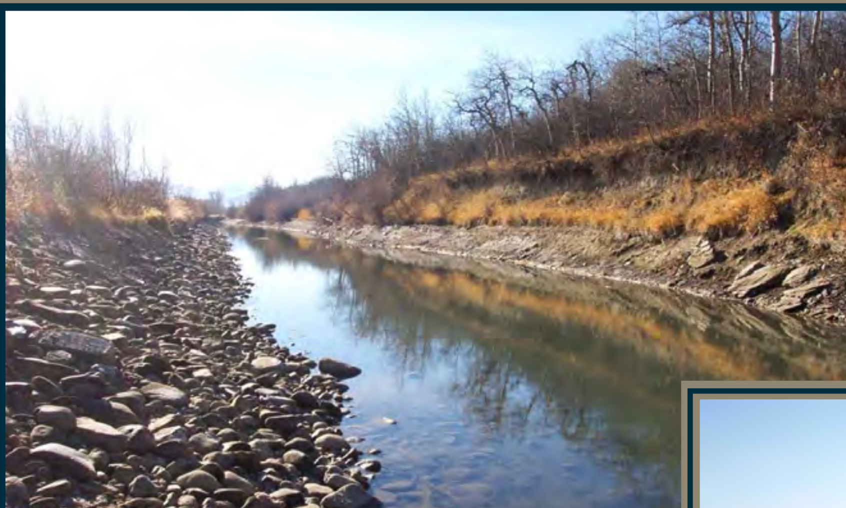
ST. MARY DIVERSION FACILITIES
HYDROLOGIC AND HYDRAULIC DESIGN CONSIDERATIONS FOR OVERALL CANAL REHABILITATION

July 28, 2006 Final



" Lifeline of the Hi-line"

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ac	-	acre
ACHP	–	Advisory Council on Historic Preservation
ACOE	–	Army Corps of Engineers
Ac-Ft	–	acre-feet (43,560 cubic feet)
AENV	-	Alberta Environment
AIRFA	–	American Indian Religious Freedom Act
ARPA	–	Archaeological Resources Protection Act
APE	–	area of potential effect
BA	–	biological assessment
BIA	–	Bureau of Indian Affairs
CFR	–	Code of Federal Regulations
cfs	–	cubic feet per second
CIP	–	cast-in-place
CMP	–	corrugated metal pipe
DNRC	–	Department of Natural Resources
DR	–	discipline reports
EA	–	environmental assessment
EIS	–	environmental impact statement
EPA	–	Environmental Protection Agency
FONSI	–	finding of no significant impact
F&WCA	–	Fish and Wildlife Coordination Act
GIS	–	geographical information system
GPS	–	global positioning system
HAER	–	Historic American Engineering Record
HDPE	–	high-density polyethylene
H:V	–	horizontal to vertical
IJC	–	International Joint Commission

MEPA	–	Montana Environmental Policy Act
MFWP	–	Montana Fish, Wildlife & Parks
MOU	–	memorandum of understanding
MR&I	–	municipal, rural and industrial
NAGPRA	–	Native American Graves Protection and Repatriation Act
NEPA	–	National Environmental Policy Act
NHPA	–	National Historic Preservation Act
NPS	–	National Park Service
NRCS	–	Natural Resource Conservation Service
NRIS	–	Natural Resource Information Service
NRPH	–	National Register of Historic Places
O&M	–	operations and maintenance
PA	–	Preferred Alternative (for context of this report, PA refers to the overall capacity that the St. Mary River Diversion Facilities will ultimately be rehabilitated)
PER	–	preliminary engineering report
PVC	–	polyvinyl chloride
RCP	–	reinforced concrete pipe
RFP	–	request for proposals
ROW	–	right-of-way
SCADA	–	supervisory control and data acquisition
SCS	–	Soil Conservation Service
SHPO	–	State Historic Preservation Office
St.	–	Saint
TD&H	–	Thomas, Dean & Hoskins, Inc.
T&E	–	threatened & endangered
TERO	–	Tribal Employment Rights Ordinance
THPO	–	Tribal Historic Preservation Office

USBR	-	United States Bureau of Reclamation
USFWS	−	United States Fish and Wildlife Service
USGS	−	United States Geological Survey

V. ACKNOWLEDGEMENTS

This report represents the combined efforts of many individuals and organizations through their input, cooperation and dedication to the overall goal of finding a workable solution towards the rehabilitation of the St. Mary Diversion Facilities. These parties include, but are not limited to, the State of Montana DNRC – Conservation and Resource Development Division, the Blackfeet Nation, the U.S. Bureau of Reclamation – Montana Area Office, and the members and supporters of the St. Mary Rehabilitation Working Group.

This Final Report supercedes the Draft version dated January 17, 2006. Review comments provided by the cooperating parties were incorporated into the Final Report where applicable.

Much of the background information contained in this report was obtained from many other sources. We have made attempts to credit the sources and ensure accuracy; however, some omissions may exist. For this, we apologize.

1.0 EXECUTIVE SUMMARY

The Milk River is the economic mainstay of North Central Montana from Havre to Glasgow. The majority of the Milk River flow utilized by irrigators, municipalities, and for recreational and wildlife benefits is diverted from the St. Mary River near Glacier National Park into the North Fork of the Milk River via a 90-year old, 29-mile long facility. Separate components include a diversion dam, canal headgates, several inverted siphons, check and wasteway structures, five hydraulic drops, and approximately 29 miles of canal. The diversion facilities are owned and operated by the U.S. Bureau of Reclamation (USBR), and many portions are in danger of failure. Sudden failure would result in severe environmental damage to the Blackfeet Indian Reservation and the St. Mary River or the North Fork of the Milk River as well as an economic catastrophe for the economies of North Central Montana.

The USBR's "North Central Montana Regional Feasibility Report" (USBR, 2004) screened numerous alternatives to reduce on-going water shortages in the Milk River Basin and concluded that the rehabilitation of the St. Mary Diversion Facilities was the most viable option and the only one that would produce positive economic benefits. That report assessed various rehabilitated canal capacities but did not provide a recommended capacity or a preferred alternative. This following report summarizes the hydrologic and hydraulic parameters and considerations necessary for proper capacity sizing and eventual designing of the replacement diversion and conveyance structures.

Water available for diversion to the St. Mary Canal is governed physically by both the amount of water available and the time of year it is available and legally by the International Joint Commission (IJC) that administers the 1909 Boundary Water Treaty between the U.S. and Canada. The 1921 IJC Order establishes guidelines to determine each country's apportionment of the natural flow and water accounting procedures to monitor and help manage the available water throughout each season. Currently the IJC utilizes a bimonthly accounting period. On the St. Mary River, an exception is allowed where the U.S. is permitted to make up to 8,000 acre-feet of deficit deliveries to Canada during certain times of the season while Canada is allowed to accumulate up to 4,000 acre-feet of deficit on the Milk River. Surplus deliveries that occur during each accounting period are forfeited and cannot be used to offset deficit deliveries that must be made up at the end of the season.

Based on flow measurements over the last 25 years, the average annual natural flow of the St. Mary River at the U.S.-Canadian Border is approximately 610,300 Ac-ft of which the U.S. apportionment has averaged nearly 246,500 Ac-ft. Unfortunately, during this same period, the U.S. has only diverted on average 175,400 Ac-ft or 71 percent of its apportionment. During dry years (below normal natural flows), the U.S. typically diverts a higher percentage (± 96%) of its apportionment than during wetter than normal years (± 44%). This shortfall is primarily the result of current IJC accounting procedures, a lack of adequate upstream storage and the diminishing conveyance capacity of the St. Mary Diversion Facilities. From approximately May 15th to July 10th, when peak runoff is occurring, the average U.S. apportioned flows general exceed the current canal capacity. During wet years, lack of demand by water users in the Milk River Basin due to above normal precipitation and storage reservoirs being replenished naturally also contributes to under-utilization of the U.S.'s apportionment. Also during wet years, storm water inflows into the canal, lack of sufficient freeboard, system safe guards, and numerous bank/slope instabilities dictate that the St. Mary Diversion Facilities be operated in a cautious and conservative manner to avoid over-topping and progressive breaching of the canal banks.

The IJC announced plans in December 2004 to establish an Administrative Measures Task Force to examine how the existing administrative procedures could be improved to ensure more beneficial use of apportioned water to each respective country. The Task Force reviewed accounting procedures, surpluses and deficits, accounting periods and other administrative measures that the group found pertinent to its task. The highlights of the Task Force's April 2006 report, as they relate to the purpose of this report, are discussed within.

Sherburne Reservoir is the only storage structure on the St. Mary River in the U.S. This reservoir allows the U.S. to capture and detain runoff originating upstream from the Swiftcurrent Creek drainage and then release it to supplement canal diversions when natural river flows begin to wane. Currently, there are no wintertime releases from Sherburne Reservoir. However, it is anticipated that eventually a year-round, release requirement up to 25 cfs may be adopted to help mitigate seasonal impacts to Bull Trout. To date, biologists with the Tribe, USFWS and USBR have not officially consulted to agree to a minimum flow requirement. Under current IJC accounting procedures and the existing diversion capabilities, this anticipated wintertime release may result in up to 6,850 Ac-ft in lost diversion potential of the U.S.'s apportionment. In 1921, the IJC had recommended the construction of the Lower St. Mary Lake storage dam (3700 feet upstream of the current diversion dam) and further recommended that the construction costs were to be borne equally between the U.S. and Canada. If this structure had been built, it would have further enabled the U.S. to attenuate the effect of high runoff events and more fully utilize its apportionment for diversion.

The diversion and conveyance facilities were originally designed for an original capacity of 850 cfs. Due to deterioration and degradation of the aging infrastructure, the existing "safe" capacity is currently on the order of 650 cfs due primarily to the sloughing and failure of the earthen canal prisms downstream of the St. Mary River siphon. Accounting for canal seepage losses upstream of the St. Mary River siphon (± 75 cfs), this equates to a "safe" diversion rate of approximately 725 cfs. In the last 10 years, the highest discharge measured at the siphon was 678 cfs and the largest diversion rate as measured at the head gates was 729 cfs. Also, inherent to the aged facilities, is the inability to manage storm water (inflows) and the lack of facility automation that results in a cautious operational approach and lost opportunities to maximize diversion of the U.S. apportionment. Also, several midseason shutdowns have been required to avoid progressive, catastrophic failures and to make the subsequent repairs. Planned maintenance and repairs often results in an early season shutdown that also reduces diversion potential. With continued aging and deterioration, these types of maintenance-related shutdowns and lost diversions will become more frequent.

The Montana Department of Natural Resources (DNRC) and Alberta Environment (AENV) jointly developed a hydrologic model to evaluate the effect of alternative IJC accounting periods and various diversion rates on the ability of the U.S. to maximize use of its apportionment. The model indicates little difference between the theoretical maximum annual diversions for weekly, bimonthly, and monthly accounting periods. Seasonal accounting produces modest gains while an annual accounting period is the single most beneficial factor that could be implemented to maximize U.S.'s diversion potential. Rehabilitating the St. Mary Canal to an increased capacity of 850 cfs or greater would further enable the U.S. to utilize its apportionment. In theory, implementing an annual accounting period and rehabilitating the diversion facilities to a capacity of 1200 cfs would allow the U.S. to divert nearly its entire average annual apportionment based on flow data from 1980 to 2004. These relationships are shown on Figure 1.1.

Rehabilitation and sizing of the replacement structures for the St. Mary Diversion Facilities must consider both seepage losses and impacts from storm water inflows. Seepage was estimated using both empirical relationships and comparisons of gaged flows at the head gates (USGS 05018000), the St. Mary River siphon (USGS 05018500) and the St. Mary – Milk River drainage divide (USGS 0501900). Total seepage is approximately 10 percent of the canal capacity. In the first segment, between the diversion dam and the St. Mary River siphon, seepage losses are on the order of 60 to 80 cfs and between 10 and 30 cfs downstream of the St. Mary River siphon. Seepage losses upstream of the St. Mary siphon are not assessed to the U.S. as they eventually return to the St. Mary River. However, between the St. Mary River siphon and the Hudson Bay divide, seepage losses are assessed to the U.S. but actually flow back to Canada via Willow Creek. Based on an average seepage loss of 20 cfs over a 183-day diversion season (April 1st to September 30th) this seepage loss of U.S. apportionment equates to approximately 7,250 Ac-ft per season or 3 percent of the 25-year average annual apportionment.

Storm water inflows from the subbasins along the canal were modeled using three distinctly different meteorological events and three different antecedent soil moisture conditions. Runoff volume for the 100-year, 24-hour storm downstream of the St. Mary River siphon is approximately 1,650 Ac-ft, which is less than observed seepage loss (mentioned above) in this segment over the course of a typical season. The storm water runoff parameters provided in this report should be used during design to cost-effectively size canal freeboard and capacity contingency for the in-line hydraulic structures. During design, the runoff parameters developed for this study should be used to develop a storm water routing curve to facilitate the overall design, as a check of the adequacy of the final design, and to setup the facility automation protocols.

The key findings, results and recommendations of this study indicate the following:

- Rehabilitation of the facilities should also include a slight over-sizing to incorporate operational flexibility. The IJC Task Force concluded this as well.

- Rehabilitation of the St. Mary Diversion Facilities should include a design capacity of not less than 850 cfs as delivered to the North Fork of the Milk River. Diversion rates should consider seepage losses, any U.S. consumptive uses internal to the facilities, and potential hydropower at the St. Mary siphon crossing.

- If diversions in excess of 850 cfs to the North Fork of the Milk are anticipated, any potential environmental impacts such as erosion, sedimentation, and flooding to the Milk River system should be evaluated.

- Incorporate a canal freeboard sufficient for a 25-year, 24-hour storm. In-line hydraulic structures should be assessed using storm water routing considering a 50-year return. Emergency wasteways and dedicated spill areas should be assessed using the 100-year return.

- Total seepage losses are estimated to be approximately 10 percent of the canal flows; these should be added to the desired diversion capacity when sizing the canal.

- Continue to lobby the IJC to change the apportionment administrative procedures to allow an extension of the accounting period and/or revoking the surplus delivery penalty so as to afford the U.S. better opportunity to utilize its apportionment on the St. Mary River.

- Lobby the IJC for accounting changes that would allow the U.S. credit for seepage losses downstream of the St. Mary Siphon (USGS 05018500). Most of these seepage losses enter Canada via Willow Creek. Current estimates indicate an annual loss of 7,250 Ac-ft, which is 3 percent of the U.S.'s average annual apportionment based on the last 25 years.

One consideration would be to reactivate USGS Station 05019000 located on the St. Mary – Milk River drainage divide. This location is ideal for determining the actual and true diversion of the U.S.'s St. Mary River apportionment into the Milk River Basin. Gaging at this location would take into account the net effect of storm water inflows, groundwater gains and seepage losses. The IJC Task Force Report also concluded this observation.

- Ultimate sizing of the rehabilitated St. Mary Facilities should consider not only current irrigation demands in the Milk River Basin, but also allow for potential future demands due to population and economic growth and expansion, changes in agricultural (value-added crops) and potential USBR project authorization for other uses. Non-irrigation demands for U.S. water within the Milk River Basin includes Reserved Water Rights, MR&I needs (municipal, recreation and industrial), Bowdoin National Wildlife Refuge, threatened and endangered species (piping plover and pallid sturgeon) and fish and wildlife in general. The IJC's *Administrative Measures Task Force Report* (2006) stated…….. "should (St. Mary Canal) rehabilitation become a reality, it would be prudent to construct the system to a capacity that would optimize the ability of the U.S. to divert its full entitlement of St. Mary River water."

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Figure 1.1 Theoretical Annual Average Diversion Potential Versus Canal Capacity

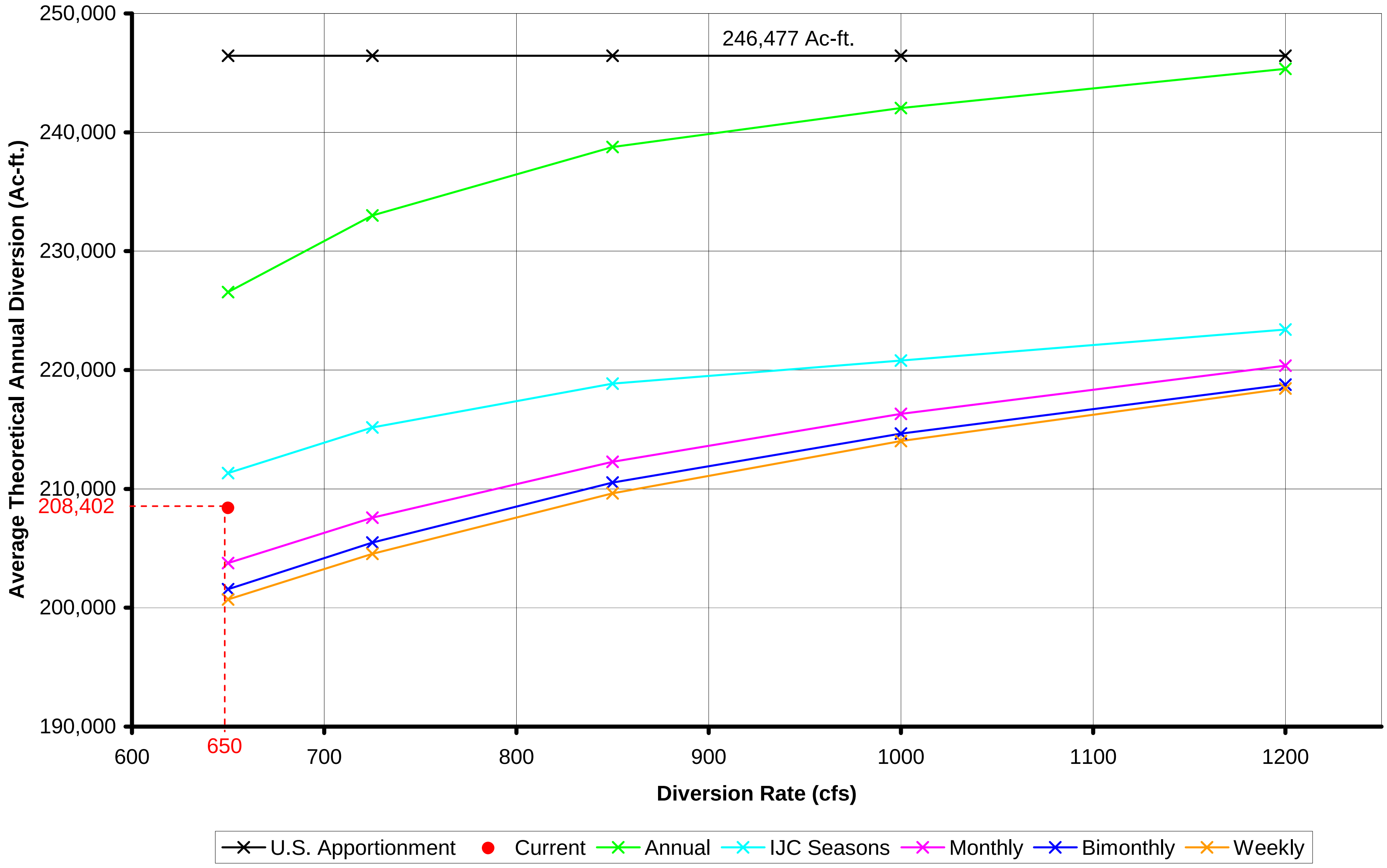


Figure 1.1

2.0 PURPOSE OF STUDY

2.1 PRIMARY OBJECTIVE

Water diverted from the St. Mary River to the Milk River via the St. Mary Diversion Facilities is essential to the economy of Montana's Hi-line Region from Havre to Glasgow, as well as the remainder of the State. However, the St. Mary Diversion Facilities, of which many of the hydraulic components are 90 years old, are in dire need of immediate rehabilitation to avert failure and avoid economic and environmental catastrophes. The "North Central Montana Regional Feasibility Report" prepared by the United States Bureau of Reclamation (USBR) screened numerous alternatives to reduce water storages in the Milk River Basin and concluded that the rehabilitation of the St. Mary Diversion Facilities was the most viable option and the only one that would produce net positive economic benefits (USBR, 2004). That report evaluated four rehabilitated canal capacities ranging from 500 to 1000 cfs but did not provide an overall recommendation regarding a preferred capacity.

This report focuses on the hydrologic and hydraulic parameters and considerations necessary to better define the optimum canal capacity for rehabilitation of the diversion facilities. The primary objective of this report is to review and summarize existing studies and background hydrologic information available on the St. Mary and Milk Rivers as well as the diversion facilities. Since this information would be used to rehabilitate the St. Mary Diversion Facilities, more emphasis was given to the St. Mary River than the Milk River. This informational review included the International Joint Commission (IJC) water apportionment requirements, USBR operational procedures of the facilities, and hydrologic parameters of the conveyance system such as inflows, seepage losses and etc.

2.2 SCOPE OF WORK

The State of Montana Department of Natural Resources (DNRC), acting as facilitator on behalf of the St. Mary Rehabilitation Working Group, issued a Request for Proposals (RFP) in 2004 to develop a "roadmap" or plan towards the primary objective of overall rehabilitation of the

Diversion Facilities. The first phase of this work was completed in February 2005 (TD&H, 2005). That report recommended in part, a study to identify the hydrologic parameters and considerations necessary for eventual capacity sizing and design of the rehabilitated facilities. This hydrologic study addresses that recommendation and evaluates the following issues:

1) Review and summarize existing hydrologic data on the St. Mary and Milk Rivers in order to characterize the physical quantity and historical seasonal occurrence of water available for diversion;
2) Review and evaluate IJC water apportionment accounting procedures and potential influences on water diversion and facility operations;
3) Review USBR operational procedures with respect to the diversion facilities and IJC requirements; and
4) Assess the impacts of canal seepage losses and storm water inflows on design and operation of the rehabilitated facilities.

For simplification, this report discusses U.S. and Canadian shares or apportionments of the St. Mary and Milk River and does not account for water right claims of the Blackfeet Nation within the boundaries of their reservation. Since these aspects are currently being negotiated as part of the Blackfeet Nation Reserved Water Rights Compact, the specific details and future ramifications cannot be fully accounted. It is assumed though, that “U.S.” and Canadian apportionments would be unaffected but that the distribution of the U.S. share may be subject to future subdivision.

3.0 PROJECT BACKGROUND

3.1 ST. MARY DIVERSION FACILITIES

The St. Mary Diversion Facilities are located entirely within the boundaries of the Blackfeet Nation in Glacier County, Montana. The Project is situated east of Glacier National Park and south of the Canadian Border. Figure 3.1 shows the location of the Diversion Facilities and the location of several hydraulic components comprising the Project.

The Diversion Facilities consist of, in part, the following key components:

- Sherburne Reservoir/Dam - Sherburne Reservoir collects and stores winter flows and spring and summer runoff from the mountains draining into the upper portion of Swiftcurrent Creek. The dam is used to regulate releases from the reservoir to supplement the U.S. share of diverted water throughout the irrigation season.

- Swiftcurrent Creek Dike - This is a manmade earthen dike below Sherburne Dam, which controls and directs creek flows and reservoir releases into Lower St. Mary Lake. Prior to construction of the Diversion Facilities, Swiftcurrent Creek flowed across an actively-forming alluvial fan and the creek channel was prone to periodic migrations following severe flood events.

- St. Mary Diversion Dam - Located on the St. Mary River approximately 0.75 miles downstream (north) of Lower St. Mary Lake, the diversion dam diverts water into the St. Mary Canal. The diversion season typically begins in early to mid March and ends late September to early October. Earlier shutdowns are initiated when large-scale maintenance or critical repairs are required.

- Canal Prism – The canal, approximately 29 miles long including siphons and drops, is a one-bank, unlined, contour canal of earthen construction. Originally, the prism consisted of

St. Mary Diversion Facilities

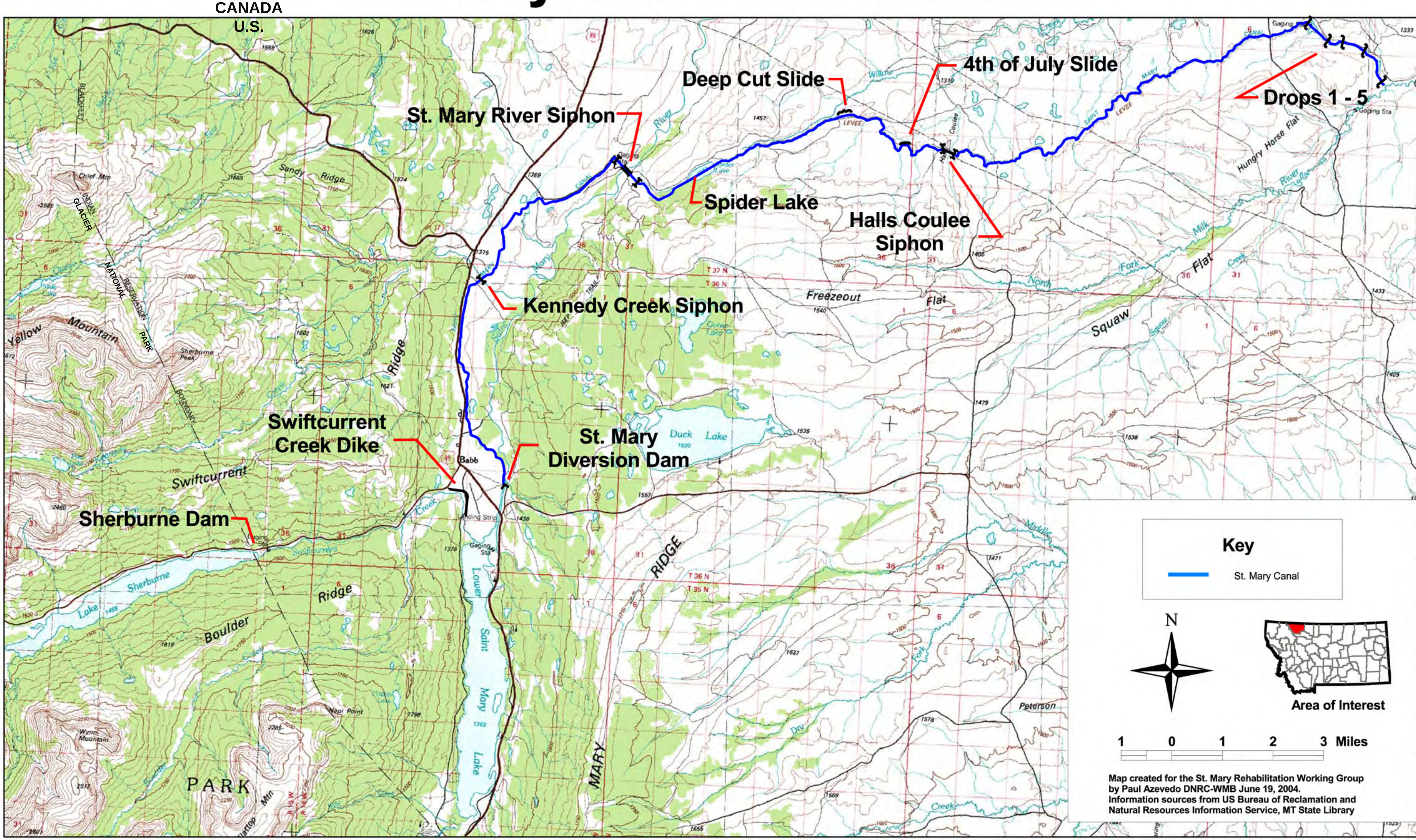


Figure 3.1

- a 26-foot bottom trapezoidal section with 2:1 (H:V) fill slopes and 1½:1 cut slopes. The invert slope is approximately 0.0001 ft/ft or 0.53 ft per mile.

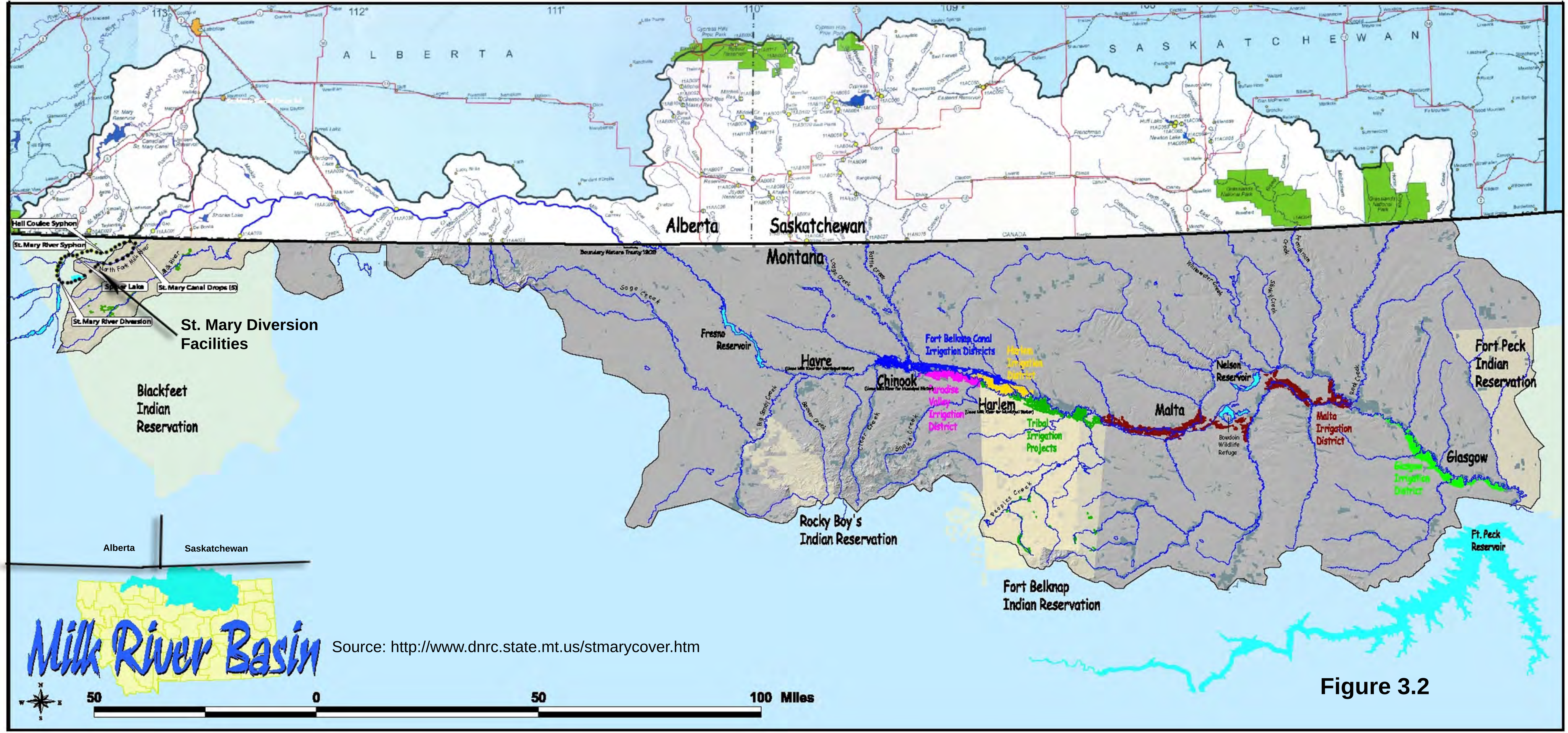
- Kennedy Creek Siphon - Kennedy Creek, similar to Swiftcurrent Creek, flows atop an active alluvial fan. The St. Mary Canal passes under Kennedy Creek through a reinforced concrete, inverted siphon. Manmade dikes upstream of the siphon crossing control Kennedy Creek's propensity for channel migration.

- St. Mary River Siphon - The diverted water crosses the St. Mary River from one side of the valley to the other through two 90-inch diameter, mild steel, inverted pipe siphons. The siphons, approximately 3,205 feet in length, cross the river atop a bridge that also serves as a Glacier County road bridge. The siphon diameter reduces to 84 inches atop the bridge.

- Hall Coulee Siphon - Another pair of inverted siphons, 1,405 feet long, conveys the diverted water across a topographical low region, Hall Coulee. Although smaller, 78 inches in diameter, the siphons are of similar construction as the St. Mary River Siphons.

- Hydraulic Drops 1 to 5 - Five separate concrete chutes and plunge pools convey the diverted water into the North Fork of the Milk River. These structures are necessary to dissipate the hydraulic energy associated with an overall elevation drop of 218 feet from the St. Mary - Milk River divide down to the North Fork of the Milk River below.

- Milk River - The natural channels of the North Fork and the main Milk River downstream of the hydraulic drops are used to convey diverted water to Fresno Reservoir and eventually to the direct and indirect beneficiaries of the Milk River Irrigation Project. The Milk River enters Canada and flows approximately 216 miles before re-entering the U.S. 50 miles northwest of Havre. Figure 3.2 shows the relationship of the St. Mary Diversion Facilities to the downstream portion of the Milk River Basin where the diverted water is utilized.



Source: http://www.dnrc.state.mt.us/stmarycover.htm

Figure 3.2

3.2 ST. MARY RIVER BASIN

The St. Mary River represents a constant and reliable source of water, which originates from high mountain streams headwatered on the east slope of the Rocky Mountains in the northeast corner of Glacier National Park (see Figure 3.3). The source of water is predominantly derived from melting snow and seasonal rainfall precipitation events. The St. Mary River flows north into Canada, connecting with the Saskatchewan River system and eventually emptying into the Hudson Bay. In the U.S., the drainage basin of the St. Mary River is approximately 465 square miles. Upstream of the U.S. – Canada Border, near Babb, MT, the St. Mary Diversion Dam diverts a portion of the St. Mary River into the Milk River Basin via a 29-mile canal system. This seasonal diversion began in the 1917 Water Year.

In comparison to the Milk River, stream flows in the St. Mary River are relatively consistent and regular from year to year. Information on measured flows is available from 1902 to the present at numerous river-gaging stations (U.S. Geological Survey, 2005). The Table below summarizes typical flow characteristics as measured at the U.S.-Canada Border (USGS Station 05020500) following construction of the Diversion Facilities.

Table 3.1 Summary Of River Discharge Statistics Of The St. Mary River At International Border (USGS Stat. 05020500)

River Discharge Statistics At International Border	Water Years 1917 to 2003
Drainage Area	465 sq. mi.
Average Annual Runoff	491,600 Ac-Ft
Annual Mean	673 cfs
Lowest Annual Mean	316 cfs (1941)
Highest Annual Mean	1285 cfs (1927)
Lowest Daily Mean	16 cfs (11/29/1936)
Highest Daily Mean	17,000 cfs (06/09/1964)
Maximum Peak Flow	23,300 cfs (06/21/1975)

(Source: USGS, 2004)

3.3 MILK RIVER BASIN

The headwaters of the Milk River originate in upland hills and plateaus east of the St. Mary River drainage. Natural Milk River water is derived from the melting of limited snowpack and seasonal precipitation events. In the U.S., the drainage basin of the Upper Milk River is approximately 493 square miles in size. Stream flows in the Milk River are more erratic year to year as compared to flows in the St. Mary River (U.S. Geological Survey, 2004). Information on the natural Upper Milk River flows at the western crossing are determined by reviewing information from USGS gaging stations located on the North Fork upstream of the St. Mary Canal outlet (06133500) and on the Milk River (06133000). A gaging station on the North Fork at the Border (06134000) reflects combined natural flow in the North Fork and St. Mary Canal diverted flows. The North Fork joins the main body of the Milk River in Canada. The Milk River flows approximately 216 miles through Canada before returning to the U.S. 50 miles northwest of Havre, MT. Another USGS gaging station (06135000) is located at the Eastern Crossing. The Table below summarizes typical flow characteristics of these four gaging stations.

Table 3.2 Summary of Discharge Statistics of Four Stations on the Upper Milk River Section

Statistics Summary	N. Fork Upstream of Canal	N. Fork at Western Crossing (1)	Milk River at Western Crossing	Milk River at Eastern Crossing (1)
USGS Station	06133500	06134000	06133000	06135000
Drainage Area	59 sq. mi.	92 sq. mi.	401 sq. mi.	2525 sq. mi.
Period of Records	1911-2003 (Seasonal)	1917-2003 (Seasonal)	1931-2003 (Seasonal)	1917-2003 (Seasonal)
Annual Mean	24.8	332.3	99.2	512.8
Highest Daily Mean	1320 (04/22/1953)	2170 (06/07/1995)	5410 (06/09/1964)	12,400 (06/12/2002)
Lowest Daily Mean	1.7 (09/17/1946)	0.0 (03/01/1940)	0.0 (07/31/1931)	0.0 (02/01/1922)
Max. Peak Flow	3090 (05/08/1967)	3670 (06/07/1995)	7930 (06/09/1964)	14,400 (06/12/2002)

All flows in cfs
(1) Annual averages include increased flows from the St. Mary Canal diversions
(Source: USGS, 2004)

It is reported that in dry years, over 90 to 95 percent of the water in the Milk River as measured near Havre is diverted from the St. Mary River. During average years, the diverted St. Mary water represents approximately 70 percent of the Milk River as measured near Havre flow from May through September. Also, it is reported that there is no natural flow in the Milk River in the late summer during 4 out of 10 years (USBR, 2004) and that it would run dry without the diverted St. Mary River water. The following Figure 3.3 represents the relationship of the Milk River headwaters relative to the St. Mary River.

3.4 USBR FACILITY OPERATIONS

3.4.1 Overview

The St. Mary Diversion Facilities are owned by the U.S. Federal Government and are operated and maintained by the U.S. Bureau of Reclamation (USBR). The USBR maintains a two-person, full-time, on-site crew based at Camp Nine to operate and maintain the diversion facilities. Camp Nine is situated along the St. Mary River near the St. Mary River siphon crossing. Since its conception, the St. Mary Diversion Facilities, as part of the overall Milk River Project, was authorized as a single-use irrigation project. As such, nearly 100% of the costs to operate and maintain the diversion and storage facilities have been borne by irrigators within the Milk River Project through an assessment on their irrigated lands. Reclamation also utilizes non-reimbursable annual appropriations from the U.S. Congress to administer the 1909 Boundary Waters Treaty with Canada. Reclamation employees regulate releases from Lake Sherburne Dam and diversions from the St. Mary River at St. Mary Diversion Dam, and perform daily accounting of flows and diversions, in accordance with apportionment procedures under the Treaty and the 1921 Order.

3.4.2 Operational Plans and Forecasting

Since 1953, the USBR has prepared annual summary reports on actual operations for a completed water year (October 1st through September, 30th) and operational plans for the coming water year on each of its water projects. For the Milk River Project, the operational plans are prepared and updated by the Reservoirs and Rivers Operation staff of the Montana Area Office. These plans not only include the storage and diversion facilities on the St. Mary River, but also

Basinal Relationships of the St. Mary Diversion Facilities

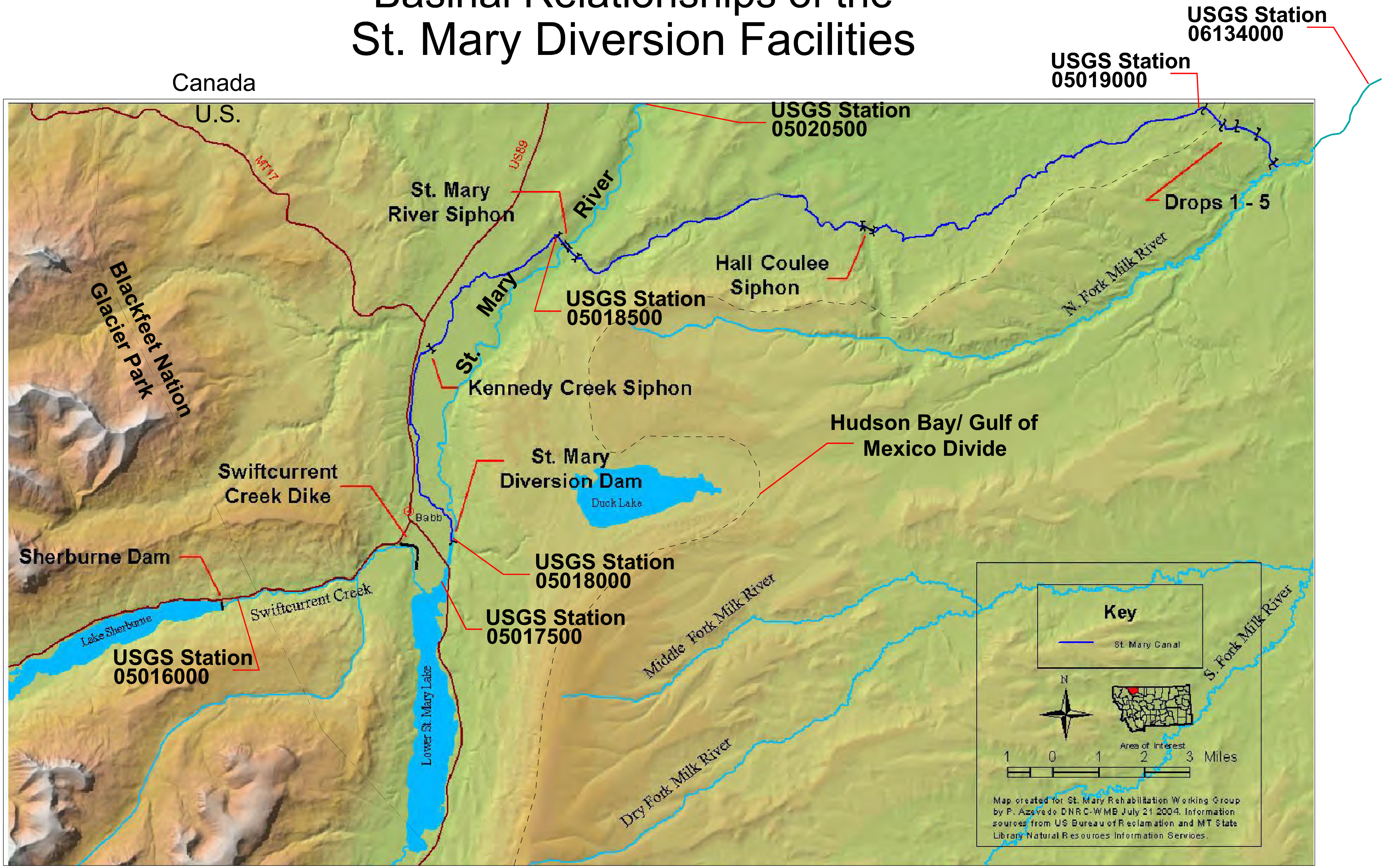


Figure 3.3

the storage and conveyance systems within the Milk River Basin. The annual summaries describe the actual weather and stream flows that occurred and provide a chronology of key operational events that transpired and impacted operations.

The future operational plans utilize current climate and snowpack data and reservoir levels to project estimated ranges of probable operation for the upcoming water year. In general, the operational plan forecast predicts a range of potential outcomes including minimum probably runoff, most probable runoff and maximum probable runoff. The most probable runoff estimates are approximated from historic median data for years with similar snowpack and antecedent stream conditions. The minimum probable runoff estimates represent historical data for years with similar conditions equal to the 10^{th} percentile which actual flows have exceeded 90 percent of the time. The 90^{th} percentile of historical data is exceeded only 10 percent of the time and is used to estimate the maximum probable runoff projection for years with similar conditions.

Each month the USBR revises the operational plan to reflect current data on reservoir levels, snowpack characteristics and overall climatic forecasting. Other factors considered include antecedent soil, stream and groundwater conditions. The USBR obtains climate, snowpack and antecedent information from the Natural Resource Conservation Service (NRCS). This information is utilized to predict runoff volumes at the U.S. – Canada Border and upstream of Sherburne Reservoir. Forecasting for the Milk River runoffs involves coordination with Canadian agencies. Each revised and updated plan projects 12 months into the future.

Sherburne Reservoir is the only active storage unit in the U.S. portion of the St. Mary Basin that allows the U.S. to capture and more favorably regulate its apportionment on the St. Mary River. Basically, Sherburne Reservoir collects and stores all off-season inflows from Swiftcurrent Creek as well as spring runoff. This water is then released as needed to supplement the U.S. portion of remaining St. Mary River natural flow for eventual diversion to the Milk River. Sherburne Reservoir has an active storage allocation of 64,248 Ac-Ft that corresponds to a reservoir level equal to the spillway elevation (4788.0). The storage relationships of Sherburne Reservoir are shown on Figure 3.4.

Currently there are no minimum wintertime releases mandated for Sherburne Dam. In addition, the current condition of the outlet gates does not permit such wintertime operation. As such, in the fall of each year, reservoir releases are terminated which dewaters Swiftcurrent Creek between Sherburne Dam and the confluence with Boulder Creek. Prior to dewatering this stretch of the Swiftcurrent Creek, USBR officials coordinate a fish salvage program with U.S. Fish and Wildlife Service (USFWS) and Blackfeet Tribal representatives. A minimal wintertime release from Sherburne up to 25 cfs may be implemented in order to support year-round fish populations and eliminate the need for the annual fish salvage program. The 25 cfs value equates to an approximate daily average of winter flows entering upstream of Sherburne Reservoir, however; biologists with the Tribe, USFWS and USBR have not officially consulted to agree to a minimum flow requirement. It is anticipated that the USBR will initiate winter releases in the future from Lake Sherburne after further consultation.

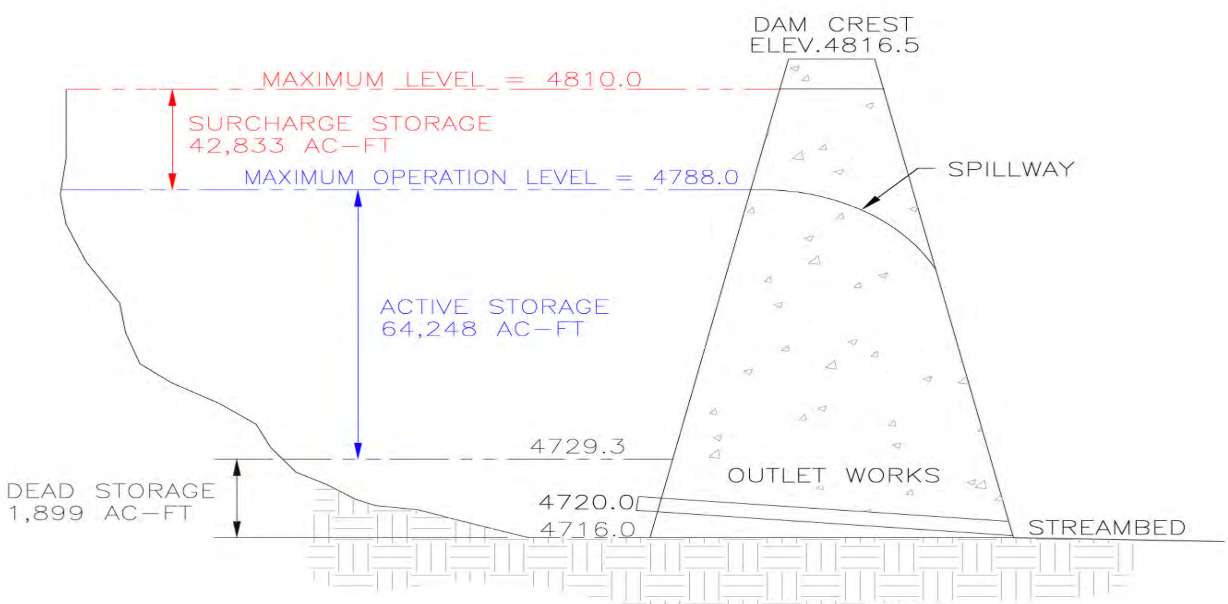


Figure 3.4 - Storage Relationship of Sherburne Reservoir (USBR Data)

The USBR's operational plan for Sherburne Reservoir is summarized as follows:

1) During spring runoff, snowpack measurements and inflow/runoff forecasts are utilized to ensure reservoir filling to 4788.0 (see Figure 3.4). Controlled releases through the

outlet works are to be regulated such that final reservoir filling coincides with the end of spring runoff.

2) Due to unfavorable hydraulic flow conditions of the spillway conduit (morning glory type spillway), the outlet gates must be open as necessary to maintain a reservoir level of 4788.0.
3) If reservoir levels exceed 4788.0, the outlet gates are to be open fully until the reservoir surface recedes to 4788.0.
4) During diversion to the St. Mary Canal, releases from Sherburne are adjusted as needed to supplement the U.S. apportionment of natural flows and to maximize diversion within the regulatory limits of IJC.
5) Once initial springtime watering-up of Swiftcurrent Creek below the dam occurs, minimum outlet gate openings are maintained to support returning fish populations.

3.4.3 Daily Diversion Operations

The two-person, full-time crew based at Camp Nine near the St. Mary River siphon crossing is responsible for the daily O&M activities during the diversion season and repairs during the off-season. During diversion, the diversion and conveyance structures are visually inspected at least three times a week. Of particular concern is the condition of the numerous areas of on-going bank instabilities located both on the downslope fill sections and in cut sections. When instabilities are observed, large participation events occur or known landslides are active, daily or near daily inspections are performed.

The Reservoirs and Rivers Operation staff, in consultation with other operations and maintenance staff, determine the beginning and ending of the diversion season. The Reservoir and River Operations staff also determines canal diversion rates and releases from Sherburne Reservoir as the season progresses. Operational adjustments are made based on Sherburne Reservoir levels, available St. Mary River flows, demand and storage within the Milk River Basin, and delivery of Canada’s apportionment. This information and operation instructions are conveyed to the on-site O&M staff to be implemented. Maximizing daily diversions to the St. Mary Canal is the responsibility of the on-site crew. This represents a balancing act of encumbered natural flows, releases from Sherburne Reservoir and potential storm water inflows. The present canal system has no operating checks, only one operating wasteway and limited canal freeboard at several locations. When the local USBR staff anticipates a significant precipitation event, the diversion discharge at the canal headgates is reduced to create canal freeboard to accommodate the potential storm water inflows. When this threat passes, normal diversion resumes. If the anticipated storm event fails to fully materialize, this cautious, although warranted, operational approach represents lost opportunities to maximize diversion of U.S. apportionment.

The on-site crew is responsible for the start-up and shutdown activities. The local staff also performs the off-season repairs such as replacing siphon joints, repairing concrete surfaces at the various structures and earthwork rehabilitation to the canal prism. Additional discussion regarding O & M activities is presented in the Preliminary Engineering and Feasibility Report (TD&H, 2006).

4.0 UNITED STATES – CANADA APPORTIONMENTS

4.1 BOUNDARY WATERS TREATY

When the Reclamation Service (now known as the Bureau of Reclamation) announced plans in 1900 (USGS, 2003) to divert water from the St. Mary River Basin to the Milk River Basin, the Canadian government protested, stating that the proposed diversion would interfere with existing Canadian appropriations along the St. Mary River. The United States government ignored the protests, contending that the diversion would have no effect on Canadian interests. Canada's response came in 1901 when the Canadian Government initiated surveys to determine the feasibility of re-diverting the water from the Milk River back into the St Mary River drainage within Canada (Simonds, 1999). This was known as the Canadian Milk River Canal (a.k.a. "Spite Ditch") of which several miles were actually constructed by 1904.

The key to the success of the Milk River Project was the successful negotiation of a treaty with the Dominion of Canada that would ensure the unrestricted passage of the combined waters of the St. Mary and Milk Rivers through Canadian territory. Although not the only dispute over waters shared by both nations, the St. Mary/Milk River dispute was one of the driving forces behind the negotiation and ratification of the 1909 Boundary Waters Treaty signed on January 11, 1909. The provisions of Article VI of the 1909 Treaty specifically address the St. Mary and Milk Rivers and reads as follows:

1) Agreement that the St. Mary and Milk Rivers and their tributaries are to be treated as one stream for purposes of irrigation and power,

2) And the waters thereof shall be apportioned equally between the two countries, but in making such apportionments, more than half may be taken from one river and less than half from the other by either country so as to afford a more beneficial use to each.

3) During the irrigation season, between the 1st of April and the 31st of October, inclusive, annually, the U.S. is entitled to a prior appropriation of 500 cfs of the waters of the Milk

River or so much of such amount as constitutes three-fourths of its natural flow, and Canada is entitled to a prior appropriation of 500 cfs of the flow of the St. Mary River, or so much of such amount as constitutes three-fourths of its natural flow.

4) The channel of the Milk River in Canada may be used at the convenience of the U.S. for the conveyance, while passing through Canada, of waters diverted from the St. Mary River.

4.2 INTERNATIONAL JOINT COMMISSION

The 1909 Treaty mandated the creation of an International Joint Commission (IJC) to implement the principles of the 1909 Treaty. The Commission consists of 6 individuals, 3 representing each country. The IJC Order of 1921 provides for the measurement and apportionment of the waters of the St. Mary and Milk Rivers and their international tributaries in the U.S. and Canada. The USGS and the Water Survey Division (WSD) of Environment Canada jointly perform these duties.

Disagreement exists between the U.S. and Canada on whether the IJC Order of 1921 properly implements the intent of the 1909 Treaty. As early as 1931, the United States attempted unsuccessfully to have the IJC change the 1921 Order. In 2003, Montana’s Governor requested that the IJC review the 1921 Order due to mounting concerns over growing water shortages in the Milk River Basin. In follow-up documentation (2004), the State of Montana identified several arguments for its earlier request. These issues included, but are not limited to, the following:

1) That the St. Mary and Milk River are not treated as “one stream” and are not “apportioned equally between the two countries”.

2) Two international tributaries of the St. Mary River, Lee and Rolph Creeks, originate in the U.S. but were excluded from apportion considerations.

3) Construction of the St. Mary Lake Storage Reservoir, which would have further enabled the U.S. to fully utilize its apportionment, was never constructed. In 1921, the IJC recommended its construction and further recommended that the construction costs be borne jointly between the U.S. and Canada.

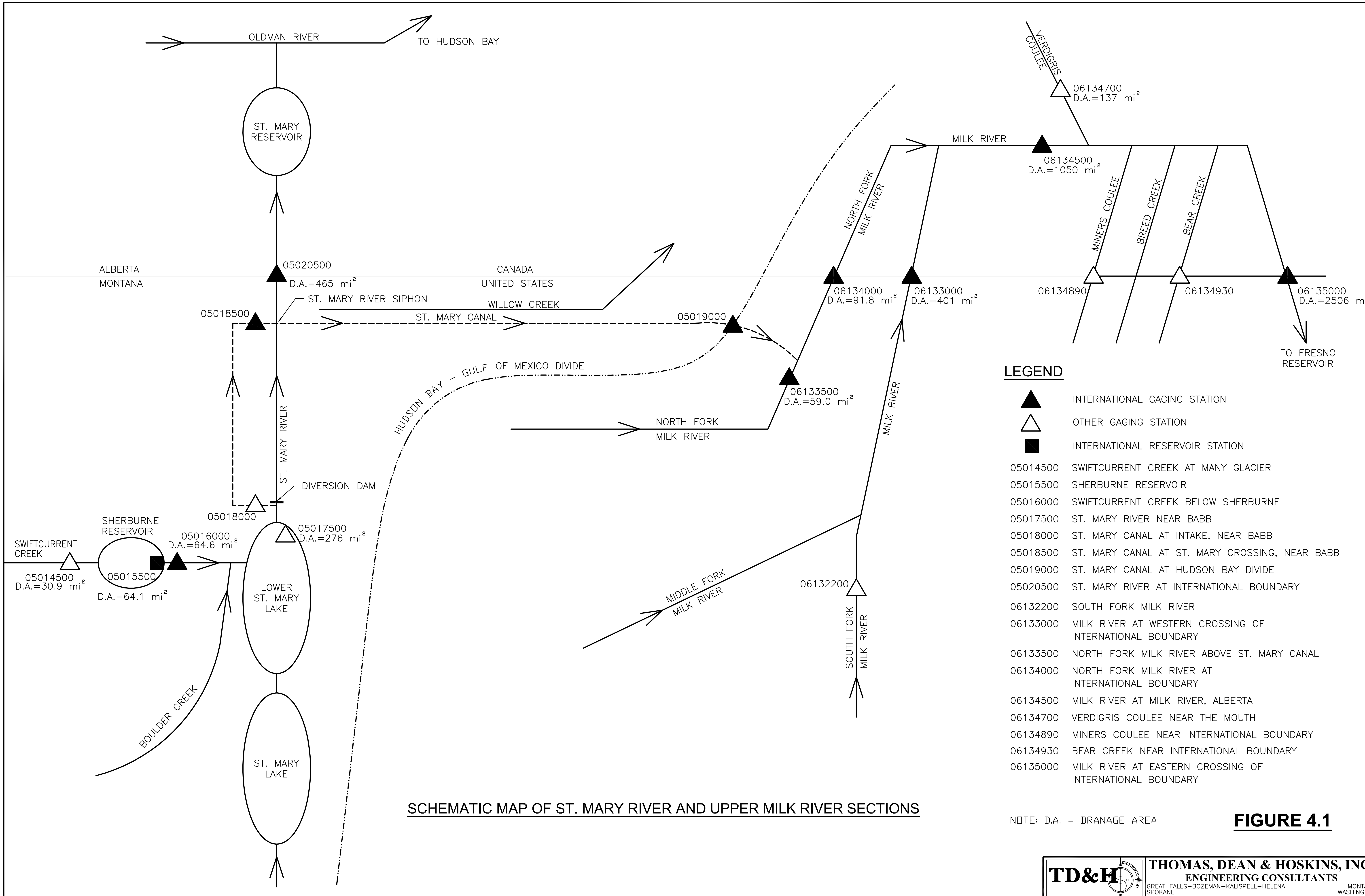
4) Current IJC apportionment accounting procedures mandate recovery of deficit deliveries of Canadian water on the St. Mary River but do not permit a credit mechanism for surplus deliveries.

5) Canadian water useage in the Milk River Basin is underestimated by current apportionment accounting procedures.

In December 2004, following a series of public meetings, the IJC announced plans to establish an Administrative Measures Task Force to examine whether the existing administrative procedures can be improved to ensure more beneficial use of apportioned water to each respective country. Specifically, the Task Force reviewed accounting procedures, surpluses and deficits, accounting periods and any other administrative measures that the group may find pertinent to its task. A final report was released in April 2006.

4.3 WATER ACCOUNTING PROCEDURES

Article VI of the 1909 Boundary Waters Treaty governs the division of the waters of the St. Mary and Milk Rivers. The 1921 Order of the IJC provides general guidelines for determining each country's apportionment and the natural flows. Division of these two rivers is performed on three main sections; the St. Mary River, the Upper Milk River (above Fresno Reservoir) and the eastern tributaries of the Milk River (USGS, 2003). With respect to rehabilitation of the St. Mary Diversion Facilities, this study focuses on the St. Mary River section with limited discussion on the Upper Milk River section. Figure 4.1 shows the schematic layout of the St. Mary River and Upper Milk River sections.



SCHEMATIC MAP OF ST. MARY RIVER AND UPPER MILK RIVER SECTIONS

FIGURE 4.1

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Each country's Field Representatives; the United States Geological Survey (USGS) and the Water Survey Division (WSD) of Environment Canada perform the natural-flow determinations, monitoring and reporting duties in joint cooperation. The duties of the Field Representatives generally follow the original 1921 IJC Order procedural guidelines but over time, some computational modifications have been proposed by the Field Representatives and adopted by the IJC through the cooperative process. In 1975, the methods, assumptions and procedures were officially documented by the Field Representatives in the manual "Procedures for the Division of the Waters of the St. Mary and Milk Rivers" (USGS, 2003). The documented methods have evolved to reflect updated and on-going improvements of computational methods and the Manual was last revised in 2003. The primary objectives of the Procedures Manual are:

1) Document the procedures and assumptions used in determining natural flows.
2) Document the reasoning for certain procedures and assumptions.
3) Act as a user's manual for determining natural flows on an interim and annual basis.

The 1921 Order states that the countries' Field Representatives "shall jointly take steps to ascertain and keep a daily record of the natural flow….". However, in the past, Field Representatives determined that a division of flow on that frequency was not practical. As such, a twice-monthly accounting period of the daily natural flows was adopted when active diversion is occurring to the St. Mary Canal. These semi-monthly, natural-flow calculations are term "provisional computations" and are necessary to provide current real-time information for water management and to ensure that each country receives its apportionment. These provisional computations are made for each of the three St. Mary – Milk River sections and are utilized to produce interim reports. An annual summary report is prepared for the IJC.

Today, Field Representatives actually perform a daily determination of natural flow and each countries apportionment. Also, staff from USBR has reportedly performed routine determinations of natural flow and apportionments on a daily basis for several years. With today's computer and communication capabilities and future automation of Sherburne Reservoir and the St. Mary Canal, a daily accounting period is possible. However, as will be discussed later in this report, the accounting period should be lengthened to facilitate the U.S. in diverting a higher percentage of its apportionment.

4.3.1. St. Mary River Section

As currently interpreted, the 1921 IJC Order states that Canada is entitled to 75% of the St. Mary River natural flow during the irrigation season when natural flow is below 666 cfs. The 1909 Treaty defines the irrigation season as April 1st to October 31st. Natural flow in excess of 666 cfs during this same time period is to be divided equally. During the non-irrigation season (November 1st to March 31st), the natural flow shall be divided equally. This distribution of the natural flow apportionments is graphically represented in the Figure 4.2 below.

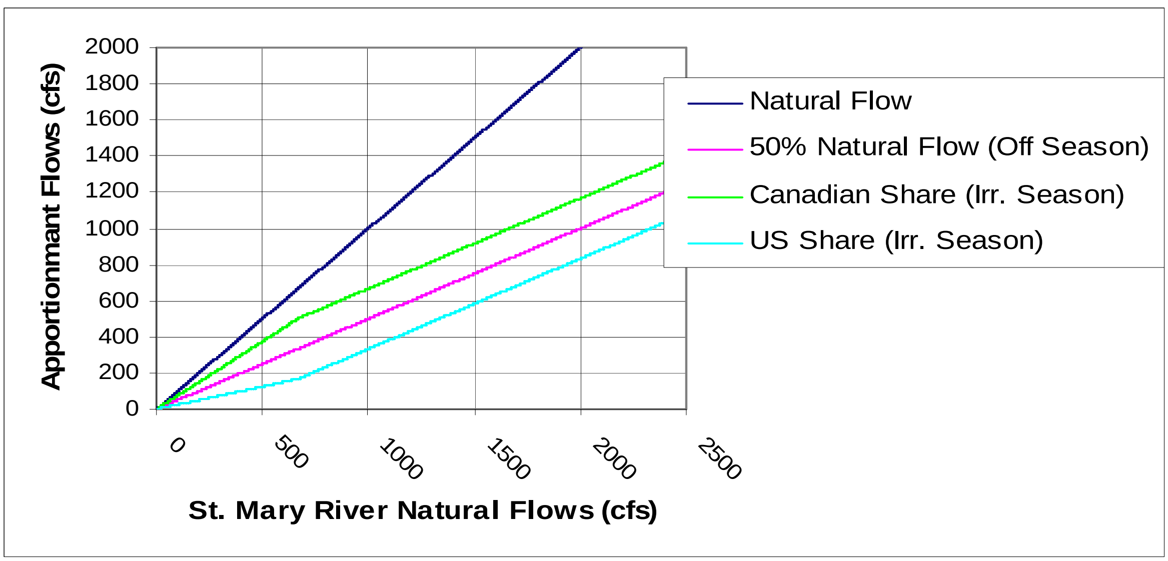

Figure 4.2 – Apportionment of St. Mary River Natural Flows per IJC.

For the purpose of share apportionments, the natural flow is determined at the International Border and is calculated to determine the theoretical, unencumbered natural flow. For the St. Mary River, the daily natural flow is calculated by summing the measured flow at the International Border (USGS Gaging Station 05020500), the flow diverted into the St. Mary Canal as measured by USGS Gaging Station 05018500, and the net change in storage of Sherburne Reservoir (USGS Station 05015500). The relative locations of these points of measurement are graphically shown on Figure 4.1.

The gaging station on the St. Mary canal (05018500) is actually nine miles downstream from the diversion dam. Seepage loses from this first reach of canal eventually return to the St. Mary River and is accounted for at the International Border Station (05020500). When dewatering of the canal and siphons begins at the end of the diversion season, discharges return to the St. Mary River and the canal gage station (05018500) reading is set and assumed to read 0 cfs.

The USGS station at Sherburne Reservoir is a reservoir station that measures the reservoir level daily at midnight. Using the reservoir rating curve for Sherburne, this fluid level is equated to a storage volume (acre-feet). The corresponding daily net increase or net decrease in storage is converted to an average daily flow (cfs). Increases in storage subtract from natural flows and are assessed to the U.S. Releases from Sherburne supplement natural flows and are credited to the U.S. A net increase in storage is treated mathematically as a positive flow while a net decrease is negative flow. Because of geographical separation from the Border gaging station (05020500), a one-day time lag is applied to net storage calculations with respect to the other two flow measurements. Evaporation loses from Sherburne Reservoir are assumed to be insignificant due to cool surface conditions, small surface area and short detention times during the summer months. Seepage loses are not considered because seepage adds to the natural flow below the dam and is measured at other gaging stations downstream.

The natural flow calculation used by the Field Representatives for the St. Mary River is described below:

$$Q_{SMNF} = Q_{IB} + Q_{SM} + Q_{ST}$$

Where, Q_{SMNF} = IJC calculated mean daily natural flow (cfs) for the St. Mary River

Q_{IB} = measured mean daily flow (cfs) at International Border (USGS 05020500)

Q_{SM} = measured mean daily diverted flow (cfs) in St. Mary Canal (USGS 05018500)

Q_{ST} = measured net change in storage of (cfs) Sherburne Reservoir (USGS 05015500)

Increase = $+Q_{ST}$, decrease = $-Q_{ST}$

Bi-monthly, provisional computations of the daily natural flows are made during the irrigation season (April 1st to October 31st) and during any period when active diversion by the U.S. is occurring, such as in March. During the off-season, monthly mean flows at the International Border are equaled to cfs-days and added to the net change in storage of Sherburne Reservoir from November 1st to the end of February to determine the overall volume of natural flow.

The IJC 1921 Order did not specifically address accounting procedures for deficit deliveries or surplus deliveries. A deficit delivery (to Canada) on the St. Mary River occurs when the U.S. utilizes, stores and/or diverts more of the natural flow of the St. Mary River than permitted by the IJC during any twice-monthly accounting period. A surplus delivery on the St. Mary River, whether intentional or not, results in Canada receiving more of the natural flow than required by the IJC. In general, deficit deliveries to Canada are to be carried over from one accounting period to the next, are therefore cumulative, and must be balanced by subsequent surplus deliveries. Surplus deliveries to Canada, on the other hand, do not carry over to the next accounting period, are therefore not cumulative and cannot be used to offset future deficit deliveries.

Because of this disparity and the inability of the U.S. to utilize its apportionment, Field Representatives modified the accounting procedures in 1991 to allow a greater beneficial use of the St. Mary and Milk Rivers by both countries. The 1991 Letter of Intent, as it was referred to, allowed the U.S. to accumulate deficit deliveries on the St. Mary River from March to May up to 2,000 cfs-days which would then be made up with future surplus deliveries or a balance of deficits between the St. Mary and Milk Rivers. Similarly, Canada was allowed a deficit delivery of 2,000 cfs-days during the summer months.

In 2001, a new Letter of Intent was adopted which further modified the 1991 Agreement. The revised agreement increased the cumulative deficit allowed by the U.S. up to 4,000 cfs-days (7,934 Ac-Ft) from March 1st to May 31st. Deficits exceeding 4,000 cfs-days were to be made up in the following accounting period. From June 1st to July 15th, the U.S. may reduce the accumulated deficit down to 2,000 cfs-days with the remainder deficit refunded with surplus deliveries after September 15th and before October 31st. The remaining deficit could also be balanced by the offsetting deficits up to 2,000 cfs-days that Canada might accrue on the Milk River or by surplus deliveries by the U.S. on the St. Mary or by a combination of both. Deficit deliveries within a given accounting period (2 weeks) are not allowed between June 1st and September 15th, but should they occur, are to be refunded in the subsequent period. Neither the 1991 nor the 2001 Agreements addressed a credit system for inadvertent surplus deliveries of St. Mary River water to Canada. In fact, the 2001 Agreement stated that surplus deliveries at the end of an accounting period are not accumulative, cannot be used to reduce an accumulative deficit and cannot be used as a credit for future deficit deliveries.

4.3.2 Upper Milk River Section

Division of the natural flow of the Upper Milk River section is similar to that of the St. Mary River except that now the U.S. is entitled to 75% of the natural flow during the irrigation season when this flow is less than 666 cfs. Natural flow in excess of 666 cfs during the irrigation season is to be apportioned equally. During the non-irrigation season (November 1st to March 31st) the natural flow shall be divided equally. The distribution of the natural flow in the Upper Milk River section is similar to that of the St. Mary River except the U.S. and Canadian shares are reversed and is graphically shown below in Figure 4.3.

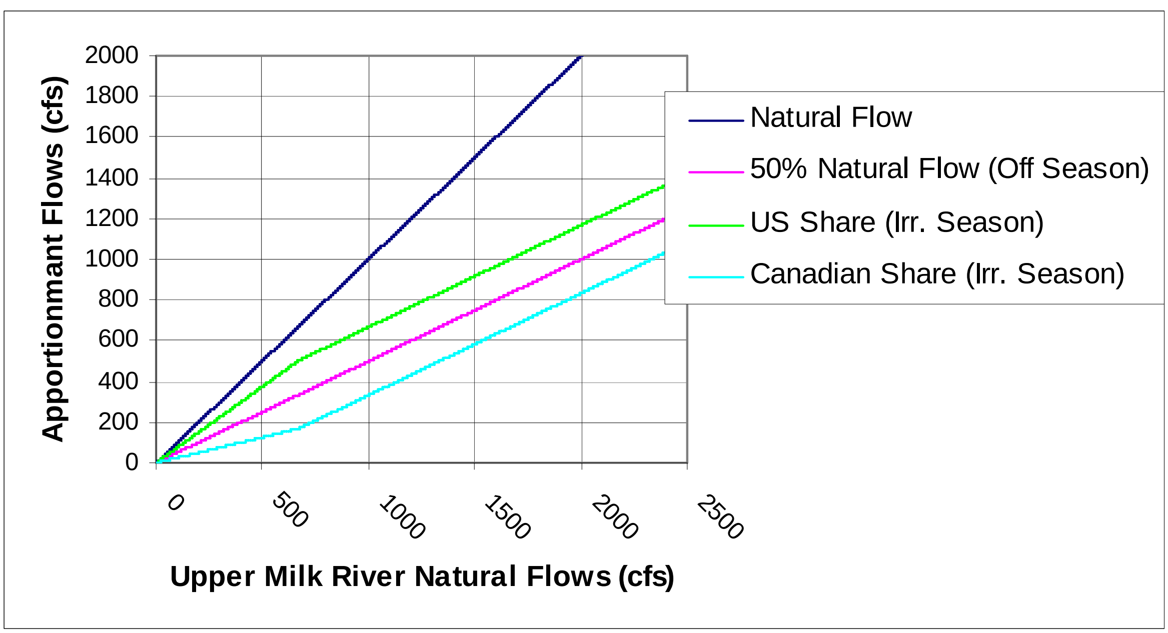

Figure 4.3 – Apportionment of Upper Milk River Natural Flows per IJC.

For the purpose of Upper Milk River apportionments, the theoretical, unencumbered natural flow is determined at the Eastern International Crossing of the Milk River (USGS Gaging Station 06135000) shown on Figure 4.1. The natural flow is calculated by summing the natural flows of the North Fork upstream of the St. Mary Canal inflow (Station 06133500) and the Milk River at the western crossing (Station 06134000), increased evaporative loses, combined consumptive uses and the net hydrologic factors.

When no diversion is occurring, the natural flow is calculated by using the measured flow of the Milk River at the eastern crossing and adding any upstream, consumptive uses (irrigation). During the non-irrigation season, the natural flow is approximated and assumed to be equal to the observed flow at the Town of Milk River in Alberta (Station 06134500).

In theory, evaporative loses are increased due to an increased surface area of the Milk River when natural flows are supplemented with diverted St. Mary River water. Evaporative loses are determined from conventional pan evaporation data and converted to stream evaporation for a given stream flow, i.e. higher stream flows have larger surface areas and higher evaporative loses. Consumptive uses include irrigation, municipal and domestic withdrawals. In 1986, the Field Representatives agreed that municipal and domestic uses were relatively small and therefore negligible. Irrigation uses by both the U.S. and Canada upstream of the eastern crossing are approximated for each country based on historic data depending on the time of year and whether the season represents a “normal” or a “dry” year. The Procedures Manual (USGS, 2003) recommends that reviews of these irrigation practices and usage rates should be conducted periodically and adjusted accordingly.

Discharges from Verdigris Coulee (Station 06134700 as shown on Figure 4.1) are generally overflows of St. Mary River Basin water moved from Ridge Reservoir. In the past, since this water did not originate in the Milk River Basin, it was treated as “negative” consumptive use in the natural flow calculations and was credited to Canada. Measured flows from Verdigris Coulee are no longer directly credited to Canada in the Milk River apportionment computations.

Currently any inflow from Verdigris Coulee is treated as any other tributary inflow and is accounted for in the “net east-west change” discussed below.

Several other hydrologic factors such as unmonitored tributary flows, groundwater gains or loses, bank storage, etc. existed but cannot be assessed individually. Therefore, the Field Representatives describe these factors collectively as the “net east-west change” when determining the natural flow in the Upper Milk River section. This natural flow parameter is determined by subtracting the combined flows measured at the western crossings of the North Fork (Station 06134000) and the Milk River (Station 06133000) from that measured at the eastern crossing (Station 06135000). Due to a separation of approximately 216 miles, a four-day lag time is applied when comparing flows at the eastern and western crossings.

The natural flow calculation used by the Field Representatives for the Upper Milk River section is described below:

$$Q_{NF} = Q_{NFWX} + Q_{E\text{-}W} + Q_{EVAP} + Q_{IRR}$$

Where, Q_{NFWX} = combined natural western flows measured at the Stations 06133500 and 06133000 (4-day lag)

$Q_{E\text{-}W}$ = net east-west factor determined by subtracting measured flows (4-day lag) at western crossing (Stations 06134000 and 06133000) from eastern crossing (Station 06135000)

Q_{EVAP} = estimated surface evaporation loses approximated from pan data

Q_{IRR} = combined U.S. and Canadian irrigation uses approximated from historical data

The current practice of the Field Representatives is that any negative flow calculated using the equation above is set to and assumed to “zero” in both the provisional and annual reports.

Similar to the St. Mary River section, the IJC 1921 order did not address deficit and surplus deliveries. On the Upper Milk River section, a deficit delivery (to the U.S.) occurs when Canada utilizes or stores more of the natural flow than permitted by the IJC. A surplus delivery, whether intentional or not, results in the U.S. receiving more of the natural flow within a given accounting period.

Prior to 1991, deficit deliveries were cumulative from one accounting period to the next and were to be corrected with subsequent surplus deliveries. Surplus deliveries within an accounting period were not cumulative and could not be "banked" towards future deficits. The 1991 Letter of Intent, allowed, in part, Canada to accrue a cumulative delivery deficit of up to 2,000 cfs-days until September 30th. This time frame was modified in 2001 such that the stated cumulative deficit was only allowed from June 1st to September 15th; after which, outstanding Canadian deficits (to the U.S.) on the Milk River could be used to offset the U.S. deficit deliveries (to Canada) incurred on the St. Mary River section. The 2001 understanding was that all remaining apportionment imbalances were to be corrected by October 31st.

4.4 RECENT DEVELOPMENTS

Releases from Sherburne flow into Lower St. Mary Lake. Storage releases in March precede the peak of naturally occurring runoff. As such, the majority of the initial releases is used to replenish Swiftcurrent Creek and Lower St. Mary Lake which are typically at seasonal lows. When storage releases exceed the combined measured flows at the International Border and in the St. Mary Canal, a resulting negative flow is computed. Prior to 2002, the procedure was to set the calculated negative flows equal to zero flow that, in theory, increased the overall Canadian apportionment. Since 2002, Field Representatives knowledge this propensity for internal storage and technically agreed to maintain and track negative flows and utilize them in the accounting procedures.

As mentioned earlier, direct measurement of Verdigris Coulee discharges and any Canadian credit has been recently changed in the Milk River apportionment computations. Any Verdigris Coulee flows are now indirectly accounted for in the "net east-west change".

Also as mentioned earlier, the Procedures Manual (USGS, 2003) recommends that reviews of irrigation practices and usage rates should be conducted periodically and adjusted accordingly.

Based on research by DNRC, it was discovered that a significant discrepancy regarding the types of irrigation as well as the number of reported acres irrigated in Canada was occurring on the Milk River. These parameters are the basis of computing consumptive uses by that country. As such procedures for reporting irrigable acres and to determine consumptive uses are currently being revised.

As stated earlier, the IJC announced plans in December 2004 to establish an Administrative Measures Task Force to examine how the existing administrative procedures could be improved to ensure more beneficial use of apportioned water to each respective country. The Task Force reviewed accounting procedures, surpluses and deficits, accounting periods and other administrative measures that the group found pertinent to its task. The highlights of the Task Force's April 2006 report are discussed below.

The IJC's *Administrative Measures Task Force Report* (IJC, 2006) concluded the following:

- Natural flow determinations could be improved by implementing additional flow monitoring stations at strategic locations within the St. Mary – Milk River Basins; by amending accounting procedures for consumptive uses by both countries; and quantifying conveyance losses in the St. Mary Canal.

- Accurate measurements of inter-basin transfers could be achieved by placing a gaging station on the rehabilitated canal before flows enter the North Fork of the Milk River.

- Longer accounting periods enabled both countries to receive a greater portion of their entitlements; Canada on the Milk River and the U.S. on the St. Mary River. Longer accounting periods must be supplemented with a mechanism to allow credit for surplus deliveries (i.e. removing the surplus delivery penalty).

The IJC Task Force developed a model to examine how lengthening the balancing period would affect the amount of receipt by each country of its apportioned share of water from the Milk and St. Mary Rivers. The results of the model showed that the United States could divert a greater volume of its St. Mary River entitlement under longer balancing periods than the current 15/16-day period. For a monthly balancing period, the diversion increases were only slightly more even though the accounting period was essentially doubled. Extending the period to a seasonal basis produced modest increases in the volume of water that could be diverted. However, the annual basis produced the most significant increases. The annual balancing period was found to, on average, provide 12.4 percent more St. Mary River to the U.S than the current balancing period. This is discussed in further detail in the next section of this report.

An annual balancing period would allow the United States to build credits for surplus deliveries during the winter when it is not diverting water down the St. Mary Canal, and during the spring, when the U.S. share of St. Mary River flow exceeds the canal capacity. It could draw on some of these credited surpluses prior to spring runoff and later during the irrigation season.

The IJC Task Force also identified other areas worthy of additional consideration and future study that were outside the limits of their official directive. Some other potential options include: Joint U.S. – Canada operations on the combined St. Mary – Milk River; infrastructure improvements and storage enhancements (i.e. storage reservoir on Milk River in southern Alberta); and water banking.

Although the Task Force Report stopped short of any recommendations; it is believed that the results of their studies and their conclusions will be reviewed by the IJC and implemented thereby affording a more beneficial use of the combined waters to each country.

5.0 HYDROLOGIC STUDIES AND MODELS

5.1 BACKGROUND

Working in concert for the purpose of providing comparison data to the IJC Task Force, Alberta Environment (AENV) and the Montana Department of Natural Resources and Conservation (DNRC) developed an agreeable data set of flow measurements from which natural flows of the St. Mary River and Milk River could be determined. The natural flows were then used in a hydrologic model to assess the effects of various canal diversion rates and alternative accounting periods. The data set includes 25 years of baseline flow data extending from November 1, 1979 to October 31, 2004 (water years 1980 to 2004). The natural flows are based on the daily USGS gaged flows and the USBR Hydromet data for Sherburne Reservoir. The mean daily flows of the data set at pertinent locations are presented on graphically Figure 5.1.

The calculation of the St. Mary River natural flows at the International Crossing (USGS Station 05020500) basically follows the IJC accounting procedures discussed in Section 4.3.1 except that additional considerations were given by DNRC and AENV to calculate the daily inflows and outflows influencing Sherburne Reservoir during the off-season. Current procedures are to determine the net change in reservoir storage during the off-season. This has been an acceptable approach since evaporation losses are negligible, seepage losses become stream flows measured at the Border and intentional wintertime releases from Sherburne historically have not occurred. However, in the future, an off-season minimum release from Sherburne Reservoir up to 25 cfs may be implemented to help mitigate seasonal impacts to Bull Trout. Biologists with the Blackfeet Tribe, USFWS and USBR have not officially consulted to agree to a minimum flow requirement. It is anticipated that the USBR will initiate winter releases in the future from Sherburne Reservoir after further consultation.

Thomas, Dean & Hoskins, Inc.
TD&H
Engineering Consultants

Mean Daily Flows of Agreed Data Set

Source: DNRC StMaryNF.xls
Time Frame: 11/1/79-10/31/04 Data Set

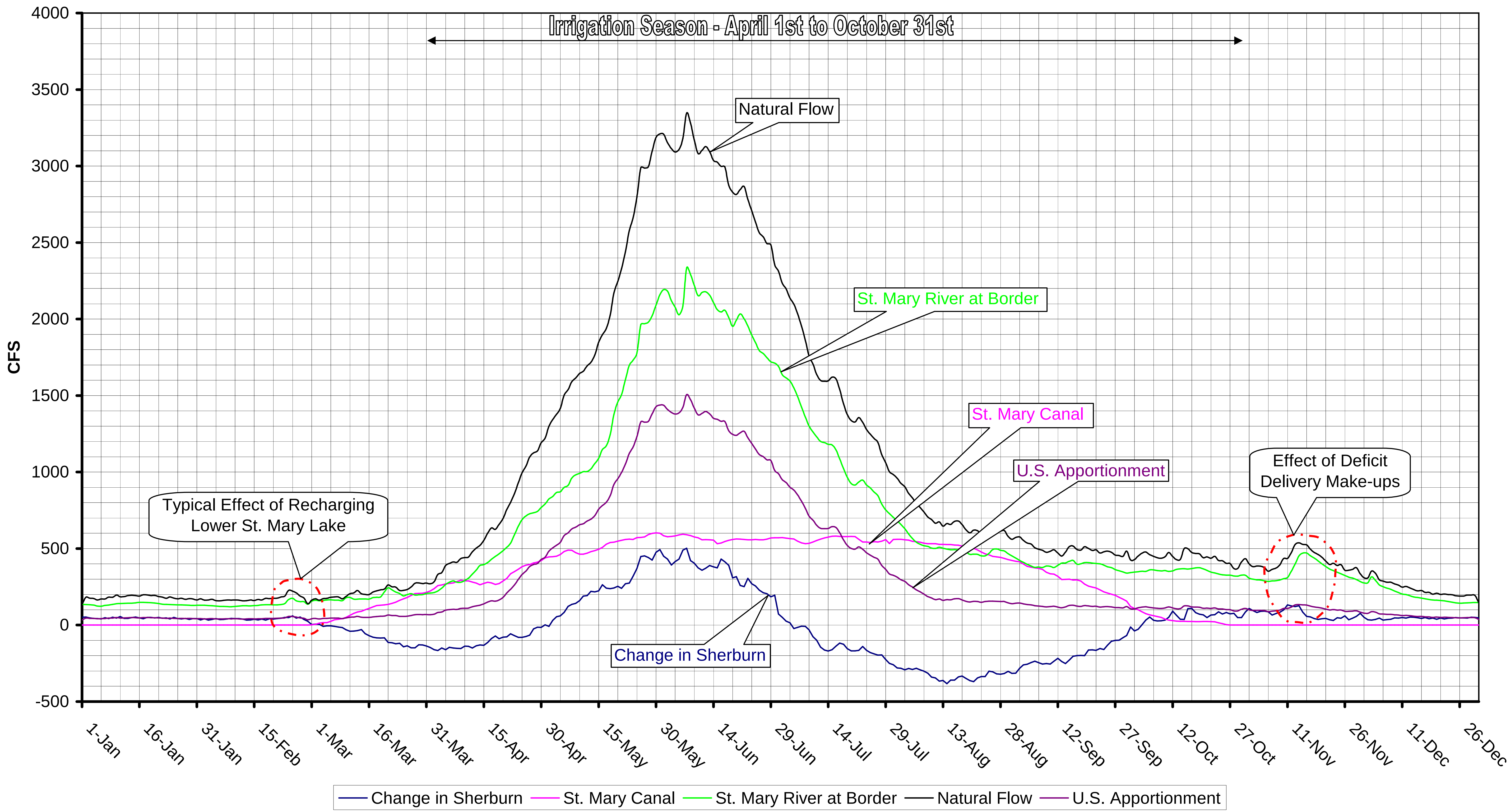

Figure 5.1

5.2 NATURAL FLOW DETERMINATIONS

Using the agreed 25-year set, the average annual natural flow of the St. Mary River at the Border was calculated to be 610,315 Ac-ft. The average annual U.S. apportionment was determined to 246,447 Ac-ft in accordance with IJC accounting procedures. The computed values for each year are provided in Table 5.1. This table also provides the actual volume of water diverted for each year as measured at the inlet to the St. Mary River siphon (USGS Station 05018500). In the last 25 years, the U.S. diverted on average 175,339 Ac-ft, which is approximately 71 percent of her apportionment.

The natural flows were ranked from driest (#1) to wettest (#25) and the averages of the 5 driest, 5 wettest, and 5 median years were determined. During the 5 driest years, the U.S. diverted approximately 96.1 percent of its apportionment while only 44.2 percent during the 5 wettest years. This is due in part, to insufficient infrastructure to collect, store and convey higher natural flows and also to a limiting IJC accounting period and/or the inability to credit the U.S. for surplus deliveries (which are forfeited).

Facility shutdowns are more likely and frequent during wet years as canal bank instabilities and slope displacements, such as at the St. Mary siphon crossing, are more problematic. Mid-season shutdowns for emergency repairs are early season shutdowns for planned repairs translate into lost opportunities for diversion of U.S. apportionment. In the last 10 years, significant leaks on the St. Mary River siphons have resulted in system shutdowns in order to avert progressive catastrophic failure and to make the necessary repairs. An example of this was in the summer of 1995 when only 85,536 Ac-ft or 26 percent of the total U.S. apportionment for that year (49 percent of 25-year average) was diverted.

Table 5.1 Comparison of Annual Natural Flows and U.S. Apportionment as Computed by IJC Task Force

Water Year	Year Ranking 1-Driest 25-Wettest	Natural Flow – St. Mary River At Int'l Border Ac-ft.	U.S. Apportionment Ac-ft.	Actual Volume Diverted by U.S. per IJC Ac-ft.
1979-1980	14	592,298	231,771	199,471
1980-1981	18	657,465	272,404	231,838
1981-1982	15	601,754	245,627	99,413
1982-1983	4	468,396	181,681	178,526
1983-1984	6	500,104	192,606	164,066
1984-1985	13	584,774	227,065	215,661
1985-1986	16	611,561	241,789	135,681
1986-1987	8	557,133	219,910	177,519
1987-1988	2	432,966	162,984	177,156
1988-1989	19	693,424	282,568	248,400
1989-1990	20	757,948	314,344	224,090
1990-1991	25	845,249	364,529	229,991
1991-1992	3	435,297	156,950	137,883
1992-1993	11	571,475	220,966	187,837
1993-1994	7	502,599	198,713	162,951
1994-1995	21	786,804	333,545	85,536
1995-1996	23	822,288	349,293	147,502
1996-1997	22	819,620	344,287	168,807
1997-1998	9	562,485	229,589	214,213
1998-1999	17	614,907	246,747	183,281
1999-2000	12	572,120	228,846	178,702
2000-2001	1	364,776	139,714	131,124
2001-2002	24	851,667	367,946	146,594
2002-2003	5	484,801	189,548	174,090
2003-2004	10	565,965	217,758	183,150
Average		**610,315**	**246,447**	**175,339**
5 Median Years				
1992-1993	11	571,475	220,966	187,837
1999-2000	12	572,120	228,846	178,702
1984-1985	13	584,774	227,065	215,661
1979-1980	14	592,298	231,771	199,471
1981-1982	15	601,754	245,627	99,413
Average		**584,484**	**230,855**	**176,217**
5 Driest Years				
2000-2001	1	364,776	139,714	131,124
1987-1988	2	432,966	162,984	177,156
1991-1992	3	435,297	156,950	137,883
1982-1983	4	468,396	181,681	178,526
2002-2003	5	484,801	189,548	174,090
Average		**437,247**	**166,175**	**159,756**
5 Wettest Years				
1994-1995	21	786,804	333,545	85,536
1996-1997	22	819,620	344,287	168,807
1995-1996	23	822,288	349,293	147,502
1990-1991	25	845,249	364,529	229,991
2001-2002	24	851,667	367,946	146,594
Average		**825,126**	**351,920**	**155,686**

Also, wet years imply a higher potential for storm water related inflows and it is likely that the USBR operated the canal in a “protective” mode due to insufficient canal freeboard and lack of system safeguards with respect to canal bank overtopping and breaching. Also in wet years, above normal precipitation and runoff is typically occurring in the Milk River Basin resulting in a low demand for irrigation water as well as storage reservoirs being replenished naturally without the need for diverted St. Mary water.

The comparison of U.S. apportionments to actual volume diverted is presented graphically on Figure 5.2. For the 1987-1988 water year Figure 5.2 would seem to imply that the U.S. actually diverted approximately 14,000 Ac-ft. more than its apportionment. During this water year, the U.S. was able to divert more than its apportionment because it utilized storage in Lake Sherburne carried over from the previous year.

5.3 THEORETICAL DIVERSION POTENTIALS

Using the calculated natural flows, DNRC and AENV developed a model and for use by the IJC Task Force to compute the maximum theoretical annual diversions to the St. Mary Canal that would have occurred under various hypothetical operating and IJC accounting scenarios. Using the same model DNRC examined how changing the canal capacity, in conjunction with longer balancing periods, could affect the maximum theoretical diversion potential that the United States could divert of its St. Mary River apportionment. Several modeling and operating regime assumptions were made to simplify these model analyses. These assumptions and model guidelines are summarized in Table 5.2

The theoretical, potential diversions for the various accounting periods and operating regimes that the U.S. could have diverted based on the last 25 years of data is summarized on Table 5.3. This data was provided by DNRC and utilizes the agreed natural flow data set. The theoretical average diversion for each scenario is presented on Figure 5.3.

The results of the model indicate that a minimum 25 cfs release from Sherburne Reservoir, under the current two-week accounting period, results in approximately 6,850 Ac-ft less water that can be diverted on average. To offset this effect either a higher diversion rate is required (±850 cfs) or a more favorable accounting period needs to be enacted.

Table 5.2 Assumptions Utilized By Hydrologic Model to Predict Theoretical Diversion Potentials

Current Canal Capacity and Accounting Procedures	
Accounting	▪ Current IJC procedures (See Section 4.3.1) ▪ Deficit deliveries to be made up in the following period ▪ Surplus deliveries are forfeited
Diversion and Conveyance	▪ 650 cfs capacity ▪ Start-up: March 15th, shutdown: October 31st ▪ 100 cfs daily steps during start-up and shutdown ▪ Discontinue diversion when flow is <100 cfs ▪ Flow consists of first, natural flow than storage releases from Sherburne
Sherburne Storage	▪ Maximum storage: 67,850 Ac-ft (1) ▪ Dead Storage: 4,000 Ac-ft (1) ▪ No minimum releases requirement ▪ All inflows retained unless required per IJC or optimize diversion
General	▪ Assume all natural flow originates upstream of diversion dam
Hypothetical Alternate Accounting Procedures and Operating Regimes	
Accounting	▪ Surplus deliveries accumulated over specific period including - 7-day - Bimonthly - Monthly - Seasonally (04/01 to 10/31 and 11/01 to 03/31) - annually
Diversion	▪ Various capacities – 650, 725, 850 and 1,000 cfs ▪ Others listed above
Storage	▪ 25 cfs minimum release ▪ Others listed above

(1) Note: USBR reports Active Storage = 64,248 Ac-ft and Dead Storage = 1,899 Ac-ft.

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Figure 5.2 Comparison of U.S. Apportionments and Actual Volumes Diverted

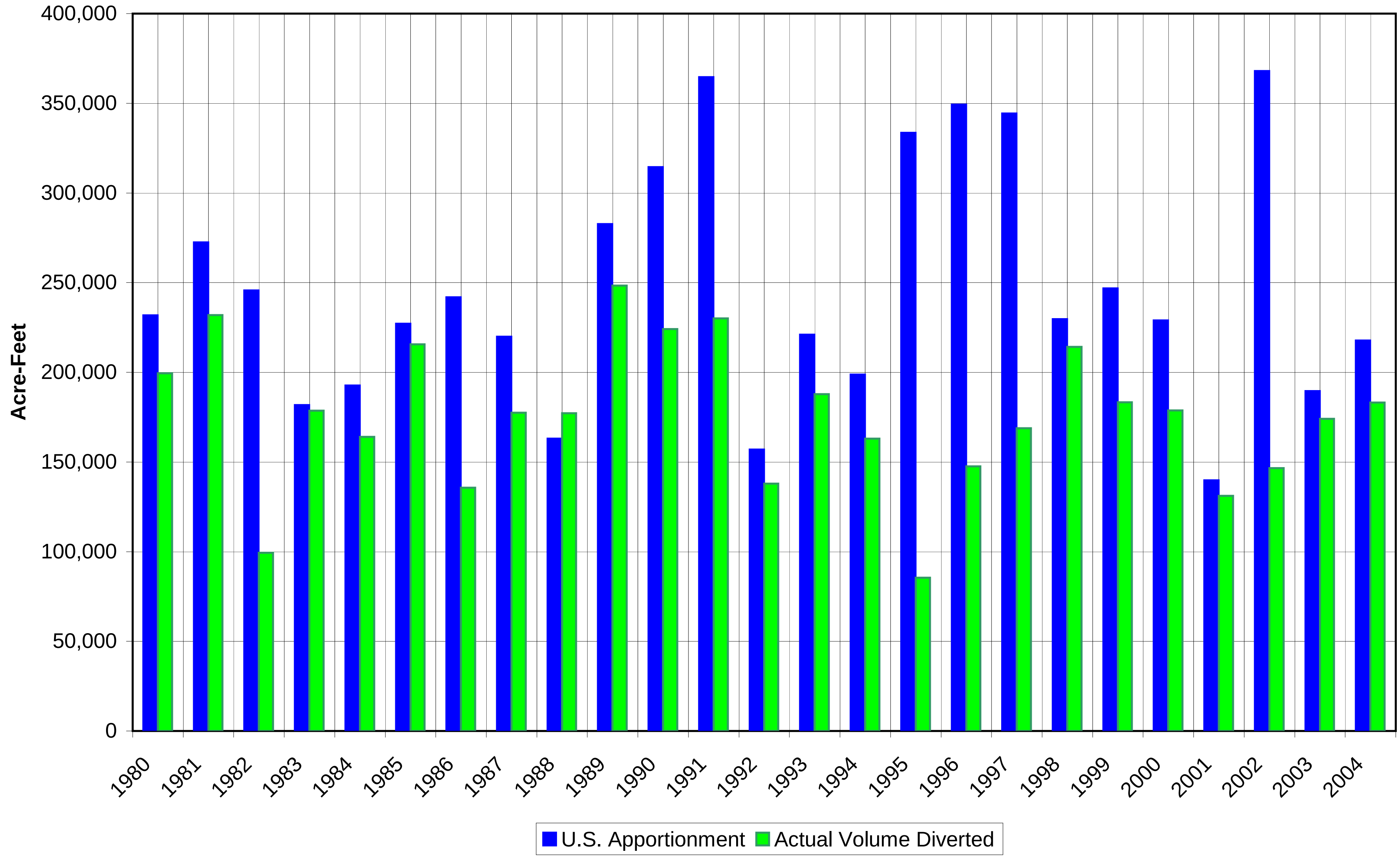

Figure 5.2

As shown on Figure 5.3, maximizing canal diversion to greater than 1000 cfs and implementing the most favorable accounting period still does not, in theory, enable the U.S. to divert its full apportionment. At a canal capacity of 1200 cfs and an annual accounting period, the theoretical diversion potential nearly approaches the 25-year annual average. Figure 5.3 also shows the relative impact of changing to a seasonal or annual accounting period versus increases in canal capacity alone. A review of the data for five driest, five median and five wettest years indicates that a larger canal and favorable accounting period has a greater influence on the U.S. to maximize potential diversions during wet years than dry years.

The IJC's *Administrative Measures Task Force Report* (2006) also concluded, in part, that lengthening the accounting period and allowing credit for surplus deliveries afforded the U.S. and Canada greater opportunity to divert their apportionments on the St. Mary and Milk Rivers, respectively.

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TABLE 5.3 SUMMARY OF THEORETICAL MAXIMUM ANNUAL DIVERSIONS TO THE ST. MARY CANAL UNDER VARIOUS OPERATIONAL REGIMES AND IJC ACCOUNTING PERIODS

Water Year	Nat Flow St. Mary R. @ Int. Boundary	U.S. St. Mary R. Entitlement	SCENARIO & CONDITION																				
			Current	Weekly				Bimonthly				Monthly				IJC Seasonal				Annual			
			650cfs Diversion 0cfs release	650cfs Diversion 25cfs Release	725cfs Diversion 25cfs Release	850cfs Diversion 25cfs Release	1000cfs Diversion 25cfs Release	650cfs Diversion 25cfs Release	725cfs Diversion 25cfs Release	850cfs Diversion 25cfs Release	1000cfs Diversion 25cfs Release	650cfs Diversion 25cfs Release	725cfs Diversion 25cfs Release	850cfs Diversion 25cfs Release	1000cfs Diversion 25cfs Release	650cfs Diversion 25cfs Release	725cfs Diversion 25cfs Release	850cfs Diversion 25cfs Release	1000cfs Diversion 25cfs Release	650cfs Diversion 25cfs Release	725cfs Diversion 25cfs Release	850cfs Diversion 25cfs Release	1000cfs Diversion 25cfs Release
1979-1980	592,298	231,771	216,973	204,683	209,688	215,838	218,691	209,382	212,356	215,612	218,484	209,382	213,263	216,074	218,484	222,967	223,208	223,504	223,498	234,706	234,751	235,057	234,885
1980-1981	657,465	272,404	232,020	222,821	228,204	231,097	237,027	223,104	226,042	234,517	237,224	230,814	230,439	234,503	237,224	247,080	245,575	246,824	245,482	256,711	270,672	269,806	270,960
1981-1982	601,754	245,627	211,447	206,471	208,994	216,247	222,405	208,305	214,627	220,601	226,547	205,805	218,393	220,963	226,391	221,802	232,301	231,017	232,330	226,629	238,242	248,000	247,150
1982-1983	468,396	181,681	171,131	163,450	164,004	164,334	165,205	163,358	164,824	165,496	165,281	163,813	164,859	165,750	164,695	165,875	165,139	165,687	164,695	182,040	181,941	182,015	181,652
1983-1984	500,104	192,606	179,143	172,850	173,809	174,545	173,391	173,509	172,717	172,869	173,388	173,034	172,806	172,932	174,298	172,801	173,310	173,177	174,330	192,029	192,308	192,327	192,690
1984-1985	584,774	227,065	206,743	199,394	200,517	204,788	207,974	198,909	201,257	205,140	209,050	203,534	204,678	206,749	208,193	206,417	206,694	207,027	209,125	223,529	223,025	223,873	225,774
1985-1986	611,561	241,789	205,648	198,191	200,627	202,439	204,461	198,515	200,393	204,613	206,091	210,777	211,158	211,514	211,375	212,279	212,274	212,049	210,564	243,943	244,615	244,412	242,886
1986-1987	557,133	219,910	201,348	195,087	197,759	198,691	198,215	195,999	198,383	198,864	197,489	196,337	197,798	199,085	198,586	199,133	199,377	199,486	199,244	220,626	220,017	220,237	220,194
1987-1988	432,966	162,984	158,575	151,067	150,841	151,016	151,232	150,800	150,611	150,766	151,543	152,005	151,843	151,533	151,866	150,917	151,089	151,532	151,787	162,081	162,910	162,751	162,768
1988-1989	693,424	282,568	251,297	242,499	245,406	249,398	253,929	243,421	247,657	253,246	255,433	246,030	250,005	255,239	261,621	255,828	261,891	261,765	261,598	262,524	281,915	282,073	282,142
1989-1990	757,948	314,344	268,324	255,416	259,013	263,638	263,876	260,357	263,317	265,376	266,177	263,008	264,299	266,387	266,892	272,286	266,592	267,158	267,238	287,436	313,939	314,041	314,147
1990-1991	845,249	364,529	243,845	237,945	247,932	263,174	283,796	237,325	249,265	265,584	283,867	237,709	249,797	268,895	292,047	252,005	264,939	285,247	308,824	279,755	284,299	305,468	330,174
1991-1992	435,297	156,950	145,906	139,389	139,768	139,944	140,323	139,853	139,703	140,064	140,028	139,904	140,337	140,496	140,751	140,065	140,197	140,425	140,513	156,528	156,206	156,658	156,648
1992-1993	571,475	220,966	204,878	197,599	198,123	198,716	198,680	197,087	198,747	198,824	199,063	199,370	200,333	200,442	200,807	200,576	200,408	200,442	200,678	220,983	221,301	221,228	221,200
1993-1994	502,599	198,713	180,436	172,908	174,093	174,896	174,765	173,587	174,191	174,709	174,657	176,637	176,723	177,145	176,919	176,857	177,087	177,145	176,919	198,091	198,739	198,817	198,632
1994-1995	786,804	333,545	247,471	233,894	253,700	270,117	287,423	240,387	253,325	269,581	288,424	243,159	255,998	276,796	291,207	249,513	275,451	307,172	315,239	251,128	275,895	309,269	333,606
1995-1996	822,288	349,293	265,938	264,793	270,029	286,157	291,357	261,532	270,619	285,641	291,015	268,446	279,058	290,694	298,273	287,223	308,561	306,692	298,717	287,223	308,561	343,180	349,122
1996-1997	819,620	344,287	251,737	243,917	255,416	270,310	290,534	245,402	255,290	270,752	291,459	247,659	259,966	279,510	293,791	259,621	285,903	324,351	327,008	269,218	297,156	339,711	344,601
1997-1998	562,485	229,589	210,426	203,555	206,614	209,474	210,209	204,011	209,168	210,890	210,018	205,977	208,701	210,264	210,197	239,265	227,467	210,510	210,308	248,612	246,816	229,913	229,320
1998-1999	614,907	246,747	228,053	221,106	225,261	229,942	231,209	220,897	226,042	229,934	231,667	221,282	226,548	230,597	231,864	230,710	231,194	231,212	231,864	245,587	246,074	246,126	246,675
1999-2000	572,120	228,846	196,332	186,952	187,454	189,537	187,833	187,309	188,728	189,508	186,500	187,381	189,599	189,285	187,221	189,957	188,624	189,660	187,221	228,622	229,406	227,494	229,010
2000-2001	364,776	139,714	133,856	125,495	127,200	127,620	129,057	126,841	128,117	127,833	129,743	127,577	126,674	127,833	129,374	126,741	128,010	128,024	129,300	139,988	138,660	141,539	139,537
2001-2002	851,667	367,946	215,783	210,630	219,542	235,622	253,249	210,475	220,291	237,829	257,298	210,078	221,227	237,949	259,051	225,787	235,928	253,265	275,118	239,293	250,893	268,134	290,135
2002-2003	484,801	189,548	174,086	165,971	167,779	170,632	173,252	166,326	169,273	172,360	173,389	172,140	172,845	173,742	174,785	175,581	175,672	175,921	175,686	189,273	189,226	189,654	189,511
2003-2004	565,965	217,758	208,649	201,538	201,862	202,264	202,604	202,049	202,104	202,725	202,334	201,943	201,938	202,355	202,144	202,075	202,166	202,235	202,884	217,339	217,457	217,232	217,815
Average	**610,315**	**246,447**	**208,402**	**200,705**	**204,545**	**209,617**	**214,028**	**201,550**	**205,482**	**210,533**	**214,647**	**203,752**	**207,571**	**212,269**	**216,322**	**211,334**	**215,162**	**218,861**	**220,807**	**226,556**	**233,001**	**238,761**	**242,049**
5 Median Years																							
1992-1993	571,475	220,966	204,878	197,599	198,123	198,716	198,680	197,087	198,747	198,824	199,063	199,370	200,333	200,442	200,807	200,576	200,408	200,442	200,678	220,983	221,301	221,228	221,200
1999-2000	572,120	228,846	196,332	186,952	187,454	189,537	187,833	187,309	188,728	189,508	186,500	187,381	189,599	189,285	187,221	189,957	188,624	189,660	187,221	228,622	229,406	227,494	229,010
1984-1985	584,774	227,065	206,743	199,394	200,517	204,788	207,974	198,909	201,257	205,140	209,050	203,534	204,678	206,749	208,193	206,417	206,694	207,027	209,125	223,529	223,025	223,873	225,774
1979-1980	592,298	231,771	216,973	204,683	209,688	215,838	218,691	209,382	212,356	215,612	218,484	209,382	213,263	216,074	218,484	222,967	223,208	223,504	223,498	234,706	234,751	235,057	234,885
1981-1982	601,754	245,627	211,447	206,471	208,994	216,247	222,405	208,305	214,627	220,601	226,547	205,805	218,393	220,963	226,391	221,802	232,301	231,017	232,330	226,629	238,242	248,000	247,150
Average	**584,484**	**230,855**	**207,275**	**199,020**	**200,955**	**205,025**	**207,117**	**200,198**	**203,143**	**205,937**	**207,929**	**201,094**	**205,253**	**206,703**	**208,219**	**208,344**	**210,247**	**210,330**	**210,570**	**226,894**	**229,345**	**231,130**	**231,604**
5 Driest Years																							
2000-2001	364,776	139,714	133,856	125,495	127,200	127,620	129,057	126,841	128,117	127,833	129,743	127,577	126,674	127,833	129,374	126,741	128,010	128,024	129,300	139,988	138,660	141,539	139,537
1987-1988	432,966	162,984	158,575	151,067	150,841	151,016	151,232	150,800	150,611	150,766	151,543	152,005	151,843	151,533	151,866	150,917	151,089	151,532	151,787	162,081	162,910	162,751	162,768
1991-1992	435,297	156,950	145,906	139,389	139,768	139,944	140,323	139,853	139,703	140,064	140,028	139,904	140,337	140,496	140,751	140,065	140,197	140,425	140,513	156,528	156,206	156,658	156,648
1982-1983	468,396	181,681	171,131	163,450	164,004	164,334	165,205	163,358	164,824	165,496	165,281	163,813	164,859	165,750	164,695	165,875	165,139	165,687	164,695	182,040	181,941	182,015	181,652
2002-2003	484,801	189,548	174,086	165,971	167,779	170,632	173,252	166,326	169,273	172,360	173,389	172,140	172,845	173,742	174,785	175,581	175,672	175,921	175,686	189,273	189,226	189,654	189,511
Average	**437,247**	**166,175**	**156,711**	**149,074**	**149,918**	**150,709**	**151,814**	**149,436**	**150,506**	**151,304**	**151,997**	**151,088**	**151,312**	**151,871**	**152,294**	**151,836**	**152,021**	**152,318**	**152,396**	**165,982**	**165,789**	**166,524**	**166,023**
5 Wettest Years																							
1994-1995	786,804	333,545	247,471	233,894	253,700	270,117	287,423	240,387	253,325	269,581	288,424	243,159	255,998	276,796	291,207	249,513	275,451	307,172	315,239	251,128	275,895	309,269	333,606
1996-1997	819,620	344,287	251,737	243,917	255,416	270,310	290,534	245,402	255,290	270,752	291,459	247,659	259,966	279,510	293,791	259,621	285,903	324,351	327,008	269,218	297,156	339,711	344,601
1995-1996	822,288	349,293	265,938	264,793	270,029	286,157	291,357	261,532	270,619	285,641	291,015	268,446	279,058	290,694	298,273	287,223	308,561	306,692	298,717	287,223	308,561	343,180	349,122
1990-1991	845,249	364,529	243,845	237,945	247,932	263,174	283,796	237,325	249,265	265,584	283,867	237,709	249,797	268,895	292,047	252,005	264,939	285,247	308,824	279,755	284,299	305,468	330,174
2001-2002	851,667	367,946	215,783	210,630	219,542	235,622	253,249	210,475	220,291	237,829	257,298	210,078	221,227	237,949	259,051	225,787	235,928	253,265	275,118	239,293	250,893	268,134	290,135
Average	**825,126**	**351,920**	**244,955**	**238,236**	**249,324**	**265,076**	**281,272**	**239,024**	**249,758**	**265,877**	**282,413**	**241,410**	**253,209**	**270,769**	**286,874**	**254,830**	**274,157**	**295,345**	**304,981**	**265,323**	**283,361**	**313,152**	**329,528**

All Values in Ac-ft.
Data Source: DNRC/ANEV Model, 2005

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Figure 5.3 Theoretical Annual Average Diversion Potential Versus Canal Capacity

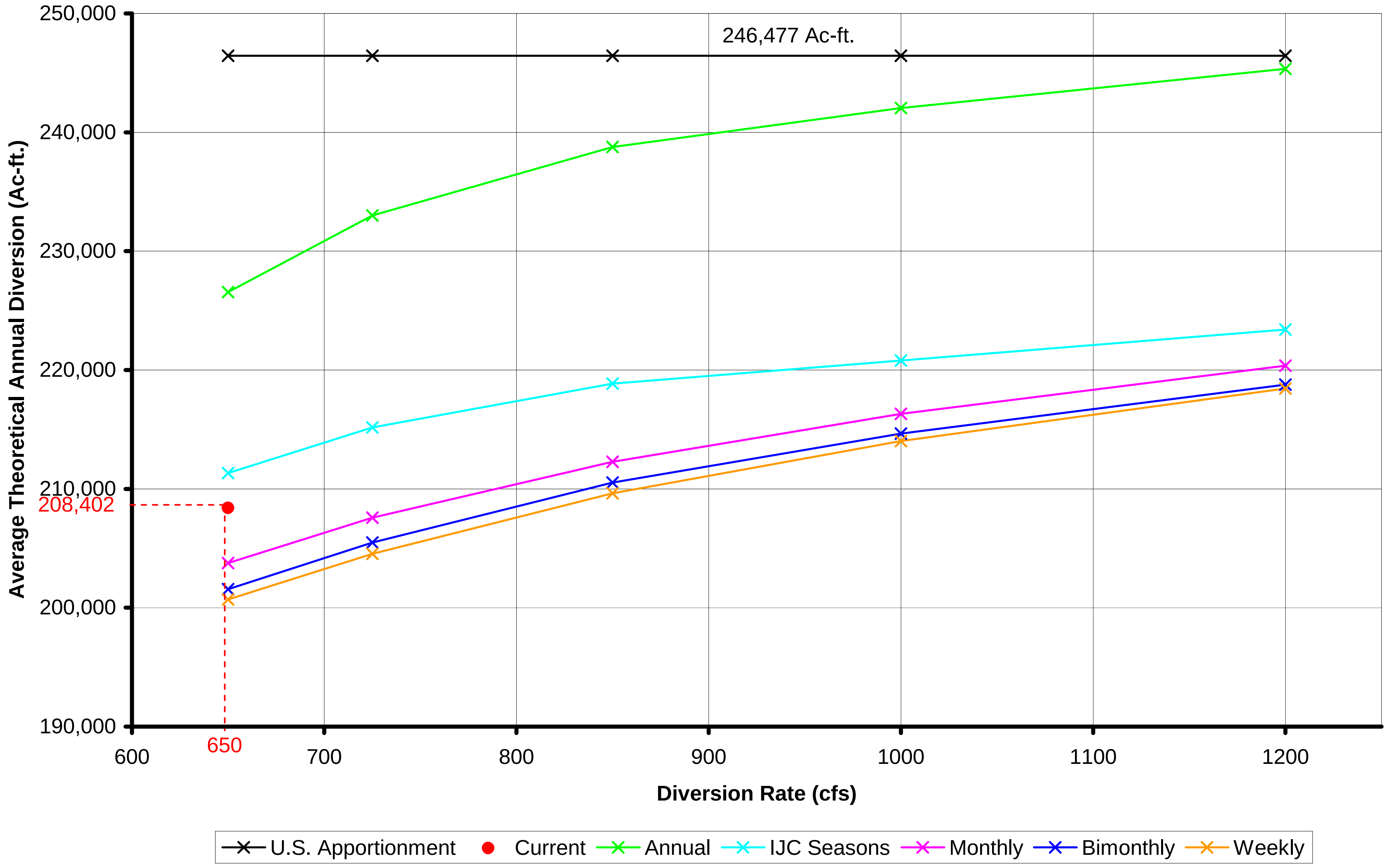


Figure 5.3

6.0 REHABILITATED CANAL PARAMTERS

6.1 OVERVIEW

The overall rehabilitation of the diversion and conveyance components of the St. Mary Canal Facilities must consider other hydrologic and hydraulic parameters other than just capacity to accommodate the desired diversion rate. These design parameters include seepage losses, evaporative losses, discrete storm water inflows and cumulative storm water routing. These other factors influence the desired canal, siphon and hydraulic drop capacities, the appropriate canal freeboard, location and size of checks and wasteways. The inflow studies are also important to determining the location and sizing of canal inlets and cross-drains or underdrains.

6.2 SUBBASIN RUNOFF FLOWS

6.2.1 Introduction

Characterizing and quantifying the impact of storm water runoff in subbasins, which the St. Mary Canal traverses, is critical to the design and sizing of rehabilitated and replacement structures. This is important not only for the canal prism itself, but also those structures impacted by potential storm water runoff such as the siphons, hydraulic drops, underdrains, inlets, checks and wasteways. For example, the design of an underdrain requires knowledge of the peak discharge at the location of the proposed underdrain. Where storm water runoff will enter the canal as inflow, runoff characteristics are required to size the drain inlet (2-bank canal) and to determine whether the inlet should be controlled or uncontrolled.

The cumulative effect of inflows has an impact on the cost-effective design of siphons, hydraulic drops, and canal freeboard. Freeboard is essentially a factor of safety with respect to canal capacity. Typically, it is not practical or cost-effective to size the conveyance structures to accommodate all potential storm water inflows. When the magnitude of inflows exceeds the canal freeboard, a mechanism for discharging or "wasting" these excess flows must be designed and properly sized. Control structures, such as siphons, hydraulic drops, checks and wasteways have a limited capacity as constructed. Their size and location (checks and wasteways) are highly dependent on transient flows associated with storm water inflows.

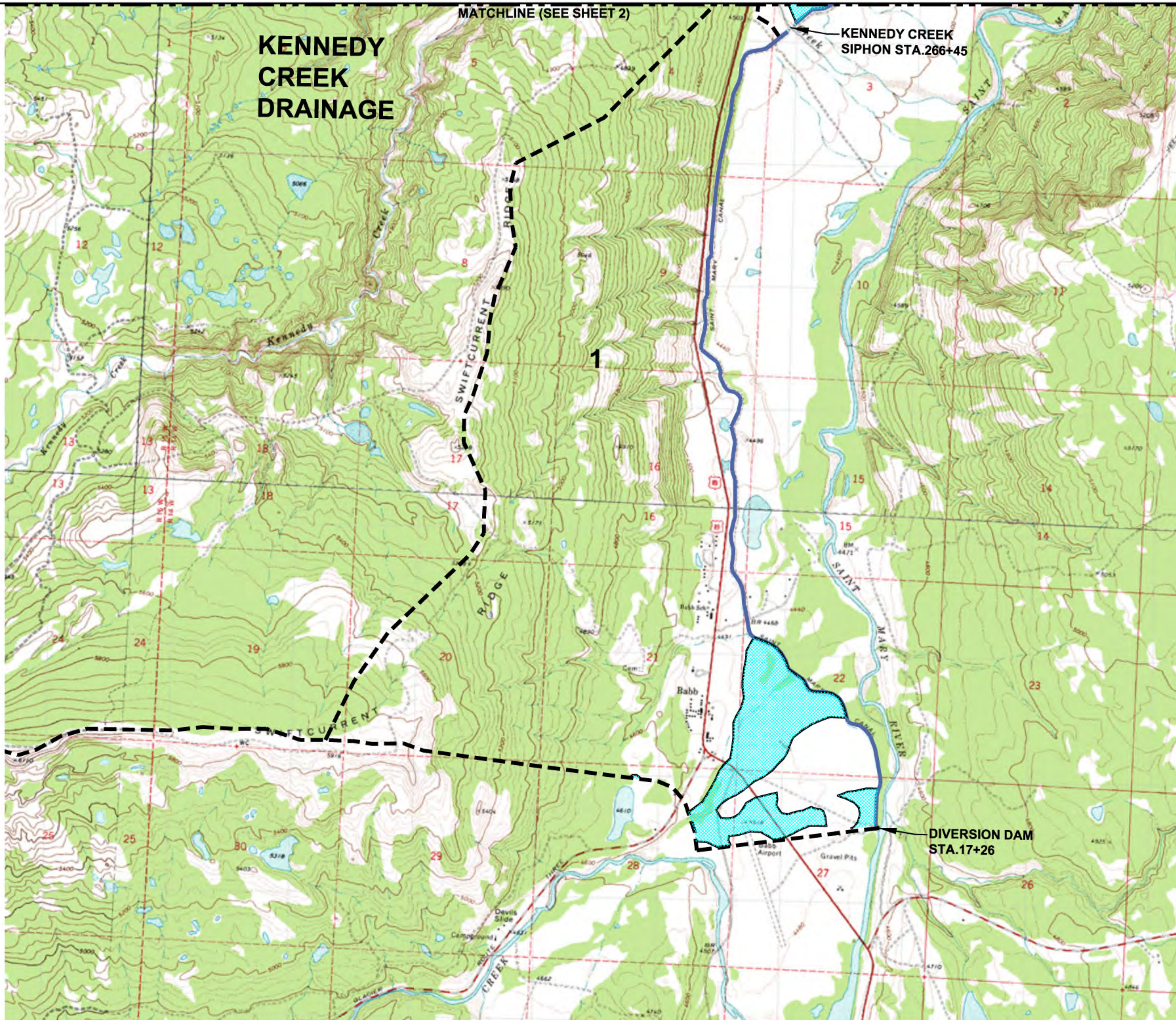
6.2.2 Subbasin Parameters

The drainage subbasins traversed by the St. Mary canal were determined from USGS topographic maps and are shown on Figure 6.1 (4 sheets). A total of 42 subbasins were identified and encompass a total aggregate area of 24,358 Ac. The Kennedy Creek subbasin was not included in this study since the canal currently crosses under this drainage outlet through an inverted siphon (Kennedy Creek Siphon). This configuration will likely not change as a result of the overall rehabilitation program. Eight of the 42 subbasins identified currently do not enter the canal as inflows. These subbasins constitute approximately 44 percent of the total area and are listed in the Table below.

Table 6.1 Subbasins That Currently Do Not Contribute Inflows

Subbasin	Existing Structure	Subbasin Drainage Area (Ac.)
Powell Creek	Underdrain – Two 66" Φ RCPs	5,546
9	Underdrain - 4.5' x 5.5' conc.	2,209
Hall Coulee	Inverted Siphon – Unrestricted	1,120
17	Underdrain – 30" Φ RCP	721
21	Underdrain – 30" Φ RCP	407
25	Underdrain – 30" Φ RCP	259
28	Underdrain – 30" Φ RCP	243
30	Underdrain – 30" Φ RCP	118
	TOTAL AREA	10,623 Ac.

The Powell Creek and Hall Coulee drainages upslope of the canal will most likely remain noncontributing subbasins but their flow characteristics are needed to quantify designs for the rehabilitated structures and for cross drainage structures.



LEGEND

- HYDROLOGIC SOIL TYPE C
- HYDROLOGIC SOIL TYPE D
- SUBBASIN BOUNDARY
- ST MARY CANAL

NOTE:
AREAS NOT DENOTED ARE HYDROLOGIC SOIL TYPE B

0 ¼ mi ½ mi ¾ mi
SCALE

FIGURE 6.1

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DATE: 07/21/06
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DNRC - CARDD
ST. MARY CANAL REHABILITATION

SUBBASIN DRAINAGES
& HYDROLOGIC SOIL TYPES

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SHEET 1 OF 4

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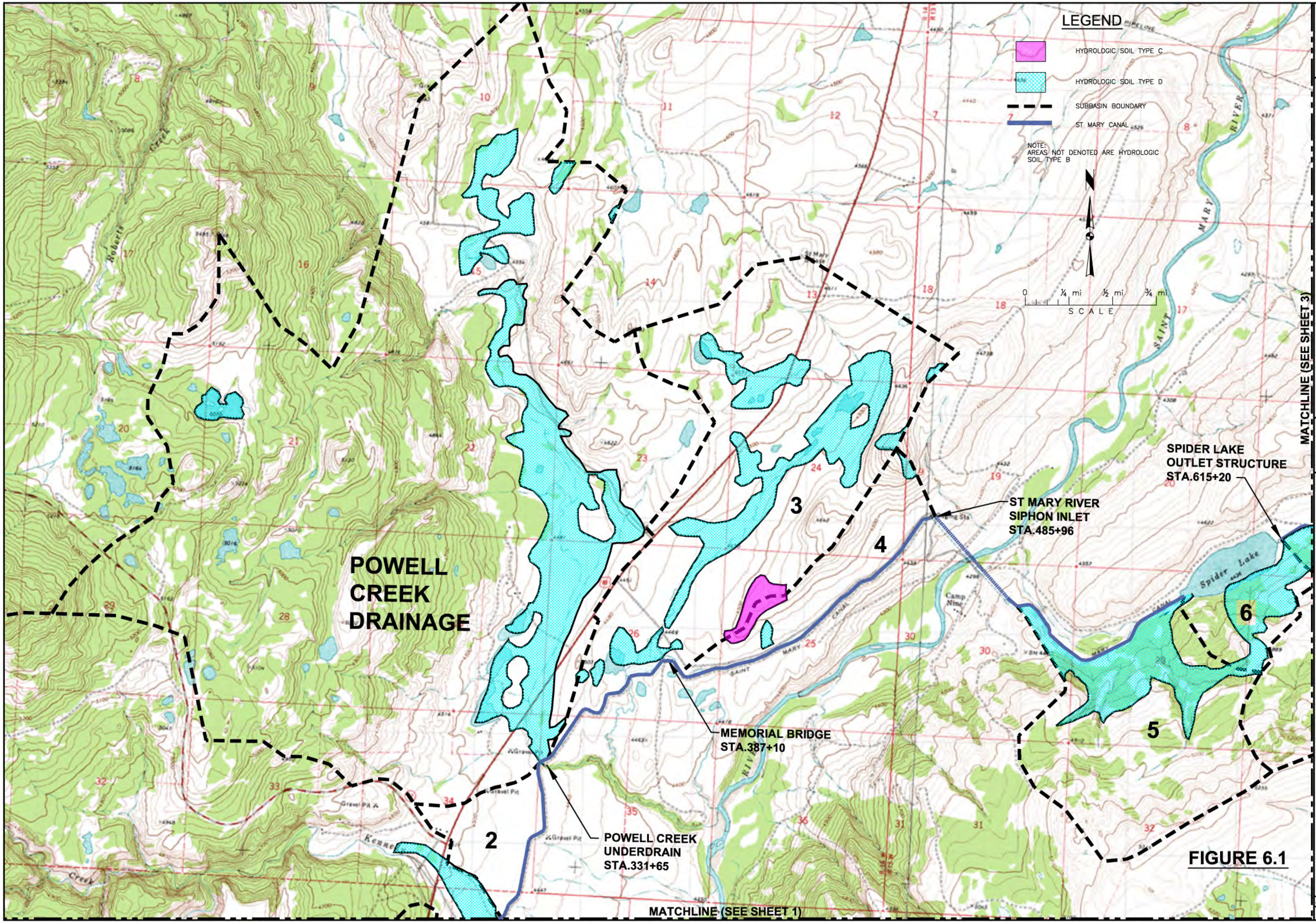

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ST. MARY CANAL REHABILITATION

SUBBASIN DRAINAGES & HYDROLOGIC SOIL TYPES

CAD NO. FIG6.1 .DWG
SHEET 2 OF 4

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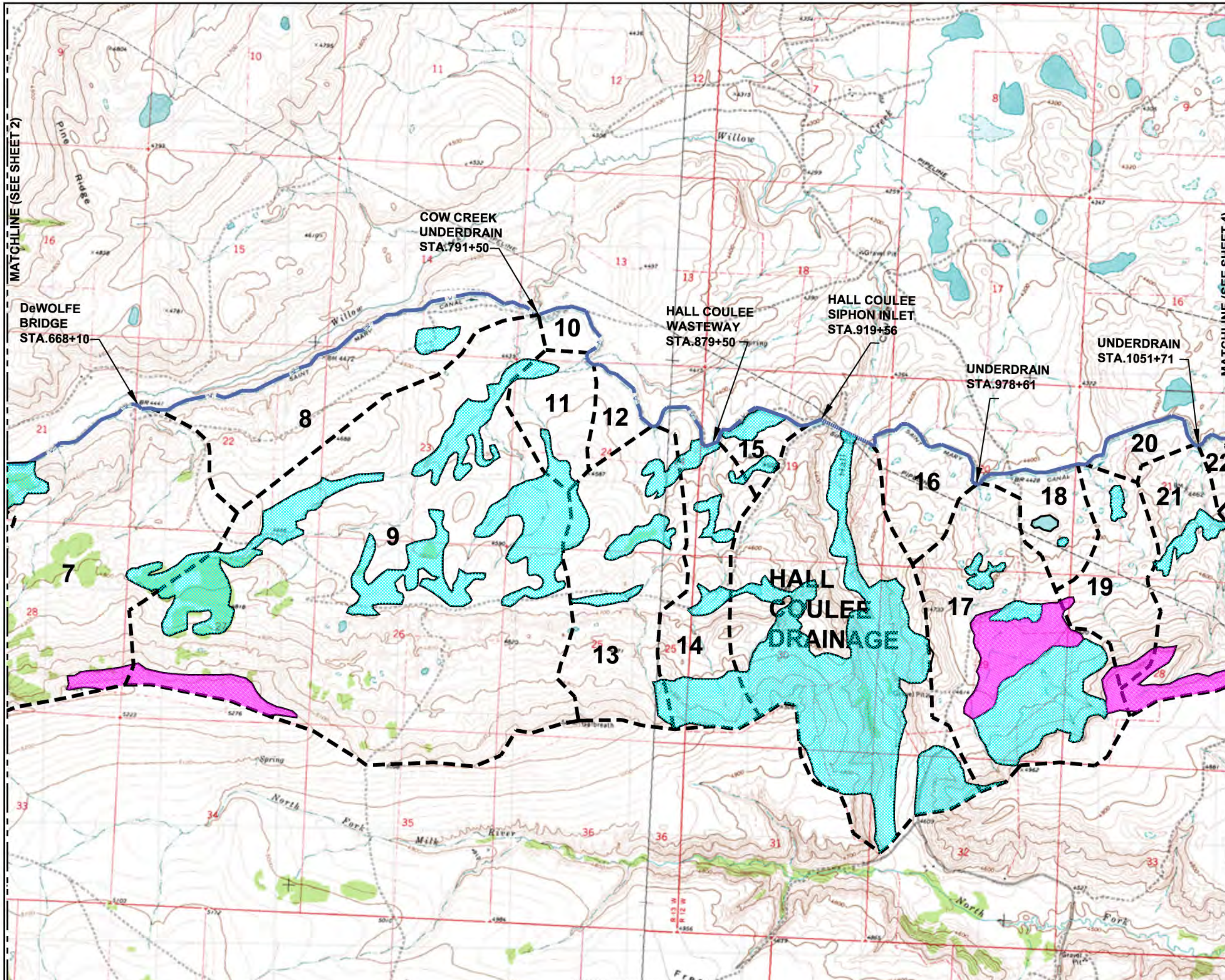

LEGEND

- HYDROLOGIC SOIL TYPE C
- HYDROLOGIC SOIL TYPE D
- SUBBASIN BOUNDARY
- ST MARY CANAL

NOTE:
AREAS NOT DENOTED ARE HYDROLOGIC SOIL TYPE B

SCALE: 0 — ¼ mi — ½ mi — ¾ mi

FIGURE 6.1

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SUBBASIN DRAINAGES
& HYDROLOGIC SOIL TYPES

CAD NO. FIG6.1.DWG
SHEET 3 OF 4

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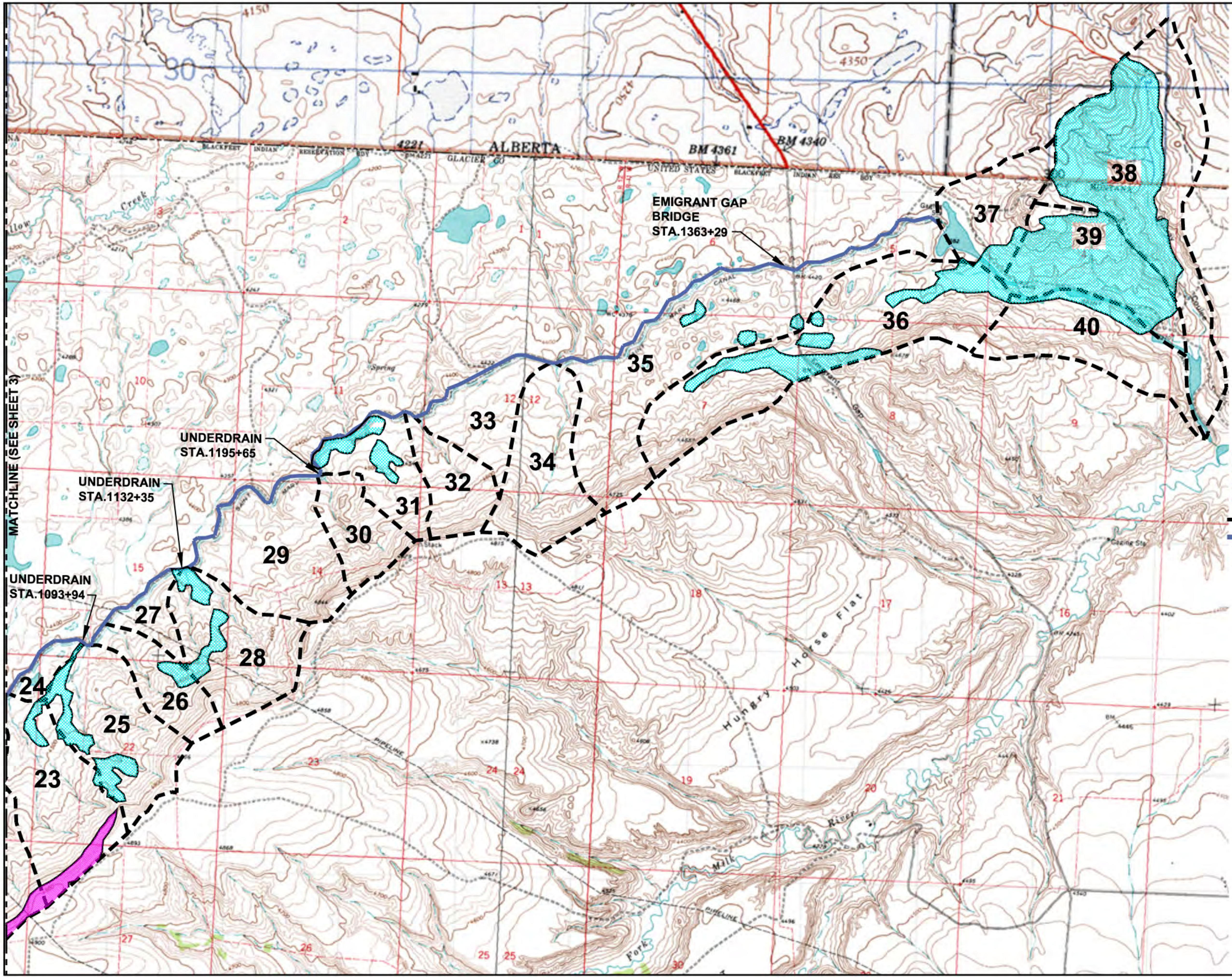

LEGEND

- HYDROLOGIC SOIL TYPE C
- HYDROLOGIC SOIL TYPE D
- SUBBASIN BOUNDARY
- ST MARY CANAL

NOTE:
AREAS NOT DENOTED ARE HYDROLOGIC SOIL TYPE B

SCALE: 0 – ¼ mi – ½ mi – ¾ mi

FIGURE 6.1

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ST. MARY CANAL REHABILITATION

SUBBASIN DRAINAGES & HYDROLOGIC SOIL TYPES

CAD NO. FIG6.1.DWG
SHEET 4 OF 4

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For runoff studies, soils are assigned one of four characteristic types or groups (A, B, C or D) based on moisture infiltration rates when thoroughly wetted (SCS, 1986). Type A is typical of desert conditions and is not applicable to soils within the study area. Soil types were determined by reviewing Glacier County soil maps available from the USDA Natural Resources Conservation Service (NRCS); formerly the Soil Conservation Service (SCS). Type B is the most common soil group with occasional occurrences of Type C and D. Figure 6.1 identifies the soil types within the study area. For this study, areas not specifically denoted as Types C and D are Type B.

Land use or cover type affects the potential runoff characteristics and is classified as either poor, fair or good. Hydrologically, a poor condition will promote higher runoff than a good condition. Aerial photos (www.terraserver-usa.com) were reviewed to assess current land use parameters. Current land use within the study area is predominantly rangeland with native grass cover. For this study, the hydrologic condition is assumed to be fair meaning grass cover is greater than 50% but less than 75%. The area of impervious cover is assumed to be 0%.

6.2.3 Runnoff Model Input Data

Two storm water runoff models were considered for use in this analysis; the Hydraulic Engineering Center's Hydraulic Modeling System (HEC-HMS) and the Environmental Protection Agency's Storm Water management Model (SWMM). HEC-HMS was designed to simulate storm water runoff from large river basins, small urban areas, and natural watersheds. SWMM was developed to simulate, among other things, runoff from primarily urban areas. The HEC-HMS model was chosen for this analysis because it is more suited for use with large drainage basins and nonurban runoff modeling. The HEC-HMS model can utilize different methods to determine runoff characteristics. The SCS Curve Number (CN) method was used in our analysis due to the available information on soil types and land use. The CN method estimates runoff potential as a function of soil cover, ground slope, land use and antecedent soil-moisture conditions.

The antecedent moisture condition (AMC) is a measure of soil-moisture conditions with respect to runoff potential prior to a storm event. The three AMC categories include; Category I- a dry soil condition with plant life not reaching the wilting point, Category II- the average soil condition, and Category III- a saturated soil condition where heavy rainfall or light rainfall with low temperatures have occurred in the last 5 days. Runoff rates were determined for each of the three antecedent conditions.

Appendix A contains tables of various CN values developed by the NRCS for antecedent moisture condition II. CN values for AMC I and II can be converted by the relationship provided by the SCS also provided in Appendix A. For a subbasin that includes multiple soil types and land uses, a composite CN value was determined (See Appendix for sample calculations).

The initial abstraction or loss (I_a) is a measure of the moisture absorbed by the soil and vegetation during the early stages of a precipitation event. Runoff will be negligible until accumulated precipitation exceeds the initial abstraction. Initial abstractions are determined for a given CN value (Appendix A).

The lag time is the time difference between the center of mass of excess precipitation and the peak of the Unit Hydrograph (UH). For ungaged watersheds, like the subbasins in this study, the SCS suggests that the UH lag time is equal to 0.6 times the watershed's time of concentration (t_c), $T_{lag} = 0.6\ t_c$. The time of concentration is a quasiphysical based parameter that can be estimated as, $t_c = t_{sheet} + t_{shallow} + t_{channel}$ where t_{sheet}, $t_{shallow}$, and $t_{channel}$ are the various travel times from the furthest point in the basin. By application of Manning's equations and the length, slope, and rainfall depth, the time of concentration can be calculated. Time of concentration and lag time for each subbasin and sample calculations are provided in the Appendix.

6.2.4 Meteorlogical Models

Subbasin runoff was determined for three distinctly different, precipitation scenarios. The first was a long duration storm over the entire study area. This scenario would typify a late spring or early summer storm coming in from the east and stalling against the mountain front. These types of storms produce a large amount of precipitation over a long period of time.

The second scenario involves a typical summer thunderstorm producing a large amount of rainfall over a small area for a short time period. This thunderstorm event is assumed to move from southwest to northeast across the area as a 2-hour event adding precipitation to each subbasin.

The third scenario looks at a typical snow melt event that may occur in late winter. It is assumed that a strong "Chinook" wind would blow from the southwest displacing frigid winter air with warm air causing a sudden warming. The winter snowpack would melt in a short time causing a significant runoff event to occur.

Scenario One – Large Basin-Wide, Long Duration Storm: The HEC-HMS Technical Reference Manual of March 2000 states "The National Weather Service (Fredrick et al., 1977) reports that …*in the contiguous US, the most frequent duration of runoff-producing rainfall is about 12 hr… at the end of any 6-hr period within a storm, the probability of occurrence of additional runoff-producing rain is slightly greater than 0.5…at the end of the first 6 hr, the probability that the storm is not over is approximately 0.75. It does not drop below 0.5 until the duration has exceeded 24 hr.*

Using observed data, Levy and McCuen (1999) showed that 24 hr is a good hypothetical-storm length for watersheds in Maryland from 2 to 50 square miles. This leads to the conclusion that a 24-hr hypothetical storm is a reasonable choice if the storm duration exceeds the time of concentration of the watershed. Indeed, much drainage system planning in the US relies on use of a 24-hr event, and the SCS events are limited to storms of 24-hr durations.

A SCS Type II Hypothetical Storm was used for this analysis. Four synthetic 24-hr storms were developed by the NRCS for different areas of the United States. Based on information presented in NRCS TR-55 publication, a Type II storm is most appropriate for Montana. For a SCS Hypothetical Storm, HEC-HMS requires total rainfall for the storm. Total storm precipitation amounts for 100, 50, 25, 10, 5, and 2-year, 24-hour storms, were obtained from the National Oceanic and Atmospheric Administration's (NOAA) and are summarized in the Table below. Copies of NOAA precipitation frequency maps can be found in Appendix A.

Table 6.2 – Total Storm Rainfall
For Various Return Periods in the Study Area

Return Period (yrs)	Duration (hrs)	Total Rainfall (in)
2	24	1.8
5	24	2.4
10	24	2.8
25	24	3.4
50	24	3.8
100	24	4.2

(Source: NOAA, 2005)

Scenario Two – Small High Intensity, Short Duration Storm: This scenario looked at the runoff from the subbasins due to a high intensity, short duration storm as would be expected from a thunderstorm moving across the study area. In order to model this scenario, a storm rainfall distribution was required as input into HEC-HMS. No storm rainfall distribution data was available for the area. However, the City of Great Falls has developed a rainfall distribution for a 100-year, 2-hour storm for use in designing storm water drainage systems in the city. A copy of their 2-hour design storms taken from the "City of Great Falls Storm Drainage Design Manual" can be found in Appendix A. The total rainfall from the 100-year, 2-hour design storm is 1.931 inches. By comparing total rainfall amounts for Great Falls (2.50 inches) and the St. Mary Canal area (2.35 inches) from NOAA's "Western U.S. Precipitation Frequency Maps" 100-year, 6-hour total precipitation isopluvials, a ratio of total precipitation between Great Falls and the St. Mary Canal area was calculated. The 100-year, 2-hour design storm rainfall distribution table was modified by this ratio to obtain a 100-year, 2-hour design storm for the St. Mary Canal area. The design storm was then assumed to move across the subbasins at a speed of 20 miles per hour with the design storm starting and ending for each subbasin based on it's distance from the diversion dam. This assumption will have no effect on individual subbasin runoff, but will tend to compress canal hydrographs calculated by the program.

The control specification tab in HEC-HMS specifies the starting and ending date and time used during the simulation. The staring time and date of 12:00:00 a.m., July 1, 2005 and an ending time and date of 11:59:59 p.m., July 3, 2005 was used. The actual time and dates have no effect on the analysis and are used for output reference only. Time step interval for the extended run simulations was set to one minute, the shortest interval allowed by the program.

Scenario Three – Maximum Expected Runoff from Snowmelt: This scenario estimates runoff from each subbasin due to a snowmelt runoff event as would be expected by a "Chinook" moving into the area in March, suddenly raising the temperatures, and melting snow that had accumulated throughout the winter.

To calculate potential snowmelt, the snowpack was assumed to have a uniform depth. For estimating the rate of snowmelt, thawing degree-day factors were used. One thawing degree-day is defined as one degree of temperature above 32°F for one day. Snowmelt factors usually range between 0.05 and 0.15 inches per degree-day. Data from the Western Regional Climate Center http://www.wrcc.dri.edu/) was used to attain the average maximum daily temperature and the hourly frequency distribution histogram for Babb in the month of March. The average maximum daily temperature of 63°F for March equates to 31-thawing degree-days. Using an average value of 0.08 inches per degree-day results in 2.48 inches of snowmelt runoff assuming that there is adequate snowpack conditions. The hourly frequency distribution histogram was used to distribute the 2.48 inches of runoff in a 24-hour period to create this snowmelt event.

6.2.5 Runnoff Flows

Runoff volumes and peak discharge rates were determined for each of the subbasins (excluding Kennedy Creek) using all three antecedent moisture conditions and each of the three different storm models. Runoff parameters were determined for the basin-wide, long duration (24-hr) storm using return periods of 2, 5, 10, 25, 50 and 100 years. The runoff design parameters for antecedent moisture conditions II (normal) for each different storm model are listed in Table 6.3. Tables for the dry and saturated soil conditions are provided in Appendix A. In general, the 24-hr storm scenario produced the largest peak runoffs and discharge volumes.

Table 6.3 Summary of Subbasin Runoff Parameters Under Antecedent Moisture Condition II (Normal)

Subbasin	Total Area (acre)	Meteorological Event													
		100 Year 24 hr Storm		50 Year 24 hr Storm		25 Year 24 hr Storm		10 Year 24 hr Storm		5 Year 24 hr Storm		100 Year 2 hr Storm		24 hr Snowmelt	
		Discharge Peak (cfs)	Total Volume (ac ft)	Discharge Peak (cfs)	Total Volume (ac ft)	Discharge Peak (cfs)	Total Volume (ac ft)	Discharge Peak (cfs)	Total Volume (ac ft)	Discharge Peak (cfs)	Total Volume (ac ft)	Discharge Peak (cfs)	Total Volume (ac ft)	Discharge Peak (cfs)	Total Volume (ac ft)
1	3556	929.93	273.63	685.34	213.20	471.36	158.22	218.04	87.84	100.72	50.47	82.40	12.82	117.64	57.17
2	201	37.31	11.01	25.42	8.23	15.65	5.77	5.35	2.78	1.82	1.32	1.04	0.13	4.50	1.57
Powel Creek	5546	755.11	418.21	565.43	325.04	398.37	240.43	196.58	132.42	99.21	75.34	58.29	18.40	138.01	85.56
3	1685	379.58	148.42	288.61	117.38	207.42	88.85	107.15	51.66	57.00	31.34	44.30	9.74	57.91	35.03
4	300	463.68	36.51	372.20	29.86	285.58	23.59	168.35	15.09	101.20	10.16	49.58	4.36	20.53	11.08
5	836	447.17	62.85	323.27	48.84	215.08	36.12	89.27	19.89	34.67	11.32	26.05	2.76	33.02	12.85
6	214	229.57	18.68	173.43	14.76	121.91	11.16	57.14	6.46	25.22	3.91	13.11	1.20	10.39	4.37
7	1012	655.94	102.91	506.18	82.64	369.12	63.80	194.63	38.80	104.55	24.76	76.93	9.07	53.94	27.34
8	463	593.39	55.14	473.30	44.99	359.97	35.45	207.81	22.53	122.40	15.08	67.85	6.36	30.79	16.47
9	2209	1281.70	288.07	1032.70	237.11	798.02	188.92	481.76	122.99	303.47	84.35	250.24	38.05	136.08	91.59
10	39	50.61	4.55	40.23	3.70	30.46	2.91	17.39	1.84	10.10	1.22	5.45	0.51	2.54	1.34
11	159	200.09	20.39	161.42	16.76	124.73	13.33	74.76	8.65	46.13	5.91	27.36	2.64	11.30	6.43
12	65	104.66	7.60	83.52	6.19	63.55	4.86	36.83	3.07	21.62	2.04	9.81	0.85	4.29	2.23
13	524	476.02	67.34	383.01	55.35	295.05	44.03	176.21	28.57	108.96	19.53	77.02	8.73	35.83	21.22
14	346	368.83	49.92	301.92	41.49	238.07	33.46	149.90	22.35	98.05	15.73	68.62	7.59	26.60	16.98
15	68	113.83	9.87	93.62	8.21	74.35	6.63	47.47	4.44	31.42	3.13	17.13	1.52	5.49	3.38
Hall Coulee	1120	618.93	156.08	503.77	129.31	394.59	103.86	245.64	68.78	159.86	48.00	135.46	22.67	70.77	51.91
16	155	173.59	18.04	137.68	14.68	103.94	11.54	59.01	7.29	34.21	4.85	20.45	2.01	10.00	5.30
17	721	590.69	107.73	485.72	89.84	385.27	72.75	246.14	49.01	163.89	34.79	128.70	17.16	53.66	37.48
18	134	174.44	16.18	139.40	13.21	106.29	10.42	61.74	6.65	36.63	4.46	20.29	1.90	9.03	4.87
19	238	217.11	28.95	173.15	23.67	131.82	18.70	76.54	11.96	45.83	8.06	31.48	3.46	15.59	8.78
20	63	101.59	7.38	81.06	6.01	61.68	4.72	35.75	2.98	20.99	1.98	9.52	0.82	4.16	2.17
21	407	366.99	52.95	295.84	43.58	228.46	34.71	137.21	22.59	85.39	15.49	60.92	6.99	28.06	16.82
22	29	37.33	3.35	29.68	2.73	22.47	2.15	12.83	1.36	7.45	0.90	4.02	0.37	1.88	0.99
23	277	262.07	34.72	210.04	28.47	161.10	22.58	95.06	14.56	58.00	9.89	39.74	4.35	18.69	10.77
24	39	61.57	4.47	49.13	3.64	37.38	2.86	21.67	1.81	12.72	1.20	5.77	0.50	2.52	1.31
25	259	313.88	33.97	253.93	27.98	196.98	22.32	119.19	14.57	74.43	10.02	45.91	4.55	18.71	10.87
26	117	123.97	14.42	99.13	11.81	75.72	9.34	44.23	5.99	26.59	4.05	17.03	1.75	7.90	4.41
27	58	75.82	6.79	60.40	5.54	45.85	4.36	26.36	2.76	15.43	1.84	8.32	0.77	3.80	2.01
28	243	252.45	30.85	202.87	25.34	156.06	20.13	92.70	13.02	56.84	8.88	37.45	3.94	16.79	9.65
29	282	287.45	32.87	227.68	26.76	171.77	21.02	97.36	13.28	56.45	8.83	35.79	3.66	18.07	9.66
30	118	173.73	13.79	138.41	11.22	105.08	8.82	60.46	5.57	35.29	3.70	17.29	1.53	7.75	4.05
31	148	247.85	20.05	202.22	16.57	158.69	13.27	98.44	8.73	63.23	6.06	32.25	2.82	11.22	6.56
32	118	123.69	13.71	98.01	11.16	73.96	8.77	41.94	5.54	24.31	3.68	15.13	1.53	7.56	4.03
33	141	175.66	16.40	139.56	13.35	105.55	10.49	60.17	6.63	34.90	4.41	19.39	1.82	9.15	4.82
34	234	206.97	27.20	163.83	22.15	123.41	17.40	69.97	10.99	40.77	7.31	27.78	3.03	14.70	7.99
35	515	505.94	61.06	401.93	49.81	304.63	39.23	174.61	24.92	102.85	16.67	67.13	7.02	33.34	18.21
36	516	309.79	65.54	248.69	53.82	191.23	42.75	114.12	27.66	70.98	18.86	57.56	8.37	31.59	20.50
37	168	240.13	21.26	193.46	17.44	149.20	13.84	88.91	8.93	54.32	6.07	29.25	2.67	11.89	6.61
38	545	422.52	89.07	351.66	74.91	283.45	61.31	187.71	42.21	129.93	30.61	107.05	15.93	42.16	32.82
39	243	446.16	47.57	380.66	40.69	316.46	33.99	223.71	24.40	165.36	18.41	111.71	10.52	25.30	19.56
40	247	339.32	31.20	273.23	25.60	210.56	20.31	125.28	13.11	76.47	8.91	42.28	3.92	17.42	9.70
Totals	24354		2530.69		2043.03		1589.18		984.70		643.53		258.77		706.44

Individual peak discharge values should be used during final design to determine the following:

- the size of underdrains where subbasin runoff is elected to pass under the canal and not be considered as inflow and
- the size of controlled and uncontrolled drain inlets where subbasin runoff is desired to enter the canal and become canal inflow.

For each runoff event scenario, a subbasin unit hydrograph was generated to model the runoff distribution with respect to time. To model the effects of storm water runoff on the conveyance canal and the related hydraulic structures, each subbasin unit hydrograph is systematically added and superimposed to the canal baseline flow. The result is a cumulative canal hydrograph. Two example subbasin runoff hydrographs for the 25-year, 24-hour storm event are provided in the Appendix A. The storm water routing analysis is utilized during the design phase for the following:

- perform a cost-effective design of the canal prism freeboard,
- determine the impact of storm-related, canal flows on hydraulic structures with limited capacity such as the siphons and hydraulic drops. Routing information would also facilitate the cost-effective sizing of these structures to accommodate an acceptable level of storm water inflows in addition to the normal diversion canal flows,
- assist in the assessment whether individual subbasin runoffs should be treated as inflows or pass under the canal through an underdrain system,
- determine the optimum location and size of emergency checks and wasteways or dedicated spill areas in order to safely manage excess storm water inflows, and
- assist with modeling and programming of an automation system for the overall facility.

6.3 SEEPAGE LOSSES

Earthen conveyance canals are subject to seepage losses when the fluid surface level (FSL) is higher than adjacent, local groundwater regimes. The primary factors influencing seepage losses include the wetted perimeter, the hydrostatic head, the hydraulic conductivity of the prism soils, and the length of the canal.

Water losses due to seepage are a significant design consideration when sizing large capacity canals of appreciable length. For the initial nine miles of the St. Mary Canal, seepage losses return to the St. Mary River and therefore do not impact U.S. apportionments that are determined at the inlet to St. Mary River siphon. However, seepage losses in the remaining eighteen miles of the canal, which have been assessed as U.S. water, return to Canada via the Willow Creek drainage. The ultimate desired diversion capacity should consider these seepage loss rates. For example, diversion at the dam must be increased by the amount projected to be lost due to seepage if a desired diversion delivery (U.S. apportionment) to the North Fork of the Milk River is to be fully realized.

Seepage loses (cfs/mile) can be estimated by using the Mortiz formula (USBR, 1967) which is given below.

$$S_L = (0.2)\, C\, (Q/V)^{0.5}$$

Where, S_L = seepage loss in cfs per mile of canal

Q = discharge of canal, cfs

V = mean flow velocity, fps

C = empirical soil factor equating seepage rates

Typical soil factors (C) were determined by the USBR officials based on field studies and are listed in the Table below:

Table 6.4 Seepage Soil Factors (USBR, 1967).

Type of Material	Value of C
Cemented gravel and hardpan with sandy loam	0.34
Clay and clayey loam	0.41
Sandy loam	0.66
Volcanic ash	0.68
Volcanic ash with sand	0.98
Sand and volcanic ash or clay	1.20
Sandy soil with rock	1.68
Sandy and gravelly soil	2.20

Using the Mortiz Equation, the predicated seepage losses were calculated along the St. Mary Canal assuming an initial diversion of 720 cfs and an average velocity of 2 fps. Soil factors were estimated based on our field observations and understanding of the regional geology. The calculations are provided in Appendix B and the results are summarized in the Table below.

Table 6.5 Estimated Seepage Losses In Current St. Mary Canal Using Mortiz Equation.

Canal Segment	Segment Length (ft)	Soil Factor	Seepage Rate (cfs/mile)	Seepage (cfs)
D.Dam to Kennedy Creek Siphon	25,060	2.2	8.3	39.6
Kennedy Creek Siphon to Powell Creek	6,419	2.2	8.3	10.1
Powell Creek to St. Mary Siphon	16,010	1.5	5.7	17.3
			Subtotal	67.0
St. Mary Siphon to Spider Check	10,226	0.41	1.5	2.9
Spider Check to Halls Siphon	30,098	0.41	1.5	8.4
Halls Siphon to Drop No. 1	47,818	0.41	1.5	13.4
Assuming Q=720cfs (initial) and V=2.0 fps			Subtotal	24.7
			Total	91.7

Comparison of Historical Flows Between Diversion Dam & St. Mary Siphon

Source: USGS Water Resources
Time Frame: 1918 to 2004

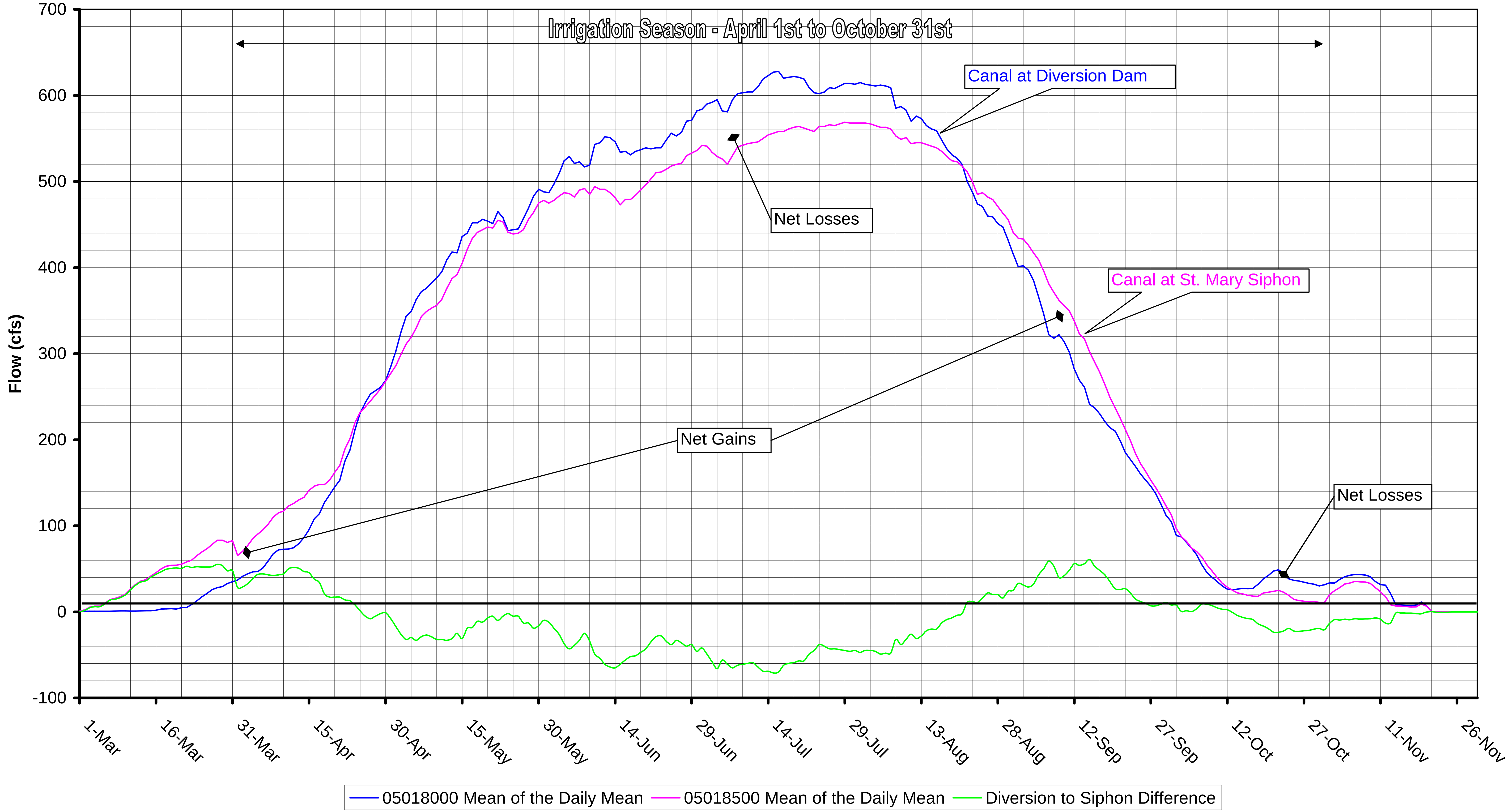
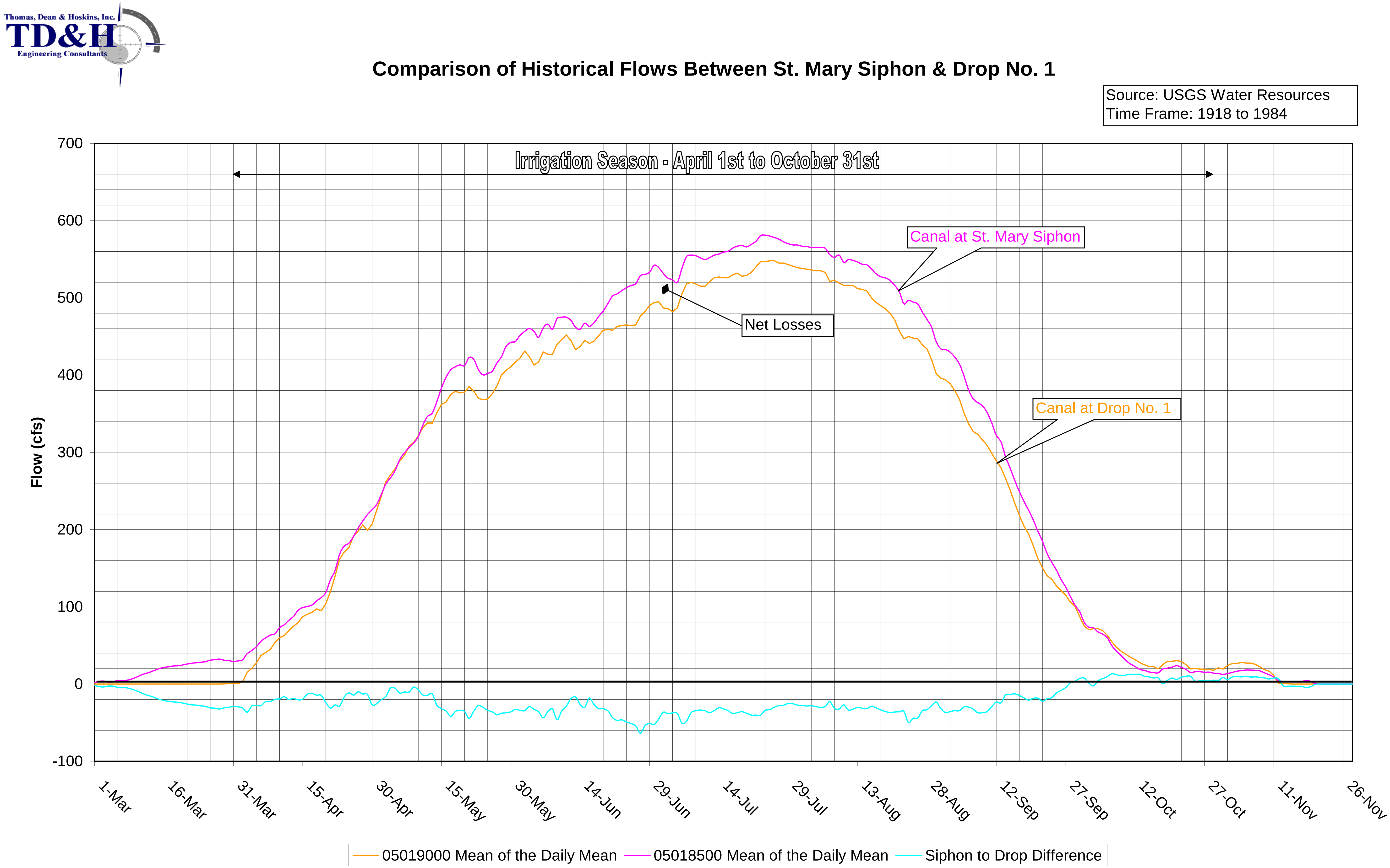


Figure 6.2



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Comparison of Historical Flows Between St. Mary Siphon & Drop No. 1
Source: USGS Water Resources
Time Frame: 1918 to 1984
Irrigation Season - April 1st to October 31st
Canal at St. Mary Siphon
Net Losses
Canal at Drop No. 1
Flow (cfs)
700
600
500
400
300
200
100
0
-100
1-Mar
16-Mar
31-Mar
15-Apr
30-Apr
15-May
30-May
14-Jun
29-Jun
14-Jul
29-Jul
13-Aug
28-Aug
12-Sep
27-Sep
12-Oct
27-Oct
11-Nov
26-Nov
05019000 Mean of the Daily Mean
05018500 Mean of the Daily Mean
Siphon to Drop Difference

Figure 6.3

The historical observed seepage loss rates were determined between the diversion dam and the St. Mary River siphon by plotting the measured mean daily mean flows as determined at the respective USGS gaging stations. The historical seepage rates were also determined between the St. Mary River siphon and the inlet at the first hydraulic drop. The graphs show typical maximum canal seepage loss rates of between 60 and 80 cfs and between 30 and 60 cfs for the canal segments before and after the St. Mary River siphon, respectively. The mean daily mean flow rates and flow differences for these two segments are shown on Figures 6.2 and 6.3. The graphs illustrate the effect of springtime watering of the canal and end of the season dewatering. Actual seepage losses, in theory, would be greater than those shown because of the net impact of storm water inflows. Evaporative losses from the canal are assumed to be negligible.

Similar comparisons were made for several individual years to eliminate the averaging effect inherent to analysis of mean daily means. Attempts were made to compare flow differences when the canal flows represented near steady-state conditions. The flow comparisons reflect considerable scatter of the observed seepage losses over different canal flows and is most likely the net effect of storm water inflows that cannot be fully assessed. It is assumed that higher seepage losses represent dry periods and lower seepage losses reflect additional flows from storm water runoff. These graphical comparisons are presented in Appendix B and are summarized in the Table below.

Table 6.6 Summary of Seepage Losses for Select Years.

Period		Average Discharge At Diversion Dam	Average Discharge At St. Mary Siphon	Average Discharge At Drop No. 1	Ave. Seepage Loss	
Beginning	Ending				Dam to Siphon	Siphon to Drop No. 1
6/24/1930	8/13/1930	632	522	500	110	22
6/29/1934	8/18/1934	815	694	683	121	11
6/23/1935	8/9/1935	832	720	700	112	20
5/18/1946	9/23/1946	652	583	574	69	9
7/5/1949	9/12/1949	603	542	533	61	9
5/23/1963	9/15/1963	--	690	676	--	14
6/4/1999	9/17/1999	651	597	--	54	--
5/10/2000	7/19/2000	648	606	--	42	--
7/30/2000	9/12/2000	576	516	--	60	--
5/31/2001	8/5/2001	698	616	--	82	--

All Flows in cfs

The predicted seepage rates correlate approximately to the observed seepage losses. The Mortiz Equation was then used to predict seepage loss rates for the rehabilitated canal at diversion discharges of 850 and 1000 cfs. This analysis was also used to determine the diversion rate required at the dam to achieve a desired delivery of 850 and 1000 cfs to the North Fork of the Milk River. The results are summarized in the Table below and the supporting calculations are provided in Appendix B.

Table 6.7 – Estimated Seepage Losses For Rehabilitated St. Mary Canal Using Mortiz Equation.

Diversion Rate at Dam	Total Seepage Losses	Discharge At Drop No. 1
850	99	751
1,000	107	893
955	105	850
1113	113	1,000

All flows in cfs

6.4 DIVERSION HEAD

6.4.1 Canal Flow Capacity.

Hydraulically, the flow capacity of the canal will be determined by the canal size, shape, roughness, discharge characteristics of in-line structures, and the elevation difference between the water surface elevation at the top of the first drop structure and the river water surface elevation at the diversion dam. The difference in ground elevation up to Drop No. 1 is about 52 feet. This roughly represents the total hydraulic head available for the canal and siphons. A complete hydraulic analysis of the system is needed in order to determine the specific canal size that is required to pass the required flow in conjunction with the replacement siphons and other in-line structures. A computer model is ultimately recommended to analyze the entire integrated system comprised of the new replacement and the effects of storm water entering the canal along the route. Storm water inflow causes varying or transient flow conditions that will affect the overall system hydraulics and size and location of checks and waste structures. Development of this model is beyond the scope of this report since it depends on the final hydraulics of the replacement structures. The assumptions of uniform steady flow and water surface elevations compatible with the existing canal operation are adequate for this preliminary evaluation.

The water surface elevation in the river must be adequate to achieve the depth of flow needed in the canal to pass the design flow with the hydraulic gradient available. The water surface in the river must be higher than in the canal in order to overcome head losses in the headgate structure and the proposed fish screens. Initially, this loss is estimated to be approximately 1.6 feet. This is roughly compatible with both the existing and proposed facilities.

Once the river level is at the required elevation to supply the canal design flow, additional increases in the river level will not significantly increase the flow in the canal. If the canal is flowing at 850 cfs and the river level was to rise an additional one foot, the flow in the canal would probably only increase by about 3.3% or 28 cfs. The length, cross-section and roughness of the canal along with the three inverted siphons are the primary factors controlling the potential diversion rate.

6.4.2 Lower St. Mary Lake.

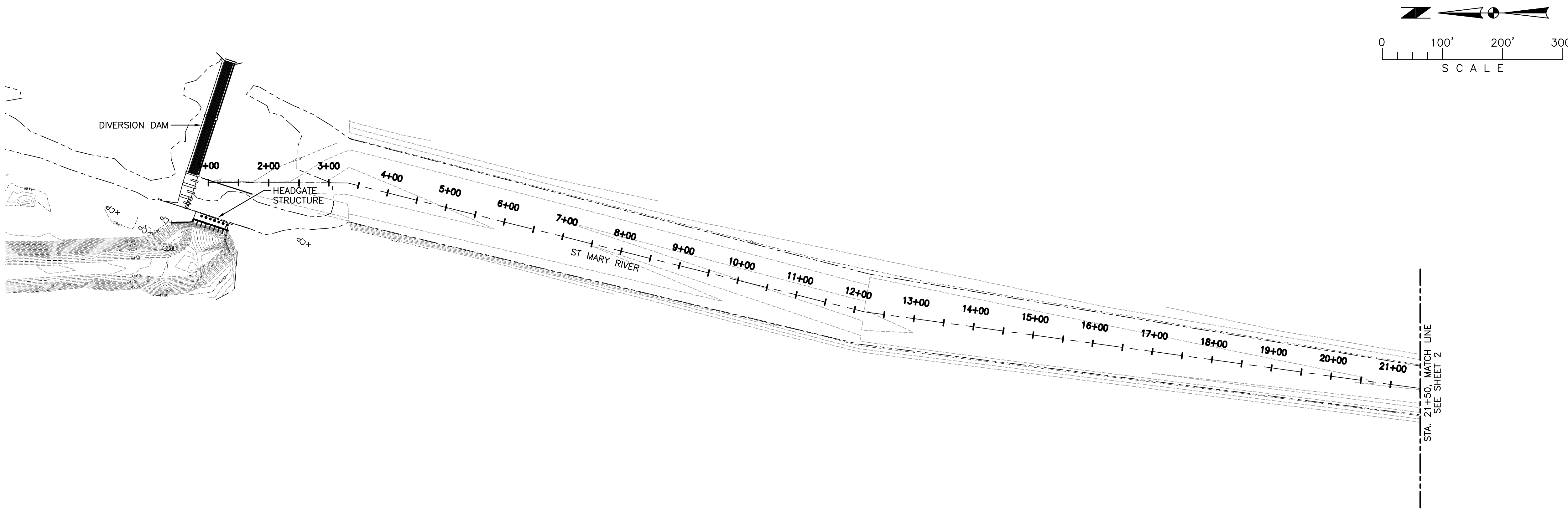
The crest of the diversion dam controls the water elevation at the dam and may also impact the water elevation in Lower St. Mary's Lake at higher discharges. When the dam is open in the winter and river flow is relatively low, the lake level is not affected by the dam. In December of 2006, the top of ice elevation in the lake was 4473.9. Actual water level would be somewhat lower. This represents a seasonal low lake elevation.

A USGS gaging station (05017500) monitors the lake level and is located on the lake about 6,500 feet upstream of the diversion dam. This USGS station is utilized to determine the flow entering the St. Mary River from the lake. Typical river flows and seasonal lake elevations during the year are shown in Figure 6.5. On average, the lake typically varies about 3.6 feet during the year. During extreme floods such as in 1964, the lake level has been as high as 4485.5 or about 12 feet higher than winter low flow elevations.

Previous reports indicate that an old river crossing located about 3,300 feet upstream of the diversion dam, just upstream of the current U.S. 93 highway bridge, controls the lake level (see Figure 6.4). A cross section of the river at this location indicates that the low point of the channel bottom at this section is 4472.4. This is approximately the same elevation as the crest of the existing diversion dam. During low flows this river section and the channel upstream of the dam control the lake water level.

During the summer when water is being diverted to the canal, the lake elevation typically rises to around 4477.2 or higher in June when runoff flows are high as indicated in Figure 6.5. The water surface elevation at the diversion dam is probably around 4474 during this higher flow period and may drop to around 4472.5 during September when flows are lower. The lake level during this period appears to be controlled by the water level at the dam and the river's hydraulic gradient between the dam and the lake. This may change at lower flows. It would be prudent to perform a surface water profile analysis during final design in order to determine the hydrologic impacts of the actual replacement dam on Lower St. Mary Lake during all anticipated flow conditions.

Based on preliminary survey data, there may be a potential opportunity to store an additional 7,000 acre-feet of water in Lower St. Mary Lake for potential diversion into the canal system by increasing the height of the crest on the diversion dam. The crest height would have to be adjustable in order to utilize the stored water. This option was considered as Proposal No. 1 in the Value Planning Final Report dated March 28, 2002 prepared by the USBR but never considered further. This potential can be fully assessed during final design when computer modeling of the canal hydraulics and the stream surface profile analyses are performed.



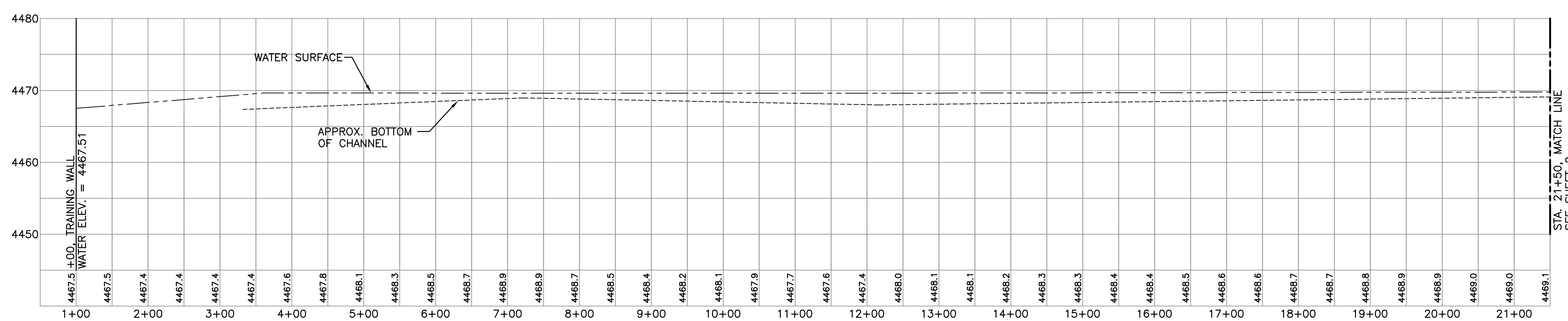


FIGURE 6.4

MONTANA ERLING A. JUEL 10740PE REGISTERED PROFESSIONAL ENGINEER

REVISIONS
BY ___ DATE ___ DESCR ___
BY ___ DATE ___ DESCR ___
BY ___ DATE ___ DESCR ___

TD&H
THOMAS, DEAN & HOSKINS, INC.
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WASHINGTON
IDAHO

DRAWN BY: MWC
DESIGNED BY: EAJ
QUALITY CHECK:
DATE: 01.12.06
JOB NO. 04-167
FIELDBOOK

DNRC - CARDD
ST. MARY CANAL REHABILITATION

ST. MARY DIVERSION FACILITIES
PLAN & PROFILE - UPSTREAM F DIVERSION DAM

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SHEET 1 OF 2

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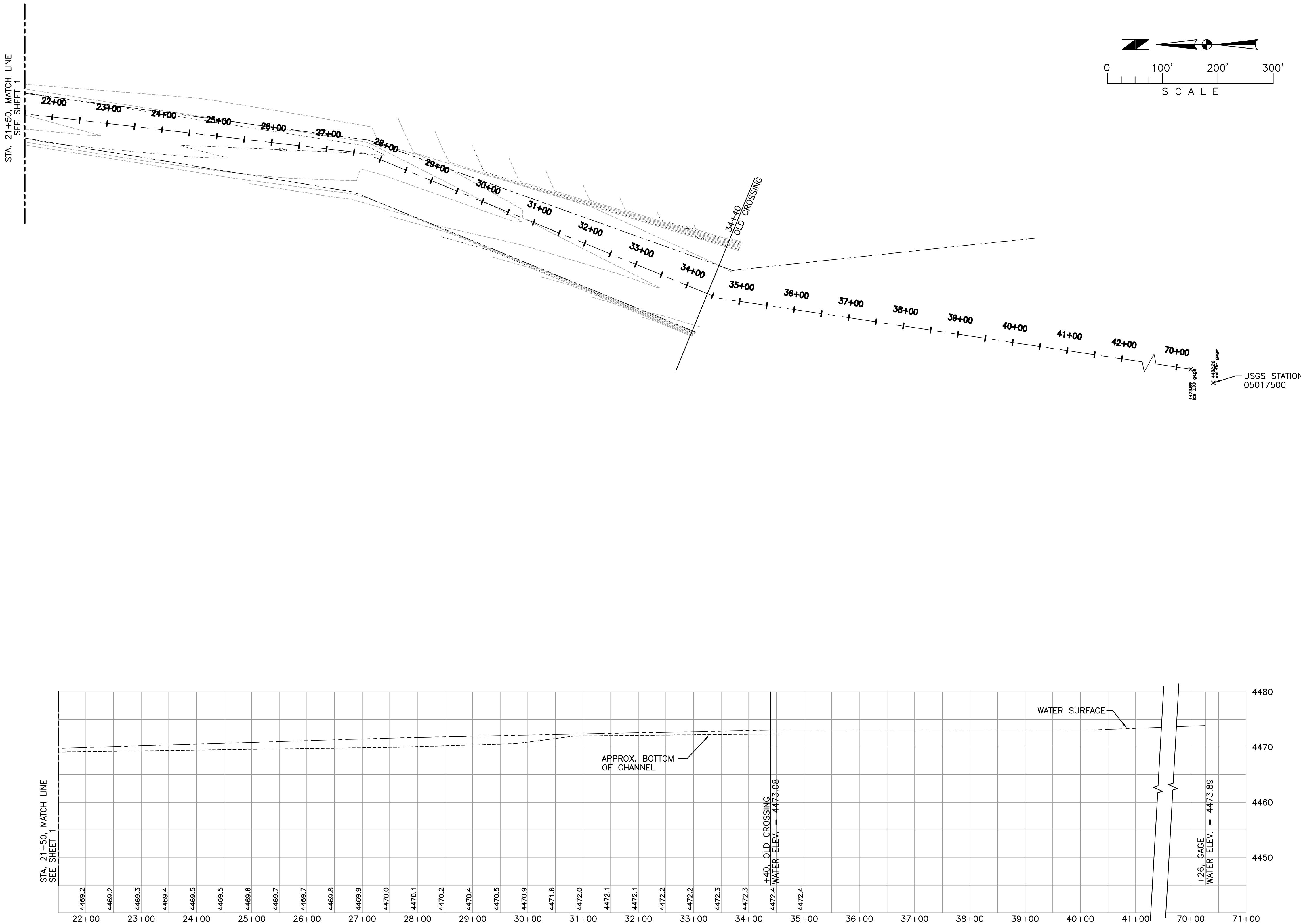

FIGURE 6.4

MONTANA REGISTERED PROFESSIONAL ENGINEER ERLING A. JUEL 10740PE

REVISIONS
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THOMAS, DEAN & HOSKINS, INC.
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SPOKANE
LEWISTON
MONTANA
WASHINGTON
IDAHO

DRAWN BY: MWC
DESIGNED BY: EAJ
QUALITY CHECK:
DATE: 01.12.06
JOB NO. 04-167
FIELDBOOK

DNRC - CARDD
ST. MARY CANAL REHABILITATION

ST. MARY DIVERSION FACILITIES
PLAN & PROFILE - UPSTREAM OF DIVERSION DAM

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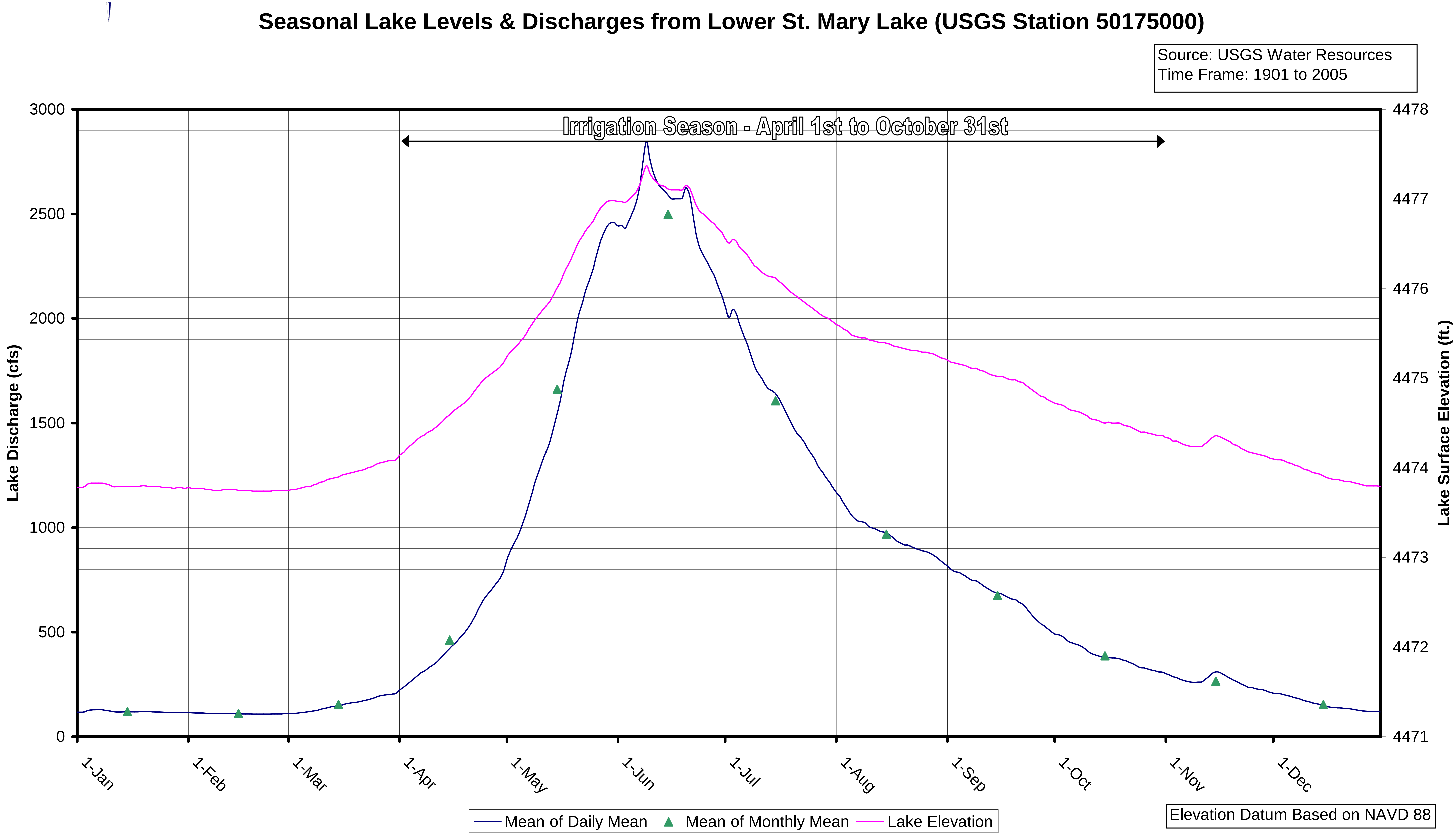
SHEET 2 OF 2



Seasonal Lake Levels & Discharges from Lower St. Mary Lake (USGS Station 50175000)
Source: USGS Water Resources
Time Frame: 1901 to 2005
Irrigation Season - April 1st to October 31st
Lake Discharge (cfs)
Lake Surface Elevation (ft.)
3000
2500
2000
1500
1000
500
0
4478
4477
4476
4475
4474
4473
4472
4471
1-Jan
1-Feb
1-Mar
1-Apr
1-May
1-Jun
1-Jul
1-Aug
1-Sep
1-Oct
1-Nov
1-Dec
Mean of Daily Mean
Mean of Monthly Mean
Lake Elevation
Elevation Datum Based on NAVD 88

Figure 6.5

7.0 SUMMARY

7.1 CONCLUSIONS

In summary, the two most significant factors influencing the ability of the U.S. to utilize its apportionment are the current IJC accounting procedures and the limitations of the St. Mary Diversion Facilities. Without additional reservoir storage to collect and meter discharges, the U.S. cannot fully utilize its apportionment each year during high runoff periods. For example, on average from May 15th to July 10th, the U.S. apportionment of the natural flow exceeds the safe diversion rate (± 725 cfs) based on the current canal capacity downstream of the St. Mary siphon (±650 cfs). The result is that the U.S. annual diversion was only 175,339 Ac-ft or 71 percent of its full apportionment between 1980 and 2004. Under current IJC procedures, surplus deliveries are forfeited. Extending the accounting period and/or allowing credit for surplus deliveries would allow the U.S. to maintain increased diversion rates when natural flows wane. The St. Mary Lake Storage Reservoir recommended by the IJC in 1921 was to be built with the costs shared equally with Canada. If constructed, this would have provided the U.S. with enhanced water management capabilities.

The models developed jointly by DNRC and AENV illustrate the following key points:

- A minimum wintertime release from Sherburne Reservoir on the order of 25 cfs would result in a loss of U.S. apportionment of approximately 6,850 Ac-ft on average.

- Extending the accounting period to a seasonal or annual method provides a greater opportunity for the U.S. to maximize its diversion than increasing the canal size.

- An annual accounting period and a 1,200 cfs canal capacity would, in theory, allow the U.S. to divert approximately 246,000 Ac-ft is her annual average apportionment over the last 25 years.

Several extenuating circumstances were identified that often preclude the U.S. from fully diverting and utilizing its apportionment. They are as follows:

- As stated above, the current IJC accounting procedures and the reduced capacity of the St. Mary Canal.

- Lack of instrumentation, automation, remote-control capabilities, an all-weather maintenance road, and sufficient canal freeboard results in a cautious and conservative operational mode during potential precipitation events, which has translated to lost diversion opportunities.

- Due to slope/bank instabilities, operational mode is cautious during wet years.

- During wet years, the demand for diverted St. Mary River water is lower because above-normal precipitation decreases irrigation demands, and because natural Milk River flows are higher and available for storage in Fresno and Nelson Reservoirs.

- The aging facilities require increased repairs. Many are emergency repairs requiring mid-season shut downs of the facilities. Planned repairs often dictate early season shut downs to minimize winter work.

Extending the accounting period and/or revoking the surplus delivery penalty will have no impact on Canadian operations since the U.S. is currently diverting at system capacity during flood flows. As natural flows decrease below approximately 1,950 cfs, the safe diversion rate (± 725 cfs) of the St. Mary Canal exceeds the U.S.'s apportionment; therefore the IJC procedures control U.S. diversion rates. Overall, allowing the U.S. to fully utilize its apportionment has a tremendous positive impact toward alleviating concerns regarding flood stress on Canadian infrastructure. Extending the accounting period and allowing credit for surplus deliveries enables the U.S. to divert more water during low to moderate flows when current IJC procedures control diversion rate rather than the capacity of the facilities. Rehabilitating the St. Mary Diversion Facilities to a capacity of no less than 850 cfs would be considered prudent. The result is that the U.S. will be able to divert even more water during high and flood flows, thus further assisting Canada.

The diversion and conveyance facilities were originally designed for a capacity of 850 cfs. Due to long-term deterioration and degradation, the current "safe" capacity varies from approximately 650 to 725 cfs depending on location. Downstream of the St. Mary River siphon, the "safe" capacity is on the order of 650 cfs due primarily to the sloughing and failure of the earthen canal prisms. Freeboard, which represents a factor of safety against over-topping, is critically small in several reaches due to reduced capacity. Accounting for canal seepage losses upstream of the St. Mary River siphon, this equates to a "safe" diversion rate of approximately 725 cfs. In the last 10 years, the highest flow measured at the siphon was 678 cfs and the largest diversion rate as measured at the headgates was 729 cfs. Because of diminished freeboard, the system is very sensitive to storm water inflows. When storm events are anticipated, USBR staff reduces diversion rates to "create" freeboard in order to accommodate potential inflows. Without adequate system safe guards, this practice is warranted to protect the canal from over-topping and progressive breaching. This protective mode of operation represents lost opportunity for diversion especially if the anticipated storm event is not fully realized. As a result of the aging infrastructure, another lost opportunity to maximize diversion is when early shutdowns are planned for extensive maintenance or repairs. Midseason shutdowns also occur due to leaks and emergency repairs.

Rehabilitation and sizing of the replacement facilities must consider seepage losses. Approximately 60 to 80 cfs is lost due to seepage from the canal prior to measurement at USGS Station 05018500. Between the St. Mary River Siphon and Drop No. 1, seepage losses range from 10 to 30 cfs depending on flow. Prior to the St. Mary – Milk River Divide (Drop No. 1) all seepage losses enter drainages that flow into Canada. In the first 9 miles, seepage losses do not affect U.S. apportionment. The remaining seepage losses equate to approximately 7,250 Ac-ft assuming an average seepage loss rate of 20 cfs per day for 183 days (April 1st to September 30th).

Estimates of seepage losses suggest that a diversion rate of 955 cfs is required to achieve a diverted flow of 850 cfs at Drop No. 1. A diversion rate of 1000 cfs will result in a combined seepage of 107 cfs and therefore a flow into the Milk River of only 893 cfs. The amount of seepage loss downstream of the St. Mary River siphon over the course of the irrigation season exceeds that amount that would currently enter as storm water inflows during the 100-year, 24-hr storm event under normal soil-moisture conditions.

Another important consideration for rehabilitation of the diversion facilities is the assessment and quantification of storm water inflows from subbasins traversed by the canal. Storm water inflows need to be superimposed on normal canal flows to evaluate and select a cost-effective canal freeboard and sizing contingency for siphons, drops and other hydraulic structures. Runoff parameters were determined for three distinct precipitation events; a basin-wide long duration (24-hr) storm, a high intensity, short duration (2-hr) storm and a rapid snowpack melting event. The 24-hr storm produced the largest potential runoff. The 25-year, 24-hr storm produced approximately 1,250 Ac-ft of runoff for all subbasins excluding Kennedy and Powell Creeks and Hall Coulee. For the subbasins that currently drain into the canal, the runoff volume is approximately 900 Ac-ft. This later volume equates to 454 cfs-days.

The peak discharges determined from the storm water analyses would be used to size canal inlet and underdrain structures. The subbasin runoff parameters are also used during the design phase to develop a storm water routing model along the canal. This model will help evaluate the size and location of various hydraulic structures as well as canal freeboard.

7.2 RECOMMENDATIONS

Based on the results of our study we offer the following recommendations and suggestions for consideration:

- Rehabilitation of the facilities should also include a slight over-sizing to incorporate operational flexibility. The IJC Task Force concluded this as well.

- Rehabilitation of the St. Mary Diversion Facilities should include a design capacity of not less than 850 cfs as delivered to the North Fork of the Milk River. Diversion rates should consider seepage losses, any U.S. consumptive uses internal to the facilities, and potential hydropower at the St. Mary siphon crossing.

- If diversions in excess of 850 cfs to the North Fork of the Milk are anticipated, any potential environmental impacts such as erosion, sedimentation, and flooding to the Milk River system should be evaluate.

- Incorporate a canal freeboard sufficient for a 25-year, 24-hour storm. In-line hydraulic structures should be assessed using storm water routing considering a 50-year return. Emergency wasteways and dedicated spill areas should be assessed using the 100-year return.

- Total seepage losses are estimated to be approximately 10 percent of canal flows; these should be added to the desired diversion capacity when sizing the canal.

- Continue to lobby the IJC to change the apportionment administrative procedures to allow for an extension of the accounting period and/or revoking the surplus delivery penalty so as to afford the U.S. better opportunity to utilize its apportionment on the St. Mary River.

- Lobby the IJC for accounting changes that would allow the U.S. credit for seepage losses downstream of the St. Mary Siphon (USGS 05018500). These seepage losses enter Canada via Willow Creek. Current estimates indicate an annual loss of 7,250 Ac-ft, which is 3 percent of the U.S.'s average annual apportionment based on the last 25 years. One consideration would be to reactivate USGS Station 05019000 located on the St. Mary – Milk River drainage divide. This location is ideal for determining the actual and true diversion of the U.S.'s St. Mary River apportionment into the Milk River Basin. Gaging at this location would take into account the net effect of storm water inflows, groundwater gains and seepage losses. The IJC Task Force Report also concluded this observation.

- Ultimate sizing of the rehabilitated St. Mary Facilities should consider not only current irrigation demands in the Milk River Basin, but also allow for potential future demands due to population and economic growth and expansion, changes in agricultural (value-added crops) and potential USBR project authorization for other uses. Non-irrigation demands for U.S. water within the Milk River Basin includes Reserved Water Rights, MR&I needs (municipal, recreation and industrial), Bowdoin National Wildlife Refuge, threatened and endangered species (piping plover and pallid sturgeon) and fish and wildlife in general. Demands for U.S. water extend downstream beyond the Milk River Project and include the Missouri and Mississippi Rivers. The IJC's *Administrative Measures Task Force Report* (2006) stated………"should (St. Mary Canal) rehabilitation become a reality, it would be prudent to construct the system to a capacity that would optimize the ability of the U.S. to divert its full entitlement of St. Mary River water."

8.0 REFERENCES

Canal and Related Structures, Design Standards No. 3, USBR, December 1967.

City of Great Falls, *Great Falls Engineering, Storm Drainage Design Manual,* June 1990.

Design of Small Canal Structures, USBR, 1978.

Figliuzzi, Sal, *Computation of Natural Flows and Development of Hydrologic Models for the St. Mary and Milk River Watersheds,* Alberta Environment, 2005.

International Joint Commission, *International St. Mary – Milk River Administrative Measures Task Force,* April 2006.

Levy, B., McCuen, R., *Assessment of Storm Duration for Hydrologic Design,* ASCE Jounral of Hydrologic Engineering, 4(3) 209-213, 1999.

Montana Department of Natural Resources and Conservation, *Summarizing the Milk River Water Supply Study, Special Report*, in conjunction with Milk River Irrigation District and U.S.B.R., July, 1990.

Simonds, Wm. Joe, *The Milk River, 2nd Draft,* Research on Historic Reclamation Projects, 1999.

Soil Conservation Service, *Urban Hydrology for Small Watersheds, Technical Report 55.* USDA, Springfield, VA, 1986.

Thomas, Dean & Hoskins, *St. Mary Diversion Facilities – Data Review, Preliminary Cost Estimate and Proposed Rehabilitation Plan* , February 2005.

Thomas, Dean & Hoskins, *Draft Preliminary Engineering and Feasibility Report – St. Mary Diversion Facilities,* January 2006.

U.S. Army Corp of Engineering, *Hydrologic Engineering Center, Hydrology Modeling System HEC-HMS, Technical Reference Manual,* March 2000.

U.S. Bureau of Reclamation, *North Central Montana Regional Feasibility Report,* October 2004.

U.S. Bureau of Reclamation, *Annual Operating Plans* **-** *Upper Missouri River Basin, Water Year 2004 Summary – Water Year 2005 Operating Plans.*

U.S. Bureau of Reclamation, *Alternatives Scoping Document*, North Central Montana, March 2003.

U.S. Bureau of Reclamation, *Saint Mary Canal O&M Condition Assessment*, Plan and Profile Drawings (and Cross Sections for 850 cfs), April 2001.

U.S. Department of Agriculture, Natural Resources Conservation Service, 2005, www.wcc.usda.gov.

U.S. Department of Commerce, Natural Oceanic and Atmosphere Administration, Western Regional Climate Center, 2005 www.wrcc.dri.edu.

U.S. Bureau of Reclamation, *Saint Mary Canal O&M Condition Evaluation*, Design Data and Calculations for 850 cfs, Volume I & II, April 2001.

U.S. Geological Survey, 2005, http://mt.water.usgs.gov/

U.S. Geological Survey, 2004, *Water Resources Data, Montana, Water Year 2003, Volume 1. Hudson Bay and Upper Missouri River Basins,* Water-Data Report MT-03-1.

U.S. Geological Survey, *Procedures for the Diversion of the Waters of the St. Mary and Milk Rivers,* in cooperation with the Water Survey Division, Meteorological Service of Canada, Environment Canada, 2003 Edition.

APPENDIX A

INPUT DATA, SAMPLE CALCULATION AND RESULTS FOR SUBBASIN RUNOFF DETERMINATIONS

Subbasin	Total Area		Hydrologic Group	Hydrologic Area	Average Cover	CN_{II}	CN_{II}	I_{aII}	CN_{I}	I_{aI}	CN_{III}	I_{aIII}
1	3555.7	acre	B	3304.9	Woods	60	61.1	1.27	41.1	2.86	79.9	0.50
			C									
	5.556	mi^2	D	250.8	50/50 Herbaceous/Aspen	76						
	P_2		**Slope (S)**	**Length (ft)**	**Manning's (n)**							
t_{sheet}	1.8		0.12	300	0.4	=	0.56				t_c	1.94
$t_{shallow}$			0.04	16040.6		=	1.38				t_{lag}	1.17

Subbasin	Total Area		Hydrologic Group	Hydrologic Area	Average Cover	CN_{II}	CN_{II}	I_{aII}	CN_{I}	I_{aI}	CN_{III}	I_{aIII}
2	200.6	acre	B	200.6	Brush	56	56	1.57	36.0	3.56	75.8	0.64
			C									
	0.313	mi^2	D									
	P_2		**Slope (S)**	**Length (ft)**	**Manning's (n)**							
t_{sheet}	1.8		0.03	300	0.4	=	0.98				t_c	1.60
$t_{shallow}$			0.01	3591.7		=	0.62				t_{lag}	0.96

Subbasin	Total Area		Hydrologic Group	Hydrologic Area	Average Cover	CN_{II}	CN_{II}	I_{aII}	CN_{I}	I_{aI}	CN_{III}	I_{aIII}
Powel Creek	5545.7	acre	B	4957.1	70/30 Woods/Brush	59	60.8	1.29	40.8	2.90	79.6	0.51
			C									
	8.665	mi^2	D	588.6	50/50 Herbaceous/Aspen	76						
	P_2		**Slope (S)**	**Length (ft)**	**Manning's (n)**							
t_{sheet}	2		0.03	300	0.4	=	0.93				t_c	4.59
$t_{shallow}$			0.02	30109.1		=	3.67				t_{lag}	2.76

Subbasin	Total Area		Hydrologic Group	Hydrologic Area	Average Cover	CN_{II}	CN_{II}	I_{aII}	CN_{I}	I_{aI}	CN_{III}	I_{aIII}
3	1684.6	acre	B	1334.6	50/50 Range/Aspen	59	63.5	1.15	43.5	2.59	81.8	0.44
			C	20.6	Range	79						
	2.632	mi^2	D	329.4	50/50 Brush/Range	81						
	P_2		**Slope (S)**	**Length (ft)**	**Manning's (n)**							
t_{sheet}	1.8		0.03	300	0.4	=	0.98				t_c	3.01
$t_{shallow}$			0.01	11798.1		=	2.03				t_{lag}	1.81

Subbasin	Total Area		Hydrologic Group	Hydrologic Area	Average Cover	CN_{II}	CN_{II}	I_{aII}	CN_{I}	I_{aI}	CN_{III}	I_{aIII}
4	299.8	acre	B	275.5	Range	69	70	0.86	51.0	1.92	87.0	0.30
			C	14.2	Range	79						
	0.468	mi^2	D	10.1	Range	84						
	P_2		**Slope (S)**	**Length (ft)**	**Manning's (n)**							
t_{sheet}	1.8		0.2	300	0.13	=	0.19				t_c	0.34
$t_{shallow}$			0.09	2746.2		=	0.16				t_{lag}	0.21

Subbasin	Total Area		Hydrologic Group	Hydrologic Area	Average Cover	CN_{II}	CN_{II}	I_{aII}	CN_{I}	I_{aI}	CN_{III}	I_{aIII}
5	835.7	acre	B	633.3	50/50 Herbaceous/Aspen	60	60.7	1.29	40.7	2.91	79.6	0.51
			C									
	1.306	mi^2	D	202.4	Aspen	63						
	P_2		**Slope (S)**	**Length (ft)**	**Manning's (n)**							
t_{sheet}	1.8		0.13	300	0.13	=	0.22				t_c	0.69
$t_{shallow}$			0.09	8160		=	0.47				t_{lag}	0.41

Subbasin	Total Area		Hydrologic	Hydrologic	Average Cover	CN_{II}	CN_{II}	I_{aII}	CN_{I}	I_{aI}	CN_{III}	I_{aIII}

Subbasin	Total Area		Group	Area	Average Cover	CN_{II}	CN_{II}	I_{aII}	CN_{I}	I_{aI}	CN_{III}	I_{aIII}
6	213.5	acre	B	117.2	20/80 Herbaceous/Aspen	53	63.4	1.16	43.4	2.61	81.7	0.45
			C									
	0.334	mi^2	D	96.3	50/50 Herbaceous/Aspen	76						
	P_2		Slope (S)	Length (ft)	Manning's (n)							
t_{sheet}	1.6		0.17	300	0.13	=	0.21				t_c	0.34
$t_{shallow}$			0.17	3049		=	0.13				t_{lag}	0.20

Subbasin	Total Area		Hydrologic Group	Hydrologic Area	Average Cover	CN_{II}	CN_{II}	I_{aII}	CN_{I}	I_{aI}	CN_{III}	I_{aIII}
7	1012	acre	B	929.8	85/15 Range/Aspen	66	66.2	1.02	46.4	2.31	83.9	0.38
			C	19.1	Range	79						
	1.581	mi^2	D	63.9	5/95 Range/Aspen	64						
	P_2		Slope (S)	Length (ft)	Manning's (n)							
t_{sheet}	1.6		0.17	300	0.16	=	0.25				t_c	0.93
$t_{shallow}$			0.08	11257		=	0.69				t_{lag}	0.56

Subbasin	Total Area		Hydrologic Group	Hydrologic Area	Average Cover	CN_{II}	CN_{II}	I_{aII}	CN_{I}	I_{aI}	CN_{III}	I_{aIII}
8	462.8	acre	B	447.3	Range	69	69.5	0.88	50.4	1.97	86.6	0.31
			C									
	0.723	mi^2	D	15.5	Range	84						
	P_2		Slope (S)	Length (ft)	Manning's (n)							
t_{sheet}	1.6		0.1	300	0.13	=	0.26				t_c	0.46
$t_{shallow}$			0.09	3515		=	0.20				t_{lag}	0.28

Subbasin	Total Area		Hydrologic Group	Hydrologic Area	Average Cover	CN_{II}	CN_{II}	I_{aII}	CN_{I}	I_{aI}	CN_{III}	I_{aIII}
9	2208.9	acre	B	1772.7	98/2 Range/Aspen	69	71.5	0.80	52.8	1.79	88.2	0.27
			C	53.6	Range	79						
	3.451	mi^2	D	382.6	90/10 Range/Aspen	82						
	P_2		Slope (S)	Length (ft)	Manning's (n)							
t_{sheet}	1.6		0.1	300	0.13	=	0.26				t_c	1.67
$t_{shallow}$			0.04	16335		=	1.41				t_{lag}	1.00

Subbasin	Total Area		Hydrologic Group	Hydrologic Area	Average Cover	CN_{II}	CN_{II}	I_{aII}	CN_{I}	I_{aI}	CN_{III}	I_{aIII}
10	39.3	acre	B	39.3	Range	69	69	0.90	49.8	2.02	86.2	0.32
			C									
	0.061	mi^2	D									
	P_2		Slope (S)	Length (ft)	Manning's (n)							
t_{sheet}	1.6		0.04	300	0.13	=	0.38				t_c	0.46
$t_{shallow}$			0.04	953.2		=	0.08				t_{lag}	0.27

Subbasin	Total Area		Hydrologic Group	Hydrologic Area	Average Cover	CN_{II}	CN_{II}	I_{aII}	CN_{I}	I_{aI}	CN_{III}	I_{aIII}
11	158.5	acre	B	136.4	Range	69	71.1	0.81	52.3	1.82	87.9	0.28
			C									
	0.248	mi^2	D	22.1	Range	84						
	P_2		Slope (S)	Length (ft)	Manning's (n)							
t_{sheet}	1.6		0.13	300	0.13	=	0.23				t_c	0.54
$t_{shallow}$			0.09	5396		=	0.31				t_{lag}	0.33

Subbasin	Total Area	Hydrologic Group	Hydrologic Area	Average Cover	CN_{II}	CN_{II}	I_{aII}	CN_{I}	I_{aI}	CN_{III}	I_{aIII}

12	65.4	acre	B	65.4	Range	69	69	0.90	49.8	2.02	86.2	0.32
			C									
	0.102	mi^2	D									
	P_2		**Slope (S)**	**Length (ft)**	**Manning's (n)**							
t_{sheet}	1.6		0.17	300	0.13	=	0.21				t_c	0.32
$t_{shallow}$			0.07	1662.6		=	0.11				t_{lag}	0.19

Subbasin	**Total Area**		**Hydrologic Group**	**Hydrologic Area**	**Average Cover**	**CN_{II}**	**CN_{II}**	**I_{aII}**	**CN_I**	**I_{aI}**	**CN_{III}**	**I_{aIII}**
13	524.4	acre	B	449.4	Range	69	71.1	0.81	52.4	1.82	87.9	0.27
			C									
	0.819	mi^2	D	75	Range	84						
	P_2		**Slope (S)**	**Length (ft)**	**Manning's (n)**							
t_{sheet}	1.6		0.23	300	0.13	=	0.19				t_c	0.88
$t_{shallow}$			0.06	9795.5		=	0.69				t_{lag}	0.53

Subbasin	**Total Area**		**Hydrologic Group**	**Hydrologic Area**	**Average Cover**	**CN_{II}**	**CN_{II}**	**I_{aII}**	**CN_I**	**I_{aI}**	**CN_{III}**	**I_{aIII}**
14	346.2	acre	B	235.2	Range	69	73.8	0.71	55.6	1.60	90.0	0.22
			C									
	0.541	mi^2	D	111	Range	84						
	P_2		**Slope (S)**	**Length (ft)**	**Manning's (n)**							
t_{sheet}	1.6		0.33	300	0.13	=	0.16				t_c	0.87
$t_{shallow}$			0.05	9163.7		=	0.71				t_{lag}	0.52

Subbasin	**Total Area**		**Hydrologic Group**	**Hydrologic Area**	**Average Cover**	**CN_{II}**	**CN_{II}**	**I_{aII}**	**CN_I**	**I_{aI}**	**CN_{III}**	**I_{aIII}**
15	68	acre	B	45.2	Range	69	74	0.70	55.8	1.58	90.2	0.22
			C									
	0.106	mi^2	D	22.8	Range	84						
	P_2		**Slope (S)**	**Length (ft)**	**Manning's (n)**							
t_{sheet}	1.6		0.1	300	0.13	=	0.26				t_c	0.43
$t_{shallow}$			0.04	1963.2		=	0.17				t_{lag}	0.26

Subbasin	**Total Area**		**Hydrologic Group**	**Hydrologic Area**	**Average Cover**	**CN_{II}**	**CN_{II}**	**I_{aII}**	**CN_I**	**I_{aI}**	**CN_{III}**	**I_{aIII}**
Hall Coulee	1120.2	acre	B	517.8	Range	69	73	0.74	54.6	1.66	89.4	0.24
			C									
	1.750	mi^2	D	548.4	Range	84						
	P_2		**Slope (S)**	**Length (ft)**	**Manning's (n)**							
t_{sheet}	1.6		0.02	300	0.13	=	0.50				t_c	1.97
$t_{shallow}$			0.02	12090		=	1.47				t_{lag}	1.18

Subbasin	**Total Area**		**Hydrologic Group**	**Hydrologic Area**	**Average Cover**	**CN_{II}**	**CN_{II}**	**I_{aII}**	**CN_I**	**I_{aI}**	**CN_{III}**	**I_{aIII}**
16	154.7	acre	B	154.7	Range	69	69	0.90	49.8	2.02	86.2	0.32
			C									
	0.242	mi^2	D									
	P_2		**Slope (S)**	**Length (ft)**	**Manning's (n)**							
t_{sheet}	1.6		0.1	300	0.13	=	0.26				t_c	0.56
$t_{shallow}$			0.03	2969.4		=	0.30				t_{lag}	0.33

Subbasin	**Total Area**		**Hydrologic Group**	**Hydrologic Area**	**Average Cover**	**CN_{II}**	**CN_{II}**	**I_{aII}**	**CN_I**	**I_{aI}**	**CN_{III}**	**I_{aIII}**
	720.6	acre	B	407.3	Range	69						

17			C	117.8	Range	79	74.7	0.68	56.6	1.53	90.8	0.20
	1.126	mi^2	D	195.5	Range	84						
	P_2		**Slope (S)**	**Length (ft)**	**Manning's (n)**							
t_{sheet}	1.6		0.03	300	0.13	=	0.42				t_c	1.31
$t_{shallow}$			0.05	11561.7		=	0.89				t_{lag}	0.79

Subbasin	Total Area		Hydrologic Group	Hydrologic Area	Average Cover	CN_{II}	CN_{II}	I_{aII}	CN_I	I_{aI}	CN_{III}	I_{aIII}
18	134.4	acre	B	127.8	Range	69	69.7	0.87	50.7	1.95	86.8	0.30
			C									
	0.210	mi^2	D	6.6	Range	84						
	P_2		**Slope (S)**	**Length (ft)**	**Manning's (n)**							
t_{sheet}	1.6		0.17	300	0.13	=	0.21				t_c	0.48
$t_{shallow}$			0.04	3113.2		=	0.27				t_{lag}	0.29

Subbasin	Total Area		Hydrologic Group	Hydrologic Area	Average Cover	CN_{II}	CN_{II}	I_{aII}	CN_I	I_{aI}	CN_{III}	I_{aIII}
19	237.5	acre	B	217.3	Range	69	70	0.86	51.1	1.92	87.0	0.30
			C	11	Range	79						
	0.371	mi^2	D	9.2	Range	84						
	P_2		**Slope (S)**	**Length (ft)**	**Manning's (n)**							
t_{sheet}	1.6		0.1	300	0.13	=	0.26				t_c	0.82
$t_{shallow}$			0.06	7936.9		=	0.56				t_{lag}	0.49

Subbasin	Total Area		Hydrologic Group	Hydrologic Area	Average Cover	CN_{II}	CN_{II}	I_{aII}	CN_I	I_{aI}	CN_{III}	I_{aIII}
20	63.2	acre	B	63.2	Range	69	69	0.90	49.8	2.02	86.2	0.32
			C									
	0.099	mi^2	D									
	P_2		**Slope (S)**	**Length (ft)**	**Manning's (n)**							
t_{sheet}	1.6		0.13	300	0.13	=	0.23				t_c	0.31
$t_{shallow}$			0.08	1233.6		=	0.08				t_{lag}	0.19

Subbasin	Total Area		Hydrologic Group	Hydrologic Area	Average Cover	CN_{II}	CN_{II}	I_{aII}	CN_I	I_{aI}	CN_{III}	I_{aIII}
21	407	acre	B	323.2	Range	69	71.4	0.80	52.6	1.80	88.1	0.27
			C	59.5	Range	79						
	0.636	mi^2	D	24.3	Range	84						
	P_2		**Slope (S)**	**Length (ft)**	**Manning's (n)**							
t_{sheet}	1.6		0.07	300	0.13	=	0.30				t_c	0.91
$t_{shallow}$			0.06	8649.7		=	0.61				t_{lag}	0.55

Subbasin	Total Area		Hydrologic Group	Hydrologic Area	Average Cover	CN_{II}	CN_{II}	I_{aII}	CN_I	I_{aI}	CN_{III}	I_{aIII}
22	29	acre	B	29	Range	69	69	0.90	49.8	2.02	86.2	0.32
			C									
	0.045	mi^2	D									
	P_2		**Slope (S)**	**Length (ft)**	**Manning's (n)**							
t_{sheet}	1.6		0.07	300	0.13	=	0.30				t_c	0.44
$t_{shallow}$			0.05	1783.6		=	0.14				t_{lag}	0.26

Subbasin	Total Area		Hydrologic Group	Hydrologic Area	Average Cover	CN_{II}	CN_{II}	I_{aII}	CN_I	I_{aI}	CN_{III}	I_{aIII}
23	277.1	acre	B	239.5	Range	69	70.5	0.83	51.7	1.87	87.4	0.29
			C	26.9	Range	79						

	0.433	mi^2	D	10.7	Range	84						
	P_2		Slope (S)	Length (ft)	Manning's (n)							
t_{sheet}	1.6		0.03	300	0.13	=	0.42				t_c	0.80
$t_{shallow}$			0.08	6142.3		=	0.37				t_{lag}	0.48

Subbasin	Total Area		Hydrologic Group	Hydrologic Area	Average Cover	CN_{II}	CN_{II}	I_{aII}	CN_I	I_{aI}	CN_{III}	I_{aIII}
24	38.5	acre	B	38.5	Range	69	69	0.90	49.8	2.02	86.2	0.32
			C									
	0.060	mi^2	D									
	P_2		Slope (S)	Length (ft)	Manning's (n)							
t_{sheet}	1.6		0.1	300	0.13	=	0.26				t_c	0.30
$t_{shallow}$			0.05	474.3		=	0.04				t_{lag}	0.18

Subbasin	Total Area		Hydrologic Group	Hydrologic Area	Average Cover	CN_{II}	CN_{II}	I_{aII}	CN_I	I_{aI}	CN_{III}	I_{aIII}
25	258.6	acre	B	214.2	Range	69	71.6	0.79	52.9	1.78	88.3	0.27
			C									
	0.404	mi^2	D	44.4	Range	84						
	P_2		Slope (S)	Length (ft)	Manning's (n)							
t_{sheet}	1.6		0.13	300	0.13	=	0.23				t_c	0.61
$t_{shallow}$			0.07	5765.2		=	0.38				t_{lag}	0.37

Subbasin	Total Area		Hydrologic Group	Hydrologic Area	Average Cover	CN_{II}	CN_{II}	I_{aII}	CN_I	I_{aI}	CN_{III}	I_{aIII}
26	117.4	acre	B	107.7	Range	69	70.2	0.85	51.3	1.90	87.2	0.29
			C									
	0.183	mi^2	D	9.7	Range	84						
	P_2		Slope (S)	Length (ft)	Manning's (n)							
t_{sheet}	1.6		0.03	300	0.13	=	0.42				t_c	0.67
$t_{shallow}$			0.1	4487.6		=	0.24				t_{lag}	0.40

Subbasin	Total Area		Hydrologic Group	Hydrologic Area	Average Cover	CN_{II}	CN_{II}	I_{aII}	CN_I	I_{aI}	CN_{III}	I_{aIII}
27	57.8	acre	B	56.8	Range	69	69.3	0.89	50.1	1.99	86.4	0.31
			C									
	0.090	mi^2	D	1	Range	84						
	P_2		Slope (S)	Length (ft)	Manning's (n)							
t_{sheet}	1.6		0.07	300	0.13	=	0.30				t_c	0.44
$t_{shallow}$			0.07	2187.9		=	0.14				t_{lag}	0.27

Subbasin	Total Area		Hydrologic Group	Hydrologic Area	Average Cover	CN_{II}	CN_{II}	I_{aII}	CN_I	I_{aI}	CN_{III}	I_{aIII}
28	242.5	acre	B	211.6	Range	69	70.9	0.82	52.1	1.84	87.7	0.28
			C									
	0.379	mi^2	D	30.9	Range	84						
	P_2		Slope (S)	Length (ft)	Manning's (n)							
t_{sheet}	1.6		0.03	300	0.13	=	0.42				t_c	0.73
$t_{shallow}$			0.09	5313.2		=	0.30				t_{lag}	0.44

Subbasin	Total Area		Hydrologic Group	Hydrologic Area	Average Cover	CN_{II}	CN_{II}	I_{aII}	CN_I	I_{aI}	CN_{III}	I_{aIII}
29	282.4	acre	B	282.4	Range	69	69	0.90	49.8	2.02	86.2	0.32
			C									
	0.441	mi^2	D									

	P_2		Slope (S)	Length (ft)	Manning's (n)							
t_{sheet}	1.6		0.03	300	0.13	=	0.42				t_c	0.65
$t_{shallow}$			0.1	4147.6		=	0.23				t_{lag}	0.39

Subbasin	Total Area		Hydrologic Group	Hydrologic Area	Average Cover	CN_{II}	CN_{II}	I_{aII}	CN_I	I_{aI}	CN_{III}	I_{aIII}
30	118.4	acre	B	118.4	Range	69	69	0.90	49.8	2.02	86.2	0.32
			C									
	0.185	mi^2	D									
	P_2		Slope (S)	Length (ft)	Manning's (n)							
t_{sheet}	1.6		0.33	300	0.13	=	0.16				t_c	0.35
$t_{shallow}$			0.09	3299.4		=	0.19				t_{lag}	0.21

Subbasin	Total Area		Hydrologic Group	Hydrologic Area	Average Cover	CN_{II}	CN_{II}	I_{aII}	CN_I	I_{aI}	CN_{III}	I_{aIII}
31	147.7	acre	B	114.8	Range	69	72.3	0.76	53.8	1.72	88.9	0.25
			C									
	0.231	mi^2	D	32.9	Range	84						
	P_2		Slope (S)	Length (ft)	Surface Description (N)							
t_{sheet}	1.6		0.4	300	0.13	=	0.15				t_c	0.39
$t_{shallow}$			0.08	3992.4		=	0.24				t_{lag}	0.24

Subbasin	Total Area		Hydrologic Group	Hydrologic Area	Average Cover	CN_{II}	CN_{II}	I_{aII}	CN_I	I_{aI}	CN_{III}	I_{aIII}
32	117.7	acre	B	117.7	Range	69	69	0.90	49.8	2.02	86.2	0.32
			C									
	0.184	mi^2	D									
	P_2		Slope (S)	Length (ft)	Manning's (n)							
t_{sheet}	1.6		0.03	300	0.13	=	0.42				t_c	0.62
$t_{shallow}$			0.11	3778.8		=	0.20				t_{lag}	0.37

Subbasin	Total Area		Hydrologic Group	Hydrologic Area	Average Cover	CN_{II}	CN_{II}	I_{aII}	CN_I	I_{aI}	CN_{III}	I_{aIII}
33	140.8	acre	B	140.8	Range	69	69	0.90	49.8	2.02	86.2	0.32
			C									
	0.220	mi^2	D									
	P_2		Slope (S)	Length (ft)	Manning's (n)							
t_{sheet}	1.6		0.13	300	0.13	=	0.23				t_c	0.48
$t_{shallow}$			0.06	3439.3		=	0.24				t_{lag}	0.29

Subbasin	Total Area		Hydrologic Group	Hydrologic Area	Average Cover	CN_{II}	CN_{II}	I_{aII}	CN_I	I_{aI}	CN_{III}	I_{aIII}
34	233.6	acre	B	233.6	Range	69	69	0.90	49.8	2.02	86.2	0.32
			C									
	0.365	mi^2	D									
	P_2		Slope (S)	Length (ft)	Manning's (n)							
t_{sheet}	1.6		0.03	300	0.13	=	0.42				t_c	0.78
$t_{shallow}$			0.07	5558.2		=	0.36				t_{lag}	0.47

Subbasin	Total Area		Hydrologic Group	Hydrologic Area	Average Cover	CN_{II}	CN_{II}	I_{aII}	CN_I	I_{aI}	CN_{III}	I_{aIII}
35	515	acre	B	503.2	Range	69	69.3	0.88	50.2	1.98	86.5	0.31
			C									
	0.805	mi^2	D	11.8	Range	84						

	P_2		Slope (S)	Length (ft)	Manning's (n)							
t_{sheet}	1.6		0.03	300	0.13	=	0.42				t_c	0.69
$t_{shallow}$			0.09	4679.4		=	0.27				t_{lag}	0.41

Subbasin	Total Area		Hydrologic Group	Hydrologic Area	Average Cover	CN_{II}	CN_{II}	I_{aII}	CN_I	I_{aI}	CN_{III}	I_{aIII}
36	515.5	acre	B	449.4	Range	69	70.9	0.82	52.1	1.84	87.7	0.28
			C									
	0.805	mi^2	D	66.1	Range	84						
	P_2		Slope (S)	Length (ft)	Manning's (n)							
t_{sheet}	1.6		0.27	300	0.13	=	0.18				t_c	1.52
$t_{shallow}$			0.03	13498.2		=	1.34				t_{lag}	0.91

Subbasin	Total Area		Hydrologic Group	Hydrologic Area	Average Cover	CN_{II}	CN_{II}	I_{aII}	CN_I	I_{aI}	CN_{III}	I_{aIII}
37	168	acre	B	148.1	Range	69	70.8	0.83	51.9	1.85	87.6	0.28
			C									
	0.263	mi^2	D	19.9	Range	84						
	P_2		Slope (S)	Length (ft)	Manning's (n)							
t_{sheet}	1.6		0.15	300	0.13	=	0.22				t_c	0.43
$t_{shallow}$			0.07	3167.5		=	0.21				t_{lag}	0.26

Subbasin	Total Area		Hydrologic Group	Hydrologic Area	Average Cover	CN_{II}	CN_{II}	I_{aII}	CN_I	I_{aI}	CN_{III}	I_{aIII}
38	544.9	acre	B	259.7	Range	69	76.9	0.60	59.2	1.38	92.1	0.17
			C									
	0.851	mi^2	D	285.2	Range	84						
	P_2		Slope (S)	Length (ft)	Manning's (n)							
t_{sheet}	1.6		0.01	300	0.13	=	0.65				t_c	1.61
$t_{shallow}$			0.03	9631.5		=	0.96				t_{lag}	0.97

Subbasin	Total Area		Hydrologic Group	Hydrologic Area	Average Cover	CN_{II}	CN_{II}	I_{aII}	CN_I	I_{aI}	CN_{III}	I_{aIII}
39	242.7	acre	B	35.7	Range	69	81.8	0.45	65.5	1.05	95.1	0.10
			C									
	0.379	mi^2	D	207	Range	84						
	P_2		Slope (S)	Length (ft)	Manning's (n)							
t_{sheet}	1.6		0.13	300	0.13	=	0.23				t_c	0.65
$t_{shallow}$			0.06	5899.5		=	0.41				t_{lag}	0.39

Subbasin	Total Area		Hydrologic Group	Hydrologic Area	Average Cover	CN_{II}	CN_{II}	I_{aII}	CN_I	I_{aI}	CN_{III}	I_{aIII}
40	247.3	acre	B	218.4	Range	69	70.8	0.83	51.9	1.85	87.6	0.28
			C									
	0.386	mi^2	D	28.9	Range	84						
	P_2		Slope (S)	Length (ft)	Manning's (n)							
t_{sheet}	1.6		0.1	300	0.13	=	0.26				t_c	0.48
$t_{shallow}$			0.09	3744.4		=	0.21				t_{lag}	0.29

SCS TR-55 Table 2-2c – Runoff curve numbers for other agricultural lands[1]

Cover description		Curve numbers for hydrologic soil group			
Cover type and hydrologic condition	Hydrologic condition	A	B	C	D
Pasture, grassland, or range – continuous forage for graving.[2]	Poor	68	79	86	89
	Fair	49	69	79	84
	Good	39	61	74	80
Meadow – continuous grass, protected from grazing and generally mowed for hay.	–	30	58	71	78
Brush – brush-weed mixture with brush the major element.[3]	Poor	48	67	77	83
	Fair	35	56	70	77
	Good	30[4]	48	65	73
Woods – grass combination (orchard or tree farm).[5]	Poor	57	73	82	86
	Fair	43	65	76	82
	Good	32	58	72	79
Woods.[6]	Poor	45	66	77	83
	Fair	36	60	73	79
	Good	30[4]	55	70	77
Farmsteads – buildings, lanes, driveways, and surrounding lots.	–	59	74	82	86

[1] Average runoff condition, and $I_a = 0.2S$.

[2] *Poor:* <50% ground cover or heavily grazed with no mulch.
Fair: 50 to 75% ground cover and not heavily grazed.
Good: >75% ground cover and lightly or only occasionally grazed.

[3] *Poor:* <50% ground cover.
Fair: 50 to 75% ground cover.
Good: >75% ground cover.

[4] Actual curve number is less than 30; use CN=30 for runoff computations.

[5] CN's shown were computed for areas with 50% woods and 50% grass (pasture) cover. Other combinations of conditions may be computed from the CN's for woods and pasture.

6 *Poor:* Forest litter, small trees, and brush are destroyed by heavy grazing or regular burning.
Fair: Woods are grazed but not burned, and some forest litter covers the soil.
Good: Woods are protected from grazing, and litter and brush adequately cover the soil.

SCS TR-55 Table 2-2d – Runoff curve numbers for arid and semiarid rangelands[1]

Cover description		Curve numbers for hydrologic soil group			
Cover type	Hydrologic condition[2]	A[3]	B	C	D
Herbaceous – mixture of grass, weeds, and low-growing brush, with brush the minor element.	Poor		80	87	93
	Fair		71	81	89
	Good		62	74	85
Oak-aspen – mountain brush mixture of oak brush, aspen, mountain mahogany, bitter brush, maple, and other brush	Poor		66	74	79
	Fair		48	57	63
	Good		30	41	48
Pinyon-juniper – pinyon, juniper, or both; grass understory.	Poor		75	85	89
	Fair		58	73	80
	Good		41	61	71
Sagebrush with grass understory.	Poor		67	80	85
	Fair		51	63	70
	Good		35	47	55
Desert shrub – major plants include saltbrush, greasewood, creosotebush, blackbrush, bursage, palo verde, mesquite, and cactus.	Poor	63	77	85	88
	Fair	55	72	81	86
	Good	49	68	79	84

[1] Average runoff condition, and $I_a = 0.2S$.

[2] *Poor:* <30% ground cover (litter, grass, and brush overstory).
Fair: 30 to 70% ground cover.
Good: >70% ground cover.

[3] Curve numbers for group A have been developed only for desert shrub.

Cross-Linking of Curve Numbers
For Various Antecedent Moisture Conditions[a]

Curve Number for Condition II	Corresponding Curve Number for Condition:	
	I	III
0	0	0
5	2	17
10	4	26
15	7	33
20	9	39
25	12	45
30	15	50
35	19	55
40	23	60
45	27	65
50	31	70
55	35	75
60	40	79
65	45	83
75	57	91
80	63	94
85	70	97
90	78	98
95	87	99
100	100	100

[a]Interpolate the values shown to obtain CNs not shown

Source: U.S. Soil Conservation Service (1972)

Sample Calc. <u>Subbasin 1</u>

Total Area = 3555.7 acre

Hydrologic soil group B = 3304.9 acre
D = 250.8 acre

Hydrologic soil group B has an average cover type of woods. Out of SCS TR-55 Table, woods with Fair condition CN = 60.

Hydrologic soil group D has an average cover type of 50% Herbaceous and 50% Aspen. Out of SCS TR-55 table Herbaceous with fair conditions CN = 89 and Aspen with fair conditions CN = 63. Hydrologic soil group D combined is equal to 50% 89 + 50% 63 = 76.

$$CN_{composite} = \frac{\Sigma A_i CN_i}{\Sigma A_i} \qquad CN_{composite} = \frac{3304.9(60) + 250.8(76)}{3555.7}$$

$$CN_{composite} = \underline{\underline{61.1}}$$

Initial Loss = I_a

$I_a = 0.2\,S$

Maximum Retention

$$S = \frac{1000 - 10\,CN}{CN}$$

$$I_a = 0.2\left(\frac{1000 - 10\,CN}{CN}\right) \qquad I_a = 0.2\left(\frac{1000 - 10(61.1)}{61.1}\right)$$

$$I_a = \underline{\underline{1.27\text{ in}}}$$

The above Curve Number and Initial Loss is for antecedent moisture condition II, CN_{II} and Ia_{II}.

CN_I = Dry Soil but not to the wilting point

CN_{II} = Average Conditions

CN_{III} = Saturated Soils; heavy rainfall or light rainfall with low temperatures have occurred in the last 5 days.

CN_I and CN_{III} must be interpolated from corresponding Curve Number table from (SCS 1972). With the corresponding CN the Initial loss can be calculated for moisture condition I and III.

The SCS Lag time $t_{lag} = 0.6\, t_c$

$t_c = t_{sheet} + t_{shallow}$

$$t_{sheet} = \frac{0.007\,(NL)^{0.8}}{(P_2)^{0.5}\, S^{0.4}}$$

N = Mannings roughness coefficient
L = flow Length
P_2 = 2year 24-hour rainfall depth in inches
S = slope of hydraulic grade line

L = 16340.6

Length for sheet flow is only good for the first 300 ft

S = 0.12 for the first 300 feet
N = 0.40 for woods with light underbrush
P_2 = 1.8 in

$$t_{sheet} = \frac{0.007\,(0.4(300))^{0.8}}{(1.8)^{0.5}\,(0.12)^{0.4}}$$

t_{sheet} = 0.56 hr

$$t_{shallow} = \frac{L}{16.1345\sqrt{S}}$$

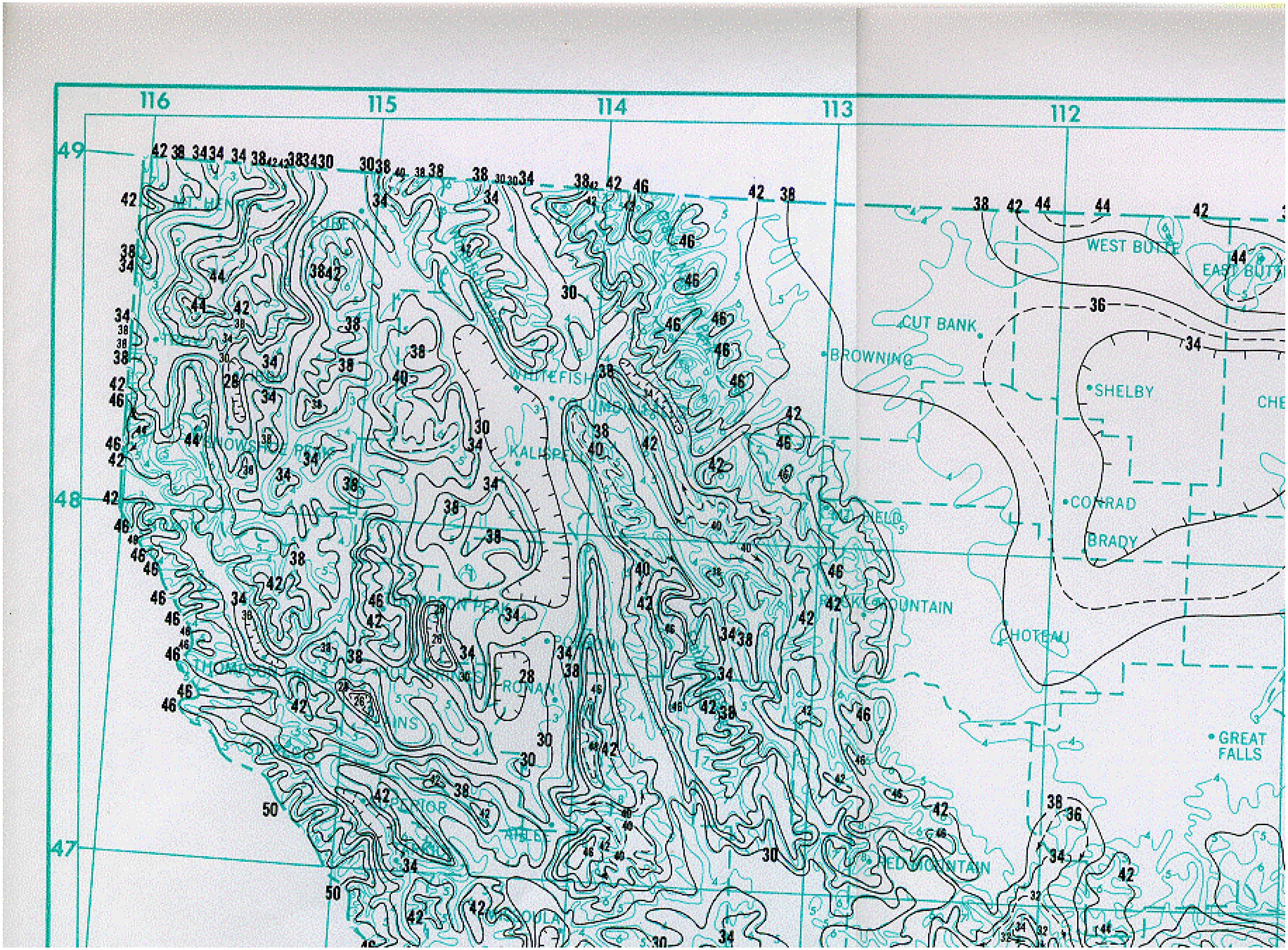
S = 0.04 for the remainder of the flow length

$$t_{shallow} = \frac{16040.6}{(3600)\,16.1345\sqrt{0.04}}$$

$t_{channel}$ = 1.38 hr

$t_c = 0.56 + 1.38 = 1.94$

$t_{Lag} = 0.6(1.94) = 1.16$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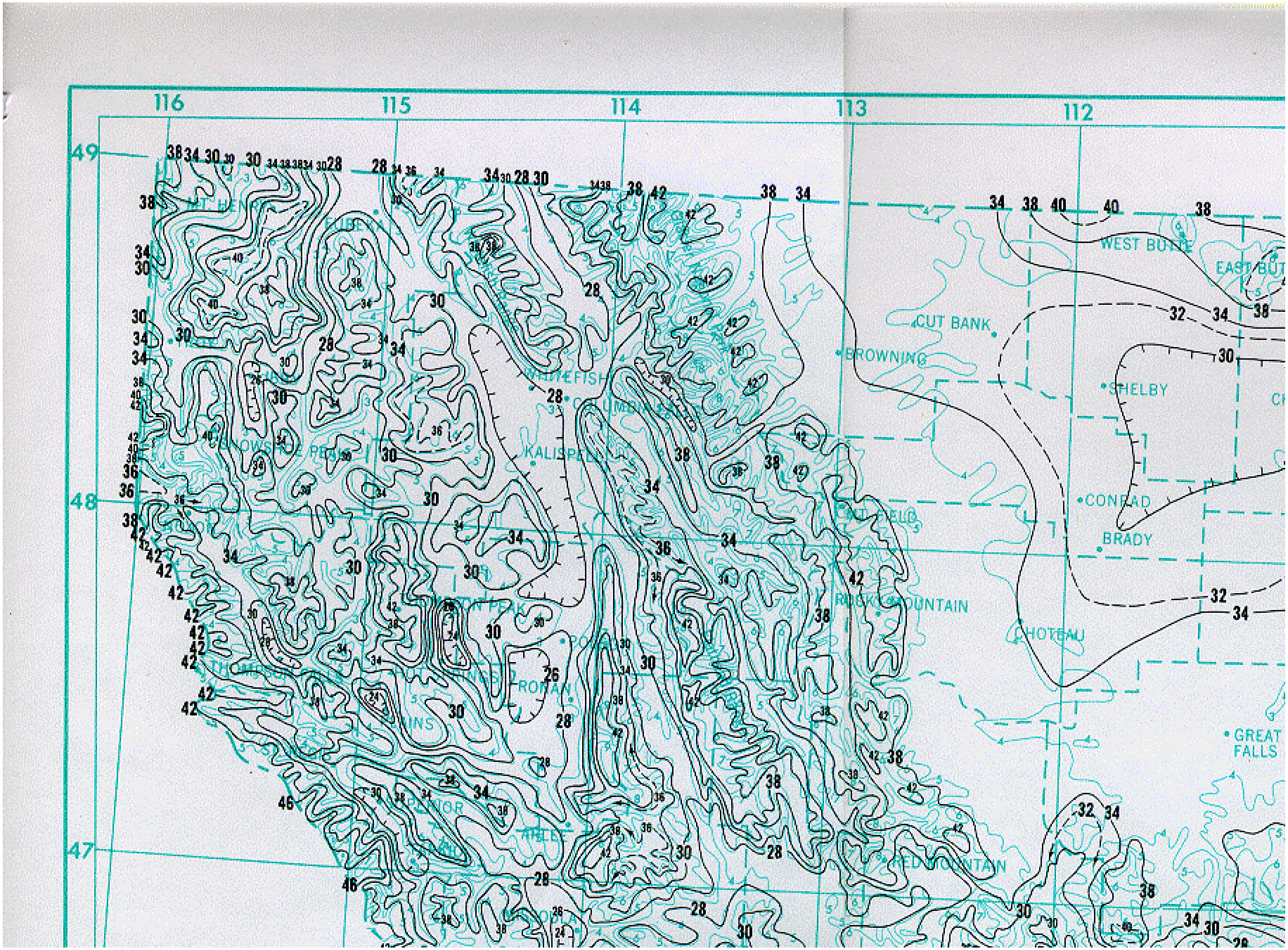
GREAT FALLS
WHITEFISH
KALISPELL
RONAN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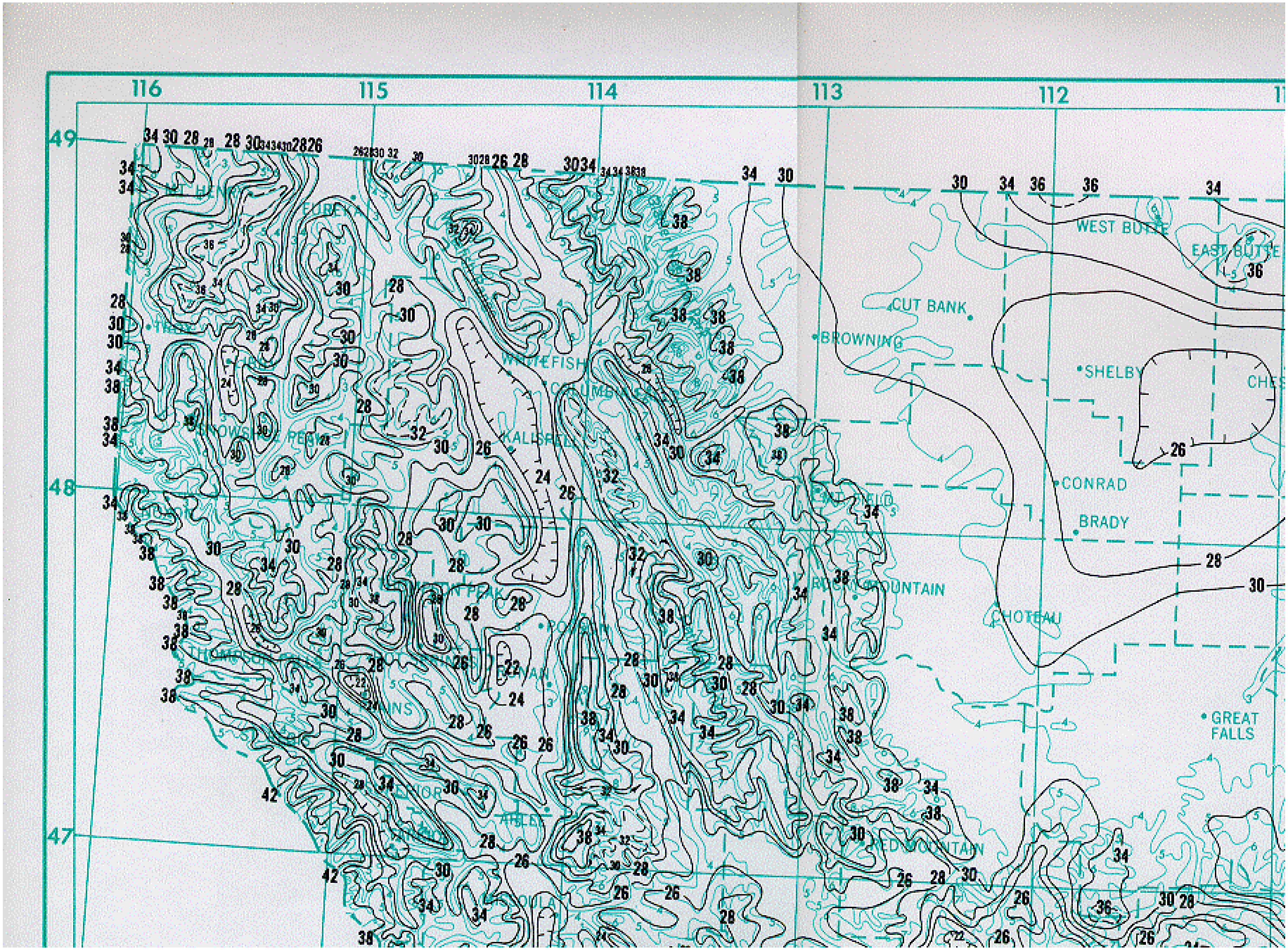
GREAT FALLS
RONAN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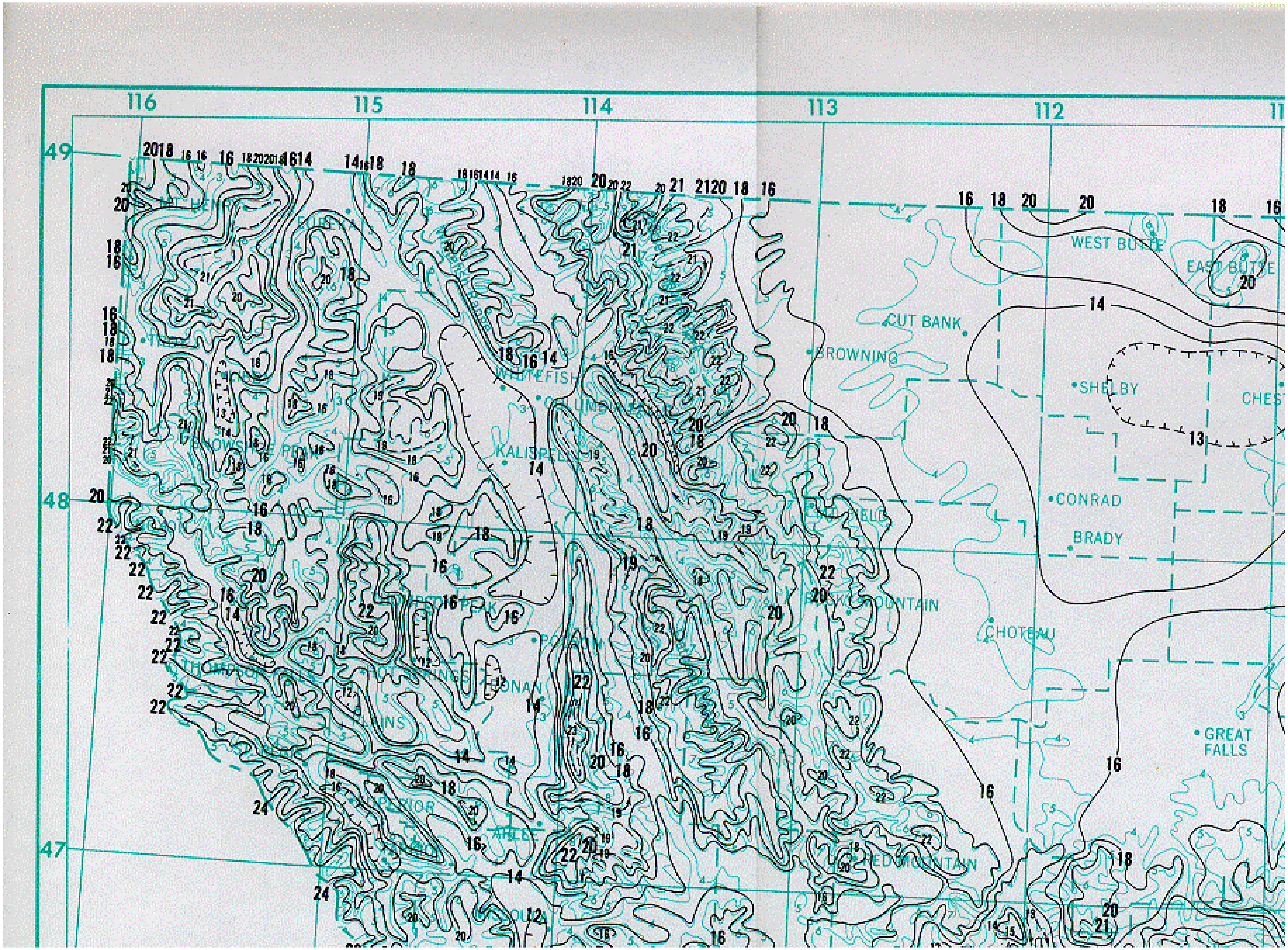
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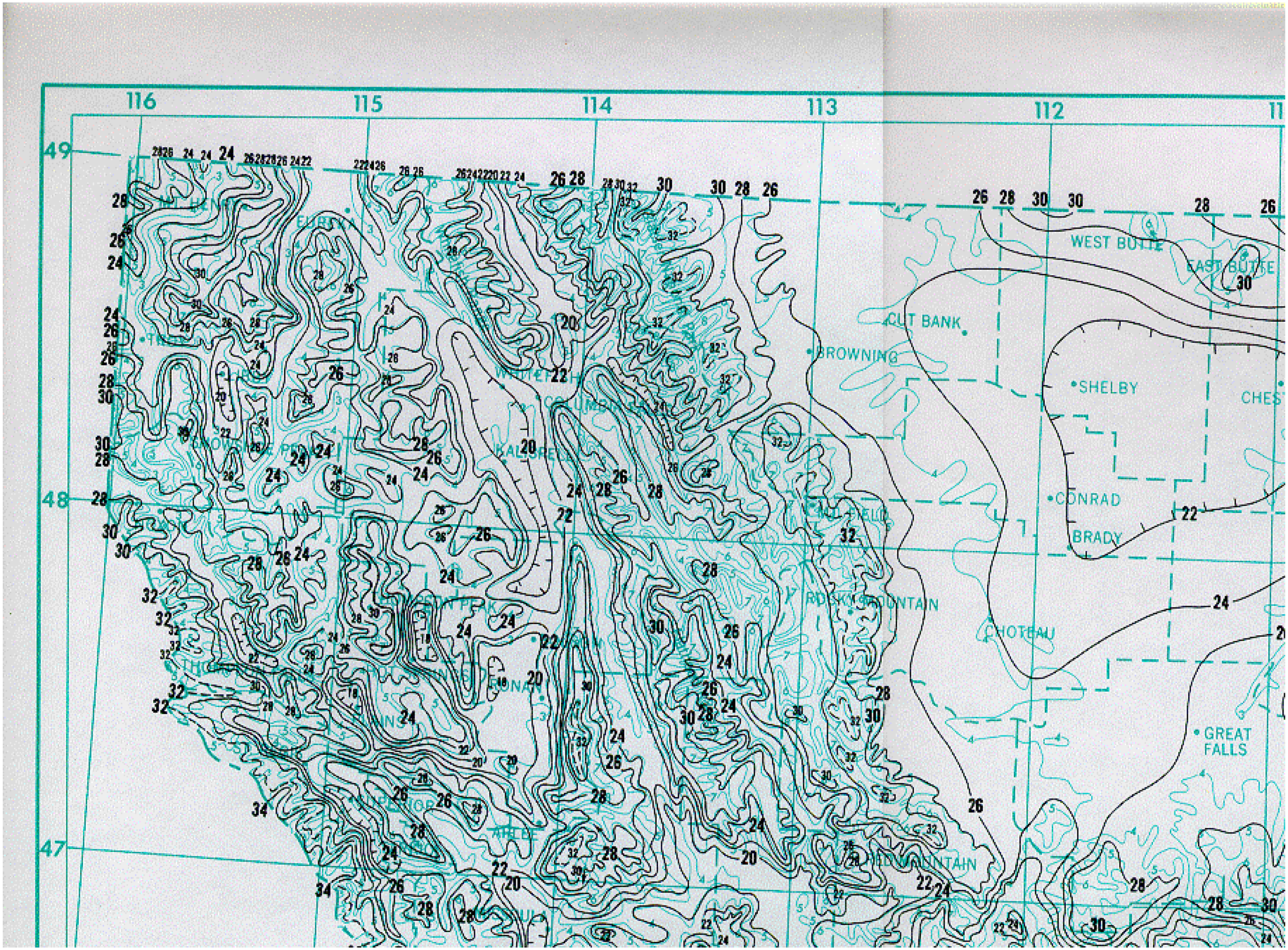
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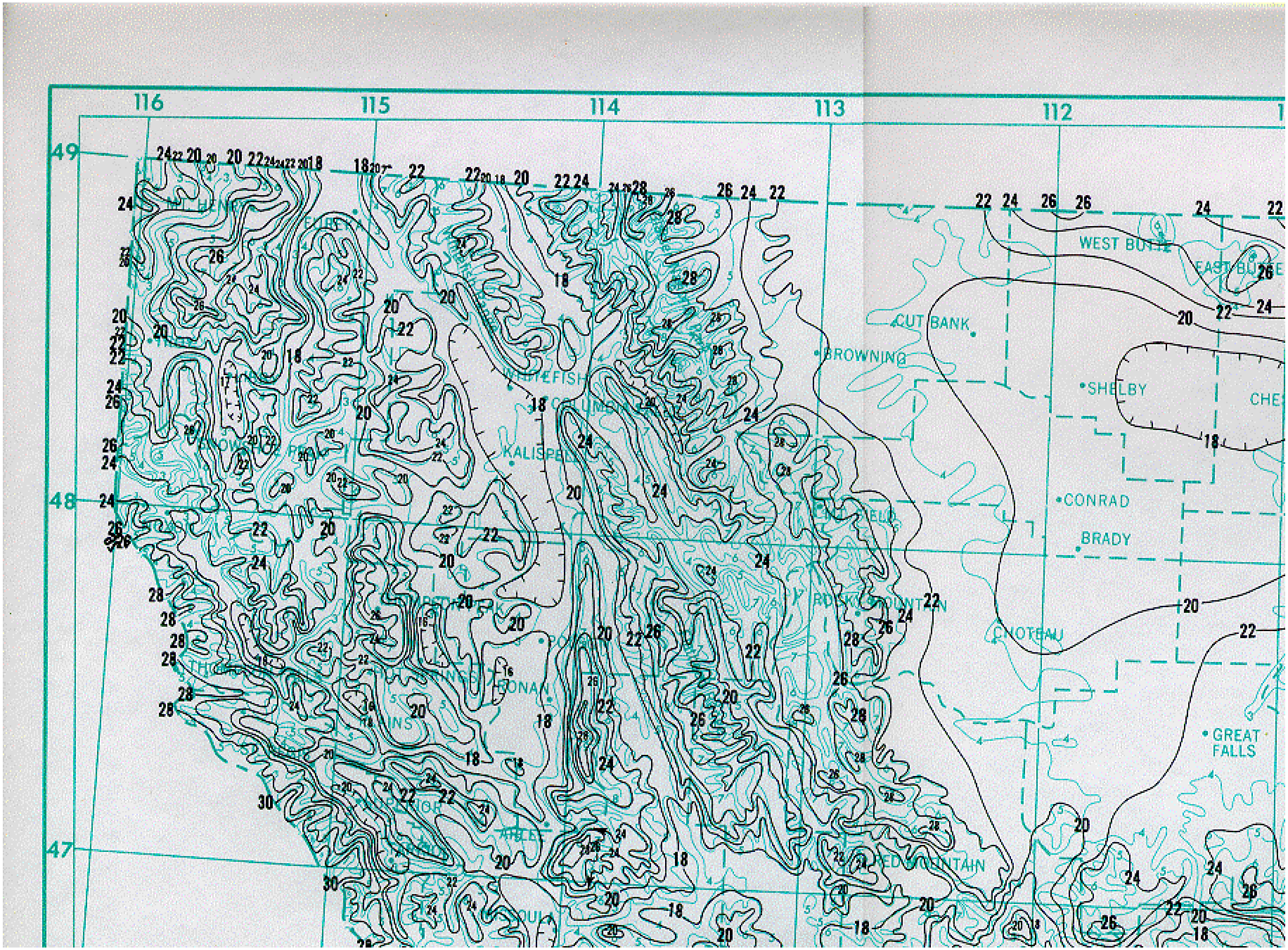
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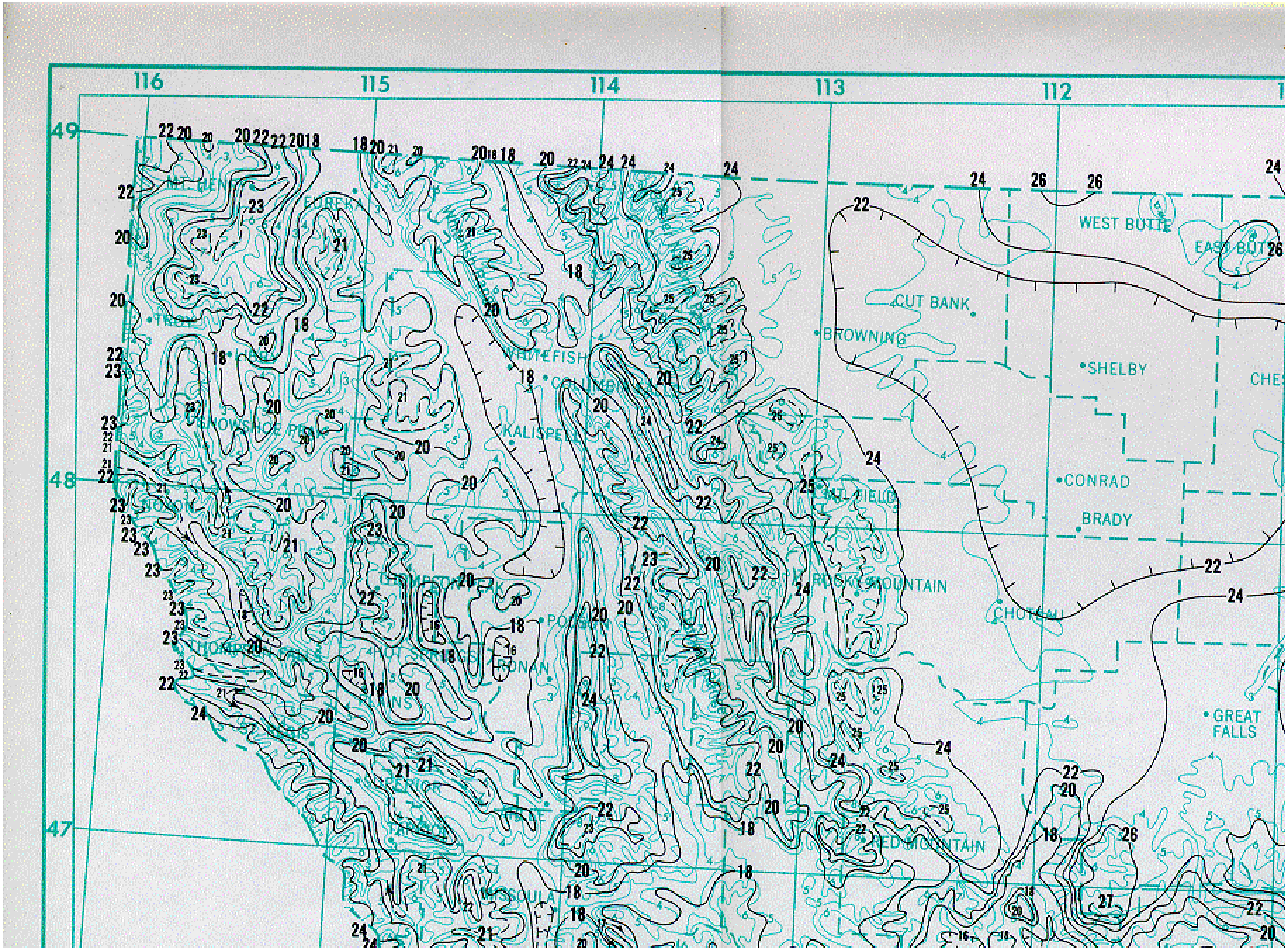
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EUREKA
TROY
LIBBY
WHITEFISH
COLUMBIA FALLS
KALISPELL
MT. FIELD
ROCKY MOUNTAIN
RED MOUNTAIN
POLSON
RONAN
THOMPSON FALLS
HOT SPRINGS
SUPERIOR
MISSOULA
SNOWSHOE PEAK

TABLE 2

DESIGN STORM RAINFALL DISTRIBUTION

(2 YR. - 2 HR. STORM)

5-MINUTE TIME INCREMENT	RAINFALL INCHES/5 MIN.	RAINFALL INTENSITY INCHES/HR.
1	0.003	0.04
2	0.020	0.24
3	0.183	2.20
4	0.092	1.10
5	0.071	0.85
6	0.057	0.68
7	0.045	0.54
8	0.037	0.44
9	0.028	0.34
10	0.023	0.28
11	0.018	0.22
12	0.017	0.20
13	0.016	0.19
14	0.015	0.18
15	0.014	0.17
16	0.013	0.16
17	0.012	0.14
18	0.011	0.13
19	0.010	0.12
20	0.009	0.11
21	0.008	0.10
22	0.007	0.08
23	0.006	0.07
24	0.005	0.06
TOTAL:	0.720 inches	

(10 YR. - 2 HR. STORM)

5-MINUTE TIME INCREMENT	RAINFALL INCHES	RAINFALL INTENSITY INCHES/HR.
1	0.004	0.05
2	0.028	0.34
3	0.308	3.70
4	0.159	1.91
5	0.121	1.45
6	0.083	1.00
7	0.074	0.89
8	0.060	0.72
9	0.050	0.60
10	0.042	0.50
11	0.034	0.41
12	0.031	0.37
13	0.028	0.34
14	0.025	0.30
15	0.021	0.25
16	0.019	0.23
17	0.017	0.20
18	0.015	0.18
19	0.013	0.16
20	0.011	0.13
21	0.009	0.11
22	0.007	0.08
23	0.006	0.07
24	0.005	0.06
TOTAL:	1.170 Inches	

(5 YR. - 2 HR. STORM)

5-MINUTE TIME INCREMENT	RAINFALL INCHES/5 MIN.	RAINFALL INTENSITY INCHES/HR.
1	0.003	0.04
2	0.014	0.17
3	0.242	2.90
4	0.125	1.50
5	0.099	1.19
6	0.081	0.97
7	0.063	0.76
8	0.051	0.61
9	0.041	0.49
10	0.035	0.42
11	0.030	0.36
12	0.027	0.32
13	0.023	0.28
14	0.020	0.24
15	0.019	0.23
16	0.017	0.20
17	0.016	0.19
18	0.014	0.17
19	0.012	0.14
20	0.011	0.13
21	0.009	0.11
22	0.007	0.08
23	0.006	0.07
24	0.005	0.06
TOTAL:	0.970 inches	

(100 YR. - 2 HR. STORM)

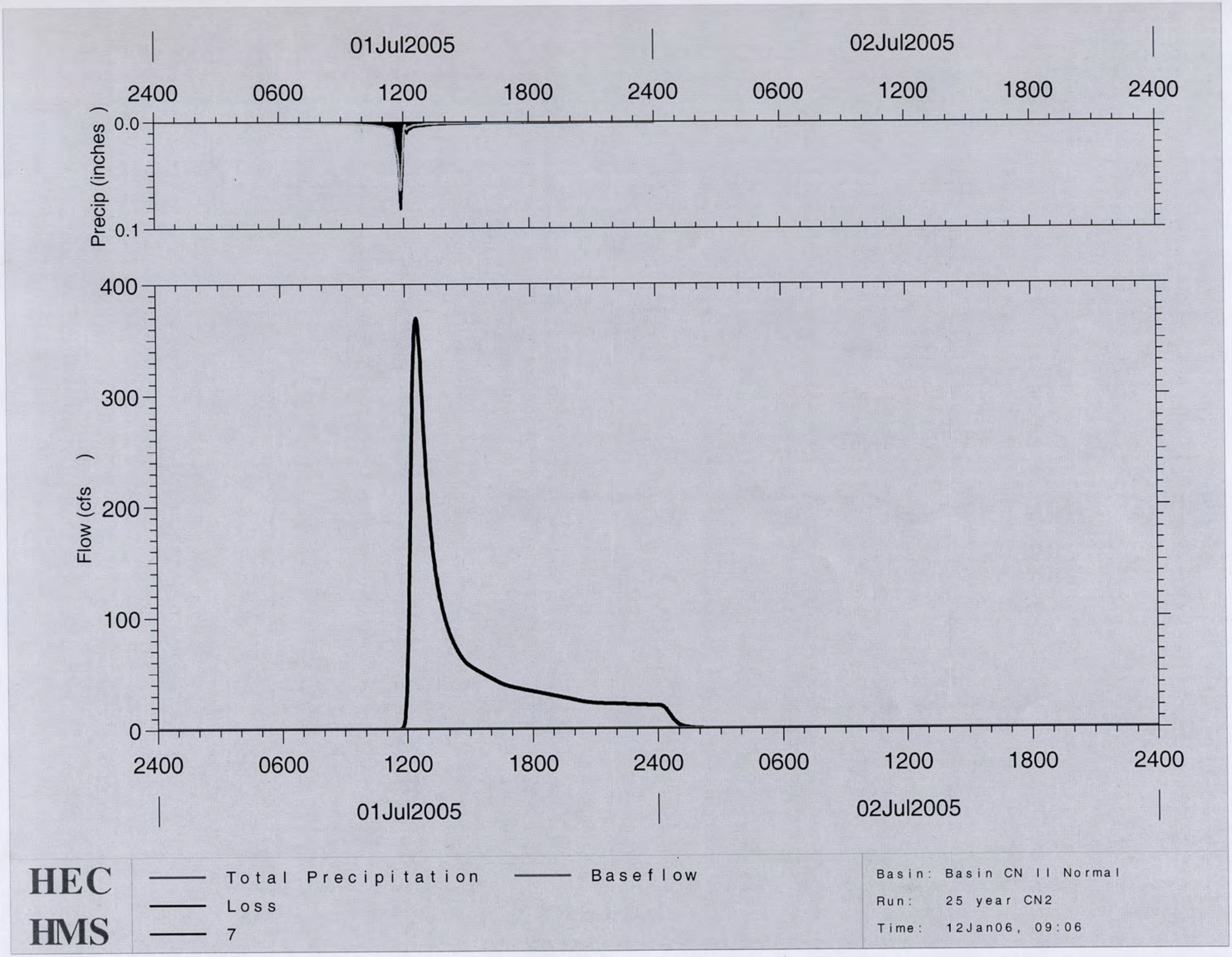
5-MINUTE TIME INCREMENT	RAINFALL INCHES	RAINFALL INTENSITY INCHES/HR.
1	0.007	0.08
2	0.020	0.24
3	0.508	6.10
4	0.242	2.90
5	0.201	2.41
6	0.165	1.98
7	0.131	1.57
8	0.108	1.30
9	0.084	1.01
10	0.070	0.84
11	0.059	0.71
12	0.049	0.59
13	0.043	0.52
14	0.037	0.44
15	0.031	0.37
16	0.027	0.32
17	0.023	0.28
18	0.021	0.25
19	0.020	0.24
20	0.019	0.23
21	0.018	0.22
22	0.017	0.20
23	0.016	0.19
24	0.015	0.18
TOTAL:	1.931 Inches	

Table A1 Summary of Subbasin Runoff Parameters Under Antecedent Moisture Condition I (Dry)

Subbasin	Total Area (acre)	Meteorological Event													
		100 Year 24 hr Storm		50 Year 24 hr Storm		25 Year 24 hr Storm		10 Year 24 hr Storm		5 Year 24 hr Storm		100 Year 2 hr Storm		24 hr Snowmelt	
		Discharge Peak (cfs)	Total Volume (ac ft)	Discharge Peak (cfs)	Total Volume (ac ft)	Discharge Peak (cfs)	Total Volume (ac ft)	Discharge Peak (cfs)	Total Volume (ac ft)	Discharge Peak (cfs)	Total Volume (ac ft)	Discharge Peak (cfs)	Total Volume (ac ft)	Discharge Peak (cfs)	Total Volume (ac ft)
1	3556	42.64	33.95	20.67	17.15	9.17	5.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	201	0.61	0.37	0.19	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Powel Creek	5546	53.97	49.40	27.77	24.29	11.83	7.70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	1685	32.62	24.93	17.14	14.48	7.98	6.67	1.26	0.47	0.00	0.00	0.00	0.00	0.00	0.00
4	300	76.41	10.92	40.95	7.68	16.01	4.93	2.55	1.84	0.76	0.57	0.00	0.00	4.41	0.77
5	836	9.65	7.31	4.43	3.57	1.99	1.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	214	6.33	3.08	2.45	1.77	1.01	0.80	0.18	0.05	0.00	0.00	0.00	0.00	0.00	0.00
7	1012	56.27	22.41	26.14	14.35	10.77	7.92	2.48	1.68	0.35	0.06	0.00	0.00	2.38	0.21
8	463	87.40	15.89	45.82	11.06	18.13	7.00	3.19	2.49	1.01	0.69	0.00	0.00	5.93	0.97
9	2209	275.53	94.19	175.78	67.91	97.85	45.22	27.00	18.87	8.59	7.17	0.13	0.01	32.79	9.07
10	39	6.79	1.26	3.39	0.87	1.28	0.54	0.23	0.18	0.07	0.04	0.00	0.00	0.44	0.07
11	159	37.64	6.51	22.06	4.67	10.55	3.09	1.99	1.26	0.56	0.46	0.00	0.00	2.78	0.59
12	65	14.60	2.11	7.12	1.45	2.26	0.90	0.39	0.30	0.13	0.08	0.00	0.00	0.76	0.11
13	524	92.20	21.58	55.82	15.48	28.49	10.23	6.34	4.17	1.86	1.52	0.00	0.00	8.63	1.95
14	346	94.30	18.43	62.24	13.71	36.29	9.55	10.41	4.52	3.01	2.10	2.12	0.17	8.55	2.51
15	68	30.32	3.68	19.83	2.75	11.25	1.92	2.76	0.92	0.67	0.43	0.60	0.04	1.84	0.52
Hall Coulee	1120	156.41	55.47	104.88	40.88	63.06	28.10	20.43	12.83	6.99	5.64	1.99	0.27	20.18	6.85
16	155	23.41	5.00	12.09	3.45	4.83	2.14	0.91	0.72	0.29	0.18	0.00	0.00	1.71	0.26
17	721	165.86	41.41	113.50	31.14	70.11	22.02	24.15	10.84	8.03	5.32	5.79	0.62	18.23	6.28
18	134	26.66	4.74	14.20	3.31	5.74	2.11	1.01	0.77	0.31	0.22	0.00	0.00	1.81	0.31
19	238	36.17	8.68	20.70	6.11	9.63	3.92	1.97	1.47	0.60	0.45	0.00	0.00	3.20	0.61
20	63	14.17	2.05	6.91	1.41	2.19	0.88	0.37	0.30	0.12	0.07	0.00	0.00	0.74	0.11
21	407	72.85	17.12	44.58	12.32	23.15	8.18	5.28	3.39	1.55	1.27	0.02	0.00	6.92	1.61
22	29	5.01	0.93	2.50	0.64	0.94	0.40	0.17	0.13	0.05	0.03	0.00	0.00	0.33	0.05
23	277	46.79	10.74	27.48	7.63	13.33	4.97	2.79	1.94	0.83	0.66	0.00	0.00	4.17	0.86
24	39	8.59	1.24	4.19	0.85	1.33	0.53	0.23	0.18	0.07	0.04	0.00	0.00	0.45	0.06
25	259	62.67	11.14	37.75	8.05	18.94	5.37	3.82	2.26	1.08	0.87	0.08	0.00	4.86	1.10
26	117	20.86	4.38	11.87	3.09	5.45	2.00	1.06	0.76	0.32	0.24	0.00	0.00	1.70	0.32
27	58	10.76	1.93	5.52	1.34	2.10	0.84	0.37	0.29	0.12	0.08	0.00	0.00	0.70	0.11
28	243	46.66	9.74	27.59	6.96	13.50	4.57	2.76	1.83	0.81	0.65	0.00	0.00	3.96	0.84
29	282	39.32	9.12	20.69	6.28	8.50	3.91	1.66	1.32	0.53	0.32	0.00	0.00	3.05	0.47
30	118	23.69	3.82	11.59	2.64	4.02	1.64	0.70	0.55	0.23	0.14	0.00	0.00	1.37	0.20
31	148	55.45	6.85	33.95	5.00	17.15	3.39	3.15	1.49	0.78	0.61	0.35	0.01	3.22	0.76
32	118	16.83	3.80	8.81	2.62	3.59	1.63	0.69	0.55	0.22	0.14	0.00	0.00	1.28	0.20
33	141	23.54	4.55	11.86	3.13	4.56	1.95	0.83	0.66	0.27	0.16	0.00	0.00	1.58	0.23
34	234	29.11	7.55	15.68	5.20	6.67	3.23	1.37	1.09	0.44	0.27	0.00	0.00	2.44	0.39
35	515	74.75	17.43	40.76	12.11	17.51	7.63	3.40	2.69	1.09	0.73	0.00	0.00	6.10	1.03
36	516	61.95	20.70	38.60	14.79	20.69	9.72	5.36	3.90	1.70	1.38	0.00	0.00	7.06	1.78
37	168	43.58	6.67	24.78	4.75	11.05	3.12	1.89	1.24	0.54	0.43	0.00	0.00	2.83	0.56
38	545	138.23	37.16	99.00	28.54	65.36	20.78	27.16	11.01	10.84	5.97	8.84	1.18	16.35	6.86
39	243	198.95	23.83	152.73	19.07	110.31	14.66	56.37	8.82	28.88	5.57	19.00	1.97	13.01	6.16
40	247	61.38	9.79	34.96	6.98	15.78	4.57	2.76	1.82	0.80	0.63	0.00	0.00	4.14	0.82
Totals	24354		641.84		439.55		275.67		109.60		45.23		4.28		55.58

Table A2 Summary of Subbasin Runoff Parameters Under Antecedent Moisture Condition III (Saturated)

Subbasin	Total Area (acre)	Meteorological Event													
		100 Year 24 hr Storm		50 Year 24 hr Storm		25 Year 24 hr Storm		10 Year 24 hr Storm		5 Year 24 hr Storm		100 Year 2 hr Storm		24 hr Snowmelt	
		Discharge Peak (cfs)	Total Volume (ac ft)	Discharge Peak (cfs)	Total Volume (ac ft)	Discharge Peak (cfs)	Total Volume (ac ft)	Discharge Peak (cfs)	Total Volume (ac ft)	Discharge Peak (cfs)	Total Volume (ac ft)	Discharge Peak (cfs)	Total Volume (ac ft)	Discharge Peak (cfs)	Total Volume (ac ft)
1	3556	2718.70	652.65	2296.60	554.87	1886.20	460.16	1301.40	325.51	939.86	242.26	808.03	134.10	306.06	258.20
2	201	147.70	31.33	122.20	26.24	97.72	21.36	63.60	14.55	43.24	10.44	35.52	5.29	14.87	11.22
Powel Creek	5546	2145.90	1006.30	1809.50	854.66	1483.70	707.85	1021.70	499.40	738.34	370.73	634.36	204.00	425.07	395.35
3	1685	988.80	331.59	842.18	283.76	699.00	237.21	493.31	170.52	364.74	128.86	326.41	73.90	156.10	136.87
4	300	920.99	70.38	804.10	61.22	687.85	52.21	515.77	39.06	403.76	30.63	253.73	19.08	40.55	32.26
5	836	1338.80	151.68	1131.10	128.82	928.96	106.69	640.17	75.27	461.55	55.88	312.24	30.75	81.02	59.59
6	214	574.99	41.82	491.49	35.76	409.55	29.87	291.29	21.43	216.93	16.17	119.24	9.23	22.65	17.18
7	1012	1537.60	214.40	1323.00	184.73	1111.60	155.71	803.86	113.81	608.41	87.35	473.54	51.88	114.74	92.46
8	463	1212.90	107.31	1056.50	93.24	901.44	79.39	672.38	59.22	523.76	46.31	351.45	28.67	61.19	48.81
9	2209	2549.10	539.63	2228.70	471.14	1910.10	403.58	1438.70	304.59	1131.70	240.79	1030.20	152.69	306.39	253.22
10	39	104.71	8.94	91.10	7.75	77.60	6.59	57.68	4.90	44.78	3.82	29.30	2.35	5.07	4.03
11	159	392.21	38.37	343.03	33.47	294.09	28.63	221.59	21.56	174.41	17.00	125.72	10.72	22.21	17.89
12	65	212.21	14.94	184.79	12.97	157.56	11.03	117.36	8.20	91.30	6.39	54.04	3.94	8.54	6.74
13	524	948.77	127.13	829.41	110.93	710.71	94.96	535.18	71.57	420.94	56.52	343.96	35.76	72.96	59.45
14	346	680.74	89.77	599.79	78.83	518.94	68.00	398.30	52.03	318.86	41.67	269.37	27.17	53.47	43.69
15	68	204.07	17.68	180.10	15.53	156.13	13.40	120.40	10.26	96.81	8.23	69.53	5.37	10.70	8.62
Hall Coulee	1120	1181.30	284.44	1037.20	249.25	893.67	214.46	680.44	163.30	540.79	130.15	508.43	84.02	163.81	136.62
16	155	363.47	35.45	315.87	30.76	268.69	26.16	199.46	19.45	154.67	15.17	107.91	9.34	20.03	16.00
17	721	1075.60	191.66	950.01	168.71	824.52	145.96	636.94	112.35	513.04	90.46	474.15	59.70	114.73	94.74
18	134	354.79	31.43	309.32	27.33	264.23	23.29	197.60	17.41	154.33	13.64	104.27	8.48	17.98	14.37
19	238	447.05	55.79	389.40	48.53	332.18	41.39	247.84	30.96	193.21	24.28	151.27	15.12	31.64	25.58
20	63	205.97	14.50	179.36	12.59	152.93	10.70	113.91	7.96	88.61	6.21	52.45	3.82	8.29	6.55
21	407	724.71	99.21	633.86	86.60	543.46	74.16	409.72	55.95	322.54	44.21	265.74	28.01	57.06	46.50
22	29	77.24	6.59	67.20	5.72	57.24	4.86	42.55	3.62	33.04	2.82	21.61	1.74	3.74	2.98
23	277	528.29	65.97	460.88	57.46	393.90	49.07	294.97	36.82	230.79	28.95	181.98	18.14	37.64	30.48
24	39	124.83	8.79	108.70	7.63	92.68	6.49	69.04	4.82	53.70	3.76	31.79	2.31	5.02	3.97
25	259	608.83	63.33	533.21	55.30	457.88	47.38	346.04	35.78	273.12	28.29	203.74	17.95	36.78	29.75
26	117	252.45	27.75	220.20	24.16	188.16	20.62	140.83	15.46	110.18	12.15	82.63	7.60	15.85	12.79
27	58	155.58	13.29	135.49	11.55	115.55	9.83	86.12	7.32	67.04	5.72	44.16	3.54	7.57	6.03
28	243	503.01	58.36	439.48	50.88	376.29	43.51	282.74	32.73	222.00	25.79	171.42	16.25	33.52	27.14
29	282	605.77	64.60	526.28	56.06	447.49	47.67	331.74	35.45	257.05	27.64	186.62	17.01	36.38	29.16
30	118	355.49	27.10	309.45	23.52	263.73	20.00	196.28	14.87	152.56	11.60	94.20	7.14	15.44	12.23
31	148	461.86	36.98	406.04	32.36	350.33	27.79	267.31	21.09	212.75	16.76	142.78	10.74	21.91	17.60
32	118	260.17	26.95	226.05	23.39	192.23	19.89	142.56	14.79	110.49	11.53	79.23	7.10	15.19	12.17
33	141	364.54	32.23	317.11	27.97	270.05	23.78	200.67	17.68	155.75	13.79	103.68	8.49	18.27	14.55
34	234	439.28	53.47	381.48	46.40	324.20	39.45	240.12	29.34	185.85	22.88	142.35	14.08	29.97	24.13
35	515	1057.00	119.19	919.31	103.54	782.76	88.14	581.80	65.72	452.03	51.37	337.99	31.78	67.31	54.16
36	516	625.05	123.95	545.56	108.07	466.64	92.41	349.98	69.51	274.27	54.78	245.67	34.50	69.98	57.65
37	168	471.11	40.40	412.13	35.21	353.41	30.11	266.36	22.63	209.57	17.83	141.57	11.22	23.38	18.77
38	545	720.42	150.81	639.08	133.26	557.63	115.84	435.50	90.01	354.48	73.10	343.67	49.15	91.91	76.41
39	243	655.22	73.62	587.52	65.65	519.58	57.70	417.14	45.83	348.48	37.98	320.62	26.70	48.54	39.53
40	247	668.02	59.29	583.97	51.68	500.64	44.18	377.20	33.22	296.68	26.17	203.83	16.47	34.28	27.54
Totals	24354		5209.06		4497.47		3801.48		2795.93		2160.05		1305.31		2282.96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0600
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1800
2400
0600
1200
1800
2400
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0.1
Flow (cfs)
400
300
200
100
0
HEC
HMS
Total Precipitation
Loss
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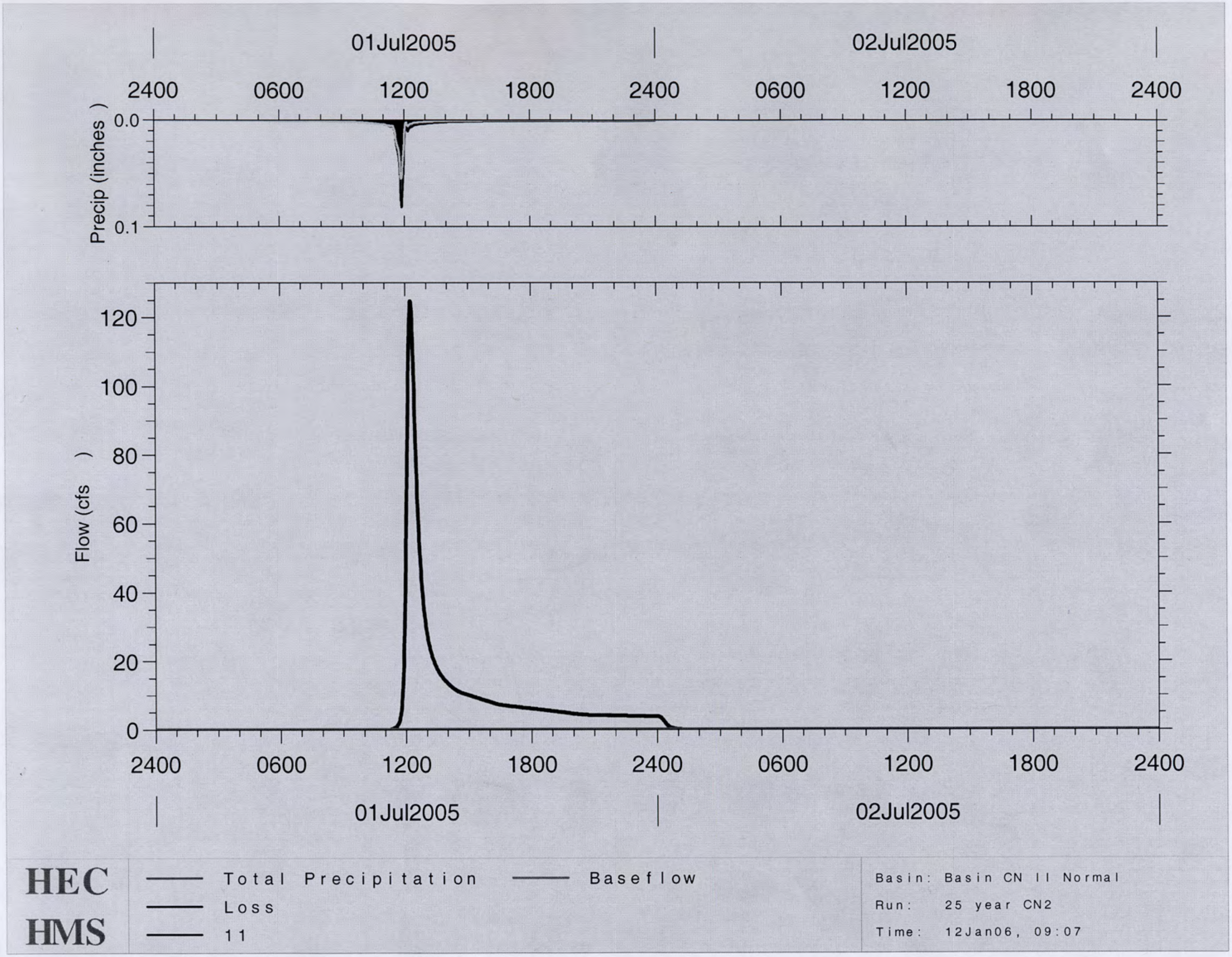
Baseflow
Basin: Basin CN II Normal
Run: 25 year CN2
Time: 12Jan06, 09:06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02Jul2005
2400
0600
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2400
0600
1200
1800
2400
Precip (inches)
0.0
0.1
Flow (cfs)
120
100
80
60
40
20
0
HEC
HMS
Total Precipitation
Loss
11
Baseflow
Basin: Basin CN II Normal
Run: 25 year CN2
Time: 12Jan06, 09:07

APPENDIX B

SUPPORT DATA AND ANALYSES FOR SEEPAGE LOSS DETERMINATIONS

ST. MARY DIVERSION CANAL SEEPAGE LOSSES ANALYSIS

The Mortiz formula (USBR, 1967) is an empirical equation that estimates seepage losses from earthen canals. The equation uses average seepage factors for various soil types based on field observations.

$$S = 0.2 \cdot C \cdot \sqrt{\frac{Q}{V}}$$

where
S = seepage loss in cfs per of canal, cfs
Q = canal discharge, cfs
V = mean flow velocity, fps
C = soil factor

Value of C	Type of Material
0.34	Cemented gravel and hardpan with sandy loam
0.41	Clay and clayey loam
0.66	Sandy loam
0.68	Volcanic ash
0.98	Volcanic ash with sand
1.20	Sand and volcanic ash or clay
1.68	Sandy soil with rock
2.20	Sandy and gravelly soil

"Current Operation"

Enter prism properties for each canal segment up to " i " segements $i := 1..6$ ORIGIN $\equiv 1$

Canal Segment. $N_i :=$	Reach Length, ft $L_i :=$	Canal Discharge,cfs $Q_i :=$	Flow Velocity, fps $V_i :=$	Soil Factor $C_i :=$
Dam_To_KC_Siphon	25060	720	2	2.2
KC_Siphon_To_PowellCr	6419	720	2	2.2
PowellCr_To_StM_Siphon	16010	720	2	1.5
StM_Siphon_To_Spider_Lake	10226	650	2	0.41
Spider_lake_To_Halls_Siphon	30098	650	2	0.41
Halls_Siphon_To_Drop_No_1	47818	650	2	0.41

$$S_i := 0.2 \cdot C_i \cdot \sqrt{\frac{Q_i}{V_i}} \qquad TS_i := 0.2 \cdot C_i \cdot \sqrt{\frac{Q_i}{V_i}} \cdot \frac{L_i}{5280}$$

Canal Segment. $N_i :=$	$S_i =$	$TS_i =$
Dam_To_KC_Siphon	8.3	39.6
KC_Siphon_To_PowellCr	8.3	10.1
PowellCr_To_StM_Siphon	5.7	17.3
StM_Siphon_To_Spider_Lake	1.5	2.9
Spider_lake_To_Halls_Siphon	1.5	8.4
Halls_Siphon_To_Drop_No_1	1.5	13.4

seepage loss, cfs per mile

Total seepage loss, cfs per segment

$$\sum_i TS_i = 91.7$$

$$\sum_{i=3}^{1} TS_i = 67.0 \qquad \sum_{i=6}^{4} TS_i = 24.7$$

ST. MARY DIVERSION CANAL SEEPAGE LOSSES ANALYSIS

The Mortiz formula (USBR, 1967) is an empirical equation that estimates seepage losses from earthen canals. The equation uses average seepage factors for various soil types based on field observations.

$$S = 0.2 \cdot C \cdot \sqrt{\frac{Q}{V}}$$

where
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0.66	Sandy loam
0.68	Volcanic ash
0.98	Volcanic ash with sand
1.20	Sand and volcanic ash or clay
1.68	Sandy soil with rock
2.20	Sandy and gravelly soil

"Find Q At N. Fork When Q = 850 cfs At Diversion Dam"

$Q_{N.Fork}$ = 751 cfs

Enter prism properties for each canal segment up to " i " segements $i := 1..6$ $ORIGIN \equiv 1$

Canal Segment. $N_i :=$	Reach Length, ft $L_i :=$	Canal Discharge,cfs $Q_i :=$	Flow Velocity, fps $V_i :=$	Soil Factor $C_i :=$
Dam_To_KC_Siphon	25060	850	2	2.2
KC_Siphon_To_PowellCr	6419	807	2	2.2
PowellCr_To_StM_Siphon	16010	796	2	1.5
StM_Siphon_To_Spider_Lake	10226	778	2	0.41
Spider_lake_To_Halls_Siphon	30098	775	2	0.41
Halls_Siphon_To_Drop_No_1	47818	766	2	0.41

$$S_i := 0.2 \cdot C_i \cdot \sqrt{\frac{Q_i}{V_i}} \qquad TS_i := 0.2 \cdot C_i \cdot \sqrt{\frac{Q_i}{V_i}} \cdot \frac{L_i}{5280}$$

Canal Segment. $N_i :=$	$S_i =$ seepage loss, cfs per mile	$TS_i =$ Total seepage loss, cfs per segment
Dam_To_KC_Siphon	9.1	43.1
KC_Siphon_To_PowellCr	8.8	10.7
PowellCr_To_StM_Siphon	6.0	18.1
StM_Siphon_To_Spider_Lake	1.6	3.1
Spider_lake_To_Halls_Siphon	1.6	9.2
Halls_Siphon_To_Drop_No_1	1.6	14.5

$$\sum_i TS_i = 98.8$$

$$\sum_{i=3}^{1} TS_i = 71.9 \qquad \sum_{i=6}^{4} TS_i = 26.9$$

$Q_{N.Fork}$ = 751 cfs

ST. MARY DIVERSION CANAL SEEPAGE LOSSES ANALYSIS

The Mortiz formula (USBR, 1967) is an empirical equation that estimates seepage losses from earthen canals. The equation uses average seepage factors for various soil types based on field observations.

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2.20	Sandy and gravelly soil

"Find Q At N. Fork When Q = 1000 cfs At Diversion Dam"

$Q_{N.Fork}$= 893 cfs

Enter prism properties for each canal segment up to " i " segements $i := 1..6$ ORIGIN ≡ 1

Canal Segment. $N_i :=$	Reach Length, ft $L_i :=$	Canal Discharge,cfs $Q_i :=$	Flow Velocity, fps $V_i :=$	Soil Factor $C_i :=$
Dam_To_KC_Siphon	25060	1000	2	2.2
KC_Siphon_To_PowellCr	6419	953	2	2.2
PowellCr_To_StM_Siphon	16010	941	2	1.5
StM_Siphon_To_Spider_Lake	10226	922	2	0.41
Spider_lake_To_Halls_Siphon	30098	918	2	0.41
Halls_Siphon_To_Drop_No_1	47818	908	2	0.41

$$S_i := 0.2 \cdot C_i \cdot \sqrt{\frac{Q_i}{V_i}}$$

$$TS_i := 0.2 \cdot C_i \cdot \sqrt{\frac{Q_i}{V_i}} \cdot \frac{L_i}{5280}$$

Canal Segment. $N_i :=$	$S_i =$	$TS_i =$
Dam_To_KC_Siphon	9.8	46.7
KC_Siphon_To_PowellCr	9.6	11.7
PowellCr_To_StM_Siphon	6.5	19.7
StM_Siphon_To_Spider_Lake	1.8	3.4
Spider_lake_To_Halls_Siphon	1.8	10.0
Halls_Siphon_To_Drop_No_1	1.7	15.8

S_i: seepage loss, cfs per mile

TS_i: Total seepage loss, cfs per segment

$$\sum_i TS_i = 107.4$$

$$\sum_{i=3}^{1} TS_i = 78.1 \qquad \sum_{i=6}^{4} TS_i = 29.2$$

$Q_{N.Fork}$= 893 cfs

ST. MARY DIVERSION CANAL SEEPAGE LOSSES ANALYSIS

The Mortiz formula (USBR, 1967) is an empirical equation that estimates seepage losses from earthen canals. The equation uses average seepage factors for various soil types based on field observations.

$$S = 0.2 \cdot C \cdot \sqrt{\frac{Q}{V}}$$

where
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0.98	Volcanic ash with sand
1.20	Sand and volcanic ash or clay
1.68	Sandy soil with rock
2.20	Sandy and gravelly soil

"Find Q At Dam To Get 850 cfs Into North Fork of Milk"

$Q_{N.Fork}$= 955 cfs

Enter prism properties for each canal segment up to " i " segements $i := 1..6$ ORIGIN ≡ 1

Canal Segment. $N_i :=$	Reach Length, ft $L_i :=$	Canal Discharge,cfs $Q_i :=$	Flow Velocity, fps $V_i :=$	Soil Factor $C_i :=$
Dam_To_KC_Siphon	25060	955	2	2.2
KC_Siphon_To_PowellCr	6419	909	2	2.2
PowellCr_To_StM_Siphon	16010	898	2	1.5
StM_Siphon_To_Spider_Lake	10226	879	2	0.41
Spider_lake_To_Halls_Siphon	30098	875	2	0.41
Halls_Siphon_To_Drop_No_1	47818	866	2	0.41

$$S_i := 0.2 \cdot C_i \cdot \sqrt{\frac{Q_i}{V_i}} \qquad TS_i := 0.2 \cdot C_i \cdot \sqrt{\frac{Q_i}{V_i}} \cdot \frac{L_i}{5280}$$

Canal Segment. $N_i :=$	$S_i =$ seepage loss, cfs per mile	$TS_i =$ Total seepage loss, cfs per segment
Dam_To_KC_Siphon	9.6	45.6
KC_Siphon_To_PowellCr	9.4	11.4
PowellCr_To_StM_Siphon	6.4	19.3
StM_Siphon_To_Spider_Lake	1.7	3.3
Spider_lake_To_Halls_Siphon	1.7	9.8
Halls_Siphon_To_Drop_No_1	1.7	15.5

$$\sum_i TS_i = 104.9$$

$$\sum_{i=3}^{1} TS_i = 76.3 \qquad \sum_{i=6}^{4} TS_i = 28.6$$

$Q_{N.Fork}$= 955 cfs

ST. MARY DIVERSION CANAL SEEPAGE LOSSES ANALYSIS

The Mortiz formula (USBR, 1967) is an empirical equation that estimates seepage losses from earthen canals. The equation uses average seepage factors for various soil types based on field observations.

$$S = 0.2 \cdot C \cdot \sqrt{\frac{Q}{V}}$$

where
S = seepage loss in cfs per of canal, cfs
Q = canal discharge, cfs
V = mean flow velocity, fps
C = soil factor

Value of C	Type of Material
0.34	Cemented gravel and hardpan with sandy loam
0.41	Clay and clayey loam
0.66	Sandy loam
0.68	Volcanic ash
0.98	Volcanic ash with sand
1.20	Sand and volcanic ash or clay
1.68	Sandy soil with rock
2.20	Sandy and gravelly soil

"Find Q At Dam To Get 1000 cfs Into North Fork of Milk"

Q_{Dam}= 1113 cfs

Enter prism properties for each canal segment up to " i " segements $i := 1..6$ $ORIGIN \equiv 1$

Canal Segment. $N_i :=$	Reach Length, ft $L_i :=$	Canal Discharge,cfs $Q_i :=$	Flow Velocity, fps $V_i :=$	Soil Factor $C_i :=$
Dam_To_KC_Siphon	25060	1113	2	2.2
KC_Siphon_To_PowellCr	6419	1064	2	2.2
PowellCr_To_StM_Siphon	16010	1052	2	1.5
StM_Siphon_To_Spider_Lake	10226	1031	2	0.41
Spider_lake_To_Halls_Siphon	30098	1027	2	0.41
Halls_Siphon_To_Drop_No_1	47818	1017	2	0.41

$$S_i := 0.2 \cdot C_i \cdot \sqrt{\frac{Q_i}{V_i}}$$

$$TS_i := 0.2 \cdot C_i \cdot \sqrt{\frac{Q_i}{V_i}} \cdot \frac{L_i}{5280}$$

Canal Segment. $N_i :=$	$S_i =$ (seepage loss, cfs per mile)	$TS_i =$ (Total seepage loss, cfs per segment)
Dam_To_KC_Siphon	10.4	49.3
KC_Siphon_To_PowellCr	10.1	12.3
PowellCr_To_StM_Siphon	6.9	20.9
StM_Siphon_To_Spider_Lake	1.9	3.6
Spider_lake_To_Halls_Siphon	1.9	10.6
Halls_Siphon_To_Drop_No_1	1.8	16.7

$$\sum_i TS_i = 113.4$$

$$\sum_{i=3}^{1} TS_i = 82.5 \qquad \sum_{i=6}^{4} TS_i = 30.9$$

Q_{Dam}= 1113 cfs

Comparison of Flows Between Diversion Dam, St. Mary Siphon, & Drop No. 1 for 1930

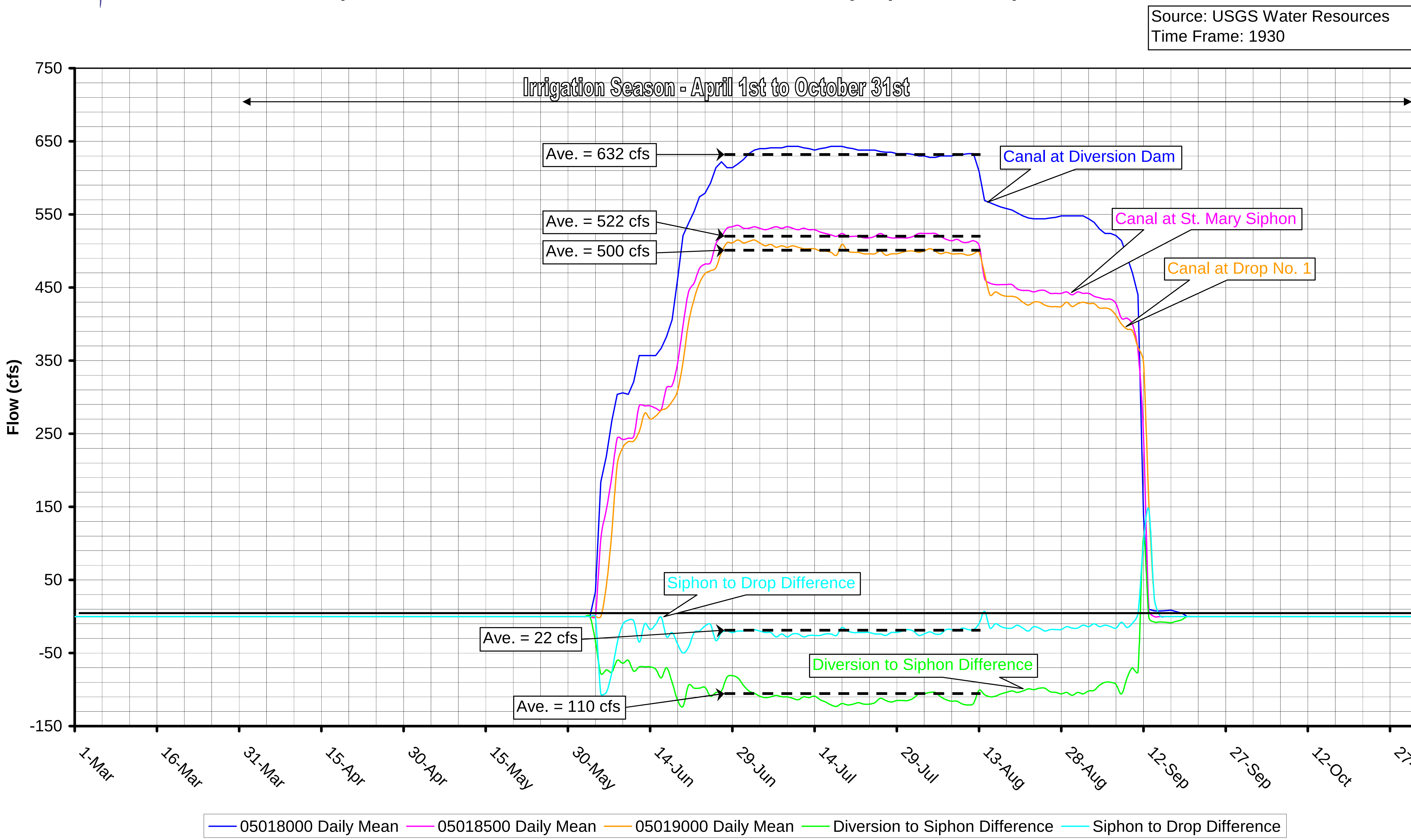

Figure B1

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Engineering Consultants

Comparison of Flows Between Diversion Dam, St. Mary Siphon, & Drop No. 1 for 1934

Source: USGS Water Resources
Time Frame: 1934

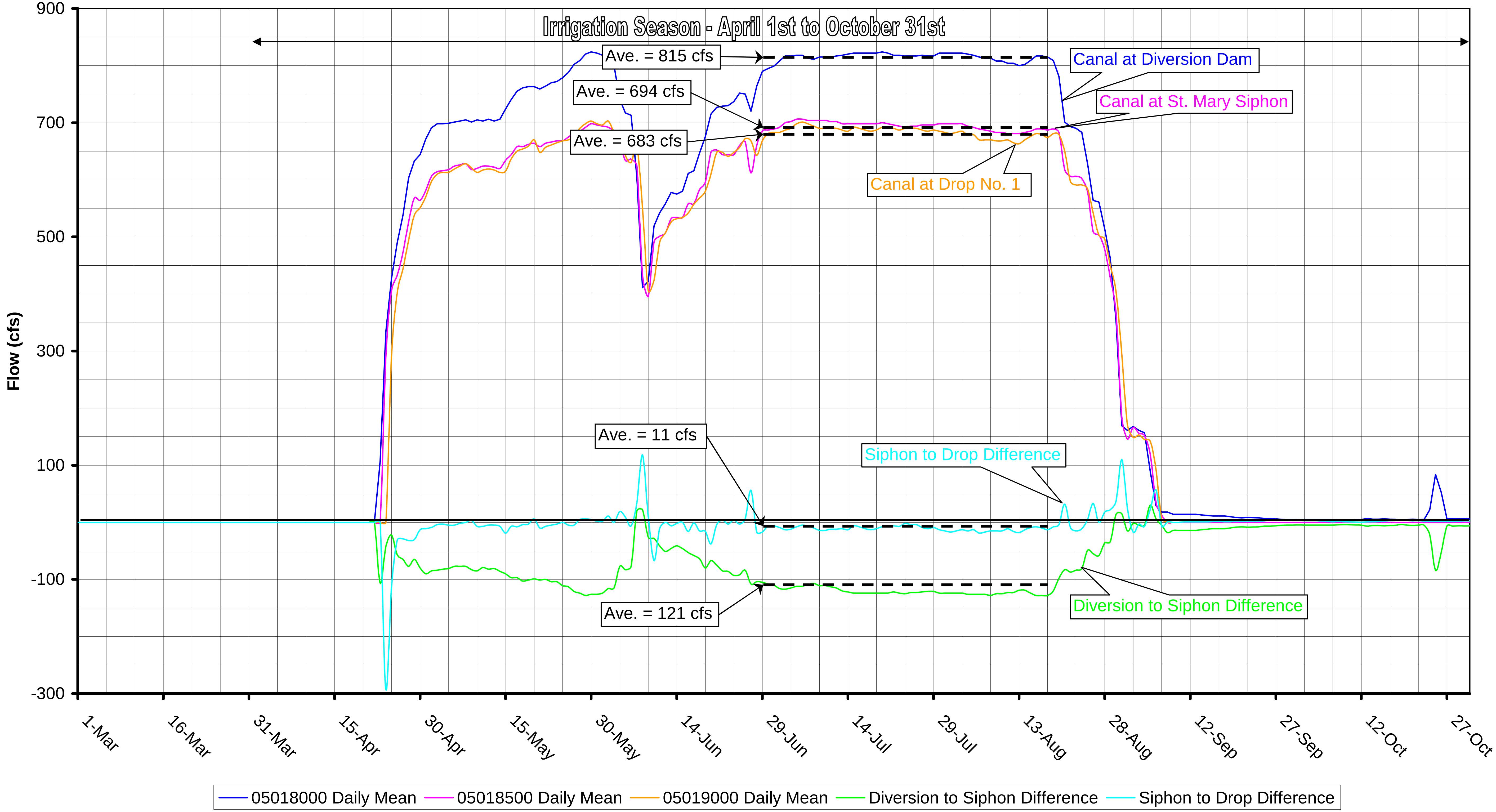

Figure B2

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Comparison of Flows Between Diversion Dam, St. Mary Siphon, & Drop No. 1 for 1946

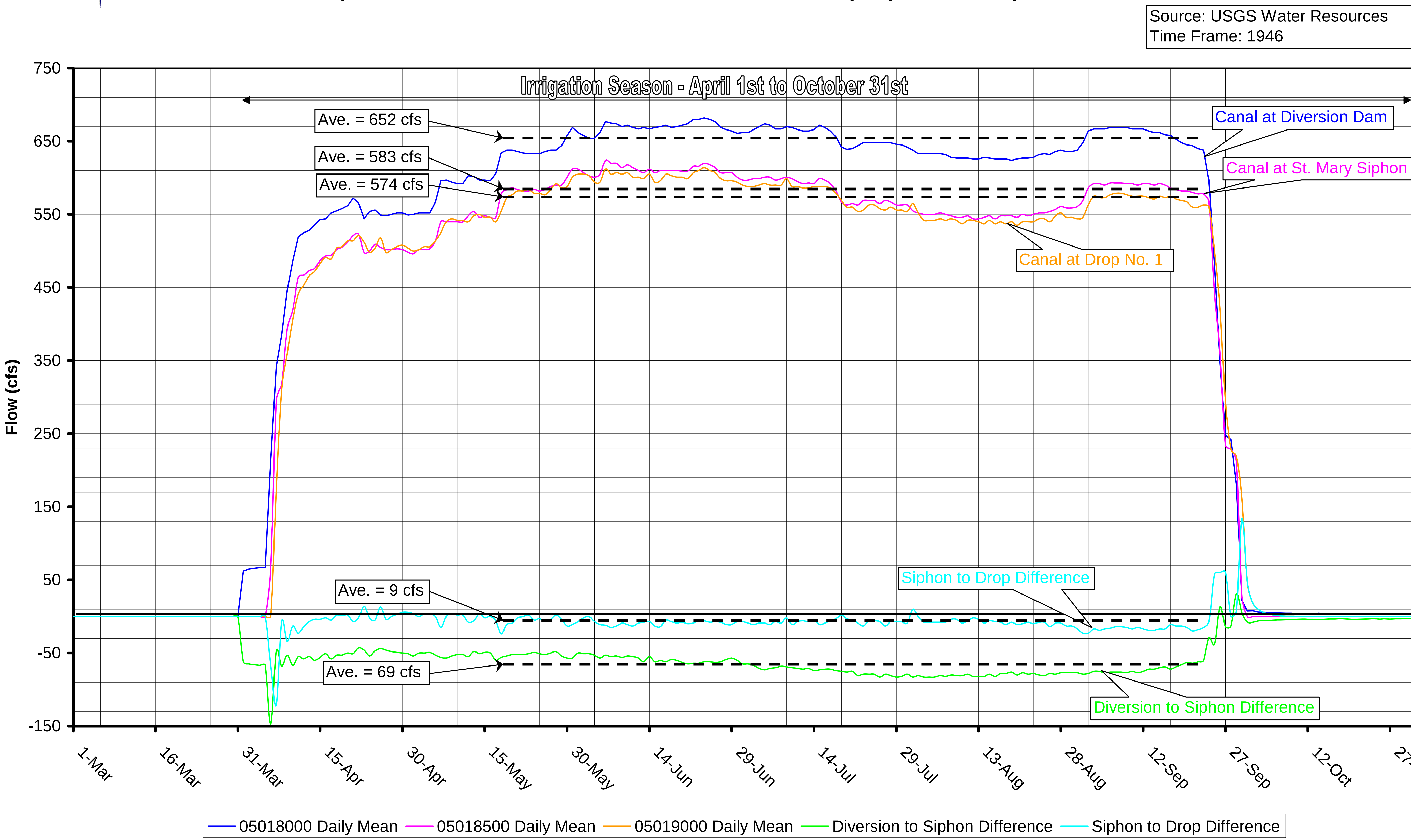
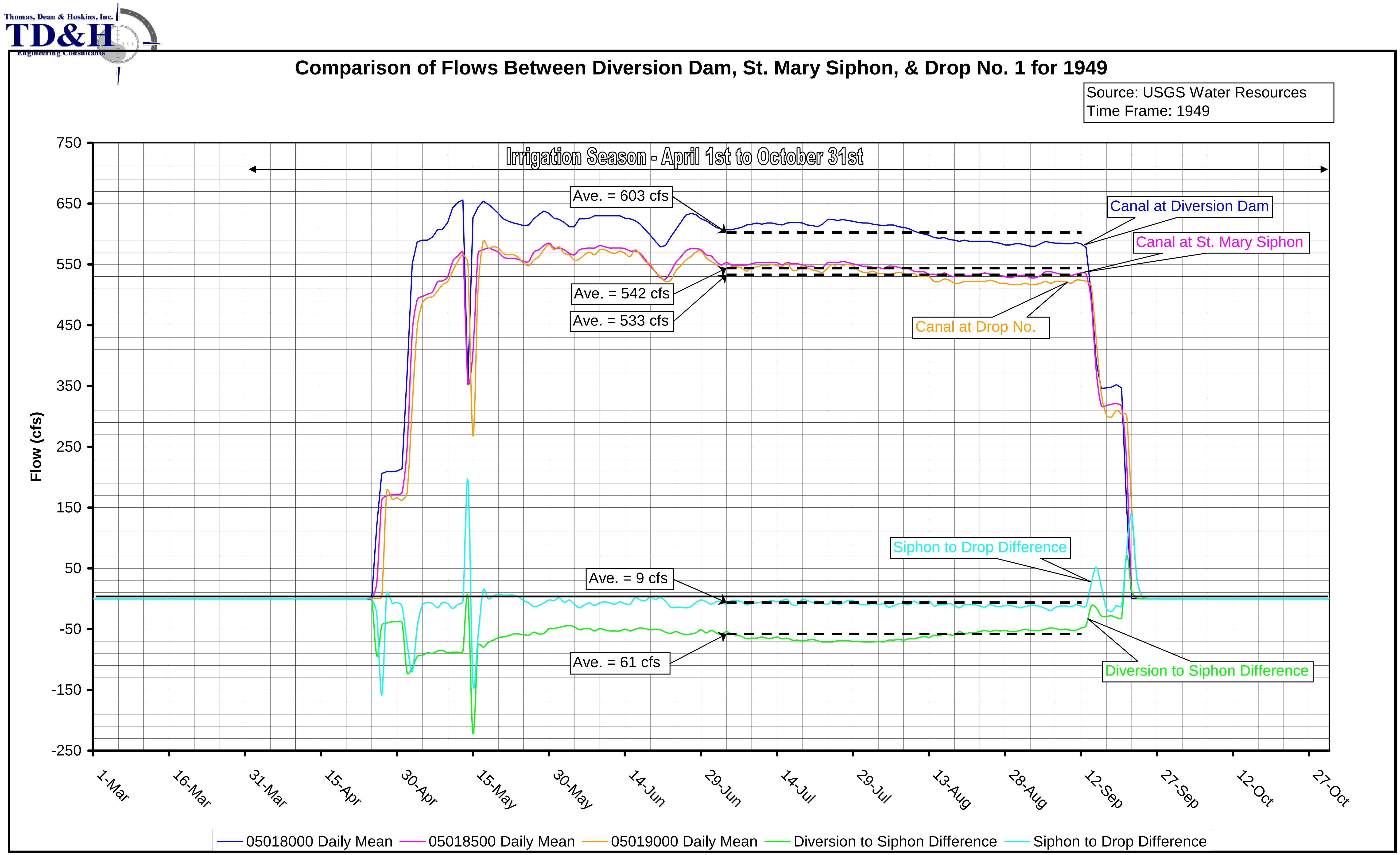


Figure B3



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Comparison of Flows Between Diversion Dam, St. Mary Siphon, & Drop No. 1 for 1949
Source: USGS Water Resources
Time Frame: 1949
Irrigation Season - April 1st to October 31st
Ave. = 603 cfs
Ave. = 542 cfs
Ave. = 533 cfs
Ave. = 9 cfs
Ave. = 61 cfs
Canal at Diversion Dam
Canal at St. Mary Siphon
Canal at Drop No.
Siphon to Drop Difference
Diversion to Siphon Difference
Flow (cfs)
750
650
550
450
350
250
150
50
-50
-150
-250
1-Mar
16-Mar
31-Mar
15-Apr
30-Apr
15-May
30-May
14-Jun
29-Jun
14-Jul
29-Jul
13-Aug
28-Aug
12-Sep
27-Sep
12-Oct
27-Oct
05018000 Daily Mean
05018500 Daily Mean
05019000 Daily Mean
Diversion to Siphon Difference
Siphon to Drop Difference

Figure B4

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Comparison of Flows Between St. Mary Siphon & Drop No. 1 for 1963

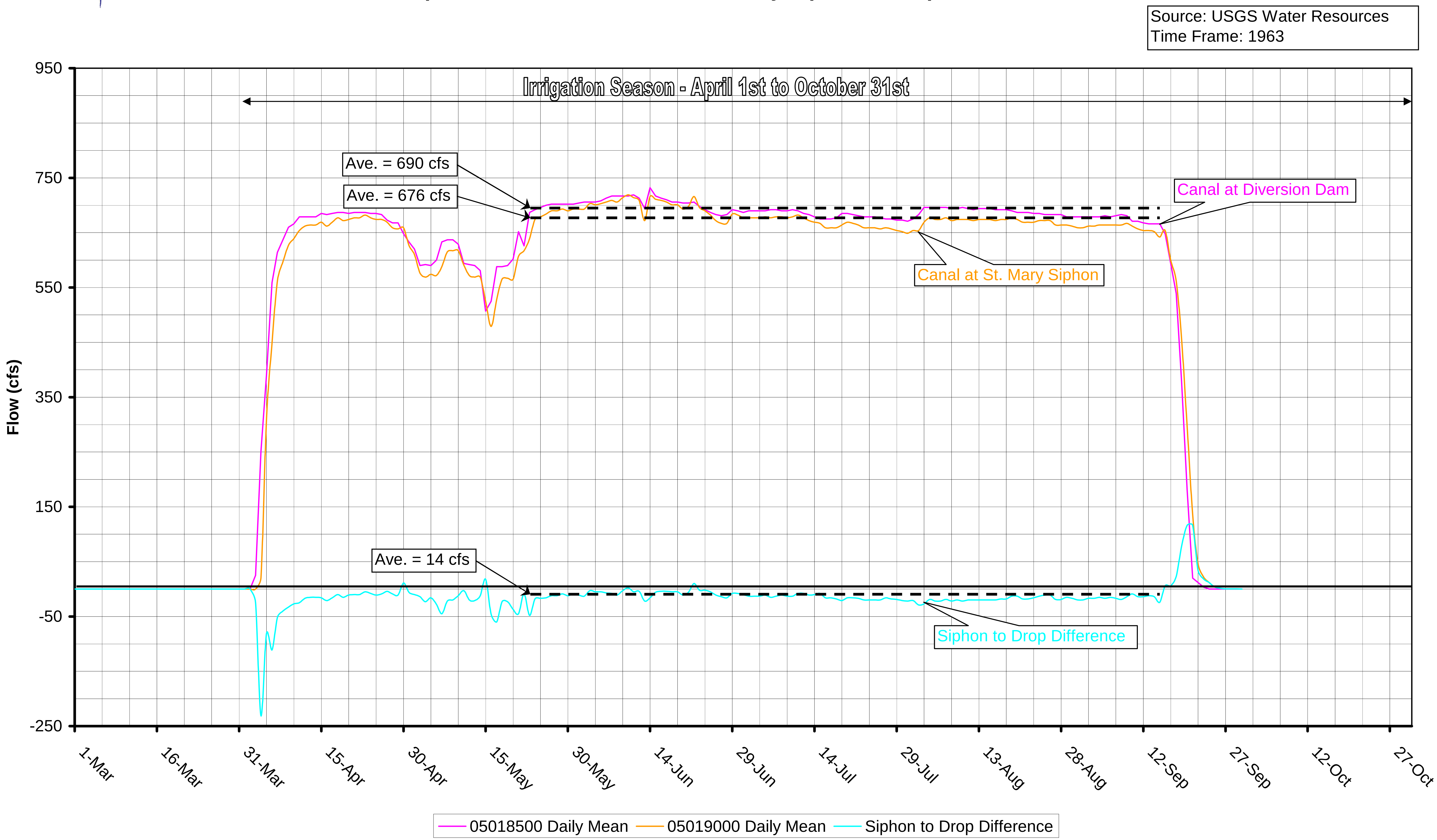

Figure B5

Comparison of Flows Between Diversion Dam & St. Mary Siphon for 1999

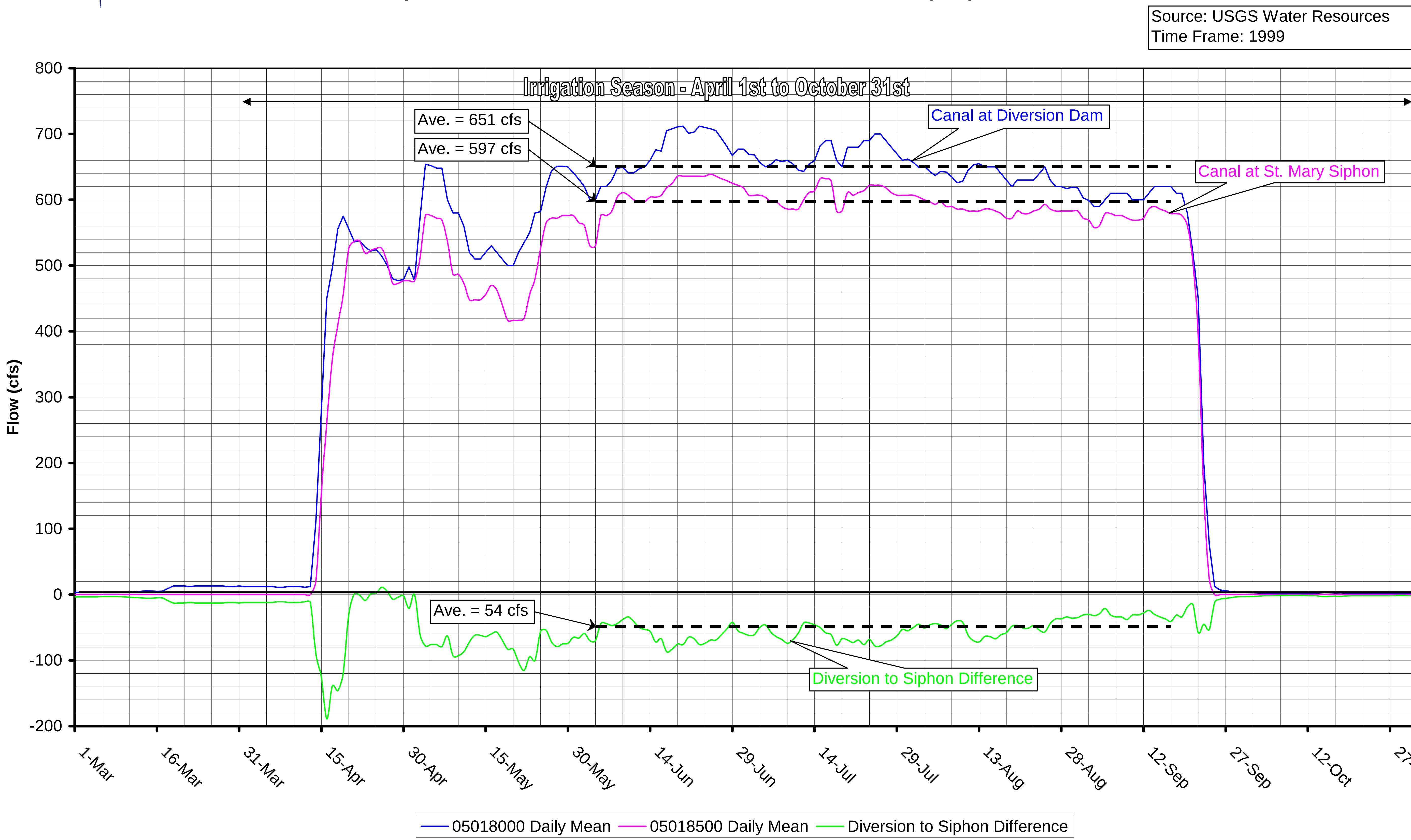

Figure B6

Comparison of Flows Between Diversion Dam & St. Mary Siphon for 2000

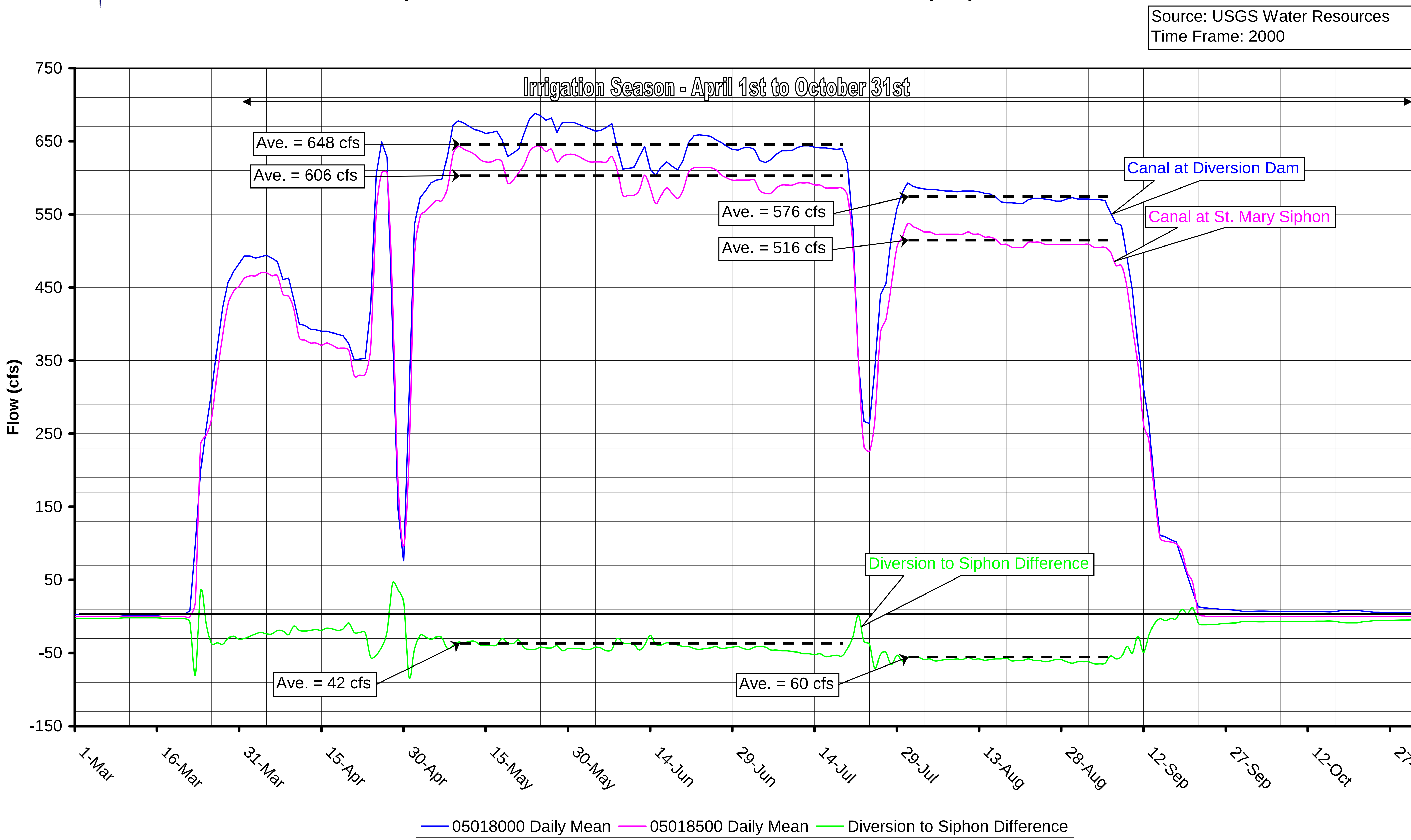

Figure B7

Comparison of Flows Between Diversion Dam & St. Mary Siphon for 2001

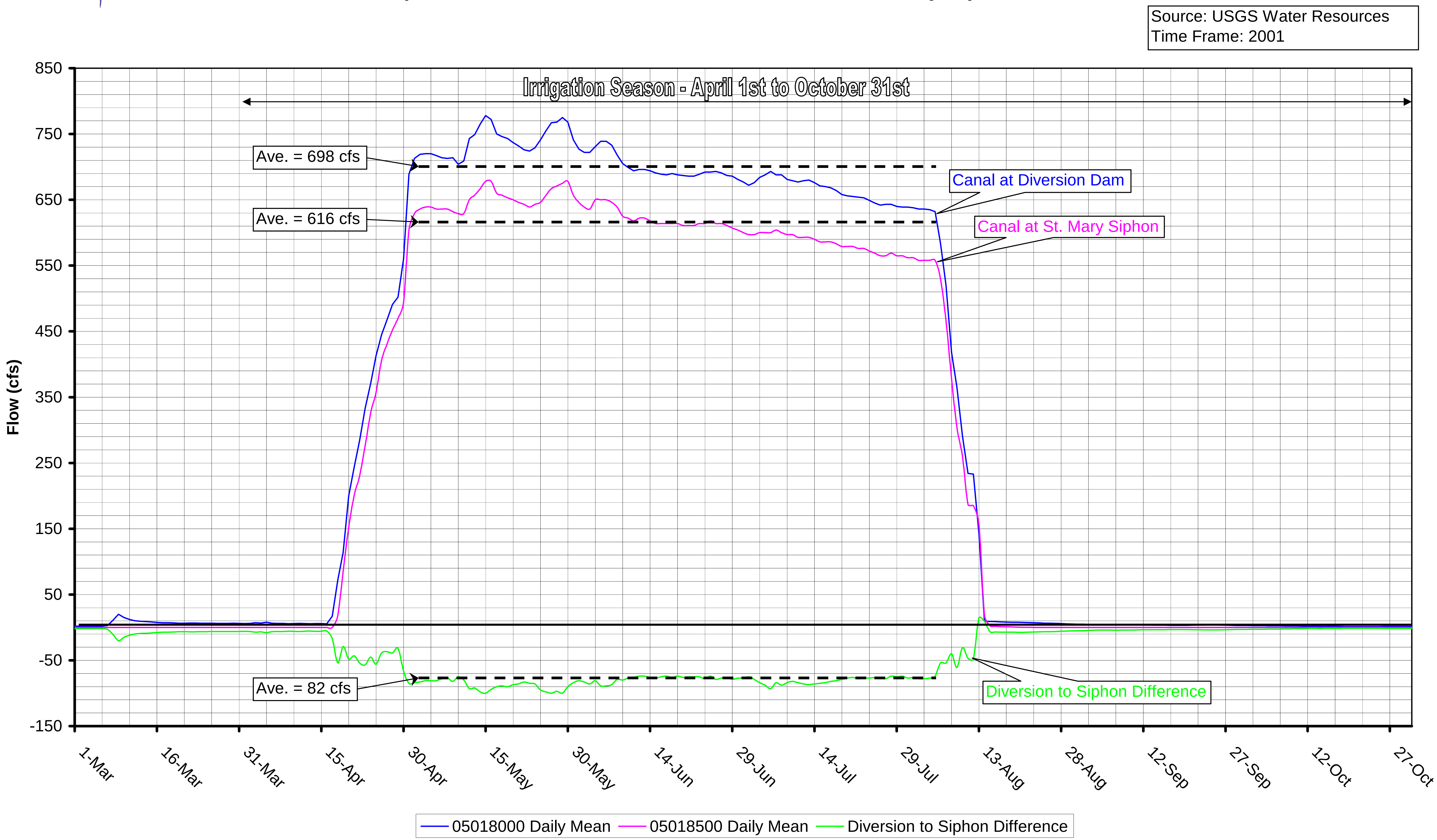

Figure B8