None	-3.51	-10.57	-10.57
Tongue River					
	112	113	21.15	29.14	21.15
Yellowstone River					
	93	94	-962.56	-38.93	-38.93
	94	96, 122, 95	1202.98	816.62	1202.98
	96	97, 112	1594.01	1355.7	1594.01
	97	98, 106	-1778.55	-1221.23	-1221.23
Total stream recharge to groundwater for study area					6197
Total discharge to streams from groundwater for study area					-6982

[a] Negative flow values indicate reaches gaining flow from underlying aquifers, while positive values indicate reaches losing flow to underlying aquifers.
[b] Higher recharge to the underlying aquifer estimated for the final value.

Appendix E: Full Year Versus Fall Streamflow Estimates for Recharge to Underlying Aquifers

	Downstream gauge	Upstream gauge	September/October sinking rate (ft^3/s)	Annual sinking rate (ft^3/s)[a]
		Powder River basin		
	141	142	214.11	127.55
	101	102, 103	112.88	1487.62
	118	119	88.96	67.26
	114	115	73.85	126.02
	113	114	71.08	72.88
	129	116	50.82	10.88
	122	126, 123	23.36	7.25
	116	117	20.33	43.09
	134	135	6.07	67.99
	107	108	1.79	-16.05
	139	140	0.28	11.72
Total			664	2006
		Williston basin		
	96	97, 112	1594.01	1291.16
	94	96, 122, 95	1202.98	1737.96
	71	81, 72, 79, 77	541.35	-403.26
	112	113	21.15	1.69
	60	61	9.87	-8.01
	73	74	8.16	-21.28
	18	19	3.52	29.96
	51	52	2.96	-0.18
	20	3	1.73	-21.05
	31	32	1.55	-36.31
	37	38	0.91	-12.22
Total			3388	2558

[a]Negative values indicate a net gain in the overall flow of the stream in that reach.

Appendix F: Comparison of the Full Stream Gauge Length Record to the Period of 1978-1980

Station number	First year of record	Last year of record	September/ October baseflow estimates (ft^3/s)	September/ October streamflow (ft^3/s)	September/October BFI	Percent difference[a]
05054500	1956	2011	1.10	2.23	49.2%	25.29%
05056000	1950	2011	13.06	17.56	74.4%	-0.88%
05056100	1957	1981	1.39	1.72	80.8%	-7.08%
05114000	1931	2011	15.81	26.56	59.5%	13.73%
05116000	1950	2011	22.43	23.80	94.2%	-29.00%
05117500	1904	2000	28.67	38.98	73.6%	-4.56%
05120000	1938	2011	33.26	46.19	72.0%	-2.23%
05122000	1938	2011	51.79	60.38	85.8%	-3.61%
05124000	1931	2011	38.95	62.40	62.4%	4.95%
05JE006	1973	2010	1.12	4.07	27.5%	28.28%
05ME006	1962	2009	224.22	272.88	82.2%	-17.47%
05MH013	1974	2010	268.38	329.11	81.5%	6.55%
05NA003	1959	2007	5.60	14.32	39.1%	-2.92%
05NB001	1960	2010	2.04	18.82	10.8%	14.41%
06115200	1935	2011	5,478.31	6,642.95	82.5%	-0.07%
06130500	1935	2011	153.13	258.01	59.4%	2.15%
06131000	1971	2005	12.90	47.75	27.0%	4.46%
06132000	1944	1999	9,838.05	11,039.34	89.1%	-24.78%
06174500	1940	2011	270.22	558.74	48.4%	3.87%
06177000	1929	2011	9,901.87	11,546.07	85.8%	-25.23%
06177500	1975	2003	0.93	1.48	62.8%	-40.08%
06177825	1976	1984	6.60	10.74	61.5%	3.66%
06185500	1959	2011	9,656.72	11,501.42	84.0%	-6.25%
06214500	1929	2011	4,246.26	4,771.48	89.0%	-1.79%
06290500	1977	2003	111.35	121.54	91.6%	0.08%
06294000	1954	2011	129.40	162.81	79.5%	-0.48%
06294500	1946	2011	2,239.79	3,322.27	67.4%	2.38%
06294700	1946	1980	2,239.79	3,322.27	67.4%	-1.22%
06295000	1978	2011	7,403.27	8,419.34	87.9%	-6.63%
06295250	1975	2005	23.71	28.41	83.5%	-2.96%
06296003	1975	2005	17.23	28.47	60.5%	-9.12%
06296120	1975	1983	6,616.07	8,799.02	75.2%	3.51%
06306300	1961	2011	191.65	241.34	79.4%	0.89%
06307500	1940	2011	239.27	262.09	91.3%	-3.39%
06307830	1974	1983	276.93	321.03	86.3%	1.14%
06308500	1947	2011	180.70	256.86	70.3%	7.75%
06309000	1929	2011	7,403.86	9,056.23	81.8%	-4.45%
06317000	1935	2011	60.35	120.83	49.9%	-13.85%

06324500	1975	2011	181.59	235.17	77.2%	-27.82%
06324710	1976	1980	134.29	244.64	54.9%	2.21%
06324970	1973	2010	0.62	0.78	79.5%	-56.79%
06326500	1939	2011	171.30	252.10	67.9%	-20.75%
06326600	1978	1991	0.26	0.49	53.1%	-28.62%
06329500	1934	2010	7,379.32	8,816.00	83.7%	-15.34%
06331000	1955	1982	9.74	10.70	91.0%	-2.36%
06334500	1957	2010	5.90	9.10	64.8%	-37.98%
06335500	1939	2010	15.88	43.86	36.2%	-7.67%
06337000	1935	2010	53.50	173.58	30.8%	3.03%
06339100	1968	2010	1.34	12.44	10.8%	10.97%
06339300	1971	1980	8.22	21.82	37.7%	7.83%
06339500	1944	2010	8.60	25.55	33.7%	11.51%
06340500	1938	2010	29.88	50.64	59.0%	10.07%
06342500	1929	2011	16,626.73	25,467.76	65.3%	-0.82%
06345500	1944	2011	11.24	18.18	61.8%	-2.21%
06348000	1947	1980	34.13	49.66	68.7%	-1.41%
06349000	1938	2011	56.98	80.31	71.0%	1.38%
06350000	1951	2010	4.27	4.76	89.7%	-27.17%
06351000	1944	1982	11.01	13.11	84.0%	-19.09%
06352000	1951	2011	2.71	4.27	63.5%	1.86%
06353000	1963	2010	5.83	8.31	70.2%	-16.59%
06354000	1935	2010	24.59	37.62	65.4%	-11.22%
06355000	1946	1994	1.19	1.50	79.3%	-15.70%
06355500	1946	2011	2.85	6.15	46.3%	11.25%
06356000	1956	1993	2.25	3.62	62.2%	-20.38%
06356500	1946	1994	9.42	16.27	57.9%	-6.35%
06357500	1944	1987	75.25	96.10	78.3%	-0.01%
06357800	1959	2010	45.61	114.94	39.7%	20.44%
06359500	1944	2010	4.61	10.02	46.0%	-15.26%
06360500	1955	2009	3.65	24.93	14.6%	8.78%
06364700	1978	1980	0.20	0.29	69.0%	0.03%
06425780	1976	1982	0.20	0.51	39.2%	-14.72%
06427500	1952	1994	6.02	6.46	93.2%	-22.19%
06438500	1951	1980	193.26	267.71	72.2%	-8.22%
06439300	1961	1993	196.79	263.52	74.7%	-12.46%
06467600	1958	1981	0.66	0.87	75.9%	-12.90%
06470000	1944	2011	84.30	111.17	75.8%	-5.15%
06646800	1960	1991	1,545.66	1,678.19	92.1%	-15.90%

[a] The difference in percent between the full year Base-Flow Index (BFI) and the period of 1978-1980.

Vita

Jennifer Marie Bednar was born May 29, 1985, in Moose Lake, Minnesota. She attended Willow River High School and was a member of the National Honor Society. She graduated with honors in May 2003. She attended St. Cloud State University (SCSU) from August 2003 to December 2008. She was awarded the annual department scholarship from the Earth and Atmospheric Science department at SCSU in 2008. She graduated with a B.A. in Earth Science in 2010, with an emphasis in geology and minor in hydrology.

Jennifer started her career as a scientist in January 2004 when she interned for the National Oceanic and Atmospheric Administration's (NOAA) National Weather Service in Chanhassen, Minnesota. She switched her interest from meteorology to hydrology in 2005 and started interning for NOAA's North Central River Forecast Center in Chanhassen, Minnesota in January 2005. In May 2006, she took the position of Contaminated Lands Intern in Minneapolis, Minnesota, for Hennepin County's Department of Environmental Services. While finishing school, Jennifer continued to work on and off for Hennepin County until she left her position in August 2011 to attend graduate school in Rapid City, South Dakota. She started working for the South Dakota School of Mines and Technology as a research assistant in August 2011. She worked as a research assistant until May 2013. Jennifer became employed as a student hydrologist for the U.S. Geological Survey (USGS) South Dakota Water Science Center in March 2012. She currently is employed by the USGS.

Jennifer is a member of the American Institute of Professional Geologists (AIPG), the Minnesota Groundwater Association (MGWA), the National Groundwater Association (NGWA), and the Geological Society of America (GSA).