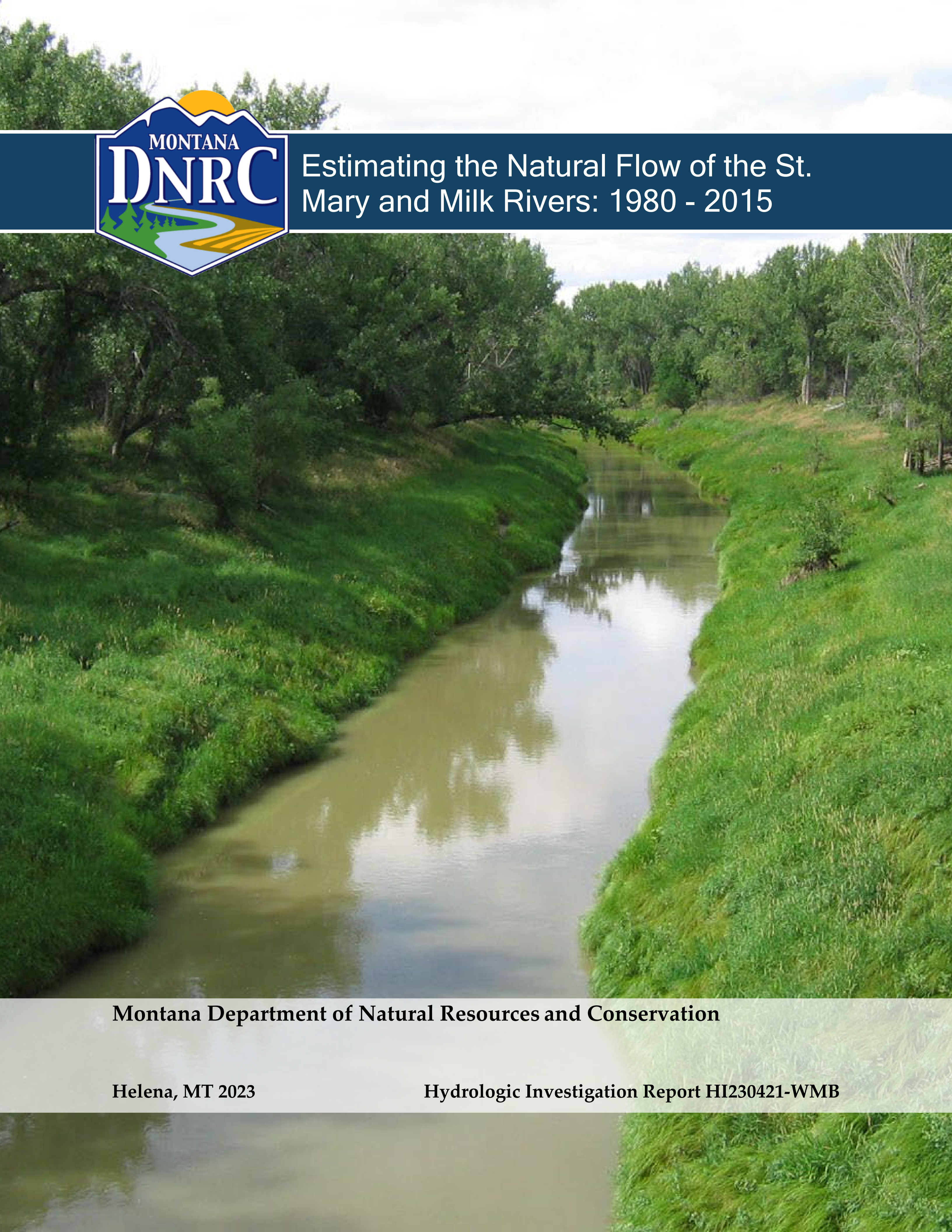

Estimating the Natural Flow of the St. Mary and Milk Rivers: 1980 - 2015

Montana Department of Natural Resources and Conservation

Helena, MT 2023

Hydrologic Investigation Report HI230421-WMB

Cover: Milk River near Vandalia, Montana. Photo by Mike Dailey, MT Department of Natural Resources and Conservation.

Estimating the Natural Flow of the St. Mary and Milk Rivers: 1980 - 2015

Hydrologic Investigation Report TM230421-WMB

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Executive Summary

Natural flows are an important piece of information for any type of water management or planning. Understanding the natural hydrology of a basin is often a necessary starting point when negotiating the distribution of trans-boundary (international, interstate, or tribal) water, and for the continued management of water following negotiations. Natural flows are also a key input to many contemporary hydrologic and water management models used for water resource planning, studying the impacts of changing water supplies, or simulation of water project operations for management purposes. In many cases, the natural hydrology of a river or stream has never been observed in the historical measurement record. This is because most water use in the western United States precedes the earliest measurement records for streamflow. Thus, natural flows must be estimated over a period when measured data does exist, typically using water balance models or calculations to account for water use and regulation.

The St. Mary and Milk Rivers are international waterways that begin in Montana. Portions of each river's water supply are shared between the United States and Canada according to the Boundary Waters Treaty of 1909 and subsequent agreements between the two countries throughout the 20th and 21st centuries. Estimation of the natural flow of each river is the cornerstone of dividing water between the United States and Canada and is done by the respective authorities for each country and reported to an international commission in charge of upholding the 1909 treaty. Each country uses St. Mary and Milk River water to irrigate hundreds of thousands of acres of agricultural land. In the United States, this includes the Bureau of Reclamation's Milk River Project, which relies on water diverted from the St. Mary River to the Milk River. Over the last two decades, the State of Montana and the Bureau of Reclamation have invested resources into developing a hydrologic and water management model of the two basins including operation of Milk River Project infrastructure. While beneficial to studying water yield, water use, and for making water management decisions, these models require comprehensive natural flows throughout the St. Mary and Milk River Basins as input. While international apportionment is the primary purpose for estimating natural flows in these basins, only natural flows at certain locations along the international boundary are needed. The modeling efforts of Montana and Bureau of Reclamation create the need for estimating natural flows at many locations throughout the St. Mary and Milk Basins.

The first daily time-step, basin-wide modeling of the St. Mary and Milk Rivers began with a Bureau of Reclamation WaterSMART Basins Study, completed in 2012. The first daily estimated natural flow dataset encompassing many locations on the St. Mary and Milk Rivers and their tributaries was developed by the Montana Department of Natura Resources and Conservation

during the Basins Study. Beginning in 2016, the Bureau of Reclamation began a follow-up Basins Study of the St. Mary and Milk Rivers to improve the methods, data, and models used, as well as incorporate more recent years in the study. The Montana Department of Natural Resources and Conservation is a collaborator on this basins study update. With changes to the original water management model and the addition of a precipitation-runoff hydrologic model to simulate streamflow across the landscape, an updated natural flows dataset was needed. This report documents the methods and assumptions used to develop an updated, estimated natural flows dataset for general use in modeling and hydrologic studies. In addition to providing daily natural flow estimates in a digital format, this report will highlight any limitations with the dataset, areas for future improvements, and appropriate uses for this data.

The Milk River. Photo by Michael Downey

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Abbreviations, Definitions, and Conversion Factors

Units of Measure and Conversion Factors

Commonly used US Customary units and conversions

*Multiply	By	To Obtain
	Length	
mile (mi)	5,280	foot (ft)
yard (yds)	3	foot (ft)
	Area	
square mile (mi^2)	640	acre
	Volume	
cubic foot (ft^3, cu. ft.)	7.48	gallon (gal.)
acre-foot (acre-ft)	43,560	cubic feet (ft^3, cu. ft.)
	Flow Rate	
cubic foot per second (ft^3/s, cfs)	40	miner's inch
cubic foot per second (ft^3/s, cfs)	448.8	gallons per minute (gpm, gal/min)
acre-foot per day (acre-ft/day)	0.504	cubic feet per second (ft^3/s, cfs)

*Conversions can be done in reverse by dividing the unit in the right column by the middle column to obtain the left column.

US Customary units to International System of Units

*Multiply	By	To Obtain
	Length	
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	2.59	square kilometer (km^2)
	Volume	
acre-foot (acre-ft)	1,233	cubic meter (m^3, cu. m)
	Flow Rate	
cubic foot per second (ft^3/s, cfs)	0.02832	cubic meter per second (m^3/s, cms)

*Conversions can be done in reverse by dividing the unit in the right column by the middle column to obtain the left column.

Degrees Celsius (°C) can be converted to degrees Fahrenheit (°F) as: $°F = (1.8 \times °C) + 32$

Degrees Fahrenheit (°F) can be converted to degrees Celsius (°C) as: $°C = (°F - 32)/1.8$

Water Year (WY) is the 12-month period from October 1 – September 30 of the following calendar year. WY is designated by the calendar year in which it ends. Example: WY 2020 is October 1, 2019 – September 30, 2020.

Abbreviations

ACI ---------Annual Crop Inventory (Canada)
AO ----------Accredited Officer
CDL---------Cropland Data Layer (US)
DNRC------Montana Department of Natural Resources and Conservation
DRI ---------Desert Research Institute
ECCC-------Environment and Climate Change Canada
ET -----------Evapotranspiration
FDC---------Flow Duration Curve
IJC-----------International Joint Commission
IQR ---------Interquartile Range
LOI----------Letter of Intent
NAIP -------National Agricultural Imagery Program (US)
NARR------North American Regional Reanalysis
NASS-------National Agricultural Statistics Service (US)
NIWR ------Net irrigation water requirement
SLC ---------Soil Landscapes of Canada
STATSGO -State Soil Geographic Database (US)
USBR -------United States Bureau of Reclamation
USGS -------United States Geological Survey
WSC --------National Hydrological Services-Water Survey of Canada

Estimating the Natural Flow of the St. Mary and Milk Rivers: 1980 - 2015

Introduction

Natural flows are vital for managing water resources. This is especially true for the St. Mary and Milk Rivers, which are Transboundary waterways shared by the United States (US) and Canada. In the US, the St. Mary and Milk Rivers are central to the US Bureau of Reclamation's (USBR or Reclamation) Milk River Project, which was one of five original projects authorized for Reclamation to build in 1903. The project includes a trans-basin diversion from the St. Mary River to the Milk River, two on-stream storage reservoirs, one off-stream storage reservoir, and eight irrigation districts with approximately 140,000 acres of irrigated lands. The management of such a large irrigation project benefits from hydrologic models capable of predicting future streamflow and assessing the potential impacts of climate change on the operation of the project. Natural flows are a primary source of input data to such hydrologic modeling endeavors. And while managing and operating a large irrigation project has many challenges that benefit from understanding the natural hydrology of the St. Mary and Milk Rivers, an even more important use for natural flows is the apportionment of water internationally.

Apportionment of the St. Mary and Milk Rivers between the US and Canada is governed by Article VI of the Boundary Waters Treaty of 1909, signed by the US and Great Britain. The Boundary Waters Treaty established the International Joint Commission (IJC) whose mission is to investigate, resolve, and prevent water disputes between the two countries. The language of apportionment in the Treaty is generalized, and arguments around its provisions led to the 1921 Order of the International Joint Commission (1921 Order), which further clarified the terms of the Treaty. More recently, two letters of intent (LOIs) were agreed upon between the US and Canada; the 2001 Letter of Intent to Better Utilize the Waters of the St. Mary and Milk Rivers, and the 2007 Letter of Intent to Better Utilize the Waters of the Eastern Tributaries of the Milk River. Together, the Treaty, 1921 Order, and LOIs determine how water is shared between the two countries. The language throughout these international agreements consistently uses "natural flow" as the reference for calculating each country's fraction of water. And the 1921 Order state's explicitly that the representatives, or representing agencies of each country:

"…ascertain and keep a daily record of the natural flow of the St. Mary River at the international boundary, of the Milk River at the Eastern Crossing, and of the eastern tributaries of the Milk River at the international boundary…"

International Apportionment creates the greatest need for estimating natural flows and the agencies tasked with calculating each countries portion, the US Geological Survey (USGS) and Environment and Climate Change Canada (ECCC) National Hydrological Services-Water Survey of Canada (WSC), have developed methods for naturalizing flow at the locations identified in the treaty. These naturalized flows are the cornerstone of natural flow estimates in the two basins and all attempts, thus far, to estimate natural flow of the St. Mary and Milk Rivers have used those data in some capacity, this study included. However, hydrologic modeling and water management needs in the basin require natural flow estimates at many more locations than just the international boundary.

The purpose of this report is to develop an estimated natural flow dataset for use in hydrologic and river system models. Specifically, for a USBR WaterSMART Basin Study (WaterSMART Basin Study Program - https://www.usbr.gov/watersmart/bsp/) for which the Montana Department of Natural Resources and Conservation (DNRC) is a cooperator. A Reclamation Basins Study was conducted a decade ago (USBR 2012a, USBR 2012b) and resulted in the development of a RiverWare™ (CADSWES 2023) river systems model for the St. Mary and Milk Rivers. The current Basins Study is an update to the 2012 Basins Study using improved methods, a more detailed river systems model, extended study period, and inclusion of paleo-hydrology from tree ring analysis. This dataset will provide a more spatially comprehensive quantification of natural flows than existed for the US portion of the St. Mary and Milk Rivers at the time of writing this report. In turn, this information can be used for infrastructure operations, forecasting, and water resources planning. Documenting the methods used to develop this dataset will allow it to be updated and used for future modeling or studies, as needed.

The St. Mary and Milk River Basins

The St. Mary River Basin begins in Glacier National Park and flows northeast through the Blackfeet Reservation in Montana before crossing the US-Canada border (Fig. 1). From the border, it continues northeast to its confluence with the Oldman River near Lethbridge, Alberta. For this study, we are focused on the US portion of the St. Mary River upstream from the international boundary, which encompasses 490 mi^2.

The Milk River Basin has a drainage area of approximately 23,800 mi^2 flowing from the Rocky Mountain Front in the foothills of Glacier National Park east to its confluence with the Missouri River just downstream from Fort Peck Reservoir. The Milk River crosses the US-Canada border near the Del Bonita Border Station on the Blackfeet Reservation, this crossing is referred to as the Western Crossing. The North Fork of the Milk River joins the mainstem near Milk River, Alberta. The St. Mary Canal conveys trans-basin diversions 29 miles from the St. Mary River, delivering the imported water to the North Fork of the Milk River just upstream of the international boundary. The Milk River flows nearly 200 mi through southern Alberta until it crosses the US-Canada border again about 50 mi upstream of Fresno Reservoir, northwest of Havre, MT. This crossing from Canada back into the US is referred to as the Eastern Crossing. Fresno Dam is a Reclamation facility constructed for the Milk River Project. It is the only major on-channel

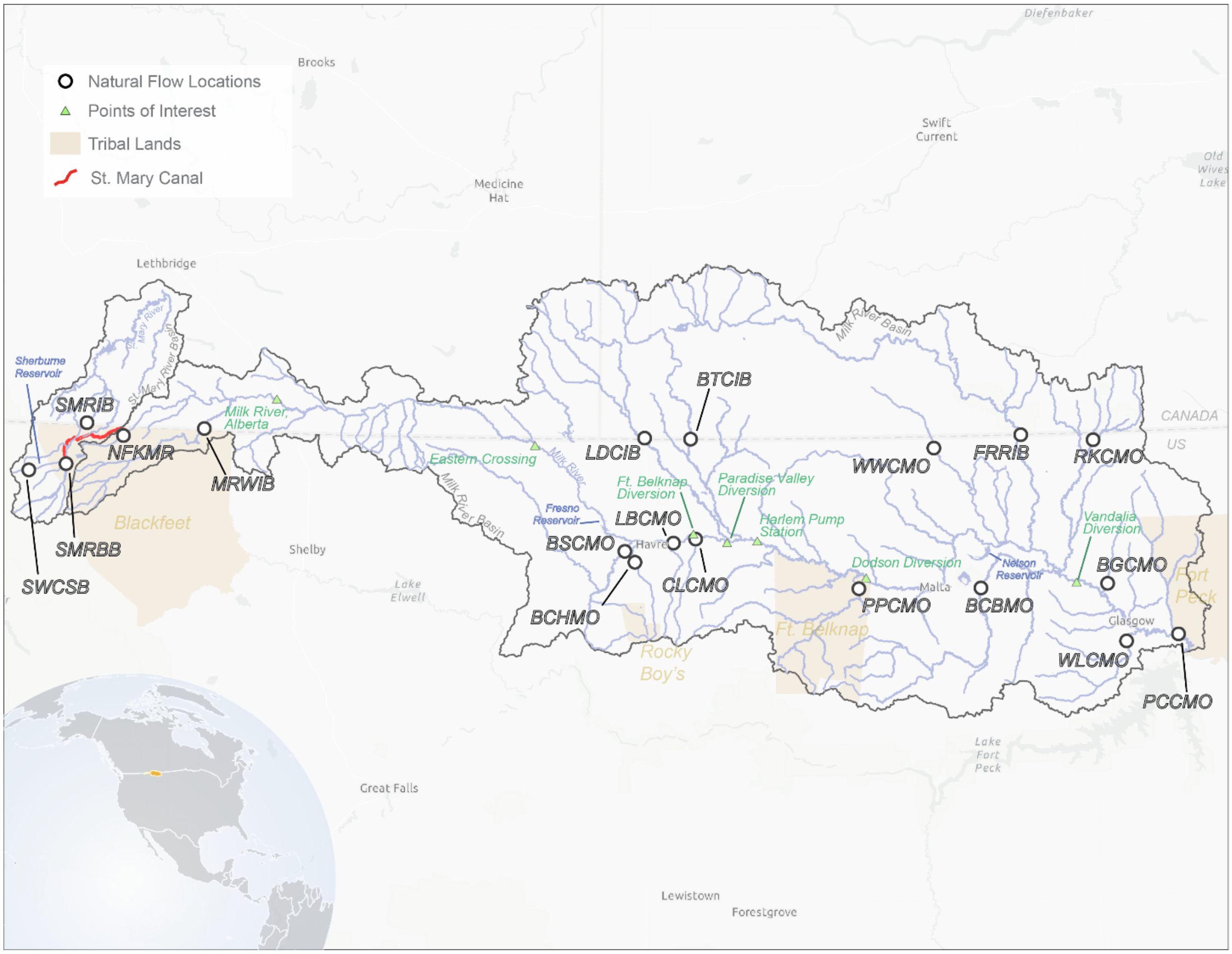

Figure 1. Map of the St. Mary and Milk River Basins showing locations where natural flow was estimated, stream channel network, and other points of interest.

storage facility on the Milk River and is used to store and release imported St. Mary water. Major tributaries to the Milk River include Big Sandy, Peoples, and Beaver Creeks flowing from the south. Lodge and Battle Creeks as well as the Frenchman River flow into Montana from the north out of Saskatchewan. Lodge Creek, Battle Creek, and the Frenchman River are collectively referred to as the Eastern Tributaries. Their headwaters are in Canada and are included in the 1921 Order as shared water bodies.

Water management in the St. Mary and Milk River Basins is complex. In some years, the imported St. Mary water accounts for as much as 95% of the flow in the Milk River. International agreements necessitate intricate accounting of natural flows in each river as well as St. Mary water conveyed via the Milk River. Imported water must travel long distances to reach its intended place of use and is subject to both human and natural consumptive losses along the way. These factors can make it challenging to operate irrigation infrastructure with consistent supply in the Milk River Basin and requires complex models to analyze non-management induced hydrologic patterns.

Previous Estimates of Natural Flows

The St. Mary and Milk Rivers have a long history of natural flow estimations. The longest record of natural flows in these basins are those submitted to the IJC for apportionment between the US and Canada. More detailed datasets of natural flows have been estimated beginning in the 1990s through the present, for use in various water management or modeling applications.

The Accredited Officers' Natural Flows Reported to the IJC

With the creation of the IJC under the Boundary Waters Treaty, "reclamation and irrigation officers" were also appointed for the US and Canada to carry out the terms of the treaty under direction of the IJC. The "reclamation and irrigation officers" are currently designated as the Accredited Officers (AO) for the two countries. The relevant agencies and working groups from each country provide measurement and apportionment calculations to the AOs which are reported to the IJC annually. For apportionment, natural flows are estimated at five locations along the international boundary (Table 1). These are calculated for division periods (e.g., twice monthly) and are used for calculating each country's share as well as any deficits accrued under the LOIs. The earliest estimates of natural flow for the St. Mary River were calculated in 1902, with the Milk River following in 1913. The methods used by USGS and WSC to estimate natural flow in the two rivers have changed over time, for the most up-to-date documentation on these estimates refer to the Procedures Manual (USGS and WSD 2018). All subsequent natural flow datasets described in this report have used (directly or indirectly) the AOs reported natural flows in some capacity.

HYDROSS Model Natural Flows

The first modeling of the Milk River Project was done by Reclamation in the 1990's using a monthly Hydrologic River Operation Study System (HYDROSS) model. The USGS developed a more comprehensive natural flow dataset as input to the model (Cary and Parrett 1995). Flow was naturalized at two sites on the St. Mary River and 11 sites on the mainstem Milk River. The AOs natural flow data reported to the IJC were used for the three St. Mary and Milk River sites at the international boundary with records extension where necessary. Natural flows were not explicitly represented for tributaries, so the Eastern Tributaries were not included in this dataset. The remainder of the mainstem Milk River sites were naturalized with a drainage area adjustment method that used index gages (where approximately natural flow is measured) to calculate the natural gains along the Milk River within sub-areas of the basin. For more information on the development of this dataset, refer to Cary and Parrett (1995).

Table 1. Historic natural flow data calculated by USGS and WSC for International Apportionment in the St. Mary and Milk River Basins

Location Name	USGS gage ID	Available Natural Flow Data*
St. Mary River at International Boundary	05020500	Annual Volume: 1902-1918 Monthly Volume: 1919-1963 Bi-Monthly Volume: 1964-2020
Milk River at Eastern Crossing of International Boundary	06135000	Annual Volume: 1913-1984 Monthly Volume: 1985-1989 Bi-Monthly Volume: 1990-2020
Frenchman River at International Boundary	06164000	10-Day Volume: 1937-1992 Bi-Monthly Volume: 1993-2020
Lodge Creek below McRae Creek at International Boundary	06145500	Annual Volume: 1951-1960 10-Day Volume: 1961-1992 Bi-Monthly Volume: 1993-2020
Battle Creek at International Boundary	06149500	Annual Volume: 1941-1956 10-Day Volume: 1957-1992 Bi-Monthly Volume: 1993-2020

*All natural flows are computed seasonally starting in March and ending in October, so annual values represent the sum of these months' volumetric flow.

The HYDROSS model operated on a monthly time-step, requiring monthly natural flow inputs. The monthly time-step is a limitation for present and future modeling efforts that use a daily time-step.

2012 Basins Study Natural Flows

From 2009 to 2012, Reclamation and the Montana Department of Natural Resources and Conservation (DNRC) conducted a 4-year study of the historic and future hydrology and water use within the St. Mary and Milk River Basins. The goals of the 2012 study were to assess 1) potential future changes to water supply and demand; and 2) performance of existing Milk River Project infrastructure in the face of changing water supplies. Because water management in the St. Mary and Milk Basins is very complex, a more sophisticated river systems model was needed to analyze water demands in the context of international agreements, tribal compacts, Montana water law, and operational constraints. One major objective of the 2012 Basins Study was to produce a daily time-step river systems model capable of accounting for policy and operations. Although the resulting RiverWare™ river systems model has been altered over the last decade, it remains the primary tool for assessing water policy, studying water supply, and planning in the St. Mary and Milk River Basins.

For the 2012 Basins Study, the river systems model required natural inflows at specific locations throughout the two basins. The model was run for a 50-year, historic period from 1959 – 2009. The associated natural flows dataset covered the same 50-year period and at the time was the most comprehensive dataset for the two rivers. Methods used to estimate the natural flows were distinct for three main regions, the St. Mary River, the Upper Milk River upstream of Fresno Reservoir, and the Milk River and tributaries below Fresno. A summary of the methods used is provided here for completeness. For more detailed information on the original model and natural flows, refer to MT DNRC's (2013) modeling technical report.

St. Mary River Natural Flows

For the 2012 Basins Study dataset, daily natural flows were computed at three locations in the St. Mary Basin: 1) Swift Current Creek at Sherburne Dam, 2) the St. Mary River at Babb, excluding Swift Current Creek, and (3) the St. Mary River at the International Boundary. All three locations had relatively intact flow data for the period of interest. The number of gages was adequate upstream of the International Boundary with little, or negligible, water use. Under these conditions, natural flow could be estimated using measured discharge, reservoir storage, and diversion data within a mass balance calculation (i.e., using a form of the governing equation $\Delta S = I - O$). This equation was used to calculate un-gaged flows between gages. The resulting gains or losses were then added to the upstream station's natural flow. Occasionally, this resulted in negative natural flow values which were eliminated by distributing an average over a variable length period surrounding the negative values. Flow at the upstream gage was averaged over the same period surrounding the negative values and daily percentages of the average were calculated using the mean daily discharges. The same daily percentages were multiplied by the downstream average to distribute the non-negative values.

Milk River and Tributary Natural Flows upstream of the Eastern Crossing of the International Boundary

Daily natural flows were computed at three locations on the Upper Milk River (upstream of Fresno Reservoir): 1) the North Fork of the Milk River at the International Boundary, 2) the Milk River at its Western Crossing of the International Boundary, and 3) the Milk River at the Eastern Crossing. More detail on the methods used at these locations is provided later in this report as the same methods were used for the most recent natural flow dataset.

Daily natural flows for North Fork Milk River at International Boundary were calculated using daily measured streamflow and adding monthly, upstream irrigation depletions distributed as constant daily values over the growing season (May – September). The stream gage used for this location was operated seasonally (i.e., March through October). Missing winter flows were set to zero because any natural winter flow from the North Fork Milk River is captured by a downstream gage operated by WSC at the town of Milk River, Alberta. These flows are included for the Milk River at Western Crossing instead. While this creates unrealistic winter flow values for the North Fork and Milk River at Western Crossing, the missing volume is included at the Eastern Crossing and all downstream locations. It is more critical within the model to accurately simulate operation of infrastructure on the lower portions of the Milk River than having the North Fork volume correct at the international boundary. Irrigation depletions on the North Fork Milk River were estimated based on 2008 and 2009 field measurements and landowner observations.

Daily natural flows for the Milk River at the Western Crossing of the International Boundary were estimated the same as the North Fork Milk River, using measured streamflow and estimated upstream depletions due to irrigation. Irrigation depletions were again estimated for the 2008 and 2009 seasons based on field measurements and landowner observations. Measured data at the Western Crossing was also seasonal. Instead of setting missing winter data to zero, data from the Milk River at Milk River gaging station (operated by WSC) was used. This gage, downstream from the confluence of the Milk and North Fork Milk Rivers is operated year-round. As a result, the natural flow of the North Fork Milk River was included in this site's winter data.

Natural tributary inflow and groundwater gains between the Western and Eastern Crossings of the Milk River were computed by subtracting natural flows at the Milk River Western Crossing and North Fork Milk River from the Milk River at the Eastern Crossing (USGS gage ID 06134700). A 4-day time lag was estimated between the Western and Eastern Crossings based on hydrograph peaks. This 4-day lag was assumed to be constant at varying discharges and the flows at the Eastern Crossing were shifted before subtracting the upstream natural flows. As a final step, the estimated depletions by irrigation in Alberta were added to the differenced flows. Irrigated acres in Alberta have increased over time. For the 2012 Basins Study, irrigated acres were estimated to have increased from 4,500 to 8,000 over the study period. The primary method of irrigation has also transitioned from flood to sprinkler, pumping directly out of the Milk River. Depletion estimates were gradually increased over time to account for these changes in acreage. Depletion estimates were started at approximately 50% of the maximum and were linearly increased up to the maximum depletions for 8,000 acres. The depletions linearly increased from a minimum in 1959 to a maximum in 2000. In the case of negative natural flows being calculated at the Eastern Crossing, the same method used on the St. Mary River sites was used here, except daily values were calculated by a 7-day moving average.

Milk River Tributary Natural Flows from Fresno Dam to the Mouth

One major challenge with creating a historic, daily dataset for the river systems model was lack of data over a consistent period of record. This was especially true for Milk River natural flow sites below Fresno Reservoir as seasonal data and incomplete periods of record are pervasive. The natural flow dataset for the 2012 Basins Study was developed completely using measured streamflow at USGS gage sites. To create a consistent period of record, many sites required extending the daily flow records. Daily data were filled in using statistical correlation with other active stream gages in the region. The USGS FILLIN program was used, which uses the Maintenance of Variance Extension Type 1 (MOVE.1) method (Hirsch 1982). When using the FILLIN program, a matrix of available streamflow data for all relevant stations in the region with overlapping periods of record between 1959 and 2009 was created. This matrix is passed to the program which then fills in missing data for a station of interest. The FILLIN program determines the best set of predictor gages and thus, different gages may be used for different periods in the record and at different target locations. The FILLIN program only extends monthly data, so all gage data was resampled to monthly averages before using the program. When gages had daily values, those were used, otherwise daily values were disaggregated from the monthly output from FILLIN. Disaggregation was done using the daily percent of monthly average flow calculated from three gages in the Milk River Basin that had year-round data (more description is provided in subsequent methods sections for specific locations).

Natural flows for tributaries of the Milk River below Fresno Dam were estimated using an identical method as Cary and Parrett (1995). The Milk River Basin below Fresno Dam was split into sub-catchments (or segments), delineated by points of interest. The tributary flows measured by available stream gages were used as natural flow in this dataset. Using the measured streamflow at gages downstream from water use and small reservoirs likely underestimated the true natural tributary inputs. The nine segments of the Milk River below Fresno Reservoir are shown below with the index gages used. The sum of the index gage drainage areas and the total drainage area for each segment were used to calculate a drainage area multiplier to account for un-gaged inflows to each segment. The multipliers are given in parenthesis for each segment and are used in the equation ($ungaged\ flow = \sum Index\ Tributary\ Flow * DA_{fraction}$). If there is no $DA_{fraction}$ for a segment, then it was assumed there were no un-gaged inflows. Note that some segments include only one tributary, as is the case with most of the larger tributaries or tributaries with abundant streamflow data.

1. Fresno to Havre ($DA_{fraction} = 0.25$)
   a. Big Sandy Creek (*USGS 06139500*)
   b. Beaver Creek (*USGS 06140000*)
2. Havre to Ft. Belknap Diversion ($DA_{fraction} = 0.25$)
   a. Little Box Elder Creek (*USGS 06141600*)
3. Ft. Belknap Diversion to Paradise Valley Diversion (no $DA_{fraction}$)
   a. Clear Creek (*USGS 06142400*)
4. Paradise Valley Diversion to Harlem ID pump ($DA_{fraction} = 0.25$)
   a. Lodge Creek (*USGS 06145500*)
   b. Battle Creek (*USGS 06149500*)

5. Harlem ID pump to Dodson Diversion ($DA_{fraction} = 0.5$)
   a. Peoples Creek (*USGS 06154550*)
6. Frenchman River (no $DA_{fraction}$)
   a. Frenchman River at International Boundary (*USGS 06164000*)
7. Frenchman River to Beaver Creek ($DA_{fraction} = 0.4$)
   a. Beaver Creek at Bowdoin (*USGS 06166000, 06164800*)
8. Beaver Creek to Vandalia Diversion ($DA_{fraction} = 2.0$)
   a. Whitewater Creek (*USGS 06156000*)
   b. Rock Creek (*USGS 06169500*)
9. Vandalia Diversion to Mouth ($DA_{fraction} = 0.6$)
   a. Buggy Creek (*USGS 06172200*)
   b. Willow Creek (*USGS 06174000*)
   c. Porcupine Creek (*USGS 06175000*)

Methods

We used the same methods as the previous 2012 Basins Study to estimate natural flows at locations on the St. Mary River and Upper Milk River (above Fresno Reservoir). The major differences for this study, compared to the 2012 Basins Study, are 1) the end use of the natural flows to calibrate a hydrologic model rather than as direct input to the river systems model and (2) updates to Lower Milk River (below Fresno) natural tributary inflows. For the current Basins Study update, a hydrologic model will provide inputs to the river systems model. We did not include natural flows for the Milk River at Eastern Crossing because it was not necessary for hydrologic model calibration because flows at the North Fork of the Milk River and the Milk River at Western Crossing characterize the headwaters region of the Milk River. Hydrologic model parameters are not expected to differ drastically between the Western and Eastern Crossing. This dataset can still be used as direct input to a river systems model, but some un-gaged inflows throughout the Milk River Basin will need to be estimated following MT DNRC's (2013) methodology. For example, natural flow at the Eastern Crossing can be calculated with the methods of MT DNRC (2013) using estimated natural flows from this study for the North Fork Milk River at the international boundary and the Milk River at the Western Crossing. Additional tributary gains not represented in this dataset could be acquired by subtracting this study's tributary inflows from total gains of the various Milk River segments used by MT DNRC (2013).

Like the 2012 Basins Study, the St. Mary and Milk River Basins can were separated into general regions where various methods were applied to estimate natural flows. For this study, we included a fourth area with differing methods, the Eastern Tributaries of the Milk River (Battle Creek, Lodge Creek, and the Frenchman River). The four general regions are: 1) St. Mary River, 2) Milk River and tributaries upstream of the Eastern Crossing, 3) the Eastern Tributaries, and 4) Milk River and tributaries from Fresno Reservoir to the mouth (excluding the Eastern Tributaries). The period covered by this dataset is shorter than the 2012 Basins Study largely due to temporal limitations of data used for natural flow estimates. For tributaries below Fresno Reservoir (excluding the Eastern Tributaries), we used modeled agricultural demands that required gridded meteorological data as input. These data have a period of record from 1980 to present. The same gridded data are being used by USBR in the current Basins Study Update as input to a hydrologic precipitation-runoff model. The estimated natural flows dataset therefore has a final period of record spanning 1980 to 2015 to accommodate Reclamation's current St. Mary and Milk River Basins Study Update.

We used the data from MT DNRC (2013) for natural flow locations on the St. Mary River and Milk River upstream of the Eastern Crossing. We also used their methods for locations in these areas to extend the natural flows datasets from 2009 to 2015. The natural flow of tributaries below Fresno Dam were not calculated in the same way as the 2012 Basins Study or Cary and Parrett (1995). Instead, a new approach was used that re-organized the river systems model to solve for natural flow given measured streamflow at the mouth of a source, upstream irrigation diversions, and return flows from diverted water. Daily diverted volumes were calculated as a function of the net irrigation water requirement (NIWR), conveyance and application efficiencies, and incidental losses. Factors affecting conveyance efficiency include canal seepage and evaporation, canal over-topping, spillway flows and wasteway flows. Factors affecting application efficiency include evaporation, surface runoff, and deep percolation. Incidental losses consist of canal seepage, open water evaporation from fields or canals, consumption by non-crop vegetation, and loss to deep aquifers. Water that is diverted but not consumed by crops or incidental losses is considered return flow.

Total crop demand, or crop evapotranspiration (ET_c), is the amount of water needed for optimized crop growth. This quantity is typically represented as an idealistic volume rather than a pragmatic or actual volume. However, it provides a consistent baseline for crop demand that is related to a specific crop's biology and growth cycle. Limitations due to agricultural practices, water availability, and other practical factors often prevent irrigators from meeting total crop demand. The NIWR is the fraction of the total crop demand that is supplied by irrigation water, rather than precipitation. The NIWR was estimated using the ET Demands Model (*https://github.com/usbr/et-demands*; Allen et al. 1998, Allen et al. 2005, Huntington and Allen 2010, USBR 2015) originally developed collaboratively by Reclamation's Technical Service Center, the University of Idaho, the Nevada Division of Water Resources, and the Desert Research Institute (DRI). This model uses the FAO-56 Penman-Monteith equation to calculate reference evapotranspiration (ET_r) for alfalfa (ASCE 2005). ET_c is calculated using ET_r and a dual crop coefficient method (Allen et al. 2005). ET Demands' dual crop coefficient method includes separation of crop consumption derived from precipitation and from irrigation using a soil moisture balance to keep track of precipitation that is carried over from day to day as soil moisture storage. ET Demands requires meteorological, soils, and crop type data as input. ET_c and NIWR were calculated on a 1/16-degree resolution grid cell and input data was averaged for each cell. Meteorological input data for daily minimum and maximum temperature, vapor pressure, shortwave radiation, and precipitation were derived from Daymet Version 3 (Thornton et al. 2016). Daily windspeed data was provided by the North American Regional Reanalysis (NARR) dataset (Mesinger et al. 2006). Other necessary meteorological input data including relative humidity, total radiation, and dewpoint temperature were empirically estimated following the methods of USBR (2015). Soils data for the US portion of the St. Mary and Milk Basins were acquired from the Natural Resources Conservation Service State Soil Geographic (STATSGO) database (USDA 2018), and from the National Soil Database, Soil Landscapes of Canada (SLC) dataset (AAFC 2011) for the Canadian portions of the basins. Crop type was assigned to each grid cell using the National Agricultural Statistics Service (NASS) Cropland Data Layer (CDL, USDA 2013) in the US and the Annual Crop Inventory (ACI, AAFC 2013) for Canada. Reclamation's Technical Service Center ran the ET Demands model and provided NIWR values for Milk River tributaries below Fresno Reservoir (excluding the Eastern Tributaries). For more information on the ET Demands model, input datasets, and data preparation, refer to Reclamation's *West-Wide Climate Risk Assessments: Irrigation Demand and Reservoir Evaporation Projections* (USBR 2015).

For each tributary location where natural flow was estimated, the upstream drainage area was delineated. The ET Demands model was used to estimate the average daily NIWR for that drainage area. We delineated irrigated areas with ESRI's Arcmap 10.8.1 using the National Agriculture Imagery Program (NAIP) aerial imagery datasets from 2005 – 2017, Montana Department of Revenue's Final Land Unit Classification data for private agricultural land use (MT DOR 2015), and mapped irrigated lands from the Montana Water Resource Survey (WRS, Montana State Engineer's Office 1962). Fields were not specifically delineated for irrigated lands in Canada, but rather, total acreages by drainage were estimated for the river systems model based on available satellite imagery, discussion with water resource managers in Alberta and Saskatchewan, and irrigation development reports for Alberta and Saskatchewan. The average NIWR for the area upstream of each natural flow location was used to back calculate diversions using a variable acreage value, variable conveyance efficiency (max = 0.5, min = 0.45), incidental loss rate of 0.14, max flow capacity of 200 cfs, and minimum diversion request of 0 cfs. Return flows were calculated using the variable conveyance efficiency (0.45 for March - June and 0.5 for June - September), and a groundwater split adjust factor of 0.7 (meaning 70% of return flow was via groundwater). Return flows were routed within the river systems model using a 1-day lag coefficient for surface water fraction and a

0.02 lag coefficient over 30 days for the groundwater fraction.

Our methodology is a common approach for naturalizing flows depleted by irrigation water use; however, a potential problem is the assumption of full season, full-service irrigation. While perhaps a valid assumption for irrigation from mainstem Milk River water sources lower in the basin, the described methodology will typically lead to an overestimation of natural flows in smaller tributaries and headwaters. Water supply in the tributaries and headwaters of the Milk River depend on the individual characteristics and responses of each drainage area, but in most years is only available consistently for irrigation in the spring. Irrigators may also opportunistically use rainfall/runoff that occurs later in the season. Therefore, the following assumptions were made regarding the level of irrigation in Milk River tributaries when adding back in depletions:

1. From Jan. 1 – June 15
   - Irrigation was assumed to be at maximum, but not at optimal, production. A 70% management factor was assumed, such that with unlimited access to water and no limitations caused by management practices 70% of optimal production can be achieved. For simplicity, this management factor was applied to the total acres irrigated by a tributary source rather than the NIWR.
2. From June 16 – June 30
   - A 35% management factor was used (half of 70%) for this date range, applied in the same way as Jan. 1 – June 15.
3. From July 1 – July 15
   - A 17.5% management factor was used (half of 35%) for this date range, applied in the same way as Jan. 1 – June 15.
4. From July 16 to end of season
   - Irrigation is assumed to cease, and acreage is set to zero.
5. After performing these calculations in the river systems model, all negative values were set to a natural flow of zero.

For the 2012 Basins Study, measured flow at the international boundary was used as input to the river systems model for the Eastern Tributaries. These stream gage sites were also used as index sites to estimate un-gaged tributary inflows for a segment of the Milk River. One major difference between this study's natural flow dataset and that of MT DNRC (2013) is the naturalization of Eastern Tributary flows. Upstream from the international boundary, the Eastern Tributaries are regulated by storage reservoirs in Saskatchewan and there is significant irrigation water use. However, the AO's and the respective agencies in the US and Canada produce natural flow estimates for the Eastern Tributaries that account for regulated flow and water use in Canada. These natural flows are summarized for their respective division periods and reported to the IJC annually. We used the natural flows reported to the IJC for Eastern Tributaries at the international boundary. To get daily data, we used the measured mean daily discharge at each stream gage to disaggregate the 10-day (pre-1993) or twice monthly (post-1993) division period volumes. This process was identical to the method for disaggregating the monthly extended stream gage records produced by the MOVE.1 method. We calculated daily percentages using the measured flows for each division period and applied those daily percentages to the natural volume for the same period. The measured flows at the gage were used before March and after October of each year because natural flows are only estimated for the irrigation season.

Complete, daily measured flow records from MT DNRC (2013) were used up to 2009. Identical methods (i.e., USGS FILLIN program) were used to fill missing records for all measurement sites from 2009 – 2015. **Error! Reference source not found.** lists all the sites where natural flows were estimated. More detailed descriptions of the methods used at each location are provided below.

Beaver Creek (Bowdoin) at Mouth (BCBMO)

We used measured mean daily streamflow at the USGS site 06166000, Beaver Creek bl Guston Coulee nr Saco MT for this location. The period of record for mean daily discharge at this site is 1920-1921 and 1981-present. This location was used as an index gage in the original 2012 Basins Study to account for Beaver Creek (Bowdoin) and Larb Creek inflows to the Milk River (MT DNRC 2013). Like the original 2012 Basins Study, we characterized these data as predominantly unimpaired streamflow and did not adjust them for this study. The only addition to the natural flows at this location was extending the period of record to include 2009 – 2015 data using the same missing value and records extension process. This site required monthly records extension (using the FILLIN program) for seasonal data and period of record extension. For missing records between 1967-1969 and 1976-1982, we used mean daily streamflow from the USGS site 06164800 Beaver Cr ab Dix Cr nr Malta, MT with a drainage area multiplier of 1.2.

Beaver Creek (Havre) at Mouth (BCHMO)

We used measured mean daily streamflow for the USGS site 06140000, Beaver Creek near Havre, MT for this location. The period of record for mean daily discharge at this site is 1918-1921. In the original 2012 Basins Study, measured flow at this location was included in the calculation of Milk River Tributary Gains from Fresno Reservoir to Havre (MT DNRC 2013). This site required monthly records extension (using the FILLIN program) for seasonal data and period of record extension. For this study, we used measured flow along with irrigation demands from the ET Demands model discussed earlier, and efficiency estimates to back-calculate natural flows. The river systems model was used to solve for the natural inflow considering an irrigation requirement, irrigated acres, and return flow dynamics. We used a value of 738 total irrigated acres with the variable acreage adjustment discussed earlier to calculate the volumetric NIR for this location. Diversions were estimated using the NIR of the irrigated acres divided by the efficiency and incidental loss parameters discussed earlier. Return flows were estimated as the volume not consumed by

Table 2. Summary of locations in the St. Mary and Milk River Basins where natural flows were estimated

Location Code	Location Name	Associated USGS site ID	Daily Flow Period of Record
BCBMO	Beaver Creek (Bowdoin) at Mouth	06167500	1920 – 1921; 1981 – present
BCHMO	Beaver Creek (Havre) at Mouth	06140000	1918 – 1921
BGCMO	Buggy Creek at Mouth	06172200	1958 – 1967
BSCMO	Big Sandy Creek at Mouth	06139500	1946 – 1953; 1984 – present
BTCIB	Battle Creek at International Boundary	06149500	1917 – 2021
CLCMO	Clear Creek at Mouth	06142400	1984 – 1996; 2002 – present
FRRIB	Frenchman River at International Boundary	06164000	1917 – present
LBCMO	Little Box Elder Creek at Mouth	06141600	1986 – 1992; 1994 – 1996
LDCIB	Lodge Creek at International Boundary	06145500	1951 – 2021
MRWIB	Milk River at Western Crossing of the International Boundary	06133000	1930 – present
NFKMR	North Fork Milk River above St. Mary Canal	06133500	1911 – present
PCCMO	Porcupine Creek at Mouth	06175000	1908 – 1924; 1982 – 1992
PPCMO	People's Creek at Mouth	06154550	1918 – 1921; 1951 – 1973; 1982 – 2009
RKCMO	Rock Creek at Mouth	06171000	1916 – 1926; 1956 – present
SMRBB	St. Mary River near Babb, MT	05017500	1901 – present
SMRIB	St. Mary River at International Boundary		1902 – present
SWCSB	Swiftcurrent Creek at Sherburne Reservoir	05014500	1912 – present
WLCMO	Willow Creek at Mouth	06174000	1954 – 1987
WWCMO	Whitewater Creek at International Boundary	06156000	1927 – 1980

crops or incidental loss. Return flows were routed back to the source using the return flow parameters discussed earlier. The daily natural flows were then calculated as:

$$Natural\ Flow = Measured\ Flow - Return\ Flows + Diversions$$

Beaver Creek near Havre is measured near Beaver Creek Reservoir, which is not represented in the river systems model. Beaver Creek Reservoir inflow data extends from 1976 through 1990. Additional records exist in paper form and the reservoir operator may have further data. Including the operation of Beaver Creek Reservoir is a potential area of improvement for this natural flow dataset. DNRC now operates three gaging stations on Beaver Creek Reservoir that measure inflows (beginning May 2021), reservoir water level and storage (beginning November 2022), and outflows (beginning October 2022). Most irrigation water use on Beaver Creek is below the reservoir.

Buggy Creek at Mouth (BGCMO)

Buggy Creek flows into the Milk River from the north, downstream from the Eastern Tributaries. There is not a lot of water use on Buggy Creek, but for this study we considered flows to be altered by irrigation depletions and were thus naturalized. We used mean daily streamflow for the USGS site 06172200, Buggy Creek near Tampico, MT for this location. The period of record for mean daily discharge at this site is 1958-1967. In the original 2012 Basins Study, measured flow at this location was included in the calculation of Milk River Tributary Gains from Vandalia Diversion Dam to the mouth (MT DNRC 2013). This site required monthly records extension (using the FILLIN program) for seasonal data and period of record extension. For this study, we used measured flow along with irrigation demands from the ET Demands model, and efficiency estimates to back-calculate natural flows. The river systems model was used to solve for the natural inflow considering an irrigation requirement, irrigated acres, and return flow dynamics. We used a value of 85 total irrigated acres with the variable acreage adjustment discussed earlier to calculate the volumetric NIR for this location. Diversions were estimated using the NIR of the irrigated acres divided by the efficiency and incidental loss parameters discussed earlier. Return flows were estimated as the volume not consumed by crops or incidental loss. Return flows were routed back to the source using the return flow parameters discussed earlier. The daily natural flows were then calculated as:

$$Natural\ Flow = Measured\ Flow - Return\ Flows + Diversions$$

Big Sandy Creek at Mouth (BSCMO)

Irrigation significantly depletes the flows in Big Sandy Creek. Gage records exist in several locations, with the longest records at Big Sandy Creek at Reservation Boundary near Rocky Boy and Big Sandy Creek near Havre. We used mean daily streamflow at the USGS site 06139500, Big Sandy Creek near Havre, MT for this location. The period of record for mean daily discharge at this site is 1946-1953 and 1984-present. In the original 2012 Basins Study, measured flow at this location was included in the calculation of Milk River Tributary Gains from Fresno Reservoir to Havre (MT DNRC 2013). This site required monthly records extension (using the FILLIN program) for seasonal data and period of record extension. For this study, we used measured flow along with irrigation demands from the ET Demands model, and efficiency estimates to back-calculate natural flows. The river systems model was used to solve for the natural inflow considering an irrigation requirement, irrigated acres, and return flow dynamics. We used a value of 2976 total irrigated acres with the variable acreage adjustment discussed earlier to calculate the volumetric NIR for this location. Diversions were estimated using the NIR of the irrigated acres divided by the efficiency and incidental loss parameters discussed earlier. Return flows were estimated as the volume not consumed by crops or incidental loss. Return flows were routed back to the source using the return flow parameters discussed earlier. The daily natural flows were then calculated as:

$$Natural\ Flow = Measured\ Flow - Return\ Flows + Diversions$$

Battle Creek at International Boundary (BTCIB)

Natural streamflow in Battle Creek at the International Boundary is calculated over a defined division period by USGS/WSC from March until October of each year. Natural flows were estimated for a 10-day division period from 1957 to 1992, and then twice monthly (15 or 16 days) from 1993 to present (see Table 1). The division period changed in the 1990’s due to greater availability of real-time data on the Eastern Tributaries, making closer monitoring of flow conditions possible. In the original 2012 Basins Study, the measured flow at this location was included in the calculation of Milk River Tributary Gains from Paradise Valley Diversion Dam to Harlem Irrigation District pumping station (MT DNRC 2013). For this study, we disaggregated reported natural flows computed by USGS/WSC into daily data based on the measured, mean daily streamflow at the USGS site 06149500 Battle Creek at international boundary. This site had a complete period of record for the natural flow period of interest with mean daily discharge from 1917 to present. Monthly records extension (using the FILLIN program) was used for missing seasonal data. The disaggregation was done by calculating the total flow measured at the gage station over the division period (10 days prior to 1993 and twice monthly after 1993). We calculated the percentage of total flow that occurred on each day during the division period and multiplied by the natural flow volume for that period. If the measured, daily flows at the gage were zero for the entire division period, but the natural flow was greater than zero for that division period, it was distributed evenly amongst the days. Naturalized flows are only reported from March to October because that is the irrigation season when water is being used or stored. For the remainder of the year, we assumed that there was no, or negligible, alteration of streamflow and the measured daily flows at the gage were used as the natural flow.

Clear Creek at Mouth (CLCMO)

We used mean daily streamflow for the USGS site 06142400, Clear Creek near Chinook, MT for this location. The period of record for mean daily discharge at this site is 1984-present. In the original 2012 Basins Study, measured flow at this location was included in the calculation of Milk River Tributary Gains from the Ft. Belknap Diversion Dam to the Paradise Valley Diversion Dam (MT DNRC 2013). This site required monthly records extension (using the FILLIN program) for seasonal data and period of record extension. For this study, we used measured flow along with irrigation demands from the ET Demands model, and efficiency estimates to back-calculate natural flows. The river systems model was used to solve for the natural inflow considering an irrigation requirement, irrigated acres, and return flow dynamics. We used a value of 943 total irrigated acres with the variable acreage adjustment discussed earlier to calculate the volumetric NIR for this location. Diversions were estimated using the NIR of the irrigated acres divided by the efficiency and incidental loss parameters discussed earlier. Return flows were estimated as the volume not consumed by crops or incidental loss. Return flows were routed back to the source using the return flow parameters discussed earlier. The daily natural flows were then calculated as:

$$Natural\ Flow = Measured\ Flow - Return\ Flows + Diversions$$

Frenchman River at International Boundary (FRRIB)

Natural streamflow in the Frenchman River at International Boundary is calculated over a defined division period by USGS/WSC from March until October each year. Natural flows were estimated for a 10-day division period from 1937 to 1992, and then twice monthly (15 or 16 days) from 1993 to present (see Table 1). The division period changed in the 1990’s due to greater availability of real-time data on the Eastern Tributaries, making closer monitoring of flow conditions possible. In the original 2012 Basins Study, measured flow at this location was used to quantify tributary inflows from the Frenchman River, which was included as its own sub-catchment rather than serving as an index for a larger sub-catchment with multiple tributaries (MT DNRC 2013). For this study, we disaggregated reported natural flows computed by USGS/WSC into daily data based on the measured, mean daily streamflow at the USGS site 06164000 Frenchman River at international boundary. This site had a complete period of record for the natural flow period of interest with mean daily discharge from 1917 to present. Monthly records extension (using the FILLIN program) was used for missing seasonal data. The disaggregation was done by calculating the total flow measured at the gage station over the division period (10 days prior to 1993 and twice monthly after 1993). We calculated the percentage of total flow that occurred on each day during the division period and multiplied by the natural flow volume for that period. If the measured, daily flows at the gage were zero for the entire division period, but the natural flow was greater than zero for that division period, it was distributed evenly to amongst the days. Naturalized flows are only reported from March to October because that is the irrigation season when water is being used or stored. For the remainder of the year, we assumed that there was no, or negligible, alteration of streamflow and the measured daily flows at the gage were used as the natural flow. It should be noted that the AOs reported naturalized flow to the IJC for the period 9/1/1994 to 9/15/1994 was -49cfs, which we considered to be zero for this study.

Little Box Elder Creek at Mouth (LBCMO)

We used mean daily streamflow for the USGS site 06141600, Little Box Elder Cr at Mouth nr Havre, MT for this location. The period of record for mean daily discharge at this site is 1986-1992 and 1994-1996. In the original 2012 Basins Study, measured flow at this location was included in the calculation of Milk River Tributary Gains from Havre to the Ft. Belknap Diversion Dam (MT DNRC 2013). This site required monthly records extension (using the FILLIN program) for seasonal data and period of record extension. For this study, we used measured flow along with irrigation demands from the ET Demands model, and efficiency estimates to back-calculate natural flows. The river systems model was used to solve for the natural inflow considering an irrigation requirement, irrigated acres, and return flow dynamics. We used a value of 311 total irrigated acres with the variable acreage adjustment discussed earlier to calculate the volumetric NIR for this location. Diversions were estimated using the NIR of the irrigated acres divided by the efficiency and incidental loss parameters discussed earlier. Return flows were estimated as the volume not consumed by crops or incidental losses. Return flows were routed back to the source using the return flow parameters discussed earlier. The daily natural flows were then calculated as:

$$Natural\ Flow = Measured\ Flow - Return\ Flows + Diversions$$

Lodge Creek at International Boundary (LDCIB)

Natural streamflow in Lodge Creek at the International Boundary is calculated over a defined division period by USGS/WSC from March until October each year. Natural flows were estimated for a 10-day division period from 1951 to 1992, and then twice monthly (15 or 16 days) from 1993 to present (see Table 1). The division period changed in the 1990’s due to greater availability of real-time data on the Eastern Tributaries, making closer monitoring of flow conditions possible. In the original 2012 Basins Study, measured flow at this location was used to quantify Milk River Tributary Gains from Paradise Valley Diversion Dam to Harlem Irrigation District pumping station (MT DNRC 2013). For this study, we disaggregated reported natural flows computed by USGS/WSC into daily data based on the measured, mean daily streamflow at the USGS site 06145500 Lodge

Creek bl McRae Creek at international boundary. This site had a complete period of record for the natural flow period of interest with mean daily discharge from 1951 to present. Monthly records extension (using the FILLIN program) was used for missing seasonal data. The disaggregation was done by calculating the total flow measured at the gage station over the division period (10 days prior to 1993 and twice monthly after 1993). We calculated the percentage of total flow that occurred on each day during the division period and multiplied by the natural flow volume for that period. If the measured, daily flows at the gage were zero for the entire division period, but the natural flow was greater than zero for that division period, it was distributed evenly to each day. Naturalized flows are only reported from March to October because this is the irrigation season when water is being used or stored. For the remainder of the year, we assumed that there was no, or negligible, alteration of streamflow and the measured daily flows at the gage were used as the natural flow.

Milk River at Western Crossing of International Boundary (MRWIB)

The same methods used by MT DNRC (2013) to estimate natural flows at this location were used in this study. The USGS and WSC cooperatively operate a gaging station on the Milk River at its Western Crossing of the International Boundary (USGS station 06133000). Daily discharge records generally are complete for this station with a period of record from 1930 to present, but it is a seasonal gage that is only operated from March through October. The measured daily discharge data at this site were adjusted to account for estimated upstream irrigation depletions to estimate the natural flow for this location. Past surveys estimated that about 2,700 acres might have been irrigated in the drainage area above the gage. In recent years, DNRC investigations estimated the irrigated area closer to 1,000 acres. Total monthly irrigation depletions for May through September were estimated for this portion of the watershed during the 2008 and 2009 irrigation seasons. We used the following monthly values estimated by MT DNRC (2013) based on measurements and conversations with landowners during the 2008 – 2009 irrigation season: May = 3.3 cfs, June = 3.0 cfs, July = 4.3 cfs, August = 1.7 cfs, September = 0 cfs. A gaging station is also operated year-round by the WSC on the Milk River near the Town of Milk River, Alberta (ECCC Gage #11AA005). Winter flows from this gage were used to fill in the missing seasonal data for the Milk River at the Western Crossing. The period of record for the Milk River at Milk River gage is 1909 to present. These winter flows also include contributions from the North Fork of the Milk River because the gage is just downstream of where the two forks of the Milk River join. The winter flow data may also include any winter inflows to the Milk River between the Forks and the gage station. The only difference in this dataset from the 2012 Basins Study is the addition of 2009 – 2015 data.

North Fork Milk River above St Mary Canal (NFKMR)

The same methods used by MT DNRC (2013) to estimate natural flows at this location were used in this study. The USGS operates a gaging station (06133500) on the North Fork of the Milk River near the International Boundary and upstream of where the St. Mary Canal discharges into the river. The gage has a period of record from 1911 to present, but it is generally only operated March through October. As of the 2012 Basins Study, no one was irrigating with North Fork water upstream of the gaging station, but there has been irrigation in the past. Daily average flows from the gaging station data were used as the basis for determining the natural flows for this station. The average amount of land irrigated in the watershed upstream of the gage was estimated to be 339 acres, with an average depletion of 0.8 acre-feet per acre. To account for the effects of this irrigation, we added the following monthly irrigation depletion amounts from MT DNRC (2013) to the 2009 - 2015 daily flows during the irrigation season: May = 1.4 cfs, June = 1.7 cfs, July = 0.7 cfs, August = 0.5 cfs, and September = 0.2 cfs. Because the gaging station was not operational during the winter, all winter input data were set to zero. In actuality, the North Fork does produce water during the winter but in this case, the combined winter inflows for the North Fork and Milk River mainstem are included in the data for the Milk River at the Western Crossing. It should be noted that these zero flow days are not representative of actual North Fork Milk River flows, especially when used for calibrating any hydrologic models. Excluding the actual flows in the North Fork and accounting for them at the Western Crossing works when using these natural flows as direct input to the river systems model; however, this may create inaccurate model fit statistics used as objective functions in the calibration workflow of any hydrologic or river systems model, for this location.

Porcupine Creek at Mouth (PCCMO)

We used mean daily streamflow for the USGS site 06175000, Porcupine Creek at Nashua, MT for this location. The period of record for mean daily discharge at this site is 1908-1924 and 1982-1992. This location was used as an index gage in the original 2012 Basins Study to account for Milk River Tributary Gains from Vandalia Diversion Dam to the mouth (MT DNRC 2013). Like the original 2012 Basins Study, we characterized these data as predominantly unimpaired streamflow and did not adjust them for this study. The only addition to the natural flows at this location was extending the period of record to include 2009 – 2015 data using the same missing value and records extension process. This site required monthly records extension (using the FILLIN program) for seasonal data and period of record extension.

Peoples Creek at Mouth (PPCMO)

We used mean daily streamflow for the USGS site 06154550, Peoples Cr bl Kuhr Coulee nr Dodson, MT for this location. The period of record for mean daily discharge at this site is 1918-1921; 1951-1973; and 1982-2009. In the original 2012 Basins Study, measured flow at this location was included in the calculation of Milk River Tributary Gains from Harlem Irrigation District pumping station to the Dodson Diversion

Dam (MT DNRC 2013). This site required monthly records extension (using the FILLIN program) for period of record extension. For this study, we used measured flow along with irrigation demands from the ET Demands model, and efficiency estimates to back-calculate natural flows. The river systems model was used to solve for the natural inflow considering an irrigation requirement, irrigated acres, and return flow dynamics. We used a value of 1419 total irrigated acres with the variable acreage adjustment discussed earlier to calculate the volumetric NIR for this location. Diversions were estimated using the NIR of the irrigated acres divided by the efficiency and incidental loss parameters discussed earlier. Return flows were estimated as the volume not consumed by crops or incidental losses. Return flows were routed back to the source using the return flow parameters discussed earlier. The daily natural flows were then calculated as:

$$Natural\ Flow = Measured\ Flow - Return\ Flows + Diversions$$

Peoples Cr bl Kuhr Coulee nr Dodson, MT is one of three sites that had adequate, year-round streamflow data in the Milk River Basin. Peoples Creek daily flows were combined with Willow Creek daily flows to create daily percentages of total monthly flows. These combined daily percentages were used to disaggregate extended monthly flows for tributaries between Fresno Reservoir and the mouth of Peoples Creek.

Rock Creek at Mouth (RKCMO)

We used mean daily streamflow for the USGS site 06169500, Rock Creek bl Horse Cr nr international boundary, for this location. The period of record for mean daily discharge at this site is 1916-1926 and 1956-present. In the original 2012 Basins Study, measured flow at this location was included in the calculation of Milk River Tributary Gains from Beaver Creek (Bowdoin) to Vandalia Diversion Dam (MT DNRC 2013). This site had a complete period of record for the natural flow period of interest. For this study, we used measured flow along with irrigation demands from the ET Demands model, and efficiency estimates to back-calculate natural flows. The river systems model was used to solve for the natural inflow considering an irrigation requirement, irrigated acres, and return flow dynamics. We used a value of 4872 total irrigated acres with the variable acreage adjustment discussed earlier to calculate the volumetric NIR for this location. Diversions were estimated using the NIR of the irrigated acres divided by the efficiency and incidental loss parameters discussed earlier. Return flows were estimated as the volume not consumed by crops or incidental losses. Return flows were routed back to the source using the return flow parameters discussed earlier. The daily natural flows were then calculated as:

$$Natural\ Flow = Measured\ Flow - Return\ Flows + Diversions$$

Rock Creek bl Horse Cr nr international boundary is one of three sites that had adequate, year-round streamflow data in the Milk River Basin. Rock Creek daily flows were combined with Willow Creek daily flows to create daily percentages of total monthly flows. These combined daily percentages were used to disaggregate extended monthly flows for tributaries between Peoples Creek and the mouth of the Milk River.

St. Mary River near Babb, MT (SMRBB)

We naturalized streamflow measured at St. Mary River near Babb (USGS site ID 05017500) as the sum of the estimated natural flow of Swiftcurrent Creek at Sherburne Reservoir (SWCSB), natural gains between Sherburne Dam and Lower St. Mary Lake, and natural inflow to Lower St. Mary Lake. This was the same water balance method applied by MT DNRC (2013) for this site in the 2012 Basins Study. The total of natural gains between Sherburne Dam and Lower St. Mary Lake as well as inflow to Lower St. Mary Lake were calculated by subtracting Sherburne Reservoir outflow, which is recorded and distributed daily by Reclamation's Hydromet Data System (https://www.usbr.gov/gp/hydromet/), from daily flows at the USGS St. Mary River near Babb gaging station. The resulting daily values were added to the estimated natural flow of Swiftcurrent Creek at Sherburne Reservoir. Occasionally, this calculation resulted in negative natural inflows, which were removed using the same averaging technique employed by MT DNRC (2013). This technique selected a period that included the negative flows and varied in length depending on how many negative values there were. Daily percentages were calculated using the daily flow divided by the sum of the period flow at St. Mary near Babb MT. This effectively smoothed the period over which negative values existed, including a number of days before and after.

St. Mary River at International Boundary (SMRIB)

For this location, we used mean daily discharge at three measurement sites, St. Mary River near Babb MT (USGS ID 05017500), St. Mary Canal at Intake near Babb MT (USGS ID 05018000), and St. Mary River at international boundary (USGS ID 05020500). The natural gains between St. Mary near Babb and St. Mary at the international boundary were calculated as:

$$Qgains = (Q_{SMRIB} + Q_{SMC}) - Q_{SMRBB}$$

Where $Qgains$ is the natural gain, Q_{SMRIB} is daily flow of the St. Mary River at international boundary, Q_{SMC} is the daily flow in the St. Mary Canal, and Q_{SMRBB} is the daily flow of the St. Mary near Babb. Occasionally, this calculation resulted in negative natural gains, which were removed using the same averaging technique employed by MT DNRC (2013). This technique selected a period that included the negative flows and varied in length depending on how many negative values there were. Daily percentages were calculated using the daily flow divided by the sum of the total period flow at St. Mary at the international boundary. This effectively smoothed the values over the period which negative values existed, including a number of days before and after. The natural flow at the international boundary was then calculated as:

$$Natural_{SMRIB} = Qnat_{SMRBB} + Qgains$$

Where $Natural_{SMRIB}$ is the natural flow at the international boundary, $Qnat_{SMRBB}$ is the estimated natural flow for the St. Mary River near Babb, and $Qgains$ are the natural gains between the locations.

Swiftcurrent Creek at Sherburne Reservoir (SWCSB)

The USGS operates a gaging station on Swiftcurrent Creek at Many Glacier (USGS site ID 05014500), which measures inflows just upstream of Sherburne Reservoir. This gage accounts for most, but not all the inflow to the Reservoir. We followed the same methods used by MT DNRC (2013) to naturalize flows at this site. We used USGS inflows along with daily Sherburne reservoir outflow and storage data, available from Reclamation's Hydromet Data System, to estimate the net inflows not captured by the USGS gage data. However, using this reservoir water balance method produced poor daily net inflow estimates where many days had negative inflows. These negative values were likely due to measurement error or reservoir losses due to evaporation and seepage exceeding the total inflows. These losses related to the reservoir are considered un-natural losses to the system as they would not occur in its absence. To remove these un-natural losses (i.e., the negative values) we used the following equation:

$$Natural_{SB} = Qin_t + \sum_{i=t}^{t-30}\left((Qout_i + \Delta S_i) - Qin_i\right) \times \frac{Qin_t}{\sum_{i=t}^{t-30} Qin_i}$$

In this equation, $Natural_{SB}$ is the naturalized flow at Sherburne Dam, Qin is the daily Swift Current Creek flow at the Many Glacier gage, $Qout$ is daily Sherburne outflow, ΔS is daily change in reservoir storage, and subscript t is the current time-step, or day in this case. This procedure adds the un-gaged portion of the reservoir inflow to the daily USGS gaged inflow at Many Glacier. The computed un-gaged inflow volumes were summed over a moving 30-day period (hence the $t - 30$) and then distributed daily, based on the inflow patterns for the Swift Current Creek at Many Glacier gage. This mostly eliminated the occurrence of negative daily gains between the gaging station and the dam, while preserving mass balance. For any remaining negative values, the un-gaged inflow was assumed to be zero. This mass balance approach has the potential to slightly overestimate the un-gaged inflows because they would include direct precipitation to the reservoir water surface. Without the reservoir, that same precipitation would undergo additional hydrologic processes to become streamflow in Swiftcurrent Creek which would include natural losses along the way. Given the small volume of un-gaged inflows, this overestimation was considered negligible to the natural flow estimate.

Willow Creek at Mouth (WLCMO)

We used mean daily streamflow for the USGS site 06174000, Willow Creek near Glasgow, MT for this location. The period of record for mean daily discharge at this site is 1954 - 1987. This location was used as an index gage in the original 2012 Basins Study to account for Milk River Tributary Gains from Vandalia Diversion Dam to the mouth (MT DNRC 2013). Like the original 2012 Basins Study, we characterized these data as predominantly unimpaired streamflow and did not adjust them for this study. The only addition to the natural flows at this location was extending the period of record to include 2009 – 2015 data using the same missing value and records extension process. This site required monthly records extension (using the FILLIN program) period of record extension. Willow Creek nr Glasgow, MT is one of three sites that had adequate, year-round streamflow data in the Milk River Basin, but the site did not have a complete period of record. The daily flows were used to create daily percentages of total monthly flows. The daily percentages were combined with those from Peoples Creek and Rock Creek to form two separate daily distribution series that cover the natural flow period of interest. We used these combined data series to disaggregate the extended monthly flows. The Peoples/Willow Creek series was used for Milk River tributaries upstream of and including Peoples Creek, while the Rock/Willow Creek series was used for tributaries downstream of Peoples Creek.

Whitewater Creek at Mouth (WWCMO)

We used mean daily streamflow for the USGS site 06156000, Whitewater Creek near international boundary, for this location. In the original 2012 Basins Study, measured flow at this location was included in the calculation of Milk River Tributary Gains from Beaver Creek (Bowdoin) to Vandalia Diversion Dam (MT DNRC 2013). This site required monthly records extension (using the FILLIN program) for seasonal data and period of record extension. For this study, we used measured flow along with irrigation demands from the ET Demands model, and efficiency estimates to back-calculate natural flows. The river systems model was used to solve for the natural inflow considering an irrigation requirement, irrigated acres, and return flow dynamics. We used a value of 1800 total irrigated acres with the variable acreage adjustment discussed earlier to calculate the volumetric NIR for this location. Diversions were estimated using the NIR of the irrigated acres divided by the efficiency and incidental loss parameters discussed earlier. Return flows were estimated as the volume not consumed by crops or incidental losses. Return flows were routed back to the source using the return flow parameters discussed earlier. The daily natural flows were then calculated as:

$$Natural\ Flow = Measured\ Flow - Return\ Flows + Diversions$$

Natural Flow Results

The following results provide a visual comparison of the measured, or observed, flow at each location and the estimated natural flow. The data are presented as daily duration hydrographs that statistically summarize the range of flows for the 35-year (1980 – 2015) study period. These graphs show a daily hydrograph for a generic year and explain the flow regime at each location. The flow regime consists of magnitude, timing, duration, and frequency of streamflow. Each day in the illustrated hydrographs represents a flow duration curve (FDC) over the 35-year study period. A FDC describes the percentage of time over a defined period that a given flow occurs. The statistics summarized in the graphs are the median flow (what could be considered "normal") and the interquartile range (IQR) for each day of the year. The IQR is bounded on the top by flows that are exceeded only 25 percent of the time (less frequent higher flows) and on the bottom by flows that are exceeded 75 percent of the time (more common lower flows).

Some locations did not have an adequate number of observed flows to construct these statistics during the study period. For developing these graphs, we used a minimum threshold of 5-years' worth of data. If a location had fewer than 5-years of data between 1980 and 2015, the hydrograph was instead constructed using the full period of record for that gage. Locations where this is applicable are noted in the figure captions. Other location specific information can be found in the figure captions as well. Note that these graphs are a general visualization of changes to the natural flow regime at each location and are not a diagnostic tool for quantifying natural flow calculation performance. Because the resulting plots display flow statistics, we explain the factors that might create differences between estimated natural and observed flows that are a product of how the statistics were calculated and do not reflect true changes to the natural flow regime. Relevant factors are explained in the figure captions.

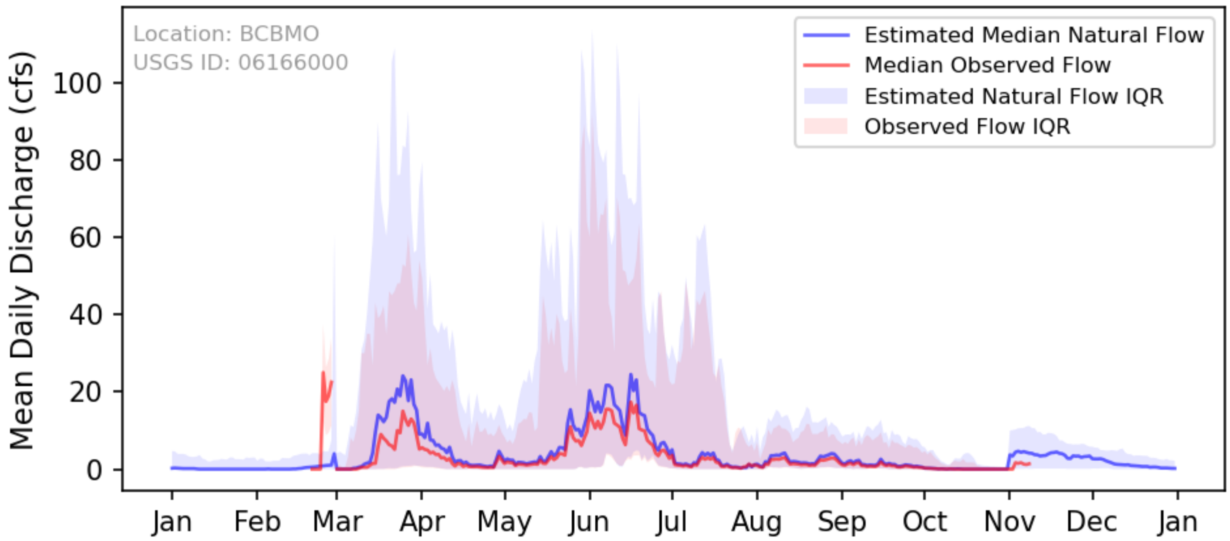

Figure 2. Graph of Beaver Creek (Bowdoin) at Mouth daily duration hydrograph summarizing 1980-2015 flow statistics for a generic year. Estimated natural flows (blue line) deviate from the observed flows (red line). This is unexpected because we assumed natural flow was equal to measured flow at this location. This discrepancy is likely caused by the records extension technique used before March 1 and after October 31, as well as missing data from 1980 for the observed flows. Anomalies and spikes in the observed data exist before March 1 and after October 31 because there is less than 35-years of measurements for a given day.

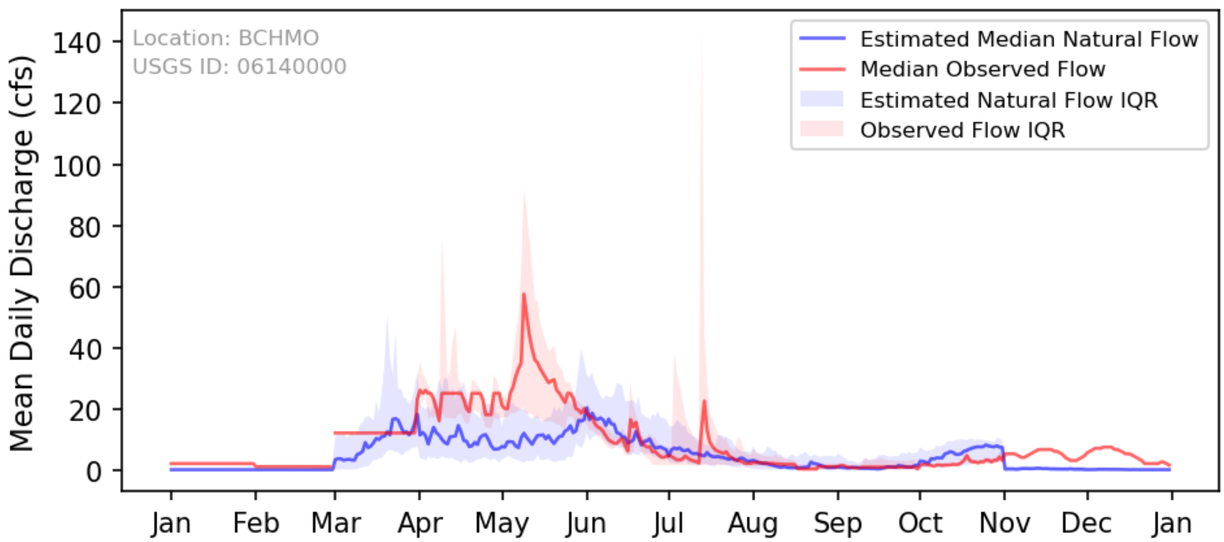

Figure 3. Graph of Beaver Creek (Havre) at Mouth daily duration hydrograph summarizing 1980-2015 flow statistics for a generic year. The full period of record was used to plot observed flow because there were fewer than 5-years of data during study period. Estimated natural flows (blue line) deviate from the observed flows (red line) after October 31 and before March 1. This is unexpected given that water use is zero for these parts of the year. This discrepancy is an artifact of extending the records for this seasonally operated gage or using zero for missing natural flow estimates. Anomalies and spikes in the observed data exist during these times of year because there is less than 35-years of measurements for a given day.

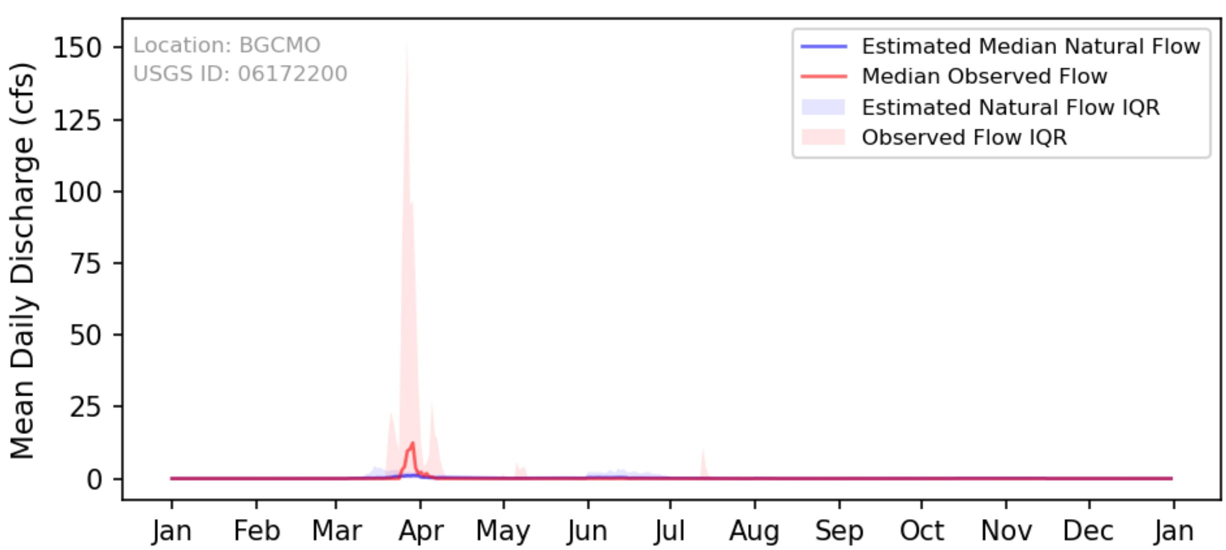

Figure 4. Graph of Buggy Creek at Mouth daily duration hydrograph summarizing 1980-2015 flow statistics for a generic year. The full period of record was used to plot observed flow because there were fewer than 5-years of data during study period. Discrepancies between observed and estimated natural flow may exist before March 1 and after October 31 due to extending data at this seasonally operated gage as well as missing observed flow data.

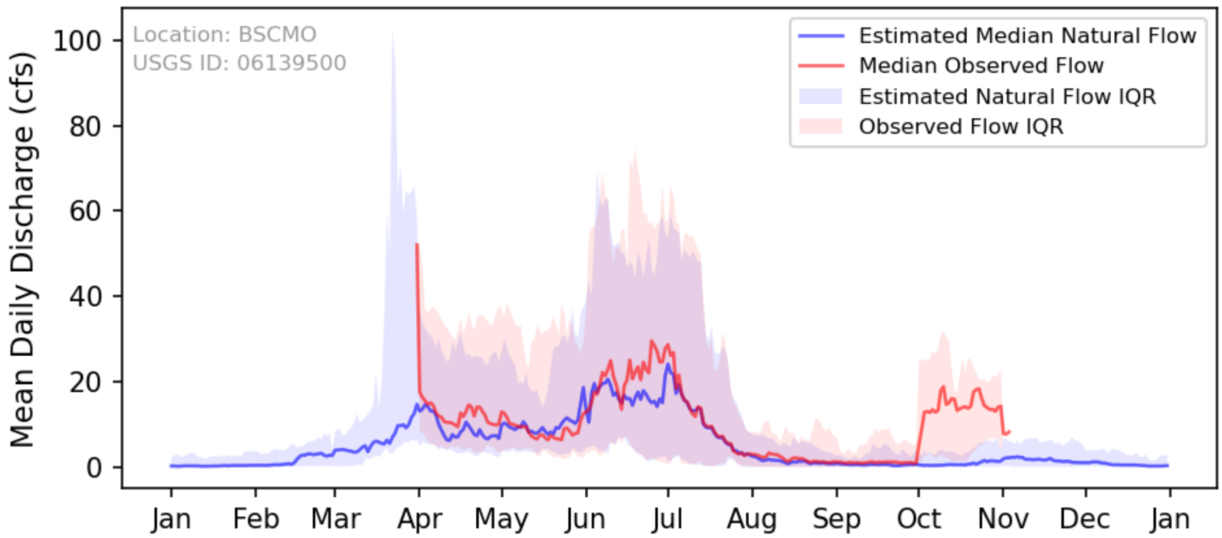

Figure 5. Graph of Big Sandy Creek at Mouth daily duration hydrograph summarizing 1980-2015 flow statistics for a generic year. Estimated natural flows (blue line) deviate from the observed flows (red line), such that observed flows are higher at times. This is likely caused by missing observed flow data from 1980 – 1983. Discrepancies after October 31 and before March 1 are also unexpected given that water use is zero for these times of year. These seasonal discrepancies are an artifact of the records extension technique used to fill data gaps when the gage was not operational. Anomalies and spikes in the observed data exist during these times of year because there is less than 35-years of measurements for a given day.

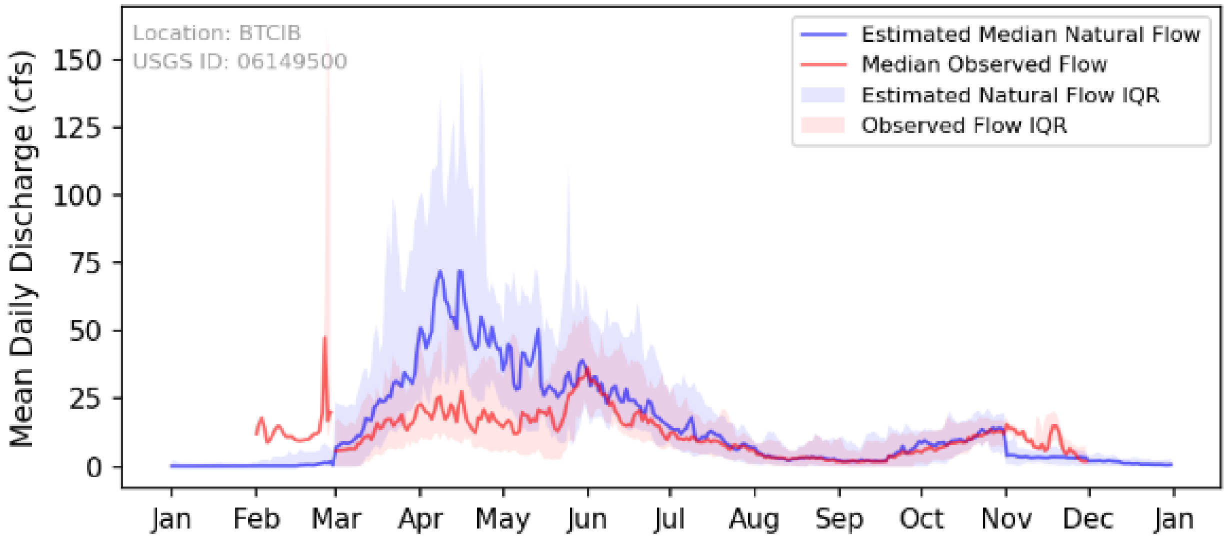

Figure 6. Graph of Battle Creek at International Boundary daily duration hydrograph summarizing 1980-2015 flow statistics for a generic year. Estimated natural flows (blue line) deviate from the observed flows (red line) in an expected way for most of the year. After October 31 and before March 1 discrepancies are unexpected given that natural flows are not reported to the IJC for these times of year and natural flow was assumed to equal observed flow. These seasonal discrepancies are an artifact of the records extension technique used to fill data gaps when the gage was not operational. Anomalies and spikes in the observed data exist during these times of year because there is less than 35-years of measurements for a given day.

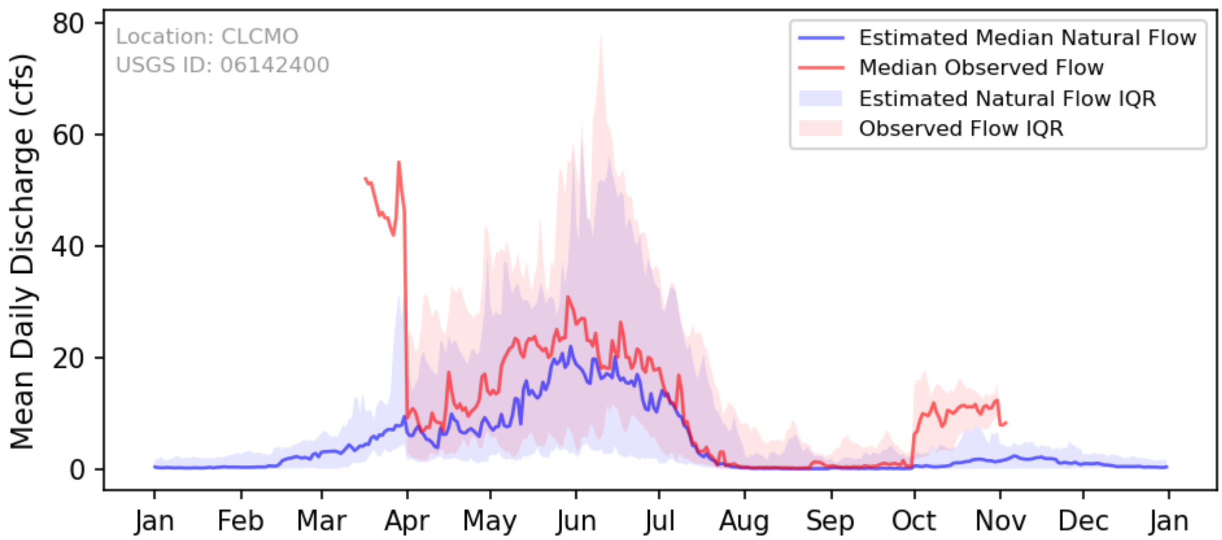

Figure 7. Graph of Clear Creek at Mouth daily duration hydrograph summarizing 1980-2015 flow statistics for a generic year. Estimated natural flows (blue line) deviate from the observed flows (red line) such that observed flows are greater than natural flows for most of the year. This is unexpected given the method used to estimate natural flows and can be explained by missing observed flow data from 1980 – 1983, and 1996 – 2002 which alters the duration hydrograph. After October 31 and before March 1, discrepancies are unexpected given that water use is zero at these times of year. These seasonal discrepancies are an artifact of the records extension technique used to fill data gaps when the gage was not operational. Anomalies and spikes in the observed data exist during these times of year because there is less than 35-years of measurements for a given day.

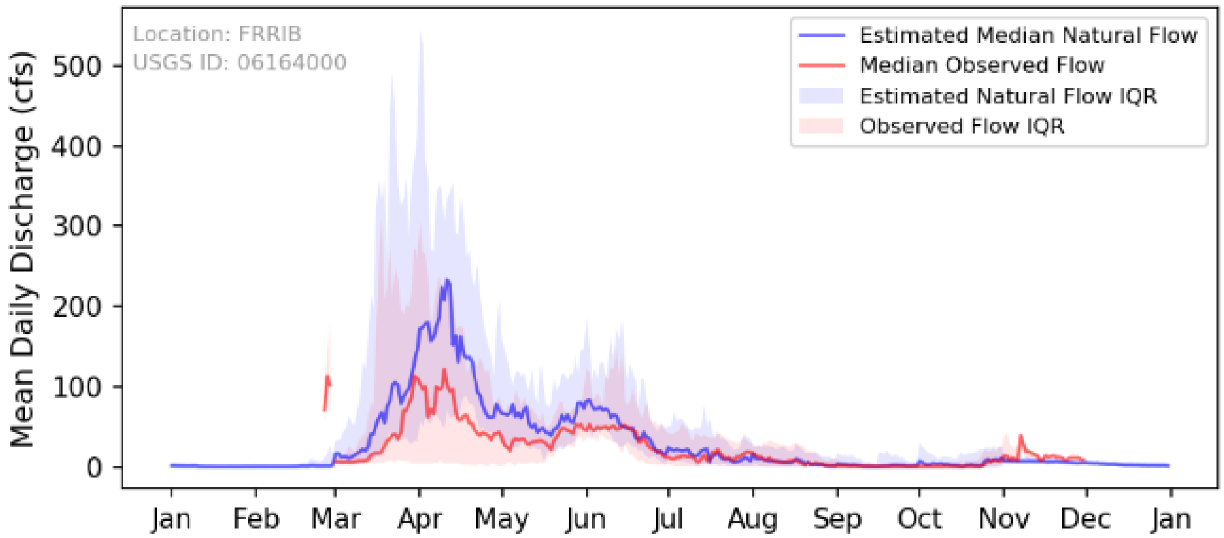

Figure 8. Graph of Frenchman River at International Boundary daily duration hydrograph summarizing 1980-2015 flow statistics for a generic year. Estimated natural flows (blue line) deviate from the observed flows (red line) in an expected way for most of the year. After October 31 and before March 1 discrepancies are unexpected given that natural flows are not reported to the IJC for these times of year and were assumed to equal observed flow. These seasonal discrepancies are an artifact of the records extension technique used to fill data gaps when the gage was not operational. Anomalies and spikes in the observed data exist during these times of year because there is less than 35-years of measurements for a given day.

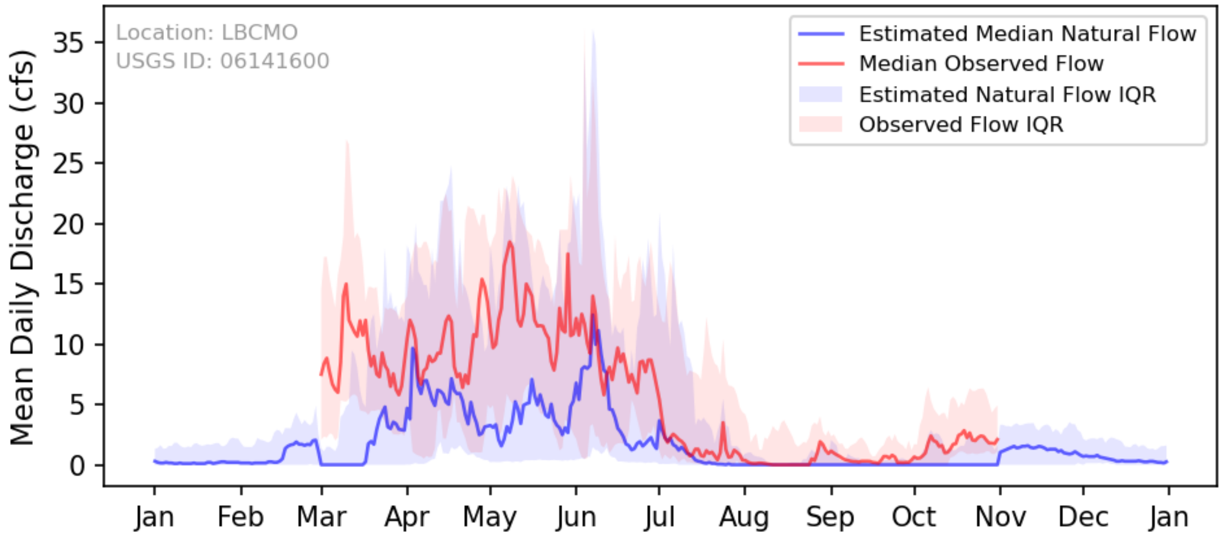

Figure 9. Graph of Little Box Elder Creek at Mouth daily duration hydrograph summarizing 1980-2015 flow statistics for a generic year. Estimated natural flows (blue line) are less than the observed flows (red line) for most of the year. This is unexpected given the method used to naturalize flows. However, this discrepancy occurs because 16 out of the 35-years in the study period are missing for the observed flow data, which alters the duration hydrograph. Discrepancies between observed and estimated natural flow may exist before March 1 and after October 31 due to extending data at this seasonally operated gage, as well as missing seasonal, observed flow data.

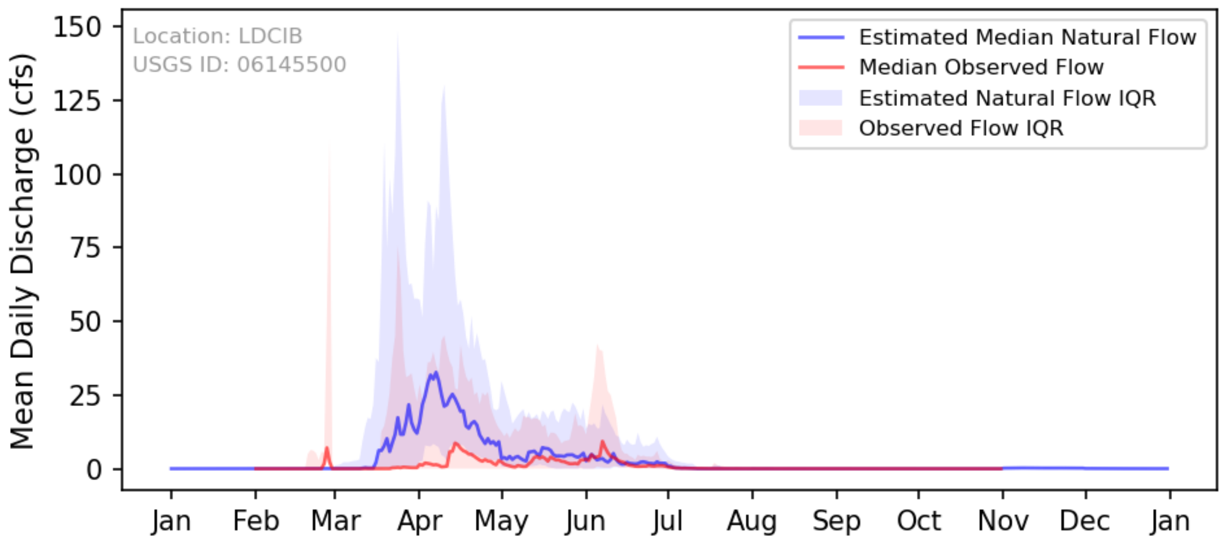

Figure 10. Graph of Lodge Creek at International Boundary daily duration hydrograph summarizing 1980-2015 flow statistics for a generic year. Estimated natural flows (blue line) deviate from the observed flows (red line) in an expected way for most of the year. After October 31 and before March 1 discrepancies are unexpected given that natural flows are not reported to the IJC for these times of year and were assumed to equal observed flow. These seasonal discrepancies are an artifact of the records extension technique used to fill data gaps when the gage was not operational. Anomalies and spikes in the observed data exist during these times of year because there is less than 35-years of measurements for a given day.

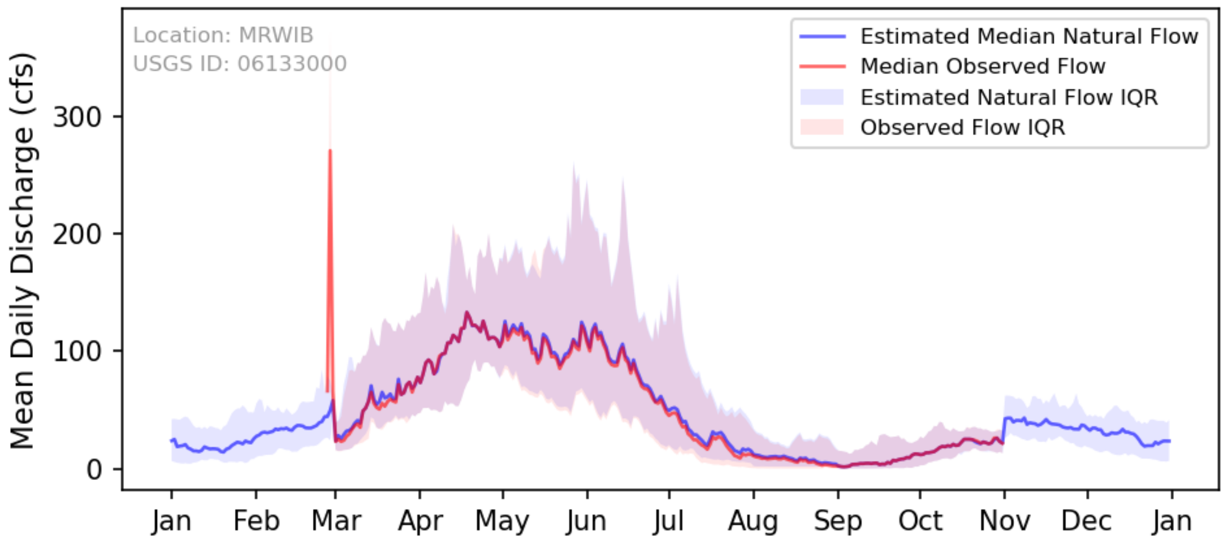

Figure 11. Graph of Milk River at Western Crossing of the International Boundary daily duration hydrograph summarizing 1980-2015 flow statistics for a generic year. Estimated natural flows (the blue line) are noticeably higher before March 1 and after October 31. This seasonal increase is a product of the method used to fill in missing seasonal data when this gage was not operational. The flows are increased because during these times of year, data from the ECCC gage at Milk River, Alberta (which is operated year-round) is used instead. These flows include the North Fork Milk River winter flows, which can be anywhere from 5 – 20 cfs. Anomalies and spikes in the observed data exist in the plot because there is less than 35-years of measurements for a given day prior to March 1 and after October 31.

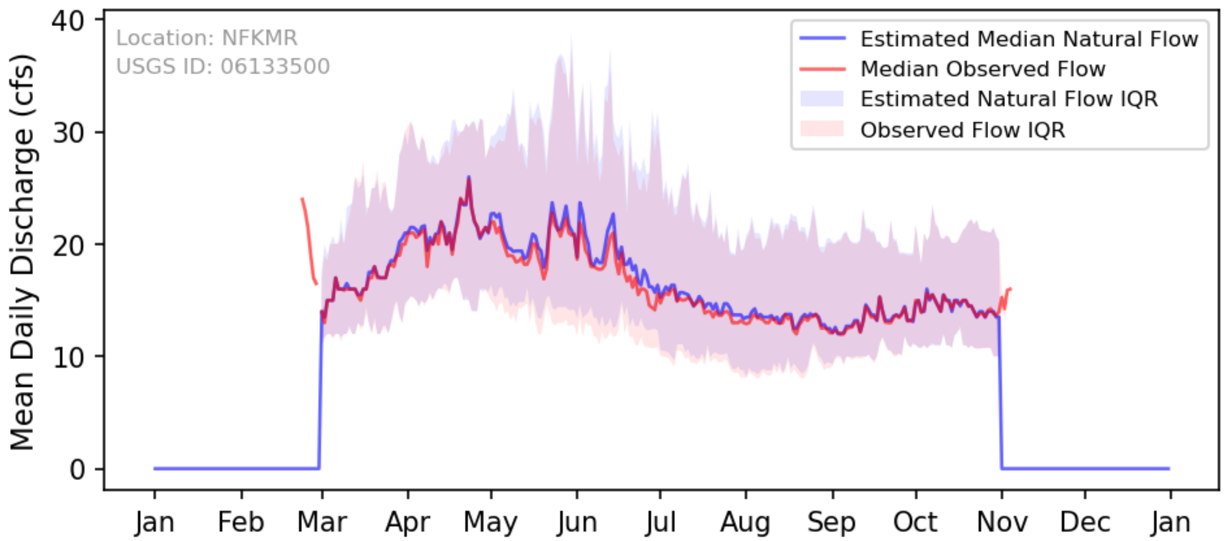

Figure 12. Graph of North Fork Milk River above St. Mary Canal daily duration hydrograph summarizing 1980-2015 flow statistics for a generic year. Estimated natural flows (the blue line) are suddenly equal to zero before March 1 and after October 31. This is a product of the method used to fill in missing seasonal data when this gage was not operational, which entailed setting missing data values to zero. North Fork Milk River flows during the winter are instead represented in the Milk River at Western Crossing location. Anomalies and spikes in the observed data exist in the plot because there is less than 35-years of measurements for a given day prior to March 1 and after October 31.

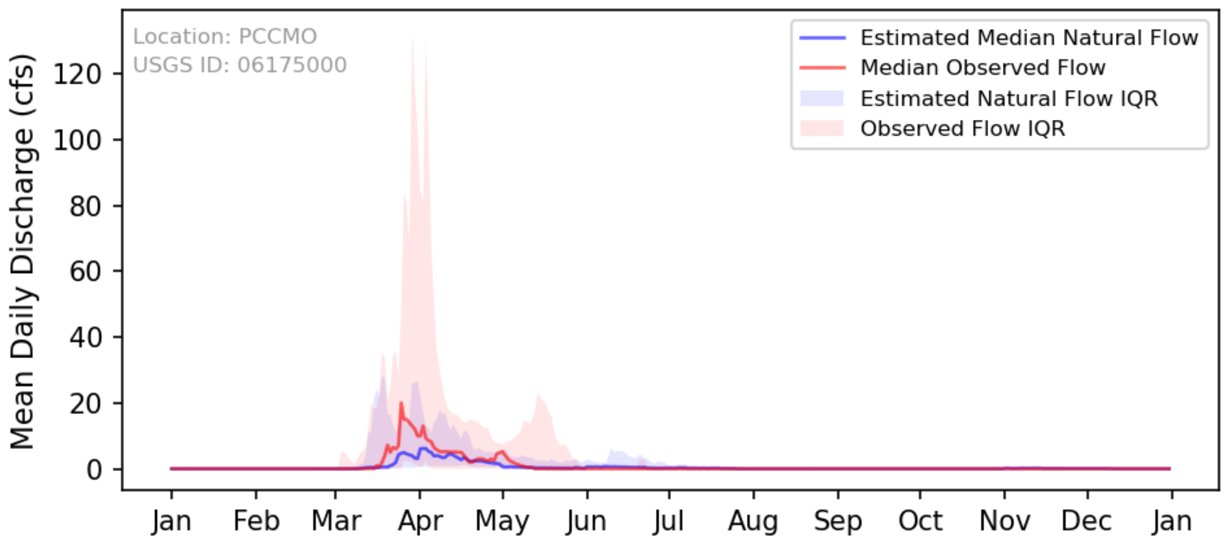

Figure 13. Graph of Porcupine Creek at Mouth daily duration hydrograph summarizing 1980-2015 flow statistics for a generic year. Estimated natural flows (blue line) are less than the observed flows (red line) for most of the year. This is unexpected because Porcupine Creek was characterized as unimpaired, meaning natural flow should equal observed flow. However, this discrepancy occurs because 25 out of the 35-years in the study period were missing for the observed flow data, which alters the duration hydrograph. Discrepancies between observed and estimated natural flow may exist before March 1 and after October 31 due to extending data at this seasonally operated gage, as well as missing seasonal observed flow data.

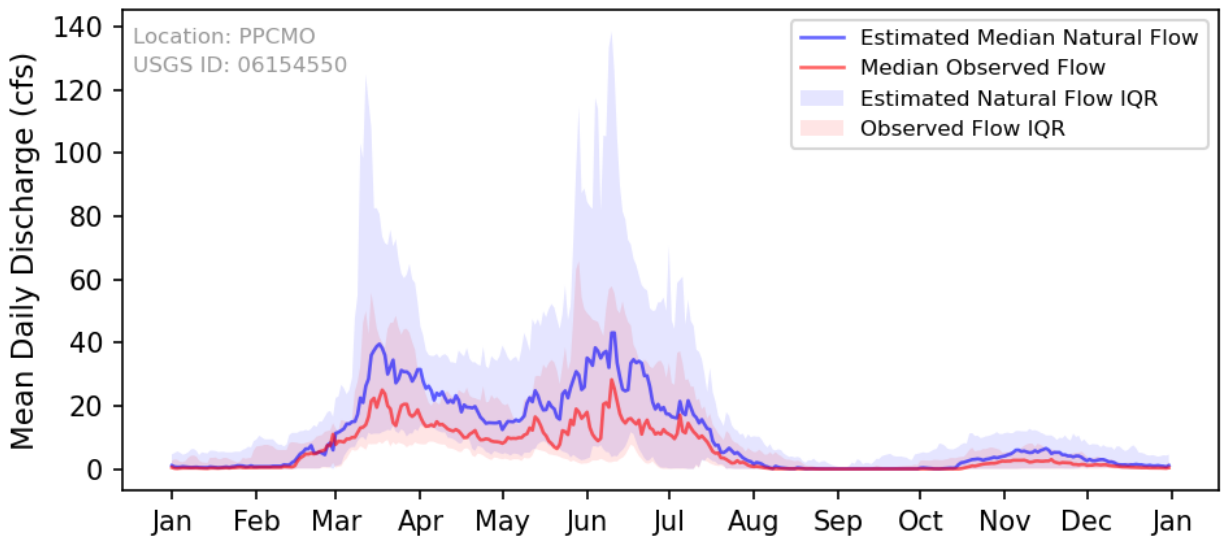

Figure 14. Graph of People's Creek at Mouth daily duration hydrograph summarizing 1980-2015 flow statistics for a generic year. Estimated natural flows (blue line) are higher than observed flow which is to be expected given the naturalization method for this location. However, some differences may occur because 8 of the 35-years in the study period were missing for the observed flow data. This was one of the few gage sites operated year-round, so anomalies created by missing seasonal data are not an issue.

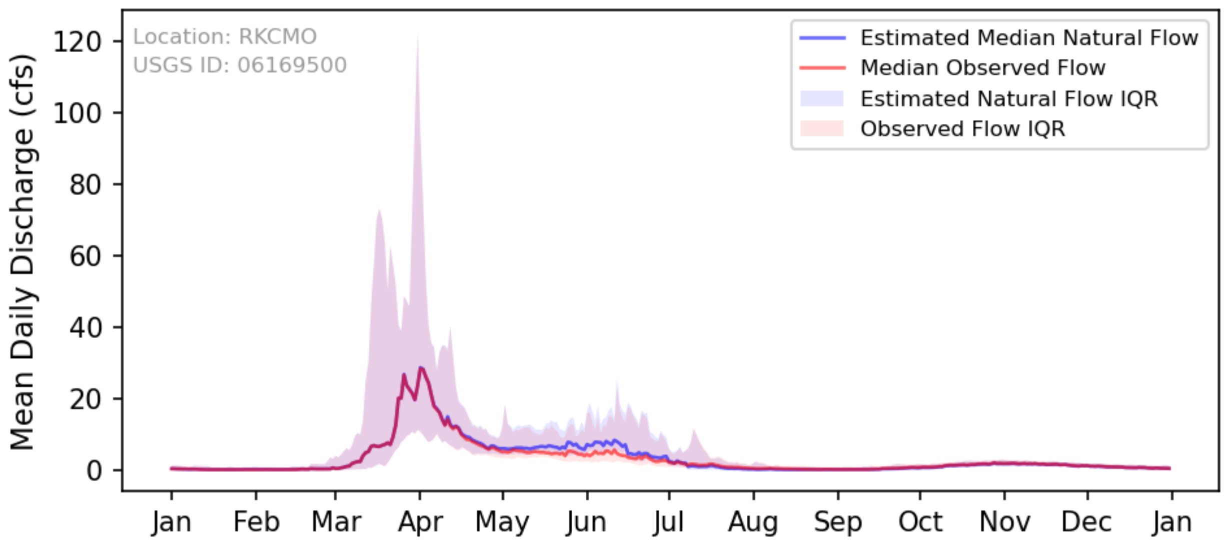

Figure 15. Graph of Rock Creek at Mouth daily duration hydrograph summarizing 1980-2015 flow statistics for a generic year. This location had a complete period of record overlapping the study period and was one of the few gage sites operated year-round, so anomalies created by missing seasonal data are not an issue.

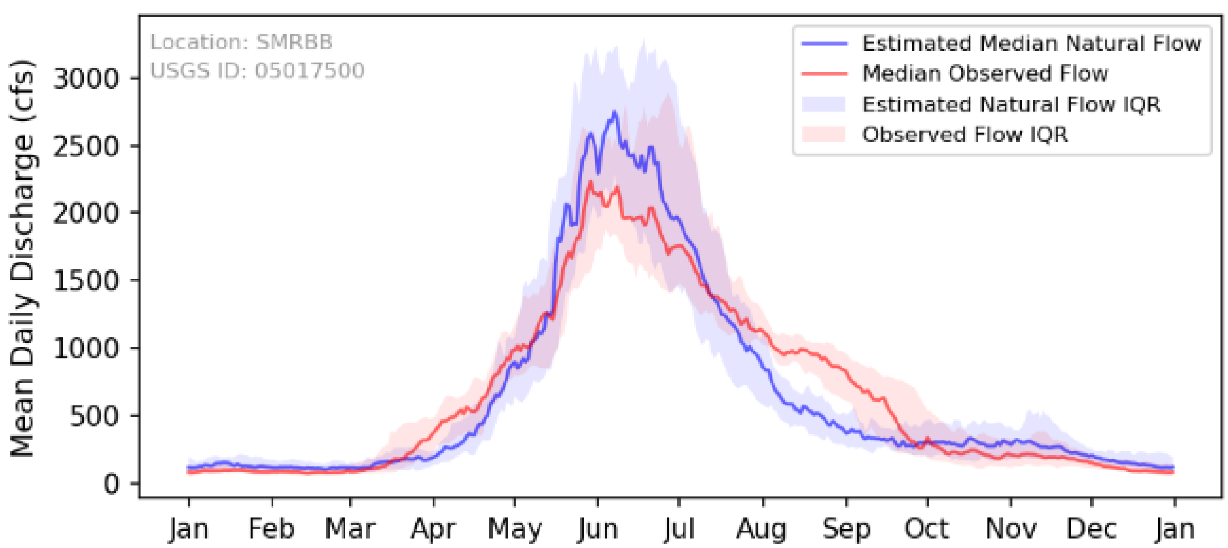

Figure 16. Graph of St. Mary River near Babb, MT daily duration hydrograph summarizing 1980-2015 flow statistics for a generic year. This location had a complete period of record overlapping the study period and was operated year-round.

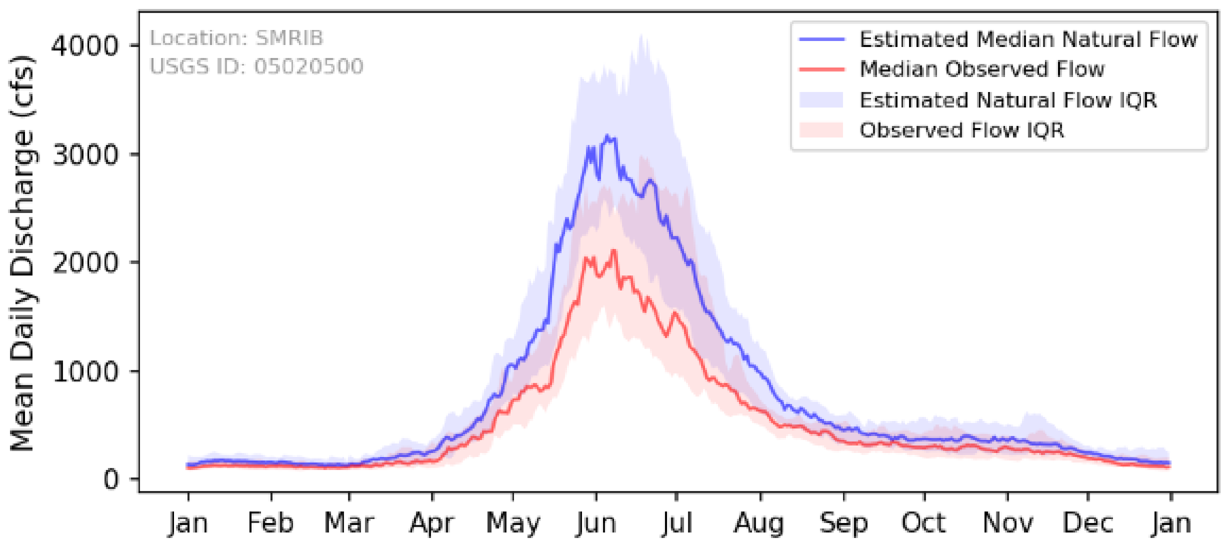

Figure 17. Graph of St. Mary River at International Boundary daily duration hydrograph summarizing 1980-2015 flow statistics for a generic year. This location had a complete period of record overlapping the study period and was operated year-round.

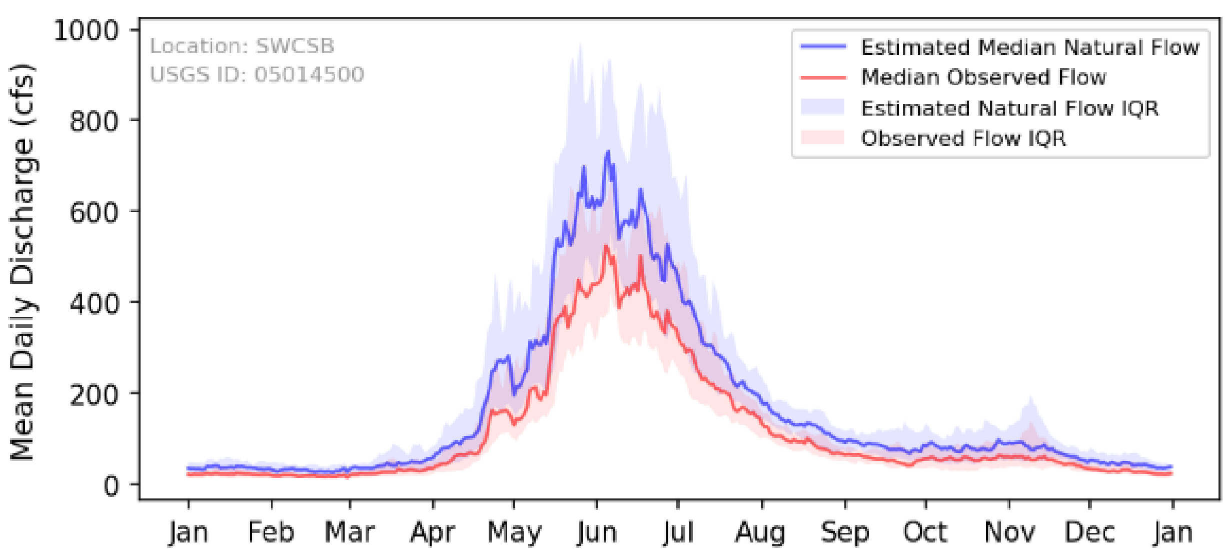

Figure 18. Graph of Swiftcurrent Creek at Sherburne Reservoir daily duration hydrograph summarizing 1980-2015 flow statistics for a generic year. This location had a complete period of record overlapping the study period and was operated year-round.

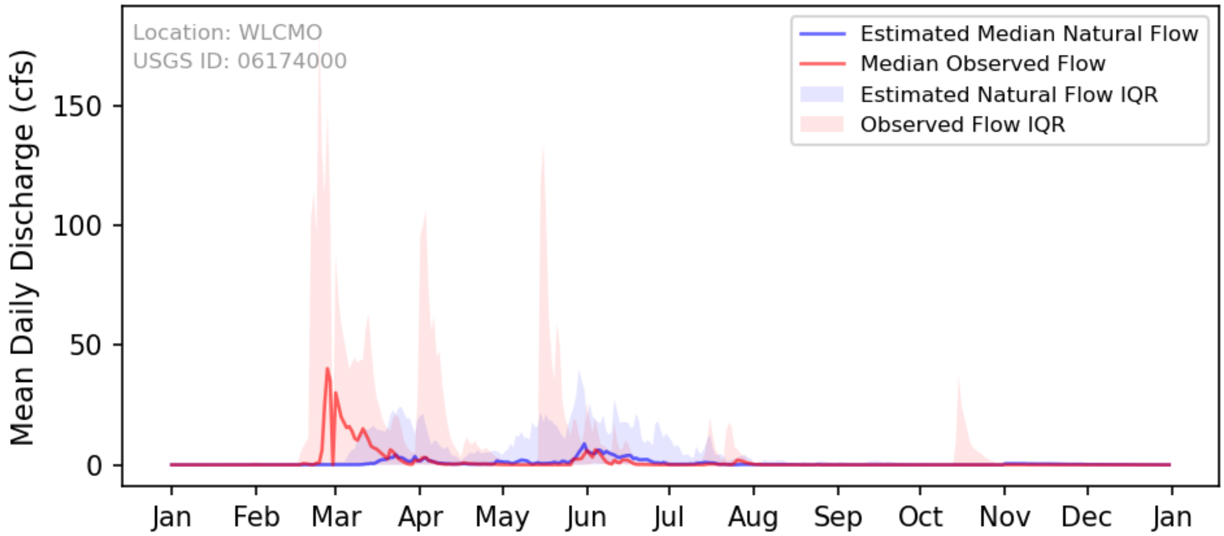

Figure 19. Graph of Willow Creek at Mouth daily duration hydrograph summarizing 1980-2015 flow statistics for a generic year. Estimated natural flows (blue line) are different than the observed flows (red line) for most of the year. This is unexpected because Willow Creek was characterized as unimpaired, meaning natural flow should equal observed flow. However, this discrepancy occurs because 28 out of the 35-years in the study period were missing observed flow data, which alters the duration hydrograph. Discrepancies between observed and estimated natural flow may exist before March 1 and after October 31 due to extending data at this seasonally operated gage, as well as missing seasonal observed flow data.

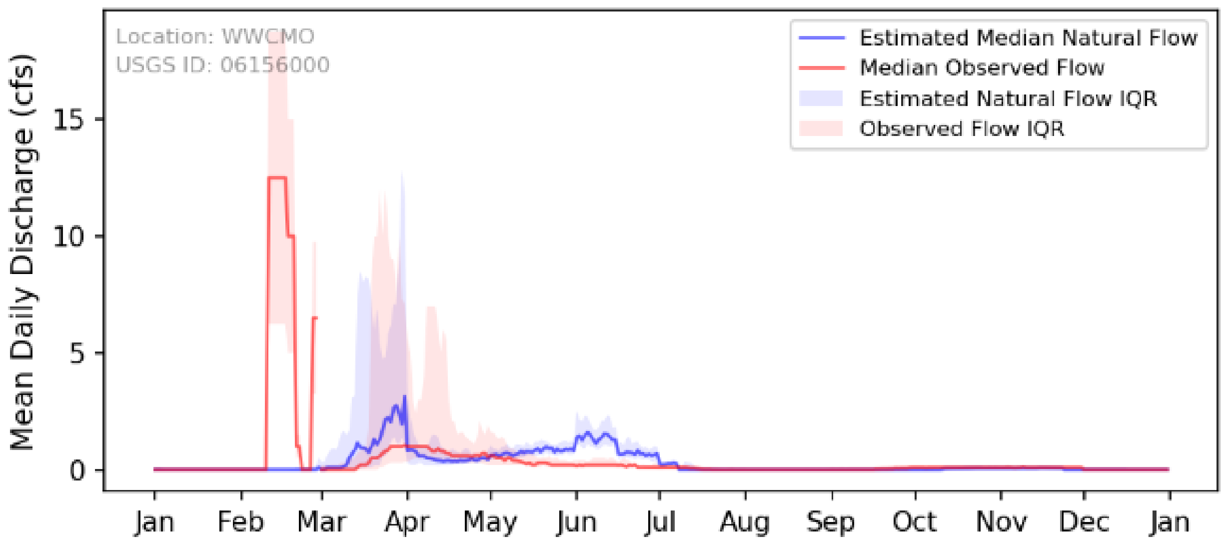

Figure 20. Graph of Whitewater Creek at Mouth daily duration hydrograph summarizing 1980-2015 flow statistics for a generic year. The full period of record was used to plot observed flow because there were fewer than 5-years of data during study period. Estimated natural flows (blue line) deviate from the observed flows (red line) mostly because the graph is not comparing the same periods. Discrepancies between observed and estimated natural flow may also exist before March 1 and after October 31 due to extending data at this seasonally operated gage, as well as missing seasonal observed flow data.

Conclusions

Natural flows are an important component to managing water resources in the transboundary St. Mary and Milk Rivers. Natural flows have a long history in these basins and have been estimated for over a century in compliance with international treaty requirements. Contemporary modeling of the St. Mary and Milk Rivers for water resource planning and operations has been ongoing since the 1990s. As models advance and more sophisticated methods are applied, input data requirements also become more intensive. Thus, natural flow estimates must improve and evolve to meet these modeling demands and provide a more robust understanding of the natural flows across the two basins. This has led to the need for estimated natural flows at many more locations than those historically used for international apportionment of water.

We developed an updated natural flow dataset for the St. Mary and Milk River Basins that includes 19 locations. This dataset provides the most spatially comprehensive natural flow dataset for the St. Mary and Milk Rivers to date. We used past methods (MT DNRC 2013) where applicable and introduced new methods for estimating natural flows on individual tributaries in the Lower Milk River. We also incorporated the long-standing natural flow estimates reported to the IJC for international apportionment at relevant locations along the international boundary.

It is the intent of this study to document the methods used to produce this dataset such that it can be reproduced, extended, or improved in the future. Although this is the most comprehensive dataset to-date, there are still noticeable improvements that could be made in future versions. Some of these improvements include updating methods used for records extension, inclusion of uncertainty in natural flow calculations, and location specific improvements. Some lower Milk River tributaries have upstream flows that are regulated by reservoirs. Beaver Creek near Havre is an example of a regulated system with three reservoirs upstream of the gage site. Including data, or estimated data, for small reservoirs on Milk River tributaries could provide more accurate natural flow estimates than those provided in this dataset. The completed dataset accompanies this report in digital format (see Supplementary Information and Digital Data for details).

DNRC Standards of Review Statement

This document has been reviewed in accordance with Category 1 standards set forth by DNRC's Water Management Bureau Standards for Review (MT DNRC 2021).

References

[AAFC] Agriculture and Agri-Food Canada. 2011. National Soil Database (NSDB): Soil Landscapes of Canada (SLC) Version 3.2. Available online https://sis.agr.gc.ca/cansis/nsdb/slc/index.html. March 2011.

[AAFC] Agriculture and Agri-Food Canada. 2013. Annual Crop Inventory 2013. Available online https://www.agr.gc.ca/atlas/apps/metrics/index-en.html?appid=aci-iac.

Allen RG, Pereira LS, Raes D, and Smith M. 1998. Crop Evapotranspiration: Guidelines for Computing Crop Water Requirements, Irrigation and Drainage Paper 56. Food and Agriculture Organization of the United Nations, Rome, 300 p.

Allen RG, Pereira LS, Smith M, Raes D, and Wright JL. 2005. FAO-56 Dual Crop Coefficient Method for Estimating Evaporation from Soil and Application Extensions. *Journal of Irrigation and Drainage Engineering*, ASCE, 131(1):2–13.

[ASCE] American Society of Civil Engineers. 2005. The ASCE Standardized Reference Evapotranspiration Equation. Task Committee on Standardization of Reference Evapotranspiration. Environmental and Water Resources Institute of the American Society of Civil Engineers. Final Report. January 2005.

[CADSWES] Center for Advanced Decision Support for Water and Environmental Systems. 2023. RiverWare River and Reservoir Modeling Tool, version 8.0.3. University of Colorado. Boulder, CO.

Cary LE and Parrett C. 1995. Synthesis of Natural Flows at Selected Sites in and near the Milk River Basin, Montana, 1928-89: U.S. Geological Survey. Reston (VA): U.S. Geological Survey. Water-Resources Investigations Report 95-4022, 46 p.

Hirsch RM. 1982. A comparison of four streamflow record extension techniques. *Water Resources Research* 18(4): 1081-1088.

Huntington JL and Allen RG. 2010. Evapotranspiration and Net Irrigation Water Requirements for Nevada. Nevada

State Engineer's Office Publication, 266 p. Available online http://water.nv.gov/mapping/et/Docs/Evapotranspiration_and_Net_Irrigation_Requirements_for_Nevada_Compiled.pdf

Mesinger F, DiMego G, Kalnay E, Mitchell K, and Co-authors. 2006. North American Regional Reanalysis. *Bulletin of the American Meteorological Society* 87:343-360. doi:10.1175/BAMS-87-3-343

[MT DNRC] Montana Department of Natural Resources and Conservation. 2013. St. Mary River-Milk River Basins Study: Model Documentation Report Including Model Revisions that Followed Completion of the Study. Helena (MT): State of Montana, DNRC. Available online https://dnrc.mt.gov/_docs/water/Hydro_science_data/St-Mary-Milk-River-Basins-Study_Model-Documentation-Report-Including-Model-Revisions-that-Followed-Completion-of-the-Study.pdf

[MT DNRC] Montana Department of Natural Resources and Conservation. 2021. Water Management Bureau (WMB) Report and Publication Guide. Helena (MT): Water Management Bureau, DNRC. http://dnrc.mt.gov/divisions/water/management/docs/wmb-report-and-publication-review-guide_final-2021-march-2.pdf

[MT DOR] Montana Department of Revenue. 2015. Final Land Unit Classification, 2015. Helena (MT). Available online https://mslservices.mt.gov/Geographic_Information/Data/DataList/datalist_Details.aspx?did={18a47176-0d37-406e-981e-570e1b003832}

Montana State Engineer's Office. 1965. Montana Water Resources Survey. Helena (MT): State of Montana.

Thornton PE, Thornton MM, and Vose RS. 2016. Daymet: Annual Tile Summary Cross-Validation Statistics for North America, Version 3. ORNL DAAC, Oak Ridge, Tennessee, USA. Available online https://doi.org/10.3334/ORNLDAAC/1348

[USBR] United States Bureau of Reclamation. 2012a. St. Mary River and Milk River Basins Study Summary Report. Milk River Project, Great Plains Region, Billings (MT), 46 p. March 2012. Available online https://www.usbr.gov/watersmart/bsp/docs/finalreport/Milk-StMary/Milk-StMary_SummaryReport.pdf

[USBR] United States Bureau of Reclamation. 2012b. St. Mary River and Milk River Basins Study Technical Report. Milk River Project, Great Plains Region, Billings (MT), 130 p. March 2012. Available online https://www.usbr.gov/watersmart/bsp/docs/finalreport/Milk-StMary/Milk-StMary_TechnicalReport.pdf

[USBR] United States Bureau of Reclamation. 2015. West-Wide Climate Risk Assessments: Irrigation Demand and Reservoir Evaporation Projections. Technical Memorandum No. 68-68210-2014-01. February 2015. 222 p. Available online https://www.usbr.gov/watersmart/baseline/docs/irrigationdemand/irrigationdemands.pdf

[USDA] United States Department of Agriculture. 2013. Montana Cropland Data Layer [online database]. Washington (DC): National Agricultural Statistics Service. Available online https://datagateway.nrcs.usda.gov/ .

[USDA] Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. 2018. U.S. General Soil Map (STATSGO2). Available online at https://sdmdataaccess.sc.egov.usda.gov. Accessed 2018.

[USGS and WSD] U.S. Geological Survey and Water Survey Division, Meteorological Service of Canada, 2018. *Procedures for the Division of the Waters of the St. Mary and Milk Rivers*. Department of Interior, Helena, Montana and Environment and Climate Change Canada, Calgary Alberta and Regina, Saskatchewan.

Supplementary Information and Digital Data

All original data produced as part of this study are included as digital datasets of spatial and tabular data. The complete Digital Data Release is available on DNRC Water Resources Division's website (https://dnrc.mt.gov/Water-Resources/Water-Science-and-Data/Basin-Studies/Lower-Missouri) or in an alternative format by request (please contact DNRC Water Resources Division, 1424 9th Ave; Helena, MT 59601, 406-444-6601).

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Back Cover: The St. Mary River upstream of the St. Mary Canal intake, June 2017. Photo by Michael Downey, MT Department of Natural Resources and Conservation.